Potsdam Institute for Climate Impact Research

Potsdam-Institut für Klimafolgenforschung e.V.

Biennial Report
1998 & 1999

Impressum

Published by
Potsdam Institute for Climate Impact Research (PIK)
Potsdam-Institut für Klimafolgenforschung e.V. (PIK)

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Printed by
UNZE Verlags- und Druckgesellschaft Potsdam, mbH

Photo and illustration credits
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The Potsdam Institute for Climate Impact Research (PIK)

Introduction, Overview and Perspectives

by Hans Joachim Schellnhuber and Manfred Stock

The Potsdam Institute for Climate Impact Research was established following a recommendation by the German "Wissenschaftsrat" to link and improve basic and applied research in the field of climate-related Earth System Analysis. This recommendation responded to 'policy-makers' increasing need to understand the implications of global changes such as the increase in atmospheric carbon dioxide and the associated climate trends. Scientists pointed out that this coupling implied strong feedbacks and that the system demanded a study in its entirety, on global *and* regional scales.

From 2001, the former Astrophysical Observatory Potsdam will be PIK's main building.

In 1992 a contribution to this field, which is now (2000) fairly well-established, was meant as a venture into new territory. Given the formidable scope of the endeavour, its outcome had to be considered uncertain at the time, but its potential impact made the risk worth taking. A recent, altogether positive evaluation of the institute, again by the Wissenschaftsrat, has concluded that the institute has reached most of its goals already and "developed, in a comparatively short period of time, into an outstanding research facility". This provides reason enough, we believe, to both review the past developments (focusing on 1998 and 1999), and to preview intended developments for the future.

From Climate Impact Research to Earth System Analysis

When climate-impact science began to be developed about a decade ago, its initial concepts seemed to be hopelessly over-ambitious. It was envisaged that high-resolution management recommendations for stakeholders could be based on genuine predictions of the environmental future. At the same time, these concepts were also naïve: a linear causal analysis, starting from civilization-generated greenhouse-gas emissions, then calculating the resulting climate perturbations, and finally evaluating the induced damages and benefits for natural and socio-economic systems, was expected to do the job properly. The experiences shared by the Potsdam Institute with the entire scientific community now tell us that a more sophisticated approach is needed. Climate is just one component of the ecosphere within the overall Earth System. This component is connected to many others by a complex causal matrix consisting of non-linear bonds and links of highly heterogeneous character.

Thus, climate-impact research could not be isolated from Earth System Analysis. Only the advancement of the latter will provide the scientific basis for answering the relevant questions concerning the right mix of *mitigation* and *adaptation measures* for managing climate change. Assembling the components of the Earth System into a numerical scheme is more than a mechanical operation, but requires careful consideration of important and less important phenomena. A major research goal, in this context, is the identification of those "strategic variables" that significantly amplify and propagate across the ecosphere-anthroposphere complex through perturbations and interactions. The respiration intensity of ecosystems as a function of temperature and other factors may be such a variable, as it is crucial for climate self-stabilization mechanisms.

The emergence and development of Earth System Analysis can be perceived as a "Second Copernican

The three buildings presently used by PIK: C4, A26, A51 - all located at the Wissenschaftspark Albert Einstein.

Revolution" that strives to understand our planetary ecosystem as a whole and to develop, on this cognitive basis, concepts for global environmental management. This has been outlined by one of us in a recent essay for the Millennium Supplement of *Nature* (Vol. 402, C19-C23). In the following we quote parts of this article.

The Second Copernican Revolution: New Insights to the Future

"There are many ways of looking forward in time. One of the most amusing (and sometimes terrifying) is the 'forward-view mirror' — contemplation of the future by reflecting on the past. If we consider the unravelling of the mysteries of the human body by physicians over the past three millennia, we see much that is relevant to unravelling the mysteries of the Earth's physique, or 'Gaia's body.'

With our present-day understanding of medical science, it seems incredible that the Hippocratic school, which based analysis and prognostics of the human body on the 'composition of the humours' of individual patients, dominated Western medicine well beyond the Renaissance. Great leaps in knowledge, such as Vesalius's anatomical revelations published in 1543, or Harvey's physiological studies in 1628, were ignored or suppressed — notably by the deans of Paris's 'infallible' medical faculty. The first scientific treatise relating contagious diseases to activities of microorganisms, rather than harmful vapours, or 'miasmas,' did not appear until 1840.

When the Enlightenment came, its ultimate triumph was based, literally, on light — the ability to process radiation received from objects of specific interest. The invention of the operational microscope in 1608 by the Dutch spectacle-maker Zacharias Jansen, realizing a proposal made in 1267 by Roger Bacon, was a turning-point in scientific history. For the first time the human eye could transcend its natural limits and begin to explore the wonders of the microcosmos.

Many more wonders awaited revelation through the processing of light — above all, the spangled nocturnal heavens with their billions of gigantic entities made so tiny by distance. Once again, faint rays of light emitted by objects had to be invigorated through ingenious devices, in this case telescopes. And so optical amplification techniques brought about the great Copernican revolution, which finally put the Earth in its correct astrophysical context.

Today, some 500 years after Copernicus, Cusanus and company, our civilization sets about visiting neighbouring planets, scrutinizing stellar objects at the brink of creation, and even tracking down extraterrestrial intelligence. This spectacular augmentation of the Renaissance impulse is being accompanied by a crescendo of other scientific activities which will soon culminate in a 'Second Copernican Revolution'. This new revolution will be in a way a reversal of the first: it will enable us to look back on our planet to perceive one single, complex, dissipative, dynamic entity, far from thermodynamic equilibrium — the 'Earth system'. It may well be nature's sole successful attempt at building a robust geosphere–biosphere complex (the ecosphere) in our Galaxy, topped by a life-form that is appropriately tailored for explaining the existence of that complex, and of itself.

Such an explanation needs eventually to encompass all the pertinent processes linking the system's constituents at all scales — from convection deep in the Earth's mantle to fluctuations at the outer limit of the atmosphere. New instruments are necessary, especially macroscopes which reduce, rather than magnify as microscopes do, giving Earth-system scientists an objective distance from their specimens — no longer too close for cognitive comfort.

There are three distinct ways to achieve 'holistic' perceptions of the planetary inventory, including human civilization:

1. The 'Bird's-Eye' Principle.

An obvious trick for obtaining a panoramic view of the Earth is to leave it, and observe it from a distance. The race to the Moon in the 1960s opened up the opportunities for this particular macroscope technique, and created the now-familiar image of our blue planet floating in the middle of a dark, cold nowhere. The trick was not exactly cheap, however, NASA's lunar ventures absorbed some US$ 95 billion overall. Now, space stations, shuttles and an armada of smart satellites are about to establish the details of a complete Earth reconnaissance.

2. The Digital-Mimicry Principle.
A more sophisticated, and less expensive, macroscope technique is simulation modelling. Here, components and processes of the original Earth system are replaced by mathematical representatives as accurate as our evolving knowledge allows. These formal chimeras are then animated electronically, to imitate the dynamic complex of real relationships in virtual spacetime. The menagerie of Earth-system models includes tutorial, conceptual and 'analogical' specimens. One significant advantage of this macroscope is that it allows a multitude of potential planetary futures to be played out, with no more a risk than a computer crash. The validation of Earth-simulation machines remains problematic, although relentless training with paleorecords can teach them satisfactory hind-casting skills.

3. The 'Lilliput' Principle.
As a third option, there is the 'incredible shrinking Earth' idea, as enacted in the Sonora Desert in Biosphere II. The idea involves rebuilding the ecosphere in flesh, blood and rock, on a scale reduced by many orders of magnitude. Such a nano-planet can be conveniently scrutinized for operational stability or emerging self-organization processes. Despite its disastrous performance, the Biosphere-II project provoked fresh scientific attitudes towards life. And in fact, the free-air experiments, which are currently being used to investigate the effect of atmospheric CO_2 enrichment on agro-ecosystems and forests, subscribe to a similar empiricist philosophy.
Most probably, the future of macroscopes will be dominated by intelligent combinations of these principles, particularly the first two. Planetary monitoring — by remote sensing and a worldwide net of *in situ* measurement devices — will be complemented and synchronized by data models to generate a continuously updated digital 'Weltbild'.
The quasi-antithetical spirits of the First and Second Copernican Revolutions may be visualized by contrasting a famous ancient allegory with a modern cartoon. The explorer featured in the figure is dressed as a doctor for two reasons. First, the continuing investigation into the Earth's physique is in many respects reminiscent of the exploration of the human body during the Renaissance. Science historians looking back from, say, AD 2300, will tell yet again a tale of incredible delusions and triumphs. And second, a significant impetus behind the Second Copernican Revolution is the insight that the ecosphere's operation may be being transformed qualitatively by human interference. So the macroscope is a diagnostic instrument, generating evidence necessary for treatment.
This means that we are confronted ultimately with a control problem, a geo-cybernetic task that can be summed up in three fundamental questions. First, what kind of world do we have? Second, what kind of world do we want? Third, what must we do to get there? These questions indicate the immensity of the challenge posed by Earth System Analysis."

New Insights to Earth System Analysis: From Past to Future

The Potsdam Institute attempts to contribute to the progress of climate-impact science within the framework of Earth System Analysis. Its favourite macroscope is simulation modelling, properly calibrated and guided – if possible – by extensive synthesis of available data from many sources. Advanced methodologies from physics, computer science and other fields are employed in order to secure the integrative character

The First and the Second Copernican Revolution.

of the studies conducted. A concise overview of recent achievements is provided by the papers in a special issue of the journal *Environmental Modeling & Assessment* (Vol. 4, Dec. 1999), entitled “Earth System Analysis and Management”, edited by H. J. Schellnhuber and F. Toth. In the following we summarize a selection of findings made by PIK members in the 1998 - 1999 period.

The Past: Green Sahara and Abrupt Desert Formation in a Computer Model

The global interaction between atmosphere, ocean currents and vegetation during the “Holocene Climate Optimum” approximately 6,000 years ago was simulated realistically for the first time ever with the aid of the interactive climate-system model of intermediate complexity CLIMBER (see page 37). This highly efficient model, developed for Earth System Analysis, can be used for both historical reconstructions and scenario analyses of the future. From the analysis of fossil plant pollen, bones and rock carvings we know that the area covered by today’s Sahara in the early Holocene was a subtropical steppe. Around 6,000 years ago the climate in the northern hemisphere was milder in summer than it is today, and especially in northern Africa there was considerably greater rainfall.

Climate changes of the past are ultimately attributable to small periodical variations in the Earth’s orbit and the inclination of the Earth’s axis, which together cause changes in the regional distribution of insolation. With the aid of CLIMBER it was demonstrated that the green cover of the Sahara was due to the non-linear interaction between atmosphere and vegetation, and that changes in ocean circulation had scarcely any effect on it. In a second step, the team succeeded in dynamically modelling the further development of the Sahara and its transformation into a desert some 5,500 years ago. Here, it was shown that the interaction between vegetation and atmosphere can lead to relatively abrupt climate changes – abrupt in comparison with the gradually changing regional distribution of insolation, which ultimately induces long-term climate variability.

The Present: Current Climate Changes in the North Atlantic/European Areas

Major climatic changes in the past have involved significant perturbations of the atmospheric circulation, sometimes in an abrupt way. This gives reason to assume that similar events could occur in the future. The question arises whether observed changes during the 20th century (global temperature increase of 0.6 to 0.7 °C) might already be attended by structural modifications to the circulation system, and so we began to search for signals of these.

Using statistics of the daily values of selected meridional differences in air pressure for the winter periods from 1881 to 1998, our researchers have succeeded in identifying such a signal of climate change. The analysis showed that the average duration of typical atmospheric circulation patterns for the North Atlantic/European areas has abruptly grown in length since the beginning of the 1970s. This signal is attributable neither to regional causes (sea-surface temperature) nor to remote influences (*El Niño*, Southern Oscillation). The evidence, rather, leads to the conclusion that global warming is the cause of this regional meteorological signal.

The findings point to the fact that the non-linear dynamic system of atmospheric circulation over Europe is changing its state with regard to several features: the westerly winds are expected to increase in intensity during the winter months. As a result, central Europe will have to face an increasing number of mild and unusually wet winters. Greater impacts must be expected through extreme events in storms and intense precipitation. Consequently, PIK is strengthening its efforts in extreme-event related research areas such as flood research.

The Possible Future: New Long-Term Studies on Global Warming

A PIK study on global warming in the new millennium has confirmed the pessimistic expectation that temperatures worldwide may increase by more than 3°C by the end of this century if greenhouse-gas emissions are not reduced. With the aid of the CLIMBER-2 model, possible climate changes are computed for up to a thousand years into the future.

Stefan Rahmstorf received the Centennial Award of the James S. McDonnell Foundation in 1999.

The Atlantic Conveyor Belt. Red circles show the regions of convection in the Greenland/Norwegian and Labrador Seas. The outflow of North Atlantic Deep Water (NADW) is shown in blue.

In another study, performed together with several other groups throughout the world, it has been shown that the carbon storage capacity of the terrestrial biosphere is limited. Calculations with the Lund-Potsdam-Jena Model and other Dynamic Global Vegetation Models (see page 33) indicate that the present buffering of atmospheric carbon dioxide concentrations and hence global warming due to CO_2 “fertilization” could be strongly reduced during the second half of the 21^{st} century. A faster rate of climate change would be the consequence.

A further subject of investigation is the risk that this warming might result in major irreversible changes in ocean circulation. Computations have indicated that anthropogenic climate change might lead to a cooling of the European region if the North Atlantic circulation ceases. The possibility of such cooling in Europe has long been a subject of speculation but so far never demonstrated in a global warming simulation. In recognition of his work in this field the PIK scientist Stefan Rahmstorf received the Centennial Award of the James S. McDonnell Foundation in 1999.

Short-Term Implications of Long-Term Climate Protection Goals

In 1999 the ICLIPS model components (see page 51) were linked to obtain an integrated assessment model that comprises the entire global climate change cause-effect chain. The various components were developed in collaboration with leading research institutes worldwide resulting in a model that exhibits several innovative features, for instance a highly efficient climate model involving all relevant greenhouse gases, a variety of climate- impact response functions modelling changes in agricultural yield, natural vegetation and water availability and, finally, a long-term economic model that takes into account technological learning. The main objective of the model is to derive emission corridors delineating the admissible scope of future emissions compatible with pre-defined constraints which are used to exclude climate impacts and socio-economic consequences of mitigation measures that are perceived as intolerable by social actors or their designated representatives, the policy-makers. By applying the model, the ICLIPS project has successfully proven the conceptual validity, numerical tractability and policy relevance of a new decision-support methodology - the Tolerable Windows Approach (TWA).

Organizing Transdisciplinary Research

The work sketched above and many other investigations were conducted in a matrix structure which emphasizes the relevance of transdisciplinary research.

PIK’s research management is based on departments. The role of these scientific units is to track down novel methodological developments in their respective fields, to support PIK’s scientific staff (including their career development) and to control the quality of the results. Four departments (Climate System, Natural Systems, Social Systems and Data & Computation) cultivate mainly discipline-oriented scientific know-how and tools. They are complemented by the department Integrated Systems Analysis, which is dedicated to methodologies that cut across the traditional scientific fields.

The actual research is carried out in projects. The dynamics of Global Change and the relevant processes in the Earth System are investigated by transdisciplinary key questions, defining interdisciplinary “core projects”.

At present, research is focused on nine core projects, which are grouped in clusters under three research angles, namely:

- global perspective,
- regional focus, and
- sectoral view.

The projects have been selected from proposals made by PIK scientists during an internal evaluation process which also involved the Institute’s external Scientific Advisory Board (SAB; see page 130). The SAB routinely evaluates our annual progress and success, providing advice on to how to continue, intensify or decrease certain activities, or even to close down a project.

New Trends in Global Change Science

International Earth-system science is now undergoing a major qualitative transition, which will be sketched in the next section. The Potsdam Institute will attempt to co-evolve adequately and to organize its future research in a timely and concise fashion.

The Second Copernican Revolution is already making itself felt by a metamorphosis of international research activities addressing past, present and future Global Change. This is most conspicuously reflected in the present developments of the International Geosphere-Biosphere Programme (IGBP) on the one hand, and the Intergovernmental Panel on Climate Change (IPCC) on the other. PIK is deeply involved (see page 29) in both cognitive adventures: three of IGBP's core activities, i.e. BAHC, DIS and GAIM, have their centre of gravity in Potsdam, and a number of PIK scientists have taken on high-profile tasks for the Third IPCC Assessment Report to be published in 2001.

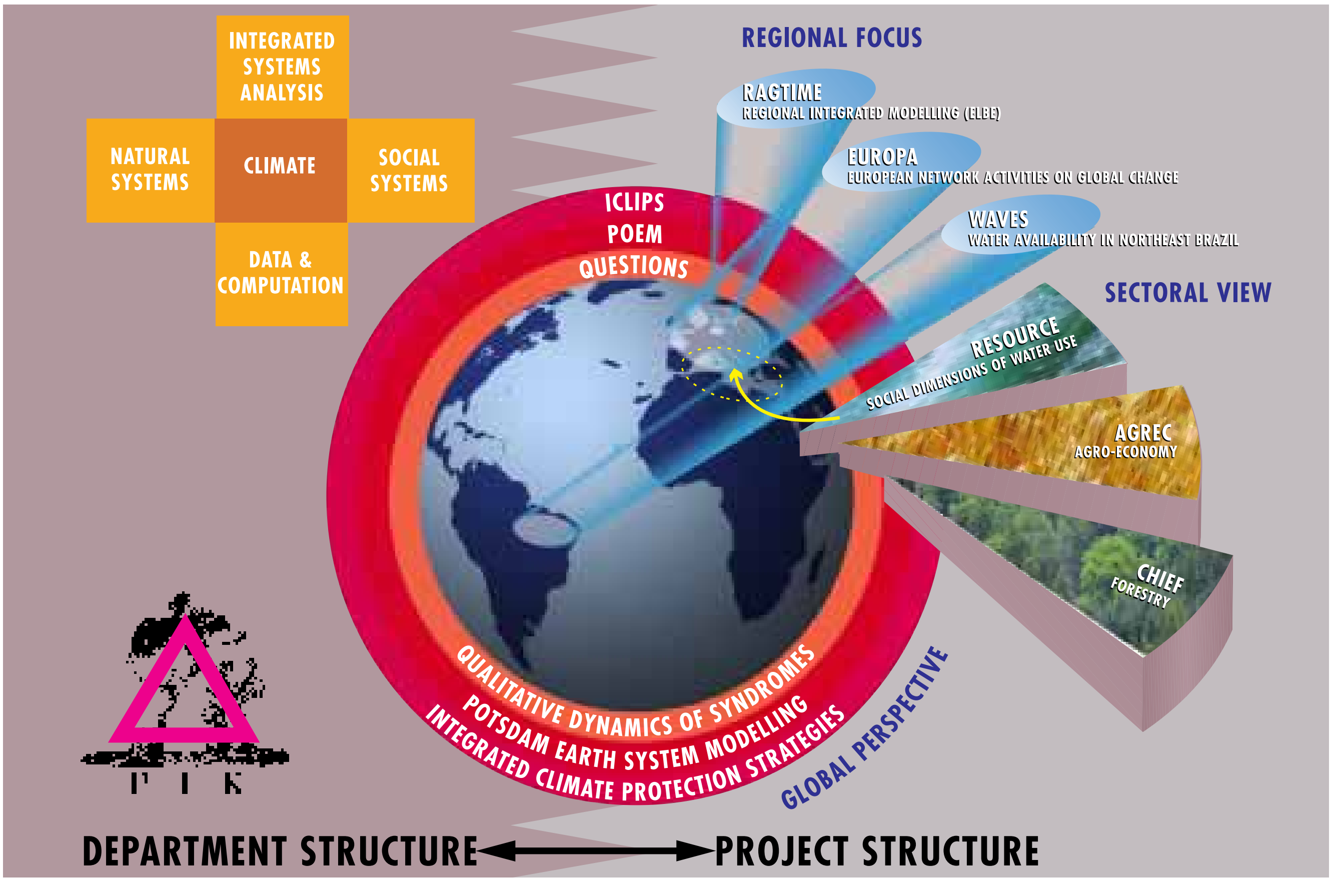
The new paradigm slowly emerging may be called the Integrated Systems Approach (ISA). Our implementation into a workable research approach focuses mainly on:

(i) the specific features of environmental problems that arise from multiple non-linear interactions and often result in irregular responses to external perturbations ("singularities"); and

(ii) the inevitable feedforward and feedback dynamics linking scientific insights and socio-political decision-making, for instance in the area of adaptation management. Here, we enter largely uncharted terrain, and novel methodologies have to be pursued (like semi-quantitative set-based modelling) in order to generate nontrivial results.

The design of the Fourth IPCC Assessment Report (work on which is likely to begin in 2002) will already take account of the new challenges, and the IGBP will probably come out of its present "synthesis phase" with a substantial commitment to co-operation with other programmes like the International Human Dimensions Programme (IHDP). This is a major step towards true Earth System Analysis and sustainability science.

The Potsdam Institute will play more than a passive role as part of this overall evolution; we therefore aim to anticipate major trends in our new research programme – TOPIK^{2k} – for the coming five years. This programme reflects not only the general scientific dynamics in the international arena but also the recommendations made by the Wissenschaftsrat and the Institute's Scientific Advisory Board.



Towards a New Research Programme: TOPIK^{2k}

PIK's new research profile will still be based on projects which are organized within a matrix structure, based on small and efficient groups of scientists. The elements of this matrix, however, will be defined more specifically and the projects will be subject to clearer guidelines. Presently, results from a new competitive round of proposals by PIK scientists is undergoing a broad internal evaluation, and projects are considered in relation to the PIK master matrix of themes and tools. So far, the following items have emerged as part of the new programme:

PIK's Thematic Research Areas or "TOPIKs"

Seven major thematic research areas have been defined. These, described below in shorthand only, are expected to represent our specific mission more precisely, and might be called TOPIKs:

- Non-linear Dynamics of the Ecosphere
- Socio-Economic Motoricity of Global Change
- Emergence of the Global Subject
- Sectoral Climate Sensitivity
- Regional Simulators
- Assessment and Management of Singular Events
- 'PIKuliar' Culture.

Each new project will have to pigeon-hole itself in one or more of these TOPIKs. The last TOPIK will deal with questions concerning uncertainties, scientific discourse and might even include somewhat "crazy" ideas.

Resources, Methods and Tools

The functions of the five scientific departments are now more clearly defined than before: their role is to develop, maintain and support the resources for the research projects and to ensure the quality of the scientific results. The following list of the characteristic scientific methods and tools of the departments is preliminary and the toolbox construction is in progress.

Integrated Systems Analysis:

- Dynamical Systems Analysis
- Concepts of Integrated Modelling
- Soft and Set-Based Modelling
- Assessing Uncertainty Implications
- Decision-Making Analysis

Climate System:

- Meteorological Data Base
- Statistical Models
- Scenario Models
- Dynamical Regional Climate Models
- Ocean Models
- Climate System Models

Foreground: excavation for the new high-performance computer. Background: the new main building (photo taken in January 2000).

Global Change and Natural Systems:

- Eco-Physiological Simulation Models
- Hydrological Simulation Models
- Forest Dynamics Models
- Generic Ecosystem Dynamics Models
- Data Bases and Data Assimilation Techniques

Global Change and Social Systems:

- Macro- and Meso-Models
- Micro-Models
- Multi-Level Models
- Conceptual Analysis
- Stakeholder Dialogues

Data & Computation:

- Modelling Environment
- Graphical Simulation Builder
- Parallelization Tools
- Model Improvement Support
- Meta Data Model and Interfaces
- Information-Technology Infrastructure and Support

Hans Joachim Schellnhuber,
Director of PIK

Manfred Stock,
Deputy Director

Epilogue

We expect that our research efforts under TOPIK^{2k} will contribute to the integrated systems approach. Earth System Analysis and management is certainly no easy task.

An insight that was once summarized in the most poignant way by Alfonso X of Castile: "If the Lord Almighty had consulted me before embarking on the Creation, I would have recommended something simpler."

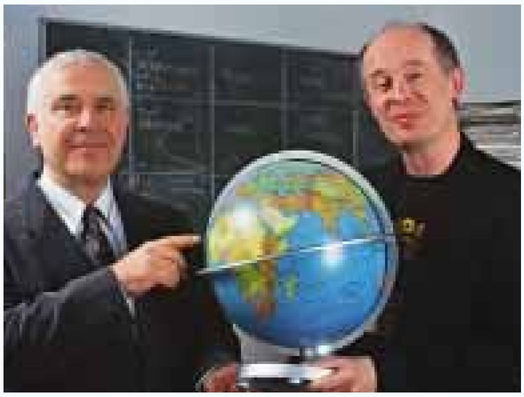
Part of the Albert Einstein Wissenschaftspark from a bird's-eye view.

Departments

Integrated Systems Analysis

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

The Integrated Systems Analysis Department seeks to develop methods and concepts to integrate the research of the various disciplines at PIK and beyond. Since the investigation of Global Change involves many fields of the natural and social sciences, such an integration is crucial to learn about global environmental management options. Integrated Systems Analysis is concerned with questions relating to qualitative and quantitative knowledge, uncertainties, scale issues and management needs. Its recent most promising developments include the application of i) expert assessments on vulnerability, ii) qualitative modelling (QUESTIONS) and iii) set-valued analysis (ICLIPS) to issues of Global Change.



Yuri Svirezhev and Hans Joachim Schellnhuber

Name	*Discipline*	*Project Contributions*
Arthur Block	Physics	QUESTIONS, POEM: COEM
Christine Bounama	Geophysics	POEM: COEM
Thomas Bruckner	Physics	ICLIPS
Martin Cassel-Gintz	Geography	QUESTIONS
Siegfried Franck	Geophysics	POEM: COEM
Martin Füssel	Applied Systems Science	ICLIPS
Hermann Held	Physics	GAIM
Annekathrin Jaeger	Biophysics	WAVES
Elmar Kriegler	Physics	ICLIPS
Maarten Krol	Mathematics	WAVES
Matthias Lüdeke	Physics	QUESTIONS
Oliver Moldenhauer	Physics	QUESTIONS
Gerhard Petschel-Held	Physics	QUESTIONS, ICLIPS, EUROPA
Hans Joachim Schellnhuber	Physics	QUESTIONS, POEM, EUROPA: WISE, ACACIA
Manfred Stock	Physics	RESOURCE; EUROPA
Anastasia Svirejeva-Hopkins	Ecology	QUESTIONS
Yuri Svirezhev	Physics, Mathematics, Genetics	POEM: COEM
Volker Wenzel	Mathematics	RAGTIME, EUROPA: ULYSSES, WISE
Kirsten Zickfeld	Physics	ICLIPS

Introduction

For many centuries the development of nature on planet Earth was more or less independent of human activities. It is the very feature of Global Change that this has changed on all relevant scales: nature's dynamic is no longer independent, but is now largely influenced by human civilization - even in its global features like climate. In other words: the one-directional relation of nature acting and influencing the development of civilizations is now bi-directional. To provide the methods to understand the features, properties and implications of this bi-directionality is the central task of the Integrated Systems Analysis Department. To this end, the department seeks to develop methods and concepts to bring together the results and knowledge of the various disciplines/ departments at PIK and beyond. It focuses on properties of the interactions of sub-systems rather than on those of the single systems themselves. This includes the analysis of the implications of these interactions with regard to global environmental management in the perspective of Sustainable Development: there is no simple set of strategies which ensures the transition to an environmentally, economically, and socially favourable future.

