INTERNATIONAL GEOSPHERE-BIOSPHERE PROGRAMME (IGBP):

THE GERMAN CONTRIBUTION

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1 INTRODUCTION

W. Cramer

The call for synthesis and integration

So far, the German national contribution to the International Geosphere-Biosphere Programme has occurred through the activities of a large number of individual scientists at German universities and research institutes. The IGBP draws its success to a large extent from such individual commitments – its strategy as a basically un-funded research organisation allowed IGBP science to develop rapidly, since existing projects and research traditions could, where appropriate, be adapted and thereby contributed towards a new common goal, the understanding of the Earth system and its alterations by human activity. The richness of the German contribution is illustrative for the breadth of German science in regional and global problems: it resulted in significant advances in every single core project of the IGBP.

The IGBP, following its successful congress in Bad Münstereifel 18-22 April 1996, is now entering a more mature stage, where the initial work, both with respect to science and implementation planning and with respect to individual scientific achievements, is reviewed against the overall goals that were set up for the programme as a whole. This stage is characterised not so much by a quality assessment of the individual achievements (this occurs permanently through the peer review system and needs not to be duplicated), but rather by an assessment of the possible level of integration across individual research projects, across different foci in the core projects, and also across the entire IGBP structure.

Integration is a much called-upon goal nowadays, since it seems to provide added value without (much) further cost by pooling diverse resources. Much less frequently, integration is seen as a scientific problem in its own right. Also, it may be noted that highly specialised and successful scientists often show reluctance towards integrating activities since these are usually opposed to precisely the specialisation and concentration on difficult problems that they have been previously investigating. This notion is based on a misunderstanding, however, since there is no way one can "choose" between in-depth research and synthesis – both are indispensable for the success of the programme.

National and international research programmes which are targeting real-world environmental problems, such as the apparent disruption of the global life support

system by human activities, will inevitably fail in achieving their goals if a suitable combination of in-depth research on one hand and integration and synthesis on the other are not recognised as one of its biggest challenges.

From this follows that there are at least four major reasons for now re-intensifying the quest of a higher level of integration through the Global Change Research programmes: First, some elements of Global Change Research, such as the assessment of human influences on the circulation of the atmosphere and the oceans, can by definition be addressed only if several communities (ocean modelling, atmospheric modelling, emission scenario development, etc.) co-operate with integration in mind.

Second, integration of Global Change Research results attempts more than simply the sum of a large number of individual studies. First when common features emerge, or when inconsistencies between individual projects indicate the absence of such features, can we learn more about the overall behaviour of the system as a whole. An example is the "CO_2 fertilisation effect" which is clearly visible in many (although not all) studies of individual leaves or plants, but it is more often absent when complex ecosystems or longer time scales are considered.

Third, integration makes relevant and exciting science in its own right. At least since the time of the first assessments of the Club of Rome, even a broader science-oriented public has shown interest in complex assessments which include many variables.

Finally, the questions which are asked by policy makers to the international science community (e.g., through the Intergovernmental Panel on Climate Change, IPCC) are to a large extent oriented towards the results of such a synthesis, rather than its individual components.

Which elements are to be integrated?

Despite the ongoing dispute about the amount of present and past human impact on the global climate system, there is nevertheless agreement about the multidisciplinary nature of the research required to answer pending questions of the global environment. Therefore, the German National Global Change Colloquium has brought together the four major international programmes WCRP, IGBP, IHDP and DIVERSITAS for a joint discussion on the potential of integration. It follows from this, that the highest level of desirable synthesis is across these programmes. To mention only a few examples, WCRP-based research in the physics of the atmosphere, for example, needs to take better account of the alterations of the land surface, IGBP's investigations of the dynamics of terrestrial and marine ecosystems needs to be more strongly based on the driving forces of human resource capture in these systems, and the changes in land suitability and ecosystem biodiversity need to be more appropriately considered against the back ground of climate change in the past and the future.

Integration must also take place within programme elements. The IGBP, for example, has a hierarchical structure which lends itself well to attempts for integration of individual results. Almost any major achievement may be located at a task or activity level (the nomenclature for these levels varies somewhat, but the principle is the same), similar and comparable achievements are being made in the same programme element, or in

programme elements that are "near" in most operational plan documents. Also, workshops and science conferences are being held at several levels through the IGBP, and almost of all of these fulfil the goal of integrating beyond individual research results. Among the more 'classical', discipline-oriented core projects, integration is now being focused as a central activity. GCTE, for example, has just concluded its "Synthesis Project", which results in a book (WALKER et al. 1997) that will be released at a Science Conference in Barcelona, Spain, in March 1998. This conference itself will be an element of integration, too, since it will be held jointly between GCTE and LUCC (a core project bridging IGBP and IHDP). A less classical approach of integration is contained in the IGBP through its cross-disciplinary core projects, such as LOICZ, or the task force on global modelling, GAIM.

A German approach to integration?

Discussions at the level of the German IGBP committee, at the Global Change Colloquium, and also in the Scientific Advisory Board to the Federal Government on Global Change (WBGU) have addressed a range of different possible scientific approaches to integration. There is not enough room in this document to present the current state of these discussions in detail. There is probably already consensus about the fact that not one single approach can be made the general backbone of a future national research strategy. What is needed, however, is an ongoing open debate about such approaches, and it is desirable that the "voluntary spirit" that has characterised much of IGBP so far, can be carried on in such a way that a) individual research results are being made available for the integration, and b) research strategies are reconsidered, where appropriate, if the integration shows that results cannot be generalised.

When such an openness is given, then the dialogue about the types of integration can be constructive. Among previous suggestions, there seem to be three main methods of integration – although individual studies may show a greater variety of them:

- Biogeophysical earth system analysis can be seen as a summary term of numerical modelling studies which aim at a fully coupled system containing atmosphere, oceans, biosphere (on land and in the ocean), cryosphere and possibly (for longer time-scales) lithosphere. These models, which previously could be subdivided into those with a very high level of generalisation (box models) and those, where one or maybe two subsystems had a much higher level of complexity (e.g., coupled ocean-atmosphere general circulation models), are now rapidly moving towards a new generation which contains all necessary elements at an intermediate level of complexity (German contributions to this field are currently among the leading studies world-wide).

- On land, regional transect studies have an established history (e.g., in geology or biogeography), but their potential for integration across disciplines in a Global Change context has been only partially explored. Nevertheless, this potential is considerable, since transects usually provide something comparable to an experimental design, where one or only a few factors are modified gradually and systematically, and therefore the impact of this change can be studied for a range of different systems. Note that transects do not necessarily need to represent straight lines on a map – in this same group we also find notional transects (defined by environmental space,

rather than geographic space). A related structure which is very important for integrative studies at the regional scale is the catchment or river basin.

- The Advisory Board to the German Federal Government on Global Change has proposed an alternative strategy for integration, the syndrome concept. This approach combines various elements of the Global Change problem, across all disciplines from emissions through climate and ecosystems to human society, into a well-defined set of indicators. With respect to these indicators, it is possible to estimate the disposition of a given region to the resulting "syndrome" of Global Change impacts, as well as estimating the extent to which the phenomenon actually occurs. Through an appropriate mathematical formalism, it is therefore possible to express a combination of variables that cannot be coupled to each other by conventional models.

Conclusion

The call for added value from German Global Change Research, notably within the IGBP, without large increase in financial resources is audible and also being heard by the science community. Simultaneously, the demand from policy-makers for reliable results as a basis for longer term decisions is increasingly strong and will likely increase further. Integration appears to be the best way to achieve such added value, but it must come on top of, rather than instead of the current suite of major research projects. If a suitable concept for integration can be found in such a way that a broad group of German scientists is motivated to contribute and to participate from its benefits, then this will likely yield a unique scientific international contribution that will be noted. The conditions for such a new approach are promising.

The most substantial basis for this new contribution lies in the German experience connected to every single one of the major IGBP core projects. In the remainder of this document, this experience is documented by short contributions written by those members of the German science community who are best informed about the contribution. It should be noted that these summaries are not intended to be provide a full inventory, but rather identify a few specific highlights.

2 BIOSPHERIC ASPECTS OF THE HYDROLOGICAL CYCLE (BAHC)

H. Hoff & J. D. Tenhunen

BAHC fosters and co-ordinates research on interactions between vegetation, atmosphere and the hydrological cycle. In accordance with the goals of IGBP to bring about more co-operation and co-ordination between Programme Elements and to promote a higher level of integration of the science activities, BAHC has updated its science agenda. A higher level of integration, co-operation and co-ordination is to be achieved through the reformulated central question of BAHC:

How do changes in biospheric processes interact with the global and regional climate, hydrological processes and water resources when driven by changes in atmospheric composition and land cover?

The overarching hypothesis driving BAHC research is:

- forcing of the hydrological cycle and the climate by land surface-biosphere changes is sometimes stronger than radiative forcing in Global Change.

Bi-directional fluxes between land surface and atmosphere, associated with land cover change will be a major research emphasis in the future.

BAHC will lead a long term global terrestrial biophysical study of fluxes of H_2O, CO_2 and energy.

BAHC research will be oriented along the following major themes:
- Energy, water and carbon fluxes at the patch scale - FLUXNET
- The role of below-ground processes
- Parametrization of land-atmosphere interactions
- Impacts of climate change on ecohydrological processes in different biome types
- Mountain ecohydrology
- Global terrestrial vegetation-climate interactions
- The influence of climate change and human activities on mobilisation and transport of matter through riverine systems
- Design, priorities and implemention of integrated terrestrial system experiments
- Contribution to the development and production of global data sets

German research provides important contributions to all of these key themes. In addition to a considerable number of BAHC relevant projects, there is a number of research initiatives in Germany that explicitly aim at BAHC research goals. These are:

Proposal cluster for landscape integration in the Ammer region. This cluster aims at developing methods for coupling hydrological and biological processes at the landscape scale. Processes in the highly structured and anthropogenically changed watershed are analysed and SVAT models and stand models developed and validated. Lateral water fluxes at all scales are also part of this work. Remote Sensing is employed for integration and interpolation of in-situ data.

The *LITFASS* (Lindenberg Inhomogeneous Terrain, Fluxes between Atmosphere and Surface, a long term study) experiment is integrated with the BALTEX experiment. It complements the work in the Southern German Ammer region by providing a regional focus for studying land-surface atmosphere interactions in a lowland region of Northern Germany. Time series allowing for hydrological modelling complement of these works.

German Ecosystem Research Centres. There is a large number of projects at these research centres in the different German regions. They contribute on a range of temporal and spatial scales to most of BAHC research themes listed above.

Transect studies in Germany, including the work of the ecosystem research centres, integrate well with the regional IGBP transect activities. The IGBP concept of terrestrial transects encompasses distributed observational studies and manipulative experiments coupled with modelling and synthesis activities. These works are organised along existing gradients of underlying biophysical parameters or gradients of land use intensity.

Earth System Analysis. This activity aims at modelling on a large scale the dynamic interactions between vegetation and atmosphere, including system stability of geosphere and biosphere. Building blocks of the model-hierarchy to be developed are Earth System models, Climate models, Global Subsystem models, and Regional Integrated Impact models.

