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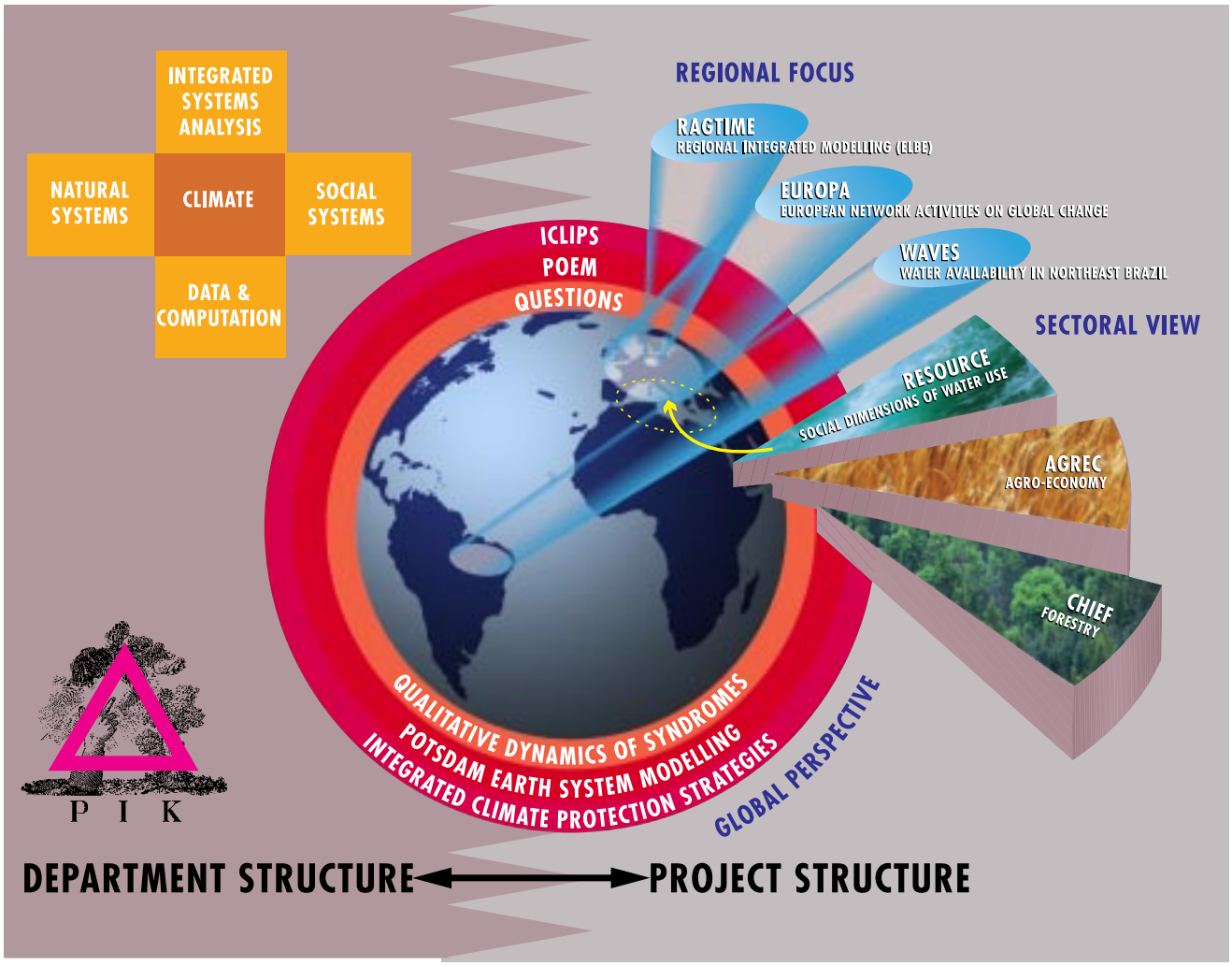


Fig. 1: Research activities at PIK.

The Potsdam Institute for Climate Impact Research (PIK)

by Hans-Joachim Schellnhuber and Manfred Stock

The Potsdam Institute for Climate Impact Research was founded in 1992, the year that the Rio Conference was expected to grind out the blue-print for global sustainable development. This conference can be seen as a reaction to primarily two fundamental changes going on in the world at that time: first, the birth of an awareness that anthropogenic climate change may be a threat as real as the ozone depletion in the stratosphere; second, the opening of a window for global environment and development governance after the end of the Cold War. The foundation of PIK as recommended by the German Science Council (Wissenschaftsrat) is just one tiny facet reflecting the new attitude towards life on Earth emerging in the early nineties. For the scientific evidence that civilization is capable of interfering significantly with the global atmospheric dynamics had become overwhelming.

But what should be done about this? Whether you want to avoid, mitigate, adapt to or tolerate climate and Global Change, you have to know much more about the potential consequences of these options for planetary and regional environmental management: What will the impacts be on nature, economy and lifestyle? What kind of scientific approach is appropriate for such impacts analysis and assessment? Which disciplines and methods from natural and social sciences have to be integrated in order to reach solid conclusions? How can we avoid the "Babylonian" confusion generally resulting from unsophisticated integration attempts?

At PIK we have begun to address these questions using standard disciplinary recipes as well as innovative transdisciplinary concepts. The scope of the scientific challenge which the Institute has to meet is rather unique, particularly as there are no established models or prototypes for conducting impact research in the international community. Yet we feel that we have made considerable progress along this sparsely populated road in the last years, and the new biennial report is going to demonstrate that.

The Conceptual Background of the PIK Approach to Environmental System Analysis

The Institute's general philosophy and methodology have been described before (e.g., in the introduction to the first biennial report 1994/95). Here, we just want to emphasize that the heterogeneity of the scientific tasks to be solved by PIK (ranging from empirical time series analysis to paradigms for ecosphere management) and the complexity of the environmental systems to be investigated call for a specific research strategy, which generally compromises between high-precision analysis and educated guesswork.

The basic PIK approach is to take up, process, summarize and assess the empirical findings from a broad variety of disciplines and institutions. Doing this yields a highly complex and interrelated knowledge base, from which meteorological, hydrological, ecological, socio-economic and transdisciplinary models are constructed. In essence, these models and their underlying data bases constitute the Institute's core capital. By means of computer simulation, these models are used for generating past, present, and future environmental realities and scenarios.

This concept sounds rather simple and straightforward, yet constitutes an extraordinary challenge. For modelling and simulation becomes unfeasible or inoperable if too many details are taken into account, and it becomes superficial or useless if important aspects are left out. Is there a way out of this dilemma? Recent developments within and outside the Institute have fortunately demonstrated that such a way indeed exists by constructing models of truly intermediate complexity. In the following, this strategy is explained briefly and its consequences for impact research are indicated.

Considering real dynamic systems of genuine (rather than perceived) complexity, we realize that this complexity is usually organized in a hierarchy of characteristic patterns, types, or entities. This holds true for the cosmos, which is structured into galaxies, milky ways and solar systems, as well as for the terrestrial biosphere with its taxonomic make-up of species, ecosystems and biomes, and for human civilization as a whole, consisting of cultures and nations that cannot always be clearly distinguished from one another and yet have particular identities. In fact, without the existence of such prototypical patterns and functional entities we would not be capable of perceiving reality in a structured way at all. Such semi-autonomous entities of reality are as a rule of "mesoscopic" character, i.e. they form an oligarchy of a finite number of elements on their respective scale levels.

The last remarks may appear as bloodless epistemological rhetoric to the reader. Their validity and usefulness could be demonstrated, however, by inspecting, say, the perpetual organization of civilization through a small set of cultural archetypes, namely the entities "village", "city", "landscape", "region" and "state". Theoretical analysis of these entities and their interactions reveal the overall structure and dynamics of human settlement, and simulation exercises of any type and ambition should rather take advantage of the "granularity" found in reality.

The temptation will be strong, of course, to try to construct or deduce the respective pattern formation quantitatively from "first principles" like the basic laws of quantum mechanics or of molecular biology. Yet this is an undertaking that is bound to fail. The rigorous theoretical derivation of effective large-scale equations of motion from microscopic dynamics has been possible so far only for extremely simple or significantly simplified systems – often on the basis of rather rigorous assumptions concerning the space of eligible solutions. The alternative approach, brute-force computer simulation, is generally inconclusive: how long would it take, for example, to mimic the behaviour of 10^{30} elementary particles until the faunic pattern "giraffe" is "invented"? And a computer-assisted individual-psychological reconstruction of the social dynamics of the 20th century is probably not capable of producing "Hitler" or "Gorbachev" as emergent types of politicians.

But even if the bottom-up approach would overcome the limitations in computational resources: it would not explain the formation of those patterns. Computations are, after all, no more and no less than a specific kind of experiment from which the scientific essence still has to be extracted by (occasionally ingenious) the interpretation of the results.

Currently there is some hope among natural scientists and mathematicians that the big enigmas about the make-up of our universe might be solved by finding one simple set of integrated field equations, which would allow us to deduce the properties of quarks as well as the curvature of space-time in one blow. Whether this dream will come true or not, environmental systems are definitely more complicated than

physical ones; therefore a "common-sense approach" to identifying and explaining the mesoscopic entities dominating our ecological reality seems appropriate. Such an approach first recognizes the existence of these entities, then studies their characteristic (or typical) behaviour, and finally constructs appropriate theories that match the observations as closely as possible – or necessary. Such a procedure has proven to be very successful even in solid state physics, where a real zoo of quasi-particles prevails.

This does not mean, however, that the heuristic strategy just outlined must proceed along purely phenomenological lines only. With the help of theories of medium analytical depth and range we may attempt to formally encode those patterns that have been discovered mainly by inspection – through parameterized differential equations or empirical look-up tables for evolutionary rules, for instance. The resulting formalism then allows models of intermediate complexity to be constructed and quantitative statements to be generated on the dynamics, the stability, and the synergies of the constitutive elements.

This strategy plays a key role in the research strategy conducted at PIK. It is employed, for example, in the way we try to simulate forest succession under changing climatic conditions or global atmosphere-vegetation interaction by means of "functional types" (core projects CHIEF and POEM/DVGM, respectively). It is reflected in the construction principle for the Earth system model CLIMBER, which anticipates characteristic climatic structures and patterns, or in the hierarchy of "hydrotopes" instrumental in the multi-scale description of the Elbe's ecohydrology (RAGTIME). It provides the basic recipe for the semi-quantitative decomposition of the mega-phenomenon "Global Change" into archetypical "syndromes" (QUESTIONS) and plays a role in the formulation of effective (reduced-form) modules for the integrated assessment of climate protection scenarios (ICLIPS). It is, in fact, rather easy to trace this strategy through most of the Institute's central or peripheral projects.

The resulting intermediate models attempt to combine quantitative description and qualitative intuition in the best possible way; thus they are often the only adequate instruments to tackle complex ecosystems. Such instruments are not easy to set up, however, and even more difficult to handle, as can be seen in the integrated modelling of river catchment areas. But there is an additional price to be paid, which is connected with the criteria for success within the scientific community: it is easier to acquire reputation, as a rule, by concentrating on a fairly limited and well-defined subject matter and scrutinizing it with the highest possible precision. Alternatively, the erudite discourse of rather broad questions demonstrating a profound knowledge of the pertinent literature is comparatively well respected. Theories of the intermediate kind fall between these extremes and continually have to resist the forces of attraction of the latter.

Up to now, however, our experience with the tasks of Earth system analysis and climate impact research has shown that we are indeed bound to remain on the "narrow path of intermediacy" if we want to provide useful answers to the most urgent questions. How PIK has been passing along that path in an act of balance between pure and applied research – that is what this biennial report is trying to demonstrate.

Departments and Core Projects as Management and Research Structures

From the beginning the Institute's management structure was department-oriented. Four "classical" departments: Impact Climatology, Natural Systems, Socio-economic Systems and Data & Computation are complemented by the Department for Integrated Systems Analysis, which has the task to combine these fields. It soon became evident, however, that we have to look at impact problems in a more general way to understand their dynamics aiming at managing solutions.

The dynamics of Global Change and the relevant processes in the Earth system are investigated at PIK by inquiring into certain transdisciplinary key questions. These key questions are beyond the scope of any individual scientific discipline. Approaches from these disciplines have to be combined using methods of systems analysis to form interdisciplinary research projects. These projects have been selected from proposals made by PIK scientists during an internal evaluation process which involved the Institute's Scientific Advisory Board (SAB). The process resulted in several fundamental research topics, called "core projects". From the start, nine core projects were selected from about twenty proposals. Progress and success of the core projects are evaluated annually by the SAB, advising PIK how to continue, intensify or decrease certain activities or even to close a core project. In this context, the role of the scientific departments is to connect the core projects closely to the methodological development in their disciplines, to support the scientific staff and to control the quality of work and results.

At present, research is done in the eight core projects listed below on global and regional scale from either an integrative perspective or with more sectoral emphasis. As number nine, the European network research activities combined in EUROPA are on the way to form a new core project; figure 1 gives an overview of these research activities at PIK.

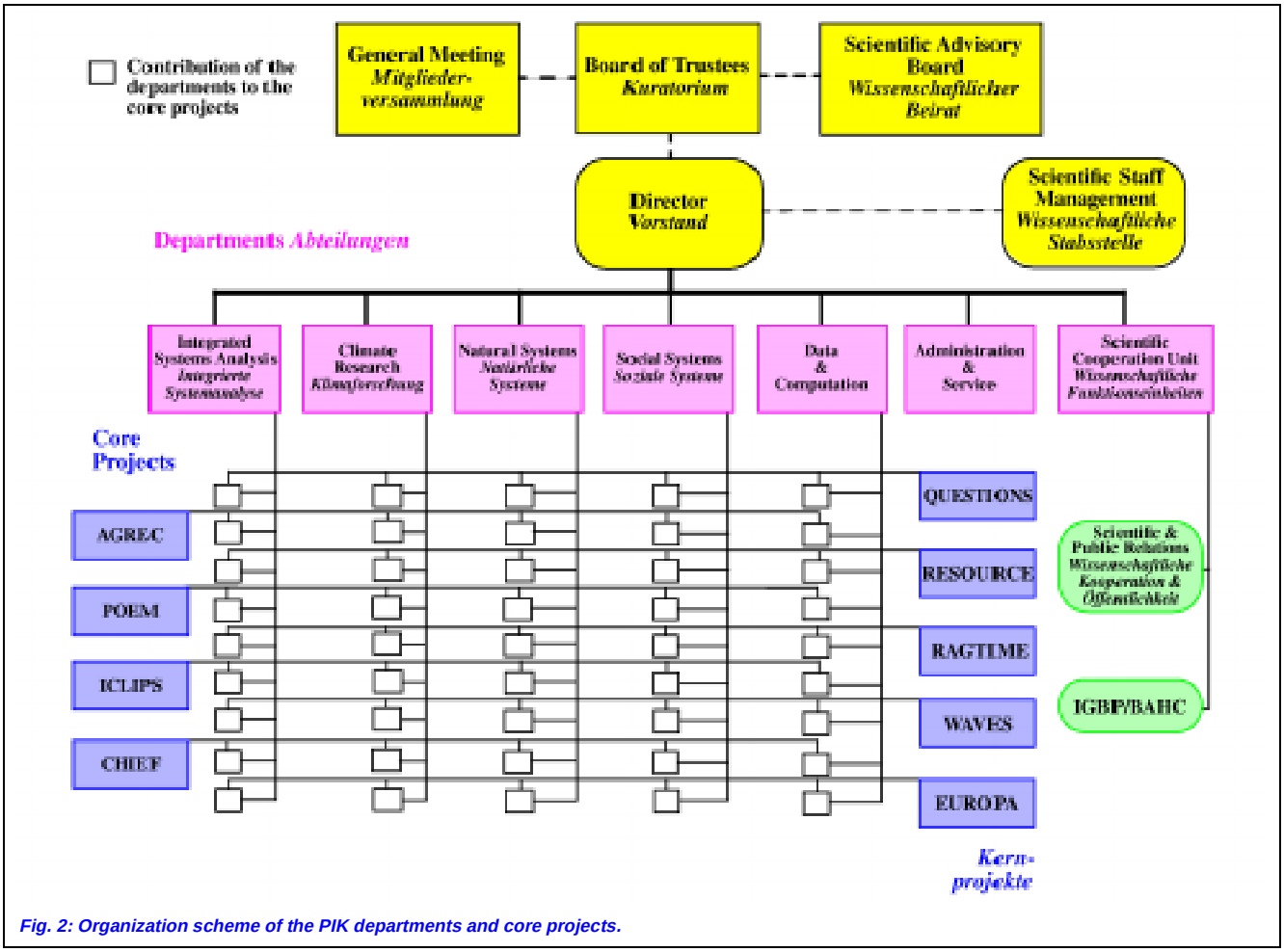


Fig. 2: Organization scheme of the PIK departments and core projects.

PIK Core Projects by Research Focus

Global perspective	*Regional focus*	*Sectoral view*
POEM Potsdam Earth System Modelling	**EUROPA** European Network Activities on Global Change	**AGREC** Assessment of Agro-Economic Impacts of Climate Change on Central and Western Europe
ICLIPS Integrated Assessment of Climate Protection Strategies	**RAGTIME** Regional Assessment of Global Change Impacts Through Integrated Modelling in the Elbe River Basin	**CHIEF** Global Change Impacts on European Forests
QUESTIONS Global Change: Qualitative Dynamics of Syndromes and Transition to Sustainability	**WAVES** Water Availability, Vulnerability of Ecosystems and Society in the Northeast of Brazil	**RESOURCE** Social Dimensions of Resource Use – Water Related Problems in the Mediterranean

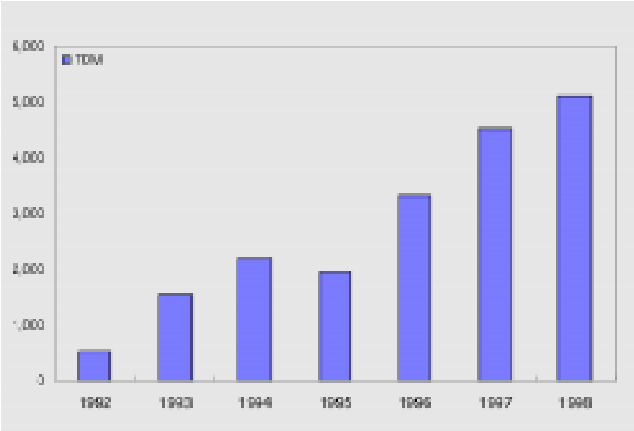


Fig. 3: Development of external project funding (Drittmittel) at PIK in Thousands of DM in the history of PIK.

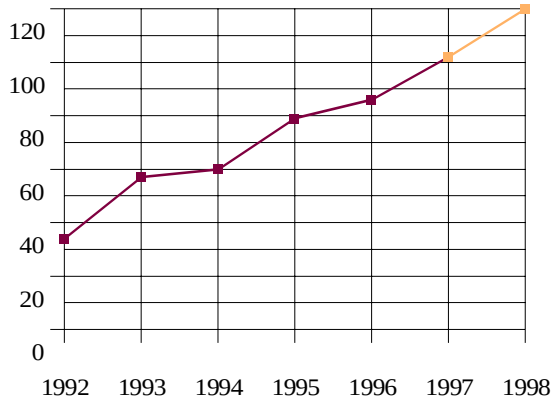


Fig. 4: Increase of employees and collaborators in the history of PIK.

The overall PIK research concept forms a matrix structure of departments and core projects shown in figure 2. This structure is a schematic representation of the interdisciplinary linkage. However, to fulfil all scientific tasks represented by the boxes in this structure adequately, is beyond the resources of PIK´s regular staff. Therefore three ways of extra support are used. First, a small additional budget is available for postdocs, students and visiting scientists working for several months up to some years at PIK. Second, international and national scientific cooperation with other institutions is highly encouraged at PIK, by organizing conferences, workshops or joint projects. These activities are particularly supported through the German national IGBP Bureau and the international BAHC Secretariat, both of which are located at PIK. Third, additional project funding from a variety of sources is continuously acquired.

The development of this additional budget of external project funding, as well as the corresponding increase in the number of staff members at PIK, are shown in figure 3 and figure 4 for the period 1992 - 1998. These figures and the development they show are representing the growth phase of PIK's research strategy into Global Change and Earth system analysis. The conceptual background of PIK's research approach and the interdisciplinary structure organising PIK's research activities can be traced in the results described in our biennial report.

Hans-Joachim Schellnhuber

Director of the Potsdam Institute for Climate Impact Research and Professor for Theoretical Physics at the University of Potsdam. Heisenberg Fellow. Research activities at the University of California in Santa Barbara and Santa Cruz. Formerly Professor (1989) and later Director at the Institute for Chemistry and Biology of the Marine Environment in Oldenburg. German Chair of the International Geosphere Biosphere Programme and Vice Chair of the Global Change National Committee of the German Science Foundation (DFG). Member of the German Advisory Council on Global Change since 1992, Chair since 1996.

Global Integrated Modelling and Assessment

POEM
Potsdam Earth System Modelling

Convening Project Leader: Hans-Joachim Schellnhuber
Project Leaders: Martin Claussen, Wolfgang Cramer, Yuri Svirezhev

A major challenge for the scientific community today is to explore the dynamic behaviour of the Earth system, as well as its resilience to large scale perturbations, such as the continuing release of fossil fuel combustion products into the atmosphere or the alteration/fragmentation of vegetation. The POEM project addresses this task on three different, but related, scales, (i) by developing a dynamic model of the land biosphere and its response/feedback mechanisms to the atmosphere, (ii) by developing a mechanistic, intermediate-resolution model of all major components of the Earth system (atmosphere, ocean, biosphere, cryosphere), (iii) by developing a model of the long-term evolutionary dynamics of the geophysical Earth system. Together, the resulting models will be used to study the stability of the Earth system under a broad range of scenarios for modified boundary conditions.

From left to right:
Martin Claussen, Hans-Joachim Schellnhuber,
Yuri Svirezhev, Wolfgang Cramer.

Motivation

Human interventions play a significant role for the Earth system. We are currently altering the character of the Earth with an increasing rate, and the present dynamic stability of the Earth system itself may be endangered. During the last 10,000 years, the climate has been rather stable in comparison with the 100,000 years before. The development of agriculture and the associated civilizations during this phase of climatic stability is probably not coincidental. An important and exciting question is therefore whether the Earth system could return to a more unstable mode if the concentration of greenhouse gases in the atmosphere continues to increase. It seems plausible that changes in the North Atlantic current could have caused drastic climate instabilities in the past and that the same could happen in a warmer climate. If so, then this could be a major threat to human society.

The core project POEM addresses the problem of Earth system stability by analysing the dynamic processes between the geosphere (the abiotic world) and the biosphere (the living world). The geosphere itself can be subdivided into the atmosphere, the hydrosphere (mainly the oceans), the cryosphere (ice masses), and the lithosphere (the upper solid Earth). There is increasing evidence that the dynamics of the Earth system cannot be determined by studying its subsystems alone. Due to the nonlinear synergisms between the subsystems the response of the entire Earth system to external perturbation drastically differs from the sum of the responses of the individual subsystem or a combination of a few of them. As a consequence, an integrated analysis of the fully coupled Earth system is required to approach a solution to the problem.

Component Models

Several PIK projects have been studying integrated systems analysis, climate system modelling, and modelling of vegetation dynamics, all at the global scale. Since 1997, these efforts have been brought together in the POEM activity. As a first step three model components are set up which all focus on particular processes of the geosphere-biosphere interaction at different time scales:

- The short-term (days to centuries) atmosphere-biosphere interactions and vegetation dynamics are addressed by the development of a Dynamic Global Vegetation Model (DGVM), incorporating physiology and stand dynamics (including disturbances).

- At the intermediate time-range of centuries to millennia the feedback between atmosphere, ocean, vegetation and inland ice becomes important. This is described by the CLIMBER (CLIMate and BiosphERe) model.
- The long-term evolution and development of the biogeochemical cycles is influenced by variations in the luminosity of the sun, plate tectonics, and changes in the geosphere, which is the focus of the CO-Evolutionary biosphere and geosphere Model (COEM).

Recent studies have shown that the Earth system may have several stable states with a complex transition structure. Hence the analysis of short and intermediate-scale changes of the geosphere-biosphere interaction must be embedded in the long-term evolution - the actual state of the geosphere-biosphere interaction depends on the Earth's history. For example, theoretical studies have shown that in the present-day climate, a large part of the Sahara could be either sparsely covered by some desert shrubs (as it is today) or more or less densely covered by subtropical vegetation. Hence the actual state of the desert can only be explained by analysing both the interaction between the atmosphere and the vegetation of the Sahara as well as its historical development.

By dividing the analysis of geosphere-biosphere interaction into three time scales it is implicitly assumed that the interaction across these time scales is weak. However, this is not yet clear at all. Therefore, in addition to the three model components, POEM encompasses a synthesis component which will be launched after its initial phase.

The POEM model components, DGVM, CLIMBER and COEM, as well as first results will be described in the following sections. After that, three specific, POEM-connected projects (ETEMA, Millennia and MGBM) are presented.

Dynamic Global Vegetation Model – DGVM

Project Leader: Wolfgang Cramer

Motivation

In a coupled Earth system model, the land biosphere represents a significant element of uncertainty. Both theoretical considerations and recent results obtained with simplified atmosphere-biosphere models have shown that the Earth system might be capable of showing either considerable inertia due to slow vegetation responses, or rapid "pulses" due to fast mobilization of carbon from the land to the atmosphere. Both possibilities even exist at the same time, since the response is likely to be different regionally, just as the current scenarios of changing temperature and rainfall differ from place to place.

These dynamics have strong implications for the overall system and hence for the future of a sustainable earth, for several reasons. First, the time constants of *carbon pools* on land, most of which are connected to vegetation or the soil, span a wide range from minutes to centuries. This is due to rapid (mostly light-driven) changes in the photosynthesis in plants, the relatively slow build-up of biomass in most ecosystems and the slow to very slow decay of organic matter in the soil. Due to this mixture of relevant time scales, it is questionable whether ecosystems can ever be in full equilibrium with the climate. This disequilibrium is even more crucial in times of rapid change in climate and CO_2, since it prohibits the estimation of carbon pools from the present climate and demands a full account of system history.

A second cause of concern are the physical feedbacks between land vegetation and atmospheric circulation. Vegetation structure directly affects roughness and albedo of the land surface, and it does so differently, depending on the time of the year, the stage of the vegetation development, or the local land use. Overall, the physical and biogeochemical feedbacks of vegetation in the Earth system may therefore accelerate or delay any general trends, and the balance between these may be different in different regions.

Developing a New Class of Model

From a modelling perspective, the most important elements of land vegetation, with respect to its dynamic behaviour on the global scale, are the pools of live and dead biomass, and all processes affecting fluxes into, between and out of these pools. In the past, most of these fluxes have been modelled using formulations of the relation between the environment and a predetermined structure of vegetation, the environment being described in terms of radiation, temperature, humidity and carbon dioxide. More recently, this underlying vegetation structure has been modelled, rather than prescribed, as a function of the (current) carbon and water fluxes. These models usually contain (i) a module for photosynthesis as the main "engine" for carbon assimilation, (ii) one for autotrophic respiration as the plants' own use of the carbohydrates it has produced, and (iii) a module for heterotrophic respiration as the overall loss of carbon from other organisms' biological activity in the ecosystem.

A Dynamic Global Vegetation Model needs to contain all of these mechanisms, but it needs to be further enhanced to not only capture the short-term response of plants to the environment (often termed ecophysiology), but also other biological processes controlling

longer term behaviour. These are all concerned with the plants' life cycle, such as establishment in a new location, growth, competitive interaction with its neighbours and responses to disturbances from natural events such as fires and storms or human activity. Earlier, these "population processes" have been simulated in another class of models, so called "gap models". A direct linkage of different gap models to cover the global biosphere, however, is presently impossible. Many parameters are known only for the few plant species investigated for gap models. More importantly, the interaction between very different plants, such as trees and grasses, requires new methods of simulating processes such as the competition for water taking place in the soil.

Crucial for the development of DGVMs is the definition of an appropriate set of Plant Functional Types (PFTs). These PFTs must be few in number so that they can be described and parameterized in the global model, and sufficient to cover at least a part of the variety in functional behaviour among plants around the globe. Once an initial set of PFTs is defined, we need to parameterize the physiological processes for each of them. In fact, some PFTs are defined directly on the basis of physiology. For instance C_3 and C_4 plants with their different photosynthetic pathways respond in a remarkable different way to climate change. Other PFT distinctions go by leaf longevity, such as deciduous and evergreen plants. Once the sensitivity of PFTs to climate and soils has been identified and formulated in the model, we assess the interactions which take place when they occupy the same locations. These competitive relationships are simulated with respect to resources such as water or light, and the different abilities of plants to capture those determine the composition of the plant community.

Even in a constant climate, this composition is never stable, however. Natural mortality of plants, or even for larger plant parts such as leaves and branches, constantly adds biomass to the "litter pool", upon which other organisms thrive and thereby influence the flux of carbon from organic substances back to the atmosphere. Mortality occurs highly erratically, usually as a result of disturbances, and thereby creates new opportunities for other plants. Later stages of the process, such as the decomposition of dead plant matter, take much longer time and may involve large quantities of carbon that are stored for long time periods - in the case of wetlands for many millennia. For studies of the global carbon cycle, it is necessary to make at least rough estimates of these overall fluxes and their sensitivities to the environment, such as temperature and moisture balance.

DGVM Development for Global Change Applications

DGVMs are usually developed against the background of a world under some kind of changing conditions. Therefore the assumption of constant environment can only be a stage in the development of the model and will ultimately fail. A changing environment is currently considered in three ways (which may also occur all at once): i) changing climate (i.e., changing spatial pattern of temperature, rainfall, radiation and other meteorological elements), ii) changing atmospheric carbon dioxide content, and iii) changing disturbance due to human land use.

Some estimates of global vegetation response to changing climate and carbon dioxide have been made using equilibrium models, while land-use-based assessments are still in their infancy. These studies have played an important role as a "diagnostic" of possible impacts of climate change, and they have also been used successfully for the first studies of biogeophysical feedbacks. Reality, however, is likely to see more complex responses and feedbacks that may be enhanced or delayed by population processes. Speculations in this respect have ranged from general insensitivity of the biosphere against change to rapid immense carbon pulses which would be produced if a large quantity of existing biomass was turned into inorganic carbon by large fires.

An underlying assumption in DGVM development is that the actual response may be very specific to a particular region. In fire-prone ecosystems such as the savannas or boreal forests, small changes in the soil moisture balance may indeed affect the fire frequency enough to change the composition and therefore structure of the ecosystem quite rapidly. Since such changes mainly depend on the moisture balance, and since plant response to changing moisture is affected by atmospheric carbon dioxide, there is yet a major uncertainty with large-scale predictions of the outcome of such a change - it almost certainly requires a sophisticated DGVM being run at a large number of locations. The result will also be affected by the prevailing climate- change scenario.

In ecosystems such as the wet evergreen rain forests, the main disturbance will most likely continue to be land use rather than climate change. Here, the DGVM only simulates direct results of external forcing, i.e. the flux of carbon from destroyed vegetation to the atmosphere, with no particular attention to plant population processes. In yet another type of ecosystem, the Arctic tundra, migration (the horizontal displacement of plant seeds or other propagules) needs to be simulated before we can estimate the change of the land surface.

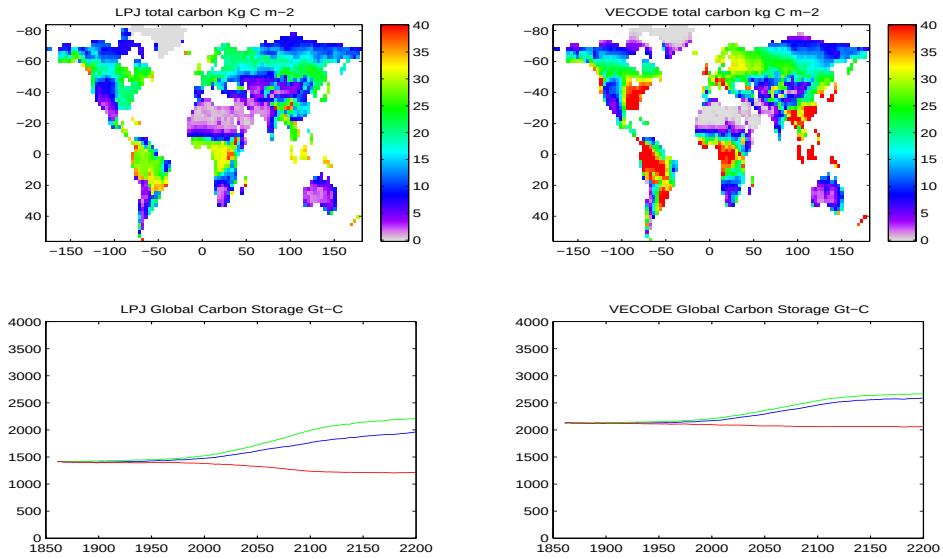


Fig. 1: The upper figures show the projected total terrestrial carbon storage (soil + vegetation) in the final decade of the transient CO_2 and climate change simulation (2190-2200) for the Lund-Potsdam-Jena (LPJ) DGVM and VECODE. The lower figures show the time series of global terrestrial carbon storage for LPJ-DGVM and VECODE for three simulations (green: CO_2 only, red: climate only, blue: CO_2 and climate change).

DGVM Developments in POEM

To investigate decade-to-century-scale dynamics of the coupled Earth system in POEM, a comprehensive DGVM is mandatory. Now, a prototype DGVM (the Lund-Potsdam-Jena DGVM, LPJ) is in place, as well as the reduced-form biosphere model in CLIMBER (VECODE) (figure 1).

Based on LPJ and VECODE, several lines of further development are pursued:

- To improve the representation of realistic disturbance in the LPJ model. For this, the current state of development in landscape-scale fire models is reviewed and results are used to enhance the existing simple scheme of fire occurrence and effects. Land use is investigated as a separate disturbance driver.
- To create a consistent framework for spatial and temporal scaling among processes, and between the driving data and the overall model. This is being carried out as part of the PIK contribution to the European consortium ETEMA (European Terrestrial Ecosystem Modelling Activity, see separate section on ETEMA)
- To integrate the comprehensive DGVM in future versions of CLIMBER.

Biospheric Model Testing and Validation

An important step in the process of testing the reliability of existing model formulations is to validate them against independent data. For global fluxes, such as the overall productivity of vegetation, even of a smaller region, such data are very difficult to obtain; however, if they exist at all, then only for a small sector within the total range of possible environmental boundary conditions. Alternative observations for model validation are satellite reflectances (soon to be used in a joint project with the FU Berlin) and measurements from the international carbon dioxide networks (site-specific, and at ocean stations), which will be used more frequently over the coming years.

An indirect means of testing models is by comparing them against each other. We assume that, if very different model formulations reach a similar result, some confidence might be placed in both formulations. We have carried out the IGBP-sponsored Intercomparison of Global Models of Net Primary Productivity, also frequently referred to as “The Potsdam Process”. Altogether eighteen modelling teams had initially agreed in using a standardized data set for executing their NPP models and to submit the data to a common archive now hosted at PIK. This process, despite being exceedingly difficult due to the large quantity of data and the high number of minor findings, has been instrumental in improving many currently available biospheric models (see figure 2 as example).

Another, more recent intercomparison project is the ongoing GCTE DGVM Intercomparison, a comparison of Dynamic Global Vegetation Models. For this activity, altogether seven models were run using output from a climate model simulation provided by the Hadley Centre (United Kingdom) for the period from 1860 to 2099, including effects of both increasing atmospheric carbon dioxide and sulphate aerosols. This scenario was applied and the simulations were continued 100 years after 2099 as a crude "stabilization scenario". The participating DGVMs, which included LPJ and VECODE,

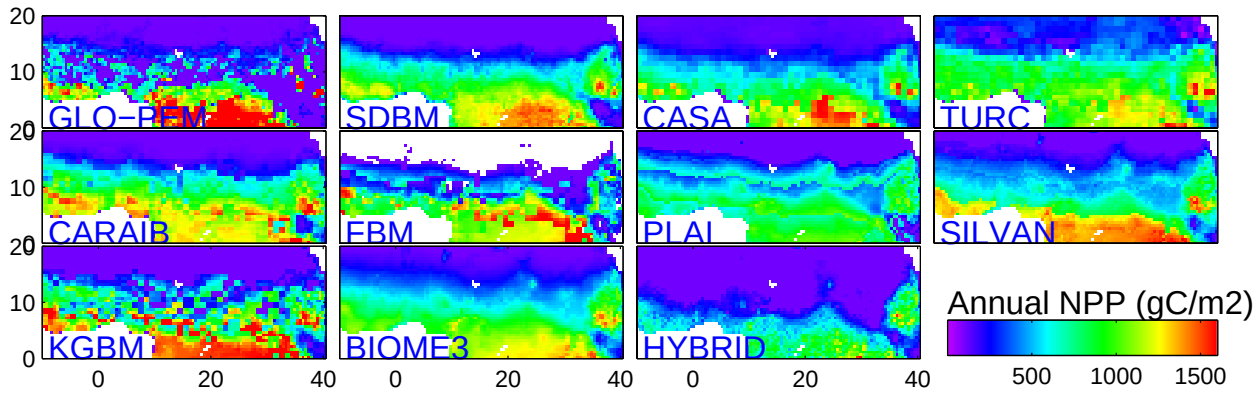


Fig. 2: Annual Net Primary Productivity (NPP) along a precipitation gradient, simulated by 11 global biospheric models in Central Africa between Sahel and Equator. In all models, the highest NPP (red) occurs in the tropical evergreen forest due to the optimal amount of solar radiation, precipitation and temperature, but the absolute levels vary considerably, as well as the spatial pattern.

have widely different levels of complexity and several of them are still in a prototype stage. Despite significant differences with respect to the quantitative values of biomass and other pools, the models showed two important features: significant inertia of land vegetation, which continued to change long after "stabilization" had occurred, a significant carbon sink in land vegetation if only carbon dioxide was changed under constant climate conditions, and a much reduced carbon sink when the climate changed simultaneously.
The intercomparisons were of twofold significance: they helped the individual modelling teams to improve their model (since several technical and other problems were discovered during the comparison procedure) and they produced a consistent result on the likely response of the land biosphere to Global Change that could not have been reached otherwise.

Climate and Biosphere Model – CLIMBER
Project Leader: Martin Claussen

Motivation
Marked progress has been achieved during the past decades in modelling the separate elements of the geosphere and the biosphere. This stimulated attempts to put all separate pieces together, first in form of comprehensive coupled models of atmospheric and oceanic circulation, and eventually as climate system models which include also biological and geochemical processes.
Within POEM, a new climate system model, called CLIMBER (CLIMate and BiosphERe), has been set up to address the interaction between geosphere and biosphere at time scales of centuries to millennia. Hence the CLIMBER activity is sandwiched in the COEM and DGVM research. On the one hand, the current state of the climate system cannot be explained without an assessment of its development throughout the Earth's history. On the other hand, details of the biospheric processes have to be properly described, which is the focus of the DGVM activity. More specifically, CLIMBER will be used to analyse the vegetation-climate feedbacks, the interaction between inland-ice masses and the role of ocean currents, and the synergism between climate subsystems operating during the last few hundred thousand years with a perspective of potential future climate changes. Some illustrative examples are given below.

The New Approach
Currently there are two basic classes of climate system models – comprehensive ones and simplified ones. Comprehensive models of global atmospheric and oceanic circulations describe many details of the flow pattern, such as weather systems and wind driven gyres in the ocean. Similarly, complex dynamic vegetation models explicitly determine the growth of plants and competition between different plant types. The major limitation in the application of comprehensive models arises from their high computational cost. To obtain an equilibrium state of the system, it is necessary to integrate a model for at least a thousand years – the time needed by the deep ocean to transport information around the globe. This time will increase further if "slower" elements of the climate system, like glaciers or the upper Earth's mantle, are included. Even using the most powerful computers, only a very limited number of experiments can be performed with such models. Another problem is the necessity of a so-called flux adjustment to obtain a realistic present climate state. The use of flux adjustments prevents the coupled atmosphere – ocean models from drifting into unrealistic climate states; however, they impose strong

limitations on the applicability of the models to climate states which are substantially different from the present one.
Due to these problems, simplified and computationally efficient models of the climate system are used for a variety of applications, in particular palaeostudies and climate change and climate impact projections. These models are spatially highly aggregated, e.g. they may represent atmosphere and ocean in two boxes, and they describe only a very limited number of processes and variables. The applicability of this class of models is limited not by computational cost but by the absence of many important processes and feedbacks operating in the real world. Moreover, the sensitivity of these models to external forcing is often prescribed rather than computed independently.
There is a gap between simple and comprehensive models which has been filled by CLIMBER. CLIMBER is a climate system model of intermediate complexity. CLIMBER computes many processes and feedbacks in the climate system, comparable with those of comprehensive models. But due to low spatial resolution and simplified governing equations, the model has a fast turnaround time. Currently some 4000 simulated years take roughly one day on one processor of the IBM SP2 at PIK. An important component of CLIMBER is the atmospheric module, which is based on a statistical-dynamical approach. This implies that the atmospheric module does not compute weather systems, but rather describes their influence on the climate.
So far, CLIMBER has been verified for present-day climate and the climate of the peak of the last ice age. Furthermore, it has been validated against other comprehensive models where data are missing and it has been shown that it behaves like the complex models when strong perturbations are imposed, as for example, a shut-down of the North Atlantic current due to a doubling of the atmospheric carbon dioxide concentration, or changes in the energy flux from the sun. In the following, two recent results obtained with CLIMBER are highlighted.

The Last Glacial Maximum
The last ice age reached its peak around 21,000 years ago. Ice sheets, up to three kilometres thick, covered the northern parts of America and Europe. The ice cover reached down to Berlin; further south, a dry, polar steppe extended as far as present-day France. The reason for the periodically recurring ice ages were slight changes in the Earth's orbit which caused changes in the solar radiation reaching the Earth. But exactly how these gradual and subtle changes in the distribution of solar radiation led to such rapid and drastic glaciation is still one of nature's unsolved puzzles. By use of CLIMBER a step forward towards solving the problem has been made.
For the simulation, only the solar radiation of 21,000 years ago was prescribed, the known ice masses were placed on the continents, and the concentration of carbon dioxide in the air was reduced to its ice age level as known from ancient air bubbles trapped in the ice of Greenland.
CLIMBER demonstrates that changes in ocean currents were a crucial factor in the cooling of the climate during the ice age, particularly in Europe. These changes encompass the southward shift of North Atlantic Deep Water (NADW) formation from approximately 65^{o}N today to roughly 45^{o} during the glacial maximum, a penetration of Antarctic Bottom Water (AABW) into the Northern Atlantic, and a substantially reduced heat transport into the high latitudes of the North Atlantic with a corresponding southward movement of the sea-ice margin to between $50^{o}$and 60^{o}N. The overall rate of NADW formation, and its outflow into the Southern Ocean, is only slightly reduced, but because the North Atlantic current was less saltier and, hence, less dense, the NADW flow was shallower than today. Unlike for today's climate, CLIMBER obtained also a formation of deep water in the North Pacific. These results seen in CLIMBER agree fairly well with recent reconstructions by geologists from ice-age sediment cores.
The entire Northern Hemisphere was on average almost nine degrees Celsius colder than it is today, according to the simulation results. Three degrees of this cooling were associated with a shift of the North Atlantic ocean circulation. Some areas even cooled by more than 20 degrees as a result of the altered currents (see figure 3).

Synergism in the Climate System of the Mid-Holocene
Remnants of the last glaciation disappeared about 7000 years ago and since then, the inland ice masses have changed little. Also the carbon dioxide concentration in the air was roughly as some 100 years ago, before industrialization. Nevertheless, the climate in the mid-Holocene, around 6000 years ago, was quite different from today's climate. Generally, the summer in many Northern Hemisphere mid-to-high latitudes was warmer, as palaeobotanic data indicate an expansion of boreal forests north of the modern treeline. In North Africa, palaeoclimatological reconstructions using ancient lake sediments and archaeological evidence indicate a climate wetter than today. Moreover, it has been found from fossil pollen that the vegetation limit between Sahara and Sahel reached at least as far north as 23°N.

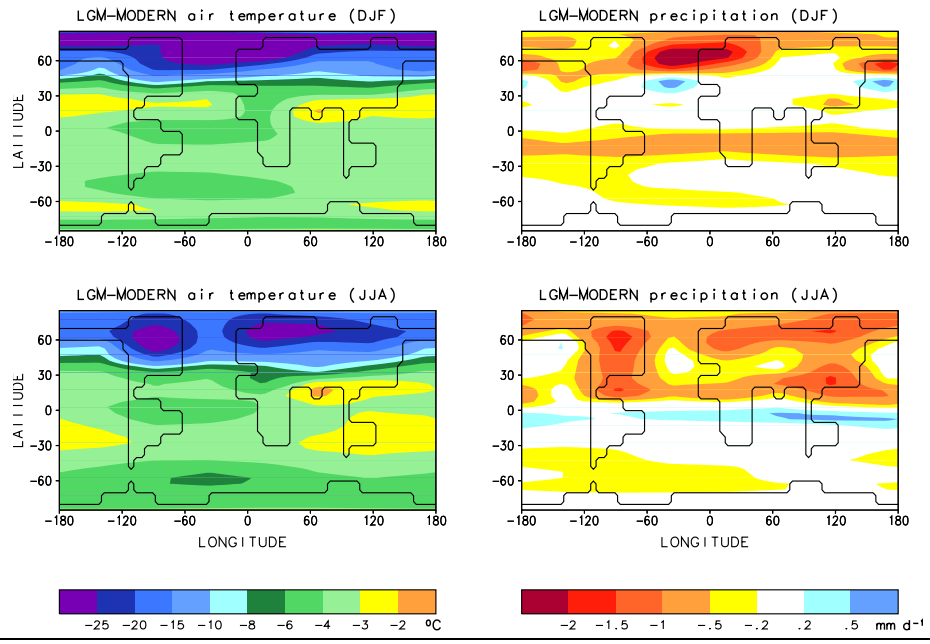


Fig. 3: Difference in air temperature (left panels) and precipitation (right panels) between the last glacial maximum (21000 years ago) and today, simulated by CLIMBER, driven by changes in the Earth's orbit and lower atmospheric CO_2. Top panels depict the northern winter months (December, January, February), the bottom panels show the summer months (June, July, August). The global cooling reaches some 6°C, with a cooling of almost 4°C in the tropics. Changes in wind and ocean currents induced changes in precipitation pattern such as a drying of the tropics and northern high latitudes, a strongly reduced Asian summer monsoon, and increased winter precipitation in some subtropical regions. Global mean precipitation was reduced by some 16%.

It is a common hypothesis that differences between modern and mid-Holocene climate were caused by changes in the Earth's orbit. Particularly, the tilt of the Earth's axis was stronger than today. This led to an increased solar radiation in the Northern Hemisphere during summer which amplified the African and Indian summer monsoon, thereby increasing the moisture transport into North Africa. However, orbital forcing alone seems to be insufficient to explain the changes in climate. Sensitivity studies using climate models have suggested that positive feedbacks between climate and vegetation exist at boreal latitudes as well as in the subtropics of North Africa. These feedbacks tend to amplify the climate change such that the boreal climate becomes warmer (than without vegetation-atmosphere feedback) and the North African climate becomes more humid. However, it is currently debated whether this feedback is strong enough to explain the greening of the Sahara reconstructed from palaeobiology.

By use of CLIMBER the response of the atmosphere to changes in the Earth's orbit of 6000 years ago are compared with the reaction of various combinations of climate subsystems (see figure 4). This analysis reveals a strong synergism as the response of the entire system turns out to be much stronger than that of various subsystems. Moreover, it becomes evident that changes in the northern hemisphere affect the climate of the Southern Hemisphere by the heat transport in the Atlantic.

Long-Term Co-Evolutionary Biosphere and Geosphere Models – COEM

Project Leader: Yuri Svirezhev

The short-time dynamics of the planetary ecosystem are addressed by the CLIMBER and DGVM activities, but important properties of the biosphere like overall stability, resilience or boundary conditions today can only be understood if the long-term evolution of the Earth system is also taken into account. This may be illustrated by investigating the present day occurrence of some nutrients, which limits present day biological productivity. These substances are part of the global biogeochemical cycles, which can be regarded as a well-balanced geophysiological system. This system is the result of the Earth's history in the sense that its sources and sinks are the result of long-term developments. They contribute to the global energy and material fluxes not only through separate biological, physical and chemical cycles, but also by biologically accelerated material transfers. For example, the biota play an important role in the chemical weathering of silicate rocks: Unlike abiotic and purely chemical weathering, microbial and vascular plants trigger several mechanisms as there are acids, morphological and mechanical effects. They increase significantly the ability of the soil to bind carbon and, as a consequence, the associate weathering rate. This process reduces the amount of carbon in the atmosphere and affects the climate itself.

As is well-known from non-linear systems theory, such an externally driven system as the biosphere may pos-

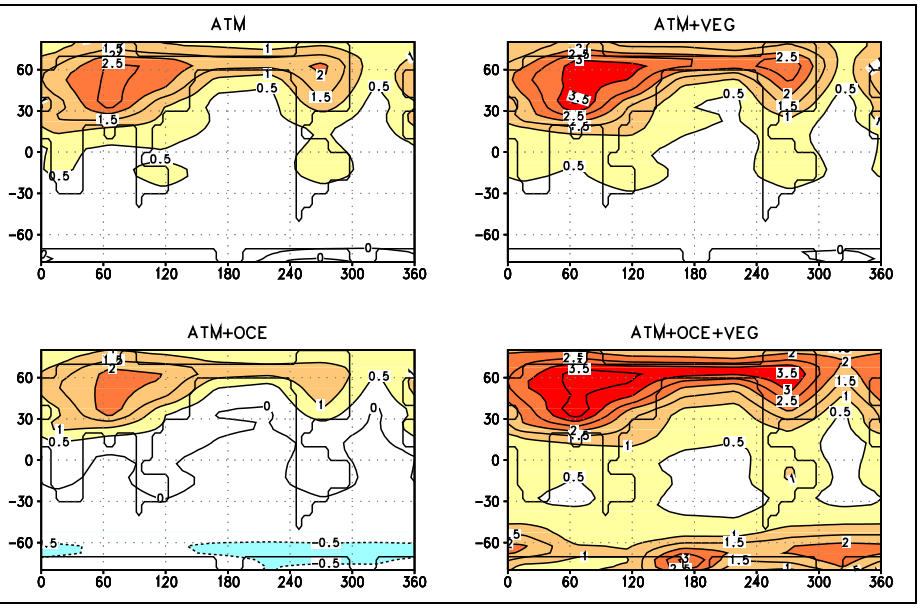


Fig. 4: Difference in air temperature between 6000 years ago and today, for the northern summer (June, July, August), simulated by CLIMBER, driven by changes in the Earth's orbit alone. The upper left panel depicts the response of the atmosphere only. The lower left panel demonstrates the reaction of the coupled system atmosphere-ocean.
The upper right figure shows the temperature increase when atmosphere and vegetation respond simultaneously.
Finally, the lower right figure indicates the change of the entire system.
On global and annual average, the response of the atmosphere alone amounts to 0.05°C, of the coupled atmosphere and ocean to -0.05°C, atmosphere-vegetation 0.2°C, and atmosphere – ocean – vegetation to 0.85°C.

sess a variety of equilibrium states with a complex transition structure. Information about existing neighbouring stable states, the character of transitions to these regions and, especially, knowledge concerning the elasticity boundaries of dominating equilibrium regions are crucial for modelling the temporal short- and mesoscale dynamics.
The main goal of COEM is therefore not to make a certain forecast for the dynamics of the biosphere, but use the techniques of dynamic system theory, structural analysis and computer modelling to get deeper insights into the limits of ecosphere dynamics as the result of the evolution of the Earth system. According to the general concept of "virtual biospheres" (Svirezhev, 1994), the contemporary Earth biosphere is one of many possible virtual biospheres, corresponding to the multiple equilibria of some nonlinear coupled dynamical system consisting of "climate and vegetation". In the course of the planet's history and its long-term evolution, this system may have passed through several bifurcation points, strongly influenced by biological feedback mechanisms.
As a basic formulation, a long-scale evolution model for the Earth system has been used. The model investigates the response of the linked components atmosphere, biosphere, and lithosphere to the increase in solar luminosity. We have extended the scheme including geodynamical processes such as the spreading rate and continental growth, illustrated in figure 5.
Such feedback schemes are useful for investigations of both the past and the future of the Earth system, including questions concerning the life span of the bio-

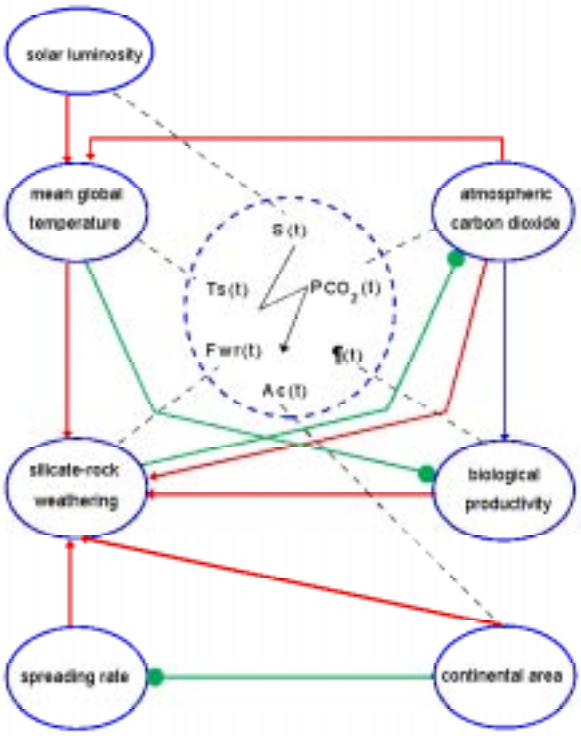


Fig. 5: Illustration of positive (red) and negative (green) feedback mechanisms within the evolution of the Earth system. The elements in the dashed circle represent the dynamical part of the model whereas the corresponding quasi-static processes (connected by dashed lines) are held in equilibrium for a longer time-scale. The „flash of lightning" inside the circle indicates a change of insolation S.

sphere. Increasing solar luminosity S will enhance the mean global temperature Ts. At temperatures approaching 50 ^{o}C, biological productivity decreases and the weathering rate is enhanced which draws down the atmospheric carbon dioxide concentration leading to lower Ts and lower silicate-rock weathering (Fwr), respectively. A similar loop exists for the impact of surface heat flow: Declining surface heat flow decreases spreading rate and silicate-rock weathering, while increasing continental area (Ac) has a negative influence on the spreading rate and, on the other hand, a positive influence on the weathering rate. The quasi-stationary values of these process intensities, which can be calculated for different epoques of the Earth's history and its future, are used as steady state values for the short-term climate-biosphere dynamics. This strategy will give hints concerning the dependence of dynamically defined system properties like, e.g., elasticity on the steady-state boundary conditions of the geosphere. In general, it is intended to reconstruct the co-evolutionary path of the biosphere and the geosphere on the basis of qualitative "phase-space portraits". The main interest focuses on the dynamic behaviour of the Earth system during transitions times when quasi-stationary states change.

European Terrestrial Ecosystem Modelling Activity – ETEMA
Project Leader: Wolfgang Cramer

Connected to the DGVM development, ETEMA is a European modelling exercise (coordinated by Martin Sykes, Lund, Sweden), focusing on predicting the ecosystem-level impacts of anthropogenic forcing. It aims to create a modular framework capable of simulating structure and function in a wide range of European terrestrial, natural and semi-natural ecosystems at patch to landscape scales. Climate - described as temperature, insolation, precipitation - atmospheric carbon dioxide concentration, and potentially, nitrogen deposition and land-use class are the main drivers. The model seeks to predict carbon, nitrogen, and water pools and fluxes, runoff, vegetation composition and vertical structure in terms of major species and functional types, net primary production, leaf area index and biomass in various components, in response to changes in the main drivers. Initially predictions will be at the patch or landscape scale; the eventual aim is to make predictions at regional or continental scales, over years to centuries.
The coupled modular framework for ETEMA (being developed at PIK) allows to test different conceptual and formal descriptions of vegetation processes and data sets of different resolutions. The main requirements of the framework are to support exchange of different process formulations without changing the remainder of the coupled model, and to be sufficiently flexible to test different approaches in vegetation modelling, e.g., the spatially explicit patch representation, with or without interaction with adjacent grid cells.
The framework consists of two parts (see figure 6):

- a driving module providing spatial and temporal interpolation (or averaging) of climate and land use/ cover data and
- a generic vegetation model consisting of three nested loops representing different levels of temporal resolution.

The innermost loop of the vegetation model (time step of hours to one day) encompasses the "fast" physical processes of photosynthesis and canopy/planetary boundary layer exchange as well as soil water balance. The intermediate loop (days to months) represents phenology and carbon allocation and adjacent processes (disturbance, fast dynamics of soil organic matter (SOM)). The outer loop (years to decades) updates vegetation composition as a result of population processes and slow dynamics of soil organic matter.
Vegetation is assumed to have a vertical layer structure. Two types of spatial configuration are proposed and are representative of the possible types of vegetation dynamic models:

- multiple patches with known position inside the macrocell (spatially-explicit models approach) and
- sets of parallel strips of known width with a regular orientation (to meet requirements of planetary boundary layer model).

Numerical Simulation and Analysis of Climate Variability on Decadal and Centennial Time Scales – Millennia
Project Leader: Stefan Rahmstorf

Climate varies on different time scales - each summer is different from the previous one, a decade of mild winters may be followed by several icy ones, and even on the scale of centuries there were considerable climatic changes, even before human activities started to have a noticeable influence. In the "Medieval Optimum" the Vikings settled now icy Greenland and grapevines grew in Yorkshire, England. Then, from about 1550 to 1850, the "Little Ice Age" took hold of Europe: temperatures were about 1 °C below those of the present century. Understanding such natural climate variations on decade to century time scales is the aim of the Millennia project.

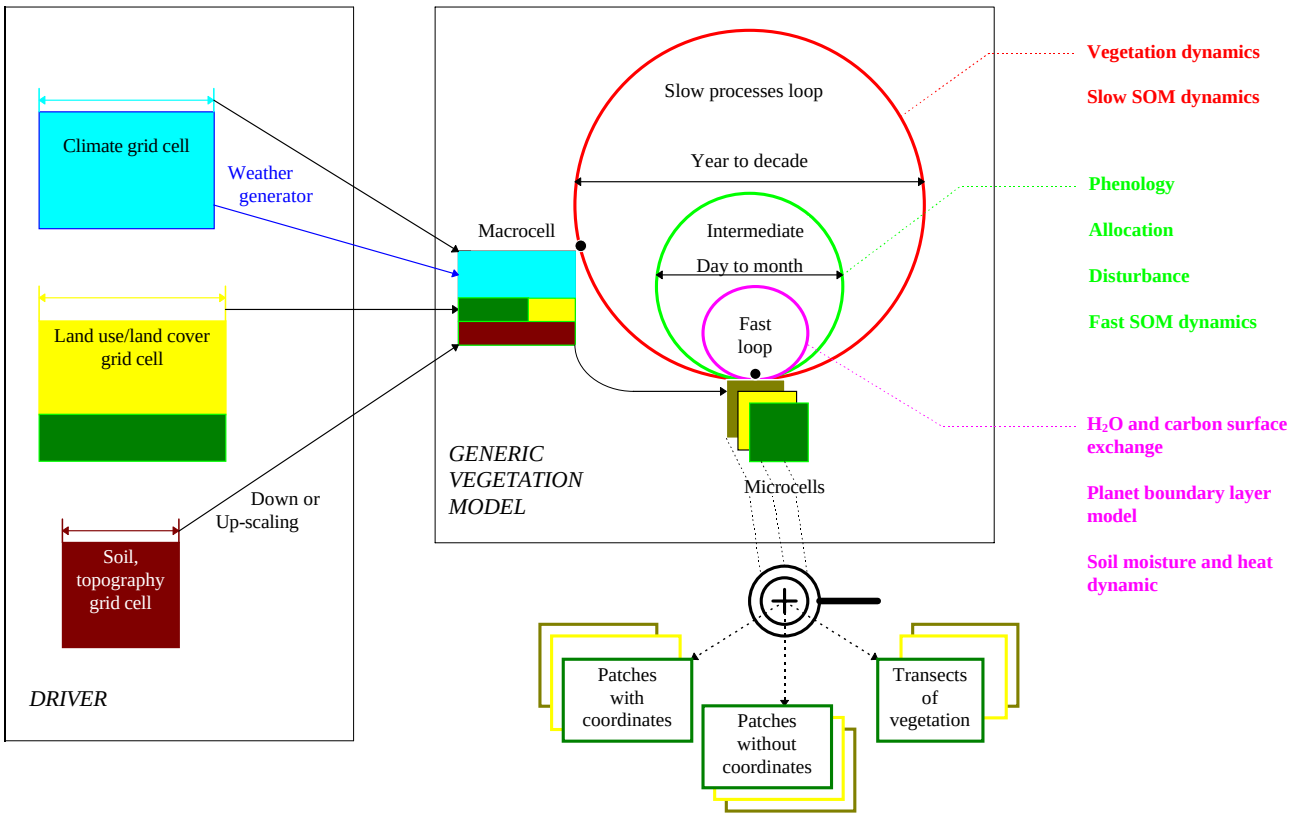


Fig. 6: The structure of the Generic Vegetation Model developed in ETEMA.

One reason why one wants to understand this climate variability is to be able to predict it. On a shorter time scale, the three to five year long climate cycles associated with El Niño events in the Pacific Ocean are now well understood and can be forecast up to a year in advance, allowing farmers to adjust their crops. In the North Atlantic Ocean there is a similar irregular climatic cycle of longer duration (~20 years), called the North Atlantic Oscillation (NAO), which has a profound influence on European climate and would be useful to predict. For this we need to understand the physical mechanism.

A second reason why we need to understand climate variability, especially on the time scale of centuries, is to separate it from the human influence on climate. Is the warming observed over the past 100 years anthropogenic or just part of a natural fluctuation of the climate system?