There are major potential pitfalls along this path of research:

- Knowledge from the natural sciences is (mostly) quantitative, whereas the social sciences primarily produce qualitative knowledge. How can they be integrated?
- There are major uncertainties both in the natural systems as well as in social systems. These uncertainties cannot be ignored. But, how can we produce reliable results in spite of these uncertainties?
- There are difficult issues of scale. Processes of Global Change range from local to global spatial scales, time scales from minutes to more than a millennium. How do these scales interact? How can we describe them?
- In more concrete terms: Decision making about mitigating Global Climate Change includes both, costs (mitigation costs) and benefits (avoidance climate-induced damages). How are decisions to be made within this field of tension? How can the two be interrelated?
- Global Change is a scientific field which is distinguished by questions often raised by politics rather than by science alone. This includes difficult normative questions, summed up as a trinity of questions. What kind of world do we have? What kind of world do we want? How do we get there?

In recent years members of the department have developed several approaches to answer these and similar questions. These approaches are applied in various projects, either as core projects or independent activities. From the broad spectrum of the department's work, some of the most promising attempts, which had been developed within the last two years covered by this report, are shortly described in the following.

Prototypical Approaches and Their Application

Expert Assessments, Indicators and Vulnerability

The manifestation of new climatic conditions will likely lead to an increase in extreme weather events such as heavy rainfall, storm, drought events etc. Extreme weather events, which can hardly be forecasted, cause a multitude of different risks not only to nature but also to modern civilization: they could, for example, lead to decreased agricultural yields and income, to severe floods, or to disturbances of traffic. It is a formidable scientific task to estimate the possible damages that might arise for ecological and human-influenced systems by climate change accompanied by increasing extreme weather events.

There are basically two elements that define the risk to be estimated here: first, the probability of the occurrence of the events and second the "values" at risk. Events to be included are hot or cold spells, heavy rain, windstorms, hailstorms, floods, foggy days, etc. By "values" we understand not only economic assets like houses, cars, machinery or monetary losses, but also possible damage to ecosystem functions, human health or social infrastructure. As a basis for the vulnerability assessment conceivable *types* of damage induced by these kinds of events have to be listed. The impact and the selective appraisal of the corresponding damage *potential* are carried out using indicators measuring the amount of vulnerable element within the region. Examples of these indicators are the length of the edges of the forest (potential for the amount of forest damaged by windstorms), the amount of winter traffic (economic damage by an ice-storm) or the number of season workers in tourism (social impacts from "bad weather" in general). The overall assessment is achieved by an expert-based classification scheme, which aggregates the individual indicators for each sector (such as agricultural systems, forest-industries, tourism, transport and traffic etc.) on community level. The goal is to inform policymakers and the general public about climate change risks by an integrated regional vulnerability assessment. So far the methodology has been applied to the German Federal State of Nordrhein-Westfalen.

Qualitative and Semi-Quantitative Modelling

As implied by their names, these methods allow us to integrate qualitative and quantitative knowledge into a single formal framework. Relations between variables are no longer specified by exact mathematical functions alone, but can be characterized by relatively weak statements like: “the higher the aspirations the higher the consumption”. An interconnected network of statements like this yields what we can call a formal qualitative model. The fact that we can include weak statements like the above one puts us in the situation to integrate qualitative knowledge into the analyses, independent of the question whether the “qualitativeness” of the knowledge is due to our limited capabilities or due to basic principles on the nature of reality (post-positivism).

Using the concept of *qualitative differential equations,* the set of compatible model outcomes is computed. An outcome is incompatible and thus not a solution of the qualitative model, taking the above example, if it includes increasing aspiration but non-increasing consumption. This type of *time behaviour* would contradict the statement on the relation between aspirations and consumptions.

Due to the only limited (qualitative) specification of interrelations one gets also a limited specification of model outcomes. In particular one gets a set of outcomes instead of a single result as in conventional modelling. The approach thus gives what we call a weak or restricted prognosis of the system under consideration.

At the Potsdam Institute pure qualitative modelling is used in the QUESTIONS project. Members of the department also act as leaders of the Task Group on “Ecological and Socio-Economic Modelling” of the European Network of Excellence in Model Based Systems and Qualitative Reasoning (MONET).

Differential Inclusions: Set-Based Modelling

The set based modelling approach of differential inclusions is mathematically related to the concept of qualitative differential equations. Here set-valued relations are used to express the connection between two variables in general and to specify the time derivative of a variable in particular. The latter describes how the change of a variable in course of time depends on other variables in the system.

According to the state-of-art we know, for example, that in case of a doubling of CO_2 in the atmosphere the temperature will increase by something between 1.5 °C and 4.5 °C. Furthermore we might assume, as it is sometimes done in simple integrated models of climate change, that the annual increment in climate related damages is related to a temperature increase T by a function T^{α} with α between two and three. The information on both issues involves intervals of number rather than exact values. This type of information can be dealt with within the framework of differential inclusions.

This set-based approach can either be used to reflect and include uncertainties, e.g. on parameter values, or it can be used within a control theoretical approach. In ICLIPS differential inclusions are used to answer the question of what emission paths are feasible over the next, say, 200 years without inducing a dangerous climate change.

From left to right:
Hermann Held, Hans-Martin Füssel, Thomas Bruckner, Elmar Kriegler, Gerhard Petschel-Held, Anastasia Svirejeva-Hopkins, Christine Bounama, Maarten Krol, Yuri Svirezhev, Hans Joachim Schellnhuber, Matthias Lüdeke, Arthur Block, Martin Cassel-Gintz, Annekathrin Jaeger

Besides representing the major methodological backbone of ICLIPS, the approach is increasingly pursued within the QUESTIONS project. In May 1999, a large international workshop on the "Theory and Practice of Differential Inclusions and Qualitative Reasoning in Global Change Research" brought together leading experts from both fields of basic research with modellers from PIK. The workshop has shown that the department's work on these issues is at the very forefront of research in this field.

These new methods are all being newly developed or applied for the first time within Global Change research in the Integrated Systems Analysis Department. In addition, some more conventional methods of non-linear dynamics (neural networks, structural stability, multi-fractal analysis), of reduced form modelling (cyclic integration, coupling of scales), and of multi-criteria analysis and game-theory are being used and developed further within the department.

Climate System

Head: Martin Claussen
Deputy Head: Friedrich-Wilhelm Gerstengarbe

The Climate System Department investigates the complex behaviour of past, present-day and future climate. Understanding the interplay between the various components of the climate system is the key to a comprehensive Earth System Analysis. The work of the department focuses on climate analysis and scenarios, climate-system modelling and ocean modelling. The research in these areas includes: i) the statistical analysis of past and present-day climatic data as well as the construction of future climate scenarios; ii) the development of a climate-system model of intermediate complexity (CLIMBER); and iii) the investigation of ocean currents, in particular the Atlantic thermohaline circulation.

Martin Claussen

Name	*Discipline*	*Project Contributions*
Eva Bauer	Oceanography	EUROPA (KLINO)
Uwe Böhm	Physics	RESOURCE, WAVES
Victor Brovkin	Mathematics	POEM
Gerd Bürger	Mathematics	POEM
Reinhard Calov	Physics	POEM
Martin Claussen	Meteorology	POEM, EUROPA (KLINO)
Andrey Ganopolski	Oceanography	POEM
Friedrich-Wilhelm Gerstengarbe	Meteorology	RESOURCE, WAVES
Alexa Griesel	Geophysics	POEM
Johann Grüneweg	Administrative Assistant	
Detlef Hauffe	Computer Science	WAVES
Claudia Kubatzki	Meteorology	POEM
Till Kuhlbrodt	Meteorology	POEM
Marisa Montoya	Meteorology	POEM
Miguel Ángel Morales Maqueda	Oceanography	POEM
Hermann Österle	Meteorology	WAVES, RESOURCE
Vladimir Petoukhov	Geophysics	POEM
Stefan Pohl	Agricultural Engineering	Historical floods since 1500
Stefan Rahmstorf	Oceanography	POEM
Peter C. Werner	Meteorology	RESOURCE, WAVES
Ursula Werner	Technical Assistant	

In 1998 the Climate Research Department was renamed the Climate System Department to reflect the increasing emphasis on climate-system research and modelling. Moreover, two groups, Climate Analysis and Diagnosis and Climate Scenarios, have merged to form the Climate Analysis and Scenarios group. In addition, a new group, Ocean Modelling, has been established because it has been realized that ocean dynamics, in particular the North Atlantic circulation, could change drastically if greenhouse gases continue to rise unchecked. Hence this component of the climate system deserves further attention.

Climate Analysis and Scenarios

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. Climate analysis concerns not only "simple" climatic mean values. For many applications in climate-impact research information about the complex character of the system is needed. Because of the non-linearity of the climate system multivariate statistical methods have to be used for analysis and diagnosis. Such methods have been developed and applied by the Climate System Department.

Methods employed for the analysis and diagnosis of climate data are also used in validating climate models. This not only helps to improve climate models but also leads to improved understanding and more appropriate exploration of model results in climate-impact research.

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 past few years using the Oracle Data Bank System. The service part of the data bank system provides information about available data sets and allows us to select meteorological parameters, regions and time periods. Statistical investigations, such as the calculation of frequency distributions, autocorrelation functions, cross-correlation, trends, spectra and smoothed series, can be performed. All results can be visualized by the Oracle Data Bank graphical tool. The PIK Data Base System is to be continuously expanded in the coming years.

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 such as the emission of greenhouse gases and changes in land use, and because these activities are hardly predictable, the climate itself cannot be forecast. Instead, estimates, or projections, of possible climate developments – climate scenarios – are computed, based on various estimates of socio-economic changes and of 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.

Climate System Modelling

The study of climate change involves the analysis of recent climates and estimates of possible future climates of the next decades and centuries. It also addresses the fragile balance among various components of the climate system such as the atmosphere, the hydrosphere (mainly oceans and rivers), the cryosphere (mainly inland ice, permafrost and snow), the terrestrial and marine biosphere, and the pedosphere (mainly soils).

In the Climate System Department a climate-system model of intermediate complexity called CLIMBER-2 (for CLIMate and BiospheRE, version 2) has been developed. In contrast to comprehensive climate models, which are currently being operated at other institutes like the Max Planck Institute for Meteorology in Hamburg or the National Center of Atmospheric Research (NCAR) in the USA, CLIMBER-2 is not meant to describe in detail and with the highest possible spatial and temporal resolution individual components of the climate system. This requires vast computer power and data storage (a 100-year simulation takes approximately half a year to run on a super-computer.) Instead, attention is focused on the interaction among all components of the climate system. Therefore, CLIMBER-2 has been developed to provide a rather coarse-scale (some 10 by 50 degrees latitude and longitude) but very efficient description of the climate system. It is at least 1,000 times faster than the comprehensive models and therefore suitable for climate-system analysis and implementation in a fully coupled Potsdam Earth-system Model.

For studies of the natural Earth system which require higher spatial resolution, a new model framework, CLIMBER-3, will be developed in cooperation with the Global Change and Natural Systems and the Data and Computation departments.

Using CLIMBER-2, questions concerning the role of vegetation in the climate system as well as the strong climate variability of the recent geological past have been and will be addressed. Examples are the variations in North Atlantic ocean circulation (see also the section on Ocean Modelling below), natural and anthropogenic changes in land cover, in particular changes in boreal and subtropical vegetation from the so-called Holocene optimum, some 6,000 years ago, to present-day climate, and the greening and desertification of today's Sahara.

Ocean Modelling

The amount of heat transported by ocean circulation rivals atmospheric transport, and ocean circulation changes played an important role in abrupt climate changes of the past (Heinrich events and Dansgaard-Oeschger events), just as they do in present-day decadal variations of the North Atlantic Oscillation (NAO) and as they most likely will do in future global warming.
A hierarchy of ocean models is used to investigate the role of ocean currents and sea ice in climate change, in particular the non-linear behaviour of the Atlantic thermohaline circulation. This model hierarchy ranges from simple tutorial models of thermohaline flow and oceanic convection to state-of-the-art global circulation models with different resolutions.
For example, a four-box model of the Atlantic has been subjected to a systematic bifurcation analysis in collaboration with the non-linear dynamics group at Potsdam University, highlighting the role of bifurcations and instabilities in ocean circulation. The same four-box model is also applied as a component of a simple integrated assessment model in conjunction with PIK's ICLIPS project.
A two-box model of seasonal open-ocean convection is being studied to understand heat storage in the water column, the stochastic nature of convection and its role in decadal climate variability.
Using CLIMBER-2, a sensitivity study investigates the stability of Atlantic circulation for many different greenhouse-gas scenarios in order to study how a circulation collapse could be prevented by timely emission reductions.
A set of state-of-the-art global ocean-circulation models of different resolutions has also been implemented and will be used both to study aspects of present-day ocean circulation and as components of the new CLIMBER-3 coupled climate models.

Staff and Guests

Front row from left to right: Reinhard Calov, Johann Grüneweg, Thomas Kleinen, Claudia Kubatzki.

Back row from left to right: Friedrich-Wilhelm Gerstengarbe, Stefan Pohl, Till Kuhlbrodt, Ursula Werner, Martin Claußen, Stefan Rahmstorf, Andrey Ganopolski, Anja Hünerbein, Peter C. Werner, Marisa Montoya, Eva Bauer, Vladimir Petoukhov, Alexa Griesel, Miguel Angel Morales Maqueda, Victor Brovkin.

Global Change & Natural Systems

Head: Wolfgang Cramer
Deputy Head: Petra Lasch

The Global Change & Natural Systems Department studies the role of land ecosystems in Global Change. Ecosystems provide food, freshwater, fibres and many other fundamental services for human life and well-being. Our research focuses on the sensitivity of ecosystems to a changing environment and on the feedbacks between the overall Earth system and the land surface. Major projects include i) development of the LPJ Dynamic Global Vegetation Model (for POEM), ii) analysis of integrated hydrological and ecological processes in large watersheds (for RAGTIME & WAVES), iii) simulation of forest growth and management (for CHIEF) and iv) the study of agriculture in a changing climate (for AGREC).

Wolfgang Cramer

Name	*Discipline*	*Project Contributions*
Franz-W. Badeck	Forest Modelling	CHIEF
Alfred Becker	Hydrology	RAGTIME
Thomas Beckmann	Water Economy	RAGTIME
Alberte Bondeau	Physics, Ecology	POEM: DGVM
Christine Bismuth	Hydrology	LAHoR
Axel Bronstert	Hydrology	WAVES
Wolfgang Cramer	Geography / Ecology	POEM: ETEMA, AGREC, CHIEF
Gabriele Dress	Administrative Assistant	
Beatrix Ebert	Mathematics	CHIEF
Markus Erhard	Geoecology	CHIEF
Uta Fritsch	Hydrology	LAHoR
Jan Gräfe	Agricultural Sciences	AGREC
Andreas Güntner	Hydrology	WAVES
Uwe Haberlandt	Hydrology	RAGTIME
Fred Hattermann	Hydrology	RAGTIME
Ylva Hauf	Geoecology	CHIEF
Thomas Kartschall	Physics	AGREC
Daniel Katzenmaier	Hydrology	LAHoR
Beate Klöcking	Hydrology, Ecosystem Analysis	RAGTIME
Valentina Krysanova	Ecohydrology	RAGTIME
Werner Lahmer	Hydrology	RAGTIME
Petra Lasch	Mathematics	CHIEF

Marcus Lindner	Forest Sciences	CHIEF
Wolfgang Lucht	Physics, Geography	POEM: DGVM
Lucas Menzel	Hydrology	EUROTAS, RAGTIME, EUROPA
Peggy Michaelis	Agricultural Sciences	AGREC
Claus Rachimow	Mathematics	RAGTIME
Jörg Schaber	Systems Analysis	CHIEF
Jan Peter Schäfermeyer	Hydrology	Lateral Flows
Stephen Sitch	Mathematics	POEM: DGVM
Felicitas Suckow	Mathematics	CHIEF
Kirsten Thonicke	Geoecology	POEM: DGVM
Bärbel Uffrecht	Information Technology	Service for several projects
Sergey Venevski	Mathematics	POEM: DGVM
Martin Wattenbach	Biology, Ecology	CHIEF, AGREC
Frank Wechsung	Agricultural Sciences	AGREC

In 1998 and 1999 the department has consolidated its tool development in all four main areas of work, i.e. general (global) ecosystem dynamics, hydrology and regionally integrated modelling (including flood-risk assessment), forest dynamics and agroecosystem sensitivities. The main challenge has been to make assessment results available in a multi-disciplinary and policy-relevant context. This was pursued in projects such as the German Forest Study, the regional impact assessments in the Elbe catchment and NE Brazil, in the co-operative Lund-Potsdam-Jena DGVM project, several European projects and in various contributions to the Intergovernmental Panel on Climatic Change (IPCC). In the near term the interdisciplinary component will be strengthened further, e.g. by more substantial contributions to policy-relevant vulnerability assessments and by a deeper involvement in the construction of a comprehensive Earth-system model in POEM (see page 33).

Department Concept

Ecosystems are the foundation of human life on Earth, providing food, freshwater, fibres and many other services, requiring only suitable climate and soils as substrate. We assess the role of land ecosystems in Global Change from two perspectives: i) just how sensitive are ecosystems to a changing environment; and ii) which physical and biogeochemical feedbacks exist between the overall Earth system and the (green) land surface?

The sensitivity question is both straightforward and complex: the geographic distribution of land ecosystems is caused by climate and human land use, 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, a system of interrelated mechanisms exists between the availability of sunlight, nutrients (including carbon dioxide) and an acceptable 'envelope' of humidity and warmth for plants - each ecosystem responds differently to certain combinations of these factors. We carry out research to better understand these mechanisms on a range of different scales from the individual leaf to whole continents.

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

No ecosystem can be seen as independent of human activities such as land use, pollution or even protection. 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 for modelling the global carbon cycle. Land-use *change* itself 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 ecosystems change in response to climate change? Are disturbance events such as fire or storms important? If adaptation occurs, then on what time scale?

- What significance does land vegetation have for global biogeochemical cycles (carbon, water and nitrogen)? Specifically, how does increasing carbon dioxide affect vegetation dynamics, and how do such changes feed back on climate?
- What impacts do regional changes in land use have on water availability, water quality, flood risk and ultimately the land-use potential of catchments?
- What is the possible impact of climate change and increasing CO_2 on the agricultural or forest potential on the regional scale? How are such changes related to changes in the market structure driven by environmental change elsewhere?

Models and Scenarios as Tools for the Analysis of Global Change Impacts

For extrapolation into the future, Global Change processes require formulations as numerical simulation models, founded on observations and experimental data. These models are developed in international networks such as the IGBP and individual partnerships with experiment- or observation-oriented research groups. Precise *predictions* of regional climate or land use are not possible, however; therefore, scenarios of potential environmental changes are used to assess the sensitivity of ecosystems to the multitude of possible future trends.

Sophisticated simulation models are available for many partial aspects of the problem such as water resources, forest succession or trace-gas and energy exchange between plants and the atmosphere. If these models are to be integrated into a global Earth system model or into regional integrated assessment models, then they inevitably need to be adapted; 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 must be made between regional and global approaches. At the regional level it is usually both possible and necessary to analyse ecosystems at a sub-process level, e.g. the dynamics of spatially linked 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 to be closed. In the past we have also developed separate models for different land-use types or economic sectors, e.g. agriculture and forestry, which require different time scales. We now increasingly focus on integrating these into a coherent picture of whole regions.

The validation of model results remains a critical difficulty and hence a great priority; direct or indirect support for simulations is derived from experimental studies (usually carried out at other laboratories with PIK scientists as collaborators) or from observational programmes.

One important area of validation work carried out by the department is the analysis of data from satellite-based sensors, particularly those that are in operation over long time periods, permitting the study of dynamic features such as ecosystem phenology.

Main Working Groups

- *Global Biosphere Dynamics* - The group is developing a dynamic ecosystem model, which is applicable on continental to global scales, but which also can be used as a component for the POEM Earth-system model. The basic hypothesis is that both physical and biogeochemical feedbacks between vegetation change and the climate system are crucial for lags and possible bifurcations of the coupled system. Key questions relate to the global carbon cycle and to the vulnerability of ecosystem services to environmental change. In addition to model development, the group is analysing long-term satellite imagery for ecosystem model validation
- *Hydrology and Water Resources* - The primary focus is on mesoscale analysis and modelling of hydrological and ecological processes. Recently the approach has been extended to include ecosystem processes more directly, as well as socio-economic and social aspects. Processes which are critical for integration and therefore receive special attention are lateral flows of water and the associated transport of material, nutrients and other substances along different pathways in river basins, the interaction between soil, groundwater and vegetation growth, and the dependence of hydrological processes (evapotranspiration, runoff generation) on increased CO_2.
- *Forests and Forestry* - In the assessment of the growth and functioning of forests, the group is working towards a novel approach to simulating dynamics in managed and unmanaged forests. The forest growth model 4C is more directly based on physiological formulations than earlier models. Tests of 4C at well observed sites in Brandenburg demonstrate its ability to reproduce the soil water budget and associated growth responses. For regional assessments, the group also uses the more widely applicable model FORSKA-M, which has been extended by forest management routines. A nation-wide pilot study of the influence of climate change on German forests now approaches its completion through a synthesis of possible responses in growth, manage-

ment, market options and social services for German forest enterprises (in co-operation with several partners at German forest research institutes).

- *Agriculture* - The AGREC group uses empirical and mechanistic models for the assessment of crop-yield impacts of short-term climate fluctuation and long-term climate shifts, applied for yield changes at the stand level, and on the regional to global scale. On the regional scale the interactions between yield and the regional water balance is studied. Based on empirical relationships the effect of short- term yield fluctuations on economic measures is predicted for selected countries. On the global scale the consequence of climate-change related yield changes for global agricultural trade is simulated using a partial equilibrium model.

International Co-operation

The department continues to be strongly involved in the IGBP (International Geosphere-Biosphere Programme) through its elements BAHC (Biospheric Aspects of the Hydrological Cycle) and GCTE (Global Change and Terrestrial Ecosystems), where many scientific contributions are made. Alfred Becker is vice-chair and one theme leader of BAHC, Wolfgang Cramer is focus leader and executive committee member of GCTE. Wolfgang Cramer is also a member of the IGBP task force GAIM (Global Analysis, Interpretation and Modelling). The department is closely allied with the BAHC core project office. Several scientists contribute as lead authors, contributors and reviewers to various reports of the Intergovernmental Panel on Climate Change (IPCC).

***Back row from left to right:** Ylva Hauf, Peggy Michaelis, Gabriele Dress, Beate Klöcking, Martin Wattenbach, Jeannette Meyer (Stud.), Uwe Haberlandt, Markus Erhard, Kirsten Thonicke, Sergey Venevski, Werner Lahmer, Franz Badeck, Stephen Sitch*

***Fourth row from left to right:** Bärbel Uffrecht, Uta Fritsch, Daniel Katzenmaier, Fred Hattermann*

***Third row from left to right:** Alberte Bondeau, Valentina Krysanova, Daniel Schwandt*

***Second row from left to right:** Jan Peter Schäfermeyer, Petra Lasch, Frank Wechsung*

***First row from left to right:** Wolfgang Cramer, Wolfgang Lucht, Thomas Beckmann*

Global Change & Social Systems

Acting Head: Ferenc Tóth
Head (from May 2000): Carlo Jaeger
Deputy Head: Marian Leimbach

The Global Change & Social Systems Department investigates the interaction between human societies and their natural environment. At present humankind is increasingly interfering with the natural Earth system. The department is concerned with the variety of anthropogenic driving forces to Global Change as well as its impact on society, politics and the economy. Areas of research include i) modelling of the long term macro-economic development, ii) integrated assessment of climate change (ICLIPS), iii) investigation of international environmental institutions and iv) past and present adaptation measures (WISE) as well as future adaptation options (QUESTIONS) for Global Change.

Ferenc Tóth

Name	*Discipline*	*Project Contributions*
Gerd Bruschek	Geography	AGREC
Katrin Gerlinger	Economics	WISE
Johann Grüneweg	Administrative Assistant	
Carsten Helm	Economics and Political Science	ICLIPS, IGR
Norbert Herrmann	Economics	WISE
Richard Klein	Environmental Science	WISE
Marian Leimbach	Economics	ICLIPS, RESOURCE
Ina Meyer	Economics	
Fritz Reusswig	Sociology	QUESTIONS, RESOURCE
Detlef Sprinz	Political Science	RESOURCE
Ferenc Tóth	Economics and Policy Analysis	ICLIPS, EUROPA: ULYSSES, EFIEA
Éva Tóthne-Hizsnyik	Economics	ICLIPS, EUROPA: ULYSSES

The concept of global environmental change emerged in the early 1980s as a result of increasing concern about the nature and consequences of long-term, large-scale interactions between socio-economic development and the natural environment. Its original geocentric character reflected observations of changes in global biogeochemical cycles and their interactions with each other, with the Earth's climate and with ecological processes. Anthropocentric aspects involving both the large variety of driving forces and the diverse set of implications of these processes for human societies were soon added. 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 will furthermore improve social and political efforts towards better Earth-system management.

The Global Change & Social Systems Department studies the social dimensions of Global Change in the following research fields.

Integrated Assessment and Macro-Economic Modelling

Major research efforts have been aimed at the development of an aggregated economic model. In combination with climate models and impact models this economic model is suited for an integrated assessment of climate change.

While designed as an optimal growth model, hence embedded within a computationally demanding intertemporal optimization framework, the economic model demonstrates a fairly high regional resolution. There are 11 regions. Economic growth in each region is affected by interregional relations (intertemporal trade, capital mobility) as well as capital accumulation, technological change and population growth.

The economic model also integrates a component that represents the cost of carbon mitigation efforts in the energy sector. By means of a new type of mitigation cost function, emission reduction is considered as a continuous process with cost-diminishing effects from "learning by doing". Within climate policy analyses we focus on the socio-economic (as well as environmental) effects of emission-rights trading which helps to meet climate protection targets cost-effectively. In this context the huge decision-making impacts of equity issues (what is a fair initial allocation of emission rights?) are demonstrated.

International Environmental Regimes

The concept of regime effectiveness revolves around the issue of whether international treaties help to solve international problems. Until recently, no measurement tool was available to answer this question. At PIK a concept on how to measure the degree of environmental problem-solving has been developed.

While there is much debate on whether environmental degradation leads to violent conflict, there has been little focus in the social sciences on what constitutes environmental change. With the help of a NATO Science Collaborative Research Grant and in collaboration with the University of Montana, we have developed a time-series based assessment tool for time-dependent changes of environmental variables. This contributes to the larger discussion of what constitutes a threshold and adds statistical criteria to the set of normative criteria in the hands of decision-makers. This method helps to find an answer to the question whether environmental causes can be sufficient conditions for violent conflict to occur.

A series of introductory and advanced courses on international environmental policies and international relations were taught at the University of Potsdam.

Vulnerability and Adaptation

Adaptation in the context of climate change refers to any adjustment in ecological, social or economic systems in response to actual or expected climatic stimuli or their effects. The ability to adapt, along with the exposure to potential impacts, significantly determines the vulnerability of a system, sector or country.

While adaptation has always been an implicit element of many projects at PIK (e.g. QUESTIONS, AGREC, ICLIPS, WAVES, RESOURCE), in 1998 the Global Change & Social Systems Department decided to strengthen its capacity in this emerging field. An explicit research effort on adaptation is now being pursued with the aim of better understanding adaptation processes and developing methodologies for adaptation assessment. The primary focus is on coastal zones, but conclusions are applicable to many sectors. Results of this work are anticipated to benefit ongoing and new research at PIK by allowing projects to include adaptation considerations, and thus conduct more realistic impact analyses.

Together with the Integrated Systems Analysis Department a regional climate impact assessment was conducted for the German federal state of North Rhine-Westphalia. In a first step, the ecological and social vulnerabilities of the region were determined, using measured data and expert knowledge on weather impacts. In a second step, a cluster analysis of German climate zones, provided by the Climate Systems Department, was used to assess the regional long-term vulnerability in terms of non-monetary adaptation costs.