In addition to these German initiatives, a number of other research groups in Germany contribute to international BAHC initiatives:

- EUROFLUX, a European-wide network and FLUXNET a global network of co-ordinated and standardised flux measurements has a number of sites in different German landscapes. With data from these sites the EUROSVAT initiative for improving land surface parameterisation in SVAT models is supported.
- The IGBP Mountain Initiative, providing a scientific base for sustainable development of mountainous regions, is programmatically driven by BAHC in Germany and will include mountain research in the Alps.
- The BALTEX experiment, part of GEWEX, with it's international secretariat located in Germany, provides water and energy balances for the Baltic Sea region but also for adjacent terrestrial systems.
- LBA, the "Large Scale Biosphere Atmosphere in Amazonia" experiment is increasingly supported through German and European research (see also IGAC report).

All of these activities contribute to the science questions of BAHC and other IGBP projects. More detailed information on German activities within these initiatives, is published in the proceeding of the workshop: "BAHC Forschung in Deutschland" from April 1997, published by the BAHC project office in Potsdam. List of principal investigators and research institutions contributing to the BAHC agenda are also listed in "IGBP Research in the Federal Republic of Germany" from 1995, published by the German IGBP Secretariat.

The German role in the BAHC programme is emphasised by the membership of three German scientists in the BAHC Scientific Steering Committee, as well as the International BAHC Project Office at the Potsdam Institute for Climate Impact Research, through funding by the German Ministry for Education, Science, Research and Technology.

3 GLOBAL ANALYSIS, INTERPRETATION AND MODELLING (GAIM)

W. Cramer

Internationally, GAIM was established as a task force rather than as a core project within IGBP. The reason for this was the perceived need of integrating results from the different core projects to achieve a greater understanding of the overall problem of *global interactions between the geosphere and the biosphere*. Fundamental to the recent development of GAIM are efforts to improve the modelling of key elements of the global carbon cycle such as the estimation of net fluxes between the atmosphere and the oceans as well as the atmosphere and the land biosphere. These include data-gathering activities, model development and application, as well as the validation of global carbon cycle models.

German contributions to GAIM have been made in all these areas; the following may serve as examples:

To improve the modelling of the entire global carbon cycle over the period of the last century, the *Carbon Cycle Model Linkage Project* (CCMLP), funded by the US Electric Power Research Institute (EPRI) and co-ordinated by the Max-Planck-Institut für Meteorologie in Hamburg, develops an improved coupled model with specific emphasis on the land biosphere. As its atmospheric component, the group uses the 3d atmospheric transport model TM2/3 and, for the ocean, the Hamburg Model of the Ocean Carbon Cycle. The land biosphere is represented by six contributed models which are used for comparison with each other or for specific purposes such as modelling the influence of human land use. Since this approach allows a full mass balance of carbon throughout the system, comparison of predicted CO_2 concentrations at measuring stations has been possible - providing one of the rare opportunities of validation for such global models. The model was largely successful in capturing the seasonal cycle of carbon uptake and release as well as several major interannual fluctuations (compare Fig. 4).

The uncertainty with regard to the biospheric carbon flux is thus clearly recognised, and more efforts are needed to improve the understanding of its relationship to climate, ambient CO_2 concentrations, nitrogen deposition and human land use. To reduce this uncertainty, GAIM has initiated (jointly with DIS and GCTE) an international *NPP Model Intercomparison Project*, which is co-ordinated by the Potsdam Institut für Klimafolgenforschung (PIK). In this project, seventeen modelling teams from many different countries have agreed to run their models on the basis of a standardised climatology (provided by PIK) and to supply their output data sets in a common format. Two workshops have been held in Potsdam, with all groups participating, where these data were analysed. Preliminary results do not indicate simple "winners" or "losers" - there seems, in contrast, to be a tendency of different models showing particular advantages in specific situations or for certain variables. Most modelling teams have received valuable insights into the relative strengths and weaknesses of their models, and the overall quality of the work in the different groups can be expected to improve.

The Model Intercomparison Strategy is now continuing at PIK (jointly with GCTE), focusing on a class of terrestrial biospheric models which explicitly deals with vegetation dynamics, the so called Dynamic Global Vegetation Models (DGVMs). Currently, six prototype models are participating in a further international intercomparison.

Another critical component in the coupled Earth system is the transport of trace gases through the atmosphere. This component, which in CCMLP is represented by only one model formulation, is studied separately by another model intercomparison, the *Atmospheric Tracer Transport Model Intercomparison Project* (TransCom2), which is co-ordinated by the School of Environmental Science and Management at the University of California, Santa Barbara, USA, with the Max-Planck-Institut für Meteorologie as a contributor. TransCom2 investigates the large-scale transport characteristics of global, three-dimensional transport models by means of simulations of sulphur hexafluoride (SF_6).

The carbon flux between the atmosphere and the biosphere is difficult to measure in any direct way, except in local investigations that are hard to scale up. Nevertheless, such

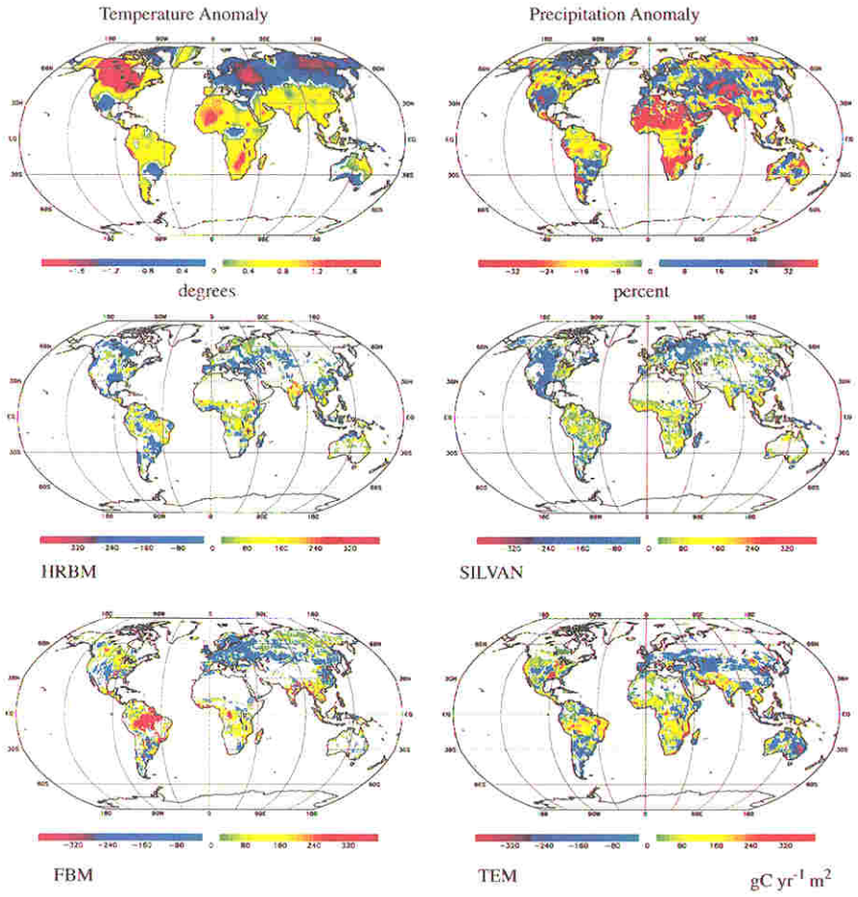


Fig. 4: *Anomalous CO_2-source flux driven by climate fluctuations in the El Niño year 1987 as simulated by four different terrestrial biogeochemical models. The upper two panels display the annual average of the observed climate data that were specified in the simulation experiments: temperature anomaly (in °C) and precipitation anomaly (as a relative deviation in %). The lower four panels show the simulated, annually integrated CO_2-source flux predicted by the High Resolution Biosphere Model (HRBM) of the University of Giessen, the Frankfurt Biosphere Model (FBM) of the University of Frankfurt, the terrestrial biogeochemical model of the Max Planck Institute of Meteorology in Hamburg (SILVAN) and the Terrestrial Ecosystem Model (TEM) of the University of New Hampshire and the Marine Biological Laboratory, Woods Hole, U.S.A. (Courtesy of M. Heimann, Max Planck Institute for Meteorology, Hamburg)*

local measurements are being used in model development, and the most important uncertainty is the comparability between measurements from different field sites. To improve on this situation, the *Global Primary Production Data Initiative* (GPPDI), co-ordinated at the US Oak Ridge National Laboratory (ORNL) in Oak Ridge, Tennessee, is carried out as an international project under both GAIM and DIS. The aim is to collect and standardise as many as possible of the existing observations of net primary productivity (NPP) and its related variables. A contribution to this project is made by PIK in connection with the NPP Model Intercomparison.

4 GLOBAL CHANGE AND TERRESTRIAL ECOSYSTEMS (GCTE)

W. Cramer

Since the onset of IGBP, GCTE has played a central role both scientifically through major contributions to the understanding of the sensitivity of terrestrial ecosystems to climate change, including their feedbacks to the atmosphere, and structurally through the development of a highly recognised operational plan. After six years of activity, the achievements to date are currently being summarised and reviewed, and the plan is undergoing minor revisions.

The *GCTE Synthesis Project*, which is very near completion at the end of 1997, was carried out through a large workshop held in 1996 in Kleinmachnow (between Potsdam and Berlin), in which all major contributors to GCTE participated and discussed developments thus far. This meeting was followed by another workshop in Santa Barbara (California) and two smaller writing meetings in Canberra (Australia) and Potsdam. The results are currently in press as a contribution to the IGBP Book Series, to be published by Cambridge University Press on the occasion of the next GCTE Science Conference in Barcelona, Spain (to be held jointly with the LUCC programme). Several key chapters are written by German lead authors.

One conclusion from the synthesis is that the main focus structure of GCTE is to be retained: Focus 1 on ecosystem physiology, Focus 2 on ecosystem structure, Focus 3 on agriculture and forestry, and Focus 4 on ecosystem complexity.

To list the breadth of German research contributions to GCTE would go beyond the scope of this report. Basically, much of the research which is being carried out by the German Ecosystem Research Centres is related to one or several of the above-mentioned foci. Frequently, measuring and experimentation programmes are linked to a modelling activity, such as within Focus one (ecosystem physiology) the recently launched EUROSIBERIAN CARBONFLUX study, funded by the European Union and co-ordinated by the Max-Planck-Institut für Meteorologie in Hamburg. This study focuses on the determination of sources and sinks of carbon dioxide and methane by means of local eddy-flux correlation measurements, vertical boundary layer and lower tropospheric concentration profile measurements from aircraft over eastern Europe and western Siberia. Other projects in this field are the EU projects "Carbon and nitrogen cycles in forest ecosystems" (NIPHYS), recently re-established as "Carbon and Nitrogen Cycling in Forest Ecosystems" (CANIF) and "Long-term carbon dioxide and water vapour fluxes of European forests and interactions with the climate system" (EUROFLUX).