Methods

In Millennia, 10 laboratories from five countries are involved. It focuses on computer modelling with global circulation models (GCMs):

- Climate variability is analysed from an existing 1250-year run of the coupled ECHAM1/LSG climate model.
- Sensitivity experiments are performed with models designed to isolate certain climatic feedback mechanisms.
- An improved coupled climate model for multi-millennia simulations is being designed and tested.

Contribution and Results of PIK

The task of PIK within the project is twofold:

- To design the ocean component for the new coupled model, based on the Geophysical Fluid Dynamics Laboratory´s (GFDL) Modular Ocean Model (see figure 7).
- To perform a range of experiments to study the role of the ocean in climate variability.

Some results of PIK experiments highlighting the role of the ocean in climate are listed below.

- The influence of Mediterranean outflow water on the North Atlantic circulation and climate was investigated.
- The teleconnection between the winds over the Southern Ocean and the flow of North Atlantic Deep

Water was found to be weak (in cooperation with the University of New South Wales, M. England).
- A numerical simulation of oceanic radiocarbon uptake and circulation was performed (jointly with UNSW, M. England), to compare the performance of different oceanic mixing parameterisations.
- A study of some properties of oceanic convection was made with a simple conceptual model.
- A fully coupled model and a simpler hybrid model were compared, using identical ocean models (in cooperation with GFDL Princeton, R. Stouffer), shedding light on the stability of the ocean currents in different models and the role of atmospheric feedback.
- A parameter sensitivity study was performed using the ocean module of CLIMBER and the GFDL ocean model, investigating the stability properties of the thermohaline ocean circulation.

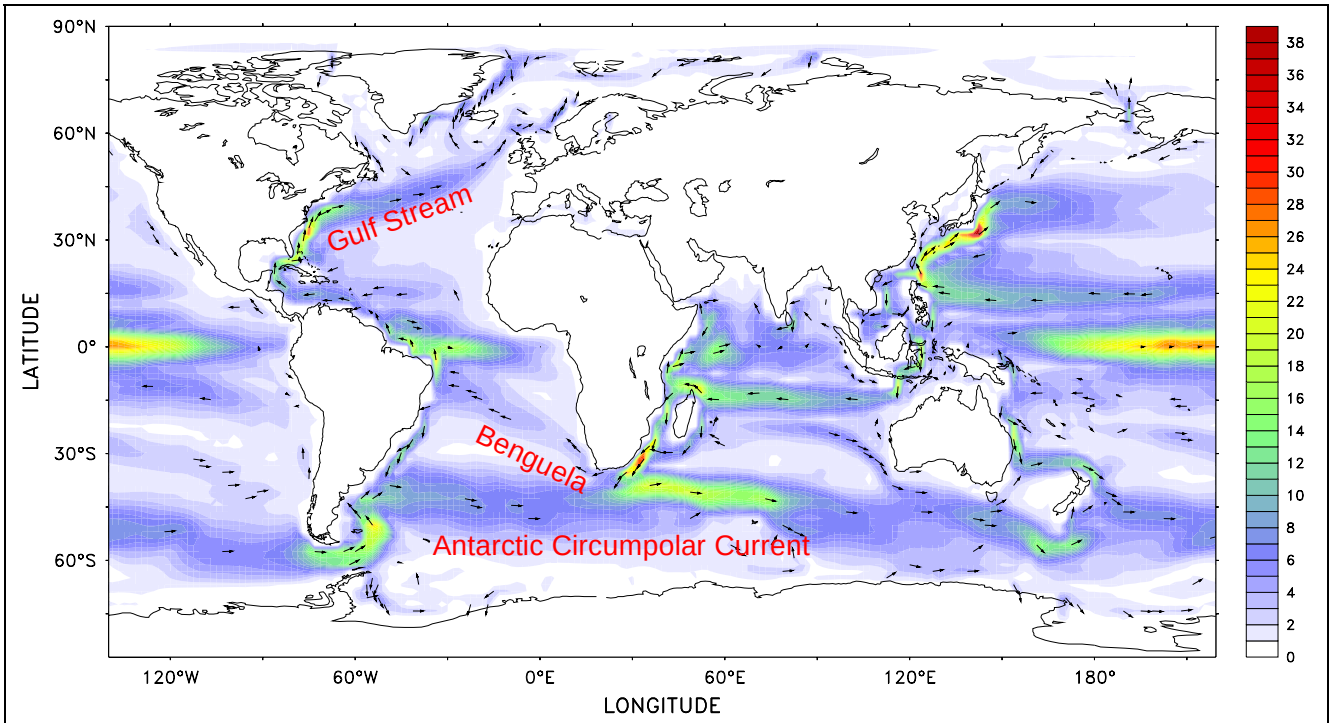


Fig. 7: Near-surface (100m) current velocities in an ocean model employed at PIK in cm/s (resolution 1.8° longitude and latitude, 24 vertical levels). The model has been implemented to study the stability and variability of the thermohaline circulation and its effect on the climate.

The New Version of the Moscow Global Biosphere Model – MGBM

Project Leader: Yuri Svirezhev

Among the variety of smooth modifications of the biosphere caused by Global Change, there might also be a chance of a transition to a totally different planet characterized by a fundamentally different pattern of climate, vegetation and land ice cover. The possibility that more than one equilibrium of the biosphere could exist and the assessment of imaginable transitions is addressed by the New Moscow Biosphere Model.

The Compartment Model

The main objective was to create a dynamic structure, treating the biosphere as a single entity in a unitary model and human society as its natural component in a co-evolutionary concept. The structure must be topologically simple and stable, and possess several equilibria. It must be slightly sensitive to quantitative data, since the main emphasis is not on the calculation of concrete trajectories, but on the determination of stability domains, in which the ecological niche for *homo sapiens* is assured. The idea is that the system of the biosphere consists of an undefined number of compartments representing, for instance, the hydrosphere, the terrestrial biosphere, the climate etc.

Besides this, there is the problem of bifurcation points, i.e. such states of the biosphere in the vicinity of which the future co-evolution of humans and the biosphere cannot be predicted in general. At this point we relinquish the compartment theory as a spatially discrete description, and consider the biosphere as a multiphase continuous active medium.

However, all the available information about the main actors of biosphere performance, e.g. global biogeochemical cycles, is presented in the form of different compartment models. Their comparison has shown that aggregation and separation of the compartments cause some fictitious dynamic phenomena to appear. So we needed to develop a special theory, which allows the dynamic characteristics of their compartmental structures to be estimated. On the basis of this theory, many of the existing models of the global carbon, nitrogen and phosphorous cycles were analysed and one rather simple structurally stable model of the global carbon cycle with two equilibria was suggested. As a result we obtained estimates of the terrestrial biota and the ocean role in the global carbon cycle. It could be said, that the ocean will remain a sink for carbon for a rather long time, for about 200 - 300 years. Estimates of the distribution of carbon sources and sinks show that, for example, the territory of Russia is a sink, and USA is a source of carbon.

Concerning the main question that climate impact researchers put to their models, i.e. what happens if we go on emitting 6-7 Gt of carbon per year, the answer given by the MGBM shows a loss of stability in the system. For this purpose a special climate model was constructed, which on the one hand produced sufficiently realistic evaluations, and on the other hand was substantially simpler in its structure than the Global Circulation Models (GCMs). The analysis of the zero-dimensional "biosphere – climate" model shows that the contemporary climatic equilibrium is disposed sufficiently close to the dangerous boundary of its stability domain. The emission to the atmosphere of a total of 600 Gt of carbon, accumulated over 100 years, reduces the stability, and subsequently the system of biosphere and climate evolves to a kind of hot desert with a temperature of ~ 35°C. The vegetation biomass would be reduced by a factor of 8 - 10.

The Anthropogenic Component

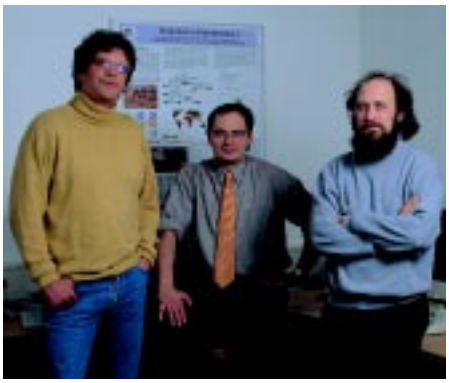
In an attempt to develop a demographic model and a model of industrial metabolism we faced the problem of quantifying simple criteria for the estimation of the degree of the environmental degradation and the level of social stress. The idea is to describe the collective dynamics of socio-economic entities by thermodynamic formalism and to add a special degree of the social stress, based on the concept of Kondratiev's waves. Concerning the degree of the environmental degradation induced by human activity, we suggest using the entropy as a physical value. The thermodynamic model of environmental degradation and its application to agrosystems has shown that we can expect a drastic decrease of crop production, caused for instance by soil erosion, in regions of intensive agriculture. This is an anthropogenic disaster, but nevertheless it is a normal thermodynamic reaction for a system trying to minimize the rate of entropy production. Therefore the sustainable crop production in most industrialized societies must be lower (by 30-40 %) than at present.

The POEM project, although drawing extensively on time and other resources of PIK staff members, has been externally supported by the European Union (ETEMA, Millennia and MGBM), NASA/USEPA (NPP Model Comparison) and the German Research Foundation: Deutsche Forschungsgemeinschaft (COEM).

QUESTIONS
Global Change: Qualitative Dynamics of Syndromes and Transition to Sustainability

Project Leader: Gerhard Petschel-Held

A vast number of environmental, social, economic, and cultural developments are endangering our common future – not only by their sheer existence and superposition but by powerful synergisms. This complexity is facing an increasing social demand for clear and simple answers in terms of policy options - not an easy task, considering how heterogeneous the world and its population are.
Not only politicians but the global society as a whole, and last but not least, scientists have to find sound answers to questions like the following: Will the growing global economy profit in the long run from further short-term overuse of natural capital, or will resource depletion and environmental degradation lead to economic losses as well? Which regions are probably affected next by large scale deforestation? Where do poverty and policy failure make people overuse their natural resource base? How will the urbanization process affect human health and regional environments?



From left to right: Gerhard Petschel-Held, Fritz Reusswig, Matthias Lüdeke

Science has been successful for hundreds of years by specialization and disciplinary segmentation of research activities. However, what we need for effective and successful research on Global Change is to integrate current disciplinary knowledge, taking into account all the complexity, interdependencies, non-linearities, transsectoral effects, and uncertainties. It is the task of the QUESTIONS project to find new methods to formulate the basic structures representing the major driving forces for Global Change qualitatively and to help to identify the most effective controls for these drives.

Diagnosis of Syndromes

The Syndrome Concept

The core project QUESTIONS tries to deal with the current core problems of Global Change such as soil erosion, deforestation, food insecurity, climate change, by establishing a new research tool: the so called syndrome approach. A syndrome is defined as a typical pattern of non-sustainable civilization-nature interactions that can be found in different regions on Earth. The important thing about this approach is that it explicitly takes into account human driving forces of Global Environmental Change. Most other Global Change models concentrate on detailed mappings of the behaviour of single systems like the biosphere, atmosphere, hydrosphere, etc., and couple human society as consumers of natural resources, e.g. for food production, transportation purposes, recreation, and so on. This “one-eyed view” often leaves aside the intricate driving processes within the anthroposphere, e.g. structural changes of the economy, changes in lifestyles, or increase of aspirations. Although the social sciences deal with these driving forces per se, they very often are inversely “one eyed”, disregarding the natural preconditions and subtle consequences of human action. The syndrome approach aimes to overcome both one-eyed strategies with sufficient complexity, thus hoping to give better insight to science.
So far, a total of 16 typical patterns of Global Change has been identified in an iterative interdisciplinary discussion process among members of the project as well as the members and collaborators of the German Advisory Council on Global Change (WBGU). The syndromes are grouped into three major classes and are listed in table 1.

Measurement of Syndrome Activity

Syndromes represent an easy-to-grasp methodology to get a comprehensive overview on the entire problem known as Global Change. Besides the description of the general structures responsible for global environmental and regional social degradation, a major task of the QUESTIONS project is to obtain geographically explicit assessments of the occurrence of syndromes. On the one hand, it is the goal to identify those regions of the world where a specific syndrome is active in a certain variety. This is important in order to verify the hypothesized cluster of causal interactions assumed to constitute the syndrome, e.g. by detailed comparisons with case-studies. Finally, these global damage maps can provide important information for sound strategies of global environmental manage-

Utilization Syndromes	
Sahel Syndrome	Overuse of marginal land
Overexploitation Syndrome	Overexploitation of natural ecosystems
Rural Exodus Syndrome	Degradation through abandonment of traditional agricultural practices
Dust Bowl Syndrome	Non-sustainable agro-industrial use of soils and bodies of water
Katanga Syndrome	Degradation through depletion of non-renewable resources
Mass Tourism Syndrome	Development and destruction of nature for recreational ends
Scorched Earth Syndrome	Environmental destruction through war and military action
Development Syndromes	
Aral Sea Syndrome	Damage of landscapes as a result of large-scale projects
Green Revolution Syndrome	Degradation through the transfer and introduction of inappropriate farming methods
Asian Tiger Syndrome	Disregard for environmental standards in the course of rapid economic growth
Favela Syndrome	Socio-ecological degradation through uncontrolled urban growth
Urban Sprawl Syndrome	Destruction of landscapes through planned expansion of urban infrastructures
Disaster Syndrome	Singular anthropogenic environmental disasters with long-term impacts
Sink Syndromes	
Smokestack Syndrome	Environmental degradation through large-scale diffusion of long-lived substances
Waste Dumping Syndrome	Environmental degradation through controlled and uncontrolled disposal of waste
Contaminated Land Syndrome	Local contamination of environmental assets at industrial locations

Table 1: Various syndromes describing the interactions and changes of nature and mankind.

ment. On the other hand, one might focus on specific regions and determine the active syndromes within the region. This helps to formulate regional specific management strategies not only adequate to temper a single syndrome, but rather adequate for a specific conglomerate of these archetypes. Within the task of performing intensity measurements to be described here, the focus is laid mainly on the first approach.

The essential starting point for any syndrome analysis is a systematic refinement of the processes indicated on the right-hand side of table 1. This reformulation makes use of a catalogue of about 80 symptoms of Global Change which have been collected by the interdisciplinary WBGU. Currently, this catalogue is subject to a detailed review process including a broad literature survey and the build-up of a data-bank able to structure the quantitative and qualitative knowledge of these symptoms. As the second basic ingredient, syndrome analysis is applying a typology of interactions, for example reinforcing, weakening, ambivalent, in order to relate the symptoms in a specific manner: within this context a syndrome can also be defined as a typical cluster of symptoms and their interactions.

There is no definite *modus operandi* for the assessment of a syndrome's activity. Ideally, just like in medical diagnosis, one would look for the syndrome specific combination of symptoms and their temporal behaviour. Quite often, however, the realization of this

ideal is hampered by a significant lack of data. In these cases, one has to find alternative ways, particularly with respect to the dynamic behaviour of the symptoms. Besides using results from global models, for instance river flow, FAO crop models, global vegetation models, it turned out to be especially beneficial to use the concept of vulnerability as a measure for high risk of damage due to syndrome specific interference with the environment.

Within the last two years, the intensities of six syndromes have been estimated. Three of these analyses have been part of the 1997 annual report of the German Advisory Council on Global Change.

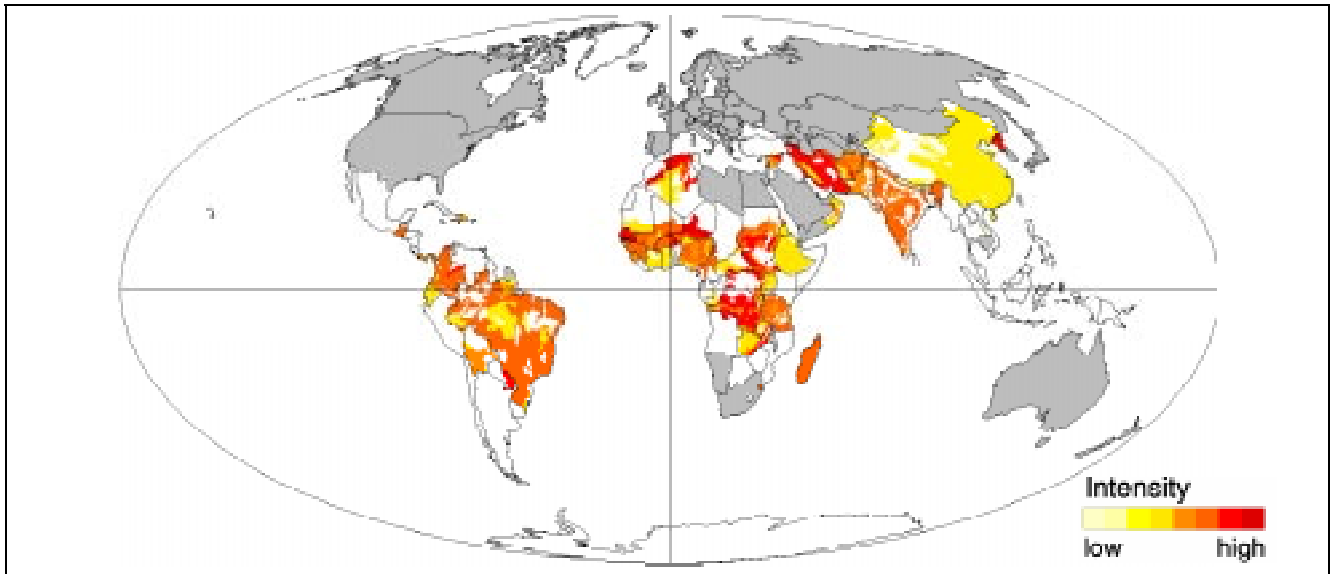


Fig. 1: Intensity of the SAHEL SYNDROME. In the indicated regions a vicious circle between an ever increasing impoverishment and a continuing soil degradation is detected to be active on the basis of data of the late 1980s and early 1990s.

The Sahel Syndrome

From the point of global relevance and the number of people affected the SAHEL SYNDROME is one of the most important patterns. This syndrome describes the typical causes and effects of an overuse of marginal agricultural land. The natural dimension of marginality might be due to climatic conditions, e.g. high interannual variability of rainfall, semi-aridity, insufficient soil or orographic conditions. If the rural population living under such productivity-restricting circumstances is depending highly on the use of natural resources for their livelihood, they will face the degradation of their environment arising from overuse of their resources. Besides economic reasons, it might be ethno-cultural, social or legal aspects which prevent the poor from obtaining alternative ways of income. As long as there is no well-balanced support for the peasants involved, massive and irreversible environmental degradations are a major threat; often, the only way out is emigration – possibly leading to vast urbanization effects described by the FAVELA SYNDROME.

Figure 1 depicts the global distribution of the SAHEL SYNDROME. Obviously it is not only the name-giving region in West Africa itself which is affected, but also many other areas throughout the world are involved: major parts of Brazil and Columbia, wide areas in South Asia, in particular the semi-arid regions of Iran, Afghanistan, Pakistan and India, and parts of China are identifiable. In all these regions, the vicious circle of impoverishment and soil degradation that constitutes the syndromes has been detected active in the late 1980s on the basis of data for soil degradation, poverty and agricultural activity from various sources. This assessment is the first attempt to obtain a systematic, data-based global overview of what is known as rural poverty-driven environmental degradation for some 20 years. The extension of the analyses to a model of the dynamics of the syndrome (see section on qualitative modelling on page 26) will then allow to give a systematic evaluation of various policy options presently discussed in politics and science. Furthermore, the assessment might be used to obtain systematically composed indicators for a sustainable development as demanded in Chapter 40 of the AGENDA 21 of the World Summit in Rio 1992: the intensity measure might be considered as a systemic indicator for a pattern of non-sustainable development.

The Dust Bowl Syndrome

Whereas the SAHEL SYNDROME is mainly encountered in developing countries and thus concerns in particular development policy, the DUST BOWL SYNDROME is a an archetype to be found especially in highly developed countries such as Germany. As the name suggests, it describes the environmental effects due to a highly industrialized and capital-intensive cultivation of land and water bodies. So far our investigations have focused on the effects of agriculture due to the excessive use of fertilizers, machinery, like tractors or combine harvesters, pesticides, or herbicides. In contrast to the subsistence farming in the SAHEL SYNDROME, the most important socio-economic component is the large scale production for the market. This may happen either for the local and/or regional market like in the European Union or for the global market, e.g. the production of cash crops in developing countries. Besides arable farming also pasturing is included in the syndrome. The environmental effects include impacts on soils for example by compacting and overfertilization, on water, e.g. by high nutrient loads due to a limited back flow from irrigation or high input of nitrates and other pollutants into the groundwater, and on the atmosphere by emissions of nitro-oxygen and other greenhouse gases.

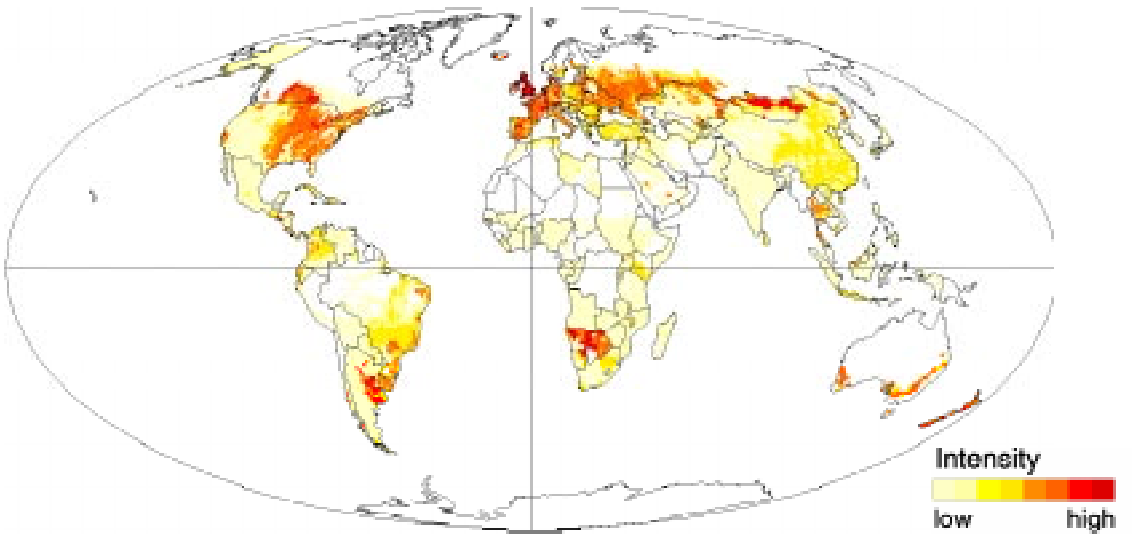


Fig. 2: Intensity of the DUST BOWL SYNDROME. The affected regions are characterized by a capital intensive crop cultivation, e.g. extensive use of either machinery, fertilizers, pesticides or herbicides, or an intensive stock-farming.

As can be seen from the map in figure 2 mainly the agricultural regions in North America, Western and Central Europe are affected by the syndrome. Additional regions detected as affected by the DUST BOWL SYNDROME are some pasture lands in South Africa, Mongolia, Australia and South America. Note that due to the still increasing use of chemicals in agriculture, almost the entire agriculturally used area is identified. This reveals that we only have a limited quality of data on global crop distributions; however, we need this information to distinguish market-oriented from subsistence farming, i.e. the DUST BOWL from the SAHEL SYNDROME.

The market-driven agricultural production within the regions affected by the DUST BOWL SYNDROME is on the demand side governed by consumption and lifestyle patterns, in particular in the prosperous countries of the Northern Hemisphere. Coffee, cacao and rubber production are examples for market oriented agriculture. This is not only effective on a local scale, but might equally be important on the global scale due to the increasing trade in human and animal food. Actions to weaken the pressure on the environment due to capital intensive agriculture are therefore not solely a question of classical agricultural politics, but equally of economic, individual, societal and institutional changes as well.

Vulnerability Assessment

The syndrome approach is not only designed to identify regions, where specific human-nature interactions have already lead to symptoms of criticality like overuse, depletion, degradation, but also to find those, where a specific syndrome might occur in the future. The leading question for this type of research is: how does a region become disposed towards a syndrome, or what makes it vulnerable to the damages that the

interacting trends will usually cause? Answering this question is important for three reasons:

1) From a logical point of view the domain of possibility includes the domain of reality. What is really happening today must be a selection of what is possible in general. Detecting regions, where the typical mechanism of a syndrome is a given reality thus presupposes that these regions are by some characteristic possible candidates for syndrome occurence. Detecting the characteristics leading to the outbreak of a syndrome is generally an important task for the disposition analysis.
2) From a genuine system analytical point of view the description of a system without regarding its future behaviour is incomplete. This holds true even more when Global Change is considered: As changes in the Earth system induced by humanity are the central focus of our research, we must — when only for analytical reasons — be interested in the future path of these changes. In the framework of our approach this means, that the domain of possibility is the potential domain of reality in some 10, 20 or 50 years. Thus the disposition of the syndromes is determined by natural, social, economic, and cultural factors only varying slowly in time.
3) From a political point of view the syndrome approach is a scientific decision supporting tool. It was designed to support the search for policy measures enabling a sustainable development. Dealing politically with Global Change not only means healing a damage that has already occurred or will inevitably do so in the near future, but also – and even more so – refers to developing long-term strategies and prevention measures. It is especially this latter aspect that underlines the importance of a careful and sound analysis of factors making a region vulnerable to the outbreak of a syndrome.

This last item No. 3 reveals some parallels between the disposition analysis and some fields of applied research that have emerged in recent years. One example is the Famine Early Warning System (FEWS), carried out by the US development agency (USAID), NASA, the US Geological Survey (USGS), and the National Oceanographic and Atmospheric Administration (NOAA). Its purpose is a short-term forecast of the vulnerability of a region for famine, using weather and vegetation data, combining them with price data for food crops. The United Nations World Food Programme (WFP) is another example here.

Syndromes might serve as a kind of global early warning system, and therefore the analysis of dispositions is one of the most important tasks to begin with. As the vulnerability of the world's regions to specific syndromes has to be identified, the mechanism of these syndromes serve as guidelines for the selection of disposition indicators. As syndromes focus on the human-nature interface, disposition indicators in general take into account qualitative and quantitative information about both natural and social characteristics which in their specific combination are responsible for a higher or lower disposition for a syndrome; thus for instance climate, soil and water belong to the natural characteristics, long-term food security, educational standards, economic growth conditions to the social characteristics. The concept of disposition addresses factors that are important on a medium to long-term time scale for phenomena and properties from various sectors, described by the different scientific disciplines. If a multitude of natural and social science information about a region have to be integrated, one has to decide on some logical clauses connecting them (for example "and" or "or") and on the weights to be given to the single factors. Syndrome oriented disposition analysis makes use of expert evaluations and case studies, leading to evaluation trees of relevant indicators, connected by fuzzy logic tools. As an example we present here the decision tree for the ASIAN TIGER SYNDROME disposition.

The Asian Tiger Syndrome

This syndrome addresses a specific economic growth pattern, aiming at high growth rates from a relatively low level of economic performance. This growth is widely directed by a strong and often authoritarian political system that neglects political participation as well as environmental issues. This implies severe and quickly rising consumption of energy and resources, accompanied by high pollution of water, air and contamination of soils. The construction of the Asian Tiger disposition decision tree was led by the question: Where are regions, that combine the following characteristics:

- good natural conditions for export oriented production: economic geography,
- good economic conditions for high growth rates: high economic stability, low labour costs and
- good cultural conditions for economic growth: attitudes and beliefs.

The final evaluation tree (see figure 3) shows the entry indicators and the logics of their combination in detail. Indicators for political stability will have to be introduced in the next step.

In the 1996/97 period five syndromes have been investigated with regard to their disposition. The final results were mapped to show which region in the world might be prone to what kind of syndrome. As men-

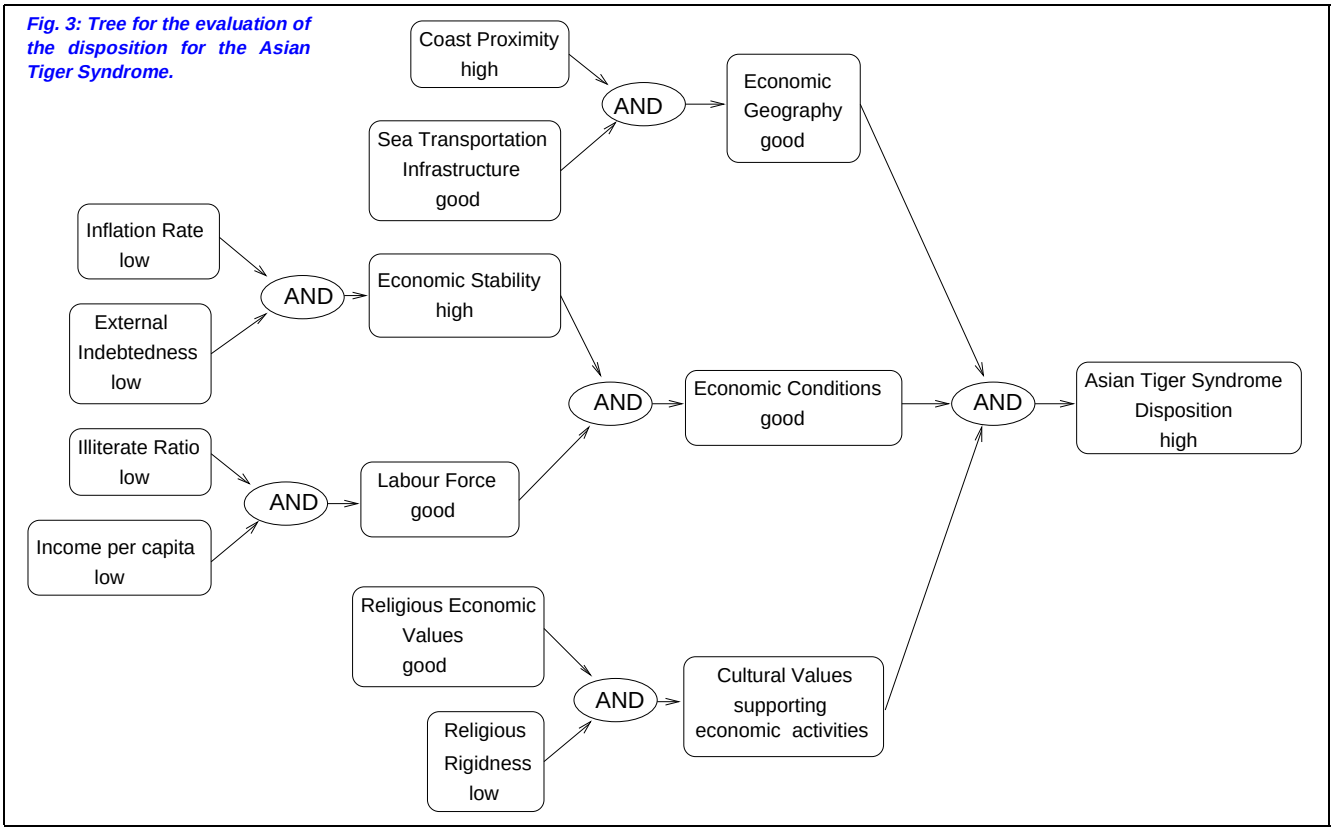


Fig. 3: Tree for the evaluation of the disposition for the Asian Tiger Syndrome.

tioned above, this sort of information is important for analytical and political reasons.

Comparative Analysis of Two Countries

To underline this claim, we compare two countries' disposition profiles with regard to five syndromes. The selected countries, Uruguay and Gabon, are under the same overall economic domain, the "upper middle income" according to the World Bank's ranking, and may therefore be compared rather easily. These profiles take into account the degree to which a specific country is disposed to a syndrome. The dispositions of Uruguay and Gabon are listed in figure 4.

The central African country of Gabon shows very high dispositions for the overexploitation syndrome. Some 85 % of the country are covered by dense tropical forest. Tropical timber was Gabon's main resource before oil began to dominate the scene; in recent years it has still accounted for some 10 % of exports. At the same time, international indebtedness is high enough – and still rising because of the falling oil prices – to execute a slight pressure upon the primary tropical forests. Sahel and Dust Bowl disposition values are medium, reflecting the facts that the agricultural potential of the country is still far from being exhausted, suitable sites are broadly available, although environmental costs might be rather high, and that in other parts of the country natural and social conditions make the overuse of agriculturally marginal sites probable. Although the hydropower potential as such is rather high, other disposing factors for the ARAL SEA SYNDROME are more or less missing in this tropical and oil-rich country (e.g. the marginal utility of irrigation for agriculture). Basic economic, geographic and cultural features lead to a low to medium disposition for the ASIAN TIGER SYNDROME, especially at coastal zones defined broadly by the rivers Gabon, Ogooué and Ngounié.

In contrast to Gabon, the Latin American country of Uruguay shows high dispositions for ARAL SEA and DUST BOWL. Both dispositions show an intricate coupling, as the agriculturally suited areas of this meat exporting country would offer even higher yields if its irrigation potentials were used more intensively. Regarding the spatial closeness of the disposed areas such a combined option gains additional plausibility. There is only a low disposition for the SAHEL SYNDROME, only in the Tacuarembó and Durazno districts we detect some moderate values. Due to almost negligible forest cover in Uruguay the country shows no disposition for the OVEREXPLOITATION SYNDROME. With respect to the ASIAN TIGER SYNDROME Uruguay shows

medium values, making it even more disposed than its neighbouring Mercosur partner country Argentina.
The briefly indicated profiles of the above mentioned states have to be completed for the other syndromes. It will then be possible to develop bundles of tuned policy measures in order to mitigate further syndrome development or, if possible, to prevent a region from initialising the syndrome mechanisms. Once more, disposition analysis offers a new and promising tool for politically relevant Global Change research.

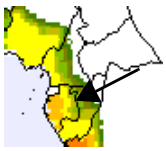
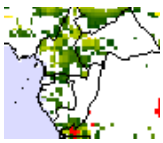
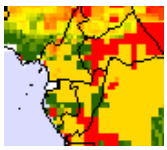
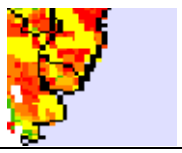
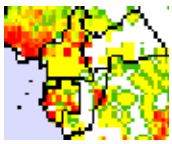
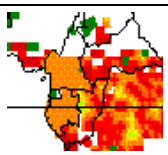
Syndrome	Uruguay	Gabon
Asian Tiger		
Aral Sea		
Sahel		
Dust Bowl		
Over-exploitation		

Fig. 4: Disposition of five syndromes, magnified for two different world regions: Uruguay and Gabon. Green=low, Red=high intensity

Indication of Core Problems of Global Change: Water Criticality

The explanatory power of syndrome analysis has to be evaluated with respect to the core problems of Global Change. Though there is a number of indications of these problems, e.g. climate scenarios, data sets on anthropogenic soil degradation, or censi and projections of population growth, there are major crises not assessed so far. Therefore, a number of adequate indicators have to be developed. In 1997 we started to assess the global water criticality.
The aim of this study which was performed in cooperation with the Scientific Centre for Environmental Systems Research (USF), Kassel, the Max-Planck Institute for Meteorology, Hamburg and the German Advisory Council on Global Change (WBGU), was to obtain an overview of the present and the future global freshwater situation. This assessment of freshwater scarcity with respect to human use has been published in the 1997 annual report of the WBGU.
To obtain a measure for freshwater criticality, the renewable water supply and the water demand have to be compared. This balance has been investigated on an annual scale which allows to identify sub-national and seasonal water shortages on a sub-basin level. Due to a lack of detailed and reliable data for present renewable freshwater resources on the global scale and the need for projections on the basis of climate scenarios, it was necessary to establish a new model. The WaterGAP1.0 model applied here has been developed at the USF in Kassel. Using simple, highly parameterized approaches, it computes the surface and groundwater runoff within 1,162 small sub-basins worldwide. In a first approximation this runoff represents the annual renewable freshwater available for human use. Besides computing the water availability for the current climate, the model has been used with the climate prognosis for 2025 by the MPI for Meteorology. It turns out that most regions of the world might have an equal or even increased water availability. On the other hand there are some regions, particularly in the developing countries of the South, where water availability decreases significantly.
For assessing water scarcity two further questions have to be addressed:

1) How much water can be made available for human use by implementing appropriate technologies, that is by water transport, reservoirs, recycling of used water by sewage plants or even additional water supply by desalination plants?
2) What is the water demand of the domestic, agricultural and industrial sector?

Step (1) is considered in a study of the global water situation for the first time. We estimated the above mentioned fraction as a function of economic capacity of a country. To assess the demand of water of the different sectors (Step 2), simple models for sub-national consumption patterns were derived within the WaterGAP model. These modules are based on distributions of population, agriculture and aridity. The projection of water demand was calculated using the IPCC projections for population and GDP (Gross Domestic Product) resulting in an overall increase in water consumption. This reflects that water saving due to improved technologies is overcompensated by population and economic growth.

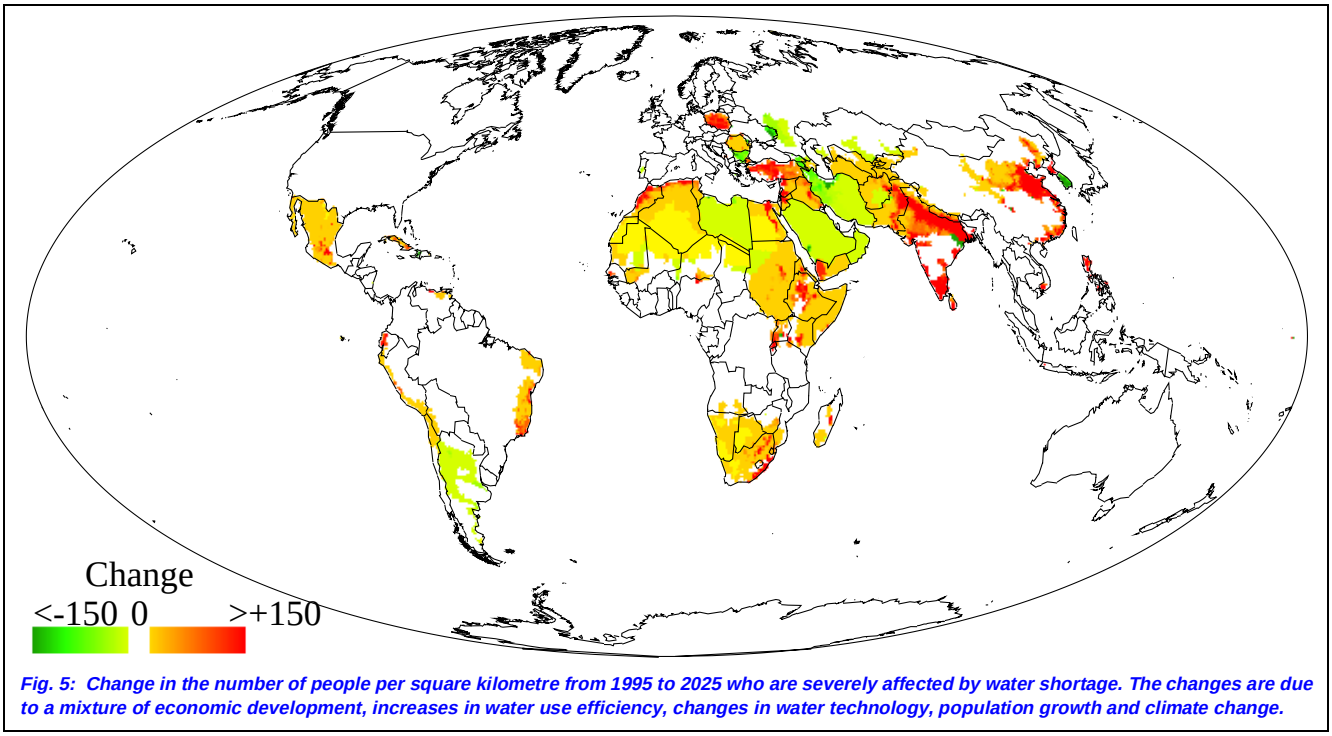


Fig. 5: Change in the number of people per square kilometre from 1995 to 2025 who are severely affected by water shortage. The changes are due to a mixture of economic development, increases in water use efficiency, changes in water technology, population growth and climate change.

In combination, regional water scarcity was estimated for the years 1995 and 2025. As one aggregated result of our geographically explicit study we calculated the number of people who are severely affected by water shortage. For 1995 we found that 2.1 billion people, which amounts to 37% of the present global population, are severely affected. This number increases to 3.3 billion in 2025, equivalent to 40% of the respective global population. In figure 5 the change in the number of people severely affected by water crisis is mapped geographically. Here the hot spots with respect to a future worsening of the situation can be identified in China, India, Pakistan, Turkey, Poland, Morocco, Algeria and Brazil.

The results imply that humanity faces a dangerous shortage of freshwater in the near future. Therefore new and innovative water-saving strategies have to be developed – including technologies, water trading and changes in consumption patterns. Moreover, these changes have to be far more effective than some positive examples of the last decade.

The analysis of water criticality performed so far, has still a number of deficiencies to be resolved in the nearest future. Besides an improved modelling of the supply side, e.g. by taking into account river flows, it is necessary to include aspects of water quality. Yet the latter is a widely open field with a tremendous lack of data and knowledge.

Methods of Qualitative Modelling

The biggest problem in modelling syndromes is the uncertainty in our knowledge about them: we do not know the details of the states of the variables, i.e. symptoms, involved, and in many cases we cannot quantify the interactions among the symptoms without reducing the view to, for example, one or the other one-eyed approach mentioned above (see page 19). This is not only due to limited efforts in assembling the data, but also due to the nature of the interactions involved. How could one quantify the relationship between variables like impoverishment, expansion of agriculture and soil degradation in a reliable and generally valid way? The only statement we have, is strong evidence for the existence of a steadily reinforcing vicious circle within the SAHEL SYNDROME, that means: we have qualitative knowledge. The challenge for our project is, to derive conclusions from qualitative knowledge only. Our method is the formalism of qualitative differential equations (QDEs) which has been developed by the “Qualitative Reasoning Group” at the University of Texas at Austin. By using this formalism it is possible to deal with entire classes of ordinary differential equations and to find all solutions compatible with a certain class. These classes are mainly defined by simple monotony assumptions like “The higher the state of poverty, the higher the rate of increase of agriculture.” Thereby, we do not have to assume certain functions for the description of our system as Denis and Donella Meadows did in their famous study “Limits

to Growth". We only assume the existence of a set of ordinary differential equations that can describe reality and use very general assumptions about the nature of these equations.

In the framework of qualitative differential equations the qualitative value (QV) of a variable will only change, if its quantitative counterpart passes values that are particularly important, the so-called landmark-values. An example for a landmark value is the point of agricultural intensity above which soil degradation occurs, called "maximum sustainable level" in the Green-Revolution Model (see below). The QDE defines that there is a soil degradation, if the QV of the variable "intensity of agriculture" is above the maximum sustainable level. Due to this functionally oriented definition of distinctive points, the actual realization, i.e. what does this sustainable agricultural activity actually look like in terms of techniques used, crops cultivated or fallow intervals, etc., might be different in different regions of the world. The possible solutions are described in terms of qualitative behaviours, which describe sequences of qualitative states. Time is in this context only ordinal, i.e., one cannot tell how much time has passed between two qualitatively different states.

Using only qualitative information, it is mostly impossible to derive unique qualitative behaviours, but several alternative behaviours can be compatible with a single QDE. This especially occurs if two different effects are working against each other, as in the Green Revolution Model, where rising intensity of agriculture increases, whereas degrading natural capacity decreases food production. In this case the system of QDEs is compatible with rising and with falling food production, and we have to include both possible outcomes in our analysis. As a next step, it is planned to improve the analysis of this branching point and to find other, rather general conditions of the interactions determining one or the other of these two outcomes.

Example – A Qualitative Model of the Green Revolution Syndrome

As a first modelling attempt, a simple model for the central mechanism of the GREEN REVOLUTION SYNDROME has been developed. The model consists of three variables: intensity of agriculture, natural capacity and food production as shown in figure 6. It is important to note that we have structured the interactions by introducing states and rates of changes as partaking variables. To gain insight into the effects of different government actions on this syndrome, two versions of the model were constructed, one including an inhibiting effect of a degraded nature on the further intensification of agriculture (version 1) and one without this effect (version 2). With version 1, it is possible to obtain a stable system with partial fulfilment of the food demand. In version 2, however, a partially covered food demand leads inevitably to the complete destruction of the natural basis of agriculture, without telling us how long this will take. It is interesting that considering the rate of change instead of the state of nature, no such stable system shows up in the possible model behaviours. In this case the destruction may last longer, but does not behave qualitatively different from version 2. It is obvious that these results are only a first step to an adequate modelling process, eventually allowing a robust evaluation of the effects of various policy actions. Yet the approach is promising, as the level of information needed is rather low and the focus is on the analysis of structures instead of single variables.

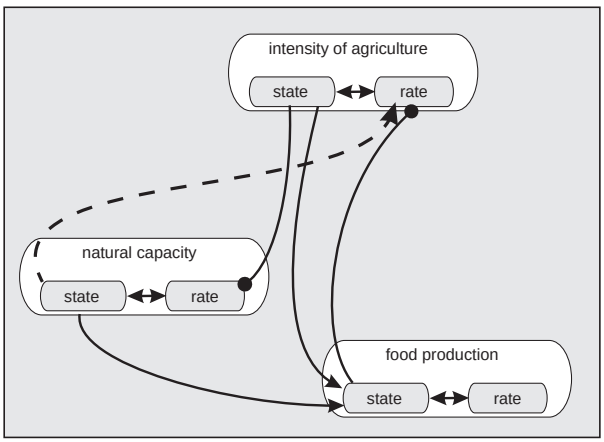


Fig. 6: Basic structure of the conceptual qualitative model for the GREEN REVOLUTION SYNDROME. The arrows indicate reinforcing interactions, the bulleted lines weakening ones. The model is realized by use of qualitative differential equations, where no further specification of actions is necessary.
To gain insight into the effects of different governmental actions in this syndrome, two versions of the model were constructed, one including an inhibiting effect of a degraded nature on the further intensification of agriculture (version 1, represented by the dashed line) and one without this effect (version 2, black lines only).

The Questions core project was partially funded by the German Federal Ministry of Education, Science, Research and Technology (BMBF).

ICLIPS
Integrated Assessment of Climate Protection Strategies

Project Leader: Ferenc Tóth

The ICLIPS project is an international and interdisciplinary research activity to provide an Integrated Assessment of Climate Protection Strategies in order to support the decision making community in the realization of the United Nations Framework Convention on Climate Change (UNFCCC). To this purpose, the innovative tolerable windows approach (TWA) is applied: on the basis of a set of pre-defined guard-rails that exclude intolerable climate change on the one hand, and unacceptable mitigation measures on the other, the admissible scope for action is sought by investigating the dynamic cause – effect relationships between society and climate. These relationships are described in an integrated manner by a model that takes into account climate impacts, the climate system itself, relevant biogeochemical cycles, emissions of different greenhouse gases, the allocation of emission rights to different nations, possible instruments for emission mitigation, and dynamics of socio-economic development. The different model parts are developed jointly with experts from leading institutes in the respective fields of global climate change. The modelling efforts are coordinated by the Potsdam Institute for Climate Research (PIK), which has initiated the project and integrates the various model components within the framework of the Tolerable Windows Approach.

Ferenc Tóth

The Tolerable Windows Approach to Environmental Policy Support

The Political Framework

At the end of the second millennium, mankind is facing a new challenge of unprecedented complexity: we need an analysis of the causes, mechanisms and potential impacts of global climate change and have to find ways towards a sustainable balance between nature and civilization. Being aware of the importance of these problems and of the urgency for precautions, over 150 countries signed and subsequently ratified the Framework Convention on Climate Change (FCCC) in Rio de Janeiro in 1992. Article 2 of this Convention calls for the stabilizing of greenhouse gas concentrations in the atmosphere at levels that "prevent dangerous anthropogenic interference with the climate system" and requires that these levels have to be achieved within a "time frame sufficient to allow ecosystems to adapt naturally, to ensure that food production is not threatened, and to enable economic development to proceed in a sustainable manner". Although Article 2 fixes an overall goal for world-wide climate policy, the details of this goal and how it might be achieved remain unclear: Below which greenhouse gas concentrations is the prevention of dangerous interference ensured? How much time do we have to spend, until the emissions need to be reduced? To what extent do we have to reduce them?

Taking these issues into consideration, the German Federal Government is giving support to the ICLIPS project. The main objective of the project is to bring together an international and interdisciplinary research group in order to carry out an Integrated Assessment of Climate Protection Strategies and especially

- to strengthen the empirical and theoretical basis of the "Tolerable Windows Approach",
- to provide an interactive computer-based integrated-assessment model which can be used by policy makers,
- to give scientific advice to decision makers, especially to those who are involved in the international negotiations of the Conference of the Parties to the FCCC, and
- to introduce the project results in the international discussion platform of the Intergovernmental Panel on Climate Change (IPCC).

The Tolerable Windows Approach

By defining guardrails for tolerable climate change, on the one hand, and acceptable mitigation measures on the other, and by investigating the chain of cause and effect that relates society and environment, it is possible to determine the remaining scope of action over the next decades. Altogether, the guardrails define sets of rather tolerable environmental and socio-economic conditions which are called "tolerable windows" (figure 1).

The tolerable windows approach therefore seeks to determine the set of all climate protection strategies that are consistent with the tolerable windows. Knowing the remaining manoeuvring space may be very helpful for all policy makers who are involved in the international negotiation process. The question which conditions are judged to be intolerable should be answered by society as a whole in the course of a (democratic) process in which policy can play an important mediating role by participating in the public education and persuasion process as well as by reflecting the judgements in defining adequate tolerable windows. Science may add, as far as possible today, the necessary insight into the relationships that exist between the different parts of the involved natural and socio-economic systems. The implementation of the tolerable windows approach in the course of the ICLIPS project requires the coupling of regionalized models for the impact of climate on natural and managed ecosystems as well as on human societies and those for natural biogeochemical cycles, climate, greenhouse gas and aerosol emissions and of instruments representing climate policy measures and influencing socio-economic development.

In the initial phase of the project in 1996/1997, a global integrated model was developed in order to study the principle issues related to the conceptual basis of the tolerable windows approach, to develop appropriate mathematical techniques, and to provide valuable results timely with respect to the Third Conference of the Parties to the FCCC in Kyoto. The ICLIPS project was able to introduce first results in the international platform of the Intergovernmental Panel on Climate Change (IPCC) at an IPCC Workshop in March 1997. Invited by the German Advisory Council on Global Change (WBGU), the project conducted an integrated analysis of climate protection strategies as part of a study prepared for the Kyoto Conference. From this analysis the Council derived specific reduction targets for the industrialized countries and recommended that these countries should reduce their greenhouse gas emissions by 11%, 23% and 43% by the years 2005, 2010 and 2020, respectively, in relation to the emissions of 1990 as the base year. In the long term (by 2050), a reduction of about 80% should be aspired.

Future project work will focus on uncertainty aspects inherent to the climate change issue. From the modelling point of view, we will concentrate on developing regionalized versions of the climate and the socio-economic model. To be effective, the project's results need to be made available to international and national policy making bodies, and to other scientists. Thus, in addition to the normal activity of scientific and popular publication, the ICLIPS project is bringing together members of these groups in several workshops and policy exercises. For that purpose, the project will provide an interactive computer-based integrated assessment model.

Methods and Models

Methodological Aspects of the TWA

The Tolerable Windows Approach starts off with an explicit normative setting of unacceptable climate impacts, policies, instruments, and generalized utilities. By the analysis of the relevant elements of the Earth system, the corresponding "tolerable windows" are intersected in order to obtain that set of climate protection strategies, which keeps the entire system within the demarcated domains. From the methodological point of view, the main objective of the tolerable windows approach is twofold: firstly, the determination of the set of all admissible emission paths which are compatible with the normative inputs and, secondly, the selection of optimal emission paths in a "second best" manner. While the second task can be embedded into a cost-effectiveness framework, generally known among scientists, the first one requires an appropriate mathematical foundation. Based on the theory of differential inclusions, several solution methods were developed. These solution methods provide necessary and sufficient descriptions for the complete set of admissible emission paths, i.e. for all emission paths which are compatible with the tolerable windows.

The boundaries of the tube of all admissible paths, which is called a "funnel" in mathematical terms, may be calculated for different climate windows and socio-economic restrictions. However, the funnels are by no means "safe" corridors because they represent only necessary conditions: although each admissible path lies within the corridor, not every arbitrary function lying within the limits of the corridor is admissible. It is possible to gain the required insight into the internal structure of the funnels by implementing an appropriate parameterisation of the emission profiles. Finally,

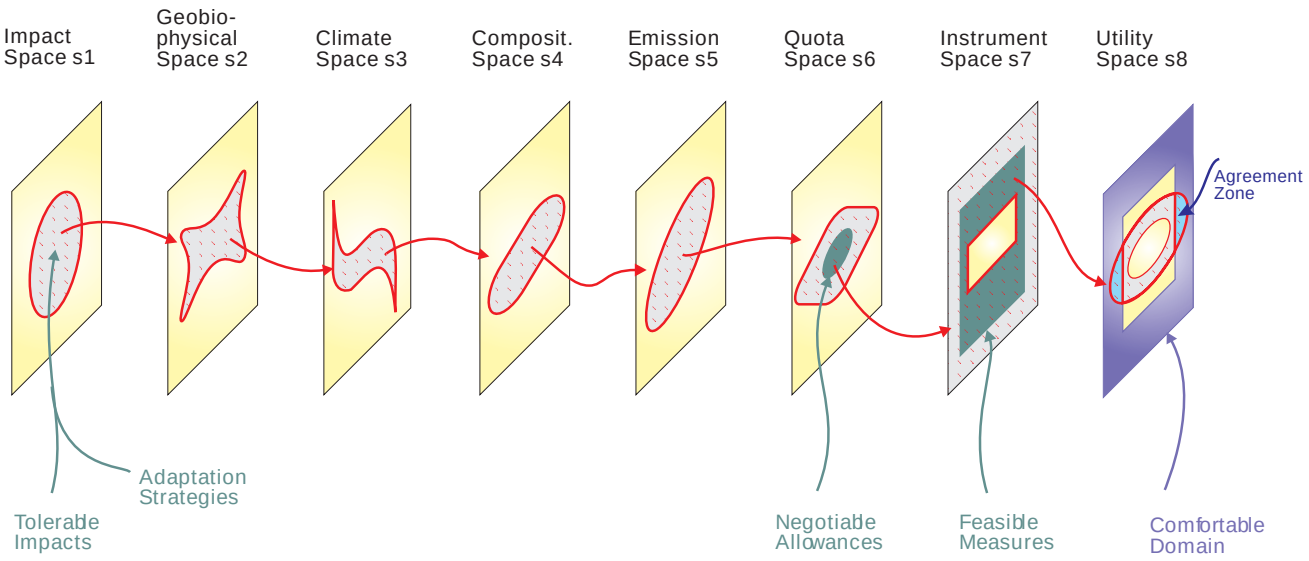


Fig. 1: The Tolerable Windows Approach is based on the normative specification of tolerable sets of climate impacts, allowances and instruments for implementation (green arrows below Spaces 1, Space 6 and 7). The related "tolerable windows" are derived successively in an inverse mode by scientific analysis (red arrows): first by analysing the additional stress levels caused by altered biogeophysical conditions that one can assume to be ecologically and socio-economically bearable (red striped areas in Space 2), a tolerable window for future climate development is deduced (Climate Space 3). In a further step, the corresponding set of admissible greenhouse gas concentrations (Composition Space 4) as well as the tolerable emission profiles (Emission Space 5) are calculated, i.e. those global greenhouse gas emission scenarios which keep the climate system within the demarcated window. Space 6 and 7 show the further filtering process in several steps.
The red-striped window in the Quota Space stands for measures to avoid an intolerable Global Change. However, only a subset of these measures can be considered to be compatible with negotiable allowances, e.g. due to equity considerations (green circle in Space 6). In the Instrument Space, measures lying within the yellow rectangle, would yield to an intolerable climate change. More ambitious climate protection instruments (red-striped rectangle in Space 7) may not be tolerated by societies. So a set of feasible policies is filtered out, which is compatible with the normative settings (green rectangle in Space 7). In Space 8 another aspect is added: the demands of civilization and welfare called Comfortable Domain and indicated by the blue external rectangle. The still admissible measures are now shown by the red-striped circle. They effect our comfortable domain only in the small area of the agreement zone (light blue). As before, the yellow field in the middle stands for an uncomfortable climate, in which we do not want to live.

the selection of a specific policy path may be carried out either by taking into account additional policy goals, which are considered as hardly quantifiable, or by minimizing the greenhouse gas abatement costs in a "second best" or "cost-effectiveness" framework.
The developed methodological tools appropriately take into account the dynamic aspects of the entire problem, e.g. restrictions on the rate of change of climate or socio-economic conditions. From this point of view, the TWA may be considered as a dynamic generalization of the critical loads concept, which has been used to determine the reductions of sulphur dioxide emissions agreed in the Second Sulphur Protocol.
The main conceptual problems of the global version of the TWA have been solved. Future conceptual work will focus on integrating uncertainty, on regionalization, and on revealing the relationship between TWA and competing approaches to integrated assessment of climate protection strategies.

The ICLIPS Climate Model

The objective of the ICLIPS Climate Model (ICM) is to describe the relationship between emissions of different direct and indirect greenhouse gases and climate change. For that purpose, a whole family of coupled sub-modules is employed. Although the sub-modules are conceptually simple, they nevertheless simulate reliably the results of more complex and therefore computationally more demanding (general circulation) models.
ICM includes all the major greenhouse gases (carbon dioxide, methane, nitrous oxide, halocarbons, tropospheric and stratospheric ozone, and stratospheric water vapour). In addition, it takes into account the radiative effects of aerosols originating from sulphur dioxide emissions and from biomass burning. ICM consists of the following sub-modules:

- biogeochemical sub-modules for turning emissions into concentrations, whereby carbon dioxide, well-mixed gases with well-defined lifetimes, i.e. methane, nitrous oxide, and halocarbons, aerosols, and not directly emitted gases are treated differently,

- radiative transfer sub-modules for calculating radiative forcing from concentrations,
- climate sub-module in the strict sense for translating radiative forcing into global mean temperature change and
- sea-level rise sub-modules for calculating sea-level change from thermal expansion of oceans and ice melting.

The carbon cycle is described according to a model by Svirezhev and Brovkin. In this model the annually averaged carbon cycle is composed of four large carbon pools: atmosphere, ocean, terrestrial vegetation and pedosphere, connected with each other by carbon fluxes.

The Concept for the Socio-Economic Model

According to figure 1, the objective of the ICLIPS Socio-Economic Model is to determine the socio-economic consequences (expressed in the utility space) that are related to tolerable emission paths by taking into account pre-defined negotiable emission allowance schemes as well as the set of feasible climate protection instruments. In order to achieve this goal, it is necessary to provide a sectoral and regional disaggregated macro-economic model, which especially includes detailed submodels for the energy sector, resource availability and for the technology sector. With respect to the instrument space (figure 1), political, economic, administrative, technological and educational instruments will have to be distinguished. Regarding the selection of utility variables, we currently restrict ourselves to the category of private income, which is the basis of most economic utility and welfare concepts. Yet we plan to relate such variables as mobility and recreation to the Orientor Concept of Bossel, where a set of generalized orientors is characterized, each of which has to be satisfied in at least a minimum quantity.

Due to the very different time scales that are important in the global climate issue, two different economic models are being developed. Firstly, we extended a Ramsey type optimal growth model based on Cobb-Douglas production functions by including components of endogenous technological change, aggregated energy input, as well as the opportunity for emission rights trade. This model is suited for long-term analysis and will be coupled with the climate model as part of the ICLIPS Integrated Assessment Model. The latter model will allow the determination of long-term climate protection strategies that are consistent with the normative formulated guardrails.

In order to assess the short-term economic implications of such strategies, a general equilibrium model (GEM) will be applied, which is currently being developed at the Kiel Institute of World Economics. In order to be realistic, the final version of this model should allow to take into account elements of market imperfections in various world regions, for example Europe, North America or the area of the former Soviet Union.

Preparing these economic models for global TWA analysis has involved two directions: starting own modelling efforts on the one hand, and applying existing models on the other hand, especially in order to provide first results of the overall approach timely for the Kyoto Conference. Therefore, the MERGE model of Manne and Richel was enhanced by including different climate restrictions and applied to determine cost-effective strategies as part of the WBGU study.

The MERGE model will be replaced as soon as the ICLIPS models are available.

Policy Analysis

Analyses of political aspects of climate change have focused on three issues: fairness concerns of climate change, analysis of the international negotiation process, and the role of scientific uncertainty in international negotiations.

1) *Fairness:* The tolerable windows approach as developed in the ICLIPS project requires a number of normative inputs. Although these will be left mainly to political decision makers, e.g. defining which climate impacts can be regarded as tolerable, equity concerns have to be taken into account in the design of model scenarios and burden sharing schemes. With respect to this, two issues were identified to be the most important ones: First, the aggregation of national utilities to an international level. This relates, among others, to the question to what extent the definition of a tolerable window should focus on regional or globally aggregated impacts. Second, how to allocate the burdens and benefits of climate change protection strategies. A critical issue in international negotiations is the international allocation of emission reductions and related cost, possibly in the form of tradable permits. The equity axioms most widely used in the economic theory of fair division have been applied to this question and thereby a relatively small set of allocations, which can be regarded as fair according to these axioms, could be identified, especially for the initial phase of the climate change regime when emissions in the South are relatively small.
2) *Negotiation process:* To assure that the model is developed in a way that it is able to address the most prominent issues in the formulation of an international climate change protection strategy, we closely monitor the international negotiation

process. As one result of this activity, a summary of the propositions currently discussed in negotiations for a legal instrument on climate change gases was presented to the workshop on fairness concerns in climate change. Furthermore, occasionally we inform other PIK projects about the current state of negotiations on climate change, so as to further the policy relevance of ongoing research activities.