Important lessons on adaptation can be learnt from studying responses to past and current weather extremes. One of the findings of the WISE (Weather Impacts on Natural, Social and Economic Systems) project, which included a management survey, was that few of the investigated companies are pursuing active adaptation to climate change. This may be caused by limited awareness of climate change impacts or by the conviction that they are able to cope with these impacts. However, a number of companies are engaged in activities aimed at enhancing robustness and resilience to current weather variability. These activities also serve to reduce vulnerability to climate change. The strongest developments in this field can be observed in the water sector in the UK.

Perception of Climate Change

Within the WISE project, the Institute conducted research to assess the influence of weather on various socio-economic sectors and the general public in Germany as part of a transnational comparison. In addi-

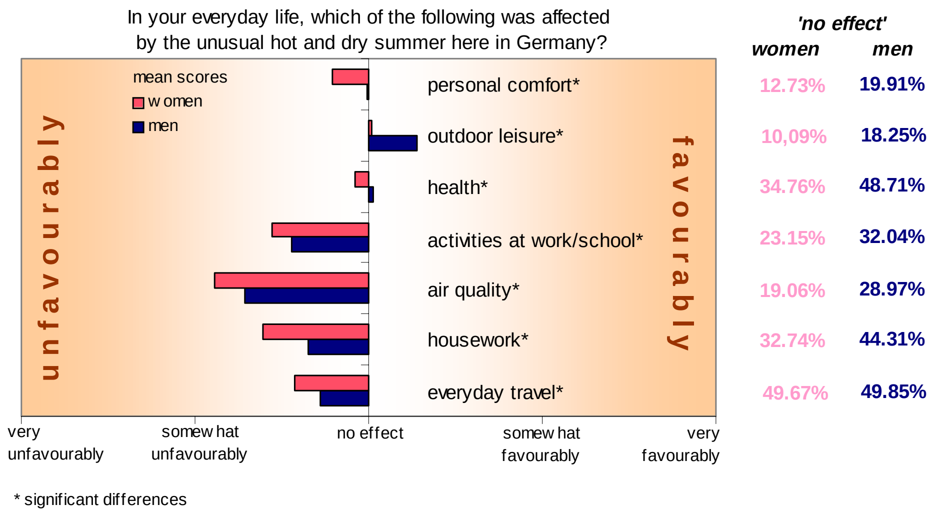


Fig. 1: Differences between women and men in their perception of hot and dry summer weather in everyday life. All respondents said that hot and dry summer weather conditions affected their everyday life less favourably excluding 'outdoor leisure activities'. Women perceived more effects of hot and dry summer weather and were less unfavourable to these conditions than men.

tion, the willingness and preparedness for adaptation to weather extremes and climate change were investigated.

The population survey aimed at investigating the public's perception of and behavioural response to unusually hot and dry summers and mild winters. In Germany, noticeable differences were found between female and male respondents in the perception of extreme weather events (see Figure 1). The study revealed that women are more sensitive to unusual hot and dry summer weather than men. But although women perceived more effects and adapted themselves more than men, no gender differences could be detected in the willingness to mitigation.

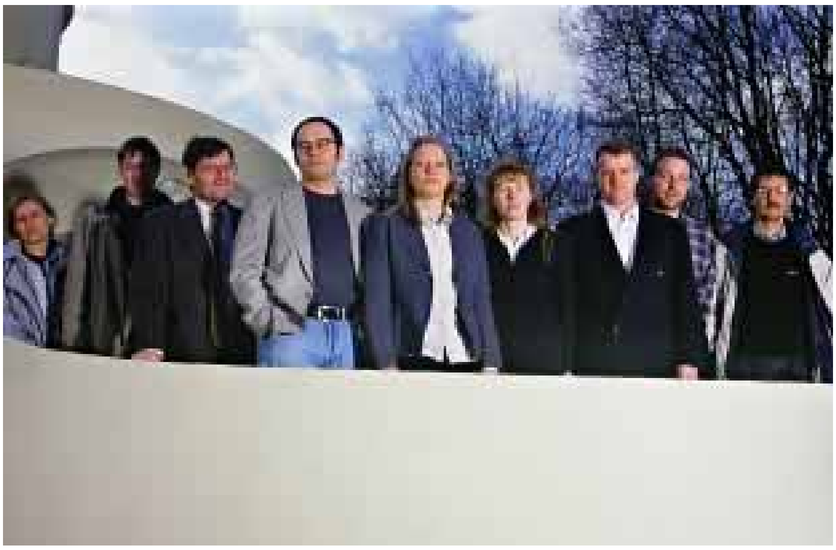
In conclusion, the study provides an important link between impacts and adaptation and between perception and action. Much of the data and information that has been collected will provide a sound basis for future research. For more information on WISE, see page 77.

Perspectives

The Global Change & Social Systems Department will undergo significant changes in future. Within a regional research network the department's resources will be concentrated on building up a social-science knowledge base that allows us to investigate long-term future developments in Europe in the context of Global Change. This general research programme includes innovative efforts in the following research areas:

- Modelling of long-term socio-economic dynamics
- Modelling political decisions on global environmental change
- Evolution of preferences and lifestyles
- Uncertainty and deliberative processes.

From left to right: Éva Tóthne-Hizsnyik, Johann Grüneweg, Gerd Bruschek, Fritz Reusswig, Ina Meyer, Katrin Gerlinger, Detlef Sprinz, Martin Weiß, Ferenc Tóth



Data & Computation

Head: Rupert Klein
Deputy Head: Karsten Kramer

The Data & Computation Department provides the information-technology infrastructure and its expertise in mathematics and computer science to the PIK community. Since Earth-system analysis has to rely heavily on modelling and computing, Data & Computation is the backbone of PIK research. Its services include: i) the maintenance of an IBM SP2 parallel computer and a Workstation/PC network with about 150 nodes; ii) support for model development and implementation as well as for the evaluation of results; and iii) the provision of tools for model integration, data visualization and scientific data management (SDM). In addition, the Data & Computation Department pursues genuine research in the field of scientific computing.

Rupert Klein

Name	*Discipline; Function*	*Project Contributions*
Nicola Botta	Fluid Mechanics; Research, Support	
Gabriele Dress	Administrative Assistant	
Michael Flechsig	Mathematics	SDM, EUROPA: WISE, RAGTIME
Dietmar Gibietz-Rheinbay	Systems Management, Electronic Publishing	POEM, WAVES, AGREC
Achim Glauer	Database Administrator	
Roger Grzondziel	Trainee	
Arnulf Günther	Computer Science; Software Engineer	
Detlef Hauffe	Software Developer	WAVES
Cezar Ionescu	Informatics; Software Developer	
Henrik Kinnemann	Computer Science	EUROPA, CLIMBER
Rupert Klein	Applied Mathematics; Dept. Head	
Karsten Kramer	Information Technology; Systems Architect	
Jörg Krywkow	Geographical Information Systems	WAVES
Martin Kücken	Climate Model Development	WAVES
Helmut Miethke	Network Administrator	
Antony Z. Owinoh	Applied Mathematics; Research	
Thomas Slawig	Numerical Analysis	
Frank Toussaint	Physics; Database Development	SDM
Markus Uhlmann	Fluid Mechanics; Numerical Simulation	
Werner von Bloh	Theoretical Physics; Research, Support	POEM
Markus Wrobel	Computer & Information Science	SDM

The Data & Computation Concept

Climate-impact research studies rely heavily on modelling and scientific computing because the length and time scales of interest for climate-impact research are too extensive to allow reliable investigations through laboratory experiments. The process of scientific computing includes the development of an abstract mathematical description of the studied system, the translation of this mathematical model into a discrete, computer-digestible analogue, its implementation on modern computing facilities, their operation, and the thorough evaluation and interpretation of the computed results. The Data & Computation Department supports the Institute's ambitious interdisciplinary goals by maintaining an extensive hardware and software pool, by contributing mathematical and computer-science expertise to a range of applied research projects and by pursuing additional disciplinary research in applied mathematics and computer science.

Scientific Computing

Numerical weather forecasting and regional climate modelling rely on numerical simulations of the time evolution of complex geophysical systems. Such an evolution is described in terms of sets of discrete equations. Generally, these equations are a discrete approximation to a set of differential equations representing a combination of the fundamental conservation principles, and additional relations derived from scale analysis and/or empirical observations. These latter "parameterizations" account for processes that take place on unresolved scales and cannot be explicitly described via discrete forms of the fundamental equations. There are a number of uncertainties associated with both the discretization of continuous models and the "parameterizations". To reduce these uncertainties we follow a twofold strategy.

Focus 1 deals with the gap between numerical solutions of the discrete equations and exact solutions of the model equations. An interaction of numerical analysis, code verification for judiciously chosen analytical tests, and validation against measured data has characterized the last decades of progresses in numerical fluid mechanics. Data & Computation aids model developers at PIK in adopting this strategy.

Another focus concerns the gap between the model equations, which are usually obtained by introducing a number of simplifying assumptions, and generally trusted, more comprehensive models. This gap is usually small in some relevant regime (hydrostatic, geostrophic) but may increase as the system evolves away from the ideal state, or may lead to cumulative errors over long integration times. An important approach to analysing this source of error is asymptotic analysis, in the sense of a generalized scaling theory. We believe that multiple-scale asymptotics provides valuable modelling support, for instance by revealing restrictions which the "parameterizations" have to fulfil, or by suggesting asymptotically adaptive methods that operate accurately and with uniform efficiency across a wide range of scales.

A typical example is the current Atmospheric Boundary Layer (ABL) analysis being done in co-operation with Prof. Julian Hunt of University College, London. The ABL is defined as the lowest atmospheric layer in which the effects of the surface (friction, heating, etc.) are felt. Turbulent transfer of heat, momentum and moisture at the earth's surface contributes substantially to the behaviour of the atmosphere.

The objective of this research is to analyse the relationship between boundary-layer processes and surface-exchange mechanisms. We extend existing theories of flow over topography on length scales of 1 km to 100 km. The analysis is based on asymptotic expansions for three sub-layers. In the lowest "inner" layer turbulent friction plays an important role. In the adjacent "middle" layer the flow is inviscid, but rotational. In the outer layer, the flow is dominated by inertia and may be considered inviscid and irrotational. The solutions obtained for each layer are matched using standard asymptotic methods.

Detailed investigations on the role of the surface cover, roughness changes, thermal and humidity effects will lead to improved estimates of surface fluxes. In addition, the results will be used as a lower boundary condition for troposphere-dynamics investigations and for parameterizations in large-scale numerical models, especially for processes over vegetation and urban areas. A comparison of numerical results with theoretical and remote-sensing data is planned.

Scientific Visualization

Complex computer simulations have the twofold goal of producing scenarios of upcoming events and of increasing scientific knowledge about a complex system. In the "scenario analyses" computed data are prepared to allow an intuitive grasp of what is actually predicted. Visualization supports the detection of particular solution "features" that are hidden within massive amounts of data.

In pursuing the second aim of gaining new insight, a scientist develops a hypothesis regarding the inner workings of the studied object and then sets out to verify the hypothesis. An ability to visualize the results of a computer simulation flexibly and in a variety of ways supports the scientist's initial intuitive search for meaningful hypotheses. Next, a *quantitative* estimate of the degree to which a hypothesis is supported by the computed results should be obtained. This requires casting the hypothesis in mathematical terms and providing a suitable norm that measures the degree of agreement. Computational evaluation of such norms for given sets of results finally yields the desired quantification of the hypothesis's correctness.

A software tool for Visual Analysis, VisAna, is under development within the Data & Computation Department. This software allows scientists to initiate inquiries into their simulation data by formulating suitable mathematical operations. These operations represent the scientific hypotheses to be evaluated and the user-defined error norms. By coupling VisAna with sophisticated visualization environments Data & Computation aims at providing an integrated tool for the scientific analysis of large-scale computational data.

Interdisciplinary Model Integration

MODENV, a software environment for coupling climate system components, is currently under development. MODENV supports the distribution and modularization of climate models by defining clear-cut, user-friendly interfaces between its components and allowing their coupling and execution in distributed computing environments. The goal is to enable the coupling of self-contained, originally "stand-alone" models. Such "legacy" (or already existing) programmes are literally *wrapped* in an intermediate software layer. This layer represents the programme to the outside world, such as a computer network or the internet, as an object that can be invoked in a well-defined fashion to complete its implemented functionalities. These object calls are translated by the software layer into function calls in the language that the programme has originally been implemented in. An in-house developed, originally "monolithic" climate-simulation system (CLIMBER, see page 37) has recently been re-compiled successfully under MODENV as a distributed system.

Part of MODENV is the Graphical Simulation Builder (GSB). This tool allows users to build, run and control simulations. Despite being part of MODENV, it may also be used as a "stand-alone" application. The elementary unit of a simulation is a pre-existing module, such as a Fortran subroutine, an executable programme, etc. A simulation is defined by these elementary units and by the connections between them. The GSB user has a high-level view of the modules as icons to be dragged and dropped onto a drawing area on the computer screen. The icons are connected graphically by directed arrows, so that the structure of a simulation resembles that of a directed graph. This high-level view of a simulation, and the low-level view, as software connections between existing components, is realized in two steps. Step one introduces a third, intermediate layer that hides the particularities of the modules, exposing a generic software interface. Thus, high-level components of GSB need no knowledge of the platform, location or implementation of the modules. Step two introduces modules that materialize the directed connections by transporting and translating data between the modules. At this level concrete coupling technologies can be incorporated to ensure efficient operation as needed in complex practical applications.

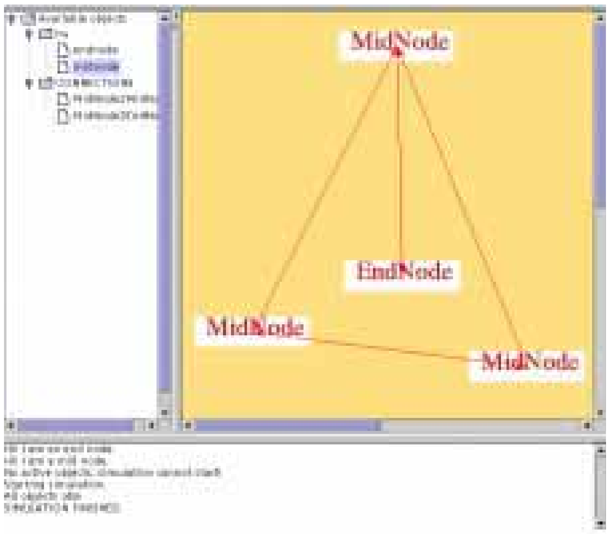


Fig. 1: The picture shows the Graphical Simulation Builder after running a simulation of a random walk. The tree in the left-hand window lists the available components, which might be running on remote machines under several different operating systems. Working with GSB, the user does not need to be aware of the distributed nature of the simulation he has built.

Scientific Data Management (SDM)

The vast complexity of scientific data on Global Change necessitates the co-ordinated design of meta databases providing information on the structure, quality, availability and storage location of the original data. During the reporting period, in close co-operation with the Deutsches Klimarechenzentrum and the Alfred-Wegener-Institut für Polar- und Meeresforschung, PIK has refined its meta data model CERA-2 (Climate and Environmental Data Retrieval and Archive System, http://pik-potsdam.de/cera). CERA-2 supports the description of spatial and temporal data and conforms to the common meta data standards (NASA-DIF, FGDC-CSDGM Level 1).

To enhance its flexibility, the CERA-2 data model is structured into a mandatory core part, where information about data coverage, attributes, spatial layout, status, access, contacts, distribution and publication is described, and into additional modules for further meta data and data description. CERA-2 can be implemented in any relational database-management system and is freely available from the CERA Home Page. Currently, CERA-2 covers about 750 entries at PIK. This number is to increase rapidly as soon as computational results are documented routinely in the meta database.

The Advanced Flexible Retrieval Interface AFRI has been developed to provide intuitive retrieval from different (meta) databases and to ensure a clear presentation of query results. Features of AFRI are network ability, platform independence, generic setup mechanisms and a graphical user interface. The generic setup mechanism allows us to query any kind of database, to change database structure and to adapt the interface to the user's demands without reprogramming. To support dynamic thematic queries, AFRI is able to handle multi-level attribute hierarchies as well as hierarchical thesaurus structures. AFRI is a Java applet and makes use of standard WWW browser technology on the Internet and the Intranet.

AFRI is coupled with the Interactive Digital Atlas IDA, a hierarchical multi-layered map collection for interactive definition of spatial queries and for representation of spatial query results from point/station meta data. Currently, there are two layers: the administrative layer consists of global sub-structures (continents), continental sub-structures (countries) and national sub-structures of Germany. Additional first and second-level national sub-structures will be made available on demand. The hydrological layer maps German river basins. A continental river-basin hierarchy is an outstanding candidate to supplement this layer because river basins are the natural integrators for parts of the hydrological cycle. Query results from point/station meta databases can be visualized with IDA, including interactions (e.g. select/deselect stations) between AFRI tabular output and IDA maps. The optimized IDA map format can be derived from coverages stored in the Arc/Info geographic information system.

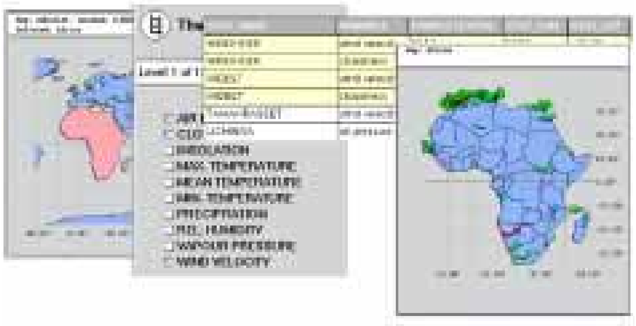


Fig. 2: The graphical user interface (GUI) developed at PIK allows comfortable selection of data from different geographical regions.

Future CERA-2 development will involve enhancements in meta data exchange in the sense of a distributed meta data management. Efforts in AFRI development will focus on interoperability between meta data and data. Visualization and download of station data after selecting appropriate stations from their meta data with AFRI will form a first milestone in this context. In the near future AFRI will be used to connect to meta databases outside the institute. IDA enhancements will include an enlargement of the map collection as well as interfaces to other digital map formats.

Computing Infrastructure

Maintaining a reliable, state-of-the-art information-technology infrastructure with the lowest possible overheads still remains a challenge. The Data & Computation Department has managed to keep pace with the tremendously accelerating rate of technological change without interrupting existing service(s). Approximately 50 new workstations and PCs have been installed to support new staff members or to replace old equipment. A centrally maintained PC-application service had been established. Cross-platform integration allows for the use of the appropriate computer platform for specific tasks while minimizing

Fig. 3: IBM 3494 tape library and harddisk subsystems (left).
Detail: Accessor of the tape library robot (right).

the efforts of transferring data and applications. It also increases the flexibility of workstation usage at PIK. All major operating systems and software applications have been updated to their actual releases throughout the Institute. After a smooth entry into the year 2000, one should also point out the precautions which were taken against date-related software errors. The installation, testing and deployment of a new parallel file system and the complete reconfiguration of our tape library were also milestones during the reporting period.

However, the most ambitious task accomplished was certainly the planning and preparation of the complete overhaul of the whole IT infrastructure. Virtually no piece of hardware or software will be left standing during the next two years. Our final computer rooms will be finished by the summer of 2000. A new local area network - based upon switched 100 Mbps and 1 Gbps Ethernet - will be installed at the same time. In August 2000 PIK will upgrade its wide area Internet connectivity to 34 Mbps (155 Mbps for the region). In the autumn we will install a high-performance 128+ cpu follow-up system to the existing IBM SP parallel computer. The new machine will provide computer services as well as file services in the 4+ TByte range. All changes to our infrastructure will soon be reflected in our redesigned Web presentation, which is also currently under development.

Contributions to the Core Projects

POEM: The parallel library GeoPar was applied to geophysiological modelling incorporating herbivore dynamics. The library will be extended by Parallel Input/Output function using the new MPI-2 Message Passing standard.

WAVES: A regional climate model has been developed on the basis of LM (Local Model), the most recent numerical weather prediction code of the Deutscher Wetterdienst (DWD). The original version of LM has been extended to include parameterizations for long-term effects that are not normally accounted for in short-term weather prediction.

From top left:
Frank Toussaint, Dietmar Gibietz-Rheinbay, Claus Rachimow, Henrik Kinnemann, Cezar Ionescu, Werner von Bloh, Antony Z. Owinoh, Michael Flechsig, Nicola Botta, Gabriele Dress, Rupert Klein, Markus Wrobel, Helmut Miethke, Thomas Slawig, Markus Uhlmann, Karsten Kramer, Jörg Krywkow

Administration

Head: Kerstin Heuer

Clockwise from bottom left:

Kerstin Heuer, Monika Kramer, Vera Großmann, Lothar Lindenhan, Annett Lindow, Günther Hilberoth, Brigitte Mierke, Frauke Haneberg, Renate Kahle

Name	*Function*
Vera Großmann	Personnel Office
Frauke Haneberg	Balance and Finance Accountant
Kerstin Heuer	Head of Administration
Günther Hilberoth	Technical Service
Renate Kahle	External Funding, Budgetary Matters
Monika Kramer	Central Service, Travel Expenses
Lothar Lindenhan	Procurement, Investment Accountancy, Building Matters
Annett Lindow	Administration Secretary, Personnel Office Assistant
Brigitte Mierke	Finance Accountant

The administration department is currently looking after approximately 130 employees (guest scientists included). Vacancies, appointments, dismissals, regular and special decisions resulting from legal statutes, matters of business travel and expenses, salaries and other forms of remuneration are all handled by the department.

In accordance with decisions taken by the body in charge of finance, the administration department prepares and manages the annual budget. During the period under review it controlled approx. 14,5 million DM annually (external funding included). Related to the budget, matters of procurement as well as financial, investment and asset accounting also belong to the administration department's workload.

Another of its tasks is the control of external funding (some 4 to 4,5 million DM annually during the period under review); this involves drawing up proposals, supervising procurements and preparing statements of account for running projects (61 projects in 1999).

Moreover, the work of the administration department includes the planning and supervision of construction work that is being carried out to give PIK a permanent home. This involves such tasks as putting work out to tender, drawing up contracts, approving constructions, etc.

Scientific and Public Relations

Coordinator: Manfred Stock

National and international scientific co-operation (see page 115) is part of PIK's research strategy. The scientific contacts are maintained by the departments and are supported by the PIK offices by organizing conferences and workshops. National and international scientists are regularly invited to hold lectures at the Institute or to stay for some time contributing to the projects.

Very close and fruitful is PIK's local co-operation with its partner universities in Potsdam and Berlin (Freie Universität). The director and the heads of departments hold joint professorships at a university. Additionally, students and young scientists from the universities perform part of their work at PIK and also participate in the universities' educational activities.

PIK plays an important role in international scientific programmes like the International Geosphere-Biosphere Programme (IGBP). Three international project offices of IGBP 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), and since January 2000 the international office of the Data and Information Services (DIS). Until December 1998 the German National IGBP Secretariat was also hosted by PIK.

PIK also contributes in multiple ways to the Intergovernmental Panel on Climatic Change (IPCC). Several PIK scientists are involved in the preparation of the Third Assessment Report (scheduled for 2001) of the Intergovernmental Panel on Climate Change (IPCC) as well as several Special Reports for the IPCC. The IPCC is an international body, established by the UN, which consists of approximately 2000 of the world's leading climate scientists. It advises the UN and governments in questions of climate change.

The International Geosphere-Biosphere Programme – IGBP

Established in 1989, the International Geosphere-Biosphere Programme aims at describing and understanding the interactive physical, chemical and biological processes that regulate the total Earth system. The IGBP focuses on the unique environment that the Earth 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 key interactions and significant changes 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 Change 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?

International core projects have been established in IGBP in order to answer these fundamental questions. PIK scientists are involved in the research and organization of a number of these core projects, chairing the respective scientific steering committees and project offices (see below).

The German National IGBP Secretariat

The mission of the National IGBP Secretariat has been to support the work of the National IGBP Committee and its chair in accordance with the overall purpose of the programme. This included the dissemination of information to the German scientific community and funding agencies about international activities, and informing the international community about German IGBP activities. The German National Committee for Global Change Research (vice chair: H. J. Schellnhuber) and its supporting secretariat have now taken over some of the responsibilities related to IGBP in Germany and the national IGBP secretariat was therefore closed on 31 December 1998.

One of the major tasks of the Secretariat was the organization of national and international conferences, workshops and meetings. This included not only the local organization of these meetings but also contacting sponsors and other funding agencies and accounting for funds. In 1998 the German IGBP Secretariat organized the following international meetings:

- the IPCC TAR Scoping Meeting in Bad Münstereifel, 27 June - 2 July 1998, jointly with the German IPCC office.
- the Workshop on the Global Paleo-Vegetation Project BIOME 6000, Jena, 6 - 11 October 1998, jointly with the Max Planck Institute for Biogeochemistry.

National meetings on the following IGBP core projects were organized: Joint Global Ocean Flux Study (JGOFS), Global Ocean Ecosystem Dynamics (GLOBEC) and Land Ocean Interactions in the Coastal Zone (LOICZ).

Scientific developments and contacts with scientists were also maintained by attending national and international conferences on Global Change by the scientific staff of the Secretariat. The IGBP-Informationsbrief was published regularly four times a year and could be obtained free of charge from the German IGBP Secretariat.

Name	*IGBP Programme Element*	*Function*
Alfred Becker	BAHC Scientific Steering Committee	Vice-Chair
Martin Claussen	BAHC Scientific Steering Committee	Member
Wolfgang Cramer	DIS Scientific Steering Group Scientific Committee for the IGBP GCTE Focus 2 (Ecosystem Structure) GCTE Scientific Steering Committee GAIM (Global Analysis, Interpretation & Modelling)	Chair, starting 2000 Member, starting 2000 Leader Member Member
Holger Hoff	BAHC International Project Office	Executive Officer
Sabine Lütkemeier	BAHC International Project Office	Project Officer
Hans Joachim Schellnhuber	GAIM Task Force Scientific Committee for the IGBP	Chair, starting 2000 Member, starting 2000
Wilhelmine Seelig	BAHC International Project Office	Administration
Gérard Szejwach	DIS International Project Office, relocated to PIK 2000	Executive Office

Biospheric Aspects of the Hydrological Cycle – BAHC

The international project office (IPO) is hosted by PIK. 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. Major IPO activities are listed below:

Coordination of BAHC science

- the IPO acts as a central communication node for the BAHC key themes and the BAHC synthesis;
- the IPO chairs the European data management for the Large-Scale Biosphere Atmosphere Experiment in Amazonia (LBA) and hence supports the European LBA office in Netherlands.

Links with other organizations

- the IPO provides linkages to the International Human Dimensions Programme (IHDP), e.g. through the organization and synthesis of a meeting on African Freshwater Resources;
- the IPO provides linkages to the World Climate Research Programme WCPR, e.g. through the joint organization of meetings, such as a workshop on root-water uptake in climate and hydrological models and a workshop on soil moisture in climate modelling.

Presentation of BAHC

the IPO produces the BAHC newsletters, maintains the BAHC homepage and has edited the BAHC implementation plan.

Organization and coordination of meetings

the IPO has been the main organizer of a number of scientific meetings, such as:

- LBA-DIS meetings in May and November 1998;
- BAHC-SSC meetings in April 1998 and May 1999;
- BAHC sessions at the 2nd IGBP Congress, May 1999;
- IGBP Earth System Model of Intermediate Complexity (EMIC) workshop, June 1999;
- Root workshop, September 1999;
- African Freshwater Resources meeting, October 1999;

BAHC Office: Holger Hoff, Wilhelmine Seelig, Sabine Lütkemeier (not present)

Raising additional funds in support of BAHC activities:

- Policy-makers' needs on water resources - IGBP funds for results-transfer activities;
- African freshwater resources - ENRICH (European Network for Research into Global Change) funds;
- Groundwater resources focus - ENRICH funds;
- Synthesis activities of BAHC - Dutch science foundation funds for integrating activities;
- Coupled modelling in hydrology - UNESCO International Hydrological Programme funds for a joint meeting.