Within Focus 2, work is concentrated on the dynamics of vegetation structure (succession). This Focus is co-ordinated by the Potsdam Institut für Klimafolgenforschung (Prof. Wolfgang Cramer) and several research projects are located there such as the BMBF-funded development of a general forest dynamics model and a key component of the EU-funded "European Terrestrial Ecosystem Modelling Activity" (ETEMA). The purpose of the latter is to develop a generic vegetation dynamics model, which is capable of simulating structural changes in vegetation under a broad range of climatic and soil texture conditions, including the effects not only of climate change but also those of changing atmospheric CO_2 content. The Project for Intercomparison of Dynamic Global Vegetation Models (DGVM Intercomparison), discussed under GAIM in this report, is also a contribution to GCTE Focus 2.

Focus 3 covers research activities on agriculture and forestry, which are regarded not only as being influenced by changes in climate and atmospheric composition but also as being actors with regard to trace-gas emissions such as carbon dioxide, methane and nitrous oxide. Experiments on the direct influence of CO_2 on growth and development of wheat are being carried out by the USDA Water Conservation Laboratory in Tucson, Arizona, and scientists from the Potsdam Institut für Klimafolgenforschung are participating in the experiment as well as in the associated modelling activities. The direct impact of CO_2 is also being studied at the Environmental Monitoring and Climate Impact Research Station Linden, operated by the Justus-Liebig-Universität Gießen in a pasture site.

Ecosystem complexity is studied in Focus 4 on a range of scales and in different systems. A specific contribution to this field is being made through the EU-funded project Global Change and Biodiversity in Soils (GLOBIS), co-ordinated by the Justus-Liebig-Universität Gießen (Prof. Volkmar Wolters, also a member of the GCTE Scientific Steering Committee). GLOBIS is an investigation of present and foreseeable effects of global climate change on the biodiversity in forest soils and how such changes will affect ecosystem processes (decomposition; C and N pools and fluxes). Species diversity, functional diversity and trophic connectivity of the animal and microbial communities are considered. A further EU project, also co-ordinated by Prof. Wolters, is "Diversity Effects in Grassland Ecosystems of Europe" (DEGREE), which investigates the modifications in the diversity of soil biota in typical European grassland ecosystems under climatic change, and the functional impact of these modifications on plant nutrient availability. German scientists from the University of Bayreuth are also participating in the EU project "Biodiversity and Ecosystem Processes in Terrestrial Herbaceous Ecosystems" (BIODEPTH), co-ordinated by John Lawton from Imperial College, Ascot, UK; BIODEPTH addresses the impact of diversity, functional groups and ecosystem structure on ecosystem functions.

5 GLOBAL OCEAN ECOSYSTEM DYNAMICS (GLOBEC)

J. Alheit

GLOBEC was introduced in 1995 by the IGBP as the newest global change core project. Its goal is "To advance our understanding of the structure and functioning of the global ocean ecosystem, its major subsystems and its response to physical forcing so that a capability can be developed to forecast the responses of the marine ecosystem to

Global Change". Its sponsors are SCOR (Scientific Committee of Oceanographic Research) and IOC (Intergovernmental Oceanographic Commission of UNESCO). GLOBEC is guided by a Scientific Steering Committee (German member: J. Alheit, Warnemünde). Its Science Plan has been recently published (IGBP-Report No. 40). The Implementation Plan is under preparation and will be presented to the international science community on the 1st Open Science Meeting at the IOC in March 1998.

GLOBEC research concentrates on four foci:

1. Retrospective analysis in the context of large-scale climate changes
2. Process studies
3. Predictive and modelling capabilities
4. Feedbacks from changes in marine ecosystem structure

GLOBEC work is carried out within four major subprogrammes and a large number of regional and national projects. German marine science institutions and scientists contribute significantly to the development of GLOBEC subprogrammes and projects.

The *"Cod and Climate Change Programme"* (CCC) in the North Atlantic is an innovative programme to advance the understanding and prediction of variability in fish stock recruitment, both in the short term (annual forecasts) and in the long term (climate effects). The central question being investigated is the effect of climate variability on major fish stock fluctuations. The core project of CCC, TASC (Trains-Atlantic Study of Calanus; funded by EU and US-NSF), concentrates on the impact of the coupled ocean-atmosphere system on fluctuations of crustacean zooplankton, the major food source of North-Atlantic fish stocks. Within TASC H.-J. Hirche (Bremerhaven) studies life cycles and reproductive biology of crustacean copepods. Whereas J. Backhaus (Hamburg) models the flow field of surface waters to explain distribution and abundance of copepods. D. Schnack (Kiel) and his team are leading the Baltic Sea component of CCC. Their EU-funded CORE (Baltic Cod Recruitment) project is a concerted effort of all riparian countries of the Baltic Sea and looks particularly into the dominant biotic and abiotic processes affecting fish and zooplankton. This includes the influence of the aperiodic salt water inflows from the North Sea into the Baltic Sea the mechanisms of which are studied by W. Matthäus (Warnemünde). E. Hagen and J. Alheit (both from Warnemünde) contribute to the retrospective analysis within CCC and have concentrated efforts on the impact of the North Atlantic Oscillation on pelagic fish stocks in the Eastern North Atlantic over the last 1,000 years.

The *"Small Pelagic Fishes and Climate Change Programme"* (SPACC) is a comparative study on the impact of climate variability on those marine ecosystems in which small pelagic fish such as sardines, anchovies or sprat play an important role (major upwelling systems off the western coasts of Europe, Africa and the Americas, Kuroshio Current, Baltic Sea, Black Sea). Small pelagic fish are an ideal group for comparative studies of how climate variability affects marine resources because of their world-wide distribution, great swings in abundance, climatic teleconnections between populations and rich retrospective data resources. SPACC research is a multi-national co-operative undertaking of northern and southern hemisphere countries involving a large number of South American and African marine research institutes. J. Hunter (USA) and J. Alheit (Warnemünde), the co-chairmen of SPACC, edited the SPACC Science Plan (GLOBEC Report No. 8) and the SPACC Implementation Plan (in press). A. Jarre-Teichmann

(formerly Kiel) co-chairs the SPACC Modelling WG. A number of physical oceanographers, zooplankton experts and fisheries biologists from Kiel and Warnemünde study the impact of physical factors on pelagic fishes in the Baltic Sea. E. Hagen and J. Alheit (both from Warnemünde) investigate the impact of climate variability on resources in marine ecosystems in northern Europe and the Eastern boundary currents of the Americas and Africa with a particular focus on teleconnection patterns. U. Struck and J. Alheit study a varved sediment core from an anoxic area off Namibia in the Benguela upwelling current with the aim to establish past marine environments and associated fish stock fluctuations over the last 5,000 years. The recovery of sardine and anchovy fish scales from the varved sediment layers is instrumental for this study.

Krill is the target species of the *"Southern Ocean GLOBEC"* programme with a particular focus on krill habitat, prey, predators, and competitors. It will be a year-round study, with emphasis on winter processes concentrating on two primary field sites. German contributions will be carried out around the Antarctic Peninsula using the German research vessel Polarstern focusing on late autumn/early winter behaviour of krill with respect to overwintering habitats (team leader: V. Smetacek, Bremerhaven). Additional activities are detection and measuring of krill shooling, swarm formation and grazing activities (U. Bathmann, Bremerhaven), investigations of age-classes and developmental stages (V. Siegel, Hamburg), determination of enzymatic and physiological characteristics of krill stages (H.-O. Pörtner, Bremerhaven, and F. Buchholz, Helgoland), studies on the under sea-ice habitat as a potential hiding ground for krill (G. Dieckmann, Bremerhaven) and investigations on krill food sources (S. Schnack-Schiel and U. Bathmann, Bremerhaven). In contrast, Australian, Japanese and South African scientists will study the second field site which is located at 70° E. Here, the same scientific approach will be followed, however, with seasonal coverage. Southern Ocean GLOBEC will be operational starting in 1999.

The *"Climate Change and Carrying Capacity Programme"* (CCCC) aims at investigating how biological productivity in the North Pacific responds to decadel-scale shifts in atmospheric and oceanic conditions. German scientists are not involved in this programme.

On a recent workshop in Warnemünde, German scientists from Bremerhaven, Hamburg, Kiel, Rostock and Warnemünde agreed to initiate an international, Baltic-wide regional GLOBEC Programme in the Baltic Sea. This will involve all riparian countries of the Baltic and build upon on-going programme elements of SPACC and CCC in the Baltic Sea which are funded by the EU and national sources.

In spring 1997, the Baltic Sea Research Institute in Warnemünde sent a research vessel to the Benguela Current to carry out co-operative SPACC studies with scientists from South Africa, Namibia and Angola. The investigations focused on the variability of frontal systems and associated impact on the plankton (team leader: U. Lass). Also, sediment cores were taken (see above).

The objective of the GLOBEC focus on *"Predictive and Modelling Capabilities"* is, inter alia, to develop multiscale biological-physical dynamical models. To advance the modelling component, GLOBEC has created its own Working Group on Numerical Modelling (German members: W. Fennel, Warnemünde, and G. Radach, Hamburg).

GLOBEC is an interdisciplinary Programme. German scientists involved in GLOBEC are from the fields of physical oceanography, palaeo-oceanography, marine geology, planktology and fisheries ecology. There are a number of linkages, both conceptual and in terms of programme co-ordination, with other Global Change Core Projects. The most obvious linkages are with other marine programmes of the IGBP, JGOFS and LOICZ which have research programmes closely related to GLOBEC. GLOBEC's emphasis on zooplankton population dynamics complements the JGOFS primary focus, which is on primary production, carbon flux and the oceanic carbon budget. GLOBEC has its roots in both, physical and biological oceanography. Consequently, there are a number of potential interfaces with the World Climate Research Programme (WCRP), especially to the World Ocean Circulation Experiment (WOCE) and the Climate Variability and Predictability Research Programme (CLIVAR) the results of which will contribute significantly to the future success of GLOBEC.

6 INTERNATIONAL GLOBAL AIR CHEMISTRY PROJECT (IGAC)

M. O. Andreae, with contributions from A. Wahner

The International Global Atmospheric Chemistry Programme (IGAC) was one of the first core projects of the IGBP. Its basic goals are the development of a fundamental understanding of the processes that regulate atmospheric chemistry, of the interactions between biosphere and atmosphere, and of the impact of human activities on the atmosphere. The scientific objectives of IGAC and its operational plan are discussed in detail in IGBP Report 32 (1994), and will not be repeated here.

German scientists were among the founding fathers of IGAC and have participated in a number of IGAC activities. A list of these activities was provided in the document "IGBP Research in the Federal Republic of Germany 1995", published by the German IGBP Secretariat. In the brief space available here it is not possible to discuss all these activities; instead, some highlights of German participation in large co-ordinated IGAC projects will be presented: BIBEX (Biomass Burning Experiment), NARE (North Atlantic Regional Experiment), and ACE-2 (Aerosol Characterisation Experiment). In addition, I will highlight the planned participation of German institutions in the LBA (Large-Scale Biosphere-Atmosphere in Amazonia) programme.