3) *Scientific uncertainty:* The complexities of international environmental problems are only poorly understood. Hence, decision makers have to negotiate about abatement measures even though they do not know the "true" model of the ecological system and have only a rough idea about the costs and benefits of their action. Research has focused on the effects of this kind of "model uncertainty" on the prospects of international cooperation. In particular, it has been analysed to what extent countries can use the veil of uncertainty to hide their distributional interests. As part of this activity, a relatively simple game-theoretic model for transboundary environmental problems has been developed.

Data Base Design and Data Base Management

The project team at PIK began preparations for the large scale socio-economic modelling activities by creating a data base of global socio-economic and natural data. This activity involves collecting the relevant data sets of various international sources, performing quality and consistency checks across the various data sets, and making the data available in a unique format.

Corridors of First Results

In the first one and a half years of the project significant scientific progress has been made. The main problems of a global version of the TWA were solved, a respective model was programmed, and first results were published and presented at different workshops. Exercises with the MERGE model resulted in profound experience in the determination of cost-effective emission paths under different climate restrictions. However, the MERGE model is used only as a substitute for the ICLIPS socio-economic model which is under construction.

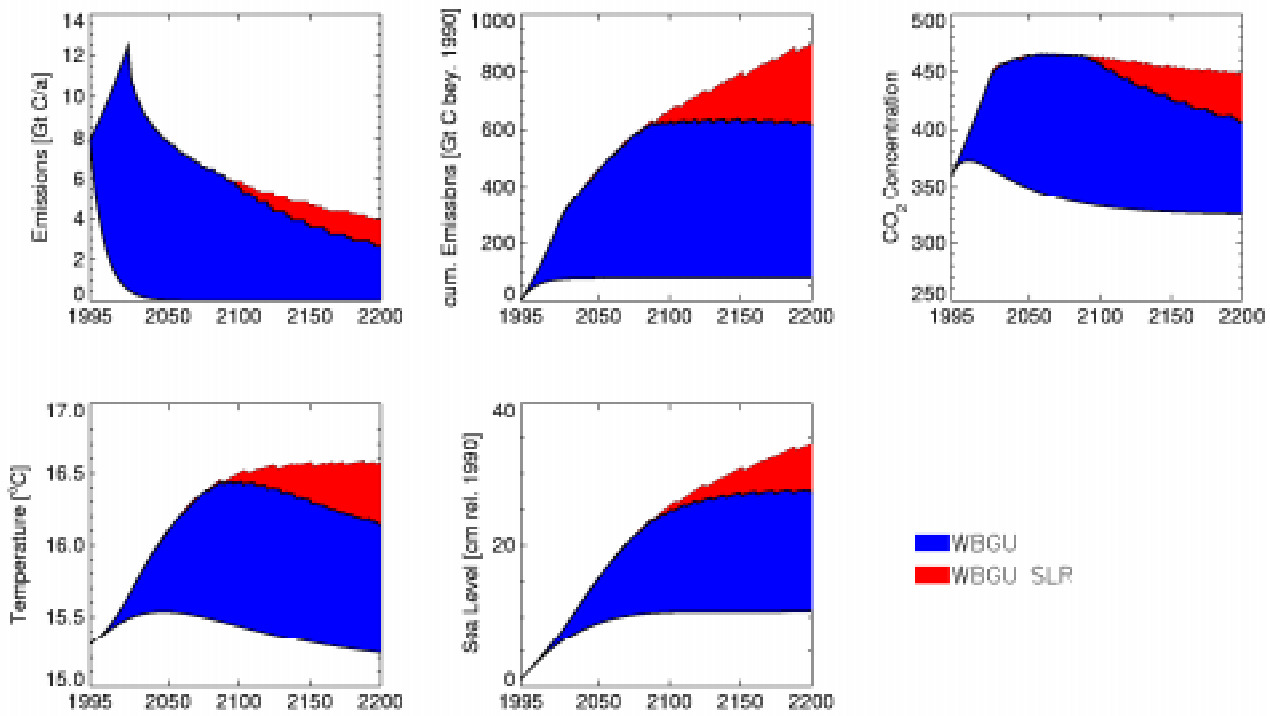


***Fig. 2:** Restriction effects on temperature and sea level rise (SLR) according to the WGBU Model from 1995 to 2200: The graphics show upper and lower bounds of corridors, i.e. guardrails, for emissions, cumulative emissions, CO_2 concentration, global mean temperature, and sea-level rise valid for the chosen tolerable windows. The WBGU Climate Model only allows a maximum temperature change of 2 °C since the preindustrial level and a maximum temperature change of 0.2 °C per decade and a maximum emission reduction rate of 10% per year. The sea level should not rise more than 30 cm since 1990 and no more than 3 cm per decade.*

Results Achieved with the WBGU Climate Model

The main results gained by our first tolerable windows exercise using the climate model of the WBGU study may be summarized as follows: in order to avoid violating the restrictions imposed by a maximum temperature change of 2 °C relative to the preindustrial level and a maximum rate of temperature change of 0.2 °C per decade ("WBGU" climate window, see figure 2) and in order to allow a smooth transition to a fossil fuel free economy, we have to reduce greenhouse gas emissions effectively in about 25 years' time at the latest, if an emission reduction rate of 10% per year should not be exceeded. However, in this case the reduction in 2020 has to be rather sharp.

In the cost-effective case, a level of nearly zero emissions is reached already in the middle of the next century. The welfare loss of this optimal path - calculated by using the MERGE model - is smaller than 1% of the respective reference value.

In the short run, i.e. up to about 2030, effective emission reduction is only determined by restrictions on the rate of temperature change. Limitations on the absolute values of temperature are important only in the long term. As part of a sensitivity analysis we also calculated the corridors for an additional restriction "WBGU SLR" case), limiting sea-level rise to 30 cm relative to the 1990 value and the rate of sea-level rise to 3 cm/decade. Due to the large time lags in the sea level behaviour, the corridors differ only in the long term from those derived from the WBGU climate window.

Results Achieved with the ICLIPS Climate Model

The ICLIPS project has participated in the preparation of a WBGU (Scientific Council on Global Change of the Federal Government of Germany) statement for the Third Conference of the Parties to the Framework Convention on Climate Change (FCCC) in Kyoto. For that purpose, the WBGU climate model was enhanced. As a first step to regionalization, corridors were calculated for two different groups of nations: industrialized and developing countries according to the so-called Annex I of the FCCC. This procedure allows to discuss equity aspects of climate protection strategies in the framework of the TWA.

The results of this exercise, which are shown in figure 3, are valid under the following assumptions: in the initial phase, global and regionalized emissions are following the IS92a scenario, which is some kind of business-as-usual scenario defined by the Intergovernmental Panel on Climate Change (IPCC). In a subsequent period when reduction takes place, all greenhouse gases (except halocarbons) and the sulphur dioxide emissions are reduced in phase with carbon dioxide emissions. All corridors were calculated for the above mentioned WBGU climate window combined with a socio-economic restriction given by a maximum global and regional emission reduction rate of 4% per year. In figure 3 a) the corridor of global emissions is given. Figure 3 b) shows the respective corridor if the IS92a scenario is followed for another 15 years. Figure 3 c) provides insight into the behaviour of the corridors of industrialized countries' emission rights, if the developing nations have no reduction commitments till equity according to the "equal per capita" principle on the basis of the population of 1992 is achieved. Finally, figure 3 d) states the respective corridor with another 15 years according to business-as-usual.

The main results may be summarized as follows. The time span, during which we can follow business-as-usual, is restricted to about 20 years, if the chosen tolerable window is not violated. Waiting 15 years without implementing emission reduction measures at all will result in a large loss of flexibility for action. Taking equity considerations into account results in an overproportional restriction of the corridor of the industrialized nations compared to the global corridor. It should be emphasized that the underlying equity consideration is specified with respect to emissions rights so that joint implementation activities are not affected by these equity issues.

A general consensus in the integrated assessment community holds that, viewing the complexity of issues in climate change and our ignorance about its many aspects, the best integrated models can only offer insight about nature, basic relationships, and key dynamic features of the problem to policy makers. The results achieved by the ICLIPS project so far have shown that, even in its early phase of development, the TWA approach can make a useful contribution to the debate and provide valuable insights for the policy process in its search for appropriate management strategies.

The ICLIPS core project is funded by the Federal Ministry for Education, Science, Research and Technology (BMBF) and the Federal Ministry of Environment, Nature Protection and Reactor Safety (BMU).

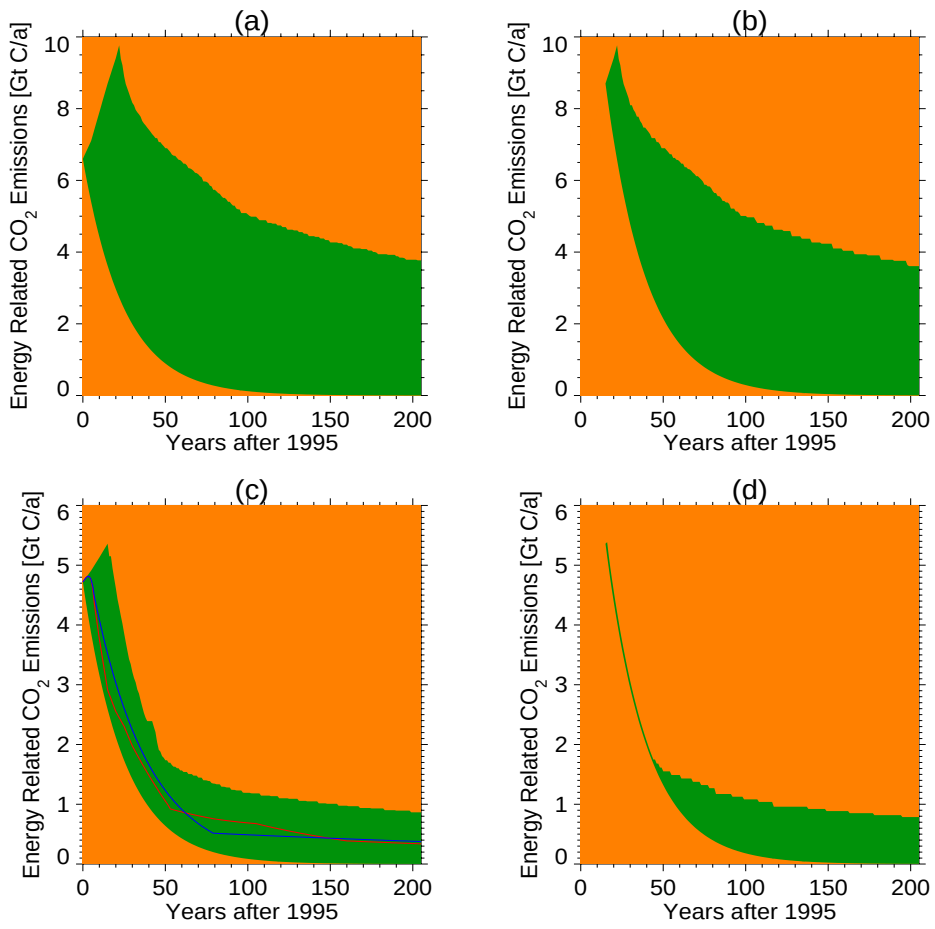


Fig. 3: Results of the new ICLIPS Climate Model: Emission corridors for global energy and cement related emissions (figures a and b) and for the industrialized countries (figures c and d). Figures b and d show the respective corridors, if the business-as-usual scenario is followed for another 15 years. Blue line: WBGU path, deduced from the red path and recommended by the WBGU in 1997 on the occasion of the Kyoto Conference.

Transdisciplinary Regional Studies

RAGTIME
Regional Assessment of Global Change Impacts Through Integrated Modelling in the Elbe River Basin

Project Leader: Alfred Becker

RAGTIME represents the regional, river basin oriented component of Global Change research at PIK. Its main objective is to investigate the impacts of climate change, of land-use and land-cover change, and of other human activities on hydrological and ecological characteristics. A modelling framework links evapotranspiration, runoff, groundwater recharge and storage, river discharge, water quality, crop yield etc. Specifically vulnerable subregions are identified and the scientific basis for response strategies that ensure a sustainable development are provided. The project is carried out in the Elbe river basin, but the developed methodology may be applied to any other river basin.

Alfred Becker and Valentina Krysanova

The Elbe River Basin as a Study Area

Regional and local scale studies on Global Change processes and impacts are particularly needed at the land surface where the most important sources and driving forces of Global Change are located These are for instance areas with changing land use and land cover, industrial complexes, cities, traffic with emissions of trace gases, different types of waste, etc. Accordingly, it is primarily at these scales that political and technical measures and regulations can be taken in order to avoid critical developments and to reduce negative or undesired effects and consequences. The regional scale is crucial for an improved understanding not only of the different mechanisms of Global Change, but also of its impacts on the environment and society.

River basins are the preferred land surface units for regional-scale studies because their drainage basin areas represent natural spatial integrators or accumulators of water and associated material transports. Changes in streamflow and river water quality indicate impacts of human activities and environmental changes. The German part of the Elbe river basin, covering an area of nearly 100,000 km^2, was chosen to carry out this case study for the following reasons:

1) It is large enough and provides a reasonable variety of environmental and socio-economic conditions as well as conflict situations resulting especially from agricultural land use, relatively high pollution loads from different sources, etc., and the need to protect the environment.
2) It is the driest of the five largest German river basins. Droughts, water stress and water deficiencies occur earlier and more frequently than in the other German river basins.
3) It is subject to considerable socio-economic changes resulting from the German unification and the transformation from the former socialist to free-market conditions.

The RAGTIME Approach

The methodological scheme of the RAGTIME approach is outlined in figure 1. Two aspects determine the results of the impact study: climate and land use, representing the two most essential control variables. They are at the same time drivers of and subject to Global Change, and need to be given as system inputs for any assessment of Global Change impacts, also in regional studies.

In this project the climate is considered as a more global phenomenon influenced by the accumulated effects of human activities. Changes in climate at regional scales are not easy to predict. A catalogue of several climate change scenarios has been developed from diagnostic studies of the past and present climate, combined with simulation results of global and

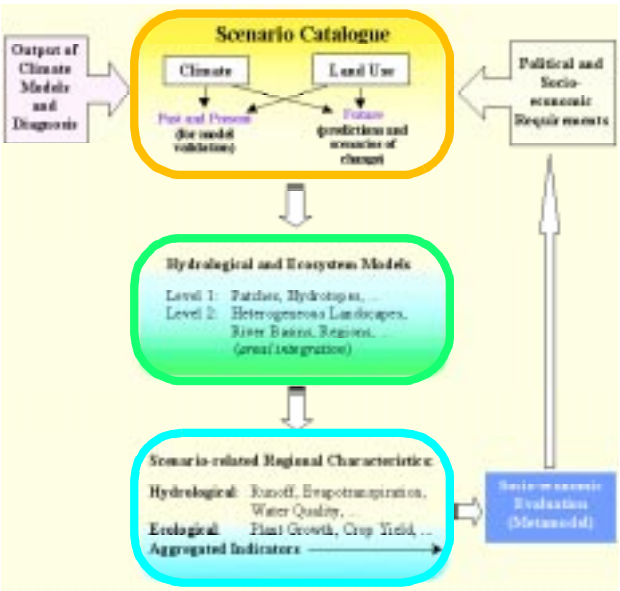


Fig. 1: Schematic representation of the RAGTIME Approach.

regional atmospheric circulation models. Land-use-change scenarios are based on local political and socio-economic driving forces. These imply guiding principles for environmental protection and natural resource preservation, group interests as those of farmers as well as regional development planning (upper block in figure 1).

Land owners and governments on a national, state, district, or local level clearly have a chance to ensure the sustainable development and human welfare of their region. The results of the scenario calculation may change with different political and social input variables. Therefore, as a separate research initiative within RAGTIME, a so-called metamodel will integrate environmental and socio-economic aspects at a relatively high spatial and temporal aggregation level using states or other administrative geographical units and years to consider annual budgeting.

The next step in the RAGTIME approach (central block in figure 1) is to model the behaviour and performance capabilities of the environment and the natural resource systems, such as water, vegetation, soil, etc. under past and present conditions. Reconstructions of the past are used for model validation. After validation these models are able to analyse any impact of Global Change from the scenario catalogue for the respective area. A special requirement is that the models should be able to model land-surface units of any form and size and also as integrated elements of heterogeneous landscapes and river basins. A bottom-up approach is to be applied because land use is often changing on relatively small areas.

The essential hydrological and ecological characteristics such as evapotranspiration, runoff, groundwater recharge, crop growth and yield, water quality etc. are the outputs of these models (lower block in figure 1). They need to be aggregated over space, e.g. a landscape or state, and time, e.g. a month, season or year, in order to be used for socio-economic evaluation and for the derivation of response strategies to avoid undesired consequences (lower right in figure 1). This forward evaluation of Global Change scenarios represents a direct step towards the integration of environmental and socio-economic aspects. A large number of land-use scenarios must be investigated (upward loop on the right-hand in figure 1) to find socio-economically and ecologically acceptable, i.e. beneficial and sound response strategies, for different land use types and area patterns in order to ensure a sustainable development.

Meso and Macroscale Hydrological and Ecological Modelling in the Elbe River Basin

Land-use change and many other anthropogenic influences normally occur on small land units. The models used in RAGTIME therefore operate with small pieces in a first step. In a second step the patches are aggregated into classes and sub-basins. Two modelling systems with polygon and raster-based spatial discretization schemes have been developed for this project. They subdivide the basins into elementary unit areas (patches), hydrotopes (Hydrological Response Units), or hydrotope classes.

The hydrological modelling system ARC/EGMO (Einzugsgebietsmodell, Engl.: catchment model) is coupled with the Geographic Information System ARC/INFO to apply the finest and most detailed disaggregation scheme into elementary unit areas. The modelling system SWIM (Soil and Water Integrated Model) applies disaggregation into hydrotopes and sub-basins. However, SWIM is capable of simulating nutrient dynamics (nitrogen and phosphorus), erosion and vegetation/crop growth in addition to hydrological processes. SWIM is coupled with the Geographic Resource Analysis Support System (GRASS). In some cases, particularly for streamflow simulation in larger basins, a modification of the Swedish model HBV is used. This model requires less input data and works with a coarser area discretization scheme than the other two models. Results of some applications of the three models are presented below.

From the first applications of ARC/EGMO and SWIM we come to the following general conclusions:

- It is appropriate to distinguish two domains of hydrological processes in modelling, that of vertical and that of lateral fluxes. Different disaggregation, aggre-

gation, and scaling techniques have to be applied for the two domains to simplify modelling, if required.

- Mixed landscapes, e.g. composed of forests, crops, meadows and settlements, should be subdivided into units of unique hydrological regime (hydrotopes), which significantly vary in their hydrological process characteristics. This ensures that sound physical models can be applied for each land cover type, using appropriate data.
- Polygons of different form and size are best suited to represent the mosaic structure of real landscapes. Spatially distributed patches with similar climate can be combined into larger modelling units (e.g. hydrotope classes) to simplify large scale modelling and to reduce computing time.
- In lateral flow modelling, simple models, like single storage reservoirs or simplified diffusion type models are most efficient. They can be applied to large river basins and sub-basins.

Modelling of Water Balance and Runoff Components in the Elbe River Basin

The first task was the basin-wide simulation of water balance components such as evapotranspiration, surface runoff and percolation in elementary areas, hydrotopes or hydrotope classes. The ARC/EGMO model was used for this purpose. First the basin was divided into 64,500 elementary units by using all available digital information on land use, soil characteristics, topography, groundwater level, the river network, sub-basins, etc., as provided by the Geographic Information System ARC/INFO. In a second step, the elementary units were aggregated to hydrotopes and hydrotope classes in order to simplify and accelerate the simulations.

Spatial interpolation of the required meteorological input data was based upon daily values of precipitation, mean temperature, relative humidity and sunshine duration from 33 climate and 107 precipitation stations. The results generally show high spatial variability which is correlated to the climate and to the underlying land-surface features, in particular land use, soil and groundwater level. As an example, the area distribution pattern of percolation available for groundwater recharge and lateral subsurface flow is shown in figure 2.

Relatively dry regions, which are especially vulnerable in case of droughts, are clearly visible in the central and eastern part of the Elbe basin. The mountain ranges of Harz, Thüringer Wald and Erzgebirge indicate a greater water availability, mainly due to larger precipitation values in these mountain regions. These results, together with others already available for 1980 to 1997, serve as a reference point for future climate

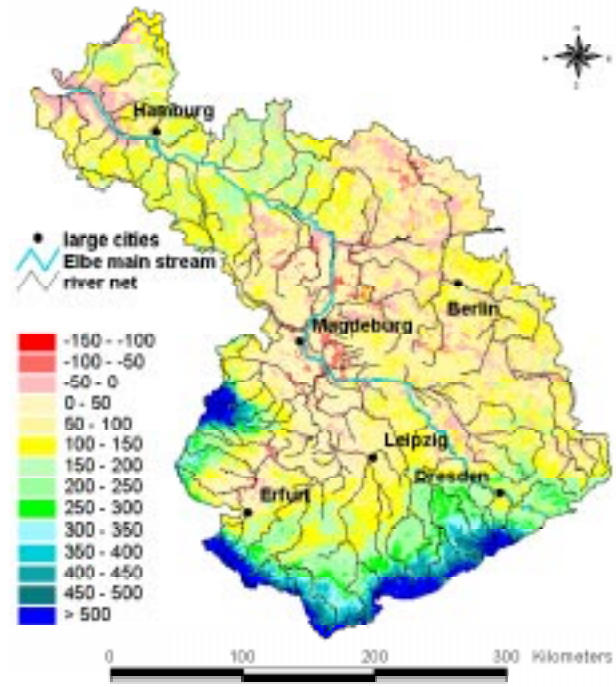


Fig. 2: Spatial distribution pattern of mean annual amounts of simulated percolation (in mm) in the Elbe river basin for the period 1983-1987 of 64.550 elementary units. The negative values show the annual capillary rise of water. Percolation generates either groundwater recharge and thus feeds a stable freshwater resource (groundwater) or lateral subsurface flows (interflow) contributing directly to the stream flow.

analyses and investigations on land-use-change impacts on hydrology and water resources.

In addition to the water balance calculations, three run off components: land surface run off, quick return lateral subsurface flow, also called interflow, and groundwater flow were simulated and analysed. The three runoff components are important to describe properly the transport of nutrients and pollutants in a river basin. This investigation was performed for 35 mesoscale sub-basins of the Elbe belonging to drainage areas of different Elbe tributaries, among them the rivers Saale, Weiße and Schwarze Elster, Unstrut, Mulde, Spree and Havel. For this purpose the HBV-D, the PIK version of HBV, and ARC/EGMO models were used.

The selected sub-basins have drainage areas of 190 to 6171 km^2 and are located in all three geographical subregions of the Elbe: the Pleistocene lowland, the loess region, and the mountainous region. An example of such a simulation in the mountainous Flöha river basin is shown in figure 3. In order to facilitate the regionalization of the obtained results, all investigated sub-basins were classified into four classes based on five generally available run off characteristics, like the specific runoff and the high flow specific runoff for the

gauges. The simulated three runoff components, taken as long-term average values, were essentially different between classes and similar within them. This confirms the obtained results, and allows them to be extrapolated for other areas and to use for water quality assessment.

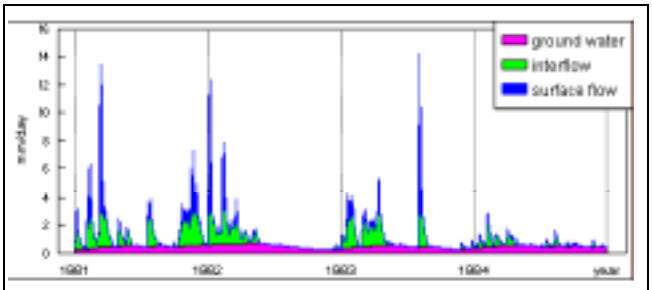


Fig. 3: Hydrograph of river discharge simulated on a daily basis for the period of 1981 to 1984 for the Flöha river basin (gauge Borstendorf), indicating the contributions of land surface runoff (in blue), interflow (in green) and base flow from groundwater (in red).

Integrated Modelling of Hydrology, Nitrogen Dynamics and Crop Growth

Five mesoscale sub-basins of the Elbe, the Buckener Au, the Dahme, the Nuthe, the Weiße Elster, and the Stepenitz, were investigated using the SWIM model. In the Buckener Au basin the model was validated both for spatial patterns and temporal dynamics. Seasonal dynamics of soil moisture were compared for three different hydrotopes: forest on loamy-sandy soil, cropland on the same soil, and wetland in the river valley. The simulated runoff components, surface runoff, interflow and percolation to groundwater, showed reasonable patterns, and the simulated river discharge was in good agreement with the measured discharge.

After the hydrological validation of SWIM in five basins, the nitrogen module, which considers different processes of nutrient cycling in soil, was tested in the Stepenitz basin (575 km^2). The robust approach as applied in SWIM for nutrient modelling in mesoscale river basins gave satisfactory simulation results for all components and flows. This is illustrated in figure 4 for the hydrotope 'cropland on loamy-sandy soil', the dominant soil type in the basin. The figure clearly illustrates the characteristic seasonal dynamics of Nitrogen-NO_3 flows and stocks, namely (a) Nitrogen-NO_3 in the five uppermost soil layers, (b) the generated lateral nitrogen flow (with direct runoff and interflow) and leaching to groundwater, and (c) the crop uptake of nitrogen. The simulated seasonal dynamics and the annual flows for this and other soil types were quite satisfactory, and the differences between soil types were reasonably represented.

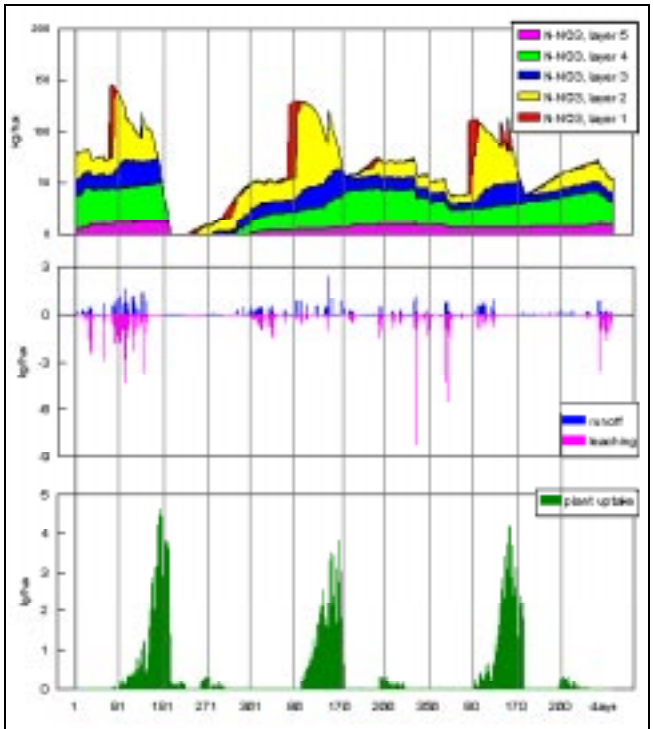


Fig. 4: Temporal variation of nitrogen fluxes and stocks over the period 1983 - 1985 (daily data) for the hydrotope "cropland on loamy sandy soil" in the Stepenitz basin:
(a) the dynamics of N-NO_3 in five soil layers (1: 0-1 cm, 2: 1-24 cm, 3: 24-40 cm, 4: 40-80 cm, 5: 80-90 cm); (b) runoff with subsurface flow (blue), leaching into ground water (pink., as negative values); (c) crop consumption (uptake).

In addition to dynamic integrated hydrological and water quality modelling, a special technique has been developed to estimate the contribution of municipal, industrial and agricultural sources of pollution to the total measured river load on an annual basis, considering land use, soils, data on point sources, and other relevant information in the studied river basin. This technique has been applied first in the basins of the Mulde, Weiße Elster, and Unstrut, and has demonstrated its applicability at larger scales.

A first regional climate-change-impact analysis was performed for the State of Brandenburg to simulate hydrological processes and crop growth. Further, the crop growth model EPIC was implemented in SWIM. The simulation results were validated for the present climate against the river basin discharge time series for three sub-basins in the region and available crop yield data for the districts (figure 5). Subsequently, an analysis of the impacts of possible climate change on hydrology and crop growth was performed, using a transient 1.5 K warming (that is 1.5 ^{o}C) scenario of climate change. With this warming, the model predicts an increase of evapotranspiration and runoff, while ground water recharge stays practically the same. The

impacts on agriculture are different for different crops, and depend on whether the carbon dioxide fertilization effect is taken into account or not. For example, wheat yield was slightly reduced if carbon dioxide fertilization was not included, while carbon dioxide fertilization resulted in an increased yield of approximately 10 %.

Socio-economic Evaluation

The results, which depend highly on the selected climate change scenario and on the differences in nutrient cycling in various soils, can be interpreted considering possible management options and policies in order to improve surface and groundwater quality.

Analogous analyses will be performed for other scenarios of climate change, and also for larger regions, such as the entire Elbe basin, or Northern Germany.

The following results can already be provided for general use:

- Water balance components for the entire German part of the Elbe basin and runoff components for mesoscale subbasins (about 35).
- Integrated modelling of hydrology, vegetation and nitrogen dynamics in the Stepenitz river basin.
- Climate-change-scenario analyses for hydrological processes and crop growth in the state of Brandenburg for the period 2022-2050 using SWIM.

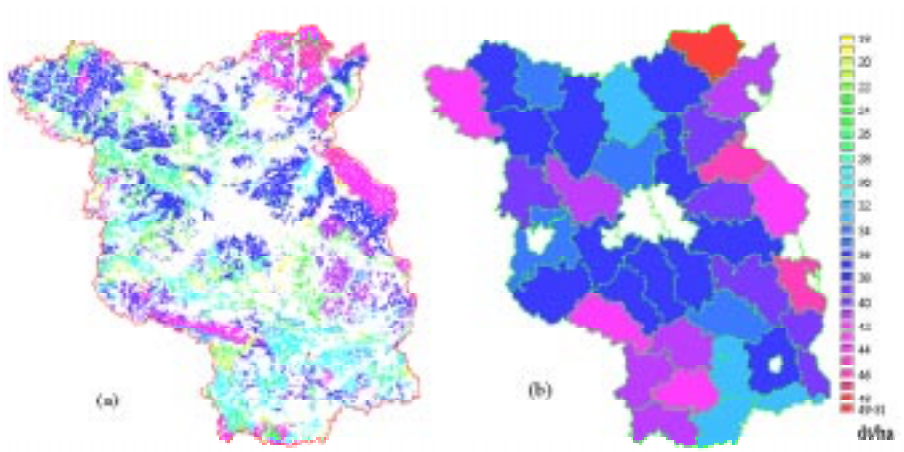


Fig. 5: Spatial patterns of winter barley yield (long term averages 1981 - 1991) for the state of Brandenburg: (a) simulated; (b) registered for the districts of Brandenburg.

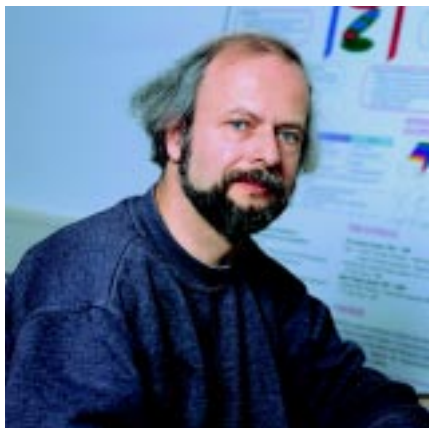
The "Elbe ecology" part of the project was funded by the German Federal Ministry of Education, Science, Research and Technology (BMBF 1995). The study "Regionalization in Hydrology" in the Upper Stör basin was funded by the DFG (German Research Foundation).

WAVES
Water Availability, Vulnerability of Ecosystems and Society in the Northeast of Brazil

Project Leader: Friedrich-Wilhelm Gerstengarbe

Semi-arid regions belong to the more vulnerable areas of the globe; moreover, the limitations imposed by water scarcity and the high variability of precipitation contribute significantly to the vulnerability of these regions. These areas cover one third of the earth, and they contain about 20% of its population. Socio-economic indicators show living conditions much below the world average. Together with the strict climatic constraints, this determines the vulnerability of the regions. It has been observed that irregularly recurring severe droughts trigger massive migration from rural areas into urban centres or more favourable regions. The central goal of the WAVES project is to understand the interactions between water availability and migration from rural areas, and to contribute to the assessment of possible pathways towards a sustainable development.

Friedrich-Wilhelm Gerstengarbe



Motivation and General Goals

Fig. 1: Investigation area, Piauí and Ceará in Brazil.

	Piauí	Ceará
Area	250.934 km²	148.016 km²
Inhabitants	2.618.900 (10/km²)	6.628.235 (45/km²)
Capital	Teresina	Fortaleza
Industry	weakly developed	moderately developed
Agriculture	maize, beans, rice, cashew, cowpea, sugar cane, cotton	
Climate	- changing trade-wind belt climate - little rain during winter p.a. 1500 mm (north) 500 mm (southeast) - T_{mean} ~ 26°C	

Fig. 2: Characteristics of the selected federal Brazilian states.

As an example the semi-arid regions of the Brazilian states Piauí and Ceará (figure 1, figure 2) are selected, which are characterized by strongly limited resources, pronounced climatic variations and social stress situations.

In order to estimate the possible consequences of climate change in semi-arid regions, interdisciplinary approaches to investigate the interactions between natural, social, and economic systems are necessary. The challenge is to combine the results of all disciplines in an overlying level “integration”. The main goals of the disciplines and the interrelations are shown in figure 3.

The integrative approach can be understood as a basic idea of the WAVES project. Integration is pursued through the representation of dynamic processes in integrated modelling, the analysis of spatial data in landscape ecology, and the construction of integrated scenarios of regional development. The integrated scenarios will serve to assess options for the sustainable management of natural resources and development potentials of societal systems.

WAVES is a joint contribution of Brazil and Germany to the Global Change Programme. It is sponsored by the German Ministry of Education and Research (BMBF) and the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq). A pre-project phase

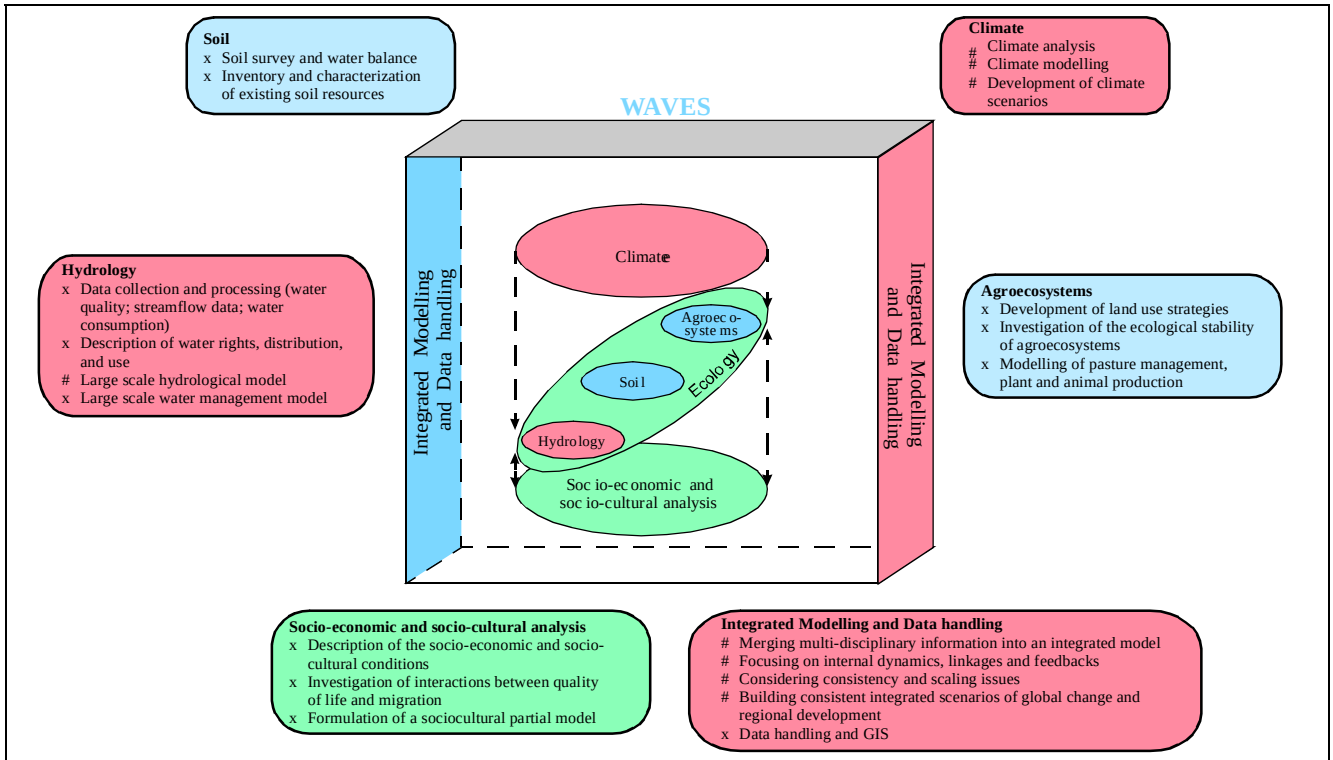


Fig. 3: Relations and goals of the disciplines. Disciplines included: climatology, hydrology, agricultural and social sciences, landscape ecology.

was carried out between 1994 and 1996. The main phase of the project started in 1997 and will last until 2000. The organizational structure of the project is described in figure 4.

Main Collaborating Institutions

Germany

- Technical University Munich-Weihenstephan
- University Stuttgart-Hohenheim
- University Kassel
- Potsdam Institute for Climate Impact Research
- Hydroisotop GmbH Schweitenkirchen

Brazil

- Universidade Federal do Ceará - Fortaleza
- Universidade Federal do Piauí - Teresina
- Universidade Federal da Bahia - Salvador
- Fundação Cearense de Meteorologia e Recursos Hídricos - Fortaleza (FUNCEME)

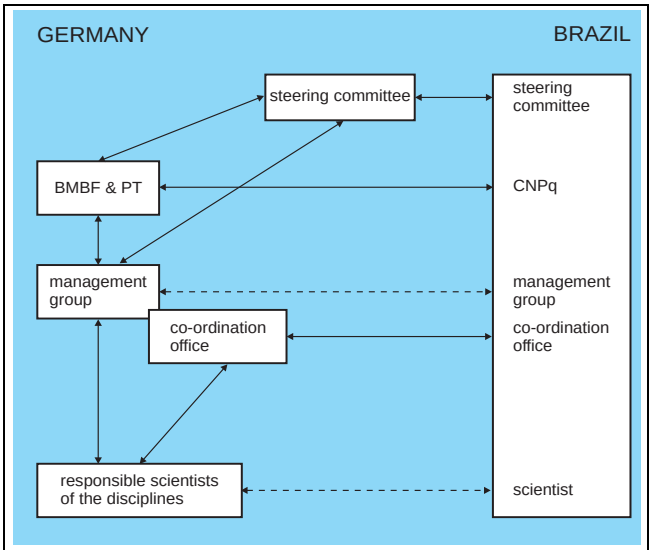


Fig. 4: Organizational structure (BMBF=German Ministry of Education and Research; PT=Executing Institutions; CNPq=Conselho Nacional de Desenvolvimento Científico e Tecnológico)

Climate Analysis and Modelling

The spatial and temporal climate conditions in Piauí and Ceará are analysed and modelled at PIK. The results will be presented in the form of scenarios of a future climate development as partial components of the integrated entire scenarios. Climate analysis provides important basic information both for the work of the participating partners and for the scenario development; and at the same time it is an instrument to verify the climate model results.

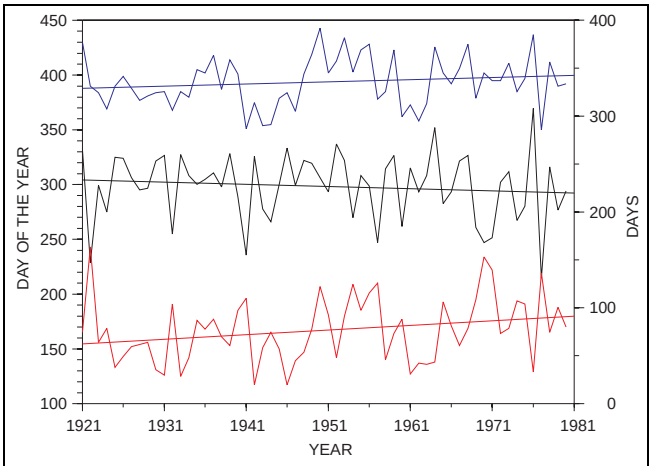


Fig. 5: Beginning (red), end (blue) and duration (black) of the dry period, Tamboril 1921 - 1980. The figure shows a strong trend to a later beginning of the dry period and a smaller trend to a later end. This shows that the dry period became shorter in recent years.

Mann-Kendall Test and Cluster Analysis

Beyond the current standard climate evaluation, our climate analysis is extended to find out, whether there are remarkable changes in the beginning, in the end, and concerning the duration and intensity of the rainy respectively dry season. The answer is an important indicator for the investigation of the migration in this area. Therefore two new statistical methods have been developed during the pre-project phase. The extended sequential version of the Mann-Kendall-Test makes it possible to describe the dry and wet periods in a statistically significant way and to represent these events in their temporal sequences. A typical result of these investigations is shown in figure 5.

The next step is the temporal-spatial description of these events using an extended version of cluster analysis. These investigations will be continued. Moreover, it is planned to develop on this basis a statistical model for the creation of future climate scenarios (e.g. CO_2 doubling) that can also be used within the framework of integrated modelling.

Additionally, the adaptation of a regional climate model will be carried out. The climate model REMO (REgional MOdel), made available by the Max Planck Institute for Meteorology, is used as a basis. At present this model is undergoing a further development in such a way that, apart from climate scenario calculation, it can be used within the integrated model at the end of the main project phase. Therefore, parameterization approaches are being improved, sensitivity investigations are being carried out, and alternative possibilities for the provision with boundary values are being introduced. Figure 5 shows an example for the simulation of precipitation within the investigation area.

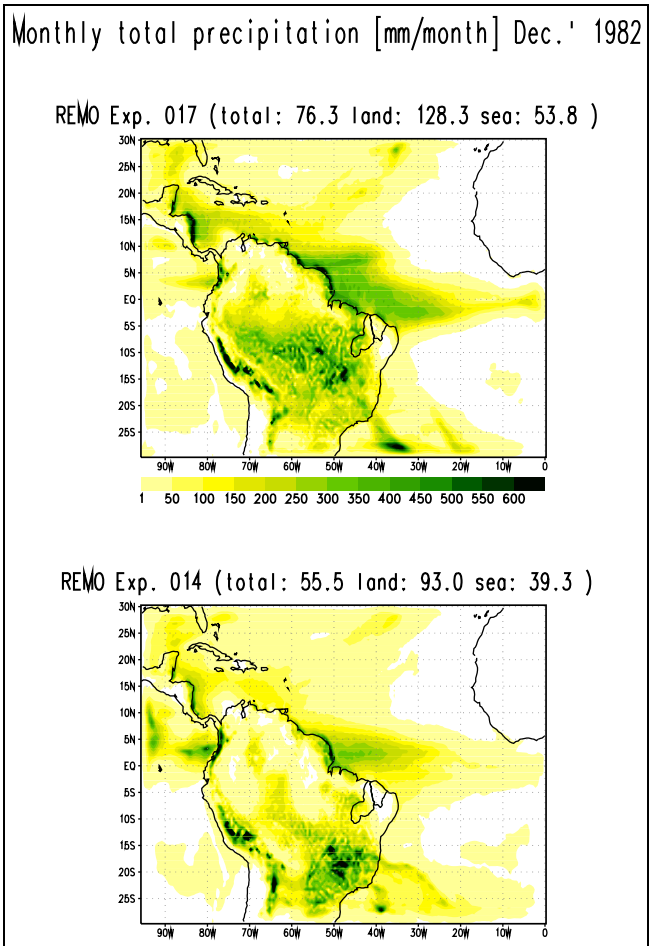


Fig. 6: The use of driving forces from an improved version of a global circulation model provides a more realistic representation of precipitation. The lower panel with Exp.14, out of 22, shows the reference version, whereas Exp. 17 In the upper panel shows an increase of 37% on average for the entire model area.

Summary

Within the main phase of the projects, information will be gained on the spatial and temporal structure of different parameters relevant to meteorology and hydrology on the basis of observed and modelled values of precipitation, temperature and humidity, and on the basis of natural variability and special climate events, which will create a basis to formulate climate scenarios as components of integrated scenarios.

Large Scale Hydrological Modelling

The central question of the WAVES project is the analysis of the relationships between water availability, quality of life and migration in the semi-arid northeast of Brazil. This has been studied extensively by three working groups: assessment of water management strategies (Hydroisotop GmbH), water management modelling (University of Kassel), and large scale hydrological modelling (PIK).

Reflecting the need for a quantitative description of the hydrological cycle covering the whole project area, the development of a large-scale hydrological model was started during the project's main phase in August 1997. This model has to be adjusted to the specific conditions of northeast Brazil, which can be characterized from the hydro-meteorological point of view as a pronounced semi-arid climate with almost all of the yearly rainfall during the rainy season of about four months duration, and from the operational-hydrological point of view as a large area of approx. 400 000 km^2 with many large, medium-size and small private reservoirs and generally scarce data.

The objective of this model, which will serve as a core component for constructing the water module of the integrated model is to give quantitative estimates of the relevant parts of the hydrological cycle, such as surface runoff, groundwater recharge, soil water storage, and storage in reservoirs, in a spatially distributed manner. The outcome of this model will supply the necessary information for the physical water availability. This information is required by a variety of disciplines, in particular water management, agriculture and socio-economics.

The concept of the model was set up during the year 1997; the scheme is shown in figure 7: the main hydrological fluxes and storage considered are surface runoff q_o, the water storage in the upper soil usable for vegetation root water uptake, also evapotranspiration ET from the soil, vegetation and open water, that is rivers and reservoirs, as well as river flow Q_r, groundwater recharge q_{gw}, the lateral fluxes in the subsurface q_l, and the fluxes to and storage in the reservoirs.

Three main landscape types have to be distinguished, i.e. the highlands, the lowlands in the vicinity of river valleys, and the intermediate sloping country. Each of these landscape types exhibits a specific hydrological regime and therefore has to be treated individually. This level of disaggregation by topography will be complemented by using spatial information about land cover, soil types, river networks, and possibly groundwater conditions. Intersecting these information levels will lead to a distinction of hydrologically similar units, which is the basic concept for the hydrological discretization of the area.

The activity so far included a feasibility study on using globally available geo-data for the purpose of large-scale hydrological modelling in northeast Brazil and an application of a simple hydrological model in combination with the GIS (Geographic Information System) processing of the mentioned data. Obviously the main scientific challenge is to develop a new, adequate hydrological model under the given constraints of scarce data information, large discretization units, and specific semi-arid climatic conditions.

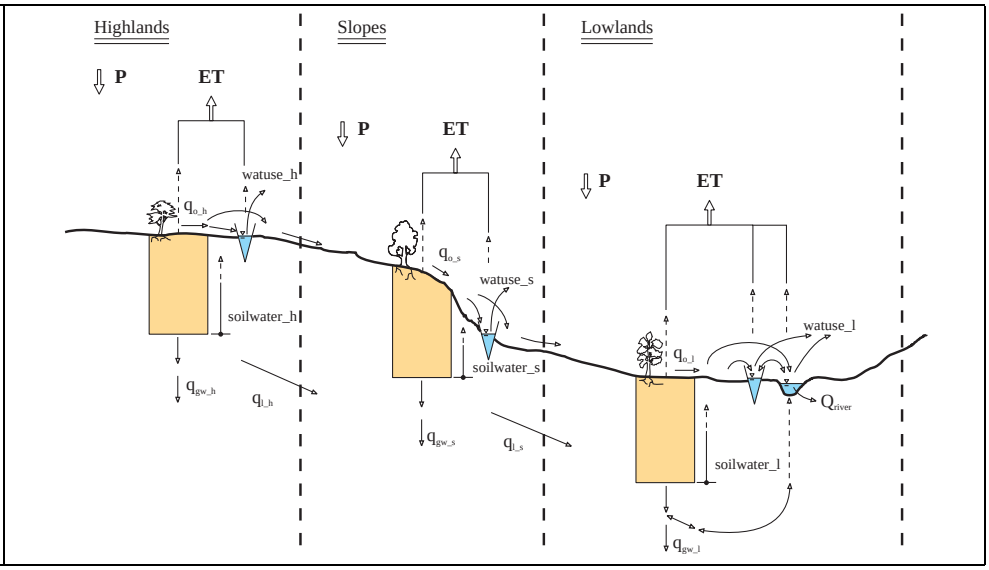


Fig. 7: Design of the large scale hydrological water balance model for highlands, slopes and lowlands. P: precipitation, ET: evapotranspiration, q_o: surface run off, q_{gw}: groundwater recharge, q_l: lateral fluxes in the subsurface.

Agroecosystems

This component of the project is being studied at the University of Stuttgart-Hohenheim. The objective is to evaluate the potential of crop production under the present soil and climatic conditions, the security of yields given climate variability, and the impacts of alterations in climate on production. Nutrient constraints to crop growth and yield will be identified, and existing simulation models for soil water dynamics, crop and animal production will be tested. Within agroecosys-

tems, activities are subdivided into four subgroups: soil science, plant nutrition, crop production, and animal production. During the pre-project phase, the actual situation of agricultural production was analysed for small spatial units in Piauí (figure 8). For this purpose an inventory of the natural resources was made and the existing soils were characterized. Also a database for rational land use and animal production was built up.

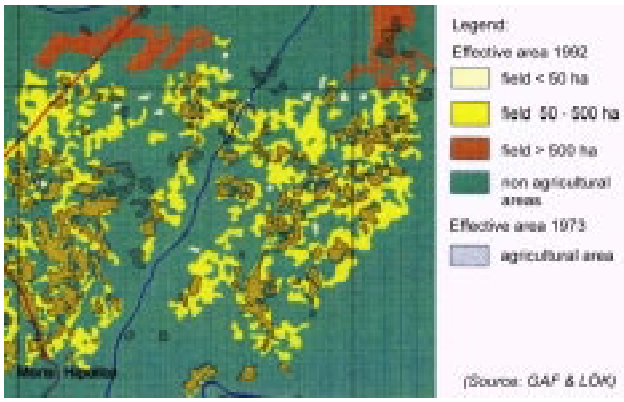


Fig. 8: Changes of the agricultural use within the Picos-area (Piauí) between 1973 and 1992.

Socio-economic and Socio-cultural Analyses

These components of the project are being studied by the University of Kassel, the University of Hohenheim-Stuttgart and the Fachhochschule Köln. Socio-cultural analyses focus on how social and environmental conditions affect human behaviour. The main aspects of human behaviour studied are the adaptation strategies adopted, e.g. migration, in dealing with deteriorating conditions. Living conditions will be expressed by an indicator for the quality of life, to be composed from the whole range of influences studied in the project. The analysis will distinguish various actor groups such as individuals, families, political and administrative units. Economic studies focus on agro-economic production models, analysing agricultural enterprises and their future development potential under current and changed conditions e.g. climate, water infrastructure, market. Data from optimization models for individual enterprises will flow into an integrating agro-economic model at the regional level, containing ecological, economic and sociological elements.

Landscape Ecology

The working group landscape ecology, at the Technical University of Munich, Weihenstephan, studies strategies for sustainable land use. The approach can be characterized as spatial analysis and planning methodology. The integration tool used is a Geographic Information System (GIS), matching the key processes of the natural and anthropogenic components of the landscape system. The hierarchy of spatial levels corresponds to the data and process descriptions used by the scientific disciplines in the project. The technical tasks of digitalization of data and geographic data processing will support the project partners.
In the pre-project phase, physical, ecosystematic and political administrative data on Piauí were processed, and assessment methods were tested.

Integrated Modelling

The common central question of the WAVES project is the analysis of the relationships between water availability, quality of life and migration in Ceará and Piauí, two federal states in the semi-arid northeast of Brazil. A basic boundary condition is formed by the influence of climate variability and possible climate change. The question connects the most limiting physical factor in northeastern Brazil, water availability, to the social issues of migratory movements, as driven by the often miserable living conditions. The purpose of integrated modelling in WAVES is to represent existing and newly generated knowledge on the problem in a formal simulation model, and to design integrated scenarios for regional development. PIK is responsible for this integrative task.
Generally, two of the most important problems in making integrated assessments are the mutual intelligibility of information between different scientific disciplines, and the manifold of scientific interconnections between the disciplines, including feedbacks. The construction of an integrated model calls for an explicit treatment of the problem of communication, including issues of transfer between different typical scales in space and time, whereas the representation of linkages between disciplines is internal, allowing for the representation of feedbacks.

Systematic Model-Based Integrated Approach

The systematic approach of integrated modelling follows similar approaches in global studies, and has been recommended in existing integrated studies of the semi-arid northeast of Brazil. Existing regional integrated assessments of climate change were generally restricted to studying agro-economic impacts, or did not pursue rigorous integrated modelling. The WAVES project has a pilot character in its use of a systematic model-based integrative approach in the assessment of sustainable development in semi-arid regions, and in the extent of scientific disciplines explicitly covered in a regional integrated model, from physics-based disciplines like climatology and hydrology to disciplines

describing human behaviour, like agricultural economics and sociology/psychology of migration.
The approach of constructing the integrated model in WAVES can best be described as a combination and iteration of a top-down approach to derive the relevant endogenous processes and to identify the important external forces driving the system, and a bottom-up approach to refine process knowledge and the parameterization of the processes.

Concept of an Integrated Model
In the pre-project phase (1996-1997), the conceptual design of the integrated model has been constructed by analysing the central problem from a systems-theory perspective. Hypotheses on what is relevant in describing the internal dynamics of the system steered the selection of variables and processes to be represented internally in the conceptual model and of boundary conditions to be captured in integrated scenarios. The conceptual model (figure 8) illustrates the main causal chains, the main linkages between scientific disciplines and the main external driving forces to be captured in integrated scenarios. In this concept, migration from the rural areas is represented as adaptive behaviour of inhabitants reacting to worsened living conditions, represented by the construct “quality of life”. Employment and income from subsistence farming, play a dominant role for life quality and they very much depend on the variable climatological and hydrological conditions. The main feedbacks are formed by societal responses to the situation in the region regarding the management of agricultural and water resources, and the effect of population dynamics on water and land use.
After the derivation of the conceptual model, it was implemented in 1997 in a prototype version of the integrated model for internal use within the project. Preliminary parameterizations of the processes to be represented in the model are merged into a model which still lacks spatial dimensions. The prototype model exhibits a modular structure where the modules roughly match scientific disciplines: climate, water availability and management, agriculture (including irrigation, crop and animal production), economics and socio-cultural science. These modules are to be replaced by full-scale geographically explicit modules from the individual disciplines. The disciplinary models will largely exist of, or build on existing models. Uncertainty issues will be studied intensively in the project by UFBa (University of Bahia, Salvador, Brazil); both stochastic and fuzzy logic methods will be considered for the explicit representation of uncertainty in the model.
A preliminary full model version is due in the summer of 1998. A fixed model version and a concise catalogue of integrated scenarios for possible regional development will be available in the summer of 2000.

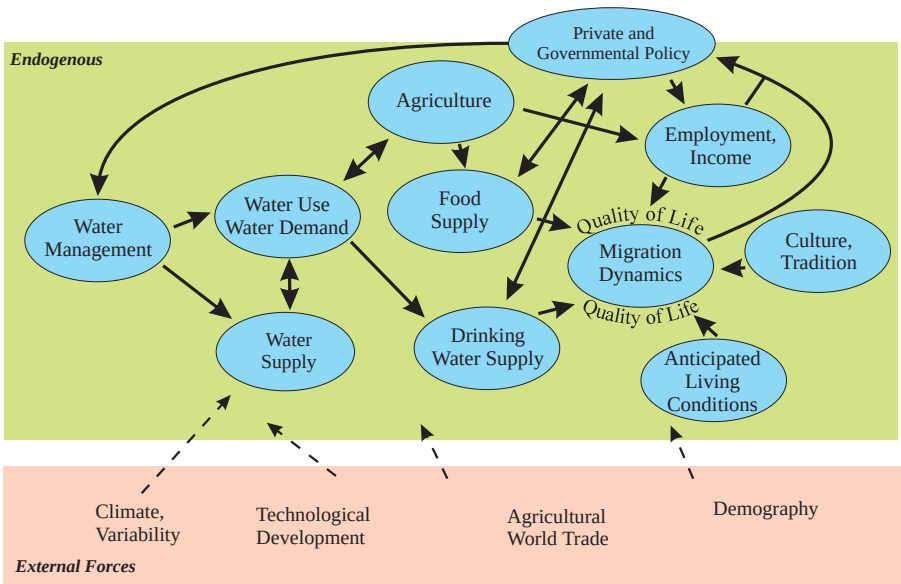


Fig. 9: Conceptual version of the integrated model: main causal chains and main linkages among the different aspects of the integrated model concept.

Scaling
A specific challenge concerns the issue of scaling. The basic data and basic process descriptions used in the project range from the point/field scale to statistics for the federal states, and the time scales used range from a few hours to months or seasons. Moreover, the geographic units or discretization principles applied, common for spatial simulations, can be very different

among disciplines (figure 9). The municipality is chosen as the basic computational unit in the integrated model. An aggregation of descriptions of processes at the point/field scale to these larger spatial scales is thus required for most of the disciplines, while disaggregation methods are also necessary in describing the economic and socio-cultural background.
The study of scaling issues is an important theme not only for the scientific disciplines in the project, but also for integrated modelling, in co-operation with FUNCEME. The relevance of the issue of scaling and the strategies to approach it go beyond the disciplinary level; moreover, the scaling issues are specifically important at the interfaces between the individual disciplines.

The WAVES project is funded by the Federal Ministry of Education, Science, Research and Technology (BMBF) and by the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) of Brazil.

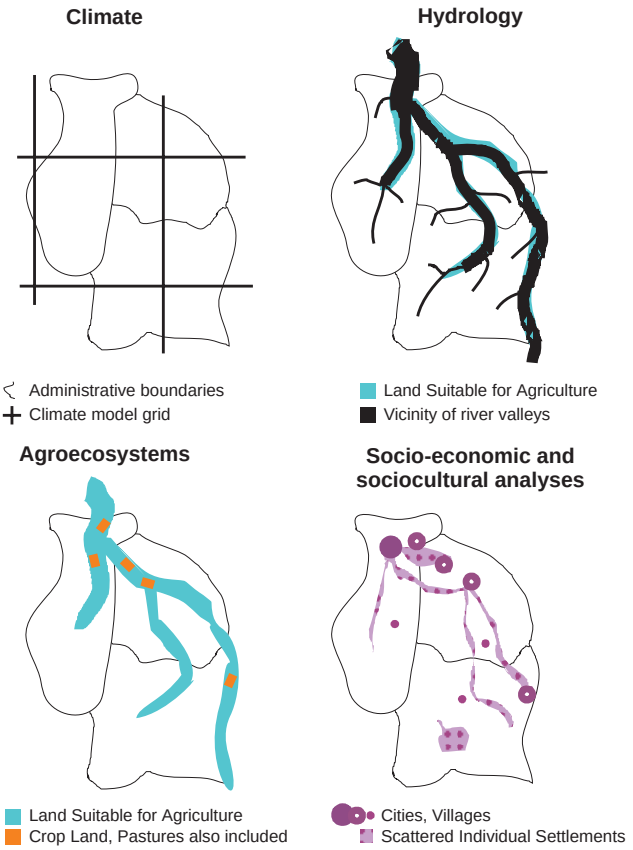


Fig. 10: Sketch of the spatial scales, typical for the various disciplines and their intersections.

EUROPA
European Network Activities on Global Change

Project Leader: Manfred Stock

Scientific cooperation and exchange with other European research institutions working on Global Change has been important for PIK from the beginning. This is reflected by a number of new project activities at PIK on a European level and with funding from the European Union. What do these EUROPA activities have in common? First of all they address vital or critical problems of climate, environment and society. Secondly, the project objectives are of general European interest embedded in a network of research institutions; and last but not least, the activities are transdisciplinary and oriented towards specific regional patterns of Global Change.

Manfred Stock

Acronym	*European Network Activity*	*Funding*	*Type*
ACACIA	A Concerted Action Towards a Comprehensive Climate Impacts and Adaptation Assessment for the EU	EU	CA
CLIMPACT	Regional Climate Modelling and Integrated Global Change Impact Studies in the European Arctic	EU	CA
ECLAT-2	European Climate Projects Support Environment: Network for Coordinated Provision of Scientific & Technical Advice for Applying Climate Data in European Climate Change Research Projects	EU	CA
EFIEA	European Forum on Integrated Environmental Assessment	EU	CA
KLINO	Climatological Change of Hydrographic Parameters in the North Sea and the Baltic Sea	DE	RD
MOUNTAIN	Environmental and Societal Changes in Mountain Regions	EU	CA
RICC	Regional Integrated Climate Change Assessment	DE	RD
ULYSSES	Urban Lifestyle, Sustainability and Integrated Environmental Assessment	EU	RD
WISE	Weather Impacts on Natural, Social and Economic Systems	EU	RD

Table 1: List of project activities under EUROPA.

Types: EU = European Funding, DE = German Funding, CA = Concerted Action, RD = Research and Development.

Scientific cooperation and exchange with other European research institutions working on Global Change is reflected by a number of new project activities at PIK. In nearly all cases both, the overall European importance of the projects and relevance have been testified through a positive funding decision in the evaluation procedure of the Environment and Climate Programme of the EU. European projects are organized in two different ways at PIK: either as they are in this chapter, EUROPA, which it is planned, will become a core project, or in relation to other core projects (see tables 1 and 2). However, as regards network activities, like cooperation, coordinations and scientific exchange, they should also be linked to the other EUROPA projects. The EUROPA projects of table 1 are either concerted actions or research projects. Both types are important for an exchange of ideas, concepts, methods, models and data bases on the European level. Although some of the projects assembled in table 1 have German funding, their subject of research is of general European interest. In particular the Regional Integrated Climate Change Assessment in Brandenburg is a pilot study that may be adapted to many other regions in Europe.