Coordination of BAHC data activities

the IPO provides a link between BAHC and IGBP-DIS and between BAHC and the International Satellite Land Surface Climatology Project Initiative II, and the IPO co-chairs BAHC key theme 8.

Support for PIK Mediterranean activities (RESOURCE, EUROPA)

- presenting PIK at Mediterranean conferences in March and October 1999;
- submission of joint proposals with Mediterranean partners to various funding bodies;
- coordinator for European Space Agency project on retrieving soil moisture from remote-sensing data.

Coordination of the BAHC synthesis

The mature IGBP core projects are undergoing a 'synthesis process', involving the summarizing and synthesizing of what has been learned hitherto in the individual core projects. BAHC initiated its synthesis in 1998 and held a number of workshops in 1999 (March, November and December), organized by the BAHC project office. The results of the synthesis will be published as a book in early 2001 and presented at the IGBP Open Science Meeting in July 2001.

Public Relations

The task of the Press and Public Relations Office is to inform the media and the public about the activities and the results of the Institute. This is done together with the scientists, who provide answers to questions of public interest in numerous lectures, briefings and interviews. The duties of the Press Office also include sending information material to interested parties as well as making information available on the World Wide Web (*www.pik-potsdam.de*), where journalists can find the latest press releases.

One of the most successful activities of the past two years was the poster exhibition entitled "Forschen für eine lebenswerte Zukunft" (*Research for a Future Worth Living*) requested by the regional government of Brandenburg and which, after its first presentation in May 1999, went on a tour of schools.

Public Relations Manager: Margret Boysen

Well received by the public was the award of the McDonnell Foundations Centennial Fellowship to Stefan Rahmstorf for his research on the north Atlantic thermohaline circulation (see page 39 and page 15). Second place in the 'publicity ratings' went to the computerized simulation of the abrupt desert formation around 5,500 years ago in the area of what is today the Sahara desert.

In 1998/99 approximately 400 articles about the PIK appeared in magazines and journals, about a third in the national press. Numerous contributions about PIK are published on the World Wide Web. Over the same period PIK scientists have given more than a hundred interviews on TV and radio.

1999 saw an increase in joint public relations activities with the Wissenschaftsgemeinschaft Gottfried Wilhelm Leibniz (WGL), which will be intensifed in the coming years.

Global Integrated Modelling and Assessment

POEM
Potsdam Earth System Modelling

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

Goals
Human interventions, such as the continuing release of fossil-fuel combustion products into the atmosphere or the fragmentation of vegetation play a significant role in the Earth system. We are currently altering the character of the Earth at 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 relatively stable compared with the 100,000 years preceding them. The development of agriculture and the simultaneous growth of civilizations during this phase of climatic stability is probably not coincidental. An important and exciting question is therefore: Could the Earth system return to a more unstable mode if the concentration of greenhouse gases in the atmosphere continues to increase?
POEM addresses the problem of Earth system stability by analysing (i) the land biosphere and its feedbacks to the atmosphere, (ii) the interactions between all major components of the Earth system (atmosphere, ocean, biosphere, ice masses) and (iii) the long-term evolutionary dynamics of the geophysical Earth system. The dynamics of - and between - the Earth´s subsystems require an integrated analysis of the fully coupled system. Due to the non-linear 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 subsystems or a combination of a few of them.

Model Components
Three main POEM components were set up in 1998/99 to focus on the particular processes of geosphere-biosphere interactions. The resulting models will be used to study the stability of the Earth system under a broad range of scenarios for modified boundary conditions.

- The short-term (days to centuries) atmosphere-biosphere interactions and vegetation dynamics are addressed by the development of a Dynamic Global Vegetation Model (LPJ-DGVM), incorporating physiology and vegetation dynamics (including disturbances).
- At the time scale of centuries to millennia the feedbacks between atmosphere, ocean, vegetation and inland ice become important. This is described by the CLIMBER (CLIMate and BiosphERe) model. This activity has received international attention since it serves as the nucleus for EMIC (Earth-system Models of Intermediate Complexity) research, e.g. in the IGBP.
- The long-term evolution and development of 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).

The results for 1998/99 obtained with the POEM model components, DGVM, CLIMBER and COEM, are described in the following sections.

Dynamic Global Vegetation Model – DGVM
Project Leader: Wolfgang Cramer

Motivation
In a coupled Earth-system model, the land biosphere represents a significant element of non-linear behaviour. Results obtained with simplified models have shown that the biosphere could be capable of showing either considerable inertia due to slow vegetation responses or, alternatively, rapid 'pulses' due to fast mobilization of carbon from the land to the atmosphere (fire). In addition, biological processes (e.g. the response of plant productivity to increased atmospheric CO_2) could offset, for example, decreases in growth that would be expected to occur if only a warming trend was considered. Responses of the biosphere to changing climate will also be different regionally, just as scenarios of changing temperature and rainfall differ from place to place - a spatially explicit model is therefore imperative for the study of these processes.
The spatial and temporal dynamics of the biosphere have strong implications for the overall system, and hence for the future of a sustainable Earth, for several reasons. Firstly, 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 many centuries. This is due to rapid (mostly light-driven) changes

From left to right: Wolfgang Lucht, Alberte Bondeau, Victor Brovkin, Sergey Venevski, Stephen Sitch, Kirsten Thonicke, Wolfgang Cramer

in the photosynthesis in plants on one hand, and the relatively slow build-up of biomass in most ecosystems and the slow to very slow decay of organic matter in the soil on the other. In consequence, one may ask whether ecosystems ever can be in true equilibrium with climate. The disequilibrium is even more crucial in times of rapid changes in climate and CO_2 since it prohibits the estimation of carbon pools from present climate and demands a full account of system history.

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

Developing a New Class of Model

From an Earth system perspective, the most important elements of land vegetation are the pools of live and dead biomass, expressed as carbon amounts, as well as all processes affecting fluxes into, between and out of these pools. Increasingly, vegetation *structure* has been incorporated into models as a dynamic feature of the biosphere (rather than an input), driven by carbon and water fluxes. As a minimum, most terrestrial biosphere models therefore contain modules for: (i) photosynthesis - the main 'engine' of carbon assimilation; (ii) autotrophic respiration - the plant's own use of the carbohydrates it has produced; and (iii) heterotrophic respiration - the (short-term) loss of carbon from other organisms' biological activity in the ecosystem. (Seventeen models of this kind, so-called Terrestrial Biosphere Models (TBMs), were compared intensively in an earlier PIK activity).

A Dynamic Global Vegetation Model needs to contain all the mechanisms of TBMs, but it also needs to capture the biological processes controlling longer-term behaviour. These processes are concerned with the plants' life cycles, such as establishment in a new location, growth, competition with neighbours and responses to disturbances from natural events (fires and storms) or human activity. Earlier, these population processes were simulated in "succession models" (see the CHIEF project on page 85). A direct linkage of different succession models to cover the global biosphere, however, is at present impossible since many parameters are known only for few plant species. More importantly, the interaction between different kinds of 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). PFTs must be few in number so that they can be parameterized in the global model, but sufficiently complex to cover at least a part of the variety in functional behaviour among plants around the globe. For each PFT we need to parameterize the physiological processes. Some PFTs are defined directly on the basis of physiology, e.g. C_3 and C_4 plants, which by their different photosynthetic pathways respond in different ways to climate change. Other PFT distinctions are made according to leaf longevity, such as between 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 regard to resources such as water or light, and the different abilities of plants to capture these resources determine the composition of the plant community.

Even in a constant climate, ecosystem structure is generally unstable. Natural mortality of plants or of 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. This mortality occurs 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, last much longer 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 developed against the background of changing conditions. These are currently considered in three ways (all of which may occur simultaneously): i) changing physical climate; ii) changing atmospheric CO_2 concentration and nitrogen deposition; and iii) changing disturbance due to human land use. Estimates of vegetation response to changing climate and carbon dioxide are now made using DGVMs, although one of the most crucial components is still in its infancy: the dynamics of human land use.
DGVM applications recognize that the actual response of the biosphere to some change is necessarily specific to a particular region. In fire-prone ecosystems such as the savannas or boreal forests small changes in the soil-moisture balance may affect fire frequency just 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, we are left with a major uncertainty for large-scale predictions of the outcome of such a change - therefore a DGVM will need to be run at a large number of locations.
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.

DGVM Developments in POEM
To investigate the decade-to-century scale dynamics of the coupled Earth system in POEM, a comprehensive DGVM is mandatory. Together with groups in Jena (Germany) and Lund (Sweden), we have continued to develop the Lund-Potsdam-Jena DGVM (LPJ), as well as the reduced-form biosphere model in CLIMBER (VECODE).

Based on LPJ and VECODE, several activities have been pursued:

- International model comparison projects under the auspices of IGBP's GAIM and GCTE, carried out at PIK, have helped to identify strengths and weaknesses in current model formulations.
- To improve the representation of disturbance in LPJ, the fire module is being developed on global and subcontinental scales. Land use is investigated as a separate disturbance driver.
- A consistent framework has been developed for spatial and temporal scaling among processes, and between the driving data and the overall model (within the European consortium "European Terrestrial Ecosystem Modelling Activity", ETEMA).
- The LPJ, along with other DGVMs, has been used to assess the future of the global carbon cycle.

CCMLP and DGVM Intercomparison Projects
The *Carbon-Cycle Model Linkage Project (CCMLP)* has brought together several research groups to study the role of the terrestrial biosphere in the Earth system using TBMs. The focus of phase 1, recently completed, was to evaluate model responses to CO_2, climate and land use for the terrestrial carbon cycle. Four models (including LPJ) were run in parallel for the period 1920-1992.

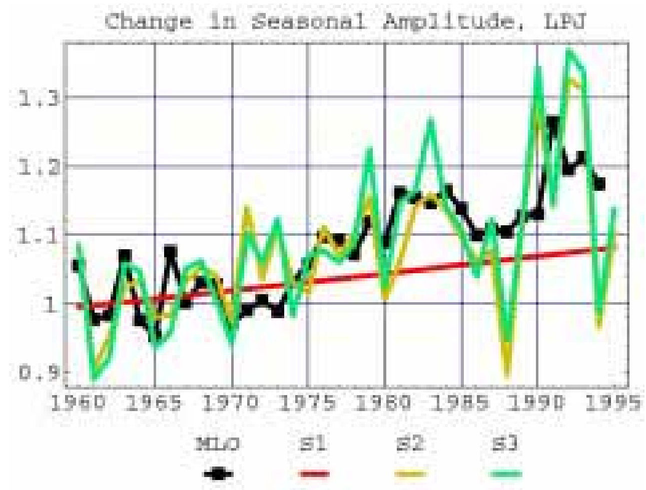


Fig. 1: The trends in the amplitude of the seasonal cycle of atmospheric CO_2 at the Mauna Loa monitoring station between 1960 and 1992, relative to the amplitude in 1960, as estimated using the fluxes of NPP and R_H simulated by LPJ, compared with the trends estimated from the observations (black line). The trends for each of three simulations are shown: increasing atmospheric CO_2 only (red line), increasing atmospheric CO_2 and climate variability (yellow line), and increasing atmospheric CO_2, climate variability, and cropland establishment and abandonment (green line).

Results indicated that the dominant influences on the terrestrial carbon cycle are the large and opposing effects of historical land-use changes and CO_2 fertilization. In comparison, the effects of climatic changes are (still) small and the direction of the response, whether source or sink of CO_2 to the atmosphere, differs among models. Nevertheless, the net fluxes over the 1980s for all four models were in agreement with inferred estimates (based on observed atmospheric CO_2 concentrations, fossil-fuel emissions and ocean fluxes as computed from a state-of-the-art ocean model). The seasonal cycle of atmospheric CO_2 is almost entirely due to the dynamics of the terrestrial biosphere, with a net flux to the atmosphere during the winter months associated with heterotrophic respiration and a net flux of carbon from the atmosphere to the biosphere during the summer as photosynthesis exceeds respiration. In the last decades an increase has been observed in the amplitude of the atmospheric CO_2 seasonal cycle at monitoring stations, indicating an increase in terrestrial biosphere activity. LPJ captured the observed trend in amplitude of the seasonal cycle of atmospheric CO_2 at the Mauna Loa monitoring station between 1960-1992 (Figure 1).

We now aim at understanding the structure and functioning of the terrestrial biosphere as part of an Earth-system model. Emphasis is placed on the role of the nitrogen cycle, CO_2 fertilization, land use and land-cover change, age-class structure together with a large data synthesis component.

The *DGVM Intercomparison Project* focused upon the global response of terrestrial ecosystem structure and function to CO_2 and climate change using six state-of-the-art DGVMs, including LPJ and VECODE. All models found increased productivity of the land biosphere resulting in a net flux from the atmosphere to the biosphere peaking at around 2050. Thereafter the net flux to the biosphere no longer increases - additional emissions would therefore contribute more directly to the atmospheric increase. In the models this levelling-off (or even decline) is due to several reasons. Mainly, the rate of increase in heterotrophic respiration from the now larger soil pools overtakes that of production, but in some cases dieback of vegetation also occurs. Overall, this result is important as it shows that the terrestrial biosphere can only be a sink for additional CO_2 emissions for a limited period, maybe the next 100 years or so. In addition, the study showed that vegetation is far away from equilibrium with climate and CO_2 forcing at the end of the forcing period (2100) and requires at least 50 years with constant forcing to reach equilibrium. This hints at important nonlinearities in the Earth system and the necessity for DGVMs to address them.

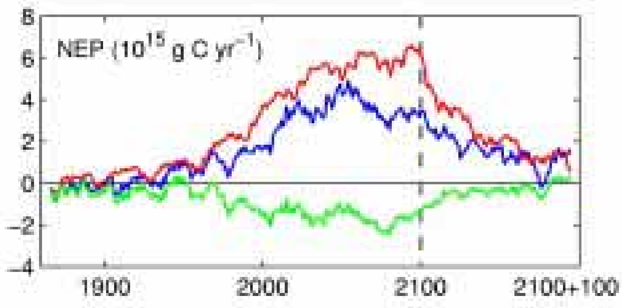


Fig. 2: Net ecosystem productivity of the terrestrial biosphere, averaged over six DGVMs, driven by increased CO_2 and/or warmer climate, derived from the HadCM2 climate model, until 2100, and by stable climate after that. The green line shows the response of climate change only, the red line the response of CO_2 only, and the blue line shows the combined response. The figure illustrates that the capacity of additional carbon uptake by the biosphere is likely to be exhausted some time during the 21st century).

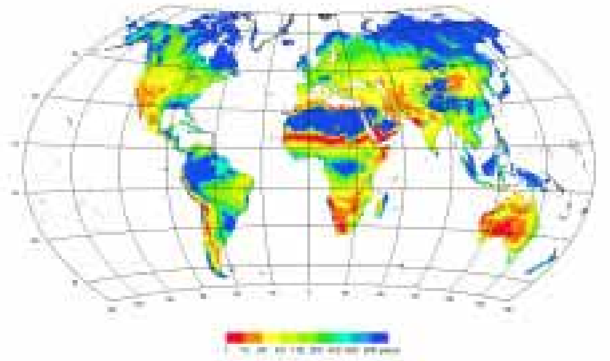


Fig. 3: Historical fire-return intervals describe the approximate time interval before a new fire would occur at the same site, here simulated by LPJ at 0.5°x0.5° longitude/latitude resolution (averaged over the period 1900 to 1995, driven by the CRU climatology).

Disturbance Dynamics

Fire is one of the major disturbance agents affecting biogeochemical cycling, i.e. atmospheric chemistry, the global carbon cycle and vegetation dynamics. In some places fire frequency influences plant competition and therefore determines vegetation structure due to selection of fire-adapted vs. non-adapted plant species. These fire-vegetation relationships may change under conditions of climatic change. It is therefore necessary to include fire in DGVMs.

The first phase of developing a global fire module for the LPJ was the simulation of burnt area amounts and their temporal dynamics. Figure 3 shows the change in fire occurrence, expressed as fire-return intervals, with climatic gradients on the global scale, illustrating a bimodal decrease in fire, when the climate is too wet to carry a fire, e.g. in undisturbed tropical rain forest, or so dry that plant growth cannot provide enough fuel for a fire, such as in semi-deserts and deserts.

Fire frequency in ecosystems with strong human influence on the fire regime, such as tropical savannas and Mediterranean-type ecosystems, are underestimated by the global fire module. The impact of the human use of fire on vegetation is currently being investigated in a regional study for the Iberian peninsula.

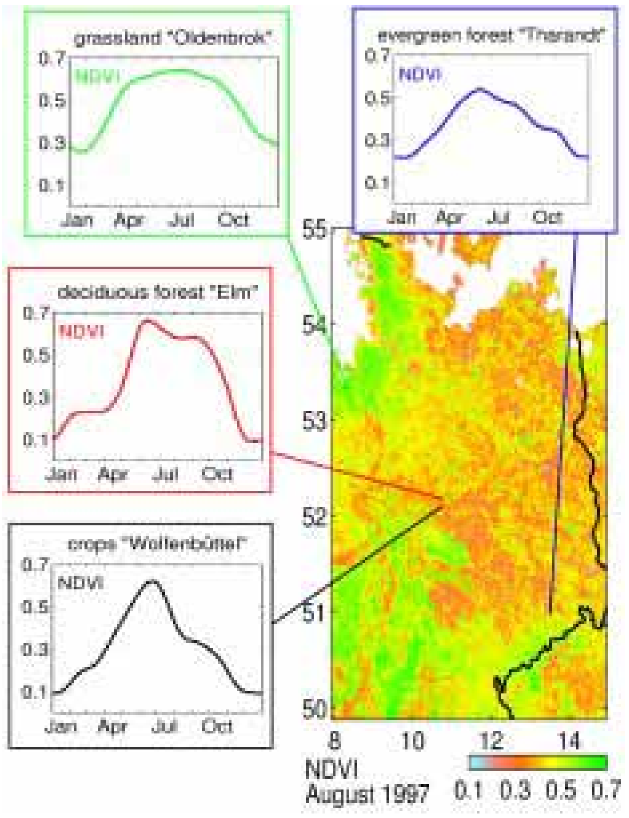


Fig. 4: The seasonal development of vegetation, which is a fine indicator of climatic conditions, can be monitored using satellite data. In this example, the Normalised Difference Vegetation Index (NDVI, the normalised contrast between the observed red and near-infrared reflectances) shows the annual cycle of greenup and senescence of four different types of land cover in 1 km daily AVHRR data.

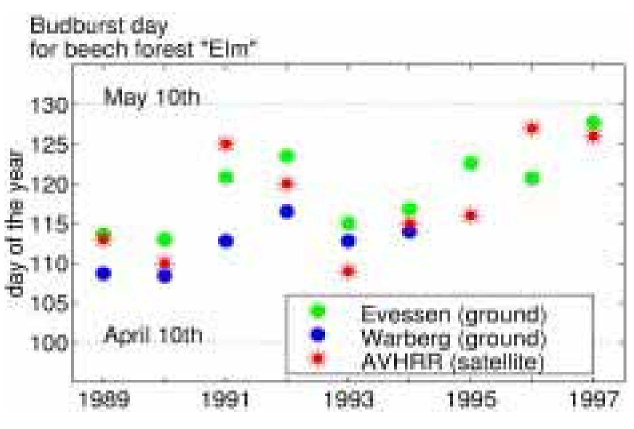


Fig. 5: Data such as shown in Figure 4 can be used to determine, for example, the date of budburst of trees in a forest, a parameter that is sensitive to climate change. Budburst days determined by observers on the ground for a period of 9 years for the Elm deciduous forest in northeastern Germany compare well with those derived from 1km AVHRR satellite observations. The advantage of satellite observation is that an analysis of vegetation phenology is possible for whole continents.

Validation of Ecosystem Models Using Satellite Data

Earth-orbiting environmental satellites provide an opportunity to globally validate and improve the seasonal cycles of vegetation simulated by a DGVM. Our emphasis is on investigating the simulated and observed spatial distributions of vegetation types, the phenological cycle with its annual changes in green leaf biomass and the inter-annual variations due to differences in weather from year to year. Improvements in each of these areas have a direct impact on the simulated carbon stocks and fluxes, evapotranspiration rates, runoff and albedo. A 1-Terabyte 10-year (1989-1998) archive of satellite data from the NOAA-AVHRR instrument showing Western Europe daily at 1 km resolution is the backbone of our research in this area. Pre-processed biophysical data products from more advanced optical sensors such as VGT, MODIS or MERIS in the near future will be incorporated into our modelling activities. We currently focus on the phenological phases for selected German and European forests; on European and global seasonal cycles of absorbed radiation and leaf area index; and on differences between the generalized representation of vegetation used in the models and the real-world features of global vegetation as seen by an earth-orbiting satellite. Examples of such features are spatial heterogeneity, regional adaptation of species, topographic effects, agriculture, irrigation, urban sprawl and other land management, and climatic effects such as El Niño periods, late frosts or droughts.

Climate and Biosphere Model – CLIMBER

Project Leader: Martin Claussen

Earth-System Models of Intermediate Complexity

To address the problem of stability in the natural Earth system one has to analyse the dynamic processes between its subsystems, the geosphere and the biosphere. During the past decades marked progress has been achieved in modelling the separate elements of the geosphere and the biosphere, focusing on atmospheric and ocean circulation, and on land-vegetation and ice-sheet dynamics. These developments have stimulated first attempts to put all the separate pieces together, first in the form of comprehensive coupled models of atmospheric and oceanic circulation, and eventually as climate-system models which also include biological and geochemical processes.

Comprehensive models of global atmospheric and oceanic circulation describe many details of the flow pattern, such as individual weather systems and regional currents in the ocean. Similarly, complex dynamic vegetation models explicitly determine the growth of plants and competition between different

Back row from left to right:
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plant types. The major limitation in the application of comprehensive models arises from their high computational cost. The troposphere, the lowest 15 km of the atmosphere in which weather occurs, reacts within a few days to changes in boundary conditions, for example insolation. However, it takes several hundred years for the deep ocean to respond and a few thousand years to reach equilibrium. The response time will increase enormously if more "slow" elements of the climate system, like glaciers and ice sheets, are involved. Even using the most powerful computers, only a very limited number of experiments can be performed with such models.

On the other hand, simplified, conceptual models of the climate system are used for a variety of applications, in particular for palaeoclimate studies as well as climate-change and climate-impact projections. These models are spatially highly aggregated; for example, they represent atmosphere and ocean as two boxes, and they describe only a very limited number of processes and variables. The applicability of this class of model is limited not by computational cost but by the lack 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.

Earth-system Models of Intermediate Complexity (EMICs) have been proposed to bridge the gap between comprehensive and conceptual models. EMICs can be characterized in the following way. EMICs describe most of the processes implicit in comprehensive models, albeit in a reduced, i.e. a more parameterized form. They explicitly simulate the interactions among several components of the climate system, including biogeochemical cycles. On the other hand, EMICs are simple enough to allow long-term climate simulations over several 10,000 years or even glacial cycles. Like those of comprehensive models, but unlike conceptual models, the degrees of freedom of an EMIC exceed the number of adjustable parameters by several orders of magnitude. Tentatively, we may define an EMIC in terms of a three-dimensional vector: integration, i.e. number of components of the Earth system explicitly described in the model; the number of processes explicitly described; and the detail of description of processes (see Figure 6).

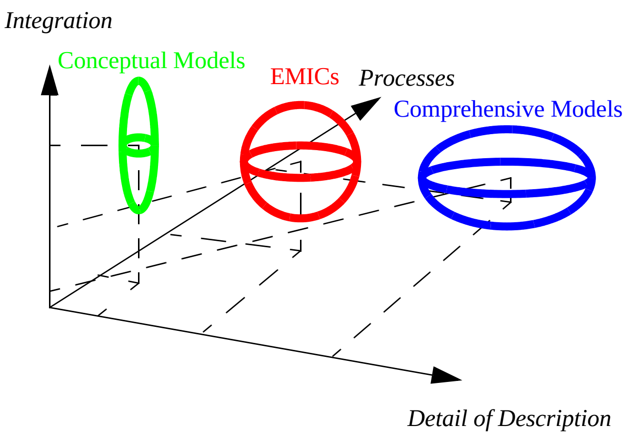


Fig. 6: Tentative definition of EMICs.

Currently, there are several EMICs in operation: 2-dimensional, zonally averaged models; 2.5-dimensional models with a simple energy balance, or with a statistical-dynamical atmospheric module such as CLIMBER-2; and reduced-form comprehensive models. EMICs have been used for a number of palaeostudies since they provide the unique opportunity of carrying out transient, long-term ensemble simulations (see example of North African desertification below) - in contrast to so-called 'time-slice' simulations in which the climate system is implicitly assumed to be in equilibrium with external forcings - which is rarely a realistic assumption. Furthermore, the climate system's behaviour under various scenarios of greenhouse-gas emissions has been investigated exploring the potential of abrupt changes in the system (see second example below). A first international workshop on EMICs was held at PIK in June 1999.

Desertification of Northern Africa at the End of the Mid-Holocene

In the so-called early and mid-Holocene, some 9,000 to 6,000 years ago, the climate was different from today's. In many northern hemisphere mid-to-high latitudes the summer was generally warmer, since palaeobotanic data indicate an expansion of boreal forests north of the modern treeline. In northern Africa, palaeoclimatological reconstructions using ancient lake sediments and archaeological evidence indicate a wetter climate than today. Moreover, it has been found from fossil pollen, lake-level records and rock paintings that the vegetation limit between Sahara and Sahel reached at least as far north as 23°N.

It is a common hypothesis that differences between modern and mid-Holocene climate were caused by changes in the Earth's orbit. The tilt of the Earth's axis has changed from some 24^{o} in the early Holocene to some 23^{o} today, and the perihelion has moved from July to January. This has led to decreased solar radiation in the northern hemisphere during summer, which has weakened the African and Indian summer monsoon, thereby decreasing the moisture transport into northern Africa. However, orbital forcing alone seems to be insufficient to explain the changes in climate over the last 9,000 years. 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 northern Africa. These feedbacks tend to amplify climate change such that boreal climate becomes warmer (than without vegetation-atmosphere feedback) and the northern African climate becomes more humid in the mid-Holocene. Hence, it appears that vegetation affects global climate to its own benefit.

Interestingly, the feedback between atmosphere and vegetation in northern Africa is strongly non-linear. Using CLIMBER it has been shown (see Figure 7) that the subtle changes in insolation of the northern hemisphere lead to rather abrupt changes in vegetation cover, in comparison with insolation, over today's Sahara. The decline of the Saharan vegetation cover some 5,500 years ago is corroborated by palaeoclimatological records. Our numerical study suggests that Saharan desertification at the end of the mid-Holocene was presumably a natural phenomenon. Deforestation by Neolithic people apparently happened in some places, but Saharan desertification can be explained without it. On the other hand, the strong climate and vegetation change should have had a profound impact on Neolithic society. It has been suggested that the foundation of a high form of civilization along the Nile river was influenced, perhaps even dominated, by migration from the increasingly arid Sahara to the more fertile banks of the river Nile.