The North Atlantic Regional Experiment (NARE) investigates the long-range transport of pollutants from Europe and North America over and across the North Atlantic, and the impact of these pollutants on air quality, the oxidative properties of the atmosphere and the radiation balance. The first large field experiment of NARE was conducted in the summer of 1993 with participation of German scientists conducting measurements of key species (CO, O_3, etc.) from aircraft and at ground sites. In this experiment, the large- scale perturbation of atmospheric composition and photochemical cycles of the region was documented comprehensively. A new and highly important result of German NARE- related research is the development of reliable techniques to measure the concentration of the hydroxyl (OH) radical, the most important atmospheric oxidant. This species has been determined for the first time over a large region in the marine atmosphere over the North and South Atlantic. These measurements are a key prerequisite for the validation of our theories and models of atmospheric chemical processes.

Fig. 5: *Aerial view of an experimental fire in Kenya, Lewa Downs Wildlife Sanctuary, 27 September 1997. The African Fire-Atmosphere Research Initiative (AFARI-97) conducted this experiment as a follow-up of the Southern African Fire-Atmosphere Research Initiative (SAFARI) and focused on characteristics of aerosol emissions from East African grassland fires. AFARI-97 was conducted under the umbrella of the IGAC Biomass Burning Experiment (BIBEX). (Courtesy of J. Goldammer, Max Planck Institute for Chemistry, Biogeochemistry Department, Freiburg)*

The Aerosol Characterisation Experiment 2 (ACE-2) took place in the region between the Iberian Peninsula, the Canary Islands, and the Azores during the summer of 1997. Its goal was to understand the processes that determine the chemical and physical characteristics of the atmospheric aerosol in an area downwind of a major industrialised region, Europe. This knowledge is essential if we are to understand the climatic impact of anthropogenic aerosols, one of the most important uncertainties in climate change. Our ability to obtain accurate and precise measurements of the chemical and physical properties of the aerosol, and to connect these measurements in a reliable way to the radiative properties of the atmosphere was tested in a series of "closure" experiments.

BIBEX (Biomass Burning Experiment) was developed to characterise qualitatively and quantitatively the emissions from biomass fires world-wide, to assess the impact of biomass burning on atmospheric chemistry and climate, and to determine the ecological and biogeochemical consequences of burning. BIBEX organised a number of internationally co-ordinated campaigns, often with leading participation of German groups. In these campaigns, the effect of fires in the savannahs of East (see Fig. 5) and West

Africa, in the grasslands and savannahs of Southern Africa, and in the boreal forests of Siberia and Canada was investigated. Another project studied the pollution from domestic use of biofuel in developing countries.

These studies show that biomass fires emit a mixture of gases and aerosols which resembles in many respects the pollutant mix from fossil fuel combustion, in amounts which on a global scale rival and in some instances exceed the emissions from fossil fuels. In particular, the large amounts of NO_x and hydrocarbons emitted from biomass burning, in conjunction with the high photochemical activity typical of the tropics, leads to the production of vast amounts of photochemical smog in the tropics. The most striking evidence for this phenomenon are the presence of haze layers covering millions of square kilometres in the tropics during the dry season, and the presence of photochemically formed ozone throughout the troposphere over large regions, but especially over the area from South America across the Atlantic to Africa. Domestic biofuel use, the main source of energy for billions of people world-wide, adds large amounts of pollutants to regional and global budgets, and is responsible for the deterioration of air quality in many developing countries. The work conducted under the auspices of BIBEX has now resulted in a fairly good assessment of the environmental role of biomass fires, with the exception of fires in the humid tropical forests, particularly deforestation fires. Technical and logistical difficulties have so far prevented us from investigating this important class of fires in the necessary detail.

In future, BIBEX will function less as a self-standing programme, but will attempt to integrate its efforts in programmes with a broader scope, in order to integrate biomass burning studies in investigations of the multidimensional interactions of human activities with biospheric and atmospheric processes. Fore example, studies of the atmospheric consequences of deforestation fires in South America will be conducted by BIBEX in the larger context of LBA.

While the experiments described in the previous sections have implicit ties from "sectoral" research (in this case, atmospheric chemistry) to other disciplines, such as meteorology, climatology, ecology, and economics, they were not conceived as integrated Global Change Research projects. This kind of integration is the challenge faced in the LBA programme, which intends to study Amazonia as an integral system with interacting chemical, biological, ecological, hydrological, economical and social processes. A large consortium of scientists from South and North America and Europe has begun to draw up detailed plans for this programme, and the first investigations have begun. At this point, the ties to the social and economic sciences need still considerable strengthening, while strong and integrated programmes are underway in the physical and biological sciences. IGAC-related research projects will address

1. the emissions of gases and aerosols from the biota, from fires, and from industrial activities in the region,
2. the transport of trace gases and aerosols at interlocking scales (from centimetres to thousands of kilometres) within the Amazon system,
3. photochemical processing in the tropical atmosphere, and the impact of photochemical pollutants on ecosystem and humans, and
4. the export of trace constituents from Amazonia to the global atmosphere and their impact on global climate and chemistry.

7 JOINT GLOBAL OCEAN FLUX STUDY (JGOFS)

G. Wefer, K. Lochte, B. Zeitzschel

Scientific basis and goals

The increase of the carbon dioxide content of the atmosphere and its possible climatic impacts (increased temperature, sea-level rise, etc.) has been discussed in literature for the past 50 years. Dependable and continuous measurement series taken over the past 30 years verify the anthropogenically caused CO_2 increase. The CO_2 content of the atmosphere has increased from 315 to 360 PPM between 1958 and 1995, primarily due to the burning of fossil fuels and the deforestation of large surface areas. Theses values are significantly higher than measurements taken from ice cores representing the past 165,000 years.

A significant portion of the CO_2 emitted into the atmosphere is taken up by the ocean - approximately 40% depending on the model being applied. This estimate must be considered with caution because it is not based on direct carbon measurements in the ocean, but on relatively simple mass balance models. In contrast to most other gases, the uptake capacity of the ocean for CO_2 is dependent not only on the physical solubility, but is also controlled by biological and chemical turnover of the oceanic ecosystem. In addition to interest in the uptake of additional CO_2 by the ocean, knowledge enabling the prediction of possibly occurring changes resulting from external (e.g., anthropogenic) "disturbances" is also very important. It is known that the world ocean contains about 50 times as much CO_2 as the atmosphere, and that small variations in the ocean carbon cycle (e.g., through warming of the surface layer and a resulting decrease in vertical mixing) would probably result in drastic associated reactions affecting the atmospheric CO_2 content and, in turn, also our climate. The ice-core investigations also indicate that large atmospheric CO_2 fluctuations have occurred over the past 150,000 years. We are, however, still far from understanding the mechanisms controlling such correlations or predicting their temporal patterns.

Great efforts are being undertaken on both the national and international levels to improve our understanding of the oceanic carbon cycle. It is critical to determine how the productivity of the ocean reacts to CO_2 influx and warming and what results can be expected in the biological processes. The complexity of the problems requires a co-ordinated international and interdisciplinary co-operation among marine biologists, marine chemists, marine geologists, and physical oceanographers.
For this reason an international scientific programme, the "Joint Global Ocean Flux Study" (JGOFS) was defined under the auspices of the "Scientific Committee on Oceanic Research" (SCOR). Collection of field data shall continue from 1991 to 1998. With the resulting data analysis and synthesis the following two goals will be pursued through 2004.

1. A better understanding of the global processes that determine the flux of carbon and associated biogenic elements in the ocean, especially with respect to correlations with the atmosphere, the seafloor, and the continents.

2. Development of possibilities for predicting variations in the biogeochemical processes related to anthropogenic activities, especially related to climate changes.

The foundation of the work is a Science Plan, which was published in August 1990 by SCOR. The concrete fieldwork, analytic work, and syntheses are contained in the Implementation Plan, which has appeared as a JGOFS Report (SCOR) and as a report of the "International Geosphere-Biosphere Programme" (IGBP - Report No. 23, 1992) German marine scientists have been influential in the development of the international JGOFS Programme, and are still active in various international committees.

Strategies of the international JGOFS Programme

The scientific work in the JGOFS Programme is based on various strategies:

1. In order to investigate temporal and spatial variability at a meaningful scale for the carbon cycle, large-scale investigations are carried out using ships and satellites. In this way, time series of carbon flux variations in the surface layer and in the water column can be documented at particular locations. A global survey of direct CO_2 measurements taken within the framework of the World Ocean Circulation Experiment (WOCE) is, for the most part, completed. At present, so-called "repeat" measurements are being carried out at the former stations after several years in order to identify long-term developments. For the productivity measurements from satellites up to now the Coastal Zone Colour Scanner (CZCS) has been relied upon. Plans for this year include the transport into space of two new sensor packages (SeaWIFS and a Japanese system) for the determination of chlorophyll content in the surface waters. Time series stations have been established near Bermuda, Hawaii and the Canary Islands. Germany, in a combined effort with Spain, has deployed a station north of Gran Canaria, Canary Islands (ESTOC, European Station for Time-Series Observations in the Ocean, Canary Islands). France has carried out a three-year time-series programme near the Kerguelen Islands.

2. Process-oriented studies will determine the course of important processes and allow the testing of hypotheses through appropriate experiments. A better knowledge of the mechanisms controlling processes related to the carbon cycle is necessary for the prediction of global environmental changes. These processes include flux rates which respond to physical forcing and to ecosystem dynamics in time frames of hours to months. Process studies have been carried out in the North Atlantic, equatorial Pacific and Indian Oceans as well as in the Southern Ocean. These studies are, for the most part, complete. German participation was notably strong in the North Atlantic (North Atlantic Bloom Study) and Indian Ocean. Participation by German scientists in process-oriented studies was also very significant in several POLARSTERN expeditions to the Southern Ocean.

3. The relationships between past climate, ocean circulation, and productivity can be grasped through the analysis of Quaternary sediments. The connection between CO_2 content of the atmosphere and global climate can be studied by evaluating past atmospheric CO_2 concentrations obtained from ice cores from the polar caps.

4. For the identification of critical processes and variables, for the extrapolation of local observations into the world ocean, and finally for the prediction of oceanic reactions to global changes, a description of the processes using mathematical models should be carried out in a framework of global syntheses.

The goals named above, i.e., understanding the biogeochemical processes in the ocean, and especially prediction of climatic changes based on these processes along with external (anthropogenic) influences, require the development of regional and global models. A prerequisite for successful execution of the plans is the close co-operation between data producers and modellers. Several meetings for the presentation and discussion of various models have been held in order to promote biogeochemical modelling in Germany. A working group "Data and Models" has been formed and entrusted with the task of working out new modelling concepts.

Within this global concept the German working groups are concentrating on the Atlantic, Southern, and northern Indian Oceans, due to the extensive research programmes which have been carried out in these areas in recent years, and other programmes which have been planned for the future.