Acronym	*European Network Activity*	*in core project*	*announced /in progress*
MAGEC	Modelling Agroecosystems Under Global Environmental Change	AGREC	in progress
DART	Dynamic Response of the Forest-Tundra Ecotone to Environmental Change	CHIEF	announced
LTEEF-II	Long-Term Regional Effects of Climate Change on European Forests: Impact Assessment and Consequences of the Carbon Budget	CHIEF	announced
ETEMA	European Terrestrial Ecosystem Modelling Activity	POEM	in progress
Millenia	Numerical Simulation and Analysis of Climate Variability on Decadal and Centennial Time Scales	POEM	in progress
EUROTAS	European River Flood Occurrence and Total Risk Assessment System	RAGTIME	in progress
CLD	Modelling the Effect of Land Degradation on Climate	RESOURCE	announced

Table 2: List of research and development projects with European funding in other PIK core projects.

A Concerted Action Towards a Comprehensive Impacts and Adaptations Assessment for the European Union – ACACIA:
PIK Contribution Leader: Hans-Joachim Schellnhuber

It is intended that this network activity will play a key role in the current process of evaluating and redesigning European research on climate change impacts. The action is co-ordinated by M. Parry, University College, London, and “includes virtually all key people in the field in Europe”, as the reviewers put it in their consensus report.
ACACIA is a three-year project, started in autumn ’97, only with minor funding for original research, but with resources for the commissioning of expert papers and the organization of workshops.
The main objectives are defined as follows:

- An analysis of the “demand side” for climate impacts research, i.e. characterization of those actors in Europe potentially interested in the results of appropriately conducted impact studies, like climate policy makers, planning agencies, business people from vulnerable economic sectors or nature conservation groups.
- A pilot version of design specifications for an in-depth assessment of the probable effects of climate change in the EU and of the array of adaptive responses. The construction will be based on current wisdom as represented by the members of the ACACIA consortium; it is meant to serve as a crucial input for the specification of the Global Change segments of the Fifth Framework Programme of the European Commission. First results are expected by summer 1998.

- A synthesis report on the state of current knowledge on the likely impacts and potential adaptations with respect to climate change in the EU. This report will amalgamate, assimilate and perhaps complement the parts and pieces available from various national, sub-national, sectoral or case studies; this will probably become a major contribution to the Third Assessment Report of the IPCC.
- A consolidated version of design specification for a comprehensive European impacts and adaptations research programme for the new decade. This full design paper shall provide a common topical and methodological platform for scientists, users and funding agencies interested in the overall topic.

Regional Climate Modelling and Integrated Global Change Impact Studies in the European Arctic – CLIMPACT
PIK Contribution Leader: Wolfgang Cramer

Although there is now almost universal agreement that human activities will cause at least some significant global warming, particularly at high latitudes, there is much greater uncertainty over the likely economic impact of such changes at the regional level. PIK is involved in this project on impact research about the European Arctic in cooperation with other institutes, supported as a European Science Foundation Science Network under the coordination of Manfred Lange at the University of Münster.
The European Arctic has been chosen as a research field for several reasons. First, although not itself a heavily populated region, changes in the Arctic may have impacts on the climate of Europe as a whole. Secondly, global climate models have already indicated that future warming will be particularly pronounced in the Arctic, more so than in temperate and tropical regions, and more so also than in the Antarctic. Sea ice and snow cover in the Arctic will likely be reduced to a much greater extent than in the Antarctic, causing a feedback effect through increased absorption of solar short-wave radiation by the ocean. The challenge for the network is firstly to determine the extent of the climate changes, and then to asses their impact.
To resolve what this impact is likely to be, progress is needed at two levels. First, it is necessary to model climate change more accurately at the regional level. This will be done both by developing new regional climate models or extending existing ones, and also by interpolating or downscaling from global models. Secondly, the socio-economic and environmental impact of these anticipated changes needs to be determined. The CLIMPACT network does not provide research funds in itself, but bundles research activities from a range of participating institutes.

European Climate Projects Support Environment: Network for Co-ordinated Provision of Scientific and Technical Advice for Applying Climate Data in European Climate Change Research Projects – Eclat-2
PIK Contribution Leader: Wolfgang Cramer

Continued enhancement and exploitation of European research successes will require continual attention to improving the co-ordination and efficiency of flows of information between the climate modelling, observed climate data and impacts research communities, and to the methods whereby such climate data are used effectively in impacts research. The overall objectives of this Concerted Action Initiative are therefore:

- To establish a framework for informing the research community within the EU Climate and Environment Programme about the sources and availability of climatological information - both observed and model-based - with particular regard to the needs of climate scenario construction.
- To develop a Support Environment that will provide scientific and technical advice to accompany the climatological information.
- To encourage the co-ordinated, consistent and efficient use of climatological information within the EU Climate and Environment Programme.
- To identify aspects of the provision, application and interpretation of climatological information relating to climate change scenarios which may require future research by the EU.

European Forum on Integrated Environmental Assessment – EFIEA
Project Leader for the PIK component: Ferenc Tóth

Integrated environmental assessment (IEA) is an active and rapidly developing field. It involves scientists and decision makers from a diversity of backgrounds and communities. Many approaches to this complicated but promising field coexist, but what is needed, is their mutual interaction. The European Forum on Integrated Environmental Assessment serves such a goal.
In addition, the EFIEA fosters cooperation between scientists and decision makers inside the European Union, communication and cooperation outside the EU, and training of IEA techniques.

One of the two main work programmes aims at improving the scientific quality of integrated environmental assessment. This programme consists of a series of workshops on methodological issues. The other work programme aims at strengthening the interaction between science and policy. It discusses particular techniques, and reviews a limited number of policy issues to which integrated assessment can contribute. The work programmes will each result in an edited volume, discussing integrated assessment as a scientific activity and as a policy advisory activity, respectively.
The project leader of the PIK component of EFIEA has also been invited to serve on the Project Steering Committee.

Climatological Change of Hydrographic Parameters in the North Sea and the Baltic Sea – KLINO
Project Leader: Eva Bauer

Changes of the regional-mean climate may develop quite differently from the global-mean climate change. Estimates of climate changes on regional scales have to consider the regional peculiarities and the specific processes in sufficient detail.
The project KLINO is focusing on the regional climate and climate changes of the hydrographic state variables of the North Sea and the Baltic Sea. A reliable prediction of ocean surface waves and currents is needed to sustain the future protection of the coastal regions, the safety of off-shore operations and the advice on favourable shipping routes. In the past, geophysical models have been developed which can now be applied for such investigations.
The project KLINO started on November 1, 1996 and runs until October 31, 1999, and is financed by the Federal Ministry for Education, Science, Research and Technology. KLINO is working in cooperation with three institutes which use three classes of models for the Atlantic scale, the basin scale, and the coastal scale with consistent forcing fields.
At PIK an ocean wave model for Atlantic scales and basin scales is employed. The observed time series of wave height in the North Atlantic show an increase of the wave height of 1-2 % per year during the past decades. There has been an ongoing debate about whether this increase is real or caused by modified measuring practices. It is also not clear whether the increase in North Atlantic wave height will have an impact on the coasts of the North Sea.
These questions will be addressed in a two-step wave modelling approach. First a high-resolution spectral wave climatology will be determined. Then sensitivity studies will be performed to estimate the effect on the regional climatology induced by the global climate change.

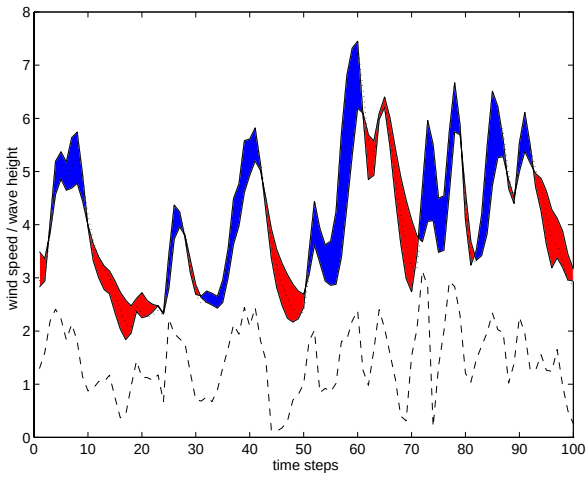


Fig. 1: Time series of significant wave height [m] and wind speed [m/s] in the storm track of the North Atlantic (52N, 20W) are obtained with the ocean wave model WAM simulating the response of the ocean waves induced by perturbing the speed of the weather stream. The reference wave height is shown (dotted) for the period October 25 to November 10, 1992 in which the time T is in steps of dT=6hours. On average, the increased storm frequency (dT=4hours) results in lower waves and the decreased storm frequency (dT=8hours) results in taller waves. During periods of storm growth the increased storm frequency leads to significantly lower waves (blue area), but in periods of storm decay waves remain taller (red area). The wind speed (dashed) is shown as friction velocity scaled with factor 5.

The spectral wave climatology is determined using the third-generation wave model WAM. The forcing fields are taken from the European Centre for Medium-Range Forecasts (ECMWF) Re-Analysis project. The wind and wave data from the atmospheric and the wave model are validated against *in situ* observations and satellite measurements.
One hypothesis is tested according to which an increased storm frequency results in higher waves. The typical storm frequency of the North Atlantic in winter is perturbed by changing the speed of the weather stream to study the sensitivity of the wave height and the wave period. The mean effects of increasing the storm frequency are slightly reduced wave heights and reduced wave periods. The mean effect is small because of opposing contributions during the stages of storm growth and storm decay (figure 1). Thus, an increase in storm frequency in the North Atlantic storm track cannot account for the observed upward trend in wave height.

Environmental and Societal Changes in Mountain Regions – Mountain

PIK Contribution Leaders: Alfred Becker (for IGBP/ BAHC) and Harald Bugmann (for IGBP/GCTE)

Mountain Regions are of global importance all over the world. They provide resources, including water, energy, food, forest products, and places for tourism, for at least half of humankind. About one tenth of the global population lives in these regions. Mountain regions are global centres of biodiversity. Due to their steep slopes and related sharp altitudinal gradients, hydrological and ecological characteristics vary clearly, sometimes drastically, with elevation over relatively short distances. Typical examples for such enormous changes are the treeline, snowline, glacier and other ecosystem boundaries. These, and related hydro-ecological characteristics, are particularly sensitive to the forces of Global Change. Changes in these boundaries can therefore be considered as an indication of Global Change, which can be analysed over long periods.

Remote sensing data, in particular high resolution satellite images of mountain regions which became increasingly available after the end of the Cold War will play an important role. Coupled with ground-based data from ongoing and planned studies, they will provide an excellent platform for Global Change studies and related model development.

Another aspect concerns the sustainability of mountain environments and societies, which are increasingly influenced and often threatened by inappropriate land use and also by globalization.

PIK scientists have been involved in the IGBP research programme on Global Change in Mountain Regions since 1996, when a proposal for a “Mountain Workplan” was prepared and published. Another European conference focused on the human dimensions, and in particular on the land use change (LUCC) component of Global Change in mountain regions.

Regional Integrated Climate Change Assessment – RICC

Project Leaders: Manfred Stock and Ferenc Tóth

“Isn’t it possible to conduct climate impact research not only in, but also for Brandenburg?” This question was asked by Brandenburg’s Minister for the Environment, Conservation and Regional Planning, Matthias Platzeck, during a visit to the Potsdam Institute for Climate Impact Research in July 1994, and it led to eight months of work on a pilot study. The focal point of it is related to a long-term regional project, i.e. RAGTIME. It was necessary, in particular, to limit the study to a few important parameters, interactions and sectors. The Brandenburg project has been further developed in the mean time. It has become an integrated regional climate impact study to develop and test methods which could be applied to other European regions as well. A variety of statistically derived climate change scenarios are used as inputs to various types of ecosystem and forest growth models, plant development simulations, and hydrological analyses. Socio-economic impacts are primarily directed towards human health and energy use. Integration across sectors and climate impacts has been improved (figure 2).

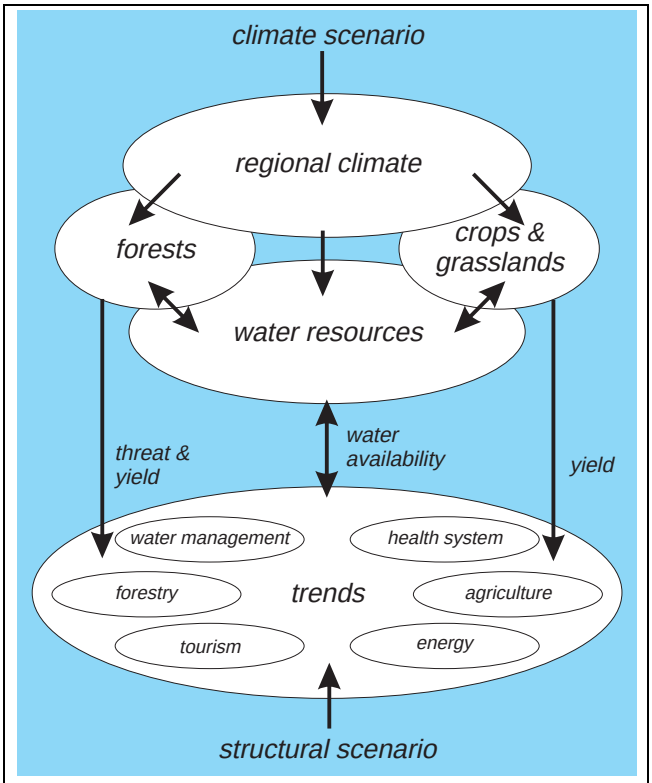


Fig. 2: Aspects considered in the framework of an integrated regional study as applied in the Brandenburg case study.

Climate Scenarios

The task considered here is the development of different transient climate scenarios for the state of Brandenburg up to the year 2050 and equilibrium scenarios after an assumed temperature increase.

An observed time series of meteorological parameters on the one hand and the information about the future development of climate on the other hand form the basis for the construction of a scenario, tested in the Brandenburg area. Information about the future climate may be expressed by a selected climate parame-

ter as calculated by the General Circulation Model GCM. The parameter used here is the expected trend of an increase in temperature. The advantage of this method is that the defects of the GCM are reduced to a minimum. At the same time, the consistency among all meteorological parameters can be ensured.
According to these conditions the expected changes or trends are imposed on the observed values of the climate parameter. By means of a special algorithm, the other observed meteorological parameters are adapted consistently to these changes, taking into consideration that the statistical characteristics have to be maintained.
The following preconditions are assumed:
Most investigations for the description of the future climate are carried out using global climate models. In the case of a further unlimited increase of the concentration of carbon dioxide in the atmosphere, these models calculate a global warming between 1.5 and 4.5 K, that is 1.5 to 4.5 C, up to the year 2100, as stated by the Intergovernmental Panel on Climate Change in 1995. For Central Europe we assume a warming of 2 - 4 K, that is 2 - 4 ^{o}C, within the next 100 years. Therefore it makes sense to define the air temperature as the reference quantity. For the Brandenburg study it is necessary to use daily values because this time scale is used in many models in climate impact research. The given trend is applied for daily mean, maximum and minimum temperatures because of their close relationship. Also, there are no indications that the assumed trend for these three parameters could be different in the Brandenburg area.
As the calculated expected warming varies over the relatively wide range of 2 - 4 ^{o}C, it is necessary to calculate several scenarios in order to obtain a rough overview of the possible developments. The following scenarios were calculated:
The basic scenario (BASC) reflects the present climate over the period from 1951 to 1990. It serves as a reference point for the evaluation of the changes within the simulations and is also used to calibrate the climate impact models.
Some of the impact models in the Brandenburg study require an equilibrium climate state for their own calculations. The climate scenarios were calculated over a time period of 55 years with different increases in temperature. And a model that fulfils the given requirements was found. As an example the most important results of the equilibrium scenario SE15 that discusses an increase of about 1.5 ^{o}C were chosen. Because of this temperature change the extremes of the temperature are changed in the same magnitude. In general, a decrease of precipitation of between 6 and 18 % can be observed, depending on the region. Simultaneously the relative humidity and the cloudiness decrease, whereas the sunshine duration and the global radiation increase. The behaviour of the extremes is different depending on the parameters.
In addition, transient scenarios were calculated describing the climate development up to a fixed date or a new equilibrium state of the climate. These scenarios provide more information on the dynamic of the climate and the ecosystems.
Altogether it can be stated that in the future in the case of all calculated scenarios Brandenburg will have more dry and warm summer periods and more moderate and wet winters.

Impact on Water Resources
Brandenburg is one of the driest regions in Germany. This condition is aggravated by the predominance of sandy soils with low water-holding capacities and by the lack of a substantial amount of water inflows to the region. Two regional water models were used to analyse the hydrological implications of climate change. Under all scenarios considered, critical low-flow values fall significantly. This result would create problems for water availability, water quality, and aquatic ecosystems.

Impacts on Agriculture
About 50 % of Brandenburg's area is in agricultural use, 77 % of which comprises cultivated areas. The most important crops are cereals with an area proportion of 52 %, followed by different forage and oil crops. These figures illustrate the importance of agriculture for food production and employment on the one hand and the responsibility for the maintenance of the traditional landscapes on the other hand. However, this responsibility is not fully acknowledged at the present time.
A quantitative study on climate impact on agriculture requires long-term regional simulations about the complex interactions of plant-growth, soil, climate and social-economic processes. Such a complex analysis has not been performed yet, so that the following discussion is restricted to a qualitative assessment of crop growth.
Except for some minor species, the crops grown in Brandenburg share some basic properties: they mature within an annual cycle, they are adapted to relatively cool temperatures, like most of the plants they assimilate carbohydrates according to the C_3-pathway**,** and suffer frequently under low water supply by the soil. For those crops and conditions it is well understood that a change of optimal temperature for daily growth to warmer temperatures together with higher growth rates and a more efficient water use can be

expected. These positive effects are due to increased atmospheric carbon dioxide concentration. But they only lead to higher biomasses and yields, the enhanced phenological development and the corresponding earlier maturity are compensated. Moreover, the final outcome depends on more factors, such as summer precipitation, achievements in crop improvement, and long-term effects of applied crop rotations. As a result of a reduced vulnerability of crops to water shortage, yields will show a lower sensitivity to the annual variations of climate, so that under a long-term perspective a more continuous food production could be possible.

Impacts on Forests
Two different modelling approaches have been used to study possible impacts on the composition, productivity, and stability of forests and natural ecosystems. Two forest succession models were applied to analyse the regional impacts of climate scenarios on the potential natural species composition of forests within the state. The species composition appears to be quite sensitive to the amount of precipitation in the projected scenarios. The simulation results under the climate scenarios with temperature increases of 0.4 K, 1.5 K, 3 K, that is 0.4 ^{o}C, 1.5 ^{o}C and 3 ^{o}C, indicate that with decreasing precipitation, especially in the case of the 3 K scenario, the share of beech forests decreases. According to both models, most forests are composed of drought-tolerant mixed deciduous forests on fertile sites and mixed pine stands on poor sites. On the other hand, a pine stand model was applied to analyse growth and yield of pine under different climate scenarios. The simulation results show that reduced water availability would result in substantially reduced yields of pine stands. Currently forestry in Brandenburg relies mainly on pure pine stands which are very sensitive to fire and pest and insect calamities. The risk of damage could increase under warmer conditions and these impacts are likely to generate significant economic losses.

Impacts on Human Health
Climate Changes may impair human health in various ways and to a varying extent. An evaluation of mortality statistics indicates that the increase in extreme summers and heat periods related to climate scenarios may cause a rise in the mortality rate due to heat stress. Observations made in Berlin in the summer of 1994 and in Chicago in the summer of 1995 show such tendencies. Even if a Mediterranean climate were to develop in Brandenburg, as the climate scenarios predict, one would not expect a rise in the incidence of dangerous diseases like malaria, or in exotic diseases such as ebola, cholera and leprosy. The conditions for the spread of yellow fever do not occur in Europe at the moment, but even a slight warming would theoretically create the living conditions required for the Asian carrier mosquito.

Urban Lifestyle, Sustainability and Integrated Environmental Assessment – ULYSSES
Project Leader: Ferenc Tóth

The Idea of the Ulysses Project
Policy makers dealing with complex environmental problems need knowledge of environmental science as well as of the social sciences to back up their decisions. The European research project ULYSSES aims at filling the gap between environmental science and democratic policy making in the climate domain. Therefore we study judgements of informed citizens on climate policy and make them available to policy makers. To support this process, the citizens will be given access to state-of-the-art computer models on environmental change.
ULYSSES chose the method of Integrated Assessment (IA) research to provide a useful overview of relevant problems and elements of possible solutions. In this context, the project is developing a procedure to include public participation in the integrated assessment.
In the framework of this Europe-wide project, PIK has been working on the following three tasks about integrated modelling of global climate change (IMAGE).

IMAGE Scenarios
This task involves development, testing and making available scenarios of the IMAGE model, developed by the Rijksinstitut voor Volksgezondheid en Milieu, Bilthoven, The Netherlands. These IMAGE scenarios serve as an important input to the focus group sessions. A broad variety of input parameters have been defined and corresponding scenarios were computed at PIK. A special procedure to download graphic result files from the workstation and display images on personal computers has been developed and implemented successfully.
At the request of the ULYSSES cooperation partners, a documentation of the IMAGE model has been prepared, including a summary of the model structure and the data flows as well as the descriptions of input files (scenario specification) and output (results) files.
PIK has also provided a scientific backup service, assistance in interpreting internal model relationships and in explaining results from various scenarios to the rest of the ULYSSES project team.

Regional Policy Panels (RPPs)
In addition to running focus group sessions with lay participants, the ULYSSES project is also organizing Regional Policy Panels. Participants at these workshops include representatives of business, industry, environmental organizations, and relevant government agencies from the city or region in question. In addition to the objectives set for the lay focus groups, regional policy panels explicitly look at the possible policy response options to the climate change problem at developing a regional scale.
The first policy panel session took place in Darmstadt in June 1997. The procedure also included elements of the policy exercise technique. The workshop has shown that regional policy panels may provide important data points to compare perception and interpretation of the climate change problem between lay people and policy makers at the regional scale as well as between groups of policy makers across various European regions.

European Venture Capital in Climate Policy Implementation
One of the most important issues in controlling greenhouse gas emissions is the cost of various control options. Huge investments will be required in developing, testing, commercialising, and marketing non-carbon and low-carbon technologies, before they will be able to compete with current fossil-based technologies. Therefore one of our objectives is to explore the interest of European venture capital in this issue. The ultimate question is whether at all, and if so, under what conditions, European venture capital would invest in research and development of non-carbon technologies. What are the most important decision criteria? What type of information is required to make an informed decision? What is the required institutional framework, and what policy initiatives should the European Union undertake in order to foster this process?
In this context, the aim of our policy exercise was to explore possible synergies between the venture capital sector and EU climate policy making. The workshop explored, the conditions under which European venture capital would invest in innovation on energy efficiency and non-carbon energy technologies. The emphasis was on helping venture capital representatives to define their own decision criteria, and to delineate policies and measures, which EU or national governments should put in place to enhance such venture capital investment.

Weather Impacts on Natural, Social and Economic Systems – WISE
PIK Contribution Leader: Hans-Joachim Schellnhuber

The objective of the project, co-ordinated by the Climatic Research Unit of the University of East Anglia (U.K.) with partners from the Vrije Universiteit Amsterdam (The Netherlands), the Fondazione Enrico Mattei Milano (Italy), and PIK, is to perform empirical studies of the impacts of climatic extremes - in particular hot summers, warm winters and wind storms - on natural, social and economic systems in Europe.
Most studies of potential socio-economic impacts of climate change draw upon scenarios of future climate and of future economic development. Another approach, which has been pursued only recently, is to analyse observed impacts of recent climate extremes on economies and societies. Empirical studies can provide useful information about the nature and scale of impacts on different sectors and upon the way in which different regions or cultures respond to them.
The impacts of recent hot summers, warm winters and wind storms on the economies, societies and natural environments of the countries of the contributing institutes are studied primarily through quantitative analysis of published economic data. A sector-wise approach is taken, and a core group of the sectors agriculture, tourism, energy, water, and fire was selected in order to allow regional comparisons on an international level. As far as possible, a monetary value is placed on the impacts which are found to result from the extreme weather conditions. In order to assess possible time-dependent changes in the sensitivities of systems to climate extremes, a comparison with the impact of an earlier event from the 1970s is carried out. In addition, transnational impacts are examined through case studies of perturbation in international tourism and the flows of agricultural produce in response to climate extremes.
On the societal level, perceptions of the impacts of climate variability among the general public will be examined by questionnaire. Identification of the extent to which adaptations have already occurred or are in progress in response to a perceived increase in certain types of extreme weather phenomena are an important component of this research. Here, the findings of the PIK project on the northern hemisphere summer of 1992 are a valuable base.
National differences and similarities in impacts, adaptations and sensitivities to climate extremes and shocks, and their possible causes, will form the main findings of the project.

Sectoral Modelling and Assessment

AGREC
Assessment of Agro-Economic Impacts of Climate Change on Central and Western Europe

Project Leader: Frank Wechsung

In AGREC, we are analysing the sensitivity of the agricultural sector of Central and Western Europe to modifications in yield and yield risk of crops caused by regional and global climate change. The regional impact of these changes will be demonstrated for Germany. Our investigations are based on simulations of the impact of possible climate change on the production potential of useable farmland. The AGREC core project uses the crop-related technological expenditure and yields as major variables. Special attention is given to the effect of elevated carbon dioxide on plant growth.

Partial equilibrium models at the European scale and farm allocation models at the German scale are used to calculate both the possible structural changes of the agriculture sector caused by climate change and the costs of maintaining conventional structures. The variability of possible climate, socio-economic and political change will be considered in scenarios.

Frank Wechsung

In 1996 and 1997, the main topics covered by AGREC were crop modelling, regional validation of crop models and the supply of yield scenarios. The implementation of the carbon dioxide fertilization effect in the PIK crop model *demeter* played a particular role. Thanks to the participation in the Free-Air Carbon Dioxide Enrichment (FACE) experiment at Maricopa, USA, it was possible to include experimental findings about the effect of carbon dioxide enrichment on wheat in the modelling effort.

Major Research Goals

Within the AGREC core project, we examine the consequences of possible climatic changes for agricultural production and the agricultural commodities market in Central and Western Europe.

Important questions in this project are:

- To what extent can the regional demand for vegetable and animal agricultural raw materials be satisfied, assuming the present structure of agricultural production and climate change?
- What structural adjustment reactions can the agricultural sector be expected to make to climate change, considering the different liberalization pathways that may be expected to affect the European agricultural commodities market?
- What costs might result from prevailing agricultural policy, which might prevent or delay the structural adjustment of agriculture to climate change?

The project aims at a scientifically profound evaluation of the effects of climate change, and will support the identification of those agricultural activities which can be modified or regionally reallocated to minimize the possible impacts (food scarcity, additional soil and water demand). It focuses on the effects of climatic change on German agriculture in a European market. The project serves to extend the methodological basis for political decision-making processes concerned with climate change mitigation measures in the agricultural sector.

In a first phase, AGREC mainly delivers yield scenarios, which describe simulated effects of climate change on agricultural crop yields. Simulations are made first at the mesoscale level for river basins and for the individual federal states of Germany, and later at the macroscale level for globally relevant agricultural production areas. The construction of yield scenarios is mainly based on process-oriented crop models. A realistic estimation of the carbon dioxide fertilization effect on plant growth, water consumption and yield is of special importance.

In a subsequent second phase, the economic consequences of yield modifications for the countries of

Central and Western Europe will be determined, and are realized regionally in Germany; the consequences are hereby traced down to the district level. Partial equilibrium models for the world commodities market and farm allocation models for Germany will be used for the transformation of yield changes into agro-economic impacts of climate change. The former serve to determine changes in European agriculture at an aggregated level, the latter allow a further regionalization of these aggregated results for Germany. The possible socio-economic and political change which may occur parallel to climate change will influence the impact of future climate on the agricultural sector. The variety of these changes will also be considered in different scenarios. The Institute for Agricultural Policy at the University of Bonn is a collaborator for these studies.
Selected results of this work will be presented in more detail in the following paragraphs.

Free-Air Carbon Dioxide Enrichment Experiment – FACE
Project Leader: Thomas Kartschall

The concentration of Carbon Dioxide in the Earth's atmosphere has increased continuously since the beginning of the industrial period, and will probably have doubled by the end of the 21st Century. Within the framework of a free-air carbon dioxide enrichment experiment conducted by the U.S. Water Conservation Laboratory (USWCL), Phoenix, Arizona, in the Sonoran Desert, concentrations of carbon dioxide, as they may be expected within the coming 50 to 75 years, were established under open-air conditions, and their impact on the agricultural cultivated plants cotton, wheat and barley was investigated. For this purpose, the concentration of carbon dioxide within the air is increased in circular plots of 22 metres diameter in the experimental field to 550 ppm (called FACE) as against 370 ppm (called AMBIENT), under otherwise undisturbed atmospheric conditions (figure 1). In the experiment, the effects for ambient and enriched atmospheric carbon dioxide and for two steps of water supply were investigated. Similar studies were realized with sufficient and limited supplies of nitrogen.

- Sufficient water supply = WET
- 50% water supply = DRY
- Sufficient nitrogen = HIGH
- 30% nitrogen = LOW

The main PIK activity in 1996/97 within FACE was the evaluation of possible short and long-term effects of elevated atmospheric carbon dioxide ($CO_2\uparrow$) for all four treatment combinations FACE-HIGH and -LOW, AMBIENT-HIGH and -LOW and their main interactions

Fig. 1: Wheat crop on 3 April 1997 showing phenological differentiation. The different nitrogen treatments are separated by a small, partly hidden, walkway (leading from the lower left towards the Sierra Istrella mountains in the background). The LOW half plot is located in the right-hand part of the photo. The half plot visible on the left-hand had full nitrogen supply [HIGH]. The accelerating effects on phenology and senescence due to the nitrogen shortage and the CO_2 enrichment (AMBIENT CO_2 outside the ring, enriched CO_2 =FACE inside the ring) including their combined effects are clearly visible.

Effects of Elevated Carbon Dioxide under Different Water and Nitrogen Supplies
As a result of the carbon dioxide enrichment, the primary photosynthesis performance rose under $CO_2\uparrow$ by up to 75%. For all $CO_2\uparrow$ variants an approximately 30% higher growth of biomass was recorded up to the middle of the vegetation period for WET and DRY. The processes of ripening and senescence were slightly accelerated under $CO_2\uparrow$. In association with other carbon dioxide effects, this led to a shortening of the grain filling period, and reduced the growth advantage for the FACE variants to 8% (WET) and 20% (DRY) in the final yield. Root growth under $CO_2\uparrow$ was also stimulated appreciably. The partial closure of the stomata under $CO_2\uparrow$ led to a recordable warming in the FACE plots through a decrease in transpiration per unit leaf area (figure 2).

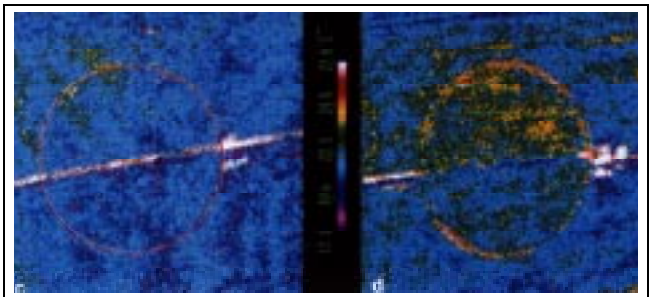


Fig. 2: Thermal scan of the (left) AMBIENT CO_2 plots (~370 ppm) and (right) FACE plots (~550 ppm).

The advantage of a greater water-use efficiency on the leaf level did not enhance the water-use efficiency on a whole-crop level, because a compensation due to

higher biomasses and a faster growth in leaf area appeared.
Previous observed and simulated results on photosynthesis and water vapour exchange for the CO_2–water experiments indicated possible acclimation and "down-regulation" effects of $CO_2\uparrow$ on photosynthesis, especially during late crop development (senescence). Therefore diurnal and seasonal trends in photosynthetic efficiency represented by the maximum saturated carboxylation rate (V_{Cmax}) were observed in order to estimate stimulating and acclimation effects on photosynthesis under ambient and $CO_2\uparrow$ in the CO_2-N experiments.
Our experimental study was made to evaluate the following three *ad hoc* hypotheses about a possible decline in V_{Cmax} on seasonal and daily time scales, and especially whether it appears or is amplified under $CO_2\uparrow$.

- Long-term (longer than a day) dilution/senescence of proteins should result in an apparent decrease in the activities of the carboxylation enzyme Rubisco.
- Rubisco can be deactivated due to metabolite accumulation.
- Accumulation of metabolites within the chloroplasts can increase resistance against electron transfer and CO_2/HCO_3^- diffusion and could lead to a short-term decline in observed photosynthetic activity.

For all three inhibition mechanisms an amplifying effect of $CO_2\uparrow$ was assumed.
The experiments carried out resulted in the following findings:

- A seasonal effect of declining V_{Cmax} for all treatment combinations was clearly visible.
- No clear evidence of a diurnal deactivation of Rubisco was found.
- A slight diurnal tendency for carboxylation efficiency to decline was observed.

The Main Results of FACE and their Contribution to PIK Model Development

During all FACE experiments $CO_2\uparrow$ was found to have a stimulating effect on photosynthesis, water use efficiency, biomass growth and grain yield. The experimental findings and simulation results clearly indicate a stronger stimulation under limited water supply but only slightly diminished effects under nitrogen shortage. No evidence was found of "down-regulation" effects of $CO_2\uparrow$ on photosynthesis. This confirms the applicability of model solutions obtained from FACE, for simulation studies on a wide range of temporal and regional scales, as performed with *demeter* for the State of Brandenburg.

Crop and Yield Modelling

The main research topic in 1997 was the evaluation of the PIK wheat model *demeter*, focused on possible short- and long-term effects of Global Change (including $CO_2\uparrow$) and how these interact on different spatial and temporal scales. This task was broken down to the following three topics:

- Improvement of existing mechanistic model formulations for gas and energy exchange on the leaf and plant canopy scale.
- Evaluation of the general validity and scalability of the improved model, obtained in FACE, to enable their use under European conditions.
- Step-by-step application of the improved model components for regional studies, as performed for the Brandenburg state-wide yield simulation study.

The development and application of the *demeter* model since 1993 has mainly been based on experimental data sets obtained from the FACE experiments. In 1997 a comparison was carried out under ambient carbon dioxide in Bernburg, Germany, in which the behaviour of the same variety of wheat as used in the FACE-Experiment, was studied under European environmental conditions. The results obtained enabled a validation of *demeter* for a typical German wheat growing region.
The advanced model is now able to reflect the energy and gas exchange on a time basis of minutes to days more accurately (figure 3).

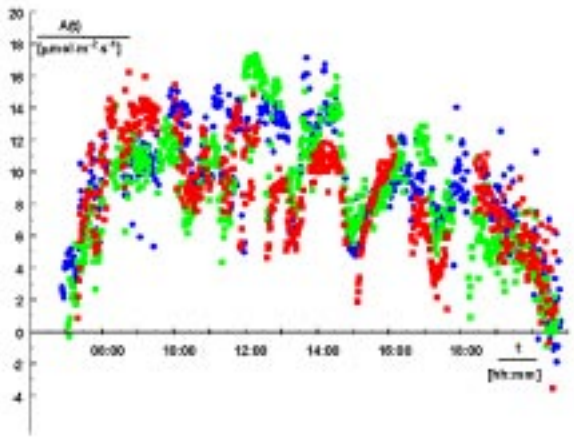


Fig. 3: Simulated and observed diurnal courses of photosynthesis rate during the Bernburg comparison study on 10 July 1997 (temporal resolution: 1 minute to 1 day). Red: simulation, green and blue: experimental data from two measurements.

In the *demeter* model all dynamic descriptions of short-term processes are interlinked leading to a day term behaviour of macroscopic and observable variables in a generic way. Therefore the short-term improvements and the more detailed knowledge about the long-term

Fig. 4: Diurnal course of flag leaf photosynthesis on 18 March 1993 during the FACE 1993 experiment in wheat. The photosynthesis shows a typical "midday depression" in the DRY plots (middle); temporal resolution: 1 hour to 1 day.

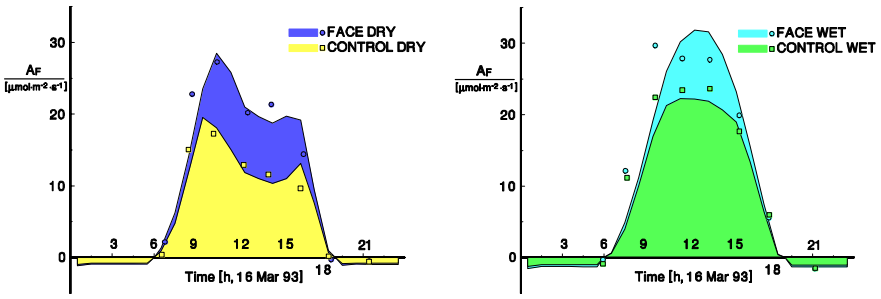
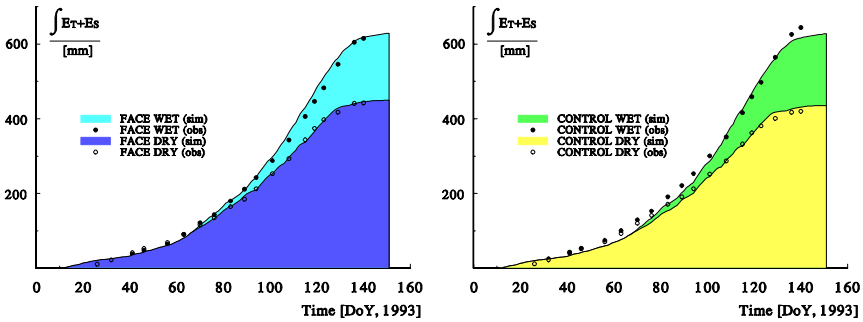


Fig. 5: Cumulative evaporation during the FACE wheat experiment in the FACE 1993 experiment in wheat (temporal resolution: 1 day to 1 year).



behaviour of V_{Cmax} (during senescence) resulted in a more stable behaviour of the macroscopic (figure 4) and long-term response. Finally an increase in accuracy for the phenology and the annual cumulative evapotranspiration (figure 5) and for the estimates for cumulative carbon fixation and final grain yield were achieved. All presented results for the CO_2-water experiments were calculated with the hourly mode of the latest version of the *demeter* wheat model using identical soil and plant parameters. The short-term simulation of photosynthesis for the Bernburg study was done using an embedded special feature of the hourly mode (a high resolution modification of the hourly photosynthesis module using minute driving forces).

The spatial scalability was the subject of the yield simulation study presented in the next paragraph. These results taken together show that the model is capable of being scaled at different temporal and spatial resolutions as is necessary for Global Change impact studies.

The Free-Air Carbon Dioxide Enrichment study was supported by the German Federal Ministry for Education, Science, Research and Technology (BMBF).

Regional Modelling of Agroecosystems

Regional Validation of Dynamic Crop Models

Climate impact studies within Europe have to consider the yield of winter wheat and other cereals as economic factors of high significance. Dynamic models are appropriate tools for yield simulation on the regional scale. In this regional study, we validated the two wheat models demeter and EPIC for further climate impact calculation using regional wheat yields from the German federal state of Brandenburg. This is different to many previous studies, where yields of experimental stations were used only for validation. The region was structured into 10 climatic subregions. The spatial distribution of soil properties was represented by projecting soil types from a 1 : 1,000,000 scale soil map on typical soil specific parameter values. 15 different soil types were taken into account. An assignment of wheat farming areas was performed by district statistics for 1991. Each soil type was given a specific portion of the total wheat area, taking into account soil quality and crop rotation preferences.

At first, demeter performed better than EPIC in describing the total spatial and temporal yield variance. Further analysis has shown that yearly aggregated demeter simulations correlate very strongly with the time series of Brandenburg mean wheat yield. However, the correlation between simulated and surveyed mean district yields was very low, mainly because of different model behaviour for the northern and southern parts of Brandenburg. In contrast to demeter, the temporal and spatial behaviour of EPIC is more consistent. The low overall performance was mainly caused by strong underestimation of the 1983 and 1990 yields. Besides uncertainties as to whether the soil, weather and land-use conditions for Branden-

burg are described representatively by the data used, both models need to be partially recalibrated to improve their regional performance for regional yield estimates in the future. The study lead us to the conclusion that overall estimates of the impact of climate change scenarios on mean wheat yields based on demeter and EPIC simulations are more reliable than simulations of the regional distribution of such an impact at this point.

Simulation of Winter Wheat Yields for the State of Brandenburg

Quantitative studies of climate impact on growth and yield of agricultural crops require the application of simulation models which should be sensitive to carbon dioxide. A simulation study was conducted on wheat growth in Brandenburg under present and future climate underlying current cultivation practice and land use structure, using data from 10 weather stations and a regional soil database.

A transient climate scenario with an 1.5 K temperature increase by the year 2050 was used. The following periods were investigated:

1) 1983-1990 (observed weather)
2) 2023-2030 (Scenario)
3) 2043-2050 (Scenario)

The atmospheric carbon dioxide for each period was extrapolated from the linear trend of the last two decades.

Plant Growth

As expected, the timing and duration of phenological phases is shifted under warmer climate (figure 6). With increasing temperature, the events of flowering and maturity are reached earlier, with overall shortening of grain filling period by 2.6 days. For the two future periods, the growth rates at the beginning of the season are much higher due to the combined effect of higher temperatures and carbon dioxide.

Accelerated phenology and increased water stress due to reduced precipitation resulted in the lowest yields for period 2. Precipitation for Period 3 was in the same range of the reference period, and the shortened season was compensated by higher atmospheric carbon dioxide (figure 7).

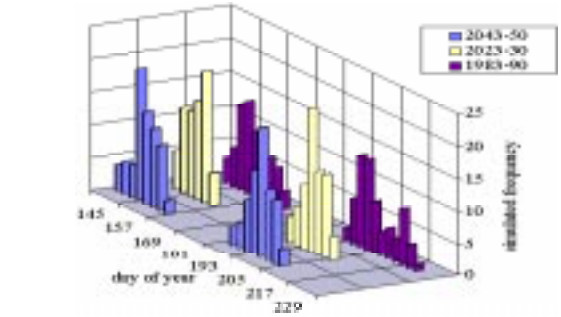


Fig. 6: Frequency distributions for simulated timing of flowering and maturity for three selected time periods.

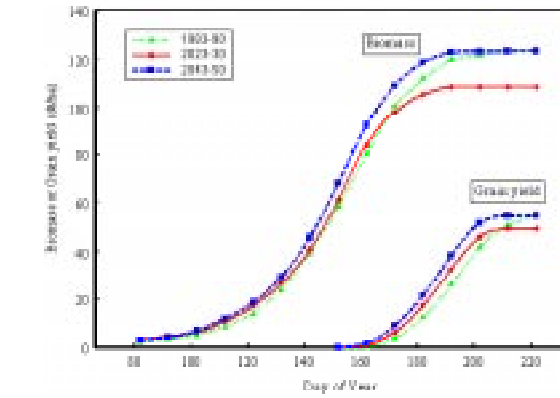


Fig. 7: Mean biomass and grain growth for three selected periods.

Regional Differentiation of Long-Term Yield

The percentage of wheat yield change is mapped for both scenario periods compared to the reference period, as affected by regional differences in soil quality and weather (figure 8).

The different yield change sensitivity of Brandenburg's subregions is clearly visible. A yield decrease for the entire State of Brandenburg was estimated with 10.6 % and 1 % for periods 2 or 3 respectively.

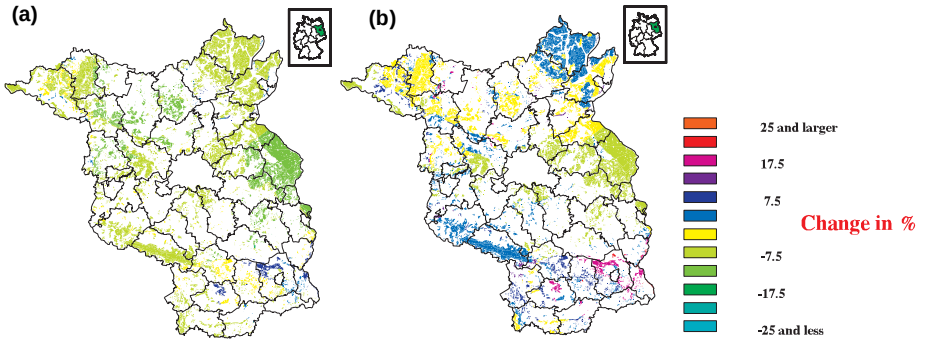


Fig. 8: Regional change of long-term wheat yield in the State of Brandenburg for periods 2 and 3. Simulated long-term mean relative change for 2023-30 (a) respectively 2043-50 (b) as compared to 1983-90.

Climate Sensitivity – Risk of Low Yields

The variance in long-term mean yield for a specific soil-climate combination affects the risks that a defined yield reduction will occur in one particular year.

Assuming a yield reduction of 20 % compared to the long-term average, it can be seen, that the climate sensitivity of yields successively decreases with increasing levels of atmospheric carbon dioxide (figure 9). Average risks for the State of Brandenburg are 18 %, 14 % and 11 % for periods 1, 2 and 3.

Conclusions of the Crop Yield Studies

The climatic impact on wheat yield depends strongly on amount and distribution of precipitation in the scenarios used. In some cases, yield losses caused by higher temperatures and increased atmospheric demand in evaporation can be compensated by higher carbon dioxide concentration. It has been possible to show that the climate sensitivity of wheat yields would decline in the State of Brandenburg under increased carbon dioxide.

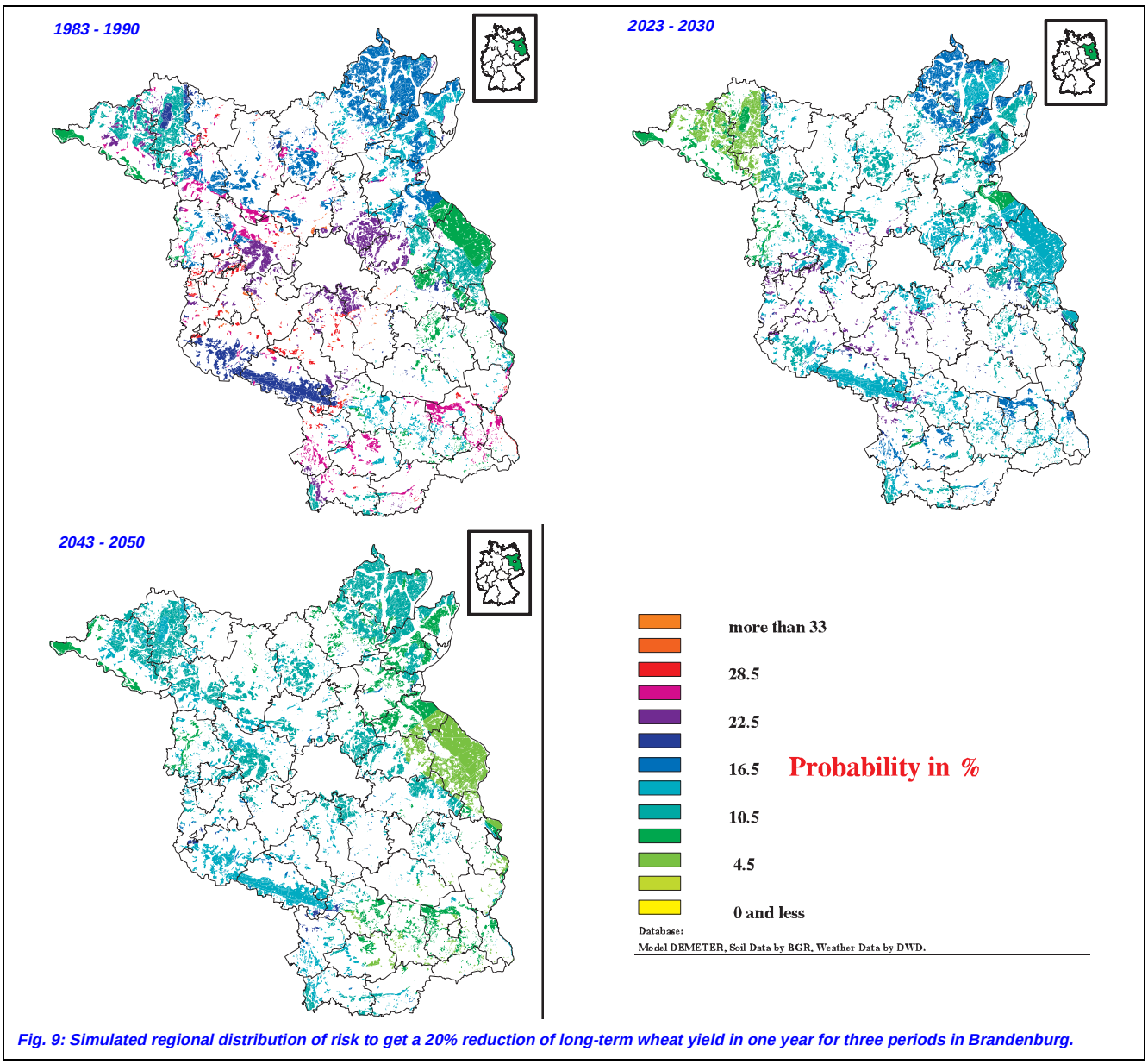


Fig. 9: Simulated regional distribution of risk to get a 20% reduction of long-term wheat yield in one year for three periods in Brandenburg.

Modelling Agroecosystems under Global Environmental Change – MAGEC
Project Leader: Wolfgang Cramer

MAGEC will provide modules of soil / plant interactions in agroecosystems to contribute to patch (<0,1 km) and regional scale (10 - 100 km) modelling frameworks already under development within the EU-TERI programme ETEMA. Specifically, the objectives of MAGEC are:

1) to evaluate the process description used by leading agroecosystem soil and plant models;
2) to use the best process descriptions to formulate new agroecosystem modules appropriate for use in patch and regional scale modelling frameworks developed elsewhere with EU-TERI
3) to test the accuracy and precision of the new soil and plant modules
4) to incorporate the agroecosystem modules into existing patch / regional scale modelling frameworks
5) to test the performance of the coupled soil / plant agroecosystem modules in patch /regional scale modelling frameworks
6) to contribute an agroecosystem module to a modelling tool (ETEMA) that will allow policy makers in the EU and individual governments to study the environmental impacts of land-use and climate change and examine scenarios for mitigation

PIK will be particularly responsible for 4) and 6), evaluating agroecosystem models developed in 1) - 3) under the full range of environmental conditions that are found in the EU. The project is coordinated by Dr. Pete Smith, Institute of Arable Crops Research, Rothamsted in the United Kingdom.

The MAGEC project is a European joint research project due to be funded from 1998 on, but initiated in the course of 1996/97.

CHIEF
Global Change Impacts on European Forests

Project Leader: Petra Lasch

Forests are one of the world's major renewable resources. Beyond their timber value, they also have a large value as providing recreational areas, wildlife reservoirs and, in some regions, protection against mass movements of mountain slopes or floods. Globally, forests hold a large fraction of the terrestrial carbon stock and they participate in rapid exchange processes between biosphere and atmosphere through photosynthesis, respiration and mineralization. Most of these processes are sensitive to climate change. Forests are not only an object of human activities but also play an active role in the global carbon cycle that in itself influences the development of the Earth system. Therefore the main goal of the CHIEF project is to assess the nature and extent of possible impacts of Global Change, concentrating on growth and species composition of forests, the economy of the forest industry and secondary values of forests. These issues shall be addressed at three different scales and at different levels of detail: the European, the German and the regional scale.

Petra Lasch

Modelling of Forest Growth and Socio-economic Consequences

Forests, whether managed or not, are known to tolerate some climatic variability, but they may respond with sudden breakdowns if certain climatic thresholds in, for example, moisture availability or windstorm intensity are exceeded. Because of the long turnover times of these ecosystems, it is important to be able to estimate the likely range of possible fates of forests over the next few decades or even centuries. It is widely accepted that the conventional tool for silvicultural planning, the yield tables, no longer provide adequate estimates of future forest conditions. This is because the environment, most notably the emission of nutrients and other pollutants, the ambient concentration of CO_2, and climate, are all changing rapidly, and towards new conditions that are unprecedented.

Within the climatic boundaries, forest management options are wide-ranging, and they cover all types of management goals as described above. Land use changes of considerable extent have occurred in the recent past and are still happening at the present time. These changes range from the transformation of forests into industrial, urban or traffic land use types, through changes in species composition to planting and regrowth of forests on land that has been set aside from agriculture due to overproduction. All these changes are fundamentally constrained by the climatic boundaries of each silvicultural species of interest, but their nature may vary widely within these boundaries.

In the densely populated regions of Central Europe, the secondary value of forests goes beyond their direct economic value for the timber industry. This must be accounted for by an assessment of the impacts of Global Change on forests, either as monetary interests of industries or public bodies depending on such values as tourism and catchment management or as non-monetary interests of other users like recreation and wildlife. The main goal of this project is to assess the nature and extent of possible impacts of global environmental change on forests in Europe. The main impacts considered are (i) on growth and species composition of forests, (ii) on the economy of the forest industry, and (iii) on secondary values of forests. To reach this goal, it is necessary to determine possible changes in the variables driving the forest ecosystem, critical limits where changes may lead to points of no return, and the potential of human management that may influence the sensitivity of the forest ecosystem. Within the scope of this project it is not feasible to approach all these issues on a European scale with the same amount of detail.

The project implementation includes the following tasks:

- Development of an improved forest model for assessing the ecological impacts of Global Change, including a submodel for forest management;
- Development of models of timber production and socio-economic consequences;

- Establishment of databases on climate, climatic change scenarios, and current forest conditions;
- Model validation for each of the three scales;
- Integrated impact assessment for the forest sector at each scale.

Development of a New Forest Gap Model

Various models of forest dynamics have been in use for the last 20 years. Their basic underlying assumption is that tree growth is determined by site conditions as climate and soils and by competition for the most important resources: light, water and nutrients. Within this framework, the fundamental processes of tree population dynamics, i.e., establishment, growth, mortality and dispersal, are formulated as functions of site conditions and competition. Only some of the most important processes can be incorporated deterministically. Other factors, which may be driven by the heterogeneity of the landscape or the variability of the weather, are simulated as stochastic processes.

These “gap models” prove to be capable of simulating the long-term dynamics of a wide range of forest ecosystems on several continents under current climate. However, many of these models contain a number of simplistic assumptions. On the other hand, ecological research has made considerable progress over the past few years, particularly in the fields of global-scale biogeochemical and patch-scale eco-physiological modelling, often invoking ecological and evolutionary theory about the functioning of plant communities. We believe that it is now possible to synthesize this current knowledge in a way that will allow a new generation of forest gap models to be formulated which are mechanistic and able to respond to the changing environmental conditions without being too complex.

The new forest gap model 4C (Forest Ecosystems in a changing Environment) will be structured as shown in figure 1.

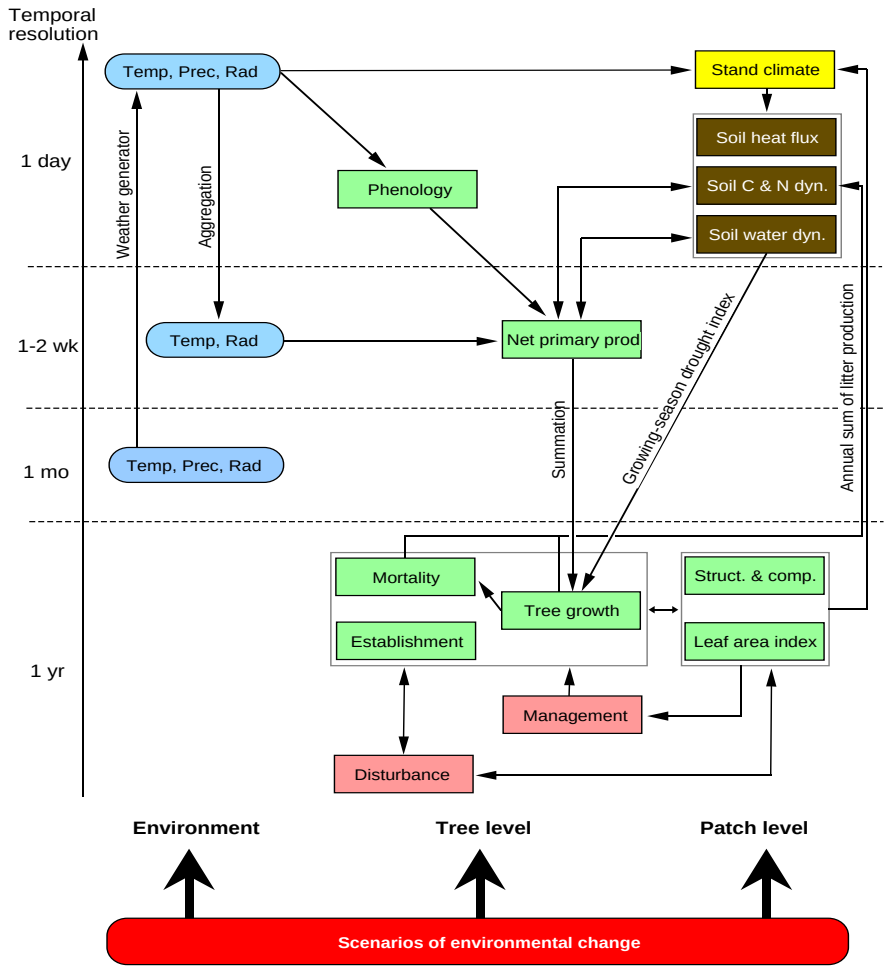


Fig. 1: The figure shows the structure of the new forest gap model 4C , which is
- based on the gap dynamics hypothesis,
- describes growth of natural and managed forests, and
- includes the carbon, water and nitrogen cycle.
The model is mechanistic and responding to changing environmental conditions, but it is not as complex as recent physiological gap models. It contains improved formulations of
- water and nutrient availability in the soil,
- the annual course of net photosynthesis,
- carbon allocation patterns as influenced by the environment,
- establishment and mortality rates, and
- management and natural disturbance processes.
In the figure rounded boxes denote external influences on forest dynamics. Rectangular boxes represent submodels. 4C distinguishes three time steps: A daily time step for soil dynamics and phenology, a time step of one to two weeks net primary production and an annual time step for tree growth population dynamics (tree establishment and mortality), management and natural disturbances. The monthly level was introduced to emphasize that for many model applications only monthly climatic input data will be available, hence requiring the incorporation of a weather generator algorithm to derive the daily input data required by the model.

Soil Submodel

The soil model consists of three parts, the water, temperature and carbon/nitrogen submodels. The soil is divided into layers with varying thickness following the horizontal structure of the soil profile. Water content, soil temperature, carbon, and nitrogen content of each soil layer are estimated as functions of the basic soil parameters, air temperature, net precipitation beneath the canopy and net deposition (nitrogen).

The essential interfaces between soil and vegetation are on the one hand the addition of organic material to the soil through accumulating litter, and on the other the withdrawal of water and nitrogen by the vegetation from the soil.

The *soil water* submodel estimates evapotranspiration, interception, snow water content and soil water content. After percolation the water loss by soil evaporation and the water uptake by roots are calculated.

The *carbon/nitrogen budget* submodel distinguishes between the carbon and nitrogen content of the primary organic matter (leaf biomass) and between compartments (leaves, needles, wood, fine roots). Mineralization of primary organic matter and humus is influenced by water content, soil temperature and pH value. The mineralized ammonium is subsequently transformed to nitrate. All processes are controlled by substrate-specific parameters. Leaching of mineral nitrogen and uptake by plants are calculated on the basis of the available soil nitrogen.

The dynamics of *soil temperature* are described by a one-dimensional heat conduction equation with the appropriate initial and boundary conditions. The upper boundary condition (soil surface temperature) is estimated from the air temperature of the last three days.

Net Primary Production (NPP) Submodel

In a first step, our NPP model was implemented at the level of the individual tree to predict maximum net photosynthesis as constrained by temperature and carbon dioxide, but with optimum water and nitrogen supply. A simple submodel for maintenance and growth respiration has been introduced, which allows NPP to be predicted. We use the model to simulate weekly or bi-weekly photosynthesis.

This approach allows an explicit, mechanistic upscaling from the photosynthesis of a single leaf to the NPP of a whole tree. We are currently developing algorithms for coupling it to the soil water and nitrogen modules described above.

Tree Growth (Allocation) Submodel

The more advanced gap models use species-specific, but static partitioning schemes to determine the allocation of NPP to the various plant compartments. It is well known that in reality the allocation patterns are strongly influenced by the environmental conditions, most notably by the availability of light, water, and nutrients. Mäkelä (1986, 1990) described a simple, consistent, but only theoretical framework to model carbon allocation patterns. We found that this framework can be elaborated to include explicitly the influence of changing environmental conditions, and that it is possible to couple this approach to the NPP scheme outlined above.

This submodel distinguishes the following state variables: foliage, sapwood and fine root biomass; heartwood biomass; average sapwood height; bole height. Note that tree diameter at breast height is not a state variable as in many other gap models; here, it is only an output variable of the model. In addition, the model does not assume allometric relationships between the various plant parts. Rather, it produces these allometric relationships as an output. From this, it is possible to predict maximum tree height as a function of the environmental conditions, which was not possible in previous gap models.

Mortality Submodel

Tree death may occur for different reasons like ageing, growth suppression, disturbances, such as fire, diseases, storms, and harvesting. The mortality model currently considers two kinds of mortality. The so-called ‘intrinsic' mortality is defined by a constant probability with a negative exponential survival curve using the species-specific life span. This approach will be replaced in the next version by an explicit modelling of ageing effects and disturbances like fire or diseases.

The second mortality function, which simulates effects of growth suppression, depends on species characteristics; that is successional types either with a short or a long life span or shade tolerance. The mortality model has to take into account that tree species differ greatly in their ability to grow slowly. Because the model is based on tree cohorts it was possible to implement a deterministic approach for calculating the annual mortality rate.