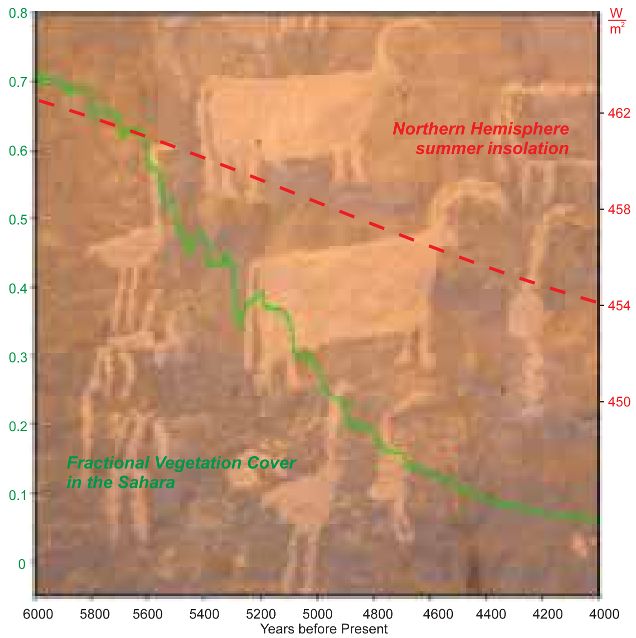


Fig. 7: The background photograph (taken by Philipp Hoelzmann) shows rock paintings of mid-Holocene fauna near Zolat el Hammad, North Sudan. Today this region, like most of the Sahara, is a hyper-arid desert, formed some 5-6,000 years ago. Climate simulations using the coupled atmosphere-ocean-vegetation model CLIMBER reveal a rather abrupt change in Saharan vegetation (the green line indicates fractional vegetation cover) which was triggered by subtle changes in northern hemisphere summer insolation (red line).

Long-Term Global Warming Scenarios

Given the successful simulation of past climatic changes, the CLIMBER-2 model was used for a series of long-term global-warming scenario simulations. These simulations extend to the year 3000, beyond the expected peak of CO_2 concentrations. Key results of this simulation are shown in Figure 8.

The findings for the 21st century of the simulation were primarily used for comparison with previous modelling results of other groups, and the CLIMBER model largely agrees with these earlier scenarios, reproducing typical features such as the enhanced warming of northern continental areas. Maximum warming occurs in the Arctic in winter and over the boreal continents in summer. The northern Atlantic region becomes less warm than other areas at the same latitude due to deep mixing and a reduction in thermohaline ocean circulation. Precipitation increases in the tropics, high latitudes and summer-monsoon regions. The patterns for the year 2200 (the time of maximum warming) resemble those for the year 2100, albeit with a larger amplitude.

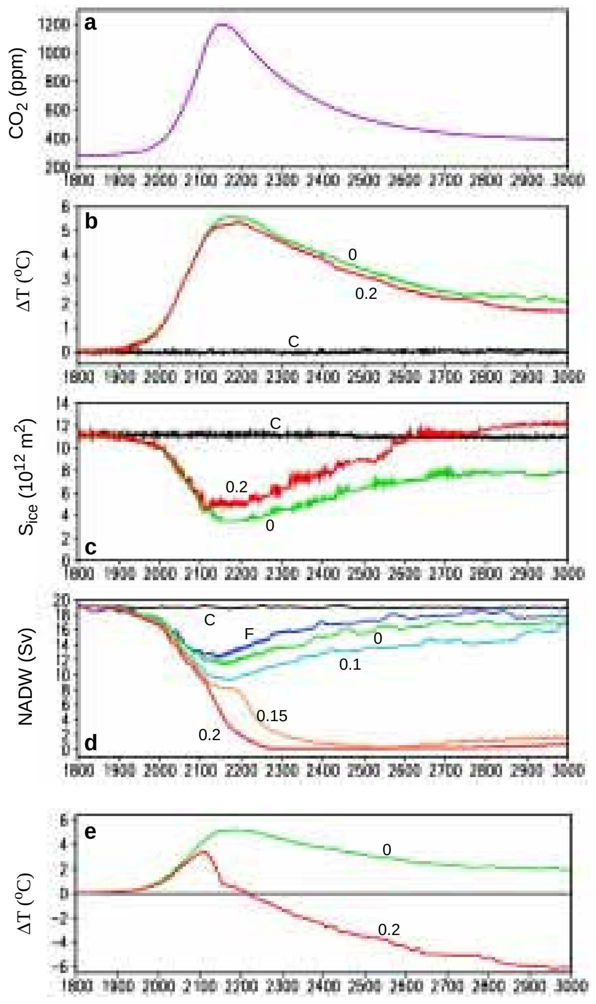


Fig. 8: Time series of key model variables in CLIMBER global warming scenarios: (a) prescribed CO_2 forcing scenario, (b) global annual mean surface air temperature change, (c) annual mean area of northern hemisphere sea-ice cover, (d) North Atlantic Deep Water circulation rate (i.e. maximum value of the meridional transport stream function), and (e) winter (DJF) surface air temperature change over the Atlantic at 55°N. The experiment labelled 'C' is a pre-industrial control run, 'F' is a run with fixed pre-industrial freshwater forcing, '0' is the standard scenario, and '0.1' etc. are scenarios with enhanced freshwater forcing.

Our simulation adds to the credibility of these earlier results, given that CLIMBER has been tested on a range of past climatic changes. Of special interest is the long-term response of the Atlantic thermohaline ocean circulation (Figure 8d). In order to investigate the uncertainty resulting from uncertain changes in the freshwater cycle, a whole range of scenarios was computed with different assumptions about the amount of precipitation and runoff entering the Atlantic in a warmer world.

The North Atlantic circulation declines strongly in all our scenarios over the next 50 years due to a thermal effect. Changes in the hydrological cycle determine whether the circulation recovers (green and blue curves) or collapses (red and orange) in the long run. Both outcomes are possible within present uncertainty limits.

This study demonstrated for the first time how global warming could eventually lead to a lasting cooling of Europe if the North Atlantic circulation collapses (Figure 8e, red scenario). Such a cooling has been the focus of much speculation, but has not previously been shown in a computer simulation.

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

Project Leader: Yuri Svirezhev

COEM is focused on specific dynamic processes within and between ecosphere subsystems. The balance and interactions between the geosphere and biosphere with regard to the limits of self-stabilization in the face of perturbations and changing external forcing are of major concern. Dynamic systems theory is well suited to uncovering qualitative phenomena and exploring fundamental ecosphere system properties. The main tasks are to analyse the critical dynamic boundaries of the ecosphere, its structural stability and, above all, its potential regulation capacity under stress.

Clockwise, from back left:
Christine Bounama, Siegfried Franck, Arthur Block,
Anastasia Svirejeva-Hopkins, Yuri Svirezhev, Werner v. Bloh

Daisyworld models of an imaginary planet

A particularly useful approach to the investigation of geosphere-biosphere feedbacks is the Lovelock-Watson model of "Daisyworld". Based on concepts of systems theory, this model sheds much light on possible mechanisms of stabilization through evolutionary adaptation of terrestrial vegetation to varying insolation. A two-dimensional extension of this model takes

into account various pertinent physical, biological and civilisatory processes like lateral heat transport, species competition, mutation, germination and habitat fragmentation. In order to reflect fundamental ecosystem dynamics based on trophic interactions, the 2D model is extended even further and herbivores are added to this imaginary planet.
The vegetarian "lattice animals" move on the grid as random walkers. As in reality the herbivores are capable of reproduction, depending heavily on their nutritional state. The interaction between plants and animals is realized by two processes: temperature-dependent reproduction of the herbivores and ingestion of daisies.

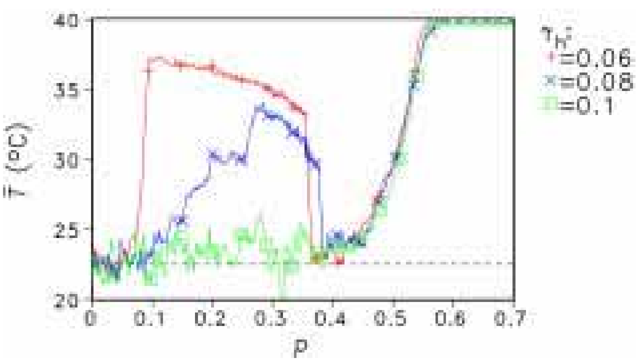


Fig. 9: Global temperature T as a function of fragmentation p for different values of herbivore mortality γ_h .

The co-dynamics of plants and animals are studied in a landscape with increasing fragmentation. The introduction of herbivores to a fragmented "Daisyworld" generated extremely rich eco-dynamics. Intensive numerical calculations have shown that a crucial parameter for the system's behaviour is the herbivores' mortality (see Figure 9): below a critical threshold for mortality several phase transitions occur with increasing fragmentation.

Qualitative Dynamics and Stable Regions
According to the concept of "virtual biospheres" the contemporary Earth's biosphere is one of several possible (virtual) biospheres, corresponding to the multiple equilibria of the non-linear dynamic system "climate+biosphere". In the course of planetary evolution this system has passed through several bifurcation points. Random perturbations have determined on which branch of the solution the system would appear.
In the simplest case the model consists of two coupled differential equations, for the temperature *T* of the planet and for the amount of vegetation *N*. This system has up to two different stable equilibria: a "dead" planet without vegetation and a "living" planet with vegetation. For the system with a carbon cycle there is an additional stable equilibrium because the "living planet" bifurcates into the "cold" and the "hot" planet with vegetation. The described model was further extended by incorporating the hydrological cycle. The phase portrait of the system is shown in Figure 10.

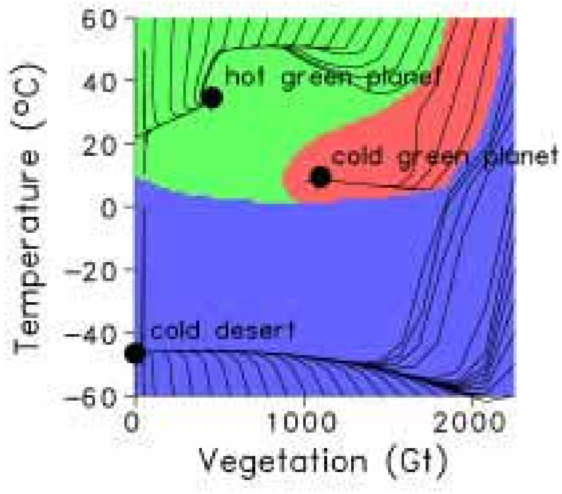


Fig. 10: Phase portrait in the temperature-vegetation domain. The different colours indicate the three stable regions.

Life Span of the Biosphere and Habitable Zones
The long-term co-evolution of the geosphere-biosphere complex from the Archaean up to 1.5 billion years into the planet's future is investigated using a new conceptual Earth-system model. The model focuses on the global carbon cycle as mediated by life and driven by increasing solar luminosity and plate tectonics. The main carbon dioxide sinks and sources are determined.
A major result is that a "terrestrial life corridor", i.e. a biogeophysical domain supporting a photosynthesis-based ecosphere throughout planetary history and future, can be identified. In contrast to results computed with geostatic models run by other groups, our findings imply a considerably shorter life span of the biosphere. We also calculated the band of orbital distances from the Sun allowing Earth-like conditions. This is the so-called habitable zone. According to the model (Figure 11) this habitable zone will collapse completely in some 1.4 billion years from now as a consequence of geodynamics.
Furthermore, we have extended the habitable zone concept to extrasolar planetary systems to calculate the probability of extraterrestrial life.

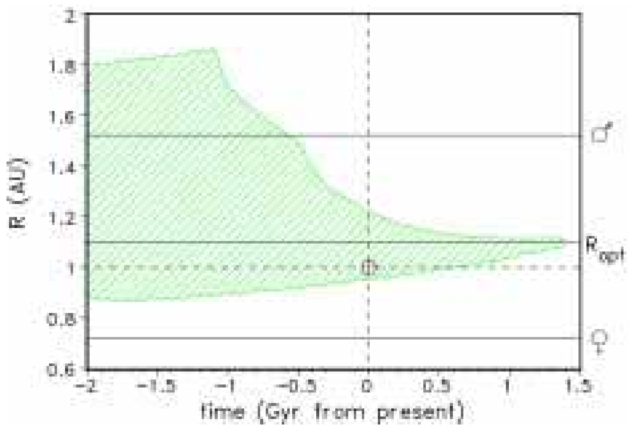


Fig. 11: Habitable zone for the geodynamic model.

Probabilistic Models of the Global Vegetation Pattern (GVP) or "Pascal's Vegetation"

This set of models of the global vegetation pattern (GVP) is based on some simple probabilistic schemes. Nevertheless, sufficiently complicated dynamics are described by a system of integro-differential equations with partial derivatives. The reduction to two age cohorts - juvenile (young) trees and mature ones - is described by two ordinary differential equations.

If we start from the planet covered by grass under our present-day climate, we can calculate the final GVP as shown in Figure 12.

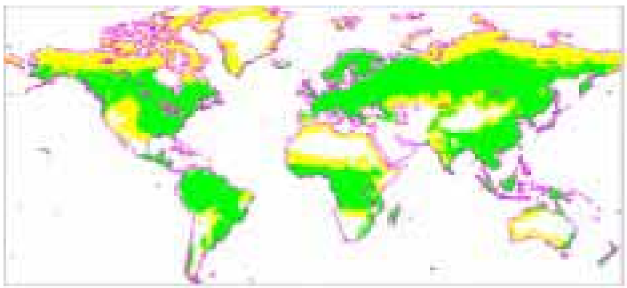


Fig. 12: Global vegetation pattern.

The critical region on the map is Eastern Siberia, where the large area is occupied by tundra when in reality it is a taiga region. This might be explained by the insufficient accuracy of the model calculations in areas with low temperatures.

Dynamic Models of the GVP or "Volterra's Vegetation"

Since Volterra's equations are widely used in mathematical ecology, it was thought wise to use them in describing the GVP. The problem was how to estimate their coefficients. We proved the theorem, which allows us a constructive method for finding their values. For this we used:

- the map of present-day vegetation types and corresponding maps of annual production and the biomass; and
- a formula describing the dependence of production on climatic parameters (e.g. Lieth's formula, which describes this dependence on annual temperature and precipitation).

After calibration we used Volterra's system to determine the dynamics of the species biomass. The coefficients of the system depend on climate parameters and change according to the chosen scenario. This helps to estimate the climate-induced shift of borders between taiga and steppe in central Siberia.

In accordance with the standard scenario of climate change, in which carbon dioxide doubles in this region, the annual temperature is expected to rise by 5 °C and precipitation by 10%. In this event both borders will shift northwards, where the borders between taiga and "forest-steppe" zones will shift by 113 km, and the borders between "forest-steppe" and steppe zones will move approximately 33 km.

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

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

Project Leader: Gerhard Petschel-Held

Back row from left to right:
Fritz Reusswig, Gerhard Petschel-Held, Arthur Block, Matthias Lüdeke

Front row from left to right:
Oliver Moldenhauer, Anastasia Svirejeva-Hopkins, Martin Cassel-Gintz

Research Goals
What can be expected in terms of environmental degradation in view of the high population growth predicted for the first half of the new century? And what about the spread of Western lifestyles? Do they contribute to the current deterioration of our natural environment? In which dimensions and to what extent is this deterioration unsustainable? How does civilization react to (global) environmental changes? All these, and many more questions need to be addressed and answered in order to understand Global Change and its potential to undermine our livelihood on the planet Earth.
The QUESTIONS project follows a new and innovative way of integrating present knowledge on these issues into a general overview of Global Change. The project seeks to classify the vast number of trends, processes, interactions and feedbacks which govern Global Change into a clear set of patterns of interaction between nature and civilization. These patterns might bring about non-sustainable development in terms of environmental, social or economic deterioration. We call these developments and the conditions and circumstances of their occurrence *Syndromes of Global Change*.
Using innovative modelling techniques like fuzzy-logic and qualitative differential equations, the project aims at bridging the gap between science and decision making in drawing up feasible management strategies to achieve sustainable development.

Diagnosis of Syndromes
The attempt to diagnose a syndrome is similar to a medical doctor's efforts in diagnosing a (human) disease. Carrying out an anamnesis requires the use of:
- quantitative data, e.g. the temperature chart or the blood count;
- qualitatively assessed symptoms, e.g. "I have a headache!"; or
- interviews, e.g. "Are there cases of hereditary diseases in your family?".

The information obtained is compared with systematized knowledge gained from previous cases in order to determine the actual disease the patient is suffering from.
In analogy, applying the syndrome concept to analysing Global Change means raising the following questions:
1) What are the general mechanisms of civilization-nature interaction which can induce potentially non-sustainable development patterns? How does one systematize the knowledge and information gained from "earlier cases"? This requires specifying the syndrome's mechanisms. For this a new qualitative modelling technique is used which is discussed in the example below. This new

methodology of syndrome specification responds to a major criticism of the syndrome concept, which stated that syndrome specification involves a critical amount of arbitrariness. The new method, which together with some prototype applications has been developed over the last two years, allows us to validate syndrome mechanisms with regard to qualitative case studies or quantitative data.

2) How can quantitative data (e.g. gross domestic product, area converted from forest to agricultural use, etc.), qualitative symptoms (e.g. Westernization of lifestyles, loss of biodiversity) and (written) history be interlaced to achieve an overall picture of a region's environment and development problems? Examples and results of applying the new updated methods are described in the remainder of this section.

Systematizing Mechanisms: The SAHEL SYNDROME

Syndromes are intended to represent patterns of civilization-nature interaction, i.e. a single syndrome should represent and describe many regions of the world. The most simple, but oversimplified pattern might be: humankind/civilization destroys the Earth. Regardless of its correctness, the statement has no potential for designing viable strategies for managing the Earth system. In order to do so, we must greatly refine the specification of the problematic interaction between civilization and nature.

If we overstep this refinement we would end up describing each single atom and its interaction with the rest of the world. This would not be feasible and would raise old philosophical and epistemological questions on, for example, Laplace's demon, Ockham's razor and the use of a map of the world at a scale of 1:1. Syndromes try to strike a happy medium.

Imagine one had a highly detailed model of a single, well-defined region, let's say the Sahel in West Africa. We would have detailed mathematical descriptions of all the relations and variables needed to assess the region's future as well as its environmental and development issues. This again is hardly feasible, but what we might know are qualitative features of the relations and variables: the higher the population growth, the more food that is needed; the more intensive the agriculture the more soil erosion and desertification there is, etc. But then it is reasonable to assume that other regions share all or some of these qualitative features originally formulated for only one or a few regions. The combination of features shared by a significant number of regions constitutes a *hazardous pattern of civilization-nature interaction.* These patterns represent the baseline for syndrome diagnosis and are only hypothesized in the first step of research. They can be formalized and tested by the use of qualitative differential equations (QDE) which allow us to compute all dynamic behaviours possible for a qualitatively specified hazardous pattern of causes and effects. This set of solutions takes the form of a "behaviour tree", i.e. it starts off with one option for the near future which then splits up into two or more possible successors, each of which again can divide, etc.

It should be stressed that though regions might share the same qualitative features of the relevant causes and effects, the actual dynamic behaviour might be different (corresponding to different branches of the tree) due to finer properties not apprehended by the qualitative specification. In many cases these finer properties are not apprehendable at all - either by limitations in our present knowledge or by principle. It would be difficult, for example, to quantify the relation between intensity of agriculture and soil degradation in such generality that it can be assumed to be valid for a sufficiently large number of regions. These limitations are the main reason for using qualitative modelling.

As a major source of information in specifying the mechanisms of a pattern one can use various detailed field studies: there are thousands of anthropologists, geographers, ecologists, biologists and sociologists who go to the regions and study the relationship between humans and nature in all detail.

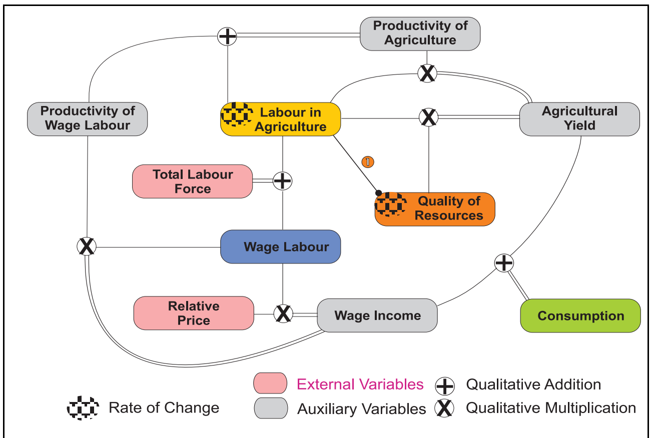


Fig. 1: Basic mechanism of the hazardous pattern of civilization-nature interaction induced by smallholder agriculture on marginal sites. This hazardous pattern is obtained from a regime of case studies and gives rise to, among other syndromes, the SAHEL SYNDROME.

As an example, a collection of studies on social coping strategies in endangered ecosystems in developing countries has been used to specify a basic mechanism of overusing marginal land. The studies are from regions in Asia (Nepal, Laos), Africa (Miombo Highlands, Eastern Cape Province, Tanzania, Botswana) and Latin America (Dominican Republic, Atlantic rainforest in Brazil, Andean Highlands in Argentina). There are serious environmental problems in all regions, particularly concerning soil degradation and the conversion of natural ecosystems. The main direct actors in the degradation process are smallholders who earn a major part of their livelihood from pastoralism or farming on marginal grounds. In their options of how to earn a livelihood the smallholders greatly depend on the political, economic or ethical constraints set by the state, large national or international companies or development agencies.

We have used the concept of qualitative differential equations in order to find out which features of causes and effects are shared by the regions, i.e. define the common pattern. To do so, we have constructed a mechanism which can be shown to be common to six out of nine studies. This mechanism is depicted in Figure 1 in which we have used symbols to represent the qualitative features of the interrelationships. The major element of the model is a rule how the smallholder allocates his/her available labour force between wage labour on the one hand and agricultural activity on the other. It appears to be reasonable to model this decision process as a rational choice in favour of that labour activity which most recently was more productive in terms of income per unit labour.

For the qualitative model specified by the mechanism depicted in Figure 1 the behaviour tree of possible behaviours is displayed in the top panel of Figure 2.

The sequence of boxes describes the possible qualitative stages of development of a region characterized by the mechanism in Figure 1. Thus, if we assume that the study regions, which are depicted in the map in the lower panel of Figure 2, are indeed described by this mechanism, one should find the history of each region represented within this behaviour tree. This "historical reconstruction" is encoded by the colours relating the top and bottom panel in Figure 2: in the map each region is coloured in the same way as the box describing its most recent history. The fact that the recent

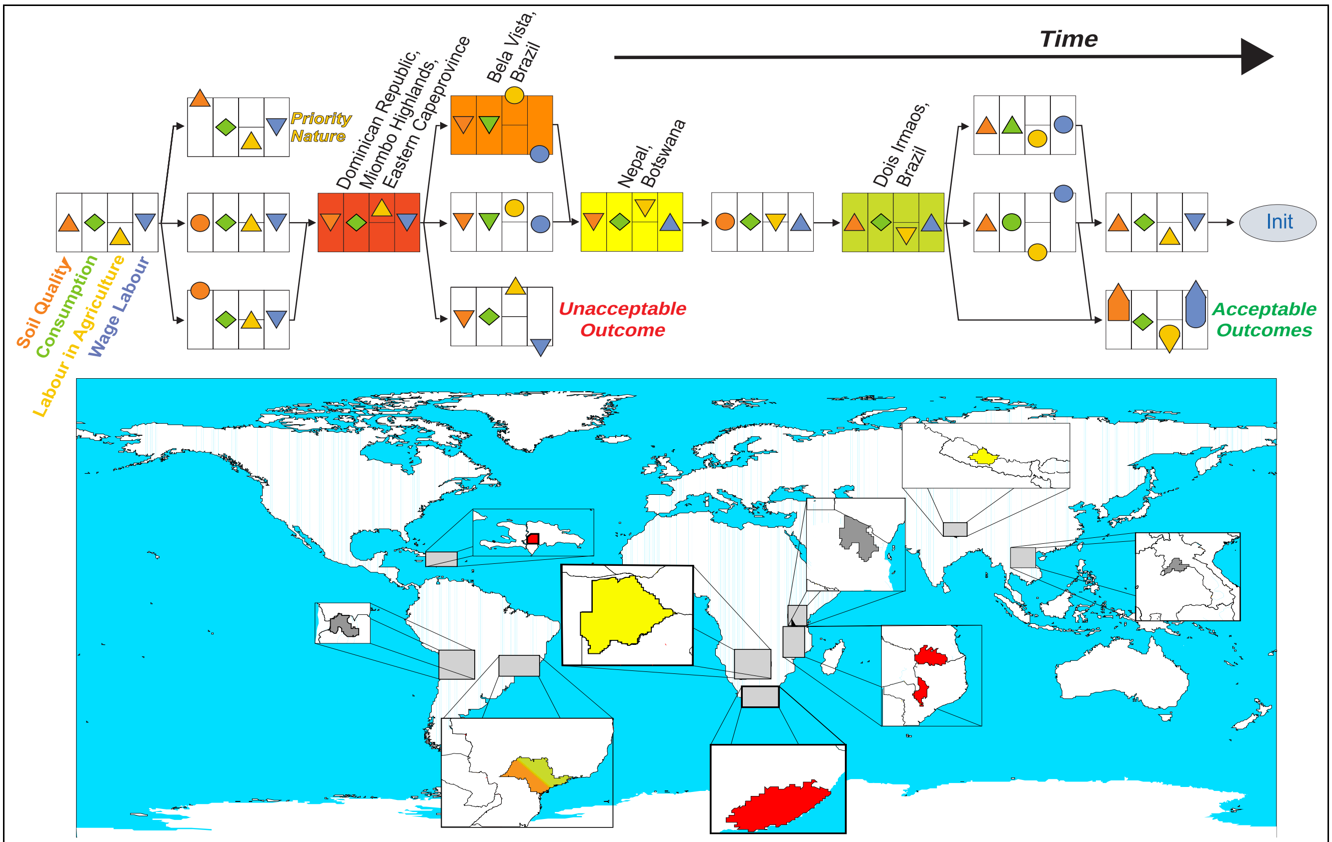


Fig. 2: Top panel: "Behaviour tree" representing all possible solutions for the qualitative model depicted in Figure 1. Each box represents a qualitative state characterized by qualitative values for each of the four variables soil quality, consumption, labour in agriculture and wage labour. An upward (downward) arrow indicates an increase (decrease) of the respective variable. A circle denotes a direction of change equal to zero. In the course of time (running from left to right) the different branches of the tree can be taken, either cycling back to the initial state (indicated by the ellipse denoted by "Init") or by the two different outcomes, one of which is favourable, the other one unacceptable.
Bottom Panel: Regions investigated in the study. The insets are coloured according to the recent history in the region, which is specified by the corresponding colour and name tags in the top panel.

history of six regions is reconstructed allows us to state that the model is free of contradiction to the observations in six out of nine regions.
From this behaviour tree we can assess the prospects for the near future of each single region:

- For the Dominican Republic, the Miombo Highlands and the Eastern Cape Province the situation is critical. If the local authorities do not succeed in providing alternative means of income, the degradation of the natural resources will continue. This might end in an insufficient supply of goods to meet the basic needs of the population (*Unacceptable Outcome*).
- Bela Vista in the Atlantic rainforest in Brazil is close to breaking point. Currently, the entire labour force is allocated to agriculture in the form of shifting cultivation. This will inevitably end when people emigrate to look for alternative means of income, probably leaving behind a devastated environment.
- The situation in the regions in Nepal and Botswana gives rise to hope for a more sustainable development. This is due to a sufficient provision of wage labour. Yet this provision has to be sustained in order to promote sustainability.
- Dois Irmaos (Brazil) has already taken some steps towards avoiding endangering ecosystems by the smallholders' agriculture. Again it is necessary to sustain the alternative means of income (in this case wage labour is provided as housekeepers on ranches of rich Sao Paoloeans).