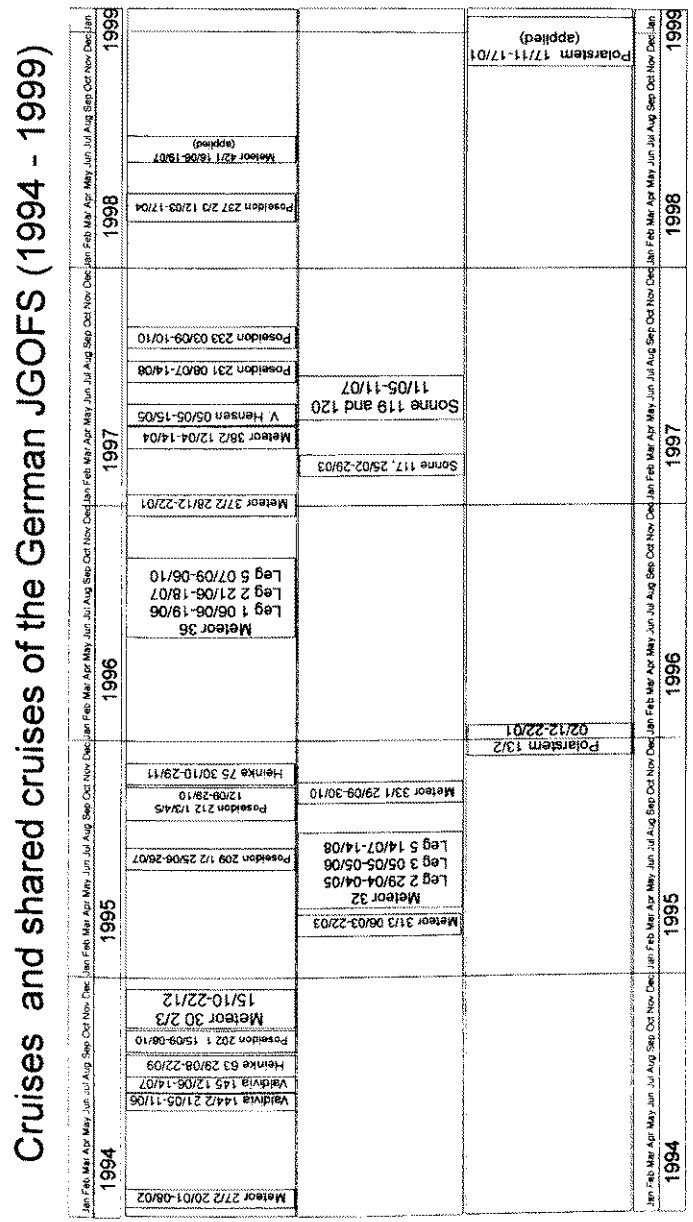
The active German participation in the JGOFS programme has been apparent from contributions by German scientists since the early planning stages, both at the national and international levels. Support of individual JGOFS working groups by the DFG and the Federal Ministry for Education, Science, Research and Technology (BMFT, today the BMBF) was initiated in early 1990. Extensive JGOFS-related studies are being carried out under two long-term existing Collaborative Research Centres (SFB's): at Kiel University, SFB 313, "Environmental Variations - the Northern Atlantic", and at Bremen University, SFB 261, "The South Atlantic in the Late Quaternary: Reconstruction of Mass Budgets and Current Systems". Additional groups are working at other universities, for example, at Hamburg, Kiel, Oldenburg, and Tübingen as well as at the Institute for Baltic Sea Research in Rostock-Warnemünde. The cruises of the German JGOFS are shown on the next page (Tab. 1).

Synthesis and modelling phase

With respect to global synthesis and modelling we are now, for the most part, in the phase of interpretation and bringing the results together with plans to have them bound by 2004.

The general goal concerns the role of this ocean region in the global carbon cycle. While the decisive progress in the better understanding of the related processes has already been achieved, the future still holds questions about prediction of the response of the system to global warming (e.g., changes in deep circulation, upwelling intensity and ecosystems, especially in coastal areas).
Specific questions include:

- How much CO_2 exchange occurs between the ocean and atmosphere, through physical and biological pumps as well as through the carbonate pump?
- To what extent does the ocean control the CO_2 content of the atmosphere?
- How do organisms react to changes in temperature and productivity?
- In what amounts and what is the composition of organic substances transported from the surface waters into the sediments (f-ratio, formation of aggregates, microbial degradation)?
- How can the model-input values such as "rain ratio" (C_{org}/C_{carb} proportion) or "Redfield ratio" (C, N, P proportions) be improved?



The note "applied " means the cruise is planned but not confirmed (until Nov. 1997). The Meteor cruise No. 33/1 in the Indian Ocean was shared in ship time and cost between the BIGSET and the JGOFS program. The Meteor cruises No. 30 and the two Valdivia cruises in the Atlantic Ocean have been shared between JGOFS and WOCE.
(Information compiled by T. Mitzka, JGOFS Data Management)

Tab. 1: *Expeditions and shared expeditions of the German JGOFS (1994 - 1999)*

- How can satellite data (SeaWIFS and others) be used in a better way to determine the global and regional productivity of the oceans?
- What are the causes for observed CO_2 variations during the past 300,000 years (jointly with PAGES)?

Perspectives for the future

In summary, it is clear that the German scientists have taken a leading role in the JGOFS project. Continued efforts in the research theme "Oceanic Carbon Cycle" are crucial in order to maintain or even improve this position. The following points should therefore be considered:

1. The interpretative and synthesis work described in the "Implementation Plan" should be carried out. This is critical to the achievement of the JGOFS goals.

2. Increased efforts are required in the interpretative phases of the important mutual research themes between JGOFS and other marine IGBP projects. Toward this goal mutual Task Teams have been appointed in the international JGOFS with PAGES and LOICZ. This will presumably also happen with GLOBEC, as this project, which is just beginning could benefit greatly from existing JGOFS data. A stronger link to the marine IGBP and WCRP projects should be a goal of the German JGOFS. This could provide a better grasp of the present and historical roles of the ocean in climatic events, and of the links between coastal and open-ocean processes.

3. The interpretative and synthesis phases of JGOFS provide the opportunity to branch out somewhat from the original goals of JGOFS and expand to include additional themes, for example, in the area of earth system modelling. This requires close co-operation between JGOFS researchers and those of other IGBP, WCRP and IHDP projects. This alteration of original orientation could require supplementary measurement programmes.

8 LAND-OCEAN INTERACTIONS IN THE COASTAL ZONE (LOICZ)

F. Pollehne

A great number of the problems arising from global change are documented in the coastal zone. Changes in the sea such as those of ocean circulation, sea level and storm frequency as well as those of land use-related processes such as eutrophication, erosion or perturbations in the natural transport balance of rivers are becoming increasingly visible at the coasts. The fact that the greater part of the world's population lives in a relatively narrow belt along the coasts links these problems directly to the future development of our societies and economies.

Within IGBP, LOICZ is investigating four key issues which are of fundamental significance in our understanding of the interaction between Global Change and the function and development of the coastal zone. These include (i) the effects which changes in external driving forces and boundary conditions have on particle flux in the coastal zone; (ii) the dynamics of the coastal zone as a result of Global Change; (iii) carbon flux and

greenhouse gas emissions; and (iv) the economic and social effects of Global Change on coastal systems. This last issue in particular already signifies the close integration of components of the IHDP into the project framework and the simultaneous study of scientific and social complexes.
At the national level, LOICZ, one of the most recent IGBP Core Projects, is still in the phase of active data acquisition in all key areas. According to the international implementation plan, this phase is to be succeeded in the years 1998-99 by a period of synthesis and integrated modelling.

The state of the national programme is adapted to this plan. The major coastal projects concerned with the North and Baltic Seas, which are largely oriented towards questions of the natural sciences, are in the evaluation phase. These include the "KUSTOS" project in the Elbe-North Sea region and the complex of research projects on the Mecklenburg-Vorpommern coast (involving three projects in the Oder-Baltic Sea region), both of which belong to the LOICZ national contribution. Projects have also been initiated which link the natural and the social sciences such as "Climate Change and Coast" and "Long-Term Strategies for River Conservation and Water Management in the Oder". For those foci of the LOICZ research concept for which no clear organisational structures had been defined, workshops of several days' duration were held to draw up longer-term national research plans and perspectives (see reports on the national workshops "Trace Gases" and "Socio-economics", published by the German IGBP - Secretariat).

The studies carried out in the area of the North Sea have mainly served to analyse mass and energy fluxes between land and sea. Satellite observations as well as findings of central interdisciplinary measurement cruises in the German Bight were used as driving force values and for the validation of high-resolution circulation and transport models which were developed for the atmosphere and water in the coastal region. They also served as a basis for an ecosystem model of the lower trophic levels. In this way model concepts and interpretation of the results provide the link between the physical, chemical and biological aspects. The regional balance sheet for water, energy and the major elements (C, N and P) in the coastal waters of the south-eastern part of the North Sea can thus be drawn up as part of the overall goal of "KUSTOS"

The "TRANSWATT" project, which is embedded in this concept, studied not only the distribution of the major biological elements in the mud flats of the North Sea coast but also their transport and the changes occurring in them. Here, too, the combination of field measurements, remote sensing and modelling made possible the first overarching description of specific structural as well as functional attributes of the mud flats. The requirements of the project were fully met by drawing up a budget of the major elements of the mud flats and describing the special role of the flats as a "bio-reactor" between the land and the open North Sea.

An overarching project design in accordance with the interdisciplinary LOICZ concept is similarly to be seen in the Baltic Sea research complex in the region of the Oder catchment area - Baltic Sea basin. This project, focused on the landward side of the coast and aimed at studying long-term strategies for conservation and water management of the Oder river, is investigating land-use changes and the resulting patterns of river discharge between the catchment area and the estuary of the river. In this region, directly influenced by anthropogenic activity, all fields of research have equal status with each other: the

scientific and the socio-economic strands of research as well as the study of the framework of environmental law under present and future political circumstances (e.g. Poland's joining the European Union).

The continuation of this project into the immediate coastal area derives from the intensive scientific research undertaken in the Oder estuary and the open Pomeranian Bight, in which transport, transformation and effects of the matter discharged into the coastal system are being studied within the framework of a three-project complex funded by the German Ministry of Education and Research (TRUMP-GOAP-ÖKOBOD).

The last project in this series is BASYS (Baltic Sea System Study). Funded by the EU, this study focuses on lateral transport into the sedimentation basin of the open Baltic Sea and the reconstruction of the more recent historical development based on the basin sediments.

This combination of research studies provides a complete view of the chain of processes from land use, via river discharge and interaction with the coastal systems, to sedimentation. This last process, in turn, makes it possible to reconstruct middle and long-term climatically and anthropogenically induced changes in the processes which precede it, thus linking the processes taking place in the water to those taking place on land. Integrated modelling of the overall system will combine the individual components with each other.