Management Submodel

There are several reasons to include a forest management module into the new forest model:

European forests have been managed for timber production over several centuries and therefore forests with a natural species composition are very rare. Thus, realistic forest development in Europe can only be simulated under consideration of typical forest management strategies.

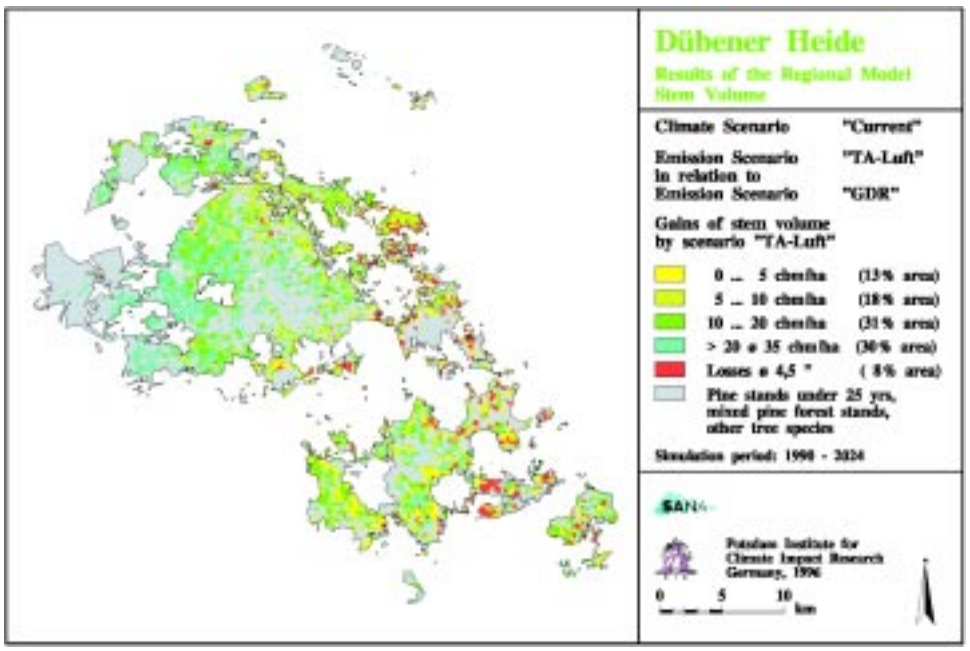
While long-term observations of natural forest dynamics are not available, we do have data-sets on the

development of managed forest stands of the economically important species. These data sets can become quite valuable for model testing and validation.
Finally, mitigation and adaptation strategies may be analysed with the extended model, making the simulation experiments more meaningful for both practical forestry and decision making.

Impacts of Pollutants on Pine Forests in the Dübener Heide

The SANA project, which included the development of the physiological growth model FORSANA as well as its regional application in the Dübener Heide case study, was successfully finished in 1996. Using rough initial stand and soil properties, management information (thinning, fertilization), pollution data and daily weather records the model FORSANA simulates the water cycle, nitrogen and carbon balance as well as stem number, diameter and height of even-aged coniferous stands over several years. The model is able to represent the measurements executed at selected sites, and produced regional predictions of pine forest growth over 35 years for more than 5000 forest stands within the Dübener Heide.

Fig. 2: FORSANA has been used to assess the potential growth response of pine forests to the changes of SO_2 concentration and nitrogen deposition that occurred in the course of the German reunification. The development of approximately 5000 stands within an area of 400 square kilometres has been simulated for a period of 30 years of current climate, and the resulting growth (emission scenario TA) has been compared with the growth estimate under unchanged deposition conditions (emission scenario GDR). The figure shows the gains and losses of stem volume by a simulation of the emission scenario "TA" in relation to the emission scenario "GDR".



Results showed that the effect of air pollution decreased foliage mass, which led to an increased importance of ground vegetation in the water, nitrogen and carbon cycles. In general the forests acted as sinks for carbon and nitrogen, even in drought years. Growth responses were relatively small compared to the sometimes large differences in driving variables, because of various feedback reactions between environmental conditions and tree growth.
At a regional level, wood production and development of other stand variables were investigated with different scenarios of air pollution and climate. The results indicated a growth increase with a decrease in air pollution in areas close to industrial centres. However, the effect decreased with distance from the sources of the pollution and growth reductions even occurred with cleaner air because of smaller nutrient deposition (see figure 2). The comparison of different climate scenarios in which the probability of arid and humid years was changed showed growth reductions particularly at sites with low soil water-holding capacity, although differences were generally less marked than in the pollution scenarios.

This project was partly funded by the German Federal Ministry for Education, Science, Research and Technology (BMBF).

Climate Impacts on Forests in Brandenburg

The "Brandenburg Study" (see Regional Integrated Climate Change Assessment, page 49) was continued in 1996/97 using new climate change scenarios and improved data on site quality. A new focus of the forest impact part is to investigate the effects of variable depths of the groundwater table on the potential natural species composition of forests in the state of

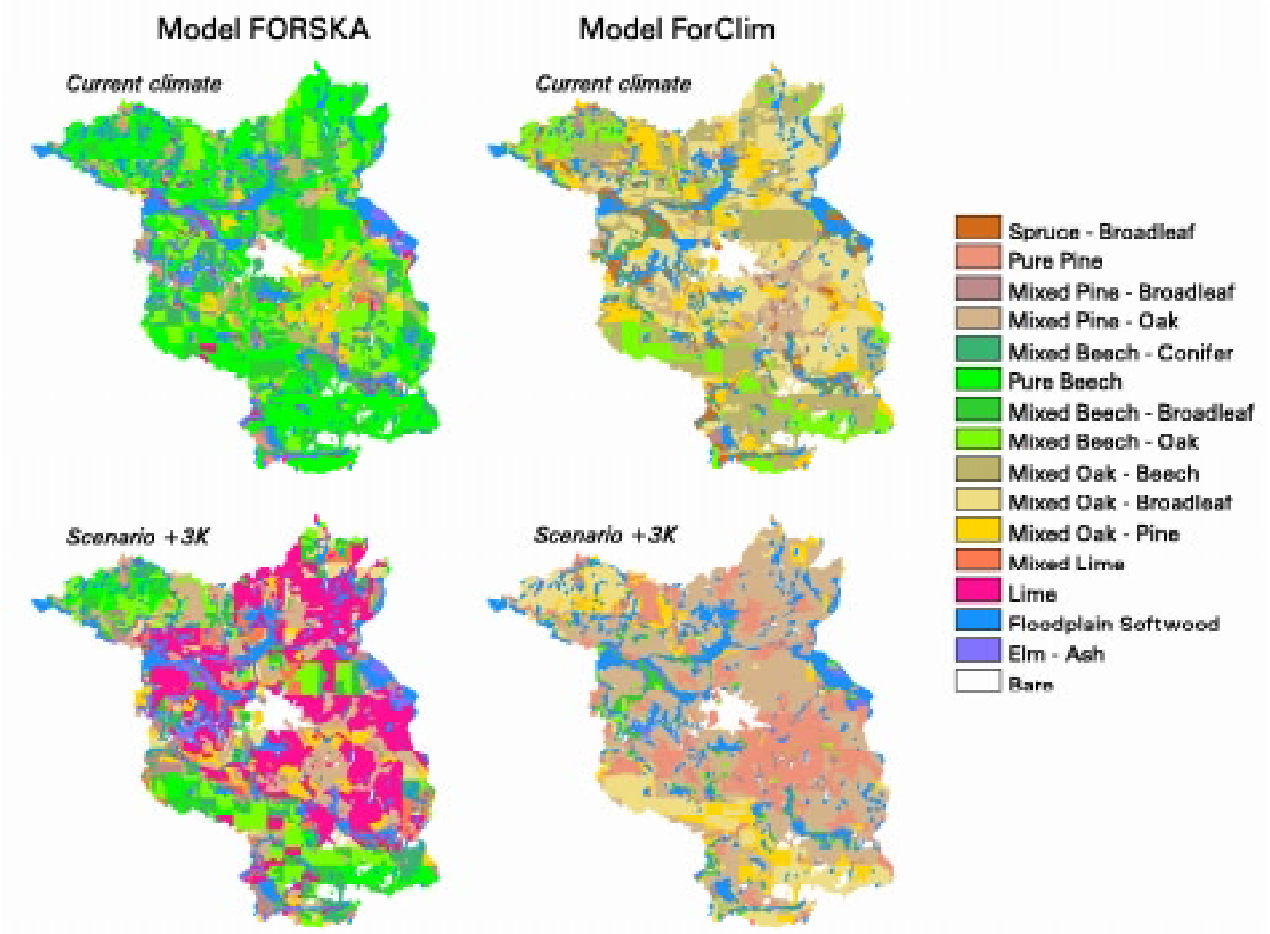


Fig. 3: Simulation of natural potential vegetation in Brandenburg for two models and two scenarios. In both forest gap models FORSKA and FORCLIM, growth functions to groundwater table were included with a species-specific parameterization. The two models show model-specific differences in species composition, however the projected changes are qualitatively similar. The models were calculated both for the current climate (upper two panels) and for a climate scenario with a temperature increase of 3 K, that is 3 ^{o}C, (lower two panels).

Brandenburg. Growth response functions to groundwater table were included with a species-specific parameterization in both forest gap models FORSKA and FORCLIM. The groundwater table is now a further site-specific input to both models, in addition to soil fertility and bucket size. The two models show model-specific differences in species composition, however the projected changes to climate change are qualitatively similar (see figure 3).

Both gap models seem to capture major spatial patterns of the current potential natural vegetation. Climate warming leads to a decline of pure and mixed beech stands, an increase of pure and mixed pine forests on poor sites, and an increase of mixed deciduous forests with oak, lime and hornbeam on fertile sites. Our investigations suggest that climate change may have considerable consequences for the future competitive relationships among tree species in Brandenburg. The regional application of forest succession models gives valuable insights into the model performance under a wide variety of environmental conditions. Furthermore, regional impact analyses could help to develop management strategies to cope with the risks of changing environmental conditions. The work will be continued with simulations of the new 4C model under different climate scenarios and connected via the Geographic Information System with simulated groundwater tables. By the end of 1998 the results of potential natural vegetation simulations will be integrated with agricultural model applications and the hydrological conclusions to form a regional impact assessment.

German Forest Sector under Global Change

The aim of this national case study is to assess the nature and extent of possible impacts of global climate change on forests and the forest industry in Germany. Several simulation models will be applied to national

forest inventory data to simulate and assess possible consequences of different climate scenarios on forest development and wood production in German forests. The new 4C gap model which is under development within the CHIEF core project and the forest growth simulator SILVA, among other methods, will be used. Additionally, the genetical adaptation and adaptability of major forest tree species will be analysed, forest management strategies to respond to or mitigate the projected changes will be investigated, and socioeconomic consequences of these scenarios for the forest industry will be estimated. Pending a larger, more comprehensive assessment at a later stage, it is expected that the study will yield insights into regional risks for German forests.

The focus of the study lies on the application of existing models of forest development and stand growth using available data sources from the first national forest inventory. For the socio-economic assessment new models need to be developed, since no suitable methodology exists for German conditions.
In a separate line of model simulations, the consequences of the projected forest growth changes for forest management and the economics of forest enterprises will be analysed (figure 4).

This project is funded by the Federal Ministry of Education, Science, Research and Technology (BMBF).

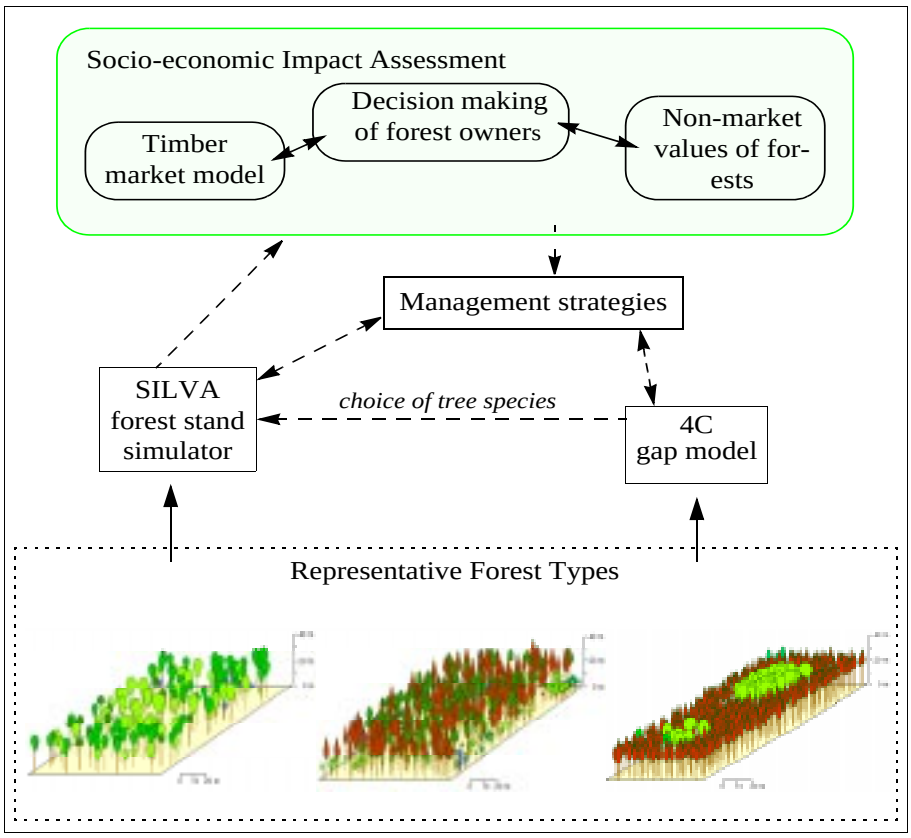


Fig. 4: In this study the consequences of the projected forest growth changes for forest management and the economics of forest enterprises will be analysed. For this purpose we will apply the forest simulation model SILVA, developed at the University of Munich, to economically important forest types on representatives sites. If stand regeneration occurs in the 110 years simulation period (1990 - 2100), information about suitable species will be taken from the 4C model output. The SILVA model then produces projections of growth and yield which will be used to analyse the impact of changing growth and yield on
- economics and decision making in generic forest enterprises,
- demand and supply on the timber markets, and
-indicators characterizing important social functions of forests (i.e. water and air purification, groundwater recharge, recreational potential).
An important link between the socio-economic assessment and the stand growth projections is the management strategies module which will be developed in order to find appropriate adaptation or response strategies in forest management. Such strategies need to take into account both, the projected environmental changes and their economic consequences.

RESOURCE
Social Dimensions of Resource Use: Water Related Problems in the Mediterranean

Acting Project Leader: Manfred Stock

The impacts of climate change are expected to increase the gravity of water-related critical problems in many parts of the globe. Fresh water is a precious resource, the value and price of which largely depend on the social and cultural dimensions of its use. The RESOURCE project focuses on the interactions between natural and social aspects of the water use and scarcity problem. It not only investigates the possible conflicts emerging from restricted water availability and rising water demand and their solutions, but also takes into account anthropogenic effects on the soil and the climate, such as of irrigated farming. The Mediterranean has been identified as a region where water scarcity problems are of increasing relevance and where an appropriate environment of available data, development projects and cooperative partners provide suitable conditions for a successful assessment.

Research Fields and Tasks

Water plays a crucial role in the livelihood and sustainable development of a region. It is not only essential for human survival and well-being, it is also important for industry and, especially, for agriculture. An integrated analysis of Global Change effects on water resources and socio-economic impacts in the eastern Mediterranean is needed in order to develop mitigation and adaptation options.

At present, the RESOURCE project contributes to the solution of water scarcity problems through research in three fields:

- Development of climate change scenarios based on the past and present climatology of the Mediterranean
- Regional integrated modelling and socio-economic studies of water prices and loss in the Mediterranean
- Regional vulnerability and risk assessment of water scarcity for the Mediterranean

The activities of the former PIK core project CLIMAGHS (Climate and Global Change Impact on the Environment and Society of the Mediterranean and the Maghreb States) have been integrated into the RESOURCE project. In CLIMAGHS the main aspect was the investigation of catastrophic events triggered by either lack of or heavy rainfall, namely droughts or floods. The Maghreb states were identified as a semi-arid subregion of interest, as well as the semi-arid regions of Israel and Jordan. The latter subregion has the advantage of better access to pertinent data and relevant scientific expertise. We plan to expand the methods and knowledge gained here to the Maghreb States later. To the best of our knowledge, this study represents one of the first attempts at a cross-disciplinary, integrated approach to analyse regional impacts of Global Change on water resources and prices in semi-arid areas.

Climatology and Climate Impact Parameters of the Mediterranean

We analysed and modelled spatial and temporal climate conditions in the Mediterranean and provided the results as input for scenarios of future climate development for the selected regions. In a first step, a standard evaluation of the present-day climate was carried out for the whole Mediterranean. This climate analysis includes the statistical description of the temporal and spatial behaviour of temperature and precipitation and will be carried on in order to obtain more data as a basis for the models. One example of the results shows strongly differing trends in precipitation within the investigation area (figure 1).

The next step is the temporal-spatial description of extreme events using multivariate statistical methods. Moreover, the development of a statistical model is planned on this basis to create future climate scenarios, e.g. the doubling of carbon dioxide that can also be used by the other partners.

Besides the statistical approach, the adaptation of a regional climate model will be carried out. The climate model MM5, made available by the Tel Aviv University, is the basis for regional modelling. At present this model is being developed not only for climate scenario calculation, but also for the investigation of weather characteristics such as precipitation, evaporation, temperature and humidity, which determine the conditions leading to desertification. Therefore, parameterizations are being improved, sensitivity investigations are being carried out and alternative options for the provision of boundary values are being introduced. This study is the first to apply a high resolution climate model for the simulation of the climate in the eastern Mediterranean in relation to the role of observed and determined potential future land use variations.

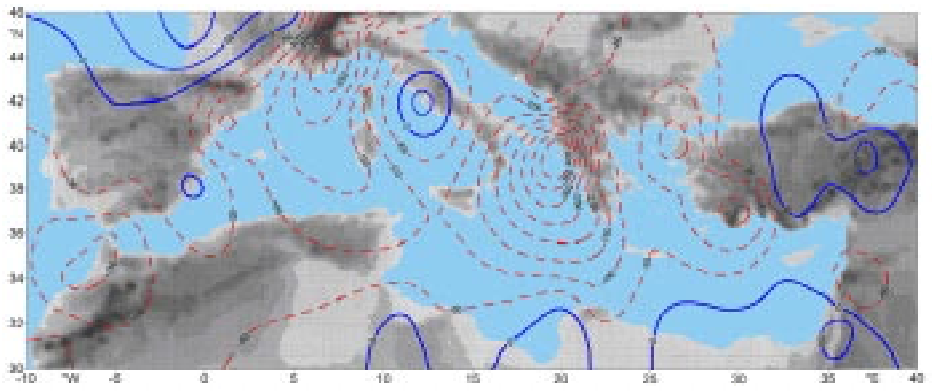


Fig. 1: Absolute linear trend (mm) of the annual sum of precipitation, period 1951 - 1993.

Summary
Within the project, information will be deduced concerning the spatial and temporal structure of different parameters relevant to meteorology and hydrology on the basis of observed and modelled values of precipitation, temperature, humidity and on the basis of natural variability and special climate events, forming a basis for formulating climate scenarios as components of land use changes.

Regional Study on Socio-economic Dimensions of Water Resources and Prices

Water Availability
Information on temperature and precipitation trends from climate scenarios for the eastern Mediterranean is translated into water balances. Water storage and water fluxes determine the amounts of water available for a given period of time. In the semi-arid to arid transitional region small changes in precipitation, temperature and potential evapotranspiration can cause drastic changes in surface water availability, groundwater recharge and ultimately plant water use. Measurements in the region and hydrological models at different scales, developed at PIK, help to understand and predict quantitative changes in the hydrological cycle as a basis for subsequent studies of the effects upon vegetation and economic and social well-being.
Not only the effects of climate change, but also other effects of Global Change alter regional water availability. Water supply as well as water demand are affected by land use changes, population growth, economic development and other trends such as urbanization. Modern irrigated farming in southern Israel for example shows a high degree of correlation with increased convection and subsequent cloud formation and rain over the same area. Regional urbanization on the other hand has a strong effect on per capita water use and pollution of surface waters.
The intensification of irrigated agriculture, associated with increasing groundwater pumping rates, depletes the underlying groundwater aquifers and degrades water and soil quality. A drop in the groundwater table leads to saltwater intrusions from the sea and subsequent salination of groundwater resources. The salination of the plant-soil-groundwater system leaves agricultural areas unsuitable for further farming.

Impact Assessments of Changes in Water Availability
In collaboration with our partner institutes in Israel, the chain of effects associated with a degradation of water resources is being monitored and modelled. Data gained from this work will be used in assessing impacts upon society, e.g. on agricultural production and other water intensive activities. A quantification of socio-economic costs of water related changes is based on the societal value of water. It will pay special attention to impacts of extreme events, such as extended periods of drought. Impacts on natural vegetation like desertification, and “non-market” impacts like changes in recreational and other non-consumptive uses of water will also be included in a regional integrated impact assessment. Economic analysis will employ partial equilibrium models, which convert damage losses into monetary values.

Regional Vulnerability Assessment of Water Scarcity Risks for the Mediterranean
The term vulnerability refers to natural and socio-economic characteristics of a region that dispose it to exogeneous or endogenous crises. Originally used in ecosystem research and human geography, we apply the concept of vulnerability to the Mediterranean region, i.e. its people and their livelihood and focus on the water problem.

As a first step for an integrated assessment of the vulnerability of the Mediterranean Basin to water-related stress and conflicts a geographically explicit criticality index, developed by the QUESTIONS core project in cooperation with a research group at the University of Kassel with J. Alcamo and the WBGU in 1997, has been used. This index might be regarded as a proxy compound measure for what is intended in a more detailed way by the RESOURCE project.

Although its detailed implementation is rather complicated, the basic idea of that index is quite simple: The vulnerability of a region to water-related problems is high if societal water demand reaches or exceeds natural water availability and, at the same time, there are no measures at hand to by-pass this shortcoming. Conversely the regional vulnerability is low if water is surplus in terms of natural availability, or if socio-technical devices, such as long-distance main pipes, deep wells, or sea-water desalinization plants can help to overcome potential water scarcity.

The criticality index thus operates with three complex terms, each of them combining different information about the Mediterranean. The first term informs about the water demand on a national level, defined as the withdrawal by agriculture, industry, and the domestic sector. The second term refers to water availability, computed on a watershed level (resolution: 0.5º x 0.5º, including 1.162 watersheds worldwide), using precipitation, temperature, relative sunshine, soil and vegetation information. As shallow surface groundwater recharge widely depends upon rainfall and evapotranspiration, the availability term includes these groundwater sources as well. Most assessments of the global water crisis only relate demand to availability and examine the change of this relation over time under different scenarios for population, food or industrial production levels. But these two factors alone do not provide enough information for estimating the entire vulnerability of a region to water-induced stress.

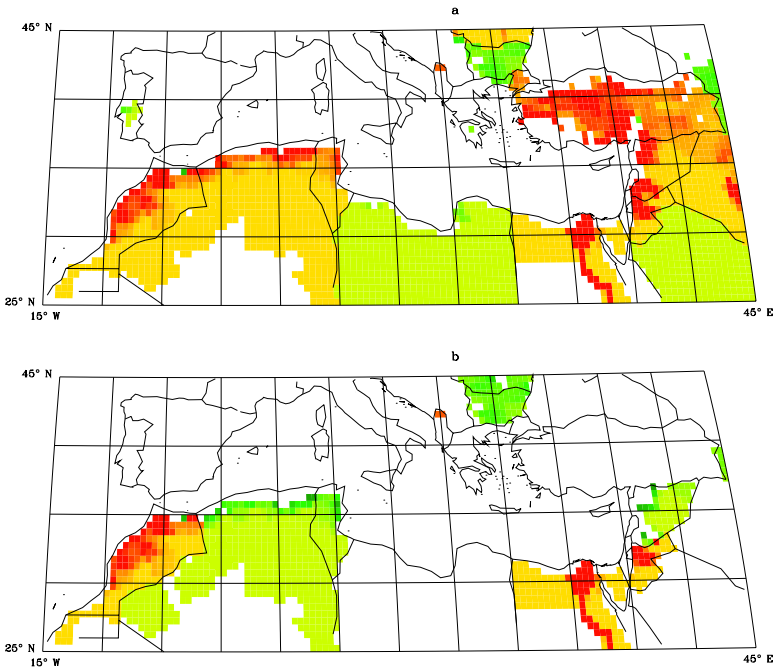


Fig. 2: Change of number of people affected by severe water crisis in the Mediterranean between 1995 and 2025 under two different scenarios: (a upper panel) if water withdrawal reaches or exceeds availability and technical compensation is only moderate, (b lower panel) if this compensation is substantial. The colours indicate situations: light to dark green meaning "better than today", yellow to red meaning "worse than today", white meaning "no change of situation" (being good or bad in 1995!). Note that even under more optimistic assumptions (b) Morocco, Egypt and Jordan will face a water crisis.

Some societies, due to their economic, political or cultural situation, have a better potential for coping with water stress than others. As a first proxy measure for this curation potential we used the GNP of a country, well aware of the fact that this measure has to be completed by others. But how effective is "money" in reducing water crisis? There is a broad discussion among economists about the exact degree of substitutability of natural capital. Some think that society will always find a way – mainly by technical devices – to overcome natural resources scarcities. Others claim that the substitutional capacities of humans are very limited. As there is no expert consensus on that point, two different cases were calculated:

- *Scenario I* assumes a relatively high degree of substitutability, leading to a rather “optimistic” estimation of water-induced regional vulnerability.
- *Scenario II* assumes a more moderate substitutability and consequently estimates higher vulnerability.

Both scenarios were computed for 1995 and for 2025. Additionally, the effects of climate change on water resources have been estimated using a scenario (IS92a) of the Intergovernmental Panel on Climate Change (IPCC), assuming an increase of carbon dioxide equivalent concentration in the atmosphere of 50 % relative to the preindustrial level.

But still the vulnerability of people within the Mediterranean Basin is not taken into account. To complete the vulnerability assessment the regional distribution of population is included. Thus it was possible to estimate the number of people in the Mediterranean affected by severe water crisis. A situation is called critical if people have to face water withdrawal with no or only limited curation potential. The two maps show a comparison between the regional criticalities in 1995 and in 2025 for both scenarios (figure 2).

One can see that regional disparities concerning water criticality will increase in either case, leading to a higher potential for resource conflicts. If low substitutability is assumed (a), the situation – measured as people affected by severe water criticalities – will be aggravated especially in Morocco, Algeria, Tunisia, Egypt, Syria, and Turkey. If economic development allows for more compensation of water scarcity (b), Algeria, Syria, and to a lower degree Turkey will better be able to cope with the situation, whereas Morocco, Egypt and Jordan will face severe water crisis. It has to be kept in mind, nevertheless, that the curation potential as derived from future GNP development is subject to various uncertainties concerning the effectiveness and opportunity costs of measures.

One can estimate that, for example, a country like Algeria, entangled in civil strife, high unemployment rates and high population growth will find it much harder to turn economic capital and technical potential into factors and facilities effectively compensating water crisis than a country like Tunisia. In any case, further aspects like those mentioned have to be integrated in order to give a more reliable picture of social, economic, political, and cultural coping potential.

Scientific Departments

Integrated Systems Analysis

Head: Hans-Joachim Schellnhuber in co-operation with Yuri Svirezhev
Deputy Head: Gerhard Petschel-Held

Staff and Guests

From left to right, back row: Gerhard Petschel-Held, Martin Cassel-Gintz, Arthur Block, Martin Füssel, Maarten Krol.

Front row standing: Volker Wenzel, Biraj Kumar Biswas, Annekathrin Jaeger, Yuri Svirezhev, Manfred Stock, Thomas Bruckner, Christine Bounama.

Front row sitting: Oliver Moldenhauer, Jürgen Kropp, Matthias Lüdeke.

Name	*Discipline*	*Project Contributions*
Biraj Kumar Biswas	Agricultural Engineering	Guest
Dr. Arthur Block	Physics	QUESTIONS, POEM: COEM
Christine Bounama	Geophysics	POEM: COEM
Dr. Thomas Bruckner	Physics	ICLIPS
Martin Cassel-Gintz	Geography	QUESTIONS
Professor Dr. Siegfried Franck	Geophysics	POEM: COEM
Martin Füssel	Applied Systems Science	ICLIPS
Annekathrin Jaeger	Biophysics	WAVES
Dr. Maarten Krol	Mathematics	WAVES
Jürgen Kropp	Chemistry	QUESTIONS
Dr. Matthias Lüdeke	Physics	QUESTIONS

Oliver Moldenhauer	Physics	QUESTIONS
Dr. Gerhard Petschel-Held	Physics	QUESTIONS, ICLIPS
Professor Dr. Hans-Joachim Schellnhuber	Physics	QUESTIONS, POEM, EUROPA: WISE, ACACIA
Dr. Horst Sterr	Geography	EUROPA:WISE
Dr. Manfred Stock	Physics	RESOURCE
Professor Dr. Yuri Svirezhev	Physics, Mathematics, Genetics	POEM: COEM
Dr. Volker Wenzel	Mathematics	RAGTIME, EUROPA: ULYSSES, WISE

The success of modern science rests to a large extent on an ever-increasing refinement and break-down of problems and methods. In order to analyse Global Change, its human causes and consequences in an adequate and sufficient manner, results of this "differentiation" process have to be re-integrated. As well as tackling this re-integration problem, the Department of Integrated Systems Analysis tries to develop methods to identify relevant properties of the Earth system as such. Further questions are asked on the determination of management strategies for a sustainable development. Some of the pertinent issues can be stated as follows:

- Is it adequate to use the natural science perspective of determinism in the description of human systems? Conversely, can we formulate laws and rules of inanimate nature in the language of say, sociology, without losing relevant details? Can we use these kinds of transcriptions to incorporate results from the other main scientific fields? Do we need to develop a new transdisciplinary language able to integrate disciplinary knowledge?
- How can we integrate normative settings often made by policy makers without violating the "scientific encoding of true and false" (Luhmann)? What type of "management strategies" can be developed for the Earth system and how can we formally assess these?
- Is it possible to describe the complexity of the Earth system, e.g. by methods of modern physics or mathematics? Can we derive a typology of Global Environmental Change either inductively or deductively?

In the following some of the recent results on questions like these are briefly presented.

Integration Methods and Strategies

There is no ideal toolbox able to provide 'best' techniques and methods for each of the 'atoms of knowledge' to be integrated into the scientific assessment of Global Change. This simple and fundamental statement can be illustrated by considering, say, the difficult issue of inter- or transdisciplinary research: quantitative modelling with clearly defined interfaces between the different components to be modelled by the respective disciplines, is just one possible approach. Scenario-building techniques using expert interviews or the development of new transactors' approaches represent certain alternatives. Yet experience at PIK as well as at other institutes, e.g. the MIT, has shown that *one* central and concerted focal point like a model or a common language of analysis is essential for the success of any interdisciplinary project. This is true not only for this type of integration. Other integration problems, such as the aggregation of processes taking place on different scales, the inclusion of knowledge with various degrees of uncertainty, or the need for comprehensible transparent interfaces to decision makers have equally to be tackled by such conceptual focal points. Again, however, there is no single best concept; rather, each type of problem, together with the basic questions to be answered, requires its own suitably and carefully developed integration concept.
Concepts developed at PIK in recent years in co-operation between members of the department and different core projects are listed in the following:

1) The method of cyclic integration rests on the idea of developing a prototype model which is subsequently tested by exponents of the partaking disciplines. After this testing phase the problems of deficiency that have emerged are assimilated to generate a second model generation, again to be evaluated by each sub-group. The cycle starts all over again.
2) Similar but somewhat more application-oriented is the meta-modelling approach. Here, an entire framework of various models is developed, which

is adequate for hierarchic integration on various levels. The different model elements of the framework are nested and can therefore be run independently.

3) Another important concept is the development of minimal models which are given by conceptual, low-dimensional sets of differential equations, with the aim of being able to explain and conjecture structural properties of the Earth system. Typical properties investigated herewith concern the number of simultaneous equilibria of the biosphere, non-linear phenomena like hysteresis effects or causes of asymmetric glaciation.
4) Particularly appropriate for including qualitative knowledge, e.g. socio-cultural expertise, on the one hand and uncertainties on the other hand is the idea of qualitative modelling. Instead of precise mathematical functions to express the variables to be taken into account, this approach uses qualities characterized by well-ordered sets of so-called landmark values (i.e. symbols representing distinct points at which the system changes its behaviour) or by linguistic variables expressed through modern methods of fuzzy logic.

It is the task of the department to provide a platform for discussing and comparing the various approaches. Yet it has to be underlined again that there is not and will not be a single best concept for integrated systems analysis.

Further, original research is undertaken advancing various mathematical and computational methods profitable for integrated systems analysis. This includes methods of *complex systems analysis* put forward in theoretical physics (neural networks, cellular automata, etc.) to describe and understand structural properties of these systems. *Control theory* is helpful for understanding fundamental methodological problems of global environmental management. Common to all analyses of Global Change is uncertainty. Modern methods of *risk assessment* provide useful tools for assessing these stochasticities – not only in the context of science but also in the context of decision making.

Complex Systems Analysis

The analysis of Global Change is facilitated by various methods of complex system theory which originated in mathematics and physics: artificial neural networks, rule-based approaches like cellular automata and fuzzy logic calculus', fractal analysis, exergy or other thermodynamic concepts, etc. However, most of the above-mentioned methods are only of limited use in an overall integrated approach because they are often developed in order to analyse or to model just a few distinct, yet highly relevant properties of a complex system. To take one example, work in the department has shown that cellular automata can be an important tool in understanding complex systems which consist of a large number of interacting entities, such as geographical units or individuals. We have extended the famous Daisy-World Model in order to analyse the climatic elasticity of a virtual planet with respect to control parameters such as landscape fragmentation or insolation. That means that this model has great epistemic relevance as it helps to explore fundamental effects and phenomena.

Neural networks provide various techniques appropriate for non-linear data analysis and highly generalized 'black box' modelling. One particular method applied at PIK is the Kohonen algorithm which can be employed for non-linear topological invariant categorization. The result is not based on strict rules or crisp decision criteria but is detected by adaptive learning; figure 1 shows an exemplary result obtained for a highly resolved climate dataset consisting of monthly mean temperature, precipitation sum, and cloudiness (CLIMATE 2.1 database). In combination with measures for topological invariance, the Kohonen algorithm allows classifications to be found which ensure that similar climates are classified as similar. For other reasons, the results obtained by such a fuzzy classification can be used for the formulation of qualitative concepts and further analytical efforts, especially in the cases in which no or only a few bits of knowledge of the underlying system are at hand.

Moreover, a neural network has been employed to obtain a reduced-form model for the net primary production of natural vegetation. This reduced-form model is based on the results of five global vegetation models. This 'best-guess' model allows the computation of the equilibrium NPP (see page 91) in a much more efficient manner than with the original models (5 sec on a workstation compared to 25 minutes on the SP2-70 parallel machine of PIK). Therefore, this model provides an optimal component for integrated assessments of climate sensitivity analyses.

Control Theory

Global Change research is often scenario-based, i.e., a set of 'possible futures' is developed on the basis of a number of general assumptions . The most prominent examples of this are the scenarios of prospective emissions of greenhouse gases in the atmosphere developed by the Intergovernmental Panel on Climate Change (IPCC). These scenarios are then used in an 'IF–THEN' mode to model the response of various subsystems, e.g. climate evolution or vegetation responses to anthropogenic perturbation.

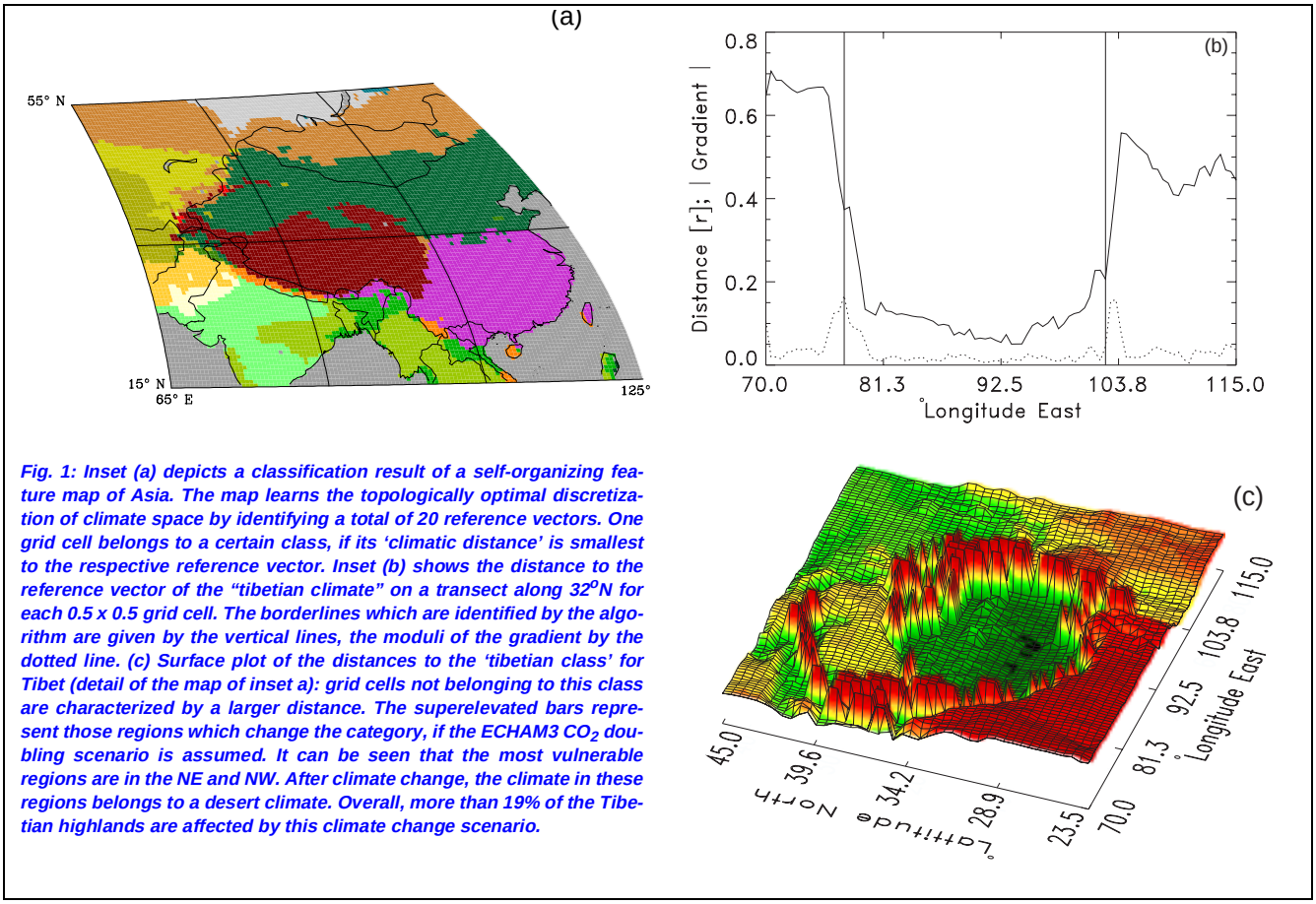


Fig. 1: Inset (a) depicts a classification result of a self-organizing feature map of Asia. The map learns the topologically optimal discretization of climate space by identifying a total of 20 reference vectors. One grid cell belongs to a certain class, if its 'climatic distance' is smallest to the respective reference vector. Inset (b) shows the distance to the reference vector of the "tibetian climate" on a transect along 32°N for each 0.5 x 0.5 grid cell. The borderlines which are identified by the algorithm are given by the vertical lines, the moduli of the gradient by the dotted line. (c) Surface plot of the distances to the 'tibetian class' for Tibet (detail of the map of inset a): grid cells not belonging to this class are characterized by a larger distance. The superelevated bars represent those regions which change the category, if the ECHAM3 CO_2 doubling scenario is assumed. It can be seen that the most vulnerable regions are in the NE and NW. After climate change, the climate in these regions belongs to a desert climate. Overall, more than 19% of the Tibetian highlands are affected by this climate change scenario.

A different approach is to work in a 'goal-oriented' way directly identifying the policy options necessary to achieve a predefined target. Possible goals include, for example, the optimization of a general welfare function which in economics is often defined in terms of macroeconomically determined consumption as a discounted function of time. Another goal, currently adopted in the ICLIPS project at PIK (see page 23) can be characterized as *pessimization*: here domains of possible states or developments of the Earth system have to be evaluated with respect to their tolerability. Then the set of strategies ensures the avoidance of these intolerabilities has to be computed.

As an example, consider the so-called conveyor belt, a large-scale ocean circulation pattern acting as a heat pump for Northern and Central Europe: according to recent results (see MILLENIA project), there is a significant chance of the conveyor belt shutting down due to anthropogenic climate change. Results from various GCM-experiments suggest a concomitant decrease of annual mean temperature in Northern and Central Europe of 10-20 °C. Without stating this positively, this state is probably intolerable and strategies to guarantee the avoidance of this cooling effect have to be sought (a task currently pursued in the ICLIPS project).

In the last two years some aspects of control theory have been developed further, to improve the methodological basis of global environmental management, i.e., what to do to achieve the predefined goal of sustainable development.

1) The concept of *differential inclusion* has been employed for the tolerable-windows approach used in the ICLIPS project. As one element of the work at PIK, a first step has been taken to construct a novel numerical method to compute a representation of all future developments and management strategies (called a *funnel*) which is compatible with a number of predefined constraints (see page 24). Further steps are planned to improve the method and the evidential power of the representation.
2) In contrast to conventional optimization theory or to the mentioned computation of the funnel, *fuzzy control* does not directly make use of projective models. Instead, local information is used together with some 'landmarks' indicating the distant targets to be met or to be avoided. A concep-

tual model has been employed to demonstrate the basic functionality of the approach taken. Within this model a simple complex function f(z) with three roots has been used. The dynamics of the system is given by a mathematical algorithm capable of finding these roots in an extremely short amount of time. The basins of attraction of each root, i.e. the set of starting points finally leading to the respective root if the system is left alone, are fractals. This implies that for a significant portion of possible constellations it is practically impossible to know which root the system is heading for. Within the simple model put up here, these roots serve as metaphors for possible outcomes of Global Change. Now, one root is assumed to be the 'good' target, the other two to be 'bad' targets which have to be avoided; thus a fuzzy control strategy is sought, which *ensures* that a good root is finally reached. It turns out that a hybrid strategy, using local information on the values of the function and its derivative, and some rough meso-scale information about direction and distance of the roots, is sufficient for this task. In figure 2 some typical paths towards the good target are shown: wherever we start (red dots), this hybrid strategy finally brings the system to the good target (blue) by completely avoiding the bad ones (yellow). Though this is only a conceptual approach it illustrates the type of management strategies needed for global environmental management: How can we reach the save harbour if knowledge is limited, uncertain and vague, in particular with respect to the global, i.e. non-local, properties of the system?

Dealing with Uncertainty: Risk Assessments

How can we estimate the climate impact on social systems and take uncertainties into account properly? One approach pursued in the department is based on the risk concept. The assessment embraces both the real stochasticities of climatic processes and the artificial stochasticities of climate predictions due to scientific uncertainties.

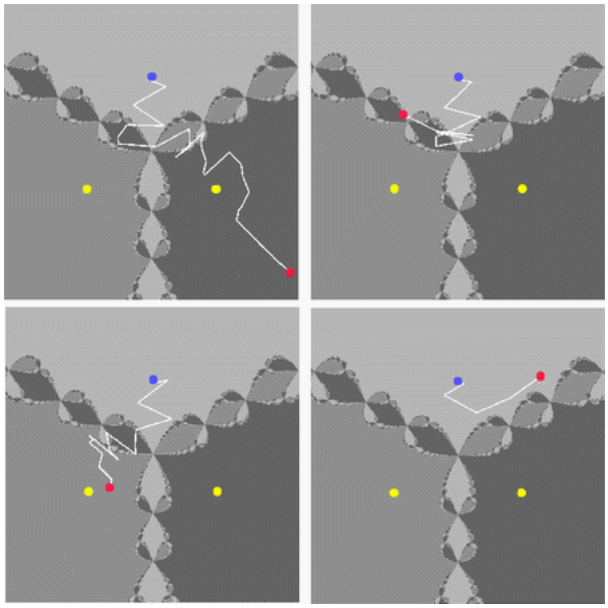


Fig. 2: Typical trajectories of root-finding walks across the fractal Cayley structure for a modified Newton method which uses some global information concerning the position of the roots. The different shadings correspond to the three basins of attraction of the roots indicated by the blue and yellow dots. The goal is to find the 'good' blue root and to avoid the yellow 'bad' ones.

This method has been worked out in some detail for the problem of regional crop production in the Kursk region (Western Russia) and the risks caused to it by global climate change. In order to get local climatic characteristics (weather), a so-called 'statistical weather generator' is used. It turns out that the current low level of risk of a major crop failure remains constant for a temperature rise of up to 1.0 – 1.1 ^{o}C mean seasonal temperature. With increasing variance, i.e. inter-annual temperature variability, the risk grows significantly, however, even if the mean temperature rises very slowly.

This shows that it is not the climate in terms of mean temperature alone that we have to care about, but rather the stochasticities, both within the climate system itself and in our knowledge about it.

Climate Research

Head: Martin Claussen
Deputy Head: Friedrich-Wilhelm Gerstengarbe

Staff and Guests

From left to right, back rows:
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Front row sitting:
Eva Bauer, Martin Claussen, Vladimir Petoukhov.

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Uwe Böhm	Physics	RESOURCE, WAVES
Dr. Gerd Bürger	Mathematics	POEM: KLIMÖKO
Dr. Victor Brovkin	Mathematics	POEM: DGVM Intercomparison, MGBM
Dr. Reinhard Calov	Physics	POEM: CLIMBER 2
Prof. Dr. Martin Claussen	Meteorology	EUROPA: KLINO
Dr. Andrey Ganopolski	Oceanography	POEM
Dr. habil. Friedrich-Wilhelm Gerstengarbe	Meteorology	RESOURCE, WAVES
Dr. Maarten Krol	Mathematics	WAVES
Claudia Kubatzki	Meteorology	POEM
Dr. Hermann Österle	Meteorology	WAVES, RESOURCE
Dr. habil. Vladimir Petoukhov	Geophysics	POEM

Dr. Stefan Rahmstorf	Oceanography	POEM: MILLENIA
Dr. habil. Peter Werner	Meteorology	RESOURCE, WAVES
Ursula Werner	Technical Assistance	service for several projects

The mission of the Climate Research Department has changed since the early years of the Institute. In the beginning, mere supply of climate data and climate scenarios to the impact research community was its main topic. Meanwhile, the Climate Research Department has come to address basic problems related to the diagnosis of climate data, design of climate change scenarios as well as climate system modelling.

Climate Analysis and Diagnosis

A prerequisite for any research related to climate is a thorough analysis of past and present-day climate on the basis of high-quality data and reconstructions from proxy data, for example an estimate of summer warmth deduced from the abundance of fossil pollen. Climate analysis concerns not only “simple” climatic mean values, such as monthly mean temperatures and annual mean precipitation. Instead, for many applications in climate impact research and information about climatic extremes is needed, for example strength and duration of cold spells or rainfall events etc. Because of the non-linear character of the climate system analysis and diagnosis of climate data are carried out by using multivariate statistical methods. Therefore, such methods have been developed and used in the Climate Research Department.

Methods, which are employed for the analysis and diagnosis of climate data, are also applied to the validation of climate models. This not only improves the climate models, but also achieves a better understanding and more appropriate exploration of model results in climate impact research.

Climate Data Base

An important tool for all climatological and climatology-based investigations is an extensive data base which satisfies the quality criteria of the specific scientific research. To fulfil these demands a climate data base has been constructed over the last few years using the Oracle Data Bank System. Besides the pure collection of data, the main philosophy is to develop algorithms to check the quality of the data and to describe their statistical behaviour. Since a multitude of different climate data banks already exist world-wide, the priority for the PIK Data Bank focused on the collection of long-term data series of daily meteorological parameters. At present 2,500 data series are available, of which 400 are longer than 50 years, 800 are longer than 20 years and 1300 are longer than 15 years. The main meteorological parameters of these series are air temperature, precipitation, relative humidity, cloudiness, sunshine duration, air pressure, wind velocity and vapour pressure. In addition to this, a number of data sets have been collected for special research tasks. For instance, grid data sets have been constructed as input for different models (regional climate models, impact models etc.). Also a couple data sets were created containing monthly values of different meteorological parameters for different time periods. These sets are used for the description of climate regions and for climate model validation.

The service part of the data bank system gives information about available data sets and makes it possible to select the meteorological parameter, the region and the time period. Statistical investigations, such as on the calculation of frequency distributions, autocorrelation functions, cross-correlation, trends, spectra and smoothed series, can be carried out. All results can be made visible by a special graphics tool.

The PIK Data Bank System will be continuously expanded in coming years.

Climate Scenarios

To explore the impact of any climate change - regardless of its origin, be it natural or anthropogenic - on natural and social systems, climate or climate change scenarios have to be formulated. A scenario is not a forecast. Because the climate system is influenced by anthropogenic activities, e.g. emission of greenhouse gases and changes in land use, and because these activities are hardly predictable, the climate itself cannot be forecasted. Instead, estimates of possible climate developments – climate scenarios – are computed, based on various estimates of socio-economic changes and associated changes in the emission of greenhouse gases – so-called emission scenarios. Tools for the construction of climate scenarios are numerical climate models, statistical models, and combinations of both. In the Climate Research Department, three general types of methods have been developed and used.

The first method is based on climate models only. Global climate models provide reliable information at rather coarse spatial scales, say at the scale of conti-

nents. To achieve a scenario for smaller regions, say a state or a river drainage basin, one has to transform this information to the scale in question. The method of so-called dynamic downstage makes use of a regional climate model which is embedded into the global model and which is run at a much higher spatial and temporal resolution than the global model. It is possible to adapt a regional model to selected regions of the world and to validate the adapted model as well as regional climate simulations.
The second method, the so-called expanded downscaling, is based on climate model results - either global or regional climate models. They are transformed to smaller scales with statistical methods, thereby providing climate scenarios at scales at which the numerical model is unreliable.
The third method is a coupled statistical model. It combines results of climate models and observations. In this method, observed long-term time series of meteorological data are prepared by statistical methods in such a way, that they reflect changes computed by climate models.

Climate System Modelling

The study of climate change not only involves the analysis of recent climates and estimates of possible future climates of the next decades and centuries, but it also addresses the fragile balance among various components of the climate system such as the atmosphere, the hydrosphere (mainly ocean and rivers), the cryosphere (mainly inland ice, permafrost, and snow), the terrestrial and marine biosphere, and the lithosphere (part of the Earth's upper mantle), which particularly includes the pedosphere (mainly the soils).
In the Climate Research Department, a climate system model of intermediate complexity, called CLIMBER (for CLIMate and BiospheRE), has been developed. In contrast to comprehensive climate models, which are currently operated at other institutes like the Max-Planck-Institute for Meteorology in Hamburg or the NCAR (National Center of Atmospheric Research) in the USA, CLIMBER is not meant to describe in detail and with the highest possible spatial and temporal resolution some components of the climate system. This requires vast computer power and data storage (a 100-year simulation would take approximately half a year on a super-computer.) Instead, attention is focused on the interaction among all components of the climate system. Therefore, CLIMBER has been developed to provide a rather coarse-scale, but very efficient description of the climate system. It is at least 1000 times faster than the comprehensive models and, therefore, suitable for climate system analysis. Moreover, CLIMBER will become a component of the Potsdam Earth System Model.
Using CLIMBER questions concerning the role of the vegetation in the climate system as well as the strong climate variability of the recent geological past will be addressed. Examples are the variations in the North Atlantic ocean circulation, the warm water radiator of Europe and most of the Northern Hemisphere, and subsequent drastic temperature changes between glacial and interglacial conditions which, if they happened today, would be a threat to human society.

Global Change & Natural Systems

Head: Wolfgang Cramer
Deputy Head: Petra Lasch

Staff and Guests

From left to right, back row:
Andreas Güntner, Thomas Kartschall, Martin Schappeit, Sergey Venevski.

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Markus Erhard, Daniel Katzenmaier, Kirsten Thonicke, Wolfgang Cramer, Petra Lasch, Alfred Becker, Jan Gräfe, Werner Lahmer, Axel Bronstert.

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Dr. Harald Bugmann	Systems Ecology	CHIEF, POEM
Prof. Dr. Wolfgang Cramer	Geography / Ecology	POEM: ETEMA, AGREC, CHIEF
Beatrix Ebert	Mathematics	CHIEF
Markus Erhard	Geoecology	RAGTIME
Jan Gräfe	Agricultural Sciences	AGREC: FACE
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Majana Heidenreich	Hydrology	
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Dr. Werner Lahmer	Hydrology	RAGTIME
Petra Lasch	Ecosystem Modelling	CHIEF
Dr. Marcus Lindner	Forest Sciences	CHIEF
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Dina Plehn	Information Technology	RAGTIME
Dr. Matthias Plöchl	Chemistry	PLAI
Werner Poschenrieder	Biology	AGREC: FACE
Claus Rachimow	Mathematics	RAGTIME
Jörg Schaber	Information Technology	CHIEF
Stephen Sitch	Mathematics	POEM
Dr. Felicitas Suckow	Ecosystem Modelling	CHIEF
Kirsten Thonicke	Geoecology	POEM
Bärbel Uffrecht	Information Technolgy	service for several projects
Dr. Sergey Venevski	Mathematics	POEM: ETEMA,
Dr. Frank Wechsung	Agricultural Sciences	AGREC: FACE

Philosophy

Terrestrial ecosystems are the foundation of human life on Earth, providing food, freshwater, fibres and many other services, and requiring only suitable climate and soils as input. We are assessing the role of land vegetation in the global context from two perspectives: i) what is the sensitivity of managed and unmanaged vegetation to a changing environment, and ii) which feedbacks occur between environmental change and the land surface.

The sensitivity question is straightforward and complex at the same time: the geographic pattern of land vegetation is known to be largely caused by climate, and the importance of both long-term trends and short-term events in climate and weather for vegetation is common sense. At the same time, an intricate system of interrelated mechanisms exists between the availability of sunlight, nutrients (including carbon dioxide) and an acceptable 'envelope' of humidity and warmth for plants - almost any vegetation type responds differently to certain combinations of these factors. The department carries out research to better understand these mechanisms at a range of different scales.

The problem of vegetation feedbacks to climate is another issue. The Earth system as a whole is influenced by the land biosphere through the physical feedbacks at the land surface through changes in surface roughness and albedo, both of which are strongly influenced by vegetation. Even more important, however, is the effect of vegetation on carbon fluxes, which represents a major part of the uncertainty in future climate change assessments. This field of research is addressed at the global scale.

The "Natural Systems" of the Earth cannot be seen as independent of human activities. The department accounts for this by carrying out regional sensitivity studies of managed ecosystems, such as forests and agrosystems, and by recognizing the crucial role of

global land use (change) for modelling the global carbon cycle. Land use change itself, however, is considered an external driving force which is best described by scenarios founded on studies by social scientists.
Typical research issues in the Natural Systems Department include the following:

- How does the structure of natural vegetation change in response to climate change? If adaptation occurs, then on what time scale?
- What significance does land vegetation have for global biogeochemical cycles, such as the cycles of carbon, water and nitrogen? Specifically, how does increasing carbon dioxide affect vegetation dynamics?
- What impacts do regional changes in the water balance have on natural vegetation, water availability and the land-use potential of specific catchments?
- What is the possible impact of climate change on the agricultural or forest potential at the regional scale?

Models and Scenarios as Means of Analysis of Global Change

Most Global Change processes are best analysed using simulation models. Since precise predictions of regional climate or land use are not possible, scenarios of potential environmental changes are used to assess the sensitivity of ecosystems to possible trends of the future. Simulation models are available for various aspects such as water resources, forest succession or for gas and energy exchange between plants and the surrounding atmosphere. If these models are to be integrated into either global Earth system models or regional integrated assessment models, then they usually need to be modified; in some cases completely new models must be developed. Our efforts are directed at finding adequate solutions at different hierarchical levels and for different sub-systems.
For the development of ecosystem simulation models, an important distinction is between regional and global approaches: at the regional level usually both is possible and necessary to analyse at a sub-process level, e.g. for dynamics of real landscapes, which are impossible to capture in a global model. Global models, on the other hand, are necessary if the cycles of water and carbon are supposed to be closed systems. Another boundary runs between different land-use types or economical sectors: for many studies, it is both feasible and necessary to use different models for agriculturally used land and for forests, especially if the specific issue relates to changes in productivity. A common feature is, however, that all projects in the department work with geographically explicit analyses for the regions under investigation.

The validation of modelling results remains a critical difficulty and hence a priority - direct or indirect support for simulations is derived from experimental studies (usually carried out in other laboratories, with PIK scientists as collaborators) or from observational programmes such as those carried out using satellite-based sensors.

Main Working Groups of the Department

Global Biosphere Dynamics

The task of this team is to develop a dynamic biosphere model, which can be used as a component for the POEM Earth system model. The underlying assumption is that physical and geochemical feedbacks between vegetation change and the climate system are crucial for lags and possible bifurcations of the coupled system. Beyond the development of a new comprehensive Dynamic Global Vegetation Model (DGVM), there are several sub-tasks which relate to i)analysing more detailed ecosystem dynamics, such as competition and disturbance (involving the ETEMA project funded by the European Union), ii) validate and improve biosphere model behaviour using satellite remote sensing data, iii) review current approaches of simulating biospheric fluxes (net primary productivity, NPP) to better understand the global carbon cycle.

Hydrology and Water Resources

A general cross-cutting issue for the department is the vertical and horizontal flux of water through all subcomponents of terrestrial ecosystems. Main goals are both to develop appropriate modules which are used by other working groups, and the integration of regional fluxes in watersheds. River discharge is an important quantity in its own right - here, however, it is primarily seen as an integrating and well-observed diagnostic of the modelling of all fluxes and hence all land surface processes in a region. Mainly connected to the RAGTIME and WAVES projects, the hydrology working group therefore works at several scales, with the major aim of providing adequate simulations of freshwater availability and water quality. A theme with recently increased emphasis is the estimation of flood risks.

Forests and Forestry

For the assessment of the sensitivity of both managed and unmanaged forests, the group primarily works towards a novel approach to simulate dynamics in managed and unmanaged forests. This new forest stand model, which is developed within the CHIEF project, includes more appropriate physiological for-

mulations of tree growth than previous forest models. It also simulates forest management explicitly. For regional assessments, the group currently uses existing tools such as the ForClim model which has been extended to provide suitable simulations of forests throughout a large range of the boreal and temperate zone of the world. A nationwide pilot study of the influence of climate change on German forests has been started in 1997 (in cooperation with several partners in German forest research institutes).

Agriculture

The agricultural sector is sensitive to Global Change processes both due to its direct dependence on climatic conditions (mainly water availability, in connection with carbon dioxide) and because of the high importance of global markets which are influenced both by climatic and socio-economic changes. For the assessment of changing yields in cereals, the group uses and further develops an advanced crop simulation model, which is parameterized using results from sophisticated experimental studies (e.g., the Free-Air Carbon dioxide Enrichment experiment in Maricopa, Arizona, USA). For other crops a range of models with varying complexity is used - together these are combined to provide a toolbox for assessing, in the AGREC project, the sensitivity of the entire agricultural sector to Global Change.

International Cooperation

The department is strongly involved in the IGBP (International Geosphere-Biosphere Programme), through its core projects BAHC (Biospheric Aspects of the Hydrological Cycle) and GCTE (Global Change and Terrestrial Ecosystems), where a range of direct scientific contributions are made. A. Becker is vice chair and one theme leader of BAHC, W. Cramer is an executive committee member of GCTE and H. Bugmann is a task leader in GCTE. W. Cramer is also a member of the IGBP task force GAIM (Global Analysis, Interpretation and Modeling). The department is closely allied with the BAHC core project office. Several scientists have contributed as lead authors, contributors and reviewers to the Intergovernmental Panel on Climate Change (IPCC).

Global Change & Social Systems

Acting Head: Ferenc Tóth
Deputy Head: Marian Leimbach

Staff and Guests

From left to right, back row:
Carsten Helm, Eva Tóthne-Hizsnyik,
Fritz Reusswig, Ferenc Tóth.

Front row:
Detlef Sprinz, Marian Leimbach

Name	*Discipline*	*Project Contributions*
Gerd Bruschek	Geography	AGREC
Carsten Helm	Economics and Political Science	ICLIPS, IGR
Dr. Marian Leimbach	Economics	ICLIPS, RESOURCE
Prof. Dr. Volker Linneweber	Psychology	RESOURCE
Dr. Fritz Reusswig	Sociology	QUESTIONS, RESOURCE
Detlef Sprinz, Ph.D.	Political Science	RESOURCE
Prof. Dr. Ferenc Tóth	Economics and Policy Analysis	ICLIPS, EUROPA: ULYSSES, EFIEA, RICC
Eva Tóthne-Hizsnyik	Economics	ICLIPS, EUROPA: ULYSSES

The broad phenomenology of Global Change gives rise to increasing concern about the nature and consequences of long-term, large scale interactions between social systems and actors and their natural environment. The mandate of the Global Change & Social Systems Department is to study both directions of these human-environment interactions. We seek to improve our understanding of the socio-economic driving forces that trigger global environmental change and, simultaneously, we endeavour to provide better assessments of the impacts of Global Environmental Change on human societies. The ultimate goal is to integrate these studies into a synoptic framework shedding light on the complex dynamics of human-

nature interactions. These insights might furthermore improve social and political efforts towards a better Earth system management.
The Department Global Change & Social Systems studies the social dimensions of Global Change in the following research fields:

Integrated Assessment and Macro-economic Modelling
An integrated assessment of climate change is a main focus of the department's activities. The aim is to integrate the variety of disciplinary models within a broader cost-benefit framework. This should allow potential damages caused by climate change to be evaluated, on the one hand, and costs of measures to mitigate climate change, on the other hand. Effective and efficient strategies to prevent and combat the additional greenhouse effect (e.g. climate policy on an international level) depend - among other things - upon consistent best-benefit frameworks.
The design of socio-economic scenarios as well as the determination of intertemporal optimized economic development paths within the Integrated Assessment framework should reflect the macro-economic system as realistically as possible. Therefore, some deficits of mathematical-economic modelling have to be overcome. Here, we worked theoretically and empirically to extend aggregated traditional growth models for the integration of components of endogenous technological progress as well as some preparatory work in order to model non-equilibrium states. We are confronted with non-equilibrium states when considering phenomena of Global Change, as there are for instance economies in transition, unemployment, migration, scarcity of land and resources.
Additional conceptual activity concentrates on combining traditional cost-benefit analysis with multi criteria decision making techniques including extended welfare indicators.