Within the hazard pattern of Figure 1 we can denote the qualitative state given in the red box as a syndrome (a qualitative "state" might well stretch over time): it bears the strong option of an unacceptable outcome. The situation of insufficient wage labour and of marginal agricultural sites is called the SAHEL SYNDROME.
This example shows how qualitative information from detailed field or case studies can be used to assess both the mechanisms as well as the current situation and future options. This method, established over the last two years, constitutes the main line of future research in the QUESTIONS project.

Quantitative Data: The OVEREXPLOITATION SYNDROME
The "modelling method" sketched in the previous section represents the most comprehensive approach to analyse syndromes. Yet, more directly, there is an attempt to assess syndromes by direct data analysis and interpretation. This method starts again with the formulation of a network of interrelations, based on qualitative analyses of case studies and reviews. Instead of being modelled, however, the network is used as a starting point for an expert to formulate an indicator for assessing the global distribution of the syndrome, which makes use of global data sets. Within the time horizon of this report this method was used to assess the global distribution of the OVEREXPLOITATION SYNDROME.
The syndrome involves the conversion of natural ecosystems and the overexploitation of biological resources. It affects both terrestrial (forests, savannahs) and marine (fishing grounds) ecosystems. The common feature is that ecosystems are overexploited without sufficient regard for their regenerative capacity. Violation of the sustainability principle leads to the degradation and even destruction of natural ecosystems, e.g. through outright clearance of forests, overgrazing of uncultivated land or overfishing.
The immediate consequences are loss of habitat, loss of biological diversity on the genetic and/or species level and erosion in the case of terrestrial ecosystems. In susceptible regions the latter can induce changes of the sedimentary load of rivers or add to flood risks. Finally, the release of CO_2 from biomass and soils enhances the greenhouse effect. For the local population the conversion of ecosystems means loss of livelihood, resulting in impoverishment and loss of cultural identity.

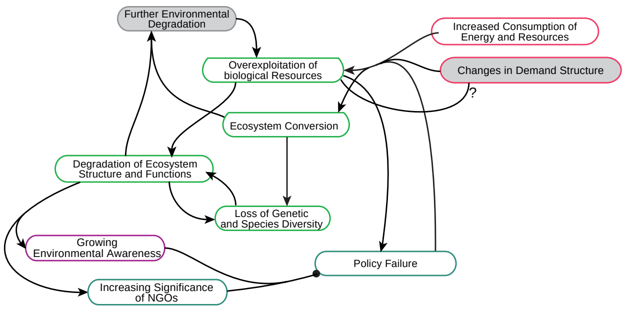


Fig. 3: Core mechanism of the OVEREXPLOITATION SYNDROME. The syndrome is mainly driven by a demand structure desiring wood, fish or other renewable resources. Often this aspect is world-market based. On the national scale the syndrome is made possible by massive policy failure. The further dynamics of resource-management policy is subject to attempts to improve the situation, promoted by, e.g., an increasing significance of non-governmental organizations. These attempts, however, are counteracted by sustained high levels of corruption, induced by, for example, a lack of democratic structures and economic benefits from the overexploitation.

One of the typical features of the OVEREXPLOITATION SYNDROME is permitting an excessive use of renewable resources for short-term gains. This policy failure in the field of land management often involves multinational corporations, lumber lobbies and high levels of corruption on the part of local and regional administrations and politicians. Usually the profits resulting from the resource exploitation are transferred to big cities or out of the country. Thus, substantial costs for the local

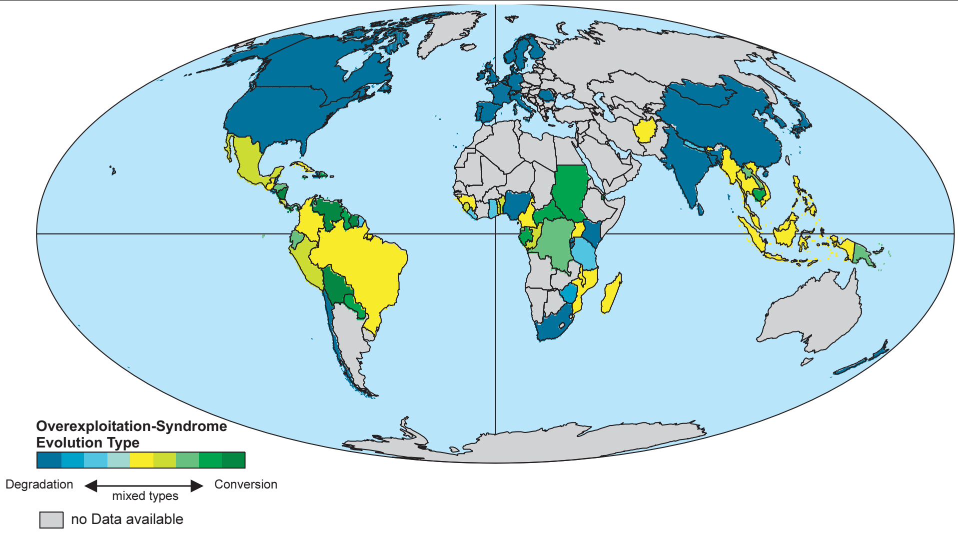


Fig. 4: Geographical distribution of the different types of the Overexploitation Syndrome. Note that highly developed countries are indicated as belonging to the degradation type due to their highly advanced level of forest management. This also applies to those countries in which the use of renewable resources is characterized by a strong fuel-wood component, e.g. South Africa, India and China. In contrast, those countries in possession of tropical forest resources are assigned to the mixed or conversion type.

economies are incurred, but minimal profits are earned in return. The core mechanisms describing this non-sustainable civilisation-nature interaction is depicted in Figure 3.
Focusing on the overexploitation of natural forests, two different evolution types of the syndrome (and mixtures thereof) can be identified, which are depicted in Figure 4:

1) the CONVERSION TYPE, which directly leads to a complete conversion of the ecosystem with the exclusion of natural succession. This result is achieved by either clear-cut or selective felling. This form of the syndrome can be observed in the clear felling of tropical rainforests with subsequent land-use changes. Regions affected are Latin America and most countries in central Africa and Southeast Asia.
2) The DEGRADATION TYPE, which results in a shift in the ecosystem structure due to structural damage. This form is typical of the exploitation of boreal forests of North America and Europe. Besides these mainly boreal forests, the forests of Mongolia, China, India and several countries in Africa are candidates for this evolution type of the syndrome.

One should bear in mind that this division does not imply a ranking of the two types with regard to non-sustainable development. For example, in regions of high biodiversity and/or rare tree species, degradation can be at least as bad as conversion.
The intensity of the syndrome is defined as a measure of the activity of the syndrome's basic mechanisms (Figure 3). The indicator for the intensity of the Overexploitation Syndrome focuses on the activity of the symptoms "Overexploitation of Biological Resources" and "Policy Failure". Both symptoms have to be active to indicate the occurrence of the syndrome. The map in Figure 5 illustrates the geographical distribution of the Overexploitation Syndrome as of the late 1990s.

Qualitative Indicators: The Dust-Bowl Syndrome in Germany

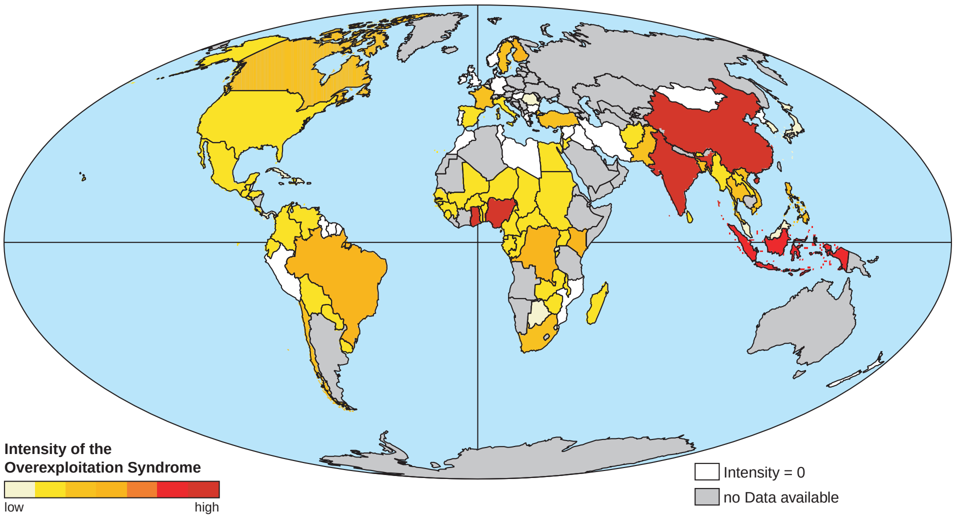
This section presents the application of a combination of the two preceding methods: the indicator for the syndrome's intensity is now formulated on the basis of the qualitative model of the syndrome, instead of a pure expert assessment.
Degradation of soils and water bodies, loss of biodiversity and degradation of air quality are the main negative environmental effects induced by highly intensified agriculture in industrial countries within the last century. We call the mechanisms behind these effects the Dust-Bowl Syndrome. At the same time a massive structural change in agriculture took place in Europe after the Second World War. This was driven, among other things, by the general economic development and significantly influenced by the GAP (the common agricultural policy of the European Economic Community). In addition, these changes produced social and economic problems in rural areas.
The common agricultural policy aimed at:

1) increasing productivity by facilitating intensification through subsidies for mechanization, the use of chemicals and the improvement of infrastructure; and
2) stabilizing farmer's income through guaranteed prices.

With regard to production the programme was successful and during the 1970s the European Community became a net exporter of agricultural goods. However, it failed with regard to:

- stabilizing rural structures ("Bauernsterben");

Fig. 5: Intensity of the OVEREXPLOITATION SYNDROME. Regions particularly affected are countries with a strong fuel-wood component, i.e. India, China and Nigeria. Indonesia is also indicated, reflecting the fact that this country is referred to as a great exploiter of tropical timber. Other countries of this category include Brazil, the Democratic Republic Congo, Canada and Finland.



- keeping public expenditure for price guarantees in acceptable macro-economic limits (particularly after the 1970s); and
- establishing an agricultural production which is acceptable in terms of environment and health.

To obtain a measure where this mechanism of social and environmental deterioration is active, which is its dynamic state, and to what degree of severity, three steps of research are performed:

Firstly, the so-called cybernetic core of the syndrome is constructed in which all relevant variables and their mutual interactions are represented. The core of the DUST BOWL SYNDROME is summarized in Figure 6 (see also Figure 1 and Figure 3).

The second step is to calculate the qualitative dynamic system behaviours which are compatible with the cause-effect scheme from Figure 6. This is done again using the concept of qualitative differential equations mentioned above. Some of these qualitative behaviours appear as paths of non-sustainability: deterioration of environmental quality, social consequences of agricultural structural change and governmental expenditures due to subsidies are all unacceptable.

In the third step, indicators are developed which allow us to discover whether a specific region is on such a dynamic "path of non-sustainability". The procedure used to derive this indicator and the result for Germany as of the 1990s is shown in Figure 7. The basic data used for a German-wide assessment for the 1990s are depicted as grey ellipses. These quantitative data are evaluated to indicate four important conditions for non-sustainability as derived from the model outcomes:

1) environmental damage;
2) detrimental production methods;
3) identical direction of change of production and change of productivity; and
4) *no* coincidence of decreasing productivity and increasing social problems.

The last two conditions follow directly from the interrelations in the cybernetic core in Figure 6: production is a monotonously increasing function of productivity (not always, but in the context of the syndrome discussed here) and problematic social consequences are a function of productivity with a threshold character. So the interrelations are valid if the conditions are fulfilled. The combination of the truth values of the four conditions is guided by the analysis of non-sustainable paths in step 2 and performed using methods from fuzzy-logic. Fuzzy-logic allows us to map vague arguments and statements, like conditions 1 and 2. Ordinary - Boolean - logic assigns only "true" and "false" to a statement, often represented by the digits 1 and 0,

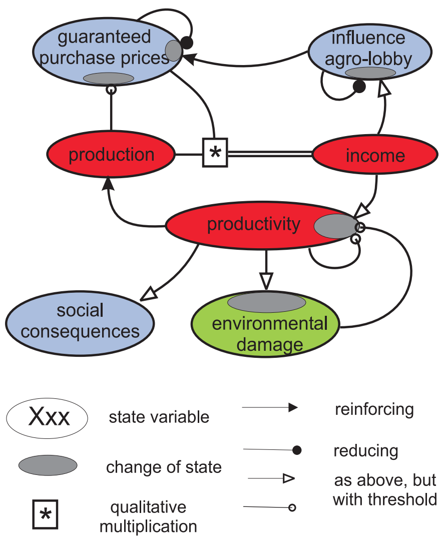


Fig. 6: Cybernetic Core of the DUST-BOWL SYNDROME in Germany.

respectively. In contrast, fuzzy-logic allows values *between* 0 and 1. Correspondingly, logical operators like “or” or “and” are also extended to be able to deal with these kinds of intermediate truth values.
Within the present analysis, “environmental damage” and “detrimental production methods” are combined with a fuzzy “or” connective - the fulfilment of at least one of the conditions is necessary. The geographical distribution of each single indicator is depicted on the right hand side of Figure 7. Environmental damage can be found particularly in eastern Germany, but also in large regions of northern and western Germany. The harmfulness of the methods, as assessed by the nitrogen balance at the farm level, shows a significant hotspot in the cattle ranges of northwestern Germany.
The “sign conditions” for production/productivity and productivity/social problems are evaluated by the use of the Boolean “and”. The combination of the resulting two intermediate truth values is done with a fuzzy “and” connective. From the right hand side of Figure 7 we observe that both conditions are fulfilled particularly in the northern parts of Germany (indicated by red).
The resulting map of the distribution of non-sustainable development due to the DUST-BOWL SYNDROME mechanism gives the following picture: the northwest (Cloppenburg, Vechta, Emsland), the five New States (formerly East Germany) with some exceptions in Thuringia, and the east of the Rhineland-Palatinate show the syndrome. By contrast, in several regions of the southern part of Germany the syndrome ended in the 1990s. This does not imply that there are no problems in the rural areas at all (see the regions with increasing social problems in Figure 7), but these are *not* induced by the DUST-BOWL mechanism.

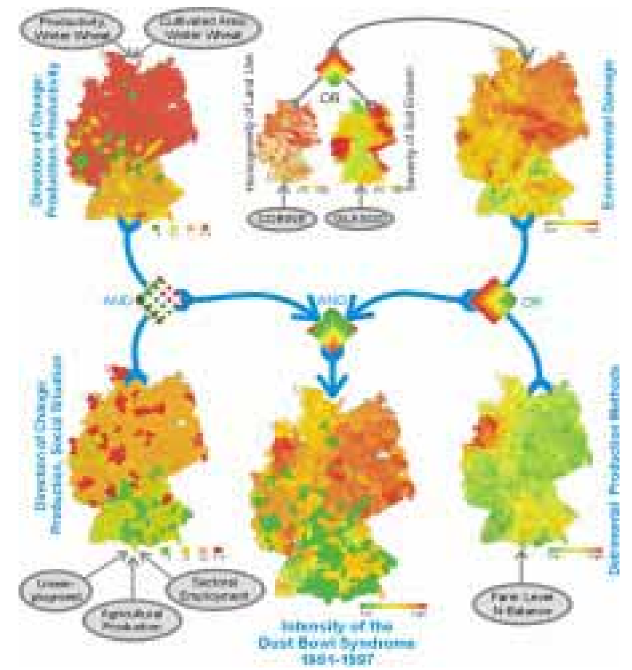


Fig. 7: Fuzzy-logic based indicator for the intensity of the DUST-BOWL SYNDROME in Germany 1991-1997. Data used: Regional Statistics 1991-1997, CORINE land-use map, GLASOD soil degradation expert evaluation and Wendland et al., 1993.

Climate Sensitivity of SAHEL-SYNDROME Disposition

The analysis of syndromes’ responses to climate change makes a major contribution to climate-impact research. As a first example, the influence of climate on regional disposition towards the SAHEL SYNDROME was investigated, as it is one of the most important patterns of Global Change, particularly with regard to famine and the malnutrition of about 1 billion people worldwide. It describes the close interlinkage between natural and socio-economic aspects of rural poverty driven degradation of soil and vegetation on marginal sites.
The main idea of identifying regions which are prone to a syndrome is to investigate whether the most important syndrome-typical interactions could become active under the natural and socio-economic conditions which prevail there. In the case of the SAHEL SYNDROME the socio-economic dimension has to evaluate the compulsion of the impoverished rural population to further intensify or expand their agricultural activities. In addition, the natural dimension assesses whether such an increase in agricultural activity would damage the natural production basis, leading to a decrease in yield resulting in further impoverishment. The disposition towards the syndrome is then calculated from quantitative data. The resulting disposition is depicted in Figure 8.
The influence of climate change on a syndrome’s disposition can be twofold:

1) prone but still unaffected regions could become infected by the syndrome via a climate change related exposure (e.g. extreme drought events in regions not previously prone to these); and
2) the disposition of a region may be modified by climate change.

In the following we concentrate on this last issue as regions with a newly emerging disposition in course of climate change require significant adaptation measures, e.g. combating poverty.
As a measure of the climate sensitivity according to the last point, we assess how large the impact of a very small change in climate would be in the worst case, i.e. if the change occurred such that the disposition changes as much as possible. This could mean, for example, temperature increase in arid regions or temperature decrease in very cold regions.

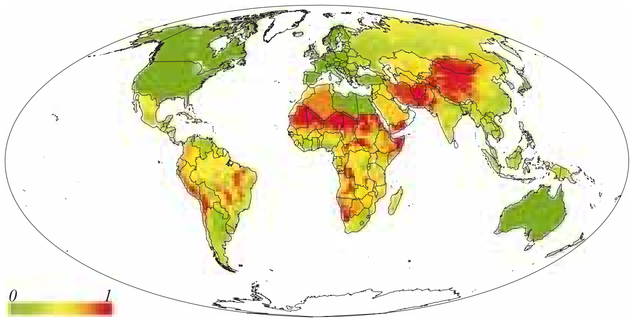


Fig. 8: Disposition of the SAHEL SYNDROME. Regions particularly prone to the syndrome specific mechanism are shown in red. It can be seen that the arid and semi-arid regions in Africa and South Asia are highly disposed. Besides, some regions in Latin America are also indicated due to limited soil fertility.

To achieve this, two new global models were incorporated into a fuzzy-logic based algorithm for determining a region's disposition towards the SAHEL SYNDROME:

- a neural-net model for plant productivity; and
- a water-balance model which assesses surface run-off considering vertical and lateral fluxes.

Both models are driven by the set of 36 monthly climatological "normals" (averages of temperature, precipitation, and irradiation over 30 years) and designed to allow very fast numerical evaluation on the global scale. The sensitivity is shown in Figure 9.

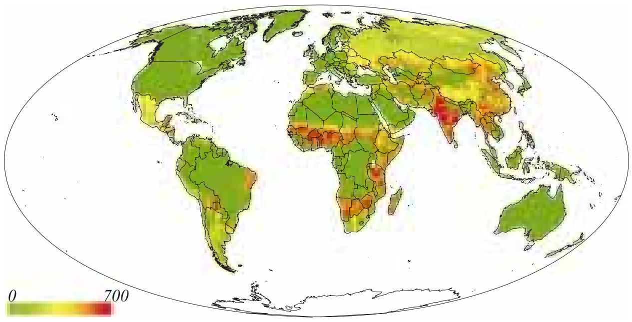


Fig. 9: Sensitivity of the disposition towards the SAHEL SYNDROME against climate change.

Again the socio-economic filter applies: regions in the north are not sensitive. This is due to the fact that the current socio-economic situation is kept constant in the analysis and that there are no subsistence smallholders in endangered ecosystems in these regions. Wide regions in the south are also of only minor sensitivity. However, this is in most cases due to the already high values of disposition today. Taken to the extreme: even adding a small amount of precipitation to the desert would hardly allow highly productive agriculture.

Of particular interest are those regions which today are either not prone or only prone to a minor degree, but where the disposition exhibits a high sensitivity to climate change. This means that today no real danger exists of the region's natural environment becoming caught up in the spiral of impoverishment and degradation. Yet this may well happen in the course of climate change.

Consider India, for example. It is a country with one of the highest population growth rates worldwide. Together with various aspects of economic and ethnic (caste-system) marginalization, it appears to be a strong candidate for degradations due to the SAHEL SYNDROME. Yet there is only a small to medium disposition, as can be seen in Figure 8, since the natural conditions are neither really bad nor really favourable. However, the region's disposition is, except for the river valleys, highly sensitive to climate change. This does not necessarily mean that it really will become more endangered, as the actual (direction of) change depends on actual climate change. Due to the high uncertainty of climate change in general, and the change of precipitation patterns in particular, we cannot really predict whether it will become worse or not. But we know that India's natural environment is at great risk of becoming degraded by the impoverishment-degradation spiral, known in our context as the SAHEL SYNDROME.

Other regions exposed to this kind of risk are the southern fringes of the Sahel in western Africa, large regions of China and Indo-China, the Yucatan peninsula in Mexico and eastern Africa (Kenya, Tanzania). In view of all the major problems facing these regions today we can hardly expect there to be good prospects for a successful adaptation to these risks. They, or rather their high proportion of poor people, might become losers of climate change. This sensitivity - or, alternatively, risk - analysis of syndromes with regard to climate change again shows the strength of the integrated approach taken within the QUESTIONS project.

The QUESTIONS core project was mainly funded by PIK, with additional contributions from HGF (Hermann von Helmholtz-Gemeinschaft Deutscher Forschungszentren).

ICLIPS
Integrated Assessment of Climate Protection Strategies

Project Leader: Ferenc Tóth

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Introduction

After the 6th Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (FCCC) in The Hague, climate-change decision makers will have to prepare themselves for the difficult choices they face with regard to the second and subsequent commitment periods of the Kyoto Protocol. The intricate and almost overwhelming issue of deriving short-term objectives from long-term climate protection goals will therefore return to the agenda.
The agreement on the Kyoto Protocol can be considered as a turning point in the history of mankind because it signals the necessity of changing course - regardless of the rather arbitrary emission-reduction target adopted. Subsequent emission reduction commitments, however, will not be interpreted in this way. History will judge them according to their actual ability to stabilize greenhouse-gas concentrations at levels that "prevent dangerous anthropogenic interference with the climate system" 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" (Article 2 of the FCCC).
As the degree of climate change mainly depends on cumulative emissions, a climate stabilization target directly translates into a specific total emission budget. Inadequate emission reductions in the next decades will consequently result in increasingly demanding mitigation efforts in the future.
Any effort to provide prudent advice to support climate-change decision makers in the realization of the FCCC therefore has to proceed along the following lines:

- Identifying the critical thresholds of climate change that should on no account be crossed even in the long term;
- investigating the "inertia" of the socio-economic system that limits humankind's future capability to quickly reduce emissions; and finally
- determining the short-term implications arising from taking into account both aspects simultaneously.

The Main Research Goals

The ICLIPS project is an international and interdisciplinary research activity whose aim is 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. One cornerstone of this project is the Tolerable Windows Approach (TWA): on the basis of a set of pre-defined constraints that exclude intolerable climate changes 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 the dynamics of socio-economic development. The different model components were 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 Impact Research, which has initiated the project and integrates the various model components within the framework of the TWA.

The Tolerable Windows Approach to Climate-Change Decision Support

The main objective of the TWA, or guardrail approach, is to support climate-change decision making by clearly separating value judgements and scientific analysis.

In order to achieve this goal, the TWA starts with a normative definition of constraints ("guardrails") that exclude those climate impacts and socio-economic consequences of mitigation measures that are perceived as intolerable by social actors or their representatives, the policy makers. In a subsequent step, a model-based scientific analysis of the "causality chain" is carried out in order to derive the set of all admissible climate-protection strategies, i.e. the set of all policy paths that are compatible with the pre-defined constraints.

The TWA can be applied in various ways in order to promote climate-change decision making: researchers, for instance, may systematically vary the guardrails as part of a sensitivity study. Individual decision makers are able to check whether their set of guardrails is consistent, i.e. whether at least one policy path is compatible with the pre-defined constraints. Equipped with whole bundles of possible and not evidently intolerable strategies, policy makers may exhibit the flexibility that is necessary for achieving compromises in climate negotiations. Alternatively, policy makers may stipulate commonly agreed guardrails beforehand. The subsequently determined admissible emission space may allow sufficient flexibility to take into account various important (qualitative) aspects that were not or could not be incorporated into the underlying quantitative assessment.

Which indicators are to be involved in the definition of guardrails is a normative issue itself. The answer to this question is consequently not pre-determined by the TWA, although two complementary application strategies are appealing in this context.

The *confinement strategy* seeks to identify those critical thresholds that are related to large-scale singular and irreversible changes in the qualitative behaviour of the climate system (e.g. global run-away greenhouse effect and shut-down of the ocean conveyor belt). Exceeding the respective systemic guardrails would incontestably represent a "dangerous anthropogenic interference with the climate system". Taking into account an increasing number of these "knock-out" criteria, and deriving the resulting, increasingly confined space of admissible future greenhouse-gas emissions will facilitate the realization of Article 2 of the FCCC.

The *relaxation strategy* proceeds the opposite way by focusing initially on the most sensitive systems or regions. Accordingly, the most binding critical level of climate change is sought below which significant impacts do not occur according to our present scientific knowledge. Compliance with the related guardrail, however, may impose an exorbitantly heavy mitigation burden that is also conceived as intolerable. It might therefore prove impossible to comply with this impact guardrail without violating guardrails defined with regard to the socio-economic consequences of mitigation measures. In this case, the social actors are forced to modify the set of normative guardrails until compatibility is achieved. This enhances the transparency of the respective social decision process. As a matter of fact, a selective weakening of some guardrails will raise the legitimate question of actual (instead of only potential) compensation, for instance in order to compensate individual losses incurred due to conflicting public interests.

Methods and Models

Methodological Aspects of the TWA

Applying the TWA requires a model-based derivation of the set of admissible climate-protection strategies, i.e. the bundle of all emission paths that are compatible with the pre-defined constraints.

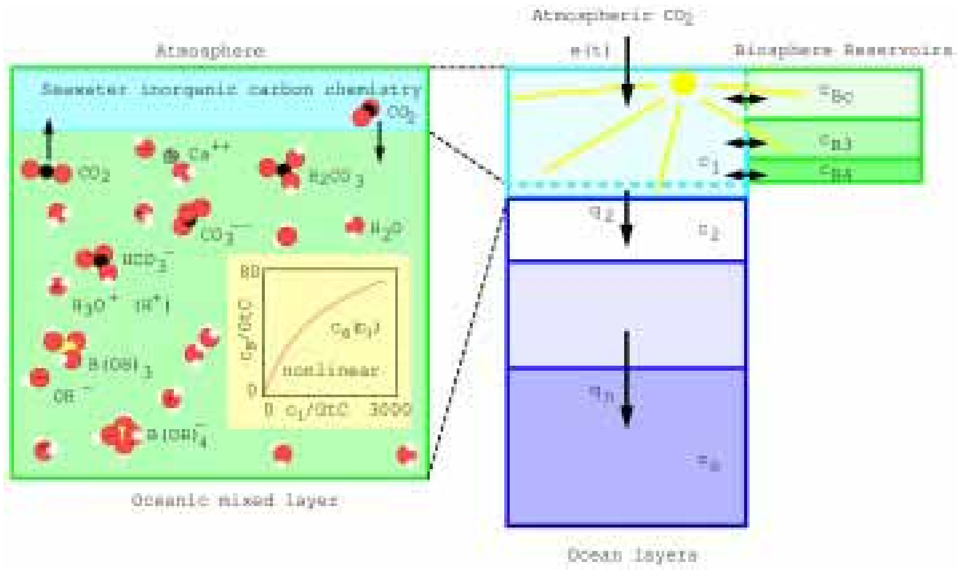
The actual determination of this bundle would require a complete inversion of an appropriately designed integrated assessment model. This is not possible with the current state of both integrated modelling and mathematical theory. Fortunately, useful results characterizing special aspects of the bundle of all admissible emission paths (e.g. emission corridors, see Figure 6) can be obtained directly, i.e. without determining the complete bundle explicitly.