An example from the Baltic Sea projects may serve to demonstrate that the observed processes and those modelled are nearly identical. For the Oder estuary and the adjacent coast, both of which are influenced by the Oder discharge, a comparison has been made between a scene of chlorophyll distribution observed with a Coastal Zone Colour Scanner (Fig. 6) and a modelled scene based on the corresponding boundary conditions (real wind field, time of year, Oder discharge) shown in Fig. 7. This was generated by a coupled circulation and biological-chemical model. Of particular note is the fact that the calculated chlorophyll distribution is the end product of a long chain of processes which includes nutrition intake, topography, meteorology, layering and lateral transport as well as the complex mutual influencing of the biological components in the pelagic region during this time of year.

Immediate advantages of these instruments for the public as well as public administration are to be seen in the recent flooding of the Oder river valley. Even before the flood wave reached the estuary, scenarios were available to forecast the further distribution of and changes in the input of matter into the coastal waters of the Baltic with varying wind conditions.

However, it is also possible, in principle, to pursue over very long time scales the course of large amounts of input from the land from cultivated soils to the sedimentary basins by both measuring and modelling. In turn, this provides an early opportunity to assess the effects of anticipated socio-economic changes in the hinterland on the development and function of coastal systems and littoral seas.

Of special significance in this connection is the impact of the recent political changes in the countries of the former Eastern bloc. In a short space of time great social and

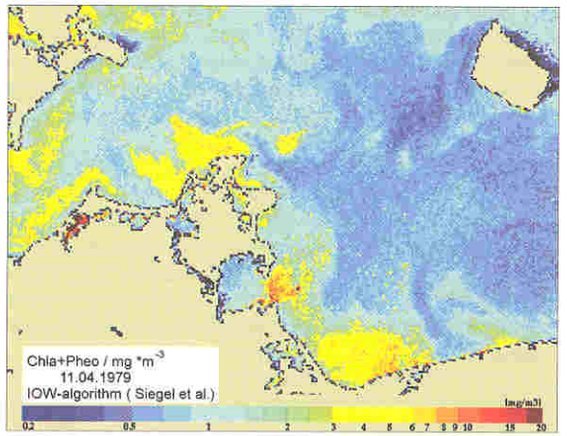


Fig. 6: Observed distribution of the phytoplankton biomass from the visible field of the Coastal Zone Color Scanner under typical (easterly) wind conditions (Courtesy of H. Siegel, Baltic Sea Research Institute, Warnemünde)

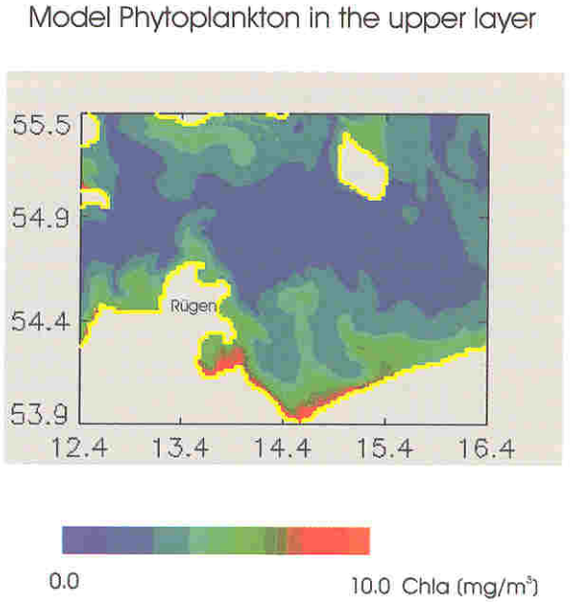


Fig. 7: *Modelled distribution of the phytoplankton biomass in the Pomeranian Bight under typical (easterly) wind conditions (Courtesy of Th. Neumann, Baltic Sea Research Institute, Warnemünde)*

economic changes have been taking place in this region which, by way of structural changes in industry and agriculture, directly leave their imprint on the discharge patterns of the Elbe and Oder rivers and which will presumably have a considerable impact on the coastal zone. Thus, at the present time, there is an opportunity of carrying out these studies within the framework of a huge natural experiment of global significance.

With regard to the future of the German LOICZ contribution, the examples of projects outlined above indicate that a research concept largely based on interdisciplinary approaches will be continued. In concrete terms this means that workshops have been, and will continue to be organised and inspired by these ideas with the special aim of strengthening the interdisciplinary components and leading to a formulation of new research goals in this area, in which the basic components (scientific, economic and sociological studies) must also continue in future to preserve their equal status and their complementary character within the programme.

9 PAST GLOBAL CHANGES (PAGES)-TERRESTRIAL

B. Frenzel & H.-J. Pachur

Terrestrial palaeoecological research in the framework of PAGES

In Germany, a wealth of palaeoecological topics are being investigated in various research projects which are focused upon the aims of PAGES:
This report briefly describes the results which have been achieved up to present as well as major problems, which will have to be studied by terrestrial palaeoecology in the near future.

1. Investigations by terrestrial and marine palaeoclimatological research groups have proved unequivocally that during the Quaternary two types of initial phase of an interglacial period existed. One is characterised by climatic oscillations as occurred during the Late-Glacial of the last glaciation. This type is characteristic of the initial phase of most interglacials. The other type lacked these climatic oscillations. This holds true for the Holstein interglacial and for deep-sea stage 11. The reasons for these differences must be studied intensively. The same holds true for the fact that these interglacials seem to have ended within a relatively long space of time (3,000 to 4,000 years), in comparison to (generally) much faster transitions from a glacial period to the ensuing interglacial.

2. According to investigations undertaken by GRIP (Greenland Icecore Project), the climate of the last interglacial was extremely variable. This cannot be confirmed by terrestrial investigations in Central Europe, even if annually layered lake-sediments are studied. Evidently the climate of the last interglacial was not more variable than that of the Holocene, whose variability increased in about 5,000 to 6,000 BP, when winter and mean annual temperatures slowly decreased in general. Yet the amplitude of Holocene climate changes never seem to have been wider than between the Medieval Climatic Optimum and the Little Ice Age. The reasons for the increasing variability of Holocene climates must be studied intensively.

3. During the final part of the last interglacial, when European climate was still mild and oceanic, the eustatic lowering of sea-level began, caused by heavy snowfalls in high northern latitudes. On the other hand no proof exists that hypothetical Tibetan inland-ice might have triggered the Nordic glaciations.

4. For the last interglacial West African tropical vegetation could be reconstructed by marine and terrestrial research. Evidently moisture was higher there than at present and the main vegetation - types differed from those of today. Simultaneously there was much more moisture available in Central Asia, too. As soon as sufficient SSTs of this remote time are available, the climatic situation of various phases of this interglacial should be modelled globally parallel to studies on climate development during this interglacial. This would help to better understand future global atmospheric circulation, if the climate is definitely becoming warmer than at present.

5. The stadial climates of the last glaciation were also studied in tropical and extratropical Africa. At those times the tropical rain forest was divided into several small refuge areas, which were quite remote from one another. The consequences of this with regard to biodiversity must be studied intensively.

6. The SSTs reconstructed by CLIMAP (Climate Mapping) for the LGM (Last Glacial Maximum) have repeatedly turned out to be inaccurate. German marine and terrestrial palaeoclimatology research groups are correcting these data so that palaeoclimate modelling groups might have better starting points for their investigations.

7. In regions of North Africa and Central Asia which are arid today, some interstadials of the last glaciation and certain phases of the Holocene experienced remarkably humid climates when huge lakes were formed. These lakes on the other hand should have become independently acting sources of water vapour for their surroundings (compare Fig. 8). Timing and significance of these sources of water vapour must be analysed in much more detail. It is worth mentioning in this connection that a new SFB (Sonderforschungsbereich) of the DFG is being planned for an analysis of the palaeoecological evolution of Central Asia. This is paralleled by Chinese research. Evidently the early and mid-Holocene atmospheric circulation patterns and those of interstadial warm climate periods differed from those of today. It is important to obtain a deeper knowledge of the whole repertoire of warm climate atmospheric circulation patterns. Modern climate modelling apparently does not take enough boundary conditions into consideration. This causes errors in the reconstruction of the regionality of former climates by climate modelling.

8. Marine and terrestrial research have shown that the CO_2 content of the Earth's atmosphere during the stadials of the last glaciation were strongly controlled by the degassing of the oceans, the changes in the terrestrial biosphere having lagged behind the degassing events of the oceans. Here much more multidisciplinary research is necessary.

9. The investigations of ice cores, annually layered lake sediments and tree-rings fix the Late-Glacial to Holocene transition in Greenland and Central Europe to about 11,500 BP (astronomical years). According to D- and ^{13}C-curves obtained from the cellulose of Southern-German tree-rings this transition lasted for about 200 to 300

years. Thus it lasted much longer than has usually been interpreted from ice cores and varves.

10. This major climate change caused an increase in moisture in various regions of the globe. The timing of this process was also governed by the geographical setting. E.g. in the hyperarid regions of North Africa the increase in moisture began some 3,000 years earlier, in some parts of Southern Tibet some 2,000 years earlier than in Central Europe. Thus there was no strict synchronicity in the amelioration of water budgets in various regions of the globe. On the other hand, various indicators of climate, like lakes, soils, peat growth, groundwater table, etc. evidently experienced different lag-times.

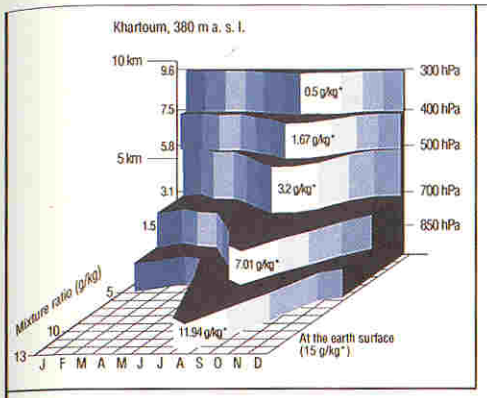
11. The major climate changes at the Late-Glacial to Holocene boundary triggered a wealth of biotic reactions, which from then on continued more or less independently of climate, and were governed by biotic factors only, like the position of former refuge areas, immigration facilities, competition, regulatory mechanisms, etc. This does not mean that from then on climate was of no importance for establishing various distribution patterns of different taxa of the animal and plant kingdoms, nor for vegetation. Exactly the opposite can be shown in climatically extreme regions. Yet under more favourable conditions the influence of climate on the distribution patterns of various taxa and ecosystems was smaller than that of biotic factors. Thus it is dangerous to reconstruct the distribution patterns of various vegetation types relying on climate only. These difficulties become even greater in regions, where complex distribution patterns of refuge areas had formerly existed, as in North and Central Africa, the Mediterranean region, as well as vast regions of Siberia and Central Asia.