International Environmental Institutions
In this research field the focus is on analysing environmental treaties, e.g. climate protocols and the process of negotiation, as well as the effectiveness of different climate policy instruments, e.g. tradeable emission permits and carbon dioxide taxes, under consideration of diverging interests of different actors. Here, methods of non-cooperative as well as cooperative game theory are applied. Closely related to the activities above is also the investigation of the international distribution of emission rights based on different equity principles. A further research focus is the effect of scientific uncertainty - a central characteristic of international environmental problems - on the international negotiation process.
In combining methodological and substantive research, another activity includes the development of a measurement instrument for the effect which international environmental treaty regimes have on countries of lessening transboundary pollution problems. We also investigate the effect of particular regime functions, such as lessening scientific uncertainty and providing systematic monitoring. By comparing the actual performance with a counterfactual for the non-treaty regime case and a political-economic social optimum, a standardized evaluation system for the performance of international environmental treaty systems was developed.
This methodology has been applied to the regulating efforts to curb acidification across Europe by way of international environmental agreements. Our research demonstrates that two agreements reached within the United Nations Economic Commission for Europe had some positive effects, but fall short of the optimal outcome.

Regional Environmental Management and Environmental Security
Research activities in this field focus mainly on water resources. The aim is to develop tools of water management suited to overcome adaptively the regional scarcity of fresh water.
A variety of efforts were undertaken to shed light more systematically on the relationship between environmental degradation and the onset of violent conflict. Water-created violent conflict is the main focus. This comprises work to derive a set of instruments to reduce the degradation of water resources and to develop a methodology to derive environmental thresholds for the future at which the outbreak of violent conflicts over water resources becomes highly probable.
A comprehensive research design is under development which specifies the passing of environmental thresholds as the sufficient condition for the outbreak of violent conflict. Furthermore the systematic specification of environment policy instruments and interventions by way of conflict management allow the simultaneous specification of the conditions for the outbreak of environmentally induced violent conflicts.

Environmental Psychology and Environmental Sociology
Within the framework of the Global Change issue the question of how social actors perceive and represent environmental risks and potential harmful situations is important. The leading question in this type of

research is: How and why are human actors and systems worldwide using their environmental resources, i.e. sources and sinks, in a way that leads to their depletion, overuse, overcharge or whatsoever. Sociology and psychology are two disciplines competent to deal with this issue. The latter focuses upon individual actors, their internal and external motives and constraints. The subject of the former is social systems as the behavioural context of individuals, their mechanisms and their effects. Recently both disciplines have developed environmental subdisciplines, inquiring into the actual ecological conditions and impacts of human attitudes and into possible changes in the future. One of the tasks is to investigate individual and social conditions for a sustainable development.
The Social Systems Department at PIK is using these disciplinary methods widely. One example for PIK activities in this field concerns the environmental aspects of modern lifestyles. Consumption levels and patterns of modern industrial societies are responsible for about 15 - 40 % of total energy and resource use and related pollution in these countries. Changing consumption patterns are therefore an important global sustainability issue. The widespread claims of environmentalists and some sympathetic researchers that we should change “our” lifestyles, nevertheless miss important aspects of social structure and dynamics of modern societies.
Empirical evidence, relying upon methods of sociology and market research, leads to a somehow more sophisticated picture of modern societies. There is no such thing as „our“ or „the“ modern lifestyle. The more developed a country, the more pluralistic its social structure, including values, attitudes, and practice.
This plurality holds true even regarding the everyday environmental performance of different lifestyles; one can find factor-five differences of carbon dioxide emissions within countries, not only between them. Strategies to change modern consumption patterns therefore have to be lifestyle-specific, not uniform. They have to take into account the way lifestyle groups actually include environmental issues (partially) into their consumption patterns, and their changes currently underway.

Syndrome Dynamics of Global Change
The main focus in this research field is the social sciences-based analysis of anthropogenic cause and effect symptoms of Global Change. This follows the Syndromes-approach as it is performed by the QUESTIONS core project, in which recently the Favela-, Green Revolution - and Asian Tigers syndromes have been receiving closer attention. This analysis comprises qualitative description and modelling by means of qualitative reasoning (e.g. fuzzy logic, expert knowledge), case studies and data analysis.
A second focus is the analysis of societal aspects of the global water crisis. As a result of this activity, the so called “criticality index” was developed, relating water supply, water demand by sectors and water-related curation potential on a global scale today and for 2025.

Data & Computation

Head: Rupert Klein
Deputy Head: Karsten Kramer

Staff and Guests

Left to right, back row: Dietmar Gibietz-Rheinbay, Markus Wrobel, Helmut Miethke, Werner von Bloh, Karsten Kramer, Martin Kücken, Michael Flechsig.

Front row: Frank Toussaint, Rupert Klein.

Name	*Discipline*	*Project Contributions*
Michael Flechsig	Mathematics	RAGTIME, SDM, CHIEF, EUROPA: WISE
Dietmar Gibietz-Rheinbay	Geography and System Administration	
Achim Glauer	Electric Engineering	
Henrik Kinnemann	Computer Science	
Professor Dr. Rupert Klein	Applied Mathematics & Computer Science	
Karsten Kramer	Electronic Technology and System Administration	
Martin Kücken	Chemistry	WAVES
Helmut Miethke	Automation Engineering	
Dr. Frank Toussaint	Physics	SDM
Werner von Bloh	Physics	POEM
Markus Wrobel	Computer & Information Sciences	SDM

The Data & Computation Concept

Climate impact research studies rely heavily on modelling and scientific computing, as the global scales considered are too large to allow a sufficient range of reliable laboratory experiments. The process of scientific computing includes the mathematical modelling of a given system, the translation of the abstract mathematical model into a digital analogue, the implementation on modern computing facilities, their operation and the intelligent evaluation and interpretation of the computed results. The Data & Computation Department supports the ambitious interdisciplinary goals of PIK by (i) maintaining the hardware and software pool of a high-level computing environment, by (ii) contributing its mathematical and computer science expertise to a range of applied research projects and by (iii) pursuing its own PIK-related research in the field of applied mathematics and computer science.

The Data & Computation department provides a general scientific computing service to the PIK research team. This includes mathematical support at the model development stage, computer science support at the stage of model implementation, runtime support in terms of hard and software and, again, computer science support during the phase of evaluation and interpretation of results. An additional major challenge for Data & Computation is to map the diverse, interdisciplinary structure of the Institute with an equivalent modelling environment on the software level. PIK will be able to match its ambitious goal of modelling environmental and socio-economic systems on a global scale only if such a common modelling environment is at hand. This should allow one to embed all of the specialized expertise found at PIK in a modular fashion and it will significantly streamline the communication between the disciplines.

Interface to the Applied Sciences

Contributions to the Core Projects

In setting up a computer simulation of a complex environmental system, it is necessary to identify a model system that is sufficiently elaborate to include all the major effects, while being sufficiently simple to allow a mathematical / computational analysis within a reasonable time span. A successful model formulation involves both a deep insight into the nature of the system and a solid mathematical underpinning. A similar combination of skills is needed in implementing a related computer code as well as in evaluating the computational data produced. Thus, there is a wide range of opportunities for mathematics and computer science support in all the various disciplines encountered at PIK.

Particular contributions to PIK core projects are:

AGREC and POEM: The sensitivity of natural and agricultural systems to climate change in Central Europe was studied. GIS technology helped to determine parameters for biome and agricultural production models and for result preparation and output.

CHIEF: Forest succession and growth models were applied to regional forest dynamics under potential climate changes using Data & Computation's parallel simulation environment (SPRINT-S). This environment enables flexible simulation experiments and regional studies with the model class used on the IBM SP-2 parallel computer. Regional studies for both the State of Brandenburg and the Dübener Heide used GIS data for model parameterization and initial value supply.

POEM: A new parallel implementation of a two-dimensional geophysiological model now uses Data & Computation's GeoPar library. The parallelization of the CLIMBER model is in preparation. A C++ object-oriented version of the same model will be developed in addition to compare efficiency vs. usability of the different implementations.

RAGTIME: Spatial and temporal data for the Elbe drainage basin have been evaluated. Typical geographical data are stored in GIS format. A temporal data model has been developed using the ORACLE^{TM} database system. Metadata from 1390 stations were stored together with about 10 million items of daily data.

WAVES: The implementation and parallelization of a regional climate model (REMO 0.1) onto the IBM SP-2 computer at PIK was finished in August 1997. In addition a statistical (cluster-analysis) algorithm was redesigned and tuned significantly.

Computing Infrastructure

A high-performance state-of-the-art information-technology (IT) infrastructure is one of the foundations of the scientific work of our Institute. Due to its importance, the infrastructure has to change perpetually, moving in an area of conflict which is spread by the demand for continuous availability, technical innovation, technical limitations and - last but not least - budget constraints.

Currently the IT-infrastructure of PIK includes a 77-processor IBM RS 6000 SP scalable parallel supercomputer, nearly 150 high-end workstations and personal computers; an appropriate storage hierarchy comprised of about 800 Gigabyte of disk storage backed by 10 Terabyte of tape storage and a computer network which connects all resources both internally and with the Internet.

Fig. 1: IBM RS/6000 SP

Fig. 2: IBM 3494 Tape Library

Fig. 3: IBM RS/6000 SP - Detail

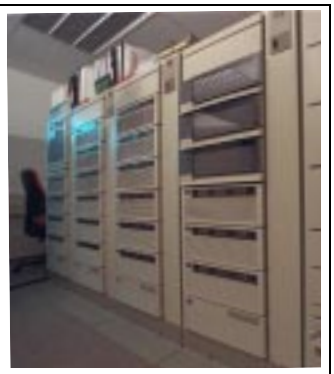

Fig. 4: Mass Storage System

During the years under review the group most notably made good progress in the following areas:

- Overall Systems Availability
  Compute server, disk- and tape storage as well as Internet connectivity availability was above 99% calculated on a basis of 24 hours operation per day, 365 days p.a.
- Internet Connectivity
  In a joint effort the Potsdam scientific community established a metropolitan area network in 1997 which strengthened the cooperation among all institutions concerned and provides a 4 Mbps B-WIN (Breitband Wissenschaftsnetz) internet connection.
- Disaster Recovery
  Today most – if not all scientific results, i.e. algorithms, data, figures, and publications are stored on digital media. One can only imagine the amount of work and knowledge gathered year by year in our Institute which could be lost, caused by one single event. Therefore our everyday backup and recovery scheme has been extended by a disaster recovery plan.
- Load Balancing and System Tuning
  A job-queuing system was installed and maintained on our main computer facility to ensure a fair and efficient usage of the system. Moreover – as the system utilization increased – we have made considerable efforts to optimize various aspects of the system, most notably the network and storage hierarchy.
- Desktop- and Web-Publishing
  Although there is a plethora of tools available in the desktop- and HTML-publishing (Hypertext Markup Language) arena, a serious effort was necessary to establish a working environment throughout the Institute which implements a common framework for PIK publications with support for both hardcopy and Internet publications, see http://www.pik-potsdam.de.

Scientific Data Management (SDM)

Several German geoscience institutes have joined to collaborate on development, implementation, and linkage of the Meta Data Bases (MDBs) at their sites to cast their data into a common structure and to make it mutually accessible. Besides PIK, the Deutsche Klimarechenzentrum (DKRZ, Hamburg) and the Alfred-Wegener-Institut für Polar- und Meeresforschung (AWI, Bremerhaven) are involved in this project, in the first phase. The Forschungszentrum Karlsruhe (FZK) has also joined in.

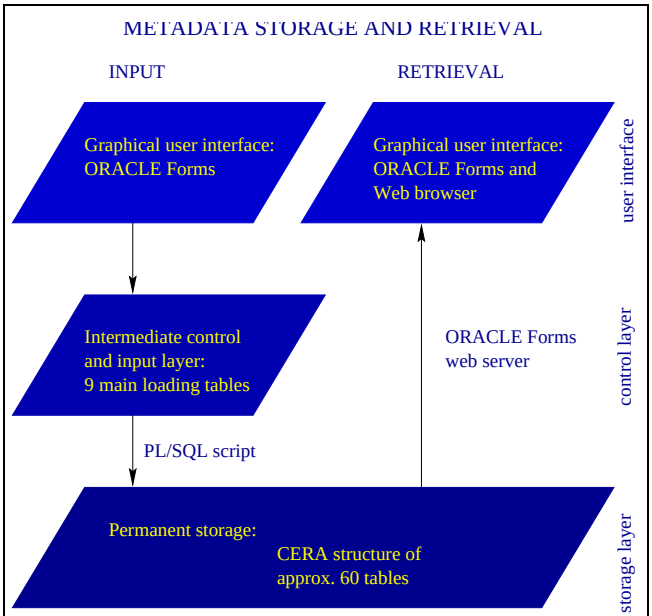

Fig. 5: The SDM storage concept at PIK consists of user layer and storage layer. For input check a loading control layer of data base tables is introduced.

The main aims of the common MDB are:

- to make accessible all geographical and other Global Change-relevant data held by any department to PIK employees and collaborators, by archiving the

place where and the form in which the data are stored,
- to give online access to the corresponding data of the other collaborating institutes, together with quality information,
- to enable researchers to survey all available data and to assess their quality and reliability,
- to coordinate the ordering and storage of data to avoid redundancies,
- to enable meta data interchange with national and international institutions by means of a distributed MDB.

In 1996 and 1997 the common data structure of the MDB has been developed and released as CERA 2.3 (Climate and Environmental Data Retrieval and Archiving System). The system has been implemented at the four sites mentioned, and also at the Fraunhofer-Institut für Atmosphärische Umweltforschung (IFU). The Institut für Meereskunde at Hamburg University (IfM) and Umweltforschungszentrum Leipzig-Halle (UFZ) are interested in taking over the developed structures and user interfaces.

The CERA database concept is highly flexible, as the necessary relational schemes are separated from those only used by few institutes. The latter are contained in modules that can be attached to the core CERA table group, if they are applicable for the respective institute.

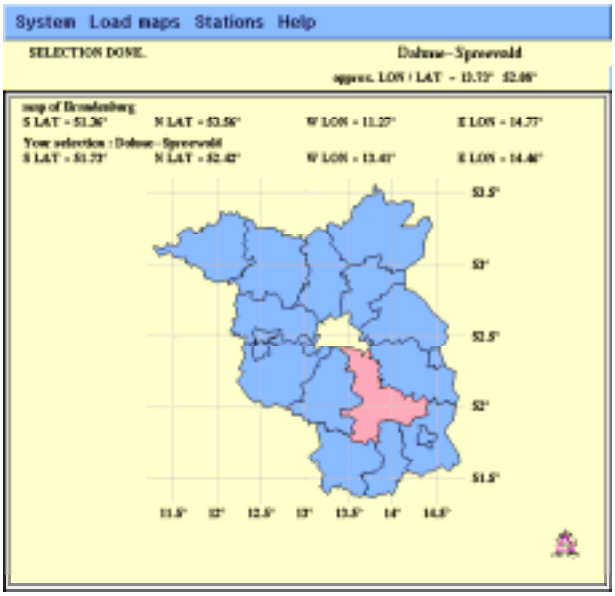

Fig. 6: The graphical user interface (GUI) developed at PIK allows comfortable selection of data from different geographical regions.

The intranet graphical user interface (GUI) developed at PIK enables comfortable hierarchical queries of different geographical coverages and keywords by any web browser. The self-adapting HTML can easily be transferred to views of the various relational data bases in use at the Institute.

Scientific Cooperation Unit

Head: Manfred Stock
BAHC Office: Michael Fosberg, IGBP Office: Sabine Lütkemeier
Scientific and Public Relations Manager: Petra Schellnhuber

From left to right: Gabriele Dress, Arne Spekat, Wilhelmine Seelig, Holger Hoff, Sabine Lütkemeier

Name	*Discipline/Function*	*Contributions to*
Dr. Alfred Becker	Hydrology	IGBP
Prof. Dr. Martin Claussen	Meteorology	BAHC
Prof. Dr. Wolfgang Cramer	Geography / Ecology	GCTE, GAIM
Gabriele Dress	Secretary	IGBP
Dr. Michael Fosberg	Forestry	BAHC
Holger Hoff	Geoecology	BAHC
Dr. Sabine Lütkemeier	Hydrogeology	IGBP
Petra Schellnhuber	Administration	PIK
Annette Schulte-Döinghaus	Secretary	BAHC
Wilhelmine Seelig	Administration	BAHC
Arne Spekat	Meteorology	IGBP
Dr. Manfred Stock	Physics	PIK, IGBP, BAHC

An essential part of PIK's research strategy is its close cooperation with partner institutions within Germany and abroad. This is organized in line with interdisciplinary projects and programmes at national and international levels using the following functions:

- Scientific and Public Relations
- Course of Lectures on Global Change
- Support to the International Geosphere-Biosphere Programme
- Support to the project Biospheric Aspects of the Hydrological Cycle

Petra Schellnhuber

Scientific and Public Relations

Coordinating Function: Scientific events are arranged and coordinated. This includes organizing conferences and workshops, assisting the reception of guest scientists and assisting these and other visitors to the Institute.

Public Relations and Contacts: Communication with the media is coordinated, interaction is maintained with associates of the Institute, and the publication of periodicals is managed.

Information Exchange between the Scientific and Administrative Departments: The scientific work of the Institute is translated on the one hand into administrative purposes, and on the other hand is conveyed as general information to the public. Contacts with collaborators and partners are managed in consultation with the heads of the department and according to the annual research plan of the Institute.

Course of Lectures on Global Change

All lecture activities at PIK including IGBP activities and workshops are summarized under the heading Course of Lectures on Global Change. This includes scientific staff of the PIK departments and international guests. A regular activity of this Lecture Course on Global Change is the PIK doctorate seminar.

The International Geosphere-Biosphere Programme – IGBP

To support the International Geosphere-Biosphere Programme (IGBP), three offices are located at PIK: the international office of the core project Biospheric Aspects of the Hydrological Cycle (BAHC), one of the four international focus offices of the core project Global Change and Terrestrial Ecosystems (GCTE, focus 2 on Ecosystem Structure), and the German National IGBP Secretariat. The three offices support, coordinate, and foster research and organize conferences and workshops.

Established in 1989, the International Geosphere-Biosphere Programme is aimed at describing and understanding the interactive physical, chemical and biological processes that regulate the total Earth system, the unique environment that it provides for life, the changes that are occurring in this system, and the manner in which they are influenced by human actions. Priority is placed on those areas in each of the fields involved which deal with key interactions and significant changes on time scales of decades to centuries which most affect the biosphere. These are most susceptible to human perturbations and will most likely lead to a practical, predictive capability.

IGBP has formulated six fundamental questions related to Global Change:

1) How is the chemistry of the global atmosphere regulated and what is the role of biological processes in producing and consuming trace gases?
2) How will global changes affect terrestrial ecosystems?
3) How does vegetation interact with physical processes of the hydrological cycle?
4) How will changes in land use, sea level and climate alter coastal ecosystems, and what are the wider consequences?
5) How do ocean biogeochemical processes influence and respond to climate change?
6) What significant climatic and environmental changes have occurred in the past and what were their causes?

Several international core projects of IGBP were established to answer these fundamental questions. PIK scientists are involved in the research and organization of some of these core projects. Wolfgang Cramer is a Focus Leader in the Scientific Steering Committee of the core project Global Change and Terrestrial Ecosystems (GCTE) and also a member of the

task force on Global Analysis, Interpretation and Modelling (GAIM).

Mission of the National IGBP Secretariat

The mission of the National IGBP Secretariat is to support the work of the National IGBP Committee and especially to support the work of its chair in accordance with the overall purpose of the programme. This includes, on the one hand, informing the national science community and national funding agencies about international activities and, on the other hand, informing the international community about German IGBP activities. The particular tasks of the Secretariat are:

- to coordinate the contribution of the Federal Republic of Germany to the International Geosphere-Biosphere Programme;
- to integrate as far as possible German concepts as well as already funded German projects into the international programme and
- to promote intensively the development of the German contribution to IGBP.

On 1 January 1996 the National IGBP Secretariat moved from the Institute of Meteorology at the Free University of Berlin, where it had been based for six years, to the Potsdam Institute of Climate Impact Research.

Activities of the National IGBP Secretariat in 1996 and 1997

One of the major tasks of the Secretariat is the organization of national and international conferences, workshops and meetings. This not only includes the local organization but also implies contacting sponsors and other funding agencies and accounting for funds.

In the above-mentioned period the German IGBP Secretariat has organized the following international meetings:

- the First IGBP Congress in Bad Münstereifel, 18-22 April 1996, jointly with the IGBP Secretariat in Stockholm.
- the Global Change and Terrestrial Ecosystems (GCTE) Synthesis Workshop in Berlin/Potsdam, 14-20 September 1996, jointly with the GCTE Core Project Office in Canberra, Australia.
- the Pilot Workshop Comparison of Forest Patch Models, 15-18 December 1996 at PIK-Potsdam and jointly organized with PIK.
- the Joint Meeting of International Group of Funding Agencies (IGFA), World Climate Research Programme (WCRP), IGBP and International Human Dimensions Programme (IHDP), 18-20 August 1997 in Potsdam, jointly organized with Helmut Kühr of the German Aerospace Research Centre Establishment Project Management for the BMBF (DLR-PT).
- An International Workshop on Effects of Global Change on Ecological Complexity 20-22 October 1997 at Schloss Rauischholzhausen, jointly organized with the University of Gießen.

National meetings on the following IGBP core projects were organized: Joint Global Ocean Flux Study (JGOFS), Global Ocean Ecosystem Dynamics (GLOBEC), Land Ocean Interactions in the Coastal Zone (LOICZ), International Global Atmospheric Chemistry Project (IGAC), Stratospheric Processes and their Role in Climate (SPARC), Biospheric Aspects of the Hydrological Cycle (BAHC).

- Extended Meeting of National IGBP Coordinators, 13 August 1996 in Bonn at the Ministry of Research
- Ad hoc IGBP Meeting, 28 April 1997 in Berlin

Scientific developments and contacts with scientists are also maintained by attending national and international conferences on Global Change by the scientific staff of the Secretariat.

Future Agenda

In future the Secretariat will continue to work closely with the German IGBP Committee, i.e. the National Committee on Global Change Research, established by the Deutsche Forschungsgemeinschaft in 1996.

Scientific Publishing IGBP

The IGBP-Informationsbrief is published regularly four times a year (1 March, 1 June, 1 September and 1 December) and can be obtained free of charge from the German IGBP Secretariat. (The latest issue is Number 29 as of 1 December 1997.)

- Bericht über den 4. JGOFS-Workshop 20./21. November 1995 in Bremen; Ed.: Giese, Martina und G. Wefer, Berichte Fachbereich Geowissenschaften, Universität Bremen 1996, Nr. 70
- Bericht über den 5. JGOFS-Workshop 27./28. November 1996 in Bremen; Eds.: Giese, Martina und G. Wefer, Berichte Fachbereich Geowissenschaften, Universität Bremen 1997, Nr. 89
- Bericht über den 6. JGOFS-Workshop 4./5. Dezember 1997 in Bremen; Ed.: Pätzold, Martina und G. Wefer, Berichte Fachbereich Geowissenschaften, Universität Bremen 1998, Nr. 109
- JGOFS-AG “Daten und Modelle” Sammlung JGOFS-relevanter Modelle in Deutschland; Eds. S. Determann, K. Herterich, Berichte Fachbereich Geowissenschaften, Universität Bremen 1997, Nr. 93
- Bericht über den zweiten deutschen LOICZ-Workshop, 16.-18. November 1995, Institut für Ostseeforschung; Ed. IGBP-Sekretariat Sabine Lütkemeier, PIK-Potsdam 1996

- Bericht über das Arbeitstreffen “Spurengase”, 13.-14. November 1996, GKSS-Forschungszentrum Geesthacht; Ed. IGBP-Sekretariat Sabine Lütkemeier, PIK-Potsdam 1997
- Report on the German LOICZ Focus 4 Workshop “The changing Coastal Regions: Past, Current and Future Human Activities - Assessment of Research Needs”, 17-18 June 1997, GKSS-Forschungszentrum Geesthacht; Ed. IGBP-Sekretariat Sabine Lütkemeier, PIK-Potsdam 1997

Biospheric Aspects of the Hydrological Cycle – BAHC

At present the IGBP is structured into 11 programme elements addressing the six fundamental questions, mentioned on page 93, and in addition, data management, capacity building and synthesis, and integration. Each of these programme elements is served by a small permanent staff to conduct the day-to-day affairs of the programme under the direction of an International Scientific Steering Committee. Alfred Becker and Martin Claussen are in the Scientific Steering Committee of the BAHC project. The International Project Office (IPO) of the Biospheric Aspects of the Hydrological Cycle (BAHC) is one of these offices. PIK is the host agency for the BAHC IPO.

The primary activities of the IPO are to facilitate the international science programme by organizing and conducting scientific meetings, to provide a clearing house for all BAHC activities and to carry out research support for the various science activities. As an example of this support the BAHC IPO coordinates the European contributions to the data and information system of LBA (Large Scale Biosphere - Atmosphere Project in Amazonia) and provides a mirror site for the LBA home page. The BAHC IPO carries out independent studies on policy makers’ needs for scientific information, facilitates research planning for major studies and provides help for synthesis and integration of BAHC science. Examples of these independent studies are the competitively funded study on defining policy makers needs’ for information on freshwater resources, the development of a synthesis and integration effort to document the first six years of BAHC accomplishments, and the development of a competitively funded proposal to develop a research study on freshwater resources in sub-Saharan Africa.

The BAHC IPO also provides support to the IGBP Global Change and Terrestrial Ecosystems Focus 2 leader (member of the PIK staff).

The BAHC IPO is becoming integrated into the PIK research agenda through supporting the RESOURCE project at PIK on Global Change and water resources and in a modelling effort to introduce disturbance into dynamic global vegetation models.

Activities of the BAHC IPO from 1995 to 1997

Among the tasks of the BAHC IPO, organizing of conferences and workshops plays a major role. In the above-mentioned period the following meetings amongst others were prepared, organized and supported financially by the BAHC IPO.

- First BAHC Science Conference and BAHC SSC Meeting in conjunction with the XX. General Assembly of the European Geophysical Society (EGS), 3-8 April 1995 in Hamburg
- UNESCO/BAHC/GCTE Workshop “Predicting Global Change Impacts on Mountain Hydrology and Ecology” 30 March - 2 April 1996 in Kathmandu, Nepal
- Chinese BAHC Science Conference, 10-12 November 1996 in Beijing, China
- Workshop “BAHC Research in Germany” at PIK, 18 April 1997 in Potsdam
- BAHC SSC Meeting, 29 May - 1 June 1997 in Polson, USA
- BAHC-LUCC Joint International Symposium on “Interactions between the Hydrological Cycle and Land Use and Land Cover”, 3-7 June 1997 in Kyoto, Japan

Scientific Publishing of BAHC

The following publications are either edited or authored by members of the BAHC IPO or appeared in BAHC-sponsored special issues of journals.

- BAHC Research in Germany, 18 April 1996, Workshop Report, BAHC IPO, 1997
- Strategies for Monitoring and Modelling CO_2 and Water Vapor Fluxes over Terrestrial Ecosystems; D. Baldocci, R. Valentini, S. Running et. al.; Thematic Issue of Global Change Biology, Nr. 2, 3, 1996
- HAPEX Sahel; Ed.: J.P. Goutorbe, A.J. Dolman, J.H.C. Gash et. al.; Special Issue of Journal of Hydrology, 188/189, 1997
- Aggregate Description of Land-Atmosphere Interactions; Ed.: J.D. Michaud, W.J. Shuttleworth; Special Issue of Journal of Hydrology, 190, 3/4, 1997
- BAHC-an update; Michael Fosberg; The Globe, 40, 1997

Zusammenfassung

Das Potsdam-Institut für Klimafolgenforschung

Einführung

1992, im Jahr der Rio-Konferenz, hatten sich die wissenschaftlichen Hinweise auf einen bevorstehenden, anthropogenen Klimawandel stark verdichtet. Gleichzeitig stellte sich heraus, daß das Wissen über die Konsequenzen rascher Klimaveränderungen, seien sie nun vom Menschen verursacht oder auf natürliche Weise hervorgerufen, ungenügend war. Wie würden sich solche Veränderungen auf die Natur, die Wirtschaft, die menschlichen Lebensgewohnheiten auswirken? Welche wissenschaftlichen Vorgehensweisen und welche natur- und sozialwissenschaftlichen Disziplinen und Methoden wären für eine seriöse Folgenabschätzung notwendig und hinreichend? Wie wären die verschiedenen Disziplinen zur Schaffung einer homogenen Forschungsstrategie zu vereinen, ohne dabei ein "babylonisches" Durcheinander zu erzeugen?
Die Gründung des Potsdam-Instituts für Klimafolgenforschung, empfohlen durch den Wissenschaftsrat, muß vor dem Hintergrund dieser Fragen gesehen werden. Das PIK ist von seiner Idee und Struktur her ein Institut ohne Prototyp oder Vorgänger, an dem ein völlig neuer Ansatz entwickelt wird, der für die Untersuchung all dieser Fragestellungen geeignet ist.

Der konzeptuelle Hintergrund des PIK-Ansatzes
Das PIK ist bestrebt, die empirischen Resultate vieler Fachrichtungen und Einrichtungen aufzugreifen, aufzuarbeiten, zusammenzufassen und ihre Einsatzmöglichkeiten zu bewerten. Auf der so entstehenden vielschichtigen und vernetzten Datenbasis kann dann jene Gesamtheit von meteorologischen, hydrologischen, ökologischen, sozioökonomischen und transdisziplinären Modellen errichtet werden, die das wissenschaftliche Stammkapital des PIK bildet und rechnergestützt die Simulation vergangener, gegenwärtiger und zukünftiger Umweltwirklichkeiten ermöglicht.
Wer nun dem System Erde, dem Globalen Wandel, den Folgen der anthropogenen Klimaänderungen etc. das Netz der Theorie überwerfen will, steht vor einer außerordentlich schwierigen Aufgabe: Aufgrund der Vielzahl von Faktoren, die relevant für die jeweiligen Prozesse sind, sowie der Heterogenität der beteiligten Komponenten, ist es denkbar schwierig, die einzelnen Wechselwirkungen zu erfassen und sie zu einem das jeweilige System erschöpfend beschreibenden Gesamtbild zu verbinden. Diese Aufgabe wird allerdings durch eine Beobachtung handhabbar, die man an allen hinreichend komplexen dynamischen Systemen machen kann. Sie soll hier mitsamt ihren forschungsstrategischen Konsequenzen kurz erläutert werden.
Wenn wir reale dynamische Systeme genuiner Komplexität betrachten, stellen wir fest, daß sich diese Komplexität zumeist in einer Hierarchie von charakteristischen Mustern, Typen oder Entitäten organisiert. Jede Stufe dieser Hierarchie wird ihrerseits durch eine Oligarchie von überschaubar vielen Elementen gebildet. Das trifft auf den in Galaxienhaufen, Milchstraßen und Sonnensystemen gegliederten Kosmos ebenso zu wie auf die terrestrische Biosphäre mit ihrem taxonomischen Artengefüge. Daß diese Ausführungen mehr sind als blutleeres, erkenntnistheoretisches Räsonieren, zeigt der Blick auf die robuste und sich laufend erneuernde Organisation einer Bevölkerung im Raum. Obwohl es prinzipiell vorstellbar ist, daß sich in einer beliebigen Landschaft eine gleichmäßige Besiedlung durch immer gleich große Gruppen, seien es nun Familien, Dorfgemeinschaften oder noch größere Konglomerate, oder umgekehrt eine Zusammenballung aller Individuen auf engstem Raum herausbildet, wird man in der Realität fast immer eine hierarchische Gesamtheit aus den Elementen "Dorf", "Stadt", "Region" und "Staat" finden. Diese Beobachtung von Strukturiertheit der Komplexität realer Systeme zusammen mit der im folgenden ausgeführten Einsicht ist konstitutiv für die Entwicklung von *Modellen intermediärer Komplexität,* welche mittlerweile zu den wichtigsten Werkzeugen des PIK geworden sind.
Zunächst einmal wird jede wissenschaftliche Theorie die dynamischen Muster der jeweils zu analysierenden Realität zur Kenntnis nehmen und versuchen, die dadurch erkannte "Granularität" des Systems auszunutzen. Je nach Größe des Systems ist dabei eine von zwei möglichen Vorgehensweisen erfolgversprechend: Bei den extrem kleinen (Elementarteilchen) und großen (Raum-Zeit-Architektur) Determinanten des Kosmos versucht man, die entsprechende Musterbildung quantitativ aus "ersten Prinzipien" (wie den Grundgesetzen der Quantenmechanik oder der Molekularbiolo-

gie) zu erklären, d.h. deduktiv herzuleiten. Bei Systemen mittlerer Größe hingegen scheitert dieses Unterfangen in der Regel – eine molekulardynamische Computersimulation mit, sagen wir, 10^{30} Teilchen wird praktisch unendlich lange brauchen, bis sie das faunische Muster "Giraffe" erfunden hat, und eine individual-psychologische Rekonstruktion der Gesellschaftsdynamik des 20. Jahrhunderts dürfte nicht zwangsläufig einen "Hitler" oder "Gorbatschow" als emergenten staatsmännischen Typ hervorbringen.
Die mesoskopischen Entitäten, die gerade unsere Umweltwirklichkeit strukturieren, lassen sich dagegen am besten auf "traditionellem" Wege erklären, d.h. indem ihre Existenz vorausgesetzt, ihr effektives Verhalten studiert und anschließend eine Theorie entwikkelt wird, die die Beobachtungen möglichst vollkommen beschreibt. Das bedeutet aber keinesfalls, daß die wissenschaftliche Auseinandersetzung mit jenen Gegenständen lediglich phänomenologisch geführt werden kann oder soll: *Theorien mittlerer analytischer Tiefe und Reichweite*, die das Fundament für die bereits erwähnten Modelle intermediärer Komplexität bilden, versuchen die durch Inspektion aufgefundenen Muster formal zu kodieren – z.B. durch parametrisierte Differentialgleichungen oder empirisch begründete Listen von Evolutionsregeln. Über den Formalismus lassen sich dann quantitative Aussagen über Dynamik, Stabilität oder Synergie der konstitutiven Größen gewinnen.
Diese heuristische Strategie spielt für die Forschung am PIK in der Tat eine wesentliche Rolle. Sie kommt z.B. in der Art zum Ausdruck, wie die Waldsukzession unter den Triebkräften des Globalen Wandels oder die globale Wechselwirkung zwischen Vegetation und Atmosphäre mittels funktionaler Typen simuliert wird (Kernprojekte CHIEF bzw. POEM/DGVM). Sie spiegelt sich wider im Konstruktionsprinzip des Erdsystem-Modells CLIMBER, das charakteristische klimatologische Strukturen und Prozesse antizipiert, oder im hierarchischen Aufbau der Elbe-Ökohydrologie aus "Hydrotopen" unterschiedlicher Skalenebenen (RAGTIME). Sie liefert das Grundrezept bei der semi-quantitativen Zerlegung des Globalen Wandels in Syndrome (QUESTIONS) und scheint u.a. bei der Formulierung effektiver ("reduced-form") Module für die integrierte Klimaschutzbewertung (ICLIPS) auf.
Intermediäre Modelle versuchen quantitative Beschreibung und qualitative Intuition bestmöglich miteinander zu verbinden; deshalb sind sie oft die einzig adäquaten Instrumente, um komplexen Umweltsystemen zu Leibe zu rücken und brauchbare Antworten auf die wichtigsten Fragen zu erhalten. Die bisherige Erfahrung mit der Erdsystemanalyse oder der Klimawirkungsforschung hat gezeigt, daß dieser schmale intermediäre Pfad weiter beschritten werden muß. Die Art und Weise, wie das PIK diesen Weg im Spannungsfeld zwischen Grundlagenforschung und Politikberatung verfolgt, demonstriert dieser Zweijahresbericht auf vielfältige Weise.

Projekte und Abteilungen –
die Forschungsstrukturen des PIK

Das Institut gliedert sich seit der Gründung in die vier Abteilungen Klimaforschung, Globaler Wandel und natürliche Systeme, Globaler Wandel und soziale Systeme und Data & Computation und eine fünfte Abteilung Integrierte Systemanalyse, die die einzelnen Gebiete verbindet.
Es wurde aber bald offenkundig, daß das Erdsystem und die Dynamik des Globalen Wandels anhand repräsentativer, abteilungsübergreifender Schlüsselfragen untersucht werden müssen. Diese wurden anfangs in einem internen Evaluierungsprozeß unter Beteiligung des wissenschaftlichen Beirats des PIK (SAB) aus einer Reihe von Vorschlägen ausgewählt. Ergebnis dieses Prozesses waren neun Forschungskomplexe, die sogenannten Kernprojekte, die von Wissenschaftlern aus den verschiedenen Abteilungen gemeinsam bearbeitet werden. Die Forschung des PIK ist damit in Form einer Matrix aus Abteilungen und Kernprojekten organisiert, dargestellt in Bild 2 auf Seite 4. Dabei ist es Aufgabe der wissenschaftlichen Abteilungen, die Kernprojekte eng an die methodische Entwicklung in den einzelnen Disziplinen anzubinden, die Wissenschaftler zu fördern und zu unterstützen und die Qualität der Arbeit und der Ergebnisse sicherzustellen. Darüber hinaus werden die Fortschritte und Erfolge aller Kernprojekte jährlich vom SAB evaluiert, der daraufhin zur Fortsetzung, Intensivierung oder Reduktion oder sogar zur Aufgabe einzelner Kernprojekte rät.
Derzeit gibt es acht Kernprojekte am PIK, die auf globaler oder regionaler Skala entweder unter sektoralem oder integrativem Blickwinkel Fragen zum Globalen Wandel untersuchen. Die Europäischen Netzwerkaktivitäten, an denen das PIK beteiligt ist, werden derzeit unter dem Namen EUROPA zu einem neunten Kernprojekt vereint. Bild 1 auf Seite 1 gibt einen Überblick über die Forschungsthemen.

Die Wechselwirkungen zwischen dem integrierten Forschungsansatz und der interdisziplinären Struktur des PIK lassen sich an den hier vorgelegten Forschungsergebnissen nachvollziehen.

Globale Perspektive	Regionale Perspektive	Sektorale Perspektive
POEM Potsdamer Erdsystem-Modellierung	EUROPA Europäische Netzwerkaktivitäten zum Globalen Wandel	AGREC Agro-ökonomische Auswirkungen des Globalen Wandels
ICLIPS Integrierte Klimaschutzstrategien	RAGTIME Regionale integrierte Modellierung im Elbegebiet	CHIEF Europäische Wälder unter dem Einfluß des Globalen Wandels
QUESTIONS Qualitative Dynamik von Syndromen des Globalen Wandels	WAVES Wasserverfügbarkeit im Nordosten Brasiliens	RESOURCE Soziale Dimensionen der Wasserverfügbarkeit

Projekte mit globaler Perspektive

POEM - Potsdamer Erdsystem-Modellierung

Derzeit verändert die menschliche Zivilisation den qualitativen Zustand des Erdsystems, also etwa die chemische Zusammensetzung der Atmosphäre oder die Struktur der Landoberfläche. Unklar ist, ob dies die Stabilität des Gesamtsystems beeinflussen könnte. Tatsächlich war das Klima der letzten 10.000 Jahre im Gegensatz zu den 100.000 Jahren davor eher stabil; die Entwicklung von Ackerbau – und damit einhergehend von Zivilisation – in dieser Periode ist vermutlich kein Zufall. Ein Teil der (natürlichen) Klimavariabilität ist wahrscheinlich durch Änderungen des Nordatlantikstroms verursacht. Die Amplitude dieser Änderung war in den letzten sechs bis sieben tausend Jahren eher gering, doch bleibt die Frage, ob ein durch den Menschen verändertes Klima wieder zu Schwankungen führen könnte.

Eine der derzeit größten wissenschaftlichen Herausforderungen besteht deswegen darin, das dynamische Verhalten des Erdsystems sowie seine Anpassungsfähigkeit an großräumige Störungen, wie die anhaltende Emission von Kohlendioxid und anderen Verbrennungsprodukten in die Atmosphäre, zu erforschen. Das Kernprojekt POEM (Potsdamer Erdsystem-Modellierung) soll zur Lösung dieser Fragen beitragen, indem die dynamischen Prozesse zwischen Biosphäre und Geosphäre, also zwischen der belebten und der leblosen Natur, analysiert werden.

Für viele Untersuchungen wird die Geosphäre in Atmosphäre, Hydrosphäre, Kryosphäre und Lithosphäre aufgeteilt. Dies ist gerechtfertigt, wenn nur gewisse Teilaspekte interessieren. Um die Dynamik des gesamten Erdsystems zu verstehen, reicht es aber nicht aus, das Verhalten der Untersysteme zu kennen und durch deren lineare Überlagerung auf das Verhalten des Gesamtsystems zu schließen. Da die Untersysteme nicht-linear miteinander gekoppelt sind, reagieren sie im Verbund anders auf Störungen, als jedes für sich allein oder in Verbindung mit nur einigen anderen. Als Konsequenz kann die Frage nach der Dynamik des Erdsystems nur durch die integrative Analyse des vollständigen, gekoppelten Systems beantwortet werden.

Die zeitliche Entwicklung des Erdsystems wird in POEM mit einer Hierarchie von Modellen untersucht. Der extrem langsame Kreislauf des Kohlenstoffs, bestimmt durch das Wachstum der Kontinente, die allmähliche Zunahme der Leuchtkraft der Sonne sowie durch die Verwitterung silikatreichen Gesteins zu Karbonatgestein, wird durch das COEM-Modell beschrieben, einem Modell der Koevolution von Geosphäre und Biosphäre. Auf Zeitskalen von Jahrhunderten und Jahrtausenden sind die Rückkopplungen zwischen Atmosphäre, Ozeanen, Vegetation und Inlandeis von Bedeutung, die mit Hilfe des Klimasystemmodells CLIMBER untersucht werden. Die vergleichsweise kurzfristige Wechselwirkung zwischen Vegetation und Klima im Bereich weniger Jahrzehnte bis Jahrhunderte, wie der Aufbau von Biomasse oder der Abbau organischer Materie im Boden, werden mit einem dynamischen globalen Vegetationsmodell erfaßt.

Das dynamische, globale Vegetationsmodell – DGVM

Auf der Kurzzeitskala von Jahrzehnten bis zu Jahrhunderten ist die Dynamik der Vegetation für den Zustand des Erdsystems insofern von Bedeutung, als sie Trends im Gesamtsystem verstärken oder verzögern kann. Zum einen liegt das an der physikalischen Rückkopplung zwischen Vegetation und Atmosphäre: Änderungen des Klimas ändern den Zustand der Vegetation und somit die Rauhigkeit der Erdoberfläche sowie die Absorption bzw. Reflexion der Sonnenstrahlung an der Erdoberfläche. Zum anderen speichern Böden und Vegetation einen Großteil des Kohlenstoffs an Land. Da die dabei relevanten Vorgänge – Photosynthese der Pflanzen, Aufbau von Biomasse und Abbau organischer Materie im Boden – auf unterschiedlichen Zeitskalen ablaufen, ist fraglich, ob das Ökosystem jemals im Gleichgewicht mit dem Klima sein kann. Dies hat für die Systemanalyse vor allem in Zeiten schneller Klimaänderungen und Schwankungen der Kohlendioxidwerte Konsequenzen, da sich dann die Menge des im Boden gespeicherten Kohlenstoffs nicht aus dem momentanen Klima abschätzen läßt, sondern die Gesamtentwicklung des Systems herangezogen werden muß (siehe auch Fig. 1 auf Seite 10).

Aus Sicht der Modellierung sind die für die globale Dynamik wichtigsten Elemente die lebende und die tote Biomasse und zwar, sowohl die jeweilige Gesamtmenge als auch alle Prozesse, die zu ihrer Bildung oder ihrem Abbau führen. Ein dynamisches, globales Vegetationsmodell muß deswegen die Photosynthese als wichtigsten Motor für die Kohlenstoffassimilation berücksichtigen sowie die autotrophe Atmung, bei der die Pflanzen die von ihnen produzierten Kohlehydrate selbst wieder verbrauchen, und die heterotrophe Atmung, bei der pflanzlicher Kohlenstoff durch andere Organismen umgesetzt wird. Neben diesen kurzzeitigen Prozessen berücksichtigen DGVMs auch das längerfristige Verhalten der Vegetation, das u.a. durch Wachstum, Konkurrenz mit benachbarten Pflanzen und natürliche Störungen (Feuer, Sturm) oder menschliche Eingriffe geprägt ist. Da die Wechselwirkungen zwischen sehr verschiedenen Pflanzen, wie Bäumen und Gräsern, schwer zu simulieren sind und viele der benötigten Parameter nur für wenige Pflanzen bekannt sind, ist es nicht möglich, die damit verbundenen Vorgänge für jede Pflanze zu modellieren. Deswegen definiert man einen geeigneten Satz funktionaler Pflanzentypen, denen die tatsächlichen Pflanzen zugeordnet werden, und parameterisiert die physiologischen Prozesse für jeden dieser Typen. Das Konkurrenzverhalten um Nährstoffe, Wasser und Licht wird dann zwischen den verschiedenen Typen abgeschätzt. Über Prozesse, die den Kohlenstoffkreislauf betreffen und mit dem – meist hinsichtlich des genauen Zeitpunktes unberechenbaren – Absterben und Zersetzen der Pflanzen zusammenhängen, werden zumindest plausible Annahmen gemacht, um sie und ihre Abhängigkeit von der Umwelt in das Modell einzubringen.

Die Entwicklung von dynamischen Vegetationsmodellen basiert auf der Annahme, daß die Antwort der Ökosysteme auf globale Umweltveränderungen stark ortsabhängig ist. Beispielsweise wirkt sich verminderte Feuchtigkeit in Savannen viel stärker auf die Brandwahrscheinlichkeit aus, als in tropischen Wäldern, wo dagegen Änderungen in der Landnutzung eine große Rolle spielen. Entsprechend wird bei den Simulationen dem regionalen Muster des Klimas eine große Bedeutung zugemessen. Je nach Region werden dann nur die Aspekte des Globalen Wandels berücksichtigt, die dort starke Auswirkungen haben.

Neben der Entwicklung eines Prototyps und seiner Weiterentwicklung zu einem umfassenden DGVM, leitet das PIK noch die vom IGBP geförderten Evaluationen bzw. Vergleichsstudien verschiedener DGVM-Modelle sowie der globalen Modelle für die Nettoprimärproduktion (veranschaulicht in Abbildung 2 auf Seite 11).

Das Klima- und Biosphärenmodell – CLIMBER

Mit Hilfe des am PIK neu entwickelten Klimasystem-Modells CLIMBER (für CLIMate and BiosphERe) wird die Wechselwirkung zwischen Geosphäre und Biosphäre über Zeiträume von Jahrhunderten bis Jahrtausenden simuliert – also die Rückkopplung zwischen Vegetation, Atmosphäre, Ozean sowie Inlandeis, und damit die (nicht-lineare) Synergie zwischen sämtlichen Komponenten des Klimasystems. Im Mittelpunkt der Untersuchungen stehen die Klimazustände der Vergangenheit, insbesondere die der letzten 150.000 Jahre, aber auch mögliche Klimaänderungen in den nächsten 1000 Jahren. Für solch langfristige Rechnungen lassen sich komplexe gekoppelte Atmosphäre-Ozean-Modelle nicht einsetzen. Ebenso erscheint es nicht sinnvoll, einfache Modelle zu benutzen, bei denen viele Prozesse, die bei komplexen Modellen berechnet werden, vorgeschrieben oder über Parameter eingestellt werden müssen. Daher wurde CLIMBER als “Modell mittlerer Komplexität” entworfen. Im Gegensatz zu den voll-komplexen Modellen berechnet CLIMBER nicht das Wetter, sondern beschreibt lediglich den Effekt des Wetters auf die mittlere Zirkulation der Atmosphäre. Ähnliches gilt für die Darstellung des Ozeans, bei der im wesentlichen nur die durch Temperatur und Salzgehalt getriebene “klimawirksame” Strömung explizit berechnet wird.

Trotz dieser vereinfachten Darstellung kann CLIMBER die globalen Strukturen des jetzigen Klimas gut wiedergeben. Auch die Reaktion des Modells auf Störungen des jetzigen Klimazustandes stimmt gut mit den Rechnungen komplexer Modelle überein.
Die eigentliche Validierung von CLIMBER erfolgt durch die Simulation vergangener Klimazustände wie z.B. des letzten glazialen Maximums, also des Höhepunktes der letzten Kaltzeit, vor gut 20.000 Jahren. Einerseits stimmt die Simulation mit paläogeologischen Rekonstruktionen dieses Zeitabschnittes überein. Andererseits konnten wesentliche Prozesse im Klimasystem identifiziert werden, die vor 20.000 Jahren zur starken Abkühlung insbesondere der Nordhalbkugel beitrugen. Dazu zählen die Verschiebung der Zone, in der das nordatlantische Tiefenwasser gebildet wird, von heute etwa 65^{o}N auf etwa 45^{o}N nach Süden, sowie der damit verbundene stark reduzierte Wärmetransport in die hohen Breiten des Nordatlantiks.
In einer anderen Studie wurde das Klima des mittleren Holozäns, also der Zeit vor etwa 6000 Jahren, untersucht (siehe Abb. 4 auf Seite 14). Damals waren die Sommer in vielen Regionen der nördlichen Hemisphäre wärmer, so daß die Baumgrenze deutlich weiter im Norden verlief als heute. Auch in der Sahara wuchs wegen des feuchteren Klimas vor 6000 Jahren eine subtropische Steppen- und Savannenvegetation. Mit CLIMBER konnte der Klimazustand realistisch nachgebildet werden. Ferner wurde gezeigt, daß das Klima des mittleren Holozäns nur durch die Synergie zwischen Vegetation, Atmosphäre und Ozean zu erklären ist. Die Atmosphäre allein reagiert viel zu schwach auf die externe Anregung, die die Klimaänderungen der letzten Jahrtausende angestoßen hat, nämlich die allmähliche, periodisch wiederkehrende Änderung in der Erdumlaufbahn und der Neigung der Erdachse.

Das Biosphären-Geosphären Evolutions-Modell – COEM

Wichtige grundlegende Eigenschaften des globalen Ökosystems Erde, wie seine derzeitige Stabilität oder die momentanen geologischen Rahmenbedingungen, lassen sich nur erklären, wenn man die langfristige Entwicklung des Erdsystems kennt. Nach der Theorie nicht-linearer Prozesse sollte dieses halboffene System eine Reihe von stabilen Zuständen mit einer komplizierten Übergangsstruktur besitzen. Das kurz- und mittelfristige dynamische Verhalten läßt sich deswegen besser analysieren und verstehen, wenn man die benachbarten stabilen Zustände und die elastischen Grenzen der stabilen Bereiche kennt.

Die Aufgabe des Biosphären-Geosphären Evolutions-Modells COEM ist es, die aus der Entwicklung des Erdsystems resultierenden Grenzen und Extrema der Dynamik der Biosphäre genauer zu analysieren. Dazu werden Methoden aus der Theorie dynamischer Systeme und der strukturellen Analyse sowie rechnergestützte Modellierungen herangezogen. Entscheidend ist die Annahme, daß die gegenwärtige Erd-Biosphäre eine von vielen möglichen Biosphären ist, die sich als Gleichgewichtselement eines aus “Klima und Biosphäre” bestehenden dynamischen Systems ergeben. Im Laufe der Langzeitentwicklung des Planeten durchläuft das System, stark von biologischen Rückkopplungsmechanismen beeinflußt, eine Reihe von Bifurkationspunkten. Auf der Basis eines Evolutionsmodells für das Erdsystem werden die langfristigen Rückkopplungsprozesse zwischen Atmosphäre, Biosphäre und Lithosphäre bei zunehmender Sonneneinstrahlung untersucht. Dieses Modellschema (Fig. 5 auf Seite 14) wurde um geodynamische Prozesse wie das Auseinanderdriften der Platten und das Wachsen der Kontinente erweitert. Die Werte, die die mittlere globale Temperatur, die Kontinentalfläche, der Kohlendioxidgehalt und die anderen Zustandsvariablen während der Rückkopplungsprozesse in der Erdentwicklung annehmen, ändern sich so langsam, daß sie als stationäre Werte für die Berechnung der Kurzzeitdynamik des Klima-Biosphärensystems eingesetzt werden können. Durch diese Strategie lassen sich die dynamischen Prozesse des Systems quasi separat analysieren.

EU-finanzierte Projekte in Verbindung mit POEM

Europäische Aktivitäten zur Modellierung terrestrischer Ökosysteme – ETEMA

ETEMA ist ein europäisches Gemeinschaftsprojekt, koordiniert von Martin Sykes, Schweden, das in enger Verbindung zur Entwicklung von DGVM-Modellen steht und darauf abzielt, die Auswirkungen menschlichen Einwirkens auf europäische Ökosysteme vorherzusagen. Dazu wurde ein modulares Gerüst entwikkelt, das Kohlenstoff-, Stickstoff- und Wasservorkommen und -kreisläufe, Abflußverhalten, Zusammensetzung der Vegetation und deren vertikale Struktur in Abhängigkeit von Klima, Kohlendioxid-Konzentration und Landnutzungsformen berechnen kann (Schema, Seite 16). Das am PIK entwickelte Gerüst soll den Austausch einzelner Komponenten erlauben, ohne daß deswegen die übrigen Teile geändert werden müssen.

Numerische Simulation und Analyse der Klimavariabilität im Bereich von Jahrzehnten und Jahrhunderten – Millenia
Ziel des internationalen Projektes ist es, natürliche Klimaschwankungen mit einer Dauer von Jahrzehnten bis zu Jahrhunderten zu verstehen. Zu solchen Schwankungen zählt zum Beispiel die kleine Eiszeit in Europa, die von 1550 bis 1850 andauerte und die auf eine ausgesprochen warme Periode im Mittelalter folgte. Ein anderes Beispiel ist die Nordatlantische Oszillation (NAO), die mit einer Periode von ca. 20 Jahren das Klima Europas mitbestimmt und die milden Winter der achtziger und frühen neunziger Jahre mit sich brachte. Ein besseres Verständnis solcher Klimaschwankungen ist zum einen nötig, um sie eines Tages vorhersagen zu können, wie es heute schon für El Niño im Pazifik geschieht. Zum anderen möchte man lernen, natürliche Klimaschwankungen besser von menschlichen Einflüssen zu unterscheiden. Schwerpunkt der Arbeit am PIK ist die Rolle des Ozeans bei diesen Klimaschwankungen. Dazu wurde bisher u.a. die Wirkung des Mittelmeerausstroms auf die Strömungen und das Klima im Nordatlantik analysiert und der Einfluß der Winde der Südhalbkugel auf die Atlantikzirkulation untersucht (siehe Abb. 7 Seite 17).

Neue Version des Moskauer globalen Biosphärenmodells – MGBM
In diesem Projekt wird untersucht, ob es mehr als einen Gleichgewichtszustand der Biosphäre gibt, und wie wahrscheinlich ein Übergang zwischen zwei möglichen stabilen Zuständen wäre. Dazu wurde ein Ansatz entwickelt, der die Biosphäre als eine Gesamtheit auffaßt, mit einer sehr großen Anzahl von Elementen, die sich aus einer Vielzahl von Zuständen der Hydrosphäre, des Klimas, der Anthroposphäre etc. ergeben. Die menschliche Gesellschaft ist dabei Teil der Biosphäre. An Verzweigungspunkten, an denen keine Vorhersage über die zukünftige gemeinsame Entwicklung von Biosphäre und menschlicher Gesellschaft getroffen werden kann, wird dieses räumlich diskrete System durch ein kontinuierliches, aktives Medium mit verschiedenen Phasen ersetzt. Jeder biogeochemische Kreislauf des Erdsystems wird durch ein entsprechendes derartiges Modell dargestellt. Mit Hilfe einer speziellen Theorie können dann Aussagen über die dynamischen Eigenschaften des Gesamtsystems und seiner Teilsysteme in dem Kreislauf gemacht werden, beispielsweise über die dynamische Verteilung der Kohlenstoffquellen und -senken im gesamten Kohlenstoffkreislauf.

QUESTIONS - Qualitative Dynamik von Syndromen des Globalen Wandels

Mit dem Projekt “Qualitative Dynamik von Syndromen” wird bei der Untersuchung der Ausprägungen und Entwicklung globaler Umweltveränderungen ein völlig neuer Ansatz verfolgt, der sogenannte Syndrom-Ansatz. Er basiert auf der Beobachtung, daß sich der Globale Wandel in einer Reihe von kritischen Symptomen äußert, wie Bodenerosion, Entwaldung, Nahrungsmittelknappheit, Bevölkerungswachstum oder Migration. Diese Symptome treten nicht isoliert sondern in bestimmten Konstellationen (Mustern) auf und sind durch ein jeweils spezifisches System von Wechselwirkungen miteinander verknüpft. Eine für viele Weltregionen typische Konstellation von Symptomen mit den zugehörigen Wechselwirkungen wird als Syndrom bezeichnet. Wichtig bei diesem interdisziplinären Ansatz ist, daß er explizit die menschlichen Eingriffe in den globalen Umweltwandel miteinbezieht. Bislang konnten 16 Syndrome identifiziert und in i) Nutzungssyndrome, ii) Entwicklungssyndrome und iii) Senkensyndrome eingeteilt werden (siehe S. 20 Tabelle 1). Beispiele sind das Sahel-Syndrom (i), das die Übernutzung marginaler landwirtschaftlicher Standorte beschreibt, das Kleine-Tiger Syndrom (ii), welches die Nichteinhaltung von Umweltstandards zugunsten einer schnellen Wirtschaftsentwicklung wiedergibt und das Hoher-Schornstein Syndrom (iii), das die Schädigung der Umwelt durch großflächige Emission langlebiger Substanzen beinhaltet. Die Identifizierung der weltweit auftretenden Syndrome ist eine gut faßbare Methode, um sich einen Überblick über die Gesamtproblematik des Globalen Wandels zu verschaffen. Durch die Modellierung all jener Regionen, die ein spezielles Symptom in einer bestimmten Ausprägung aufweisen, und Vergleich dieser Studien lassen sich die Mechanismen aufdecken, die das Syndrom hervorrufen und eventuell noch verstärken und schließlich “Behandlungsstrategien” finden. Das stark normativ geprägte Denken über “Nachhaltige Entwicklung” bekommt durch die hier durchgeführte Fokussierung auf verschiedene Muster der Nicht-Nachhaltigkeit eine genauere analytische Grundlage.
In diesem Projekt werden Syndrome analysiert sowie in ihrem derzeitigen Ausmaß identifiziert und kartographisch erfaßt. Außerdem wird die Disposition möglichst vieler Regionen für die einzelnen Syndrome untersucht und schließlich die mögliche zukünftige Entwicklung der Syndrome modelliert (siehe die Abb. 1 auf Seite 21 und Abb. 2 auf Seite 22).

Bisher gibt es noch keine definierte Vorgehensweise, nach der man die Existenz von Syndromen und ihre Stärke abschätzen könnte. Die naheliegende Vorgehensweise, anhand der syndromspezifischen Konstellation von Symptomen und ihrem zeitlichen Verhalten einen direkten Zugriff auf die Syndrome zu haben, scheitert derzeit meist aufgrund mangelnder Daten. In diesen Fällen muß man auf alternative Methoden zurückgreifen, etwa indem man die Ergebnisse globaler Modelle benutzt. Insgesamt wurde in den letzten zwei Jahren die weltweite Intensitätsverteilung von sechs Syndromen untersucht.

Die Anfälligkeit für die Syndrome

Der Syndromansatz dient nicht nur dazu, diejenigen Regionen zu identifizieren, die aufgrund entsprechender Wechselwirkungen zwischen Natur und menschlichem Verhalten bereits Symptome des Globalen Wandels zeigen, sondern auch die Gebiete zu finden, in denen ein spezifisches Syndrom in der Zukunft auftreten könnte. Dies führt auf die Frage: Nach welchen Kriterien ist eine Region disponiert, d.h. anfällig, für ein spezielles Syndrom? An welchen charakteristischen Merkmalen erkennt man, daß dort in der Zukunft ein Syndrom auftreten kann? Die Beantwortung dieser Frage gibt einen ersten Einblick in die Mechanismen, die bei der Ausbildung von Symptomen in einem disponierten Gebiet ablaufen. Darüber hinaus ist die Kenntnis dieser Regionen aus Sicht der Politik extrem wichtig, da hier durch gezielte und spezifische Präventionen der Ausbruch von Syndromen vielleicht zu verhindern ist.