The identification of the main characteristics of an entire family of admissible emission paths is fundamentally different from the methodology involved in traditional approaches to integrated assessments. Policy-evaluation and policy-optimization frameworks e.g. primarily deal with a single emission path either by investigating the consequences of a pre-defined scenario or by deriving the (generally unique) “optimal” emission path that maximizes welfare (as in cost-benefit analyses) or minimizes mitigation costs subject to climatic constraints (as in cost-effectiveness analyses).

In order to handle the set-valued character of the solution sought by the TWA, the basic methodological problem was reformulated in terms of the “Theory of Differential Inclusions”, which is designed precisely to deal with this kind of dynamic non-uniqueness. It provides appropriate definitions, a consistent theoretical background (e.g. theorems of existence), and even some solution methods that are applicable as long as the underlying climate and economy models are fairly simple.

For large-scale models like the current version of the ICLIPS model we have developed a transparent and generally applicable solution method. Accordingly, the boundaries of emission corridors can be obtained by successively solving a multitude of dynamic optimization problems. Each of these problems is solved subject to intertemporal constraints which encompass the pre-defined environmental, climatic, social and economic guardrails as well as the dynamic relationships between climate impacts, climate, and society.

Fig. 1: ICLIPS carbon-cycle model. The composite layer, which comprises the atmosphere and the oceanic mixed layer, is magnified on the left. The model includes an explicit treatment of the non-linear sea-water inorganic carbon chemistry, which results in a decreasing solubility of additional CO_2 in sea-water as background concentrations rise. The resulting non-linear relationship between anthropogenic carbon c_s in the oceanic mixed layer and anthropogenic carbon c_1 in the composite layer is depicted explicitly.



The ICLIPS Climate Model

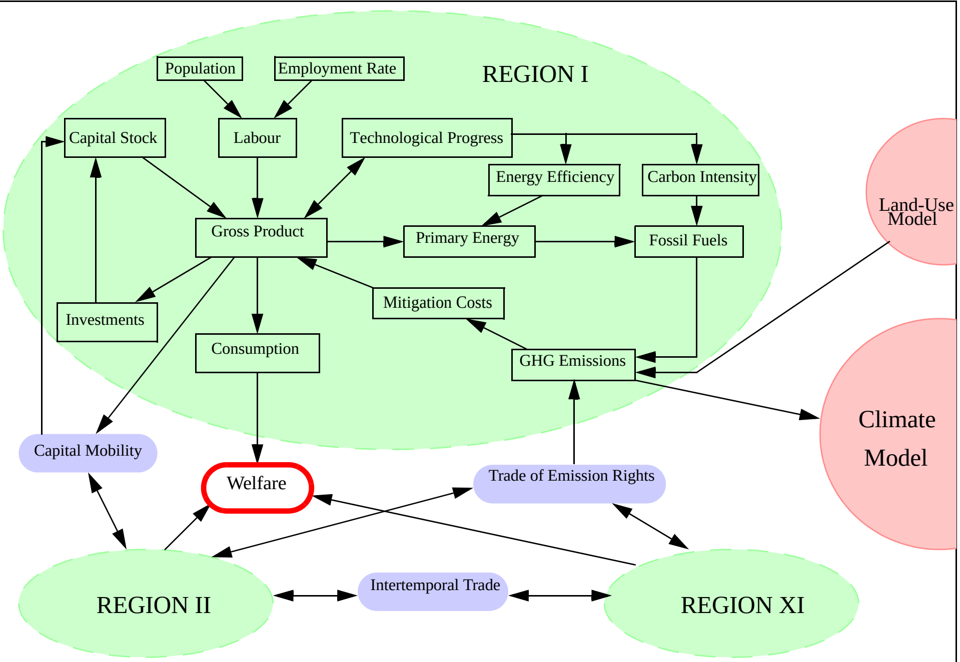
The application of General Circulation Models (GCMs), which are the most sophisticated climate models currently available, is excluded by their enormous computational demand. Climate system modelling within the TWA can therefore only be addressed by strongly aggregated climate models that are numerically efficient while reproducing the results of GCMs with sufficient accuracy.

The ICLIPS climate model, which links the economic and the climate-impact components of the ICLIPS integrated assessment model, fulfils both requirements. The model takes into account all important greenhouse gases (carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, sulphur hexafluoride, tropospheric and stratospheric ozone, and stratospheric water vapour) and aerosols by modelling their dynamic atmospheric behaviour as well as the radiative forcing originating from changes in the concentration of the respective substances in a parameterized way.

The ICLIPS climate model primarily delivers the time-dependent evolution of various pertinent climate-change indicators (changes in global mean temperature, precipitation and cloudiness as well as sea-level rise). These indicators, however, can be combined with static climate-change patterns derived from GCMs in order to obtain a first-order approximation of regional changes in various climate attributes.

The carbon-cycle module developed at the Max Planck Institute for Meteorology in Hamburg takes into account 4 oceanic layers as well as 3 biosphere reservoirs acting on different time scales in a non-linear way (Figure 1). Due to these and further enhancements

Fig. 2: The ICLIPS long-term economic growth model.



compared to previous reduced-form climate models, the ICLIPS climate model reflects a state-of-the-art understanding of the complex dynamic behaviour of the subsystems involved.

The ICLIPS Socio-Economic Model

The model network integrates two economic models: a Ramsey-type optimal growth model and a general equilibrium model. These models serve complementary functions. While the growth model supports long-term policy analyses by imitating the climate policy decision-making process at the international level, the general equilibrium model focuses on the economic behaviour of sectorally disaggregated actors as a reaction to the framework conditions set by international climate policy. The general equilibrium model was developed by project partners at the Kiel Institute of World Economics. It determines economic implications (trade flows, shifts in sectoral output, regional welfare, energy consumption, etc.) of alternative climate protection strategies.

The long-term economic growth model is presented in Figure 2. It is directly coupled with the climate model and a land-use change model. The latter was developed by project partners at the Battelle Pacific Northwest National Laboratories (Washington, D.C.). The economic growth path computed by this model is driven by exogenous population and endogenous investment dynamics as well as by a simple technological diffusion model. The growth path is modified due to interregional linkages and climate policy interventions. The cost of reducing greenhouse gas emissions is determined by dynamic mitigation cost functions. This novel approach, developed in collaboration with project partners at the International Institute for Applied System Analysis in Laxenburg, regards emission reduction as a continuous process with endogenous cost-diminishing effects from “learning by doing” rather than as a succession of independent decisions, as modelled by traditional mitigation cost functions.

Three types of interregional relations between the 11 major economic regions represented in the model are distinguished:

- *Intertemporal trade* in the composite good is possible by allowing temporary trade balance deficits. Since just a single composite good is produced, trade in commodities is not relevant.
- *Capital mobility* is modelled on the basis of differentials in regional return rates to capital. In order to adjust capital transfers to those amounts observed in reality, their volume is limited in the model.
- *Emission rights trading* allows to realize emission abatement in those regions where it is cheapest. In this way, specific emission reduction goals can be achieved at lower cost. Ceilings on emission rights trading may be imposed to enforce that some emission reductions are carried out at home. Since the initial allocation of emission rights exerts a decisive influence on the price and the volume of traded

emission rights, different allocation schemes can be investigated (see example below).

Results of an application of the integrated ICLIPS model in a cost - effectiveness framework are presented in Figure 3. In this model run, we applied the WBGU (German Advisory Council on Global Change) climate window (mainly characterized by a maximal global mean temperature change of 2°C relative to the pre-industrial level and a maximal rate of change of 0.2°C per decade) as a constraint. Additionally, we assumed that the allocation of emission rights follows a gradual transition from the "grandfathering principle" to an equal per-capita allocation reached in 2050.

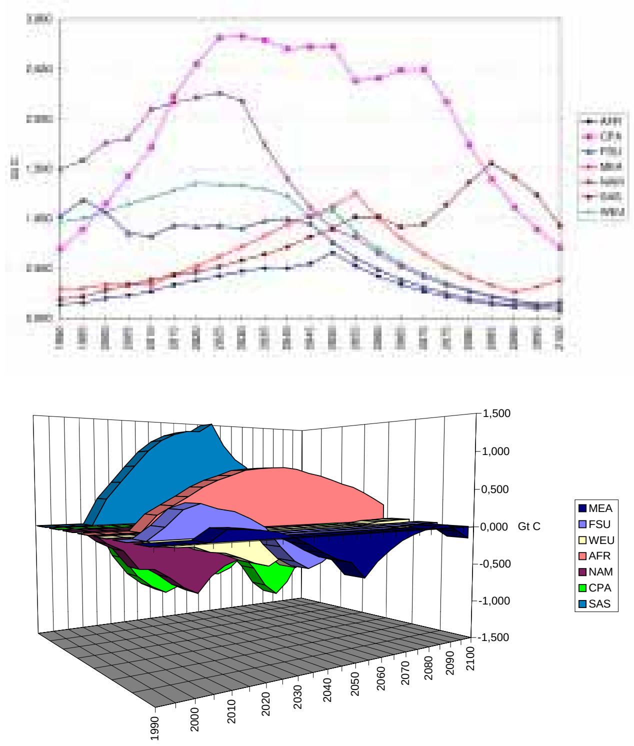


Fig. 3: Cost-effective regional emission paths (top) and trade of emission rights (bottom) in accordance with the climate window proposed by the German Advisory Council on Global Change (WBGU) in 1995. Abbreviations: AFR - Sub-Saharan Africa, CPA - Centrally Planned Asia (mainly China), FSU - Former Soviet Union, MEA - Middle East/ North Africa, NAM - North America, SAS - South Asia (mainly India), WEU - Western Europe.

According to the emission profiles depicted in Figure 3, a drastic emission increase is expected in China within the next 30 years. While the overall efforts in emission reduction are considerable and mainly imposed on the industrial world, the transition phase to form a less energy- and carbon-intensive economy is relatively long. Whereas Africa and South Asia export emission rights over the entire time span considered, China soon becomes an importer.

The ICLIPS Climate Impact Model

The modelling of climate-change impacts in integrated assessment models of climate change has traditionally been dominated by two different approaches. In a *policy-optimization framework*, implemented for instance by cost - benefit analyses, all costs and benefits of climate-change mitigation and adaptation options have to be expressed in a common metric. Climate-change impacts are typically represented by so-called damage functions that state a statistical relationship between (changes in) global mean temperature and the associated monetized climate damage. In a *policy-evaluation framework*, the biogeophysical impacts of climate change are simulated by process-based, sectoral impact models for a limited set of climate-change scenarios. Their socio-economic consequences may be explored subsequently.

The TWA is a representative of the *policy-guidance framework*. Impact modelling in this context is intended to facilitate the normative specification of *impact guardrails*, i.e. levels of climate-change impacts that are perceived as undesirable by stakeholders. This overall aim requires the ICLIPS impact model

- to provide regionalized impact projections that are specified in biophysical units, at least for those systems where commonly agreed (market) prices do not exist;
- to be so flexible that virtually all future climate evolutions can be assessed as to their compatibility with the pre-defined guardrails; and
- to be computationally very efficient.

In order to meet these partially conflicting goals, the concept of *climate impact response functions* (CIRFs) has been developed. In its present form, a CIRF represents the cause-effect relationship between climate variables on the one hand and an aggregated impact indicator on the other hand. CIRFs are based on multiple simulations with process-based, geographically explicit impact models. Therefore, they combine the sectoral and regional specificity of these models with the universality and computational efficiency of economic damage functions.

An important aspect in the development of CIRFs, when being used as reduced-form impact models in an integrated assessment model, is to ensure their compatibility with the other model components. The principal output of the ICLIPS climate model consists of time paths for the global mean temperature, the amount of sea-level rise, and the atmospheric concentrations of all important greenhouse gases. The gap between these aggregated indices of climate change and the more detailed data requirements of most process-based impact models is bridged by means of a scaled scenario approach. This approach is based on the

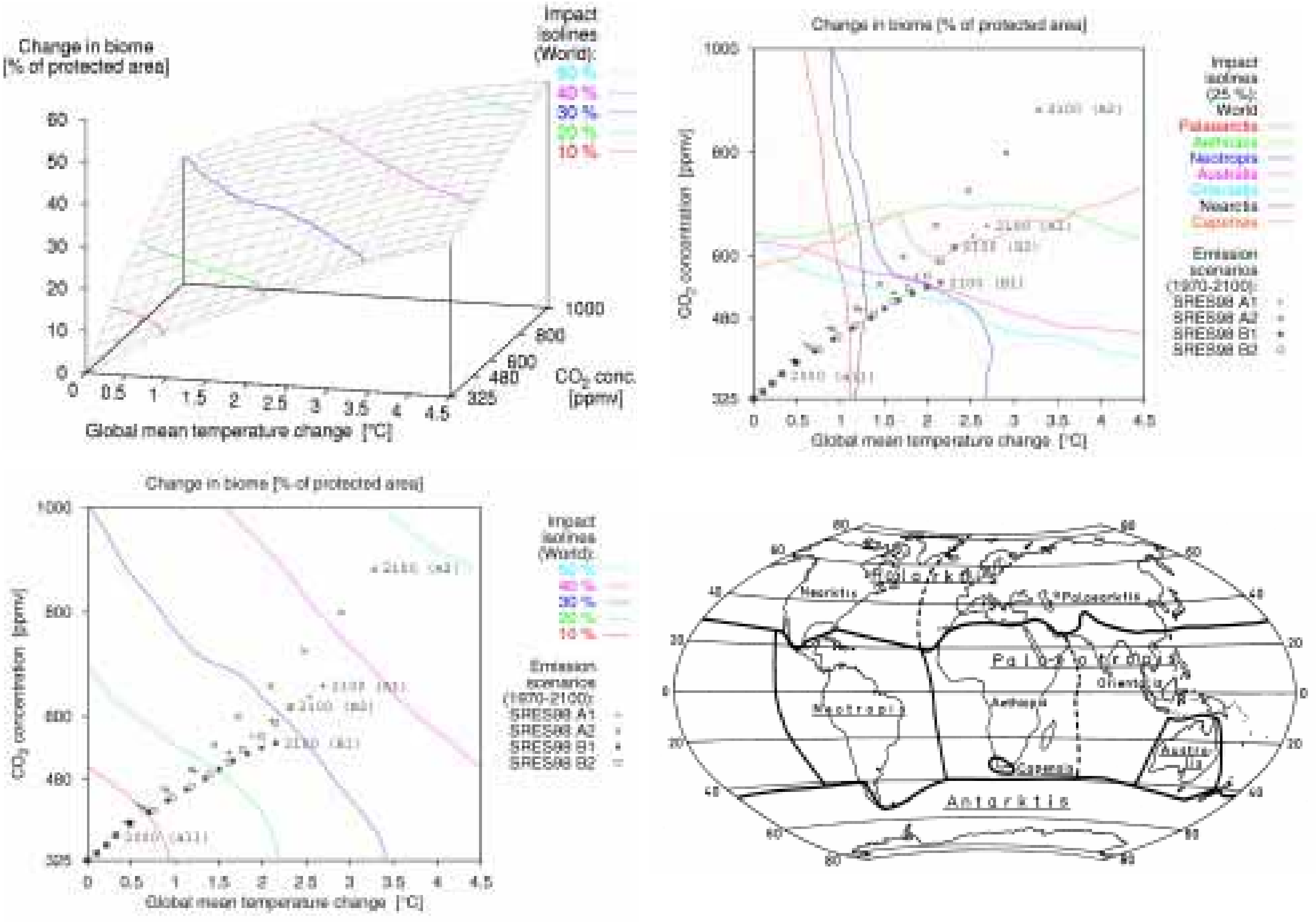


Fig. 4: Climate-impact response functions depicting the percentage of endangered protected areas (like nature reserves) for an extensive range of changes in climate (x axis) and CO_2 concentration (y axis). A nature reserve is marked as "endangered" if the present biome (the basic vegetation unit, e.g. tropical evergreen forest or temperate deciduous forest) is no longer viable in a changed climate.
Left column: Response surface diagram (top) and impact isoline diagram (bottom) for globally averaged vegetation impacts. The coloured isolines depict the boundaries of the climate windows for selected impact guardrails, referring to "losses" from 10% up to 50% of the world's protected areas. The time paths of four baseline emission scenarios developed by the respective body of the Intergovernmental Panel on Climate Change are depicted in decadal steps, starting from the current climate in the lower left corner.
Right column: Multiple isoline diagram for exemplary impact guardrails that limit losses of protected areas to 25% in each biogeographic region.

separation of the transient response from the spatial variability in the climate-change signal simulated by experiments with coupled ocean-atmosphere general circulation models (GCMs). While the atmospheric concentration of carbon dioxide (CO_2) and sea-level rise follow their own distinctive time paths, changes in the pertinent atmospheric climate variables (i.e. seasonal temperature, precipitation, cloudiness, and humidity) over time can be approximated by scaling static climate-change patterns of these variables synchronously with the amount of global mean temperature change. We thus use the latter and, in the case of vegetation impacts, the CO_2 concentration, as independent variables for the CIRFs, and are nevertheless able to include the spatial and seasonal variability of the original climate-change signal.

The computation of a CIRF involves applying a suitable process-based impact model to the range of climate futures spanned by the independent variables of the CIRF, and deriving selected aggregated impact indicators from the bulky simulation results. A global vegetation model (BIOME 1) and a crop suitability model (FAO-AEZ), both adapted to allow for the direct effects of enhanced CO_2 levels on plants, and a global water model (WaterGAP 1.0), developed by project partners from the Center for Environmental Systems Research at the University of Kassel, have been used to assess climate-change impacts on natural vegetation, potential agricultural production, and fresh-water availability, respectively. In order to facilitate sensitivity analyses, all CIRFs have been computed based on climate-change patterns derived from three recent GCMs, with varying spatial coverage, and for impact

indicators that assume different levels of adaptation to climate change.
Exemplary results for vegetation impacts in protected areas, both globally averaged and for individual biogeographic regions, are shown in Figure 4. The overall dose - response relationship between two indicators of climate change and an impact indicator, as stated by the CIRF, is visualized in its *response surface diagram*. The respective *impact isoline diagram* focuses on the translation of impact guardrails into constraints for climate parameters ("*climate windows*"), and the regionally varying sensitivity of a system to climatic changes is most clearly depicted in a *multiple isoline diagram*.

Applying the ICLIPS model within the Tolerable Windows Approach

The various components of the ICLIPS model described so far have been successfully linked in order to obtain an integrated assessment model that comprises the entire cause - effect chain, and thus relates driving socio-economic activities to climate impacts.
As a result, an efficient model (see Figure 5) has been obtained that can be applied in three different modes:

- identifying least-cost emission paths that comply with pre-defined climate thresholds ("cost-effectiveness analysis");
- finding emission paths that minimize the degree of climate change subject to given socio-economic constraints; and
- delineating emission corridors that depict the admissible scope for future greenhouse-gas emissions compatible with normatively defined guardrails.

The TWA exhibits considerable flexibility with regard to various procedural and outcome-related normative settings. This is important as these settings are influenced by various individual and social perceptions and therefore will obviously differ among social actors. Consequently, the current version of the ICLIPS model offers an extensive list of indicators which may be involved in the normative definition of guardrails:

- *Impact guardrails* may refer to changes in biomes (overall or restricted to protected areas), stable and total forest area, agricultural yield (for various adaptation levels), and water availability, both globally and for suitable defined regions.
- *Climatic guardrails* may involve the degree and rate of temperature and precipitation changes as well as the magnitude and pace of sea-level rise.
- *Socio-economic constraints* may restrict the emission reduction rate and losses measured by various economic indicators (gross domestic product, per-capita consumption and welfare, both globally and regionally) relative to the "business-as-usual" case.

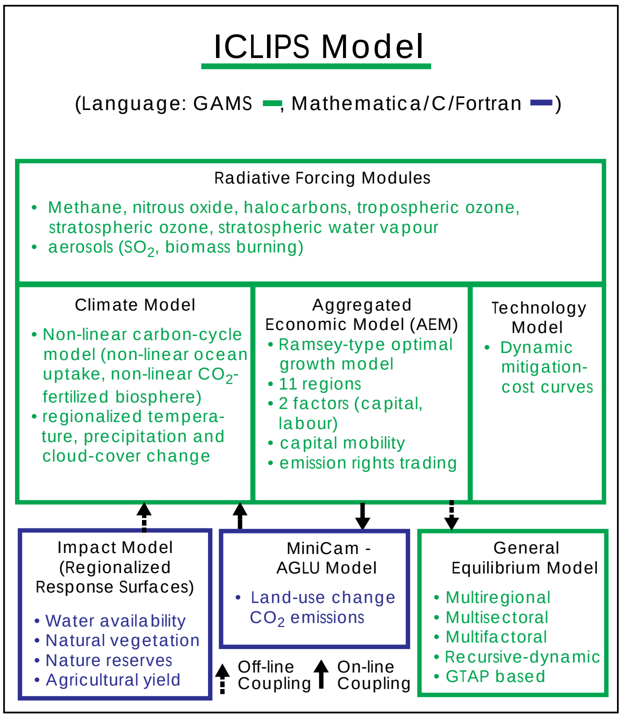


Fig. 5: Structure of the ICLIPS integrated assessment model.

In order to facilitate normative judgements that focus on economic sustainability rather than on the deviation from a "business-as-usual" path, minimum values for increases in per-capita consumption may be stipulated alternatively. In addition, caps on emission rights trade, the admissible deviation of income losses burdening different generations, and target years for an equal per-capita allocation of emission rights can be defined.
Three indicators were selected for an exemplary application of the fully-coupled ICLIPS model, based on the following normative guard-rails:

- *Impact constraint:* the percentage of the world's nature reserves where the present biome is no longer viable under changed climatic conditions should not exceed 30%.
- *Socio-economic constraint:* per-capita income losses, compared to the reference case, should not exceed 2% in any region at any time.
- *Equity constraint:* equal per-capita allocation of emission rights should be achieved by 2100.

It should be emphasized that the numerical values chosen here serve as an example within an "if - then" framework only. They should not be misinterpreted as preferred or even politically feasible recommendations. Obviously, specific values could only be obtained through an intensive policy-science dialogue, for instance during a policy exercise as envisaged for the next phase of the ICLIPS project.

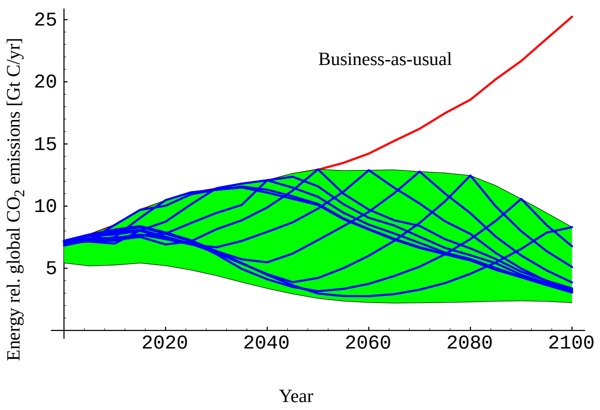


Fig. 6: Exemplary result obtained with the fully-coupled ICLIPS integrated assessment model. Depicted is the emission corridor (green) which delineates the set of all admissible emission paths, and the reference emission path (red) of the ICLIPS model.

The main results of the TWA exercise described above are summarized in Figure 6. The depicted emission corridor delineates the bundle of all emission paths which are compatible with the pre-defined constraints. Consequently, every point within the corridor belongs to at least one admissible path whereas every path that leaves the corridor (for instance the assumed "business-as-usual" path) is clearly intolerable. However, not every arbitrarily chosen path within the corridor is necessarily an admissible one. For instance, the upper boundary of the corridor is not an admissible path; it is rather determined by the maxima of the blue paths which reach the upper bound only temporarily. As the corridor clearly shows, global greenhouse-gas emissions are not allowed to exceed 13 gigatonnes of carbon (GtC) in any year if the normative settings are not to be violated.

In the first three and a half years since its inception, the ICLIPS project has developed an integrated assessment model that comprises several innovative features (for instance, a highly efficient climate model taking into account all pertinent greenhouse gases, climate-impact response functions, and a long-term economy model including dynamic mitigation cost functions) compared to then state-of-the-art models. By applying this model, the ICLIPS project has successfully proven the conceptual validity, numerical tractability and policy relevance of a new decision-support methodology - the Tolerable Windows Approach.

A major part of the ICLIPS core project is funded by the German Ministry for Education and Research (BMBF) and the Federal Ministry of Environment, Nature Protection and Reactor Safety (BMU).

Transdisciplinary Regional Studies

RAGTIME
Regional Assessment of Global Change Impacts Through Integrated Modelling in European River Basins

Project Leader: Alfred Becker

From left to right:

Michael Flechsig, Uwe Haberlandt, Werner Lahmer, Valentina Krysanova, Thomas Beckmann, Fred Hattermann, Claus Rachimow, Beate Klöcking, Bernhard Ströbl

Not present: Alfred Becker

Introduction

Regional-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 on these scales that political and technical measures and regulations can be taken in order to avoid critical developments and reduce negative or undesired effects and consequences. River basins are 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.

Main Research Goals

RAGTIME represents the regional, river-basin oriented component of Global Change research at PIK. First investigations began in 1995. They were markedly intensified from 1997 to 1999 and will soon be transferred into a more comprehensive regional integration approach within the externally funded GLOWA Elbe project (see “The Integration Approach of GLOWA Elbe” on page 65).

RAGTIME represents the regional, river-basin oriented component of Global Change research at PIK. First investigations began in 1995. They were markedly intensified from 1997 to 1999 and will soon be transferred into a more comprehensive regional integration approach within the externally funded GLOWA Elbe project (see “The Integration Approach of GLOWA Elbe” on page 65The main objective of RAGTIME 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. One basic goal is to identify environmentally sensitive areas and suggest measures for their protection. Modelling frameworks have been developed, allowing the simulation of evapotranspiration, runoff, groundwater recharge and storage, river discharge, water quality, crop yield, etc. The primary RAGTIME study area is the Elbe river basin in eastern Germany (Figure 1).

Recently studies have been extended to other river basins, e.g. the Odra river basin. Many of these studies have been implemented within externally funded projects, as listed on page 65.

Hydrological and Ecohydrological Modelling

In order to describe hydrological and ecohydrological processes and phenomena in their effects on climate and land-surface features, three modelling systems have been developed and applied for RAGTIME studies:

- ARC/EGMO for hydrological modelling with any space and time resolution;
- SWIM for integrated hydrological/ vegetation/ water-quality modelling in river basins and on the regional scale; and
- HBV-D, a distributed version of the Swedish model HBV, mainly for hydrological modelling on larger scales.

Fig. 1: Overview of the German part of the Elbe river basin and the sub-basins studied in detail.

Hydrological Modelling

All components of the water balance have been simulated with ARC/EGMO and HBV-D on a daily basis in the framework of the Elbe Ecology project, at first in the whole basin and then in more detail in the tributary river basins indicated in Figure 1. The models were validated at the outlets of about 30 sub-basins, and flow components (surface runoff, interflow and groundwater flow) were calculated.