12. In Ancient Egypt and the Near East written reports of past weather and climatic conditions are decipherable from about 3,000 BC. Written reports for the Mediterranean region exist from about 700 AD. During this research the pertinent vocabulary had first to be established in many cases. These data are important for studying the history of climate during the time mentioned in the East African tropics, Abyssinia, and the Near East. Moreover they might to a certain extent be linked with investigations on deep-sea cores from the north-western Indian Ocean and the Arabian Sea. The written reports about measurements of water-gauges on the river Nile clearly document the end of the mid-Holocene humid period in Eastern North Africa. On the

Fig. 8: *The trigger function of palaeo-lakes and palaeo-swamps during the Early to Middle Holocene, illustrated by a hyperarid area in the eastern Sahara. Evidence confirming the existence of extensive water vapour sources in the eastern Sahara during the Early to Middle Holocene suggests that a self-regulating regional precipitation regime prevailed. The northward shift of the easterly jet stream produces convection processes. The presence of water-vapour sources on the ground (palaeo-lakes, palaeo-swamps, broad riverine plains) may induce precipitation according to the pattern of squall-line formation. A short-term increase in precipitation results in recharge of the near-surface aquifers creating the necessary conditions for the formation of lakes and swamps which in turn supply water vapour for regional precipitation. A self-stabilising effect is created that is able to offset long-term variations in precipitation. Disregard of such self-regulating mechanisms may cause an observer to mistakenly assume a systematic, globally controlled increase in precipitation. (Courtesy of H.-J. Pachur, Free University of Berlin)*

Palaeo-summer situation in Western-Nubia

Approximately 9000 – 4000 before present



d Duration (days)
Palaeo hydrology
Present hydrology
Palaeo fauna - based on excavated bone fossils

Tertiary
Cretaceous
Jurassic
Triassic
}Silurian
Devonian
Carboniferous
Ordovician/Cambrian
Precambrian basement
Tertiary volcanic rocks
Aquiclude
Sand dune, aeolian sand

other hand they provide a detailed description of past human activities in these dry regions. Thus it is hoped that they will contribute strongly towards a better understanding of natural versus anthropogenic changes in the water-budgets of these climatically vulnerable regions.

13. These interrelations between spontaneously acting and anthropogenic changes in the water budget of Central Europe were intensively studied in a research project of the DFG on "Fluvial geomorphodynamics during the Upper Quaternary". Evidently during early and mid-Holocene times Central European water-budgets were dominated by changes in climate and by the immigration of new forest taxa the transpiration of which was higher than that of previous plant communities. Yet from the end of Atlantic times onwards man's influence on the Central European water budget rapidly became of utmost importance. The same seems to hold true for North Africa and Central Asia. It is hoped that much more detailed knowledge will result from the above-mentioned SFB of the DFG.

14. To model possible early human impact on climate it is important to know the surface areas cleared of forests during various phases of the past. This very difficult task is being undertaken in close co-operation with international research-groups within the European Science Foundation research project "European climate and man since the last glaciation". It seems that in Europe during the times of fully developed neolithic cultures approximately 20-30% of the land below 700 m were already cleared of forests. At least the influence of agriculture and later of mining and ore-smelting, reflected in the aerosol of the lower atmosphere, can be traced by analysing the chemistry of ombrogenous peat-bogs in Europe since the end of neolithic times.
However, up to present no answer has been found to the question whether the intensification of the European summer monsoon, beginning at the same time, was caused by increasing human activities or by spontaneous changes in the general circulation of the atmosphere.

15. In this connection investigations into the history of changes in European lake levels have not proved to be very helpful. It is true that during the Late-Glacial and the early Holocene European lake levels were chiefly governed by climate and possibly by spontaneous changes in the vegetation of the lake's drainage basins. Yet from the onset of neolithic times human impact became decisive. This unfortunate situation is also aggravated by the fact that phases of European lake level changes are very often either inadequately proved or inaccurately dated. Thus it is extremely dangerous to rely on lake level changes as indicators of past climates without having scrupulously analysed the facts.

16. The European history of weeds reveals that soil erosion and the chemistry of the soils have increasingly been influenced by man since the beginning of neolithic times. Man tried to counteract these negative effects by liming and fertilising the fields from about the Iron Ages onwards. On the other hand forest clearances and the establishment of directly or indirectly man-made plant communities caused a strong increase in European biodiversity. The same seems to have happened in other regions of highly developed cultures at that time. These processes strongly influenced the surface albedo. Yet it is still not known, whether man-induced changes in the

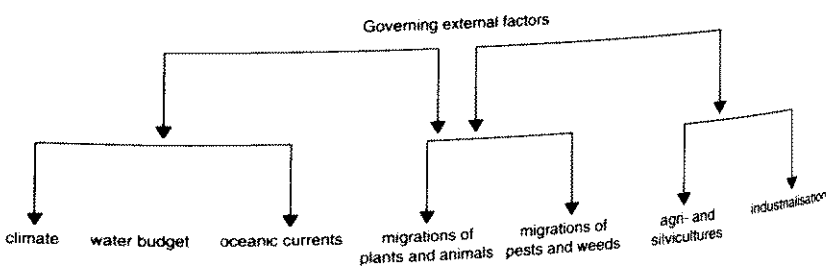
radiation budget have influenced climate to a perceptible degree. In this respect, too, much more interdisciplinary research work is necessary.

17. Dendroclimatological investigations using the contents of stable isotopes in the cellulose of tree rings have shown that the Medieval Climatic Optimum occurred at exactly the same time in Europe and Tibet. The same holds true for the Little Ice Age. In both these phases various minor oscillations of climate took place, the amplitude of which may sometimes even have exceeded 2° K in summer temperatures. Thus both these major phases were of continental importance, at least in Eurasia.

18 Many of the results mentioned were published in 1992 in the "Atlas of Palaeoclimates and Palaeoenvironments in the Northern Hemisphere; Upper Pleistocene - Holocene" in co-operation with the Russian and the Hungarian Academies of Sciences. Since most of the data compiled has been corroborated in the meantime by international research, it has become even more important to improve the data sets of SSTs of various phases of the past to give climate modellers a sound basis for their difficult research.

From everything that has been said it seems to be important with regard to future multidisciplinary and international research to concentrate on the following topics:

Stability, regulating mechanisms, vulnerability and evolutionary trends in spontaneous and man-made ecosystems on a global and regional scale



Ecosystems:

Allogenic ecosystems
(e.g. wadden sea, shifting sand dunes, plankton associations, associations on flood plains, debris flow and snow-avalanche fans and their biocenoses)

They respond rapidly to external triggering.
Displacements? In which direction?
Transformation? Into which system?
What about transformation into autigenic ecosystems: never/blocked/slowly/fast?

Autigenic ecosystem
(e.g. dense forests, ombrogenic peat-bogs, dwarf shrub communities)

Problem:
Spontaneous or man-made.
Does there exist a vulnerability caused by the evolution history of the ecosystem investigated?

Regulatory mechanisms

Preserving:
how long, how effectively?

Leading to new situations:
Into which direction?
How rapidly?
Regularly or stepwise?

Aim of research:

Evaluation of the stabilising capacity, the vulnerability, threshold value, probable tendencies of evolution (qualitatively, in scale, in time, where) under given boundary conditions.

Evaluation of quality and strength of feedback mechanisms.

10 PAST GLOBAL CHANGES (PAGES) - MARINE

K. Herterich, with contributions from M. Sarnthein, G. Wefer, B. Grieger, S. Lorenz, S. Mulitza, U. Pflaumann, M. Weinelt, U. Wyputta

Palaeoclimate reconstruction of time series and time slices

The reconstruction and comprehension of past climate variability requires the synthesis of proxy data evaluation and numeric modelling. Data are indispensable as model boundary conditions and to validate models. On the other hand, models can calculate quantities on which no data are available and reveal data inconsistencies. While at present three-dimensional general circulation models which can be run over palaeoclimatic time scales to generate time series are still under development, models of ocean and atmosphere are used to reconstruct time slices.
To analyse the natural past climatic variability the Kiel palaeoclimate research group focuses on two scientific topics: i) the reconstruction of time-slices and ii) of high resolution time series of the last 65,000 years.

Ad i) As the first time slice the Last Glacial Maximum (21-17 ka) was chosen as the scenario for an extremely cold environment with a maximum extension of ice sheets. Another time slice in reconstruction is the interval of the postglacial Meltwater event, representing a phase of rapid natural climatic changes which may serve as an analogue of potential manmade climatic disturbances.

Ad ii) Abrupt climatic changes (like Dansgaard-Oeschger or Heinrich events) are common natural events as documented in super high resolution climatic records from ice cores and marine sediments. Thus, the time series can contribute to understand the extremely rapid and serious natural climatic deteriorations having affected especially Europe repeatedly in the past and will also do in the future.

The (Greenland Ice Sheet Project) GISP2-$\delta^{18}O$ "temperature" record (Fig. 9, central curve), recently generated (Grootes et al. 1997), serves as a varve census based precise timescale monitoring the Dansgaard-Oeschger cycles. It provides the proof for the rapidity of natural dramatic climatic changes which occurred on a decade scale only. The origin of the changes, however, cannot be extracted from the ice core climatic records but have to be searched in the marine record.

The $\delta^{18}O$ curve of sediment core PS2644 (Fig. 9, top curve) from the western Iceland Sea which can be correlated exactly to the GISP2 climatic curve, allows for the study of the processes controlling climatic change: repeated multiple meltwater events released from the surrounding ice sheets interrupt or even reverse the oceanic thermohaline circulation (North Atlantic salinity conveyor belt).
For comparison the Vogesian tree pollen record (Woillard & Mook 1982), already established 25 years ago, is shown in Fig. 9, base curve. This pioneer study reflects the actual impact of global oceanic disturbances on the Mid-European climate and has been recently fully confirmed by newer records from the French working group in Marseilles (PAGES terr./GCTE).

Since 1989 the Collaborative Research Centre (Sonderforschungsbereich) No. 261 at the University of Bremen has carried out extensive geological, geophysical and