Um herauszufinden, ob eine Region anfällig für ein bestimmtes Syndrom ist, wählt man anhand der syndrom-inhärenten Mechanismen eine Reihe von geeigneten Indikatoren für die Disposition aus. Im Fall des Sahel-Syndroms sind derartige Indikatoren beispielsweise die Bodenqualität und das Klima, das Bevölkerungswachstum und die langfristige Sicherheit ausreichender Ernährung. Da Syndrome an der Schnittstelle zwischen Mensch und Natur ansetzen, müssen die Indikatoren sowohl natürliche als auch soziale Charakteristiken abfragen. Die Analyse von Dispositionen für ein Syndrom führt – unter Verwendung von Expertenwissen, Modellergebnissen und Fallstudien – auf einen Entscheidungsbaum mit relevanten Indikatoren (siehe Fig. 3 auf Seite 24). Kennt man die Werte der Indikatoren in einer bestimmten Region und deren Wichtung, so kann die Disposition dieser Region für das betreffende Syndrom abgeschätzt werden. Diese Vorgehensweise sei am Beispiel des Kleinen-Tiger-Syndroms skizziert. Bei diesem Syndrom kommt es typischerweise zu rasch aufholendem Wirtschaftswachstum im Verein mit steigendem Energie- und Ressourcenverbrauch. Das Verhalten wird durch ein undemokratisches politisches System gefördert, das Umweltbelangen und Partizipationsbestrebungen eine niedrige Priorität einräumt. Starke Wasser- und Luftverschmutzungen sowie Bodenkontamination sind die Folge. Um den Entscheidungsbaum für dieses Syndrom zu erstellen, mußte folgende Frage beantwortet werden: Welche Regionen weisen gute natürliche Bedingungen für eine exportorientierte Produktion auf, bieten gute ökonomische, politische und soziale Voraussetzungen für hohe Wachstumsraten und eine kulturelle Disposition, die wirtschaftlichem Wachstum förderlich sind? In den vergangenen zwei Jahren wurden die regionalen Dispositionen für fünf Syndrome berechnet und die Ergebnisse kartiert (siehe Fig. 4 auf Seite 25).

Methoden der Qualitativen Modellierung

Das größte Problem bei der Modellierung von Syndromen ist das mangelhafte Wissen über sie: Einzelheiten über den Zustand der beteiligten Symptome sind häufig unbekannt. Oft können auch die Wechselwirkungen zwischen ihnen nicht ohne Einschränkung quantifiziert werden. Dies liegt zu einem Großteil in der Natur der Wechselwirkungen begründet: Welche quantitativen Aussagen sollten über die Beziehung zwischen “Verarmung”, “landwirtschaftlicher Expansion”, “Übernutzung von Böden” und anderen Symptomen getroffen werden?

Deswegen mußte eine Methode gefunden werden, die geeignet ist, Schlußfolgerungen auf der Basis qualitativen Wissens zu liefern. Am PIK wird dazu der Formalismus der Qualitativen Differentialgleichungen verwendet, bei dem mit Klassen gewöhnlicher Differentialgleichungen gerechnet wird. Als Ergebnis erhält man alle Lösungen, die mit einer Klasse konform sind. Diese Klassen werden meist durch einfache, monotone Aussagen wie “Je höher der Zustand der Armut, desto höher ist die Zunahmerate der Landwirtschaft” charakterisiert.

In dem Formalismus ändert sich der Zustand einer Variable nur, wenn bestimmte Schwellenwerte überschritten werden. Die möglichen Lösungen liefern das qualitative Verhalten, das sich als Folge qualitativer Zustände darstellt. Allerdings können keine Aussagen über die Zeitspanne zwischen zwei Zuständen getroffen werden. Dennoch bietet diese Methodik eine vielversprechende Alternative zu den üblichen Modellierungsverfahren, die nur dazu in der Lage sind, scharf-quantitative Daten und Zusammenhänge zu verarbeiten.

ICLIPS - Integrierte Klimaschutzstrategien

1992 unterzeichneten und ratifizierten 150 Staaten die Rahmenvereinbarungen zum Globalen Klimawandel (FCCC) in Rio de Janeiro. Gemäß Artikel Zwei verpflichten sie sich damit, die Konzentrationen der Treibhausgase in der Atmosphäre auf Werte zu stabilisieren, die "gefährliche anthropogene Eingriffe in das Klimasystem ausschließen". Dabei sollen diese Werte innerhalb eines Zeitraumes erreicht werden, der "eine natürliche Anpassung der Ökosysteme erlaubt, eine ausreichende Nahrungsmittelproduktion gewährleistet und ökonomisch eine Fortentwicklung gemäß dem Prinzip der Nachhaltigkeit ermöglicht". Wie dieses Ziel erreicht werden soll und wie es im Detail aussieht, wird in Artikel Zwei nicht spezifiziert: Unterhalb welcher Konzentration von Treibhausgasen tritt sicher kein gefährlicher Eingriff auf? Wieviel Zeit verbleibt noch, bevor die Emissionen von Treibhausgasen reduziert werden müssen? In welchem Umfang müssen wir sie reduzieren?

In dem internationalen und interdisziplinären Forschungsvorhaben ICLIPS werden Methoden und Werkzeuge ausgearbeitet, die eine integrierte Abschätzung von Klimaschutzstrategien erlauben und derartige Fragen beantworten. Sie sollen zumindest teilweise für politische Entscheidungsträger direkt handhabbar sein. Das von der Bundesregierung geförderte Projekt wurde vom Potsdam-Institut für Klimafolgenforschung initiiert und wird hier auch koordiniert. Kernstück ist der sogenannte Fensteransatz, der bei Vorgabe von – aus gesellschaftlicher Sicht – nicht-tolerierbaren Klimafolgen die Bestimmung derjenigen Klimaschutzstrategien erlaubt, die ein Verbleiben des Klimas im zulässigen Bereich sicherstellen. Andererseits schließt er aber auch die Klimaschutzstrategien aus, deren sozioökonomische Konsequenzen gesellschaftlich nicht akzeptiert werden.

Mit dem bisher ausgearbeiteten Ansatz wurden erste konkrete Ergebnisse erzielt: Um eine Temperaturänderung von mehr als 2 °C gegenüber dem vorindustriellen Wert und eine Änderungsrate von mehr als 0,2 °C pro Jahrzehnt zu vermeiden sowie um einen schrittweisen Übergang zu einer Energieversorgung ohne Verwendung fossiler Brennstoffe zu ermöglichen, muß spätestens in etwa zwei Jahrzehnten die Emission von Treibhausgasen effektiv verringert werden. In diesem Fall müßten anschließend aber extreme Einschnitte bei der Emission erfolgen. Auf kosteneffektivstem Wege ließe sich das Einhalten der Klimaschranken durch eine Klimaschutzstrategie realisieren, die zu weniger als 1% Wohlstandsverlust – gemessen am privaten Einkommen – führen würde.

In einer weiterführenden Studie wurde untersucht, wie sich der Handlungsspielraum für emissionbeschränkende Maßnahmen ändert, wenn in den nächsten Jahren zunächst kein verändertes Verhalten bei den Emissionen erfolgt. Dabei bestätigte sich, daß wir maximal noch etwa zwei Jahrzehnte soviel Treibhausgase in die Atmosphäre emittieren dürfen, wie gemäß den heutigen Prognosen zu erwarten ist. Wird dieser Zeitraum überschritten, so besteht unter den gegenwärtigen Annahmen keine Möglichkeit mehr zu verhindern, daß das Klima den oben angegebenen Bereich verläßt. Aber auch, wenn nur bis 2010 ungedrosselt weiter emittiert wird, schränkt sich der Handlungsspielraum sehr stark ein. Schließlich wurde auch berücksichtigt, daß, gemäß Annex I des FCCC, Entwicklungsländer einen geringeren Beitrag zur Absenkung der Globalen Emission von Treibhausgasen leisten müssen als Industrieländer. Die Berechnungen mit dem Fensteransatz ergaben nicht nur, daß dadurch die Emissionen der Treibhausgase in den Industrieländern insgesamt noch stärker reduziert werden müssen, sondern auch daß sich der Handlungsspielraum über den gesamten berechneten Zeitraum von 200 Jahren drastisch einschränkt. Quantitative Aussagen sind aus Abbildung 3 auf Seite 34 zu entnehmen.

Ein großer Vorteil des Ansatzes ist, daß ausgehend vom "Fenster" tolerierbarer Klimaänderungen *schrittweise* die daraus folgenden Implikationen berechnet werden, die das vorgegebene Klimafenster rückwirkend stärker beschränken (siehe Bild 1, Seite 30). Beispielsweise wird im ersten Schritt ermittelt, welche geophysikalischen Konsequenzen, z.B. welchen Anstieg des Meeresspiegels, die vorgegebenen Klimaänderungen nach sich ziehen könnten und bei welchen Klimaänderungen sich daraus unzumutbare ökologische oder sozioökonomische Folgen ergeben würden. Daraus ergibt sich ein neues "tolerierbares" Klimafenster. Im nächsten Schritt werden die klimatischen Entwicklungen untersucht, die sich an die tolerierbaren Klimate anschließen würden. Die beiden folgenden Schritte zielen nun auf die Eingriffsmöglichkeiten des Menschen ab: In ihnen werden die zugehörigen Treibhausgaskonzentrationen sowie die Emissionsprofile ermittelt, die das Klimasystem im tolerierbaren Fenster halten. Bis hierher sind die einzelnen Schritte zwischen Klimawandel und Emission über naturwissenschaftliche Modelle gekoppelt. In die noch verbleibenden Berechnungen gehen weitere normative Vorgaben ein, nämlich die in Verhandlungen multilateral abgestimmten jeweiligen Emissionsbeschränkungen sowie die Einschränkung, daß ein

Teil der klimatologisch erfolgversprechenden Maßnahmen gesellschaftlich nicht durchsetzbar sind. Zuletzt werden mit einem sozioökonomischen Modell die Auswirkungen auf den Wohlstand der Bevölkerung aus den Emissionsvorgaben errechnet, bzw. welche Vorgaben zu einer tolerierbaren Änderung des Lebensstandards führen könnten. Dieses letzte Fenster legt damit fest, welche Maßnahmen in allen Bereichen (Klima, geobiophysikalische Folgen, Langzeitklima, Politik, Wirtschaft, Gesellschaft) zu akzeptablen Änderungen führen. Diese schrittweise Berechnung sorgt zum einen für Transparenz, zum anderen hat sie den Vorteil, daß die einzelnen Teilmodelle – Klimamodell, sozioökonomisches Modell – unabhängig voneinander ausgetauscht werden können, so daß überholte Modelle ohne großen Aufwand durch verbesserte ersetzt werden können.

Projekte mit regionaler Perspektive

RAGTIME - Regionale integrierte Modellierung im Elbegebiet

Der Globale Wandel ist zwar ein weltumspannender Prozeß, an seinem Ursprung sind aber maßgeblich regionale und lokale Störungen des terrestrischen Ökosystems beteiligt, wie beispielsweise Veränderungen in der Landnutzung, Kohlendioxidemissionen sowie Produktion und Lagerung diverser Abfälle. Um den Globalen Wandel verstehen sowie politische und technische Maßnahmen zur Verminderung oder Vermeidung negativer Entwicklungen ableiten zu können, ist eine Analyse aller wesentlichen Prozesse auf regionaler Ebene Voraussetzung. Bei diesen Untersuchungen ist es sinnvoll, die natürlichen Strukturen des Ökosystems zu berücksichtigen, etwa Flußläufe, Gebirge, Waldgebiete etc., weil diese spezifischen Einfluß auf die Dynamik der beteiligten Prozesse haben.
Das Projekt “Regionale integrierte Modellierung im Elbegebiet” beschäftigt sich speziell mit den Mechanismen und Auswirkungen des Globalen Wandels im Einzugsgebiet der Elbe (ca. 100.000 km²). Flußgebiete stellen landschaftsintegrierende Einheiten für Wasser und darin mitgeführte Stoffe dar, die Aussagen über qualitative und quantitative Änderungen aufgrund anthropogener Einflußnahmen sowie allgemeiner Umweltveränderungen erlauben. Der in der Modellregion Elbe entwickelte Modellierungsansatz und die Untersuchungsmethoden lassen sich grundsätzlich auch auf andere Flußgebiete übertragen, in denen die Bedeutung von Wasser für die gesellschaftliche Entwicklung hohe Bedeutung hat (vgl. hierzu die Kernprojekte “Soziale Dimensionen der Wasserwirtschaft” RESOURCE und “Wasserverfügbarkeit im Nordosten Brasiliens” WAVES).

Der RAGTIME-Ansatz
Mit Hilfe des in RAGTIME entwickelten integrierten Modellierungskonzeptes lassen sich bei Vorgabe von regionalen Klima- und Landnutzungsszenarien die Auswirkungen auf natürliche Ressourcen wie Wasser, Böden, Vegetation usw. berechnen (Bild 1 auf Seite 36). Für diese naturräumlichen Untersuchungen werden je nach Fragestellung verschiedene Modelle eingesetzt, insbesondere SWIM und ARC/EGMO, die eine Modellierung auch kleinräumiger Landoberflächeneinheiten erlauben. Dadurch läßt sich die reale “Mosaikstruktur” der Landschaft am besten wiedergeben, und Änderungen der Landnutzung können effektiv abgebildet werden. Für großskalige Modellierungen können kleine, hydrologisch ähnlich reagierende Gebiete zu größeren Einheiten zusammengefaßt werden. Während ARC/EGMO aufgrund seiner sehr feinen Flächenunterteilung insbesondere für Untersuchungen von Landnutzungsänderungen prädestiniert ist, erlaubt SWIM bei gröberer Flächenuntergliederung zusätzlich zur Simulation hydrologischer Größen eine Modellierung der Stickstoff- und Phosphatdynamik, des Getreidewachstums sowie der Bodenerosion. Die Ergebnisse der Simulationsrechnungen spiegeln die ökologischen und hydrologischen Charakteristiken der untersuchten Region wieder und sind gleichzeitig Grundlage für eine sozioökologische Bewertung und die Entwicklung von Maßnahmen zur Verhinderung negativer Entwicklungen. Ein dazu entwickeltes “Metamodell” verdichtet die naturräumlichen und sozioökonomischen Daten und Ergebnisse auf einer relativ groben räumlichen und zeitlichen Ebene (administrative Einheiten, Jahre).

Ergebnisse der naturräumlichen Modellierung
Mit Hilfe von ARC/EGMO wurde das Elbegebiet zunächst hydrologisch beschrieben. Dazu hat man das Einzugsgebiet auf der Basis verfügbarer Grundlagenkarten in 64.500 “Elementarflächen” untergliedert und verschiedene Wasserhaushaltsgrößen, wie Verdunstung, Sickerwasserbildung und Oberflächenabfluß, in Tagesschritten flächendeckend berechnet. Die meteorologischen Eingangsdaten von 33 Klima- und 107 Niederschlagsmeßstationen wurden pro Simulationsschritt mit Hilfe eines geeigneten Interpolationsverfahrens auf die Einzelflächen übertragen. Die Ergebniskarten weisen u.a. Teilgebiete der Elbe aus, die in Trockenperioden besonders gefährdet sind (siehe Abb. 2 auf Seite 37).
Darüber hinaus konnten mit Hilfe von ARC/EGMO und einer modifizierten Version des schwedischen Modells HBV in 35 Teileinzugsgebieten die wichtigsten Komponenten des lateralen Wasserabflusses – Oberflächen-, hypodermischer und Grundwasserabfluß – berechnet werden. Diese spielen eine wichtige Rolle für den Transport von Nähr- und Schadstoffen und für Untersuchungen der Wasserqualität, wie sie anschließend mit SWIM durchgeführt wurden. Die Ergebnisse dienten u.a. auch dazu, die Nebenflußgebiete in vier grundsätzlich verschiedene Klassen einzuordnen.
Nach der hydrologischen Validierung in fünf Teileinzugsgebieten der Elbe wurde das Modell SWIM im Einzugsgebiet der Stepenitz (575 km²) zur Simulation der Stickstoffdynamik eingesetzt. Die für verschiedene Bodenschichten und Abflußkomponenten erzielten Ergebnisse sind durchaus geeignet, erste Empfehlungen für Änderungen landwirtschaftlicher Praktiken zugunsten der Boden- und Grundwasserqualität zu formulieren (siehe Abb. 4 auf Seite 38).
Neben diesen Untersuchungen zur Wasserqualität simulierte die Projektgruppe mit Hilfe von SWIM auch die Auswirkungen einer möglichen Klimaänderung auf den Wasserkreislauf und die Erträge unterschiedlicher Getreidesorten im Land Brandenburg. Dazu wurde ein Klimaszenario aus der Klimaabteilung des PIK verwendet, das eine Erwärmung um 1,5 °C innerhalb der nächsten 100 Jahre annimmt. Die Berechnungen ergaben eine Zunahme der Verdunstung und des Oberflächenabflusses, während die Grundwasserneubildung nahezu unverändert blieb. Die Auswirkungen auf die Erträge hingen von der Getreidesorte ab sowie davon, ob ein Düngeeffekt durch eine Zunahme der Kohlendioxidkonzentration berücksichtigt wurde oder nicht. Insbesondere konnte gezeigt werden, daß die Ergebnisse der Simulationsrechnungen sowie daraus ableitbare Bewirtschaftungsempfehlungen empfindlich auf die jeweils angenommene Klimaänderung reagierten.

WAVES - Wasserverfügbarkeit im Nordosten Brasiliens

Semi-aride Regionen gehören bei den zu erwartenden Klimaänderungen zu den gefährdeten Gebieten auf der Erde. Vor allem Wasserknappheit und starke Schwankungen bei den Niederschlägen tragen signifikant zur Verletzbarkeit dieser Regionen bei. Die semiariden Gebiete bedecken etwa ein Drittel der Erdoberfläche und sind von 20 % der Weltbevölkerung besiedelt, wobei die Lebensbedingungen im allgemeinen unter dem globalen Durchschnitt liegen. Aufgrund häufig auftretender Dürreperioden kommt es zur Abwanderung von großen Teilen der Landbevölkerung in die Städte oder andere weniger gefährdete Gebiete. Hauptziel des WAVES-Projektes ist es, die Wechselwirkungen zwischen Wasserverfügbarkeit und Migration aus ländlichen Gebieten zu verstehen, um so mögliche Wege einer nachhaltigen Entwicklung besser einschätzen zu können. Dies soll zunächst am Beispiel der brasilianischen Bundesstaaten Piauí und Ceará erarbeitet werden, die durch stark begrenzte Ressourcen, deutliche Klimaschwankungen und soziale Spannungen geprägt sind. WAVES ist ein Gemeinschaftsbeitrag Brasiliens und Deutschlands zum *Global Change Programme*. Die Hauptphase des Projektes begann 1997 und wird bis 2001 dauern.
Um die Auswirkungen eines Klimawandels auf semiaride Gebiete abzuschätzen, müssen die Beziehungen zwischen der Natur und den sozialen und ökonomischen Systemen untersucht werden, was aufgrund der Vielzahl unterschiedlicher Faktoren nur mit interdisziplinären Mitteln möglich ist. Entsprechende Teilprojekte beschäftigen sich mit der Analyse und Modellierung des Klimas und der Agrarwirtschaft, der Beschreibung des Wasserhaushaltes und der Vegetation sowie mit den sozioökonomischen und soziokulturellen Bedingungen.
Zur Beantwortung der zentralen Frage reicht es nicht, die Ergebnisse aus den einzelnen Disziplinen einander gegenüberzustellen. Vielmehr wird daran gearbeitet, aus den Modellen der Einzelprojekte ein integriertes Gesamtmodell zu entwickeln, in dem die jeweiligen Systeme bzw. die sie beschreibenden Teilmodelle auf der Basis ihrer Wechselwirkungen miteinander gekop-

pelt werden (siehe Abb. 3, Seite 41). Auf der Grundlage von Szenarien, in denen mögliche Entwicklungen aller Teilsysteme gemeinsam beschrieben sind, werden Wege für einen nachhaltigen Umgang mit den natürlichen Ressourcen sowie Entwicklungspotentiale sozialer Systeme aufgezeigt.

Klimaanalyse und Klimamodellierung
Die durchgeführten Analysen der räumlichen und zeitlichen Klimabedingungen in Piauí und Ceará liefern die grundlegenden Informationen für die Entwicklung möglicher Klimaszenarien. Aus diesen werden die Klimakomponenten für das integrierte Gesamtszenarium gebildet. Dazu werden sowohl beobachtete als auch berechnete Niederschlags-, Temperatur- und Feuchtigkeitswerte verwendet. Mit Hilfe speziell entwickelter statistischer Verfahren wird untersucht, ob es zeitliche Veränderungen hinsichtlich Beginn, Ende und Dauer der Regen- bzw. Trockenzeiten gibt (siehe Abb. 5, Seite 42). Die Ergebnisse sind wichtige Indikatoren bei der Untersuchung der Migration. Außerdem wird ein dynamisches Klimamodell im regionalen Maßstab an die Untersuchungsregion angepaßt und mit einem großräumigen hydrologischen Modell gekoppelt.

Großräumige hydrologische Modellierung
Für die zentrale Fragestellung des Projektes ist es wichtig, den gesamten Wasserkreislauf der untersuchten Region quantitativ erfassen zu können. Dazu wurde mit der Entwicklung eines Modells zur großräumigen Beschreibung der hydrologischen Bedingungen begonnen, das dann auf die spezifischen Verhältnisse Nordostbrasiliens mit seinem ausgeprägten semi-ariden Klima – fast alle Niederschläge fallen in der viermonatigen Regenzeit – und einer insgesamt recht dürftigen Datenlage angepaßt werden muß (siehe Abb. 7, Seite 43). Das Modell soll in der Lage sein, quantitative Abschätzungen der relevanten Komponenten des Wasserkreislaufs in räumlicher Differenzierung zu liefern, insbesondere den Oberflächenabfluß, die Grundwasserneubildung, die Wasserspeicherfähigkeit des Bodens und die Speicherung in Staubekken. Dadurch erhält man einen detaillierten Überblick über die physikalische Wasserverfügbarkeit in der Region. Dies ist unverzichtbar für die Untersuchung der Landwirtschaft, Wasserwirtschaft und der sozioökonomischen Bedingungen. Dieses Modell wird das Kernstück bei der Entwicklung des Wassermoduls für das integrierte Gesamtmodell sein.

Integrierte Modellierung
Für die Rückkopplung innerhalb der wissenschaftlichen Einzeldisziplinen werden die relevanten sektoralen Prozesse in unterschiedlichen Zeit- und Längenskalen zunächst interdisziplinär-kompatibel definiert.
Das WAVES-Projekt untersucht die Effizienz nachhaltiger Entwicklungen in semi-ariden Gebieten mit Hilfe eines Modellierungsansatzes, der die verschiedenen Disziplinen integriert und systematisch auf verschiedenen Einzelmodellen aufbaut. Dabei übertrifft die Bandbreite der wissenschaftlichen Einzeldisziplinen – angefangen mit Klimatologie und Hydrologie, die auf physikalischen Gesetzmäßigkeiten aufbauen, über die Agrarökonomie bis hin zu der Soziologie/Psychologie der Migration, die menschliches Entscheidungsverhalten beschreiben – die bisher erprobten integrativen Untersuchungen. Dieser Umstand macht WAVES zu einem Pilotprojekt. Um das integrierte WAVES-Modell aufzustellen, wird die Beziehung zwischen Wasserverfügbarkeit und Migration aus zwei Richtungen angegangen: Zum einen werden die relevanten internen Prozesse sowie die von außen steuernden Kräfte großräumig untersucht, zum anderen werden in den Teilprojekten die Mechanismen der Einzelprozesse teilweise detailliert nachvollzogen, um die Prozeßparameter des integrierten Modells abschätzen zu können. In dem erarbeiteten Modellkonzept (siehe Abbildung 9, Seite 45) ist die Landflucht als eine Anpassung der Bevölkerung an die sich verschlechternden Lebensbedingungen definiert. Beschäftigung und Einkommen auf der Basis von Ackerbau und Viehzucht sind wichtige Faktoren für die Lebensqualität. Diese hängen stark vom Klima und der Wasserverfügbarkeit ab. Derzeit existiert eine erste Modellversion, allerdings ohne räumliche Auflösung, die aus einzelnen Modulen aufgebaut ist. Diese werden später durch die in den Teilprojekten entwickelten, verbesserten Module ersetzt. Dabei muß noch berücksichtigt werden, daß die Prozesse in den Einzeldisziplinen sowie die benötigten Daten teilweise eine ganz unterschiedliche Zeit- und Raumauflösung erfordern.

Deutsche Kooperationspartner
Die Agrarwirtschaft, die soziokulturellen und sozioökonomischen Bedingungen sowie die Landschaftsökologie werden an den Universitäten Stuttgart-Hohenheim, Kassel, der Fachhochschule Köln sowie der Technischen Universität München untersucht.

EUROPA - Europäische Netzwerkaktivitäten zum Globalen Wandel

Die Kooperation mit anderen Europäischen Forschungsinstituten war und ist für die Arbeit des PIK von großer Bedeutung. Mittlerweile gibt es eine ganze Reihe von Gemeinschaftsprojekten und -aktivitäten, die allesamt von allgemeinem europäischem Interesse und wissenschaftlicher Relevanz sind. Folgende europäische Projekte werden im Rahmen der Kernprojekte durchgeführt:

- Modellierung von agroökonomischen Systemen unter Einfluß des Globalen Wandels (MAGEC) in AGREC
- Dynamische Reaktion der Wald-Tundra Zone auf Umweltänderungen (DART) in CHIEF
- Regionale Langzeiteffekte des Klimawandels auf europäische Wälder, Folgenabschätzung und Konsequenzen des Kohlenstoffhaushalts (LTEEF-II) in CHIEF
- Europäische Aktivität zur Modellierung terrestrischer Ökosysteme (ETEMA) in POEM
- Numerische Simulation und Analyse der Klimavariabilität im Bereich von Jahrzehnten oder Jahrhunderten (Millenia) in POEM
- Flußüberschwemmungen in Europa und Risikoabschätzung (EUROTAS) in RAGTIME
- Modellierung der Effekte von Landdegradation auf das Klima (CLD) in RESOURCE.

Alle weiteren europäischen Projekte sollen unter dem Namen EUROPA zu einem neuen Kernprojekt zusammengebunden werden. Sie werden im folgenden kurz beschrieben (siehe auch Übersichten auf den Seiten 47 und 48).

Konzertierte Aktion zur umfangreichen Folgen- und Anpassungs-Bewertung für die Europäische Union – ACACIA

Dieser Netzwerkaktivität, koordiniert von M. Parry, University College, London, soll bei der laufenden Evaluierung und Neustrukturierung der europäischen Klimafolgenforschung eine Schlüsselrolle zukommen. Ziel ist es zu ermitteln, welche Akteure oder welche Institutionen auf die Ergebnisse der Klimafolgenforschung angewiesen und an ihr interessiert sind. Weiterhin sollen die interessierten Zielgruppen charakterisiert werden. Das Projekt wird mit einem Bericht über den gegenwärtigen Wissensstand zu möglichen Folgen und Anpassungsstrategien der Klimafolgenforschung, bezogen auf die EU, abschließen.

Regionale Klimamodellierung und integrierte Folgenforschung zum Globalen Wandel in der europäischen Arktis – CLIMPACT

Die Arktis ist aufgrund der Auswirkungen, die ein dortiger Klimawandel auf Europa haben könnte, von allgemeinem Interesse. Modellrechnungen deuten zudem darauf hin, daß eine künftige Erwärmung in der Arktis ausgeprägter sein könnte als anderswo. In CLIMPACT, das von M. Lange, Universität Münster, koordiniert wird, sollen sowohl das Ausmaß als auch die Auswirkungen des Klimawandels untersucht werden.

Netzwerk für eine koordinierte wissenschaftliche und technische Unterstützung bei der Verwendung von Klimadaten – ECLAT-2

Ziel dieser konzertierten Initiative ist es, durch den Aufbau eines Netzwerkes allen im EU Klima- und Umweltprogramm beteiligten Wissenschaftlern die verfügbaren klimatologischen Daten, Quellen und weitere Informationen zugänglich zu machen und zu einem koordinierten, konsistenten und effizienten Gebrauch klimatologischer Informationen anzuregen.

Europäisches Forum zur integrierten Umweltbewertung – EFIEA

Die integrierte Umweltbewertung unter Einbeziehung von Wissenschaftlern und Akteuren ist ein sich dynamisch rasch entwickelndes Gebiet. Es fehlt hierbei aber an einer systematischen Abstimmung der unterschiedlichen Ansätze. EFIEA dient als Diskussionsforum, soll zu Kooperationen auf diesem Gebiet anregen und zur Verbesserung der Qualität der verwendeten Ansätze beitragen. Dabei soll die Zusammenarbeit zwischen Politik und Wissenschaft gefördert werden, indem u.a. einige politische Maßnahmen konkret unter Gesichtspunkten der integrierten Umweltbewertung untersucht werden.

Klimatologie und Prognose klimainduzierter Änderungen hydrographischer Größen in Nord- und Ostsee – KLINO

Das PIK erstellt für dieses Verbundprojekt eine hochaufgelöste, spektrale Klimatologie des Seegangs für die Nord- und Ostsee. Schwerpunkt der Untersuchung liegt auf der Bestimmung der Fernwirkungen der nordatlantischen Sturmregionen auf küstennahe Gebiete. Dafür wurde u.a. das operationelle Seegangsmodell am PIK erweitert, um die Auswirkungen der Klimaveränderungen im Atlantik auf die Klimatologie des Seegangs in Küstennähe bestimmen zu können. Das Pro-

jekt wird durch das Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie finanziert.

Umweltveränderungen und sozioökonomischer Wandel in Bergregionen – Mountain

Das Forschungsprogramm Mountain untersucht die Folgen des Globalen Wandels in Bergregionen. Dabei interessiert insbesondere die Abhängigkeit der Auswirkungen von der Höhenlinie bzw. vom Gradienten. So wird erwartet, daß die Regionen, in denen sich schon unter natürlichen Bedingungen die hydrologischen oder ökologischen Eigenheiten ändern, besonders sensibel auf Änderungen des Klimas oder der Landnutzung reagieren. Beispiele dafür sind die Lage der Baum- oder Schneegrenze, die Ausdehnung von Gletscher- oder Feuchtgebieten. Ein wesentlicher Aspekt betrifft die Nachhaltigkeit von Umwelt und Kultur in Bergregionen unter dem Einfluß des Globalen Wandels.

Regionale integrierte Studien zu Auswirkungen des Klimawandels – RICC

Auf der Basis einer Pilotstudie für das Land Brandenburg werden Methoden für integrierte Regionalstudien generalisiert und weiterentwickelt. In diesem Pilotprojekt wurde konkret für das Land Brandenburg eine regionale, integrierte Untersuchung zu den Auswirkungen eines möglichen Klimawandels durchgeführt. Insbesondere wurden anhand unterschiedlicher Klimaszenarien die Folgen für die Wasserressourcen, die Wälder, die Landwirtschaft sowie die menschliche Gesundheit und die Energiewirtschaft analysiert. Die mittlerweile weiter verbesserte Brandenburgstudie ist insbesondere wegen ihres Modellcharakters für andere regionale Untersuchungen in Europa von Bedeutung.

Klimaszenarien:

Um die Folgen eines Klimawandels abzuschätzen, muß zunächst ein Szenario für die Klimaentwicklung der Region erarbeitet werden. Das setzt eine Absicherung des zu erwartenden Temperaturanstiegs voraus. Bei ungeminderter Zunahme der Kohlendioxidkonzentration in der Atmosphäre prognostizieren globale Zirkulationsmodelle eine weltweite Erwärmung um 1,5 bis 4,5 °C bis 2100, für Zentraleuropa wird ein Temperaturanstieg zwischen 2 und 4 °C erwartet. Da neben der Temperaturentwicklung andere Klimaparameter eine Rolle spielen, reicht für verläßliche Folgenabschätzungen ein einziges Klimaszenario nicht aus. Neben einem Referenzszenario für das gegenwärtige Klima wurden deswegen mehrere Übergangsszenarien entwickelt. Sie zeichnen sich alle durch mehr warme und trockene Perioden im Sommer und gemäßigte und feuchte Winter aus.

Auswirkungen auf die Wasserressourcen:

Zwei regionale Wassermodelle wurden zur Abschätzung der Implikationen des möglichen Klimawandels benutzt. Für die angenommenen Übergangsszenarien errechnet das Modell eine Unterschreitung der kritischen Durchflußwerte in den Flüssen über einen verhältnismäßig längeren Zeitraum. Das könnte eine Verringerung der Wasserverfügbarkeit, eine Minderung der Wasserqualität und eine Beeinträchtigung der aquatischen Ökosysteme bewirken.

Auswirkungen auf landwirtschaftliche Erträge

Eine quantitative Untersuchung der Auswirkungen, die ein möglicher Klimawandel auf landwirtschaftliche Erträge hätte, erfordert regionale Langzeit-Simulationen. Eine derartige Studie wurde bisher nur für Weizen durchgeführt (vgl. AGREC Seite 111). Für andere Nutzpflanzen können bisher nur qualitative Abschätzungen vorgenommen werden. Ein Temperaturanstieg aufgrund höherer Kohlendioxidkonzentrationen wirkt sich auf den Wachstums- und Reifungsprozeß in zweifacher Hinsicht aus: Zum einen verkürzen höhere Temperaturen das Reifen der Körner, zum anderen nimmt das Wachstum aufgrund der Dünge-Effekte des Kohlendioxids zu. Während ersteres ertragsmindernd ist, steigert das zweite den Ertrag. Ob sich effektiv höhere oder niedrigere Erträge ergeben, kann erst durch entsprechende Rechnungen für die betroffenen Regionen und ihre Struktur gezeigt werden.

Auswirkungen auf Wälder und natürliche Ökosysteme:

Die Auswirkungen eines Klimawandels auf Wälder wurden mit zwei verschiedenen Ansätzen untersucht: Anhand von Sukzessionsmodellen, die beschreiben, wie eine Lücke im Bestand infolge der Konkurrenz verschiedener Spezies um Licht, Wasser und Nährstoffe aufgefüllt wird, kann die künftige Zusammensetzung simuliert werden. Mit einem Modell für Kiefernbestände wurden Wachstum und Ertrag speziell von Kiefern bei Klimaänderungen berechnet. Die Simulationen zeigten für Brandenburg, daß Buchenbestände infolge steigender Temperaturen und abnehmender Niederschläge zurückgehen, stattdessen auf nährstoffreichen Böden gemischte Laubwälder, auf nährstoffarmen Böden gemischte Kiefernbestände wachsen würden. Der Ertrag der Kiefernbestände würde seinerseits bei sinkenden Niederschlägen signifikant zurückgehen.

Auswirkungen auf die menschliche Gesundheit:

Die Auswertung von Sterbestatistiken weist auf teilweise zunehmende Todesfälle aufgrund der prognostizierten extremen Sommer hin. Hingegen wird bei Krankheiten wie Malaria, Ebola, Cholera oder Lepra keine Zunahme in Mitteleuropa erwartet.

Urbaner Lebensstil, Nachhaltigkeit und integrierte Umweltabschätzung (ULYSSES)
Dieses europäische Forschungsprojekt soll mögliche Distanzen zwischen Umweltforschung und demokratischem Handeln in der Klimapolitik überbrücken. Anhand von Diskussionsgruppen mit Bürgern zu jeweils einem umweltrelevanten Thema werden Meinungsbilder erstellt, die Politikern zugänglich gemacht werden sollen. Dadurch soll eine öffentliche Beteiligung an der Klimapolitik erreicht werden. Dies setzt voraus, daß die Beteiligten einen möglichst vollständigen Überblick über die relevanten Probleme und mögliche Lösungen haben. Ein Beitrag des PIK besteht darin, umfassende Szenarien zu den Auswirkungen des globalen Klimawandels zu entwickeln und diese den Diskussionsgruppen zur Verfügung zu stellen. Weiterhin beteiligt sich das PIK an der Ausrichtung von regionalpolitischen Foren mit Vertretern aus Wirtschaft, Politik und von Umweltorganisationen. In ihnen geht es um explizite, regionale Antwortstrategien zum Globalen Wandel. Außerdem untersucht das PIK die Frage, ob und unter welchen Bedingungen in Europa Kapital zur Entwicklung von Technologien, die fossile Brennstoffe nur minimal gebrauchen, zur Verfügung gestellt wird. Zu diesem Thema wurde ein Workshop mit Vertretern möglicher Investoren organisiert.

Auswirkungen klimatischer Extrema auf natürliche, soziale und Wirtschaftssysteme (WISE)
In diesem Gemeinschaftsprojekt britischer, niederländischer und italienischer Forschungseinrichtungen sowie dem PIK werden anhand veröffentlichter ökonomischer Daten die Auswirkungen heißer Sommer, warmer Winter und heftiger Windstürme auf sozioökologische Systeme in den beteiligten Ländern untersucht. Dies ist ein alternativer Ansatz der Klimafolgenforschung zu den Modellierungen sozioökonomischer Systeme auf der Basis von Klimaszenarien.
Die Auswirkungen auf Landwirtschaft, Tourismus, Wasser, Energieverbrauch und Brandgefahr werden regional erfaßt und überregionale Vergleiche angestellt. Soweit möglich sind die durch extreme Wetterbedingungen verursachten Kosten zu ermitteln. Um festzustellen, ob sich die Empfindlichkeit der sozioökonomischen Systeme auf klimatische Extrema ändert, werden die Auswirkungen derzeitiger Wetterperioden mit entsprechenden Beobachtungen aus den frühen 70er Jahren verglichen. Die sozialen Auswirkungen werden anhand von Befragungen analysiert, wobei insbesondere interessiert, ob bereits Anpassungen an veränderte Wetterbedingungen stattgefunden haben.

Projekte mit sektoraler Perspektive

AGREC - Agro-ökonomische Auswirkungen des Globalen Wandels

Das Kernprojekt “Agro-ökonomische Auswirkungen des Globalen Wandels” (AGREC) untersucht die Folgen eines möglichen Klimawandels auf die landwirtschaftliche Produktion und den Agrarmarkt in Zentral- und Westeuropa am Beispiel Deutschlands. Wichtige Fragen sind in diesem Zusammenhang:

- Inwieweit kann bei verändertem Klima die Nachfrage nach tierischen und pflanzlichen Rohstoffen abgedeckt werden, wenn die gegenwärtige Agrarstruktur beibehalten wird?
- Welche strukturellen Anpassungen des Agrarsektors an Klimaänderungen sind möglich und realistisch?
- Welche Kosten hätten vorbeugende agrarpolitische Maßnahmen, die eine strukturelle Anpassung an Klimaänderungen abwenden oder verzögern könnten?

AGREC soll zur Identifizierung derjenigen landwirtschaftlichen Aktivitäten beitragen, deren Modifizierung oder regionale Verschiebung Folgen einer möglichen Klimaänderung mindern könnten. Eine Hauptaufgabe besteht darin, mit Hilfe mechanistischer, prozessorientierter Ertragsmodelle Ertragsszenarien zu entwickeln, wobei die Abschätzung der Düngeeffekte des Kohlendioxid auf Pflanzenwachstum, Wasserverbrauch und Ertrag besonders wichtig ist. Daran anschließend sollen die ökonomischen Konsequenzen veränderter Nutzpflanzenerträge für Zentral- und Westeuropa analysiert werden.

Freiluftexperimente zum Anstieg des Kohlendioxids in der Atmosphäre – FACE
Die Kohlendioxidkonzentration in der Erdatmosphäre ist mit Beginn der Industrialisierung kontinuierlich gestiegen und wird sich bis zum Ende des 21. Jahrhunderts wahrscheinlich verdoppelt haben. Um die Auswirkungen dieser Entwicklung auf landwirtschaftliche Nutzpflanzen abschätzen zu können – etwa auf

Baumwolle, Weizen und Gerste – wurden in Arizona vom U.S. Water Conservation Laboratory Freiluftexperimente (Free-Air Carbon dioxide Enrichement; FACE) durchgeführt, an denen das PIK beteiligt war. Dabei wurden auf dem Versuchsfeld Düsen in kreisförmiger Anordnung (∅=22m) installiert (Bild 2 auf Seite 56), die die Nutzpflanzen innerhalb der Versuchsanordnung mit Kohlendioxid begasten. Die Konzentration des Kohlendioxid in der Luft wurde dadurch auf die für die Mitte des 21. Jahrhunderts prognostizierten Werte angehoben. Untersucht wurden die Kurz- und Langzeiteffekte des Kohlendioxid i) unter unveränderten Bedingungen, ii) mit einer zusätzlich um 30 % reduzierten Stickstoffversorgung bzw. iii) einer zusätzlich um 50 % reduzierten Wasserversorgung. Als Kontrolle dienten die auf dem Feld unter normalen Bedingungen wachsenden Nutzpflanzen. Bei allen Experimenten zeigte sich, daß bei einem höheren Kohlendioxidangebot die Pflanzen ihre Photosynthese steigern, durch Schließen der Stomata die Verdunstung reduzieren, damit das Wasser effizienter nutzen und gleichzeitig mehr Biomasse und Körner produzieren können. Diese Stimulation ist bei einem geringeren Wasserangebot deutlich größer als bei einem normalen, bei einem geringeren Stickstoffangebot nur leicht größer als bei einem normalen. Entgegen früheren Annahmen wurden keine Effekte gefunden, die auf eine "Akklimatisierung" an höhere Kohlendioxidkonzentrationen hindeuten (siehe Abb. 4 und 5 auf Seite 58).

Modellierung von Getreideerträgen

Auf der Basis der in den FACE-Experimenten gewonnenen Daten wurde 1993 begonnen, das Modell *demeter* zur Simulation des Wachstums von Weizen weiterzuentwickeln, so daß nun u.a. das physiologische Verhalten und der Energie- und Gasaustausch von Weizen mit einer Auflösung von Minuten bis zu Tagen, simuliert werden können. Für die Zielsetzung in AGREC wird zur Zeit überprüft, inwieweit das Modell *demeter* auf das europäische Wachstumsverhalten mit welchen Modifikationen anwendbar ist. Dazu wurden im sachsen-anhaltinischen Bernburg an der im FACE-Experiment untersuchten Weizensorte bei natürlicher Kohlendioxidkonzentration umfangreiche Freilandmessungen durchgeführt, und diese mit entsprechenden Simulationen verglichen (Bild 3 auf Seite 57). Daneben wurden für das Bundesland Brandenburg regional aufgegliederte Weizenerträge mit *demeter* simuliert und mit den tatsächlichen mittleren Erträgen des dort angebauten Weizens verglichen. Die Untersuchungen in Bernburg zeigten, daß das Verhalten der amerikanischen Weizensorten auch unter europäischen Wachstumsbedingungen mit *demeter* korrekt beschrieben wird. Die Ertragssimulationen für das Land Brandenburg ergaben hingegen systematische Abweichungen, die darauf zurückzuführen sind, daß die in den FACE-Experimenten verwendeten Weizensorten ein anderes Ertragsniveau erzielen als die in Brandenburg angebauten. Dies macht eine entsprechende systematische Korrektur einiger pflanzenspezifischer Parameter im Modell *demeter* bei der Anwendung auf andere Weizensorten erforderlich.

Simulation von Weizenerträgen für Brandenburg

Um festzustellen, wie sich mögliche Umweltänderungen auf die Erträge von Winterweizen auswirken, wurden mit dem Modell *demeter* die Weizenerträge bei den gegenwärtigen Wetter- und Umweltbedingungen und unter einer prognostizierten Klimaentwicklung untersucht. Die Simulationen erfolgten für drei Perioden: 1) 1983 - 1990, 2) 2023 - 2030 und 3) 2043 - 2050. Die Klimavorgaben der ersten Periode basierten auf beobachteten Wetterdaten, daneben waren für diese Periode die mittleren Erträge aller Landkreise in den einzelnen Jahren verfügbar. Bei der zweiten und dritten Periode wurden Szenarien u.a. mit einem allmählichen Temperaturanstieg um 1,5 °C bis 2050 und einer linearen Zunahme der Kohlendioxidkonzentration gemäß dem Trend der beiden letzten Jahrzehnte angenommen. Die Simulationen zeigten, daß die Weizenerträge Brandenburgs relativ unempfindlich gegenüber den verwendeten Szenarien sind. Von entscheidender Bedeutung für das Simulationsergebnis waren die Annahmen über Niederschlagsmenge und -verteilung sowie der Kohlendioxid-Düngungseffekt, der niedrigere Wachstums- und Ertragsaspekte weitgehend kompensierte (Bild 9 auf Seite 60).

CHIEF - Europäische Wälder unter dem Einfluß des Globalen Wandels

Wälder gehören zu den weltweit wichtigsten erneuerbaren Ressourcen. Sie liefern Holz, sind Erholungsgebiete, Lebensraum für Tiere und Pflanzen und bieten Schutz vor Hochwasser und Bodenerosionen. Global gesehen speichern Wälder einen Großteil des terrestrischen Kohlenstoffs und sind durch Photosynthese, Atmung und Mineralisierung an dem schnellen Austausch zwischen Biosphäre und Atmosphäre beteiligt. Dadurch spielen sie eine wichtige Rolle im Kohlenstoffkreislauf, der seinerseits die Entwicklung des

Erdsystems mitbestimmt. Zwar reagieren einerseits die meisten der Austauschprozesse empfindlich auf Klimaänderungen, andererseits tolerieren Wälder aber in einem gewissen Rahmen Klimaschwankungen. Erst wenn bestimmte Schwellenwerte z.B. in der Wasserversorgung oder der Windgeschwindigkeit überschritten werden, bricht das System plötzlich zusammen. Ziel des Kernprojektes CHIEF ist es daher, Art und Ausmaß möglicher Folgen des Globalen Wandels für i) Wachstum und die Artenzusammensetzung der Wälder, ii) die Waldbewirtschaftung und Forstökonomie und iii) die sekundären Waldfunktionen zu bestimmen. Die Untersuchungen werden unterschiedlich detailliert in europäischem, nationalem und regionalem Maßstab durchgeführt.

Regionale Studien

Wirkungen von Luftverschmutzungen auf Kiefernwälder in der Dübener Heide

Innerhalb der letzten zwei Jahre führten wir zwei regionale Studien durch. Im SANA-Projekt wurde die Entwicklung von über 5000 Kiefernwäldern in der Dübener Heide berechnet, wozu der Wasserkreislauf, die Stickstoff- und Kohlenstoffbilanz sowie Höhe und Durchmesser der Stämme und die Zahl der Bäume in gleichalten Beständen simuliert wurden. Dazu wurde das in CHIEF entwickelte Waldwachstumsmodell FORSANA benutzt, das, ausgehend von einer gegebenen Boden- und Bestandsinitialisierung, die Entwicklung von Kiefernwäldern unter Berücksichtigung von Witterung, Deposition, Düngung und Bewirtschaftung simuliert. Die Ergebnisse zeigten u.a., daß bei starker Luftverschmutzung die Blattdichte abnimmt, wodurch die Bedeutung der Bodenvegetation für den Wasser-, Kohlenstoff- und Stickstoffkreislauf steigt. Selbst in trockenen Jahren nehmen die Wälder jedoch mehr Kohlenstoff und Stickstoff auf, als sie abgeben (Bild 2 auf Seite 65).

Simulationen mit verschiedenen Klima- und Depositionsszenarien ergaben, daß in der Nähe von Industriezentren die Bäume um so stärker wachsen, je geringer die Luftverschmutzung ist. Dieser Effekt schwächt sich mit zunehmender Entfernung der Emittenten ab bis hin zu einem verminderten Wachstum aufgrund reduzierten Nährstoffangebots. Weitere Untersuchungen zeigten, daß sich Verminderungen im Wasserangebot, vor allem bei einer geringen Wasserspeicherkapazität des Bodens, auf das Wachstum auswirken.

Klimafolgen für Wälder in Brandenburg

Im Rahmen der *Brandenburgstudie*, in der die regionalen Auswirkungen von Klimaänderungen am Beispiel Brandenburgs untersucht werden, wurden mögliche Folgen für die Wälder abgeschätzt. Dazu verwendete man zwei Sukzessionsmodelle, die die Waldentwicklung auf kleinen Waldparzellen beschreiben. Die Modelle wurden so erweitert, daß in die Berechnung des Wachstums der verschiedenen Baumarten auch der Grundwasserspiegel einfließt. Simulationen mit beiden Modellen ergaben, daß sich Klimaänderungen stark auf die Zusammensetzung der Waldbestände in Brandenburg auswirken können (Bild 3 auf Seite 66). Bei einem angenommenen Temperaturanstieg um 3 °C gehen die Buchenbestände zurück und stattdessen breiten sich auf schlechten Böden Kiefernbestände, auf guten Böden Laubmischwald (Eichen, Linden, Hainbuchen) aus.

Nationale Wirkungsanalyse für den Sektor Forstwirtschaft

In Zusammenarbeit mit sieben anderen forstwissenschaftlichen Arbeitsgruppen werden im Projekt *Wälder und Forstwirtschaft Deutschlands im globalen Wandel* die Folgen von Klimaveränderungen für die Forstwirtschaft in Deutschland analysiert (Bild 4 auf Seite 67). Ein Ziel dieses Projektes ist es auch, optimierte Waldbewirtschaftungsstrategien als Reaktion auf veränderliche Umweltbedingungen zu entwickeln.

Entwicklung eines neuen Wald-Sukzessionsmodells

Sukzessionsmodelle, die seit ca. 20 Jahren zur Beschreibung des dynamischen Verhaltens von Wäldern verwendet werden, basieren auf der Annahme, daß das Wachstum von Bäumen von den Standortbedingungen, die durch Klima und Bodenqualität gegeben sind, und der Konkurrenz benachbarter Pflanzen um Licht, Wasser und Nährstoffe abhängt. Die bisher verwendeten Modelle beinhalten eine Reihe vereinfachter Annahmen, obwohl mittlerweile das Wissen über funktionale Abläufe in Pflanzengemeinschaften weit fortgeschritten ist. Deswegen wird in CHIEF das neue Sukzessionsmodell 4C entwickelt. Es simuliert das Wachstum natürlicher und bewirtschafteter Wälder unter Berücksichtigung des Wasser-, Kohlenstoff- und Stickstoffkreislaufes. Wichtige Prozesse werden mechanistisch beschrieben. In fünf Teilmodellen werden Wasser- und Nährstoffangebot im Boden, der jährliche Verlauf der Nettophotosynthese, die Verteilung der Kohlenstoffanreicherung auf die einzelnen Pflanzenteile aufgrund von Umwelteinflüssen, Zu- und Abgangsraten in den Populationen sowie menschliche Eingriffe und natürliche Störungen beschrieben (Bild 1 auf Seite 63).

RESOURCE - Soziale Dimensionen der Wasserverfügbarkeit

Regionale Frischwasserressourcen spielen eine herausragende Rolle als Lebensgrundlage und als Basis für die soziale, ökonomische und kulturelle Entwicklungsfähigkeit einer Region. Ohne sie wären weder Landwirtschaft noch Industrie möglich. Umgekehrt entstehen durch Wasserknappheit viele Probleme bis hin zu regionalen Auseinandersetzungen um knappe Ressourcen. Der Mittelmeerraum gehört zu den Regionen, wo Wasserknappheit und die damit verbundenen Probleme derzeit zunehmen, und die daran beteiligten Mechanismen gut beobachtet werden können. Zur Vermeidung von ernsthaften Konflikten und nachhaltigen Schädigungen des Ökosystems ist es notwendig, bald geeignete Maßnahmen zu finden. Mit dem Projekt Soziale Dimensionen der Wasserwirtschaft trägt das PIK zur Abschätzung der Anfälligkeit der Region durch Wasserknappheit und den damit verbundenen Folgen bei. Auf den Ergebnissen dieser Untersuchungen aufbauend, sollen Strategien zur Minderung der Verknappung einerseits und zur Anpassung an die Wasserverhältnisse andererseits entwickelt werden.
Die Aktivitäten des ehemaligen Kernprojekts *Auswirkungen des Globalen Wandels auf die Umwelt und die Gesellschaft der Mittelmeer und Maghreb Staaten* (CLIMAGHS), in dem Flut- und Dürrekatastrophen untersucht wurden, sind in RESOURCE aufgegangen.

Regionaldatenbank klima- und wasserrelevanter Parameter
Eine wichtige Voraussetzung für Trendanalysen zur Wasserknappheit einer Region ist die Entwicklung von Klimaszenarien. Dafür wird in RESOURCE die räumliche und zeitliche Struktur meteorologischer und hydrologischer Parameter basierend auf beobachteten und gemessenen Temperatur-, Niederschlags- und Feuchtigkeitswerten sowie der natürlichen Variabilität, analysiert (Beispiel in Bild 1 auf Seite 69). Eine so entstandene Datenbank für den Mittelmeerraum wird weiter ausgebaut.

Regionale Untersuchung sozioökonomischer Dimensionen von Wasserverfügbarkeit
In semi-ariden Regionen können schon kleine Änderungen der Niederschlagsmengen, der Temperatur und der Verdunstung drastische Änderungen im Wasserdargebot bewirken. Mit Hilfe regionaler Messungen hydrologischer Größen und der am PIK entwickelten hydrologischen Modelle können quantitative Vorhersagen über Änderungen im Wasserkreislauf getroffen werden. Dies ist eine notwendige Voraussetzung, um die Folgen für die Vegetation sowie den sozialen und wirtschaftlichen Wohlstand abschätzen zu können. Allerdings beeinflussen nicht nur Klimaänderungen die Wasserverfügbarkeit. Bevölkerungswachstum, wirtschaftliche Entwicklung und Änderungen der Landnutzung können beispielsweise ebenfalls positive oder negative Auswirkungen auf die Wasserressourcen haben. In Zusammenarbeit mit israelischen Partnerinstituten werden für die östliche Mittelmeerregion die entsprechenden Verkettungen analysiert und modelliert. Mit Hilfe der daraus resultierenden Trends für die Wasserverfügbarkeit sollen die Auswirkungen auf die Gesellschaft, beispielsweise durch eine verminderte landwirtschaftliche Produktivität, abgeschätzt werden. Eine Verminderung der Lebensqualität, etwa durch Dezimierung von Erholungsgebieten, sowie die Folgen für die natürliche Vegetation, etwa durch Versteppung, sollen ebenfalls durch eine regionale, integrierte Folgenabschätzung ermittelt werden. Bei der Analyse der ökonomischen Auswirkungen werden die Schäden und Verluste in monetären Werten dargestellt.

Abschätzung der regionalen Anfälligkeit für Wasserverknappung im Mittelmeerraum
Der Begriff der Anfälligkeit bezieht sich auf alle natürlichen und sozioökonomischen Eigenschaften einer Region, die sie für Krisen disponieren. Eines der Ziele in RESOURCE ist die integrierte Abschätzung der Anfälligkeit für Krisen und Konflikte im Zusammenhang mit Wasserressourcen für den Mittelmeerraum. Als erster Schritt dazu wurde ein geographisch bezogener kritischer Index auf die Region angewendet, der im Kernprojekt QUESTIONS gemeinsam mit einer Arbeitsgruppe an der Universität Kassel entwickelt wurde. Die Idee, die dem Index zugrunde liegt, ist im Prinzip einfach: Die Anfälligkeit einer Region für wasserinduzierte Probleme ist stark, wenn der Wasserverbrauch der natürlichen Wasserverfügbarkeit entspricht und gleichzeitig keine Maßnahmen zur Eindämmung dieses Problems zur Verfügung stehen. Umgekehrt ist sie schwach, wenn entweder genug Wasser natürlich vorhanden ist oder die Knappheit ausgeglichen werden kann, etwa durch Entsalzungsanlagen für Meereswasser, Tiefbrunnen oder Pipelines.
Der kritische Index bedient sich dreier komplexer Parameter, die jeweils verschiedene Informationen über den Mittelmeerraum miteinander kombinieren: Der erste bezieht sich auf den nationalen Wasserverbrauch, der zweite auf die berechnete Wasserverfügbarkeit und der dritte auf das Potential einer Gesellschaft, bei effektiver Wasserknappheit die Ressourcen mit Hilfe der oben angesprochenen Einrichtungen künstlich auf-

zufüllen. Allerdings herrscht keine Einigkeit darüber, in welchem Ausmaß der dritte Index eine tragfähige Rolle spielt. Diese Tatsache kann bei der Abschätzung der regionalen Anfälligkeit für wasserinduzierte Krisen berücksichtigt werden, indem die Rechnungen parallel mit mehr oder weniger starker Wichtung des dritten Parameters durchgeführt werden. Zwei Simulationen für das gegenwärtige und das für 2025 prognostizierte Klima, bei denen in einem Fall dem dritten Index eine hohe Relevanz, im anderen eine niedrige eingeräumt wurde, ergaben z.B. für Marokko, Jordanien und Ägypten u.a. folgendes: Selbst wenn diese Länder in der Lage wären, Entsalzungsanlagen, Tiefbrunnen usw. einzurichten, um der Wasserknappheit entgegenzuwirken, gerieten sie dennoch in eine massive Wasserkrise (Bild 2 auf Seite 70).

Wissenschaftliche Abteilungen

Abteilung Integrierte Systemanalyse

Der Erfolg moderner Wissenschaft beruht zu einem großen Teil auf einer immer feiner werdenden Zergliederung der betrachteten Probleme und Systeme. Um nun den Globalen Wandel, seine zivilisatorischen Ursachen und seine Auswirkungen auf Natur und Gesellschaft zu untersuchen, müssen zahlreiche Resultate dieses Ausdifferenzierungsprozesses reintegriert werden. Der Grund dafür ist u.a. die hohe Komplexität der Systeme, die es nicht erlaubt, erst die Einzelteile zu untersuchen und die Teilergebnisse dann additiv zu einem Gesamtresultat zu kombinieren. Neben diesem Problem der Re-Integration widmet sich die Abteilung Integrierte Systemanalyse Fragen zur Identifikation von Strategien für eine nachhaltige Entwicklung, erkenntnistheoretischen Problemen und der Weiterentwicklung von Methoden, die eine Analyse relevanter Eigenschaften des Erdsystems an sich erlauben. Konkret lassen sich einige der behandelten Fragestellungen wie folgt benennen:

- Ist es angebracht, die naturwissenschaftliche Perspektive “deterministischer Systeme” auch auf soziale Systeme anzuwenden? Oder umgekehrt: Lassen sich Regeln und Gesetze der unbelebten Natur auch in der Sprache der Soziologie ausdrükken, ohne daß dabei wichtige Details verlorengehen? Muß ein neuer transdisziplinärer Sprachgebrauch eingeführt werden, um Wissen aus einer Disziplin in eine andere einzubringen?
- Wie können normative Vorgaben durch die Politik integriert werden, ohne daß die “wissenschaftliche Kodierung von richtig und falsch (Luhmann)” verletzt wird? Wie lassen sich Strategien für eine nachhaltige Entwicklung formal beschreiben und bewerten?
- Kann die Komplexität des Erdsystems überhaupt durch Methoden der modernen Physik oder Mathematik adäquat beschrieben werden?

Methoden und Strategien

Die Erfahrungen, die in den vergangenen Jahren in integrierten Projekten gemacht wurden, z.B. bei der Zusammenführung von Prozessen, die auf unterschiedlichen Skalen ablaufen, haben gezeigt, daß es vorteilhaft ist, einen zentralen und gemeinsamen Fokus im Projektteam zu haben, etwa ein gemeinsames Modell oder ein gemeinsamer Formalismus bei der Analyse. Das bedeutet allerdings nicht, daß es eine einzige “beste” Herangehensweise gibt. Vielmehr ist auf der Basis der konkreten Fragestellung eine adäquate Vorgehensweise zu entwickeln, die diese Aufgabe erfüllen kann. Innerhalb der Abteilung werden hier insbesondere Methoden der *zyklischen Integration*, der Metamodellierung, der Entwicklung von Minimalmodellen oder der formalen qualitativen Analyse und Modellierung entwickelt.

Komplexe Systemanalyse

In den letzten ca. 20 Jahren sind in der Physik und Mathematik zahlreiche Methoden zur Analyse komplexer Systeme entwickelt worden, die Aussagen über fundamentale Eigenschaften dieser Systeme, wie z.B. Zahl der Freiheitsgrade oder topologische Merkmale, erlauben. In der Abteilung wurden hier u.a. zelluläre Automaten genutzt, um eine räumlich explizite Erweiterung des berühmten “Daisy World” Modells von Lovelock zu untersuchen. Hierbei wird die Antwort eines virtuellen, nur aus Pflanzen unterschiedlicher Farbe bestehenden Planeten auf Kontrollparameter wie Fragmentierung der Landschaft oder Sonneneinstrahlung simuliert. Zu den wichtigsten Resultaten zählt der Nachweis der Existenz eines für die klimatische Stabilität des Planeten kritischen Schwellenwerts. Andere Anwendungen betreffen die Nutzung künstlicher neuronaler Netze für die Entwicklung einer

nicht-linearen, nachbarschaftserhaltenden Kategorisierung, z.B., des Klimas oder für die vereinfachte und hocheffiziente 'reduzierte Modellierung' der natürlichen Vegetation.

Kontrolltheorie
Zahlreiche Untersuchungen zum Globalen Wandel arbeiten mit Szenarien, d.h., basierend auf Annahmen über mögliche "Zukünfte" einiger treibender Größen werden – z.B. mit Hilfe von Modellen – Aussagen über die Reaktion davon abhängiger Variablen untersucht. Im Gegensatz dazu versucht die Kontrolltheorie Strategien und Methoden für das Erreichen expliziter Zielvorgaben zu entwickeln. Hierbei leistet die Abteilung methodisch-konzeptionelle Beiträge über Differentialinklusionen und Fuzzy-Steuerung. Erstere werden zur Formalisierung des sog. Pessimierungs-Paradigmas verwendet, in dem unter Vorgabe explizit als nicht-tolerabel angesehener Erdsystemzustände (z.B. Abschalten der für Nord- und Mitteleuropa als 'Wärmepumpe' agierenden nordatlantischen Tiefenwasserbildung bei einer globalen Erwärmung) Strategien für die garantierte Vermeidung solcher Zustände gesucht werden. Darüber hinaus wurden in einem konzeptionellen Modell zur Fuzzy-Steuerung erste Ansätze für solche "Vermeidungsstrategien" entwickelt, die im wesentlichen nur auf Kenntnissen lokaler, zeitlich und räumlich begrenzter, Information auskommen.

Abteilung Klimaforschung

Die Abteilung Klimaforschung konzentriert sich auf grundlegende Probleme im Zusammenhang mit der Diagnose von Klimadaten, der Erstellung von Szenarien zum Klimawandel und der Modellierung des Klimasystems. Dies ist eine Ausweitung der ursprünglichen Aufgabenstellung, die anfangs nur die Zulieferung von Klimadaten und Klimaszenarien an die anderen Abteilungen beinhaltete.