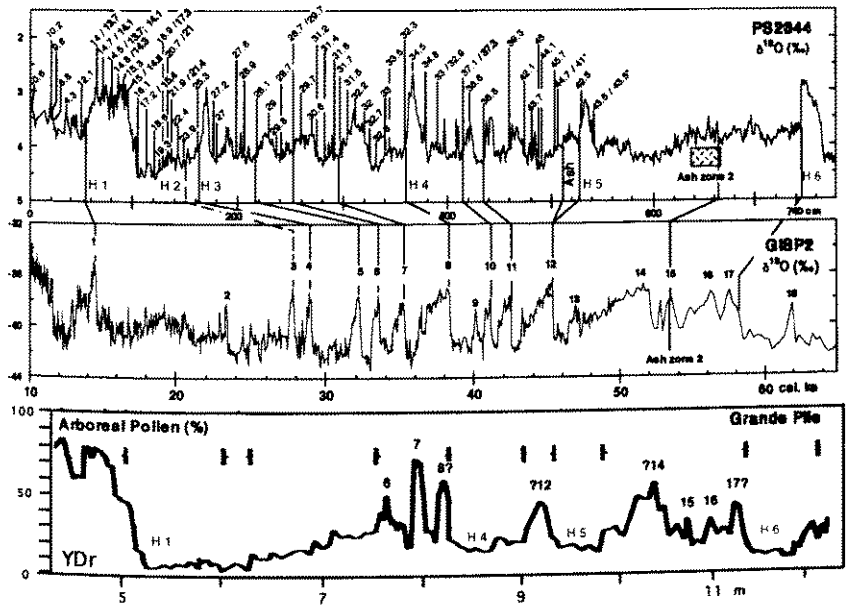


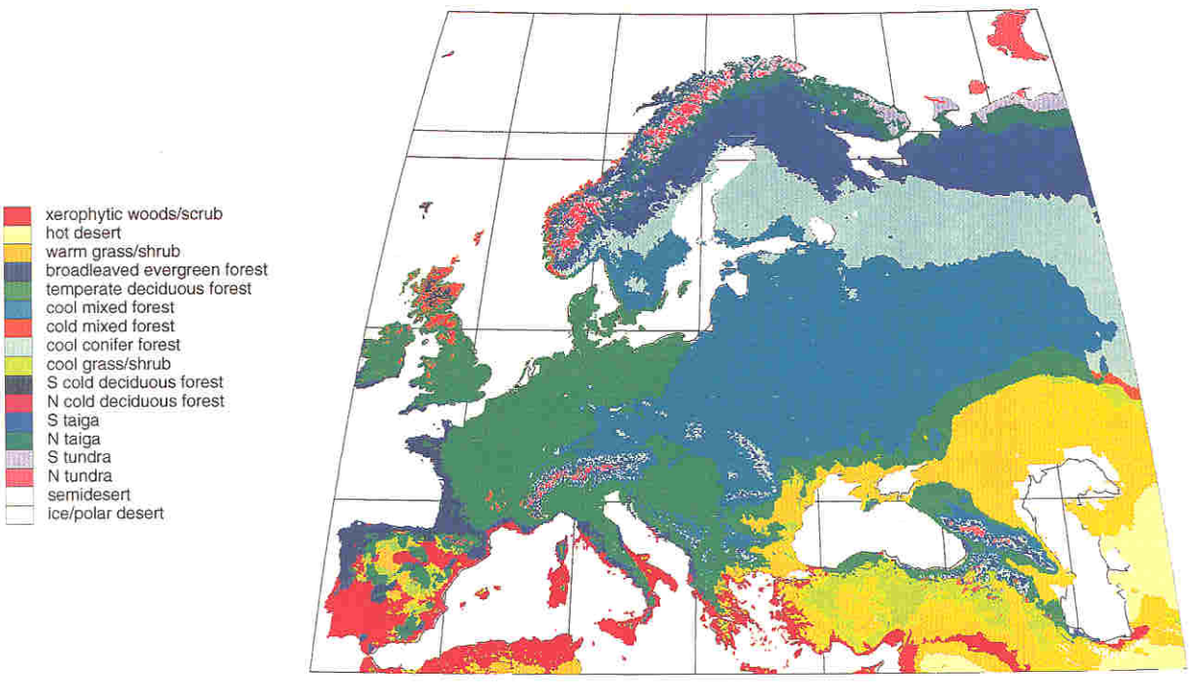
Fig. 9: *Three super high resolution time series of rapid natural climatic changes during the past 65,000 years.*
a) Oxygen isotope ratios of calcitic planktonic foraminiferal tests selected from sediment core PS2644, Western Iceland Sea versus core depth. Low $\delta^{18}O$ values indicate mainly small polar ice volumes, i.e. warm climatic periods. The numbers indicate absolute ^{14}C ages (determinations Kiel Leibniz Lab.): those in bold type are from benthic, those in plain type from planktonic carbonate; asterisks indicate samples measured in Gif-sur-Yvette, France; H1 to H6 mark the position of major meltwater events (Heinrich layers).

b) Oxygen isotope ratios of water (vs. SMOW) from GISP2 ice core from Central Greenland versus absolute calendar ages (in 1,000 years BP) (Grootes et al. 1997). Numbers indicate the rapid warm temperature deviations at the beginning of the interstadial stages (equivalent to the warm parts of the Dansgaard-Oeschger cycles).

c) Tree pollen percentages in the Grande Pile section versus depth in the peat profile (Woillard & Mook 1982). High percentage values indicate warm climatic intervals. YDr = Younger Dryas cold interval, H1 to H6 mark the position of the Heinrich events, the other numbers correspond to the Dansgaard-Oeschger cycles.
(Courtesy of U. Pflaumann, University of Kiel)

BIOME 1.1

current climate



BIOME 1.1

climate 2070-2099 (HadCM2 modified)

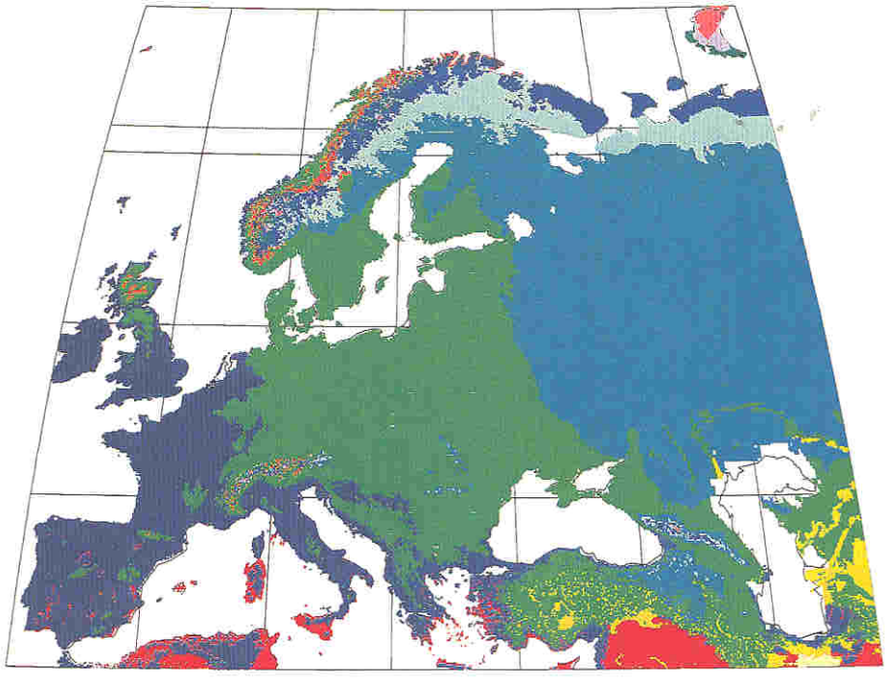


Fig. 10: *Distribution of the potentially natural vegetation in Europe, estimated by the equilibrium model BIOME 1.1 a) Current Climate (p. 68) b) With a climate scenario derived from a transient simulation of the Hadley Centre Coupled Ocean Atmosphere Model (HadCM2) for the end of the next century. (Courtesy of W. Cramer, Potsdam Institute for Climate Impact Research, Potsdam)*

geochemical investigations on the various current and productivity systems of the South Atlantic. The central theme of this research is the reconstruction of current and productivity systems in the South Atlantic on both time slices and high resolution time series for the last 300,000 years. Investigations of sediments have revealed that the production of North Atlantic Deep Water (the "nordic heat pump") decreased during glacials. This reduction may has been directly caused by a decrease in energy and salt inputs from the South Atlantic. To test this hypothesis with ocean models, boundary conditions for the time-slice of the Last Glacial Maximum are currently established at the University of Bremen at about 56 coring sites throughout the equatorial and South Atlantic. The investigations include the reconstruction of temperature, salinity, thermocline depth, nutrient concentration and productivity.
The Palaeoclimate Modelling Intercomparison Project (PMIP) investigates the physical mechanisms of climate change and the sensitivity of climate models to different parameterisation schemes. 18 atmospheric general circulation models from 8 countries participate in PMIP. With these models simulations of the atmospheric circulation for 6,000 years before present (BP), when summer insolation was enhanced in the Northern Hemisphere (Climatic Optimum), and 21,000 years BP, corresponding to the Last Glacial Maximum (LGM), were performed. The boundary conditions used for these two time slices were agreed upon among the PMIP-contractors. The results of the palaeoclimatic model simulations were collated in order to determine why they agree in some aspects and differ in others. Furthermore, a detailed model-data comparison takes place. These palaeoclimatic intercomparisons will lead to an improvement of the models' parameterisations, and on the other hand the cause of mismatches between marine and terrestrial data can be elucidated.
For an intercomparison of the model results the average and local standard deviations of several quantities of six atmospheric models participating in PMIP were computed. The largest differences between the glacial and the modern models' 2m-temperature, which are -24°C, occur over Europe and North America due to the extension of the European and North American ice sheets. While over the oceans the temperatures are closely tied to the prescribed SSTs, the global mean standard deviation between the models overland amounts to 4°C for the present climate and to 5°C for the LGM runs. The larger latter value indicates that model uncertainties are indeed increased for climate states different from the modern one. This is not a consequence of a larger spatial temperature variance over land for the LGM, which is even slightly smaller (18.2°C compared to 18.7°C for the control runs). The root-mean-square temperature difference over land between LGM and modern climate is 7.8°C, implying a "signal to noise ratio" larger than unity in the model response. For a better reconstruction of the atmospheric circulation during the LGM yielding a better agreement between models and data improved sets of boundary conditions are desirable.

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THE HUMAN DIMENSIONS OF GLOBAL ENVIRONMENTAL CHANGE - SOCIAL SCIENCE RESEARCH IN GERMANY

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This document presents an introduction to the potential role and present state of research in the field of the Human Dimensions of Global Environmental Change in Germany. The role of the social sciences in the field of Global Change Research is discussed, and the scientific issues and the German contribution to the international programmes described. This first report is of a somewhat preliminary nature and by no means exhaustive.

1 THE ROLE OF THE SOCIAL SCIENCES IN GLOBAL ENVIRONMENTAL CHANGE RESEARCH

During the last decade of global environmental change research, the focus of interest has changed. After a period dominated by the investigation of causes of environmental problems by the natural sciences, the human dimensions of global environmental change are being reflected on more and more. By now, it has become apparent: to explain and predict the course of global environmental changes, the human driving force, the consequences, and the human responses must be understood.

The German Advisory Council on Global Change (Wissenschaftlicher Beirat Globaler Umweltveränderungen WBGU, 1996) stressed the fact that human action is the cause of global environmental change, but it is also affected by the latter. In their third and most important role humans react to these changes by adapting to the damage which has occurred and by taking precautionary measures to avoid causing further damage, which means that the social and the natural sciences have complementary roles in managing global environmental change and in finding practical solutions for environmental problems. Indeed, it is expected that social sciences will contribute to the prevention of damage to the physical environment caused by society, with the second focus on mitigation strategies.

The social sciences and the humanities provide a whole range of disciplines, with a great variety of concepts, methods and research questions but also a richness of answers to Global Change issues. While major disciplines such as psychology, sociology, economics, political science, cultural geography, ecology, law, education or medicine have already made significant contributions, there is still an urgent need for overall co-ordination and an integrative research strategy within the social sciences.

2 MAJOR TOPICS OF SOCIAL SCIENCE GLOBAL ENVIRONMENTAL CHANGE RESEARCH AT THE INTERNATIONAL LEVEL

Almost all human activity has some potential relevance to Global Change. A complex of social, political, economic, technological, and cultural variables, sometimes referred to