Klimaanalyse und Diagnostik
Voraussetzung für jede klimabezogene Forschung ist eine sorgfältige Analyse des Klimas in der Vergangenheit und in der Gegenwart auf der Basis von qualitativ hochwertigen Daten und durch Rekonstruktion aus sekundären Befunden wie beispielsweise die Abschätzung der Sommertemperaturen anhand der gefundenen Menge fossiler Pollen. Klimaanalyse betrifft nicht nur die "einfachen" klimatischen Mittelwerte wie mittlere Monatstemperatur und mittleren Jahresniederschlag. Für viele Anwendungen in der Klimafolgenforschung werden vielmehr Informationen über klimatische Extrema benötigt, beispielsweise Härte und Dauer von Kälteperioden. Wegen des nichtlinearen Charakters des Klimasystems werden die Klimadaten mit Hilfe von multivariaten statistischen Methoden analysiert und diagnostiziert. Derartige Methoden werden in unserer Abteilung entwickelt und angewandt.
Die Methoden für die Datenanalyse und -diagnose werden außerdem für die Bewertung von Ergebnissen aus Klimamodellierungen herangezogen. Dies trägt nicht nur zur Verbesserung der Modelle bei, sondern auch zum besseren Verständnis und zu einer angemessenen Bewertung der Ergebnisse der Modellierung in der Klimafolgenforschung.

Ein wichtiger Fundus für alle klimatologischen Untersuchungen ist eine umfangreiche Datenbank, die den Qualitätsansprüchen der einzelnen wissenschaftlichen Untersuchungen entspricht. Zu diesem Zweck erstellte die Abteilung in den vergangenen Jahren eine Klimadatenbank, und es wurden Algorithmen zur Qualitätskontrolle und statistischen Analyse entwickelt. Da bereits eine Vielzahl unterschiedlichster Klimadatenbanken weltweit existiert, werden in der PIK-Datenbank schwerpunktmäßig Langzeitserien von meteorologischen Daten gesammelt, die täglich erhoben worden sind. Gegenwärtig verfügt sie über 2.500 Datenreihen, von denen 400 länger als 50 Jahre, 800 länger als 20 Jahre und 1.300 länger als 15 Jahre sind. Die wichtigsten meteorologischen Parameter der Daten sind Lufttemperatur, Niederschlag, relative Feuchtigkeit, Bewölkung, Sonnenscheindauer, Luftdruck, Windgeschwindigkeit und Dampfdruck. Darüber hinaus wurden für spezielle Aufgaben weitere Datenreihen gesammelt.

Klimaszenarien
Um die Auswirkungen jeglichen Klimawandels auf natürliche und soziale Systeme zu untersuchen, müssen zunächst Klimaszenarien entwickelt werden. Dabei handelt es sich nicht um Vorhersagen! Da menschliche Aktivitäten – etwa die Emission von Treibhausgasen, Veränderungen in der Landnutzung – das Klima maßgeblich beeinflussen, und da diese Aktivitäten kaum vorhersagbar sind, kann auch das Klima selbst nicht vorhergesagt werden. Stattdessen werden anhand verschiedener Einschätzungen der wirtschaftlichen und sozialen Entwicklung und, damit verbunden, der Entwicklung von Treibhausgasemissionen, Ein-

schätzungen möglicher Klimaentwicklungen – sogenannter Klimaszenarien – berechnet. Ausgangspunkt bei der Erstellung von Klimaszenarien sind numerische Klimamodelle, statistische Modelle und Kombinationen von beiden.

Klimasystemmodellierung
Die Untersuchung des Klimawandels bezieht sich nicht nur auf die Analyse vergangener Klimate und die Abschätzung der Klimaentwicklung in den nächsten Jahrzehnten oder Jahrhunderten. Darüber hinaus interessiert auch die Wechselwirkung zwischen den verschiedenen Komponenten des Klimasystems, wie Atmosphäre, Hydrosphäre (in erster Linie Meere und Flüsse), Kryosphäre (vor allem Inlandeis, Permafrost und Schnee), die marine und die terrestrische Biosphäre und die Lithosphäre (Bereich des oberen Erdmantels), die insbesondere die Pedosphäre (hauptsächlich die Böden) enthält.
In der Abteilung Klimaforschung wurde ein Klimasystemmodell mittlerer Komplexität namens CLIMBER entwickelt. Im Gegensatz zu den komplexen Modellen arbeitet CLIMBER nicht mit größtmöglicher Raum- und Zeitauflösung, was umfangreiche Rechenleistungen und Speicherkapazitäten beanspruchen würde. Vielmehr soll das Zusammenspiel aller Komponenten des Klimasystems untersucht werden. Deshalb liefert CLIMBER eine zwar relativ grobskalige aber effiziente Beschreibung . Es ist mindestens tausend mal schneller als die komplexen Modelle und eignet sich deswegen für die Klimasystemanalyse. Außerdem soll CLIMBER Teil des Potsdamer Erdsystem-Modells werden.
Mit Hilfe dieses Modells sollen Fragen nach der Rolle der Vegetation im Klimasystem ebenso beantwortet werden, wie die Ursache für die starken Klimaschwankungen der letzten Eiszeit. Beispiele dafür sind die deutlichen Änderungen in der Nordatlantischen Strömung, der Warmwasserheizung Europas und großer Teile der nördlichen Hemisphäre, und als Folge davon drastische Temperaturänderungen zwischen eiszeitlichen und zwischeneiszeitlichen Bedingungen. Ein Wiederaufflackern dieser Klimaumschwünge heutzutage würde eine massive Bedrohung für die menschliche Gesellschaft darstellen.

Abteilung Globaler Wandel und Natürliche Systeme

Ökosysteme sind die Produzenten von Nahrung, Süßwasser, Holz und anderen Lebensgrundlagen und damit die Voraussetzung allen menschlichen Lebens auf der Erde. Dafür benötigen sie lediglich fruchtbare Böden und ein geeignetes Klima. In der Abteilung Globaler Wandel und Natürliche Systeme untersuchen wir die Rolle der Landvegetation aus zwei Blickwinkeln: i) wie empfindlich reagieren natürliche und kultivierte Vegetation auf Veränderungen in der Umwelt und ii) welche Rückkopplungsmechanismen bestehen zwischen Veränderungen der Vegetation und der Atmosphäre?
Die Frage nach der Empfindlichkeit ist einfach und zugleich kompliziert: Einerseits ist das geographische Muster der Landvegetation offensichtlich klimabedingt; die Bedeutung langfristiger Klimatrends liegt ebenso auf der Hand wie die kurzfristige Entwicklung des Wetters. Gleichzeitig gibt es ein kompliziertes Wechselspiel zwischen der Verfügbarkeit von Sonnenlicht und Nährstoffen (darunter Kohlendioxid) sowie ausreichender Feuchtigkeit und Wärme für die Pflanzen. Die Arbeit in der Abteilung zielt darauf ab, dieses Wechselspiel auf verschiedenen Skalen zu untersuchen und dabei die Mechanismen, die auf der jeweiligen Maßstabsebene zum Tragen kommen, zu identifizieren und besser zu verstehen.
Eine globale Frage ist die Bedeutung der Vegetation für das Klima. Änderungen in der Struktur der Landoberfläche sowie deren Albedo, die beide stark von der Bodenvegetation abhängen, beeinflussen durch physikalische Rückkopplungen das gesamte Erdsystem. Noch wichtiger ist die Bedeutung der Vegetation für den Kohlenstoffkreislauf, eine der größten Unsicherheiten bei der Abschätzung der Auswirkungen künftiger Klimaänderungen.
Die “Natürlichen Systeme” der Erde können nicht losgelöst von menschlichen Aktivitäten betrachtet werden. Dazu werden in der Abteilung regionale Studien zur Empfindlichkeit von kultivierten Ökosystemen wie Forst- und Ackerflächen angestellt. Außerdem untersuchen wir die Rolle der globalen Landnutzung und deren Änderung, um dies bei der Modellierung der globalen Kohlenstoffkreisläufe einzubringen. Die Änderung der Landnutzung an sich wird am besten durch die von Sozialwissenschaftlern entwickelten Szenarien beschrieben.
Typische Forschungsthemen der Abteilung sind: Wie ändert sich die natürliche Vegetation als Antwort auf eine mögliche Klimaänderung? Auf welchen Zeitskalen findet – wenn überhaupt – eine Anpassung statt? Welche Bedeutung hat die Landvegetation für die globalen biogeochemikalischen Kreisläufe wie den Koh-

lenstoff-, Wasser- oder Stickstoffkreislauf? Wie wirkt sich der Kohlendioxid-Anstieg auf die Vegetationsdynamik aus? Welche Auswirkungen haben regionale Änderungen der Wasserbilanz auf die natürliche Vegetation, die Wasserverfügbarkeit und das Hochwassermanagement? Welche möglichen Auswirkungen haben Klimaänderungen auf die regionale Forst- und Landwirtschaft?
Da präzise Vorhersagen über die regionale Klimaentwicklung und Landnutzung nicht möglich sind, wird bei der Abschätzung der Empfindlichkeit des Ökosystems gegenüber künftigen Trends auf mögliche Umweltszenarien zurückgegriffen. Die meisten Prozesse des Globalen Wandels lassen sich am besten mit Simulationsmodellen analysieren. Derartige Modelle zur Untersuchung unterschiedlicher Aspekte wie Wasserverfügbarkeit, Entwicklung von Waldbeständen oder Gas- und Energieaustausch zwischen Pflanzen und ihrer Umgebung existieren bereits. Um sie für Untersuchungen zu implementieren, die je nach Fragestellung das gesamte Erdsystem oder integrativ einzelne Regionen beschreiben, müssen sie jedoch modifiziert, in manchen Fällen sogar neu entwickelt werden. Die Bewertung von Ergebnissen der Modellierungen im Verhältnis zu Beobachtungen ist dabei ein schwieriges Problem und ist deswegen ein weiterer Schwerpunkt der Arbeit, u.a. unter Nutzung von Satellitendaten und Daten aus Feldexperimenten.

Arbeitsgruppen der Abteilung

Globale Dynamik der Biosphäre
In der Gruppe wird ein umfassendes Modell zur Beschreibung der Gesamtdynamik der Biosphäre (DGVM) entwickelt, das später in das POEM-Erdsystem Modell integriert werden soll. Ihm liegt die Annahme zugrunde, daß physikalische und biogeochemische Rückkopplungen zwischen Vegetationsänderungen und dem Klima verantwortlich für die Trägheit und für Bifurkationen des gekoppelten Systems sind. Neben der Entwicklung des Modells gibt es weitere Aufgaben die sich mit i) der detaillierteren Analyse der Dynamik des Ökosystems beschäftigen und dabei beispielsweise Konkurrenz und Störungen berücksichtigen, ii) das Verhalten der Biosphärenmodelle anhand von Satellitendaten bewerten und verbessern und iii) die derzeitigen Ansätze zur Simulation der Biosphärenkreisläufe überprüfen, um den globalen Kohlenstoffkreislauf besser zu verstehen.

Hydrologie und Wasserressourcen
Der Wasserkreislauf ist für alle Aspekte der Klimawirkung auf Landökosysteme von zentraler Bedeutung. Grundsätzlich zu unterscheiden sind die vertikale und die horizontale Fließrichtung des Wassers. In der Gruppe werden Module für Simulationen in anderen Arbeitsgruppen entwickelt. Außerdem werden regionale Flüsse in die Einzugsgebiete integriert. In enger Verbindung mit dem RAGTIME und dem WAVES Projekt arbeitet die Hydrologie-Arbeitsgruppe daran, die Wirkung von Änderungen des Klimas oder der Landnutzung auf Frischwasserverfügbarkeit und Wasserqualität in unterschiedlichen Skalen zu simulieren.

Wälder und Forstwirtschaft
Die Gruppe erarbeitet einen neuen Ansatz, mit dem die Dynamik von kultivierten und natürlichen Wäldern simuliert und damit die Empfindlichkeit gegenüber Umweltveränderungen abgeschätzt werden kann. Dieses im Kernprojekt CHIEF entwickelte Modell berücksichtigt gegenüber früheren Waldmodellen auf angemessenere Weise die Physiologie des Baumwachstums und simuliert explizit die Waldbewirtschaftung. In einer bundesweiten Pilotstudie werden seit 1997 die Auswirkungen eines Klimawandels auf die Wälder in Deutschland untersucht.

Landwirtschaft
Zwei Faktoren des Globalen Wandels beeinflussen den Agrarsektor entscheidend: Die klimatischen Bedingungen, vor allem die Wasserverfügbarkeit in Verbindung mit dem Kohlendioxidangebot, sowie der Weltagrarmarkt, der seinerseits empfindlich von klimatischem und sozioökonomischem Wandel abhängt. Für die Ertragsabschätzung verwendet die Gruppe ein von ihr entwickeltes modernes Simulationsmodell für Weizenerträge, dessen Parametrisierung auf den Ergebnissen von Freiluftexperimenten (Free-Air Carbon dioxide Enrichment, in Maricopa, Arizona, USA) basiert. Für andere Getreidearten werden eine Reihe unterschiedlich komplexer Modelle verwendet. Sie alle werden im Kernprojekt AGREC eingesetzt, um abzuschätzen, wie empfindlich der gesamte Agrarsektor auf den Globalen Wandel reagiert.

Internationale Kooperationen
Die Abteilung ist über die IGBP-Kernprojekte BAHC (Biospheric Aspects of the Hydrological Cycle) und GCTE (Global Change and Terrestrial Ecosystems) eng in das Internationale Geosphären-Biosphären Programm eingebunden, in das eine Vielzahl wissenschaftlicher Beiträge direkt einfließt. Darüber hinaus engagieren sich viele Mitarbeiterinnen und Mitarbeiter persönlich in Funktion und Koordination des IGBP und weiterer internationaler Programme.

Abteilung Globaler Wandel und Soziale Systeme

Der Globale Wandel mit seiner Vielzahl von Erscheinungsformen ruft eine wachsende Beunruhigung über die Konsequenzen langfristiger, weitreichender Wechselwirkungen zwischen sozialen Systemen und ihrer natürlichen Umgebung hervor. Die Abteilung Globaler Wandel und Soziale Systeme untersucht beide Richtungen dieser Mensch-Umwelt-Beziehung. Ziel ist es, unser Verständnis über die sozioökonomischen Triebkräfte zu verbessern, die den Globalen Umweltwandel auslösen, um die Auswirkungen des Globalen Umweltwandels auf die menschliche Gesellschaft besser abschätzen zu können. Letztendlich sollen diese Studien in ein ganzheitliches Gerüst münden, das die komplexe Dynamik der Wechselwirkung zwischen Mensch und Natur erhellen soll. Wir untersuchen die sozialen Dimensionen des Globalen Wandels auf folgenden Gebieten:

Makroökonomische Modellierung
Die Bereitschaft, zur Verhinderung eines Anstiegs der Treibhausgase in der Atmosphäre effektive und effiziente Strategien einzusetzen – was groß angelegt nur über eine internationale Klimapolitik organisiert werden kann – läßt sich entscheidend durch Kosten-Nutzen-Analysen motivieren. Die Entwicklung eines Modellgerüstes, das derartige Analysen unterstützt, und die Einbettung vieler geeigneter Modelle aus den Einzeldisziplinen in dieses Gerüst ist das Ziel dieser Forschungsaktivitäten. Es soll die Bewertung potentieller, durch den Klimawandel verursachter Schäden ermöglichen und die Kosten ermitteln, die durch Maßnahmen zur Eindämmung des Klimawandels entstehen. Kernpunkt solcher Analysen ist die Ermittlung zeitlich optimierter Pfade der wirtschaftlichen Entwicklung. Deren Plausibilität hängt entscheidend davon ab, inwieweit Defizite der mathematisch-ökonomischen Modellierung bei der Abbildung der Dynamik makroökonomischer Systeme und bei der empirischen Fundierung sozioökonomischer Szenarien überwunden werden können.

Internationale Umwelteinrichtungen
Dieser Forschungsschwerpunkt beschäftigt sich – unter Berücksichtigung der unterschiedlichen Interessen der einzelnen Parteien – mit der Analyse von Umweltverträgen, insbesondere mit den Klimaprotokollen und den Verhandlungsprozessen an sich, sowie mit der Effektivität der verschiedenen politischen Instrumente zum Schutz des Klimas, z.B. handelbaren Emissionszertifikaten oder Kohlendioxidsteuern. Dazu werden sowohl Methoden der nicht-kooperativen wie auch der kooperativen Spieltheorie angewandt. Angrenzend an diese Aktivitäten untersuchen wir auch die auf unterschiedlichen Gleichheitsprinzipien beruhende, internationale Verteilung von Emissionsrechten. In einem weiteren Punkt beschäftigen wir uns damit, wie sich die Unsicherheit wissenschaftlicher Aussagen – ein zentrales Charakteristikum globaler Umweltprobleme – auf internationale Verhandlungsprozesse auswirkt.
Auch entwickeln wir ein Meßinstrument für die Effizienz internationaler Umweltverträge hinsichtlich der Verringerung grenzüberschreitender Umweltverschmutzung. Um die Umsetzung internationaler Umweltverträge bewerten zu können, haben wir ein standardisiertes Evaluierungssystem entwickelt. Es wurde bereits auf Abkommen angewandt, mit denen die Umweltverschmutzung in Europa reguliert werden soll.

Regionales Umweltmanagement und Umweltsicherheit
Unter dieser Überschrift werden Themen, die im Zusammenhang mit Wasserressourcen stehen, untersucht. Ziel ist es, Werkzeuge für das Wassermanagement zu entwickeln, die sich zur Überwindung regionaler Frischwasserknappheit eignen.
Insbesondere beschäftigen uns die kriegerischen Konflikte um Wasserressourcen. In diesem Zusammenhang werden u.a. Methoden entwickelt, die eine Minderung der Ressourcen verhindern sollen. Mittels eines speziell auszuarbeitenden Verfahrens soll prognostiziert werden, oberhalb welcher umweltbezogener Schwellenwerte gewaltsame Auseinandersetzungen um Wasserressourcen zu erwarten sind.

Umweltpsychologie und -soziologie
Eine der Hauptfragen zum Sozialverhalten des Menschen als Risikofaktor für eine stabile Umwelt ist, warum und auf welche Weise die zivilisierte Menschheit weltweit die natürlichen Ressourcen durch Übernutzung und Verschmutzung mißbraucht und damit zerstört. Soziologie und Psychologie scheinen geeignete Disziplinen zur Untersuchung dieses Phänomens zu sein. Letztere konzentriert sich auf das Individuum, seine inneren und äußeren Motive und Zwänge, während erstere die sozialen Systeme im Umfeld des einzelnen untersucht.
Die weitgesteckten Forderungen von Umweltaktivisten vernachlässigen wichtige Aspekte der Sozialstruktur und der Dynamik moderner Gesellschaften. So verlangen sie u.a., daß wir “unseren” Lebensstil ändern sol-

len, obwohl mit Hilfe von Methoden aus der Soziologie und der Marktforschung empirisch gezeigt wurde, daß es so etwas wie “unseren” oder “den” modernen Lebensstil nicht gibt. Je stärker ein Land entwickelt ist, desto pluralistischer ist seine Sozialstruktur einschließlich der Werte, Einstellungen und Verhaltensweisen. Diese Pluralität erstreckt sich auch auf den täglichen Umgang mit der Umwelt; so findet man innerhalb eines Landes um den Faktor fünf differierende Unterschiede in den verbraucherseitigen Kohlendioxidemissionen. Strategien zur Änderung des Musters modernen Konsumverhaltens müssen deswegen spezifisch auf unterschiedliche Lebensstile zugeschnitten sein.

Dynamik der Syndrome des Globalen Wandels
Hauptaufgabe dieser Forschungsaktivität ist die sozialwissenschaftliche Analyse der anthropogenen Ursachen und Symptome des Globalen Wandels. Dabei verwenden wir den Syndrom-Ansatz, der im Kernprojekt QUESTIONS beschrieben wird.

Abteilung Data & Computation

Klimafolgenforscher und -forscherinnen sind in besonderem Maße auf digitale Modelle und die mit ihrer Hilfe durchgeführten Simulationen auf Hochleistungsrechnern angewiesen, da die betrachteten Systeme kaum experimentell untersucht werden können. Der Komplex *Modellierung und Simulation* umfaßt die mathematische Modellierung eines gegebenen Systems, die Diskretisierung des abstrakten mathematischen Modells, die Formulierung von Algorithmen und deren Implementierung auf modernen Rechenanlagen, die eigentlichen Berechnungen und die sorgfältige Bewertung und Interpretation der Ergebnisse. Die Modellierung komplexer, nichtlinearer Wirkungszusammenhänge von Umwelt- und sozio-ökonomischen Systemen im regionalen und globalen Maßstab erfordert einen hochgradig transdisziplinären Modellierungsansatz, der nur mit Hilfe einer flexiblen, objekt-orientierten Softwareumgebung umgesetzt werden kann.
Die Abteilung Data & Computation unterstützt folgende Facetten der Forschung des PIK:

- Modellierung: mathematische Modellbildung, Diskretisierung, Algorithmen.
- Programmierung: Software Analyse und Design, objekt-orientierte Programmierung, Datenmodellierung.
- Produktion: Höchstleistungsrechner, hierarchisches Speichermanagement, Datennetze, rechnerbasierte Kommunikation und Publikation.
- Interpretation: Statistik, Visualisierung.

Transdisziplinarität – Beiträge zu den Kernprojekten
Die rechnergestützte Simulation komplexer Umweltsysteme erfordert mathematische Modelle, die alle wesentlichen Mechanismen umfassen müssen, aber nicht zu komplex sein dürfen, damit Berechnungen innerhalb vertretbarer Zeiten möglich sind. Erfolgreiche Modellierung bedingt deshalb eine genaue Kenntnis der betrachteten Systeme und deren mathematischer Eigenschaften. Eine ähnliche Kombination von Fachwissen wird für die Formulierung von Modellen in Programmiersprachen und die Auswertung und Prüfung der produzierten Daten benötigt. Dies bietet der Abteilung Data & Computation weitreichende Möglichkeiten sowohl für eigenständige Forschungen in den Bereichen Mathematik und Informatik als auch für die aktive Teilnahme an transdisziplinären Forschungsaktivitäten des PIK. Einige ausgewählte Beiträge zu PIK Kernprojekten:
AGREC und POEM: Für eine Studie zum Einfluß möglicher Klimaänderungen in Mitteleuropa auf die Produktivität natürlicher und landwirtschaftlicher Systeme wurden spezielle Techniken geographischer Informationssysteme eingesetzt, um Modelle zu parametrisieren und Resultate zu verarbeiten .
CHIEF: Die Sukzessions- und Wachstumsdynamik von Wäldern im regionalen Maßstab unter möglichen Klimaänderungen wurde mit Hilfe der in der Abteilung D & C entwickelten parallelen Simulationsumgebung SPRINT-S berechnet. Das ermöglicht die einfache und flexible Durchführung komplexer Simulationsexperimente und räumlich expliziter Modellstudien auf Parallelrechnern.
POEM: Die neue parallelisierte Implementierung eines zweidimensionalen geophysiologischen Modells verwendet die in der Abteilung entwickelte GeoPar-Programmbibliothek. Die Parallelisierung des CLIMBER-Modells ist in Vorbereitung. Gleichzeitig soll dieses Modell in einer objekt-orientierten Version implementiert werden, um numerische Effizienz und Programmqualität der verschiedenen Versionen vergleichen zu können.
RAGTIME: Die Abteilung baute ein geographisches Informationssystem mit geprüften Geo- und Raumdaten und eine relationale Zeitreihendatenbank für den deutschen Teil des Elbe-Einzugsgebietes auf. In letzterer sind Metadaten von über 1400 Meßstationen und etwa 19 Millionen Datensätze erfaßt.

WAVES: Die Portierung und Parallelisierung eines regionalen Klimamodells (REMO 0.1) wurde abgeschlossen. Ein Algorithmus zur Clusteranalyse konnte wesentlich verbessert werden.

Rechnerinfrastruktur
Die hochleistungsfähige informationstechnische Infrastruktur ist eine wesentliche Grundlage der wissenschaftlichen Arbeit des PIK. Hardwareseitig besteht sie gegenwärtig aus einem 77-Prozessor Parallelrechner (Typ IBM SP), Festplattenspeicher mit einer Kapazität von 800 Gigabyte, die durch 10 Terabyte Bandspeicher ergänzt und gesichert werden, sowie 150 Workstations und PCs. Alle Ressourcen sind durch ein Rechnernetzwerk intern und mit dem Internet verbunden. Die Verfügbarkeit der Serversysteme lag im Berichtszeitraum bei über 99%. In gemeinsamer Anstrengung konnte 1997 ein Regionales Hochleistungsdatennetz der Potsdamer Wissenschaftseinrichtungen errichtet werden, das dem PIK – neben verbesserten Möglichkeiten der Kooperation innerhalb der Potsdamer- und Berliner Wissenschaftslandschaft – den Zugang zum Breitband-Wissenschaftsnetz und dem Internet mit einer Bandbreite von gegenwärtig 4 Mbps gestattet.
Im Bereich Software wurde zur Effizienzsteigerung der für den Erfolg des PIK wesentlichen Dokumentations- und Publikationsarbeit eine digitale Publikationsumgebung etabliert, die allen Mitarbeitern des Hauses einen standardisierten Rahmen für die Produktion von Druck- und Online Publikationen im World-Wide-Web bietet. Erwähnenswert sind weiterhin die Anstrengungen, die zur Optimierung der Speicherhierarchie unternommen wurden, die Einrichtung einer Lastverteilung für Parallelrechner und Workstations und – last but not least – die wesentlich verbesserte Datensicherheit (allgemeine Datensicherung und Katastrophenschutz).

Wissenschaftliches Datenmanagement
Eine Reihe geowissenschaftlicher Institute in Deutschland haben sich zusammengeschlossen, um ihre Datenbestände mit Hilfe von Metadaten zu beschreiben und durch ein standardisiertes Metadatenmodell gegenseitig zugänglich zu machen. An diesem Projekt sind neben dem PIK das Deutsche Klimarechenzentrum, das Alfred-Wegener-Institut für Polar- und Meeresforschung und das Forschungszentrum Karlsruhe beteiligt. 1996 und 1997 wurde ein gemeinsames, modular aufgebautes Datenmodell für Klima- und Umweltmetadaten entworfen (CERA 2.3) und bei allen beteiligten Einrichtungen implementiert. Das PIK entwickelte auf der Basis dieses Datenmodells eine allgemein einsetzbare, grafisch-interaktive Schnittstelle zwischen Mensch und Maschine, die durch den Einsatz der Programmiersprachen Java und Hypertext Markup Language eine sehr komfortable, standort- und plattformunabhängige Navigation durch die geographisch verteilten Datenbestände ermöglicht.

Wissenschaftliche Funktionseinheiten

Ein wesentliches Element in der Forschungsstrategie des PIK sind die Kooperationen mit Partnerinstituten innerhalb und außerhalb Deutschlands. Diese Zusammenarbeit wird dadurch erleichtert, daß die Forschung bei interdisziplinären Projekten und Programmen auf nationaler und internationaler Ebene abgestimmt wird. Zur Unterstützung dieses Prozesses gibt es am PIK die folgenden Einheiten:

- Wissenschaftliche Kooperation und Öffentlichkeit
- Kolleg Globaler Wandel
- Unterstützung des Internationalen Geosphären-Biosphären Programms (IGBP) und
- Biosphären Aspekte des Hydrologischen Kreislaufs (BAHC), ein Kernprojekt des IGBP

Wissenschaftliche Kooperation und Öffentlichkeit
Koordination: Wissenschaftliche Begegnungen werden organisiert und arrangiert, beispielsweise durch Workshops, Konferenzen sowie durch die Betreuung von Besuchern und Gastwissenschaftlern.
Öffentlichkeitsarbeit und Kontakte: Kommunikation und Austausch zwischen den Medien und Institutsangehörigen werden ebenso in die Wege geleitet wie die Publikation von regelmäßigen Veröffentlichungen. Auch der Informationsaustausch zwischen den wissenschaftlichen Abteilungen und der Administration wird durch diese Einheit gefördert und unterstützt.

Kolleg Globaler Wandel
Die am PIK gehaltenen Vorlesungen einschließlich der IGBP Aktivitäten, der Einladung von Gastwissenschaftlern und Workshops werden unter dem Namen “Kolleg Globaler Wandel” zusammengefaßt. Beteiligt an diesen Aktivitäten sind sowohl Wissenschaftler des PIK als auch internationale Gäste. Der Aufenthalt von Gastwissenschaftlern am PIK soll zukünftig weiter ausgebaut werden.

Das Internationale Geosphären-Biosphären Programm – IGBP

Das IGBP ist 1989 mit dem Ziel ins Leben gerufen worden, die miteinander wechselwirkenden physikalischen, biologischen und chemischen Prozesse zu beschreiben und zu verstehen, die das gesamte Erdsystem sowie die einzelnen Untersysteme regulieren. Die Änderungen in diesen Systemen sollen ebenso untersucht werden wie die Art und Weise, auf die der Mensch diese Systeme beeinflußt.

Derzeit gliedert sich das IGBP in 11 Kernprojekte, die sich mit den sechs grundlegenden Fragen zum Globalen Wandel beschäftigen, die vom IGBP formuliert wurden.

Zur Unterstützung des Internationalen Geosphären-Biosphären Programms (IGBP) sind das Büro des internationalen Kernprojektes Biosphären Aspekte des Hydrologischen Kreislaufs (BAHC), eines von vier Fokus-Büros für das Projekt Global Change and Terrestrial Ecosystems (GCTE, focus 2 on Ecosystem Structure) und das deutsche nationale IGBP Sekretariat am PIK untergebracht.

Das nationale Sekretariat des IGBP hat die Aufgabe, die Arbeit des nationalen IGBP und insbesondere die des Vorsitzenden zu unterstützen. Die wichtigsten Aufgaben bestehen darin,

- die Beiträge der Bundesrepublik Deutschland zum internationalen IGBP zu koordinieren,
- Forschungskonzepte Deutschlands sowie bereits finanzierte Forschungsprojekte, soweit es geht, in das internationale Programm einzubinden,
- die Entwicklung deutscher Beiträge zum IGBP intensiv zu fördern,
- die nationale Wissenschaftsgemeinschaft über die internationalen Arbeiten zu informieren und
- nationale und internationale Konferenzen, Workshops und Meetings zu organisieren.

Im Berichtszeitraum wurden insgesamt fünf internationale und 13 nationale Meetings ausgerichtet. Die wissenschaftlichen Publikationen der Mitarbeiter des nationalen IGBP Sekretariats sind auf Seite 94 aufgelistet.

Biosphären-Aspekte des Hydrologischen Kreislaufs – BAHC

Das Sekretariat (IPO) des BAHC, eines der 11 Kernprojekte des IGBP, ist im PIK untergebracht. Die Mitarbeiter organisieren und leiten wissenschaftliche Meetings und unterstützen auf wissenschaftlicher Grundlage die verschiedenen Forschungsaktivitäten. Im Berichtszeitraum wurden insgesamt 25 Workshops und Konferenzen organisiert und finanziell unterstützt. Darüberhinaus untersuchen sie in eigenen, unabhängigen Studien, welche wissenschaftlichen Informationen von Seiten der Politik benötigt werden.

Die Mitglieder des BAHC-IPO sind in die Forschungsarbeiten des PIK integriert, beispielsweise das Kernprojekt RESOURCE, das sich dem Thema Globaler Wandel und Wasserressourcen widmet. Des weiteren waren sie auch an Verbesserungen von globalen dynamischen Vegetationsmodellen beteiligt. Wissenschaftliche Publikationen sind auf Seite 95 aufgelistet.

Appendix

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PIK in the Media

Broadcasts about PIK Research

Broadcasts	Date	Topic
NTV Newspunkt	21.02.96	Entwicklungspolitische Aspekte des Wassermangels
SAT 1 „Vera am Mittag“	16.03.96	Talkshow (Lahmer)
RTL Punkt 12	13.06.96	Weltwüstentag (Becker)
BB-Radio	18.06.96	Brandenburg-Studie (Stock)
RTL Nachtjournal	18.06.96	Überschwemmungen und Klimaänderung
Hessischer Rundfunk	05.07.96	UN-Klimakonferenz, weltweite Klimaveränderungen (Stock)
Antenne Brandenburg	08.07.96	Klimagipfel und CO_2-Reduzierung (Stock)
ORB Brandenburg Aktuell	08.07.96	Anläßlich der UN-Klimakonferenz Bericht über die Arbeit des PIK (Schellnhuber)
ZDF Apropos Film	08.07.96	Extremwetterverhalten und Analogien mit dem Film „Twister“ (Gerstengarbe)
ZDF Heute Nacht	09.07.96	Das Wetter und sein Wandel
NTV, Newspunkt	10.07.96	UN - Klimagipfel (Sprinz)
ORB Dossier	13.07.96	Was bringen Konferenzen? (Schellnhuber)
ORB	13.07.96	UN-Klimagipfel
Spiegel - TV	14.07.96	Klima & Globaler Wandel (Schellnhuber)
MDR-Dresden	08.08.96	Unwetter Spanien
MDR	08.08.96	mehrere Telefoninterviews, Wirbelstürme, Überschwemmungen u.a
N3 Prisma	27.09.96	Bericht über Ozeanzirkulation (Rahmstorf)
ZDF Abendjournal	07.10.96	Die 15 wichtigsten Erkrankungen des Systems Erde – Katastrophenforschung und Lösungsvorschläge
Deutsche Welle (North America Program)	16.12.96	The Mission of the Potsdam Institute for Climate Impact Research (Sprinz)
Bayrischer Rundfunk - Morgenmagazin	10.04.97	Klimaänderungen (Gerstengarbe)
HR 3 - Morgenmagazin	15.04.97	Orkane (Werner)
NTV	Ende Juni 97	Oderhochwasser (Bronstert)
ORB	10.07.97	Wetterextreme (Hochwasser in Polen und Tschechien) (Claussen)
Antenne Thüringen, Infotainment am Nachmittag	30.07.97	Oderhochwasser (Kropp)
RTL Nachtjournal	05.08.97	Oderhochwasser und möglicher Zusammenhang mit dem Treibhauseffekt bzw. dem El Niño (Petschel-Held)
Österreichischer Rundfunk	06.08.97	Diskussion um den Treibhauseffekt (Claussen)
MDR	12.08.97	Hörfunkinterview zum Oderhochwasser (Stock)
MDR	12.08.97	Hörer-Expertengespräch zum Oderhochwasser (Stock)

Broadcasts	Date	Topic
SFB /B1 – Nach der Flut – Fakten, Analysen, Handlungen	18.08.97	Oderhochwasser (Werner)
Norddeutscher Rundfunk	19.08.97	Globale Süßwasserkrise (Reusswig)
Süddeutscher Rundfunk	27.08.97	El Niño (Claussen)
BBC World Service – News Hour	27.08.97	Thermohaline Zirkulation im Treibhaus (Rahmstorf)
Hessischer Rundfunk	02.09.97	Thermohaline Zirkulation im Treibhaus (Rahmstorf)
Landeswelle Thüringen	02.09.97	Treibhausklima (Claussen)
NewsTalk Radio Berlin	17.09.97	Waldbrände in Indonesien, Klima und El Niño (Plöchl)
National Public Radio, Boston – Living on Earth	Sept. 97	Thermohaline Zirkulation im Treibhaus (Rahmstorf)
English Language Austria Programmes	Sept. 97	Thermohaline Zirkulation im Treibhaus (Rahmstorf)
NTV Nachrichten	24.09.97	Waldbrände in Indonesien, Klima und El Niño (Plöchl)
Deutschlandradio Berlin – OrtsZeit Akzent	24.09.97	Waldbrände in Indonesien, Klima und El Niño (Plöchl)
RTL Nachtjournal	25.09.97	Waldbrände in Indonesien, Klima und El Niño (Plöchl)
ORB Radio Eins	26.09.97	El Niño (Claussen)
WDR Köln	26.09.97	Waldbrände – Auswirkungen auf das Klima (Claussen)
Hessischer Rundfunk	01.10.97	Pressekonferenz im Rahmen der 4. Deutschen Klimakonferenz in Frankfurt – Thema: Klimawandel, El Niño, Waldbrände – Auswirkungen auf Europa (Claussen)
Deutschland Radio Berlin	10.10.97	El Niño - Wetterextrema (Claussen)
SAT1 Nachrichten	10.10.97	El Niño und Hurrikan Pauline (Claussen)
MDR	12.10.97	Hörfunkinterview zum globalen Smog / El Niño (Stock)
Deutschlandfunk	Mitte Oktober 97	Ursachen der Waldbrände in indonesischen Wäldern (Cramer)
Antenne Bayern – Mittagsmagazin	18.10.97	El Niño (Gerstengarbe)
SFB Inforadio	22.10.97	Die Verhandlungen eines Protokolls über Klimaschutzmaßnahmen (Helm)
Süddeutscher Rundfunk, S2 Forum	25.10.97	Studiodiskussion zum Klima allgemein, El Niño, Treibhausklima (Claussen)
ORB, Ozon-Magazin	25.11.97	Interview zum Kyoto Klimagipfel, Treibhauseffekt (Stock)
RTL Nachtjournal	01.12.97	Interview zum Kyoto Klimagipfel (Stock)
ORB Hörfunk	02.12.97	Interview zur Naturkatastrophen (Stock)
NTV	06.12.97	Interview zum Thema “Klima und Klimamodellierung” (Claussen)
NTV	06.12.97	Interview zu Kyoto Klimagipfel (Stock)
Radio 100,6	11.12.97	Interview zur “Bewertung der Verhandlungsergebnisse von Kyoto” (Helm)
ORB, Sendung Ozon	16.12.97	Klimadaten (Gerstengarbe)

PIK Research in Newspapers and Magazines

Newspaper/Magazine	Date	Topic
Kölnische Rundschau	Anfang Jan. 96	Erderwärmung
Berliner Morgenpost	15.01.96	Veröden die Wälder zur Steppe – sechs Klima-Szenarien des PIK
Die Welt	31.01.96	Mehr Dürre und Regen in einer wärmeren Welt
Vital	Heft 1/96	Umwelt-Report: Interview zum Thema Klima-Veränderung
Bild der Wissenschaft	Heft 2/96	Die Weltgefahren des 21. Jahrhunderts
PUTZ	Heft 2/96	Vier Jahre Arbeit auf dem Neuland Klimafolgenforschung
IGBP-Informationsbrief	01.03.96	German IGBP-Secretariat moves to PIK-Potsdam
IBM Magazin Märkische Allgemeine Zeitung	08.03.96	Geschenkpapier und Schleife – ein alter Zopf? Müll vermeiden, Energie sparen: Expertentagung am PIK
FOCUS	Mai 96	Klimaänderungen / Brandenburgstudie
Die Welt	14.06.96	Forscher befürchten Wetterextreme
Europa Magazin	Nr. 449/96	Das PIK-Potsdam und seine Arbeit
BZ	22.05.96	Es wird heißer
TAZ	19.06.96	Vom Winde verweht
TAZ	27.06.96	Nachhaltige Forschung
Frankfurter Rundschau	27.06.96	Deutschland trägt überproportional zu Umweltproblemen bei – Krankheitsbilder der Erde
Berliner Morgenpost	09.07.96	UN-Klimagipfel
Deutscher Forschungsdienst	08.08.96/ Heft 16	Steppe von der Elbe bis zur Oder?
Bildwoche	02.10.96/ Nr. 44	Steppe von der Elbe bis zur Oder?
Frankfurter Rundschau	08.10.96	Wissenschaftler sagen Zeitalter der Katastrophen voraus
Forschungszentrum Karlsruhe	Okt. 96/ Nr. 3,5	Klimaforschung und internationale Klimapolitik
Märkische Allgemeine	17.12.96	Höherer Seegang durch Treibhauseffekt?
Die Welt	15.01.97	Zur Person – Porträt zum Vortrag an der Urania
Tagesspiegel	03.02.97	Der Mensch ändert wahrscheinlich das Klima
Das Sonntagsblatt	21.02.97	Die Menschheit steht vor einer Existenzkrise
Sparkassenmagazin	Heft 3/97	Eine Frage der Folgen – Expertengespräch
TAZ	April 97	Wenn der Atlantik die Heizung abstellt: Thermohaline Zirkulation im Treibhaus
Süddeutsche Zeitung	19.06.97	Springende Wirbel im Atlantik: Nordatlantische Oszillation
Potsdamer Neueste Nachrichten	17.07.97	Wohin führt uns der Treibhauseffekt? – Reportage über das PIK
FOCUS	Juli 97	"Deutschland unter" – Überschwemmungen in Deutschland

Newspaper/Magazine	Date	Topic
Freitag	08.08.97	Die Oder als Modell für den Klimawandel
TAZ	19.08. 97	Kohleflöze als Klimakiller – Treibhausgasquellen für Methan und Stickoxide, bzw. andere Quellen von CO_2 als Verbrennung fossiler Brennstoffe
BZ an Sonntag	17.08.97	Report zur Naturkatastrophen, Hochwasser und Klimaänderung
Münchner Abendblatt	28.08.97	El Niño
Tagesspiegel	28.08.97	Schon eine Verlangsamung des CO_2-Ausstosses hülfe: Thermohaline Zirkulation im Treibhaus
Tages-Anzeiger Zürich	05.09.97	Damoklesschwert über dem Atlantik: Thermohaline Zirkulation im Treibhaus (Rahmstorf)
Bild	25.09.97	El Niño
Spiegel	26.09.97	Waldbrände – Auswirkungen auf Europa
Augsburger Allgemeine	26.09.97	Waldbrände – Auswirkungen auf Europa
Bild	26.09.97	Waldbrände – Auswirkungen auf Europa
Frankfurter Rundschau, u.a.	01.10.97	Pressekonferenz im Rahmen der 4. Deutschen Klimakonferenz in Frankfurt zu Klimawandel, El Niño, Waldbrände – Auswirkungen auf Europa
Berliner Morgenpost	29.10.97	El Niño
Tagesspiegel	30.10.97	Die ganze Erde in einem Modell (Symposium der Wiss. Akademien in Berlin)
Tagesspiegel	02.11.97	"Dann wird der Wald nicht überleben können" – Interview zur Klimaänderung
Neues Deutschland	04.11.97	Der Klimawandel ist längst im Gange (Kyoto Klimagipfel)
Berliner Zeitung	05.11.97	Schlechte Zeiten für Propheten
Focus	17.11.97	"Malaria in Europa" – Folgen der globalen Erwärmung
Hamburger Abendblatt	22./23.11.97	Journal Wissen – zum Klimawandel (Schellnhuber)
Hamburger Abendblatt	29.11.97	Brandenburgstudie, Infektionskrankheiten
Frankfurter Rundschau	29.11.97	Zu bremsen wird immer schwieriger – Interview zur Welt im Treibhausjahrhundert (Schellnhuber)
Neue Ruhr Zeitung	29.11.97	Kyoto Klimagipfel
Berliner Zeitung	01.12.97	Interview zum Kyoto Klimagipfel
Tagesspiegel	03.12.97	Bäume haben keine Beine – Kyoto Klimagipfel
BZ	11.12.97	Bewertung der Verhandlungsergebnisse von Kyoto

External Funding

Project Name	Acronym	Reference No.	Sponsor	Total Funding	Period of Funding	Project Leader
Nationale Koordinierungsstelle des deutschen IGBP + Workshops	IGBP	01LG9503/9	BMBF/DLR PT-USF	DM 2.361.378	01.01.96-31.12.98	Schellnhuber Lütkemeier
Integrierte Abschätzung von Klimaschutzstrategen: Methodisch-naturwissenschaftliche Aspekte	ICLIPS (1)	01LK9605/0	BMBF/DLR PT-USF	DM 2.056.579	01.07.96-30.06.99	Tóth
Integrierte Abschätzung von Klimaschutzstrategen: Sozio-ökonomische Aspekte	ICLIPS (2)	10402815	BMU-UBA	DM 1.020.640	01.07.96-30.06.99	Tóth
Globaler Wandel: GIS-gestützte Erfassung und Modellierung der Syndromdynamik	QUESTIONS	01LG9401/5	BMBF/DLR PT-USF	DM 1.726.091	01.10.94-31.12.97	Petschel-Held Block
BAHC/IGBP „Internationales Kernprojektbüro: Biosphärenaspekte des Wasserkreislaufs	BAHC	01LG9501/3	BMBF/DLR PT-USF	DM 968.780	01.03.95-28.02.97	Schellnhuber
Auswirkungen der Landnutzung auf den Wasser und Stoffhaushalt der Elbe und ihres Einzugs-gebietes	ELBEOEKO	0339577	BMBF/PT BEO	DM 963.698	01.01.97-30.06.99	Becker
Wasserverfügbarkeit im semiariden NO-Brasiliens - Klimaanalysemodellierung und großskaliges hydrologisches Modell	WAVES-K	01LK9712/1	BMBF PT DLR	DM 753.400	01.08.97-31.07.2000	Bronstert Gerstengarbe
Wirkung von Klimaänderungen auf Vegetation: Entwicklung eines allgemeinen Modells für die Klimafolgenforschung	VEGEKLIM	01LK9408/2	BMBF/DLR PT-AUG	DM 709.057	01.07.95-30.06.98	Cramer
Wasserverfügbarkeit im semiariden NO-Brasiliens - Integrierte Modellierung	WAVES-I	01LK9713/4	BMBF PT DLR	DM 652.450	01.08.97-31.07.2000	Bronstert Krol
Untersuchung der Auswirkungen erhöhter atmosphärischer CO_2-Konzentrationen auf Weizenbestände innerhalb des Free Air Carbon Dioxide Enrichment-Experimentes Maricopa (USA)	FACE	0339626	BMBF/KfA PT-BEO	DM 456.100	01.11.93-31.12.96	Kartschall
Untersuchung der Auswirkung erhöhter atmosphärischer CO_2-Konzentrationen innerhalb des Free-Air Carbon Dioxide Enrichment-Experiments: Ableitung allgemeiner Modellösungen	FACE2U	01LK9535/5	BMBF/DLR PT-USF	DM 444.243	01.04.96-31.05.98	Kartschall
Klimatologie und Prognose klimainduzierter Änderungen hydrographischer Größen in Nord- und Ostsee; *Teilprojekt A*: Seegangsberechnungen zur Gewinnung einer spektralen Seegangsklimatologie	KLINO	03F0185A4	BMBF/PT-BEO	DM 401.541	01.11.96-31.10.99	Claussen

Project Name	Acronym	Reference No.	Sponsor	Total Funding	Period of Funding	Project Leader
Wasser- und Stoffrückhalt im Tiefland des Elbe-einzugsgebiets	WaStor	0339585	BMBF/KfA PT-BEO (über ZALF)	DM 359.741	01.10.97-30.09.2000	Becker
Wälder und Forstwirtschaft Deutschlands im globalen Wandel	WALD-STUDIE	01LK9528/2	BMBF PT DLR	DM 312.225	01.07.97-30.06.2000	Cramer
Quantifizierung des Einflusses verschiedener (baulicher und Renaturierungs-Maßnahmen) auf den Verlauf von Hochwasserereignissen am Beispiel ausgewählter Flußgebiete	FLOOD	20204508	Umweltbundesamt (UBA)	DM 310.200	01.10.97-30.09.2000	Bronstert
Untersuchung spezieller Probleme bei der Integration von Klima- und Ökosystemmodellen	KLIMÖKO	01LK9325/8	BMBF/DLR PT-USF	DM 275.953	01.09.95-28.02.98	Werner
Analyse und Modellierung der klimatischen Bedingungen (Teilproj. 300) integrierte Modellierung (Teilproj. 700)	WAVES-PIAUI	01LK9312/9	BMBF/DLR PT-USF	DM 293.407	01.08.94-31.12.96	Schellnhuber/ Gerstengarbe
Nutzung naturwissenschaftlich-technischer Datenbanken durch Forschungseinrichtungen in den neuen Bundesländern	WTI PIK	08NDF13	BMBF/PT-FIZ	DM 211.162	01.07.93-31.12.97	Suckow
Regionale Auswirkungen des anthropogen bedingten Treibhauseffektes in Nordrhein-Westfalen - Die Anfälligkeit Nordrhein-Westfalens für einen möglichen Klimawandel	RANK	WVB5-8818.3.11	MURL, NRW	DM 209.720	01.10.97-31.03.99	Block Reusswig
Großskalige hydrologische Modellierung (und Projektverlängerungen)	SPP	BE1575/2/ 1,2 3 4	DFG	DM 193.800 DM 96.900 DM 97.000	15.09.93-31.3.97	Lahmer Becker
Evolutionsmodelle des Systems Erde	EMSE	MWFK 24/2599-04/035-1997	MWFK Brandenburg	DM 140.100	01.01.97-31.12.1997	Schellnhuber Franck
Evolutionsmodelle des Systems Erde	EMSE	MWFK 24-04/035-1998	MWFK Brandenburg	DM 140.100	01.01.98-31.12.1998	Schellnhuber Franck
Verbundvorhaben Wasserkreislauf; Planung und Akquisition Datenzentrum Weser / Elbe	WKL	07VWK01/6	BMBF PT GSF Uni Hannover	DM 83.575	01.01.97-31.12.1997	Becker
Simulation der Wechselwirkungen zwischen Biosphäre und globalem Klima	IBM	9200	IBM Deutschland GmbH	DM 75.000	01.12.92-29.02.96	Schellnhuber
Wissenschaftlicher Beirat der Bundesrepublik Deutschland „Globale Umweltveränderungen“	WBGU	01LG9201	BMBF/DLR PT-USF	DM 68.605	01.09.93-30.06.96	Schellnhuber

Project Name	Acronym	Reference No.	Sponsor	Total Funding	Period of Funding	Project Leader
Kurzstudie und Workshop CO_2 Senken	SENKE	0339687	BMBF/KfA PT-BEO (über MPI HH)	DM 41.600	1.10.96-31.3.97	Cramer
IGFA IPO Officers Meeting	OFFICE	IGBP 648 A	Royal Swedish Academy of Sciences Stockholm	DM 18.247	18.08.97-22.08.97	Lütkemeier
Einbindung der Katastrophenanfälligkeit	IDNDR-GSF	V-14-2-97	BMBF-GSF	DM 12.000	per 31.12.97	Reusswig
Gestaltung regionaltypischer Agrarlandschaften Nordostdeutschlands	GRANO	Unterauftrag 0339694A	BMBF-BEO über ZALF	DM 8.119,20	01.11.96-31.12.97	Wechsung
VENICE	VENICE	INTAS 93-1918	INTAS	DM 4.155,75	01.05.93-31.04.96	Svirezhev
MAB-Workshop	MAB	NUDP6/96	Nationalkomitee für das UNESCO Programm der Mensch und die Biosphäre	DM 2.206,14	13./15.6.96	Linneweber
Workshop San Diego	MEDECOS III	28-3881-1/91(97)	MWFK/HSP III	DM 1.985	25.09.97-31.10.97	Thonicke
European Terrestrial Ecosystem Modelling Activity	ETEMA	ENV4-CT95-0052	EU Environment and Climate Programme	ECU 291.000	01.05.96-30.04.99	Cramer
Dynamic Response of the Forest-Tundra Ecotone to Environmental Change	DART	ENV4-CT97-0586	EU Environment and Climate Programme	ECU 189.984	48 months	Cramer
New Version of the Moscow Global Biosphere Model	MGBM	INTAS-94-1154	INTAS	ECU 121.400	01.05.95-31.04.97	Schellnhuber
Numerical Simulation and Analysis of Climate Variability on Decadal and Centennial Time Scales	MILLENNIA	ENV4-CT95-0101	EU Environment and Climate Programme	ECU 120.000	01.03.96-28.02.98	Rahmstorf
Urban Lifestyles, Sustainability, and Integrated Environmental Assessment	ULYSSES	ENV4-CT96-0212	EU Environment and Climate Programme	ECU 110.000	01.05.96-30.04.99	Tóth
International Governmental Organizations and National Participation in Environmental Regimes: The Organizational Competents of the Acidification Regime	IGR	EV5V-CT94-0390	EU SEER II Programme	ECU 80.120	01.04.94-31.10.96	Sprinz
International Governmental Organizations and National Participation in Environmental Regimes: The Organizational Competents of the Acidification Regime	IGR	EV5V-CT92-0185	EU SEER II Programme	ECU 36.720	01.04.94-31.03.96	Sprinz

Project Name	Acronym	Reference No.	Sponsor	Total Funding	Period of Funding	Project Leader
Modelling and Parameterization of the “Air-Vegetation-Snow-Soil”	AVSS	INTAS-96-1935	INTAS	ECU 31.500	36 Monate	Claußen
River Basin Modelling and Flood Mitigation Integrated Environmental Assessment	RIBAMOD	EV4V-CT96-0263	EU Environment and Climate Programme	ECU 25.000	01.06.96-31.05.98	Bronstert
Baltic Basin Case Study	BBCS	EV4V-CT96-0269	EU Environment and Climate Programme	ECU 5.000	01.07.96-30.06.99	Cramer
An Analysis of Interregional and International Water Distribution and Conflict Problems The River Jordan System	CONFLICT	1214--047068.96/1	Schweizerischer Nationalfonds zur Förderung der wissenschaftlichen Forschung	Sfr. 101.668	01.10.96-31.09.97	Schellnhuber
The Role of Environmental Thresholds	ROLE	CRG#97035	NATO	BEF 210.000	noch nicht festgelegt	Sprinz

New EU-Projects with External Funding in 1997

Project Name	Acronym	Reference No	Sponsor	Total Funding	Period of Funding	Project Leader
European Forum on Integrated Environmental Assessment	EFIEA	ENV4-CT98-1216	EU Environment and Climate Programme	noch nicht festgelegt	36 Monate	Toth
European River Flood Occurrence and Total Risk Assessment System	EUROTAS	ENV4-CT97-1091	EU Environment and Climate Programme	ECU 174.980	36 Monate	Bronstert
Modelling the Effect of Land Degradation on Climate	CLD	ENV4-CT97-00696	EU Environment and Climate Programme	ECU 120.000	36 Monate	Claussen
European Climate Support Environment: Network for the Co-ordinated Provision of Scientific and Technical Advice for Applying Climate Change Data	ECLAT 2	ENV4-CT97-0256	EU Environment and Climate Programme	noch nicht festgelegt	36 Monate	Bürger
Long-term Regional Effects of Climate Change on European Forest: Impact Assessment and Consequences for Carbon Budget	LTEEF-II	ENV4-CT97-1175	EU Environment and Climate Programme	ECU 97.625	30 Monate	Cramer
A Concerted Action Towards a Comprehensive Climate Impacts and Adaptation Assessment for the European Union	ACACIA	ENV4-CT98-0119	EU Environment and Climate Programme	noch nicht festgelegt	noch nicht festgelegt	Schellnhuber
Weather Impacts on Natural, Social and Economic Systems	WISE	ENV4-CT97-0448	EU Environment and Climate Programme	ECU 195.564	11.97-31.10.99	Schellnhuber

Modelling Agro-ecosystems under Global Environmental Change	MAGEC	ENV4-CT97-0693	EU Environment and Climate Programme	ECU 214.000	36 Monate	Cramer
Environmental and Social Change in Mountain Regions	MOUNTAIN CHANGES	ENV4-CT97-0233	EU Environment and Climate Programme	noch nicht festgelegt	10 Monate	Becker
Regional Climate Modelling and Integrated Global Change Impact Studies in the European Arctic	CLIMPACT	ENV4-CT98	European Science Foundation	noch nicht festgelegt	1998-2000	Cramer

Scholarships at PIK

Project Name	Acronym	Reference No	Sponsor	Total Funding	Period of Funding	Project Leader
Investigations Regarding the Environment-dependent Architecture of Spring Barley for the Extension of an Agro-ecosystem Model	BARMOD	1000/177	DBU	DM 54.000	01.08.93-31.07.96	Gräfe
Direct Impacts of the Enrichment of Atmospheric CO_2 Concentrations on the Energy Balance and on Evapotranspiration (nominiert für den Leopoldina Preis 1995)	FACE-Balance	334-3740-096-1	Deutsche Akademie der Naturforscher „Leopoldina“	DM 25.800 + DM 49.548	15.01.96-15.07.96	Grossman

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International Institute for Applied System Analysis (IIASA), Laxenburg
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Center for Weather Forecasting and Climate Studies (CPTEC-INPE), Cachoeira
Fundação Cearense de Meteorologia e Recursos Hídricos (FUNCEME), Fortaleza
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Universidade Federal Do Ceará, Fortaleza, Ceará
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Czech Republic
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Department of Geography, Masaryk University, Brno
Denmark
Danmark Farmaceutiske Hojskole (DFH), Institute for Environmental Chemistry

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Danish Meteorological Institute (DMI), Copenhagen
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European Forest Institute, Joensuu
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Laboratoire de Météorologie Dynamique (LMD) du CNRS (Centre National de la Recherche Scientifique), Paris
Laboratoire d'Oceanographie Dynamique et de Climatologie (LODYC), Paris
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Institut für Ökologische Wirtschaftsforschung (IÖW), Berlin
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United States Department of Agriculture (USDA), Agricultural Research Service, Grassland, Soil and Water Research Lab., Temple, Texas
US Dept. of Energy, Oak Ridge National Laboratory, Tennessee
Usbekistan
Central Asian Hydrometeorological Research Institute, Glavgidromet Sanigmi, Tashkent

Acronyms

AABW	AntArctic Bottom Water
ACACIA	A Concerted Action Towards a Comprehensive Climate Impacts and Adaptation Assessment for the EU
AGREC	Assessment of Agro-Economic Impacts of Climate Change on Central and Western Europe
B-WIN	Breitband-Wissenschaftsnetz
BAHC	Biospheric Aspects of the Hydrological Cycle
BMBF	Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie / Federal Ministry for Education, Science, Research and Technology
BMU	Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit / Federal Ministry for Environment, Nature Protection and Reactor Safety
CERA 2.3	Climate and Environmental Data Retrieval and Archiving System
CHIEF	Global Change Impacts on European Forests
CLD	Modelling the Effect of Land Degradation on Climate
CLIMAGHS	Climate and Global Change Impact on the Environment and Society of the Mediterranean and the Maghreb States
CLIMBER	Climate and Biosphere Model
CLIMPACT	Regional Climate Modelling and Integrated Global Change Impact Studies in the European Arctic
CNPq	Conselho Nacional de Desenvolvimento Científíco e Tecnológico
COEM	Long-Term Co-Evolutionary Biosphere and Geosphere Models
CRU	Climate Research Unit, University of East Anglia
DART	Dynamic Response of the Forest-Tundra Ecotone to Environmental Change
DFG	Deutsche Forschungsgemeinschaft
DGVM	Dynamic Global Vegetation Model
ECLAT-2	European Climate Projects Support Environment: Network for Coordinated Provision of Scientific & Technical Advice for Applying Climate Data in European Climate Change Research Projects
ECMWF	European Centre for Medium-Range Weather Forecasts
EFIEA	European Forum on Integrated Environmental Assessment
EGMO	Einzugsgebietsmodell
ETEMA	European Terrestrial Ecosystem Modelling Activity
EUROPA	European Network Activities on Global Change
EUROTAS	European River Flood Occurrence and Total Risk Assessment System
FACE	Free-Air Carbon Dioxide Enrichment Experiment
FCCC	Framework Convention on Climate Change
FEWS	Famine Early Warning System
FORESEE	Forest Ecosystem in a Changing Environment
GAIM	Global Analysis, Interpretation and Modelling
GCM	Global Circulation Model
GCTE	Global Change and Terrestrial Ecosystems
GEM	General Equilibrium Model
GFDL	Geophysical Fluid Dynamics Laboratory
GIS	Geographisches Informationssystem / Geographic Information System
GNP	Gross National Product
GRASS	Geographic Resource Analysis Support System
GUI	Graphical User Interface
HTML	Hypertext Markup Language
ICLIPS	Integrated Assessment of Climate Protection Strategies
ICM	ICLIPS Climate Model
IEA	Integrated Environmental Assessment
IGBP	The International Geosphere-Biosphere Programme

IPCC	Intergovernmental Panel on Climate Change
KLINO	Klimatologie und Prognose klimainduzierter Änderungen hydrographischer Größen in Nord- und Ostsee / Climatological Change of Hydrographic Parameters in the North Sea and the Baltic Sea
LTEEF-II	Long-Term Regional Effects of Climate Change on European Forests: Impact Assessment and Consequences of the Carbon Budget
LUCC	Land Use and Land Cover Change
MAGEC	Modelling Agroecosystems under Global Environmental Change
MGBM	The New Version of the Moscow Global Biosphere Model
MILLENNIA	Numerical Simulation and Analysis of Climate Variability on Decadal and Centennial Time Scales
MOUNTAIN	Environmental and Societal Changes in Mountain Regions
MWFK	Ministerium für Wissenschaft, Forschung und Kultur des Landes Brandenburg / Ministry for Science, Research and Culture of the State of Brandenburg
NADW	North Atlantic Deep Water
NCAR	The National Center for Atmospheric Research
NOAA	The National Oceanic and Atmospheric Administration
NPP	Net Primary Productivity
P-MAN	Potsdam Metropolitan Area Network
PFT	Plant Functional Type
POEM	Potsdam Earth System Modelling
QDE	Qualitative Differential Equation
QUESTIONS	Global Change: Qualitative Dynamics of Syndromes and Transition to Sustainability
RAGTIME	Regional Assessment of Global Change Impacts Through Integrated Modelling in the Elbe River Basin
REMO	Regional Model
RESOURCE	Social Dimensions of Resource Use: Water Related Problems in the Mediterranean
RICC	Regional Integrated Climate Change Assessment
SANA	Spacial and Temporal Dynamics of Ecosystems under Changing Emission Conditions -Dübener Heide
SDM	Scientific Data Management
SLR	Restriction Effects on Temperature and Sea Level Rise
SOM	Soil Organic Matter
SWIM	Soil and Water Integrated Model
TWA	Tolerable Windows Approach
ULYSSES	Urban Lifestyle, Sustainability and Integrated Environmental Assessment
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
USAID	U.S. Agency for International Development
USGS	U.S. Geological Survey
USWCL	US Water Conservation Laboratory
WAVES	Water Availability, Vulnerability of Ecosystems and Society in the Northeast of Brazil
WBGU	Wissenschaftlicher Beirat der Bundesregierung “Globale Umweltveränderungen” / German Advisory Council on Global Change
WCRP	World Climate Research Programme
WFP	United Nations World Food Programme
WISE	Weather Impacts on Natural, Social and Economic Systems
ZALF	Zentrum für Agrarlandschafts- und Landnutzungsforschung / Center for Agricultural Landscape and Land Use Research
4C	is equal to FORESEE