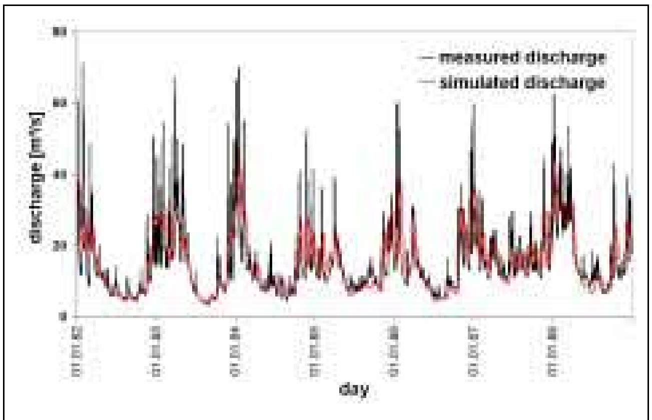


Fig. 2: Measured and simulated basin discharge obtained with the model ARC/EGMO in the Upper Stör basin in northern Germany.

As an example of modelling results, Figure 2 shows measured and simulated daily discharge time series for the Upper Stör basin in northern Germany. These analyses formed the basis for the regionalization of results and for land-use and climate-change impact studies (see below).

Integrated Ecohydrological Modelling

Integrated ecohydrological modelling was performed in several river basins (mostly in the Elbe drainage area) using the SWIM model (Soil and Water Integrated Model). The most important focus points in 1998-1999 were: (i) comparison of nitrogen dynamics in two meso-scale basins, which belong to two typical subregions of the Elbe; and (ii) validation of the erosion module.

(i) The objective of the comparison of nitrogen dynamics was to analyse the factors affecting nitrogen export from diffuse agricultural sources of pollution. Two river basins with different relief and soil types were selected: the Stepenitz basin (575 km^2) in the Pleistocene lowland and the Zschopau basin (1504 km^2) in its mountainous subregion (see Figure 1). Arable land is the dominant land-use type in both basins. The following crops were simulated: spring and winter barley, and winter wheat. Two different nitrogen (N) fertilization schemes were applied in the simulations, the FM scheme (three to four applications in spring), and the FO scheme (the same amount applied once in spring). In both cases one additional application was carried out in autumn.

The analysis of differences in the modelled nitrogen dynamics in different soils leads to the following conclusions (see Figure 3):

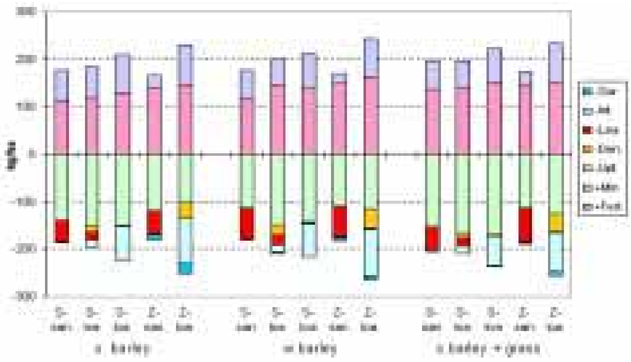


Fig. 3: Comparison of nitrogen balance components simulated with the SWIM model for representative soils in the Stepenitz (S) and the Zschopau (Z) basins (sandy: san, loamy-sandy: lsa, and loamy: loa). The components studied are: losses with surface runoff (Sur), interflow (Int), leaching to groundwater (Lea), denitrification (Den), plant uptake (Upt), mineralization (Min) and fertilization (Fert).

(a) N wash-off has different pathways in different soils. While in sandy soils leaching to groundwater prevails, and in loamy soils mainly lateral N wash-off with interflow occurs, partitioning between both pathways is observed in soils of intermediate texture.
(b) N losses with surface runoff are higher in the Zschopau basin due to its mountainous character and larger proportion of loamy soils.
(c) Mineralization is highest in loamy soils, mainly due to higher water availability in these soils.
(d) Application of the FO fertilization scheme leads to higher N wash-off and lower N utilization (crop uptake divided by the sum of fertilization and mineralization).
(e) The overall utilization of nitrogen is higher in the Stepenitz than in the Zschopau basin. Hence, fertilization needs are higher in the Zschopau basin due to more intensive runoff processes and thus the higher risk of losses.
In general, the simulated behaviour of nitrogen is in agreement with observation data reported in the literature. The modelling results clearly reflect the differences in the pathways of nitrogen loss from different soils, as well as the influence of climate and agricultural practices (fertilization rates and timing, rotation schemes) on nitrogen export. These differences can serve as a basis for further scenario evaluation and eventually for recommendations on improving agricultural practices in order to reduce water-quality problems.

(ii) An important component of SWIM is its erosion module. It includes (a) the modified RUSLE (Revised Universal Soil Loss Equation) approach for estimation of sediment load in sub-basins (based on runoff volume, peak runoff rate, slope length and steepness, and soil erodibility) and (b) the sediment routing including deposition and degradation in streams (based on the sediment delivery ratio concept). Since adequate data for validation of the erosion module are not available in the Elbe river basin, the validation was performed in the Glonn basin (392 km^2), located in Bavaria. General characteristics of the basin are: elevation 450 to 559 m above sea level, domination of loamy and loess soils (60.3%), and domination of arable cropland in land use (73%). The average long-term precipitation in the basin is 880 mm year^{-1}.
The simulations were performed for 1981-1995, the first four years being considered as calibration period. Three disaggregation schemes (10, 42 and 162 sub-basins) were applied in order to study scaling effects. The average sub-basin areas were 39.2, 9.3 and 2.4 km^2 respectively, and the corresponding average hydrotope areas were 0.82, 0.36 and 0.19 km^2.

Fig. 4: Comparison of the measured and simulated accumulated sediment load in the Glonn basin, 1983–1995, performed with SWIM.

The model represents flood events quite well both in the calibration and validation periods. The efficiency of runoff simulation is in the range of 0.66 - 0.80. The average annual sediment yield in sub-basins varied from 0.2 t ha^{-1} yr^{-1} in dry years to 6.8 t ha^{-1} yr^{-1} in wet years. Scaling effects were found to be much more important in the modelling of sediment transport as compared to runoff simulation. When the second disaggregation scheme into 42 sub-basins was used, both peaks of the sediment load and total annual balance were close to the measured ones (see, for example, accumulated sediment load in Figure 4). Correlation coefficients calculated for the full sets of measured and simulated loads (daily time step) were 0.71 for the first six years, and 0.68 for the whole period. Finally, the annual amounts of simulated and measured sediment loads were compared. The correlation coefficients between these time series were 0.97 for the first six years, and 0.66 for the whole period.
The study confirmed the ability of SWIM to simulate sediment yield and transport on the river-basin scale. It

demonstrated that hydrological processes play a dominant role in controlling sediment yield and transport, because most of the sediment yield is produced during a few high flow events in a year.

Regionalization for Large-Scale Assessment of Water Resources

With the increasing spatial extent of the study regions the application of complex dynamic models developed for smaller scales becomes more and more problematic. This is due to (i) the large amount of data required, (ii) uncertainties using averaged parameters for larger simulation units, (iii) possible changes in governing processes and (iv) time consuming computations. For the effective assessment of the availability of water resources on larger scales a concept for quantitative integration and regionalization of results from different research groups has been developed. Its core is a so-called second-order model or metamodel, which uses results from dynamic process models applied on smaller scales and simple balances and expert knowledge for generalised calculations of water and nutrient fluxes. It will finally incorporate 'intelligent' conceptual, statistical and knowledge-based approaches, allowing rapid scenario analyses for large river regions in a spatially distributed manner on monthly to annual time steps.

Essential climatological control variables for modelling hydrological and ecological processes are precipitation, temperature, radiation and humidity. As an initial step to facilitate modelling on different scales and ensure the comparability of modelling results, a raster climate data set for the German part of the Elbe river basin has been prepared. It comprises daily values of these variables on a 5 x 5 km raster for the period from 1981 – 1996, based on interpolations from approximately 1500 precipitation stations and 100 climate stations. Starting point for the interpolation was a comparison of four different methods: Nearest Neighbour, Inverse Distance, Ordinary Kriging and External Drift Kriging. Based on cross validations External Drift Kriging, as the most advanced approach, has proved to be the best interpolation method for temperature, humidity and radiation using elevation data as additional information, while Ordinary Kriging was the most favourable interpolator for precipitation.

The first component realisation of the metamodel was a large-scale regionalization of river-flow components required for flow-path differentiation and subsequent water-quality assessments in the Elbe river basin. Using simulation results provided by the hydrological models ARC/EGMO and HBV-D for a number of gauged mesoscale catchments, different conventional and geostatistical methods are applied to regionalize the base-flow index BFI (i.e. the ratio of base flow to total flow) taking a number of physical catchment attributes and observed climate data as independent variables. Cross validations show that the applied regionalization techniques are suitable even for regionalizing a fairly small sample of BFI values within a large region like the Elbe river basin (Figure 5).

The next step is the development of a tool for the assessment of nitrogen leaching. Considering the highly non-linear character of nitrogen dynamics this would normally require the application of detailed, small-scale models with many parameters. Since those cannot be applied at large scales, a fuzzy-rule based approach is suggested as a fast, transparent and parameter parsimonious alternative within the metamodel framework. The fuzzy rules are defined and calibrated using results from simulation experiments with, for instance, the SWIM modelling system. Subsequently, more results from other dynamic models as well as expert knowledge can be incorporated into the system.

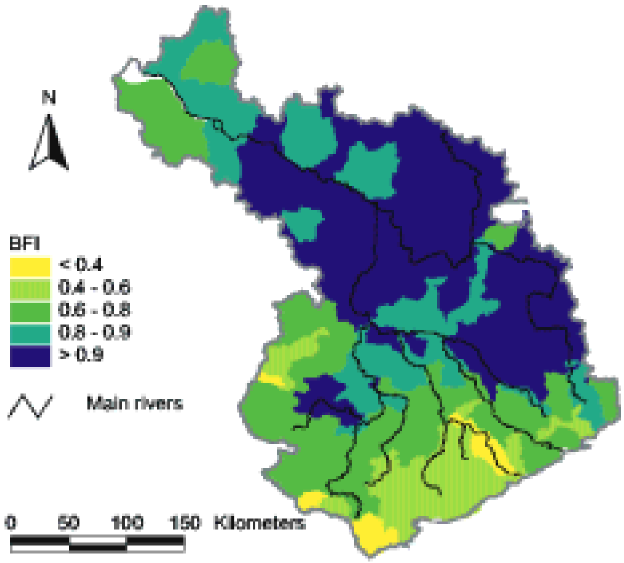


Fig. 5: Long-term average base flow index distribution for the Elbe river basin.

Study of Impacts of Changing Land Use and Climate

A major aim of the modelling activities described above is to provide the scientific basis and tools for the study of impacts of climate and land-use change on hydrological and ecological processes. From the simulation experiments carried out in the last two years for this purpose with the modelling systems SWIM and ARC/EGMO, three are briefly described below. The impact studies in the state of Brandenburg were performed in cooperation with the AGREC project.

Land-Use Change Impact Study in the Stepenitz Basin

One impact study was carried out in the Stepenitz river basin (see Figure 1) as part of the 'WaStor' project. After careful model validation (ARC/EGMO) with reference to the present conditions and available discharge records, four land-use scenarios were developed (Table 1) and investigated.

Table 1: Overview of the conversion modes and derived scenarios for changing arable land into four other land-use types. The scenarios are based on the indicators groundwater depth (GWD), topography (slope) and soil productivity (soil number SN). Resulting hydrological impacts are represented in the form of changes in mean annual totals for evapotranspiration (ET), groundwater recharge (GWR), surface runoff formation (SR) and basin discharge (BD).

conversion mode	scenario	conversion of arable land	area [km²]	percentage of arable land [%]	percentage of basin area [%]	mean annual changes in water balance components [mm/year]			
						ET	GWR	SR	BD
A		with slope >= 4% into dry pasture	15.8	4.4	2.5	0.04	0.05	-0.01	0.03
[illegible]		with GWD <= 0.75m into meadow	100.8	28.0	17.6	-0.20	0.18	0.38	0.20
[illegible]		with SN <=29 and GWD >= 4.5m into forest	38.7	10.5	6.8	7.10	-6.85	-0.14	-6.97
[illegible]		with SN <= 29 and 0.75m < GWD < 4.5m into open land	30.3	8.5	5.3	0.11	-0.23	-0.17	-0.29
		integrated impact of scenario 4	183.4	51.0	32.0	7.18	-7.34	0.07	-7.18

Almost 80 % of the total basin area is under intensive agricultural use. Generally, the conversion of arable land into grassland ('dry pasture') is preferred in areas with deep groundwater and considerable slope (to reduce erosion potential), whereas the conversion into meadows is restricted to areas with shallow groundwater. Forestation is a preferred land-use change mode in areas with deep groundwater and bad soils (small soil numbers), which have a fairly wide distribution in the flatlands of the Stepenitz basin. As an alternative, the conversion of arable land into open/bare land is a generally favoured conversion type in these areas.

Simulations on a daily basis were performed for the reference scenario (actual land use) and the four scenarios of change listed in Table 1 (period 1981 to 1993). The results for the mean annual totals of the water-balance components evapotranspiration ET, groundwater recharge GWR, surface runoff SR and basin discharge BD show that moderate changes in land use result in only small changes of these components. In the case of scenario 4 these changes amount to about +1.5%, -7.3%, +0.1% and -4.2% as compared to the actual land use. Larger reductions of basin discharge would occur only in the case of forestation of large areas. This, however, seems to be an unrealistic option in view of the already existing water deficit in the region.

Land-Use Change Impact Study in Brandenburg

Water resources, ecological and socio-economic conditions in Brandenburg are strongly affected by brown coal mining in the southeast of the federal state. In an area of more than 2000 km^2 groundwater was pumped out to depths of 100 m and more and released into the rivers. Now these water resources need to be replenished. This results in decreasing river discharge, in particular in the Spree river, and may lead to general shortages in water availability. Land-use change is one possible option to counteract this development.

Over the last decade a tendency towards deintensification in the use of agricultural land occurred in the federal state of Brandenburg. The increase in a *temporary "set-aside"* within crop rotations was the main measure used to decrease the intensification level on arable land.

Another effective way to deintensify crop production and, at the same time, protect environmentally sensitive areas, is to create buffer zones by converting the arable land close to river courses (river corridors) into grassland (*permanent "set-aside"*). The latter is an efficient way to reduce nitrate pollution and sediment load in rivers.

Therefore, the primary objective of our study was to analyse the effects of these two alternatives of deintensification in the use of arable land on water resources in Brandenburg. The modelling study was performed using the SWIM model.

Existing relationships between soil quality and crop share for northeastern Germany were used to define a reference scenario A, based on three basic crop rotation schemes, which are related to three soil classes: 'poor' (sandy soils), 'intermediate' (loamy-sandy soils) and 'good' (loamy and loess soils). A stochastic crop generator is applied in SWIM to distribute the crops across the 'fields' (patches of arable land) year by year in such a way that the crop distribution varies spatially according to the differences in soil quality and corresponds every year to the predefined mean crop distribution in the region. After that three types of land-use change scenarios were developed and applied:

- modification of the basic rotation scheme by increasing the portion of temporary "set-aside" areas (scenarios B, C and D), whereby scenario D has the largest portion of set-aside: 60, 40 and 30% for poor, intermediate and good soils, respectively;
- introducing river corridors of 150 and 500 m width in the original land-use map and converting cropland within them into meadows (permanent "set-aside" scenarios A150 and A500);
- combinations of temporary and permanent "set-aside" schemes.

In scenarios B, C and D (Figure 6) the evapotranspiration (ET) decreased in the cropland area rather uniformly on all soils, and consequently the average soil moisture increased. This resulted in higher runoff and

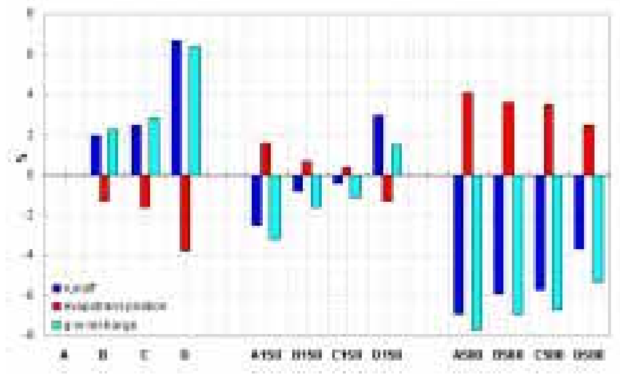


Fig. 6: Assessment of impacts of temporary "set-aside" (scenarios B, C, D), permanent "set-aside" (A150, A500), and their combinations on runoff, evapotranspiration and groundwater recharge in the state of Brandenburg performed with the SWIM model.

groundwater recharge. The regional impact of land-cover changes as assumed in scenarios B and C, however, was minor for the total area. Only the more significant changes in scenario D resulted in notable increases in the average regional runoff and groundwater recharge (+6.7 and +6.4%, respectively).

The conversion of cropland into meadows within river corridors decreased the cropland portion of Brandenburg by 16.5% and 54% respectively. The shift in the relative share of different soil qualities and deintensification as in B, C and D increased runoff on cropland between 5.3 (scenario A150) and 35.4% (scenario D500) depending on the assumed width of the river corridor and the share of temporary set-aside assigned to the scenario. However, the conversion of former cropland to meadows within river corridors decreased runoff and increased evapotranspiration on them quite significantly. It resulted in an increased evapotranspiration up to +4.1%, decreased runoff down to -6.9%, and decreased groundwater recharge down to -7.7% for the total area (scenario A500).

Thus, two opposite tendencies were established. Temporary "set-aside" within a crop-rotation scheme would result in decreasing ET and increasing runoff and groundwater recharge in the region, whereas permanent "set-aside" within river corridors would reduce runoff and increase evapotranspiration. Land-use changes in terms of deintensification may compensate for the expected decrease of discharge in the river Spree over the coming period, if these changes assume increases in the portion of temporary "set-aside" areas, and do not include conversion of arable land into meadows (or forests). Runoff increases might be even greater with decreasing production intensity on the remaining area for arable crops, due to reduction in regional transpiration as a consequence of the lower leaf area index.

Climate-Change Impact on Hydrology and Crop Yield in Brandenburg

These impact studies were performed with the SWIM model for Brandenburg, applying two transient 1.5 K scenarios of climate change developed at PIK: wet scenario W15 and dry scenario D15. Three periods were compared: 1981 - 1992 (control period A), 2022 - 2030 (period B) and 2042 - 2050 (period C). Atmospheric CO_2 concentrations for the reference period A and the two scenario periods B and C were set at 346, 406 and 436 ppm (parts per million) respectively. According to the wet scenario W15, precipitation is expected to increase in Brandenburg: +5.2% and +11.7% on the average in periods B and C respectively. According to the dry scenario D15, precipitation is expected to decrease slightly in the period B (-1.7%) and quite significantly in the period C (-11.3%).

Due to the uncertainties connected with the CO_2 fertilization effect on vegetation, especially on the regional scale, three types of scenarios were considered in our study: (I) climate change only; (II) climate change combined with adjustment of net photosynthesis to higher CO_2 concentration based on experimental data for C3 and C4 crops (factor alpha); and (III) climate change combined with adjustment of net photosynthesis *and* evapotranspiration to higher CO_2 concentration (alpha and beta factors).

According to the simulation results for scenario D15 (see Table 2), evapotranspiration is expected to increase moderately under changing climate. The decrease of groundwater recharge is notable, especially for period C. Runoff also decreases significantly in period C, responding to the decrease in precipitation. This can be even more pronounced in some seasons, leading to a higher risk of droughts.

The D15 scenario also leads to a reduced crop yield for all the crops in the "climate change only" case. The

Table 2: Effect of climate change scenario D15 on hydrological processes and crop yield in Brandenburg.

Simulation experiments	*Hydrological flows / crop yield*	*Change to the reference scenario A, %*	
		period B	*period C*
I Climate change only	evapotranspiration	+5.7	+4.9
	gr-water recharge	-12.2	-31.5
	runoff	-1.9	-22.6
	yield: w. barley	- 4.7	-8.0
	yield: w. wheat	-14.3	-17.6
	yield: maize	-7.1	-12.0
II Climate change combined with factor α	yield: w. barley	+1.8	+1.7
	yield: w. wheat	-7.5	-5.8
	yield: maize	-4.0	-7.0
III Climate change combined with factors α and β	yield: w. barley	+2.7	+4.6
	yield: w. wheat	-7.1	-5.2
	yield: maize	+8.4	+8.4

impact of higher atmospheric CO_2 (alpha factor, variant II) compensated for climate-related crop yield losses for barley. The negative changes were still preserved in scenario D15 for wheat and maize. The assumption that in addition stomatal control of transpiration is taking place on the regional scale (beta factor, variant III) led to a further increase in crop yield, which was larger for maize than for barley and wheat. Still negative changes were preserved for wheat in scenario D15, variant III.

The Integration Approach of GLOWA Elbe

In the GLOWA Elbe project, starting in 2000, the main emphasis will be on a stronger integration of the hydrological and ecological issues with economic, social and political aspects. The general approach towards this integration is outlined in Figure 7. This complex approach combines and structures the most important actions considering the existing degrees of freedom to achieve sustainable regional development (catalogue of problems, tasks and “master scenarios”; fields for actions and management; ranges for the development of unmanageable conditions; selection of indicators and criteria for evaluation). Another essential feature is participation, i.e. the involvement of stakeholders, interest groups and potential decision-makers in the research and evaluation process, thus taking the diversity and incompatibility of often conflicting interests into account when seeking solutions to pending problems. Its objective is to identify possibilities of compromise and trade-off solutions and to provide decision support.

For this purpose sectoral and disciplinary contributions are combined in such a way that they can be compiled as inputs to corresponding software systems, for instance Multicriteria Analyses (MCA). The result of this compilation is presented in matrix form with different alternative solutions as lines and different evaluation criteria as columns. In this way, different proposals for solutions with regard to different evaluation criteria can be compared and a ranking of the alternatives drawn up. The criteria are based on environmental, economic and social sustainability indicators selected in agreement with stakeholders and interest groups, who are later involved in the process of evaluation and implementation of results and, eventually, in decision-making (see Figure 7). Another genuine part of this procedure is equity analysis (EA). Input is the equity matrix containing the subjective evaluations of the alternatives by the interest groups in a fuzzy-linguistic form. This matrix is processed to determine the potentials for coalitions between the interest groups as a prerequisite for compromise solutions.

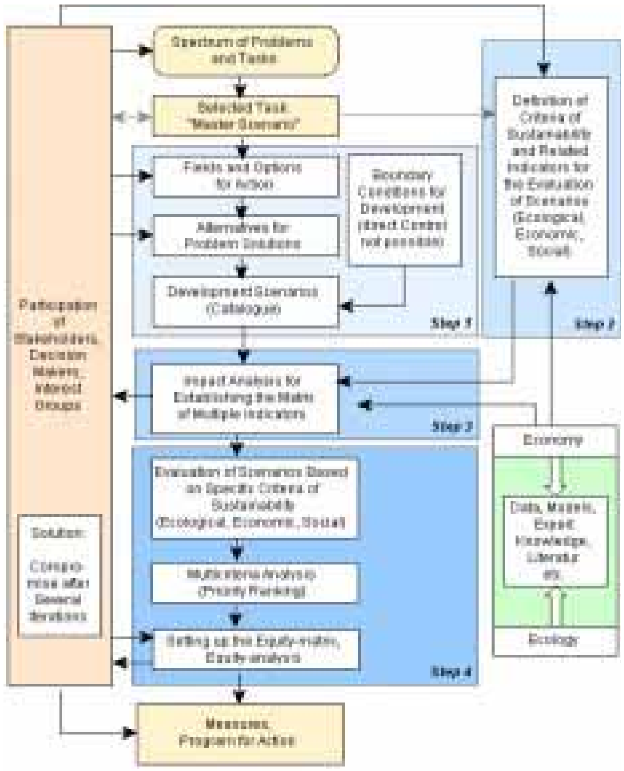


Fig. 7: RAGTIME integration scheme, also applied in GLOWA.

External Funding Support for RAGTIME

Most of the research within RAGTIME received external funding support from the following German organisations:

- the German Ministry of Education and Research (BMBF),
- Brandenburg State Office for Environment (LUA)
- the German National Science Foundation “Deutsche Forschungsgemeinschaft” (DFG).

Important projects were:

- Elbe Ecology: “Dynamic multiscale modelling of water and nutrient balance”, BMBF, 1997/2000
- WaStor: “Water and material retention in the lowlands of the Elbe river basin”, BMBF, 1997/2000
- “Water availability and extreme flood events in the Elbe and Odra river basins”, BMBF, 1999/2000
- “Probability of flood in the Nuthe river basin”, LUA, 1998
- “Stabilization and improvement of the regional water balance in Brandenburg”, LUA, 1999/2000
- “Interdependence of lateral flow and soil-moisture distribution”, DFG, 1998/2000
- GLOWA Elbe, BMBF, starting in 2000.

European Flood Research

The *Flood Research* working group of the *Global Change & Natural Systems* department is participating in two major European flood projects which aim at quantifying storm-runoff generation mechanisms on catchment to river-basin scales and assessing the consequent risks associated with environmental changes:

- LAHoR (Quantification of the influence of the land surface and river discharge conditions in the Rhine basin)
- EUROTAS (European river flood occurrence and total risk assessment system)

During the 1990s Europe was affected by several extreme floods. Their frequent occurrence has sparked off a debate on the causes of this phenomenon and on the impact of human activities on flood runoff in general. Besides the obvious effect of technical river development on streamflow, the influences of land-use/land-cover as well as climate changes have been discussed in this context. However, it is still uncertain in which way, to what degree and at which spatial scale these changes are likely to affect storm-runoff generation and subsequently the extreme discharges of large rivers.

In particular land-surface conditions have been identified as playing a key role in this process. Therefore, the focus of both projects is on altered land-surface conditions and their implications for flooding conditions in large river basins. Consequently, both projects, which investigate different river basins (Rhine and Elbe), apply a jointly developed new method for the assessment of land-use changes.

LAHoR

PIK contribution leader: Axel Bronstert

Being part of the INTERREG Rhine-Maas Activities (IRMA), LAHoR is an EU-funded project within the INTERREG II C programme for regional development which aims at quantifying flood risk for the Rhine basin under altered environmental conditions. The contribution to LAHoR being carried out at PIK is an investigation of the impact of altered climate and land-surface conditions on storm-runoff generation at a scale from 100 to 500 km². Three different catchments within the Rhine basin have been selected which represent different characteristic land-use patterns with either dominantly urban, agricultural or forestal structure. For these three exemplary catchments, land-use and land-cover scenarios are being designed and hydrological response to these scenarios is being simulated using a physically-based distributed hydrological model. Both procedures are based on gridded spatial information.

Land-use scenarios are delineated using the newly developed model LUCK (Land-use change modelling kit). Based on a suitability evaluation and the present land-use neighbourhood relationships, the current land-use map is modified pixelwise. The procedure gradually transforms a user-defined percentage of land-use change into a spatial distribution. LUCK can be used for the decrease or increase in all land-use types and produces an altered land-use map that represents scenario conditions in a realistic manner (Figure 8).

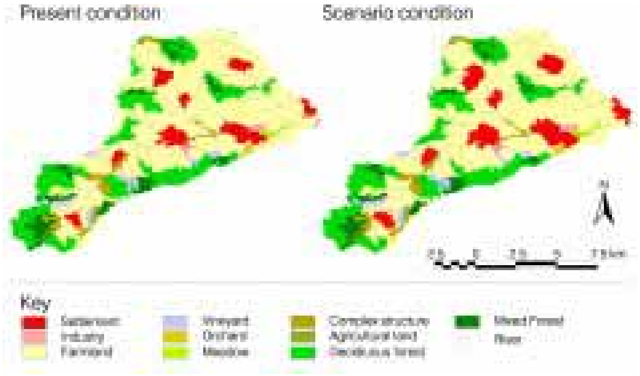


Fig. 8: Urbanisation scenario for the Lein catchment (115 km²) with a settlement increase of 10%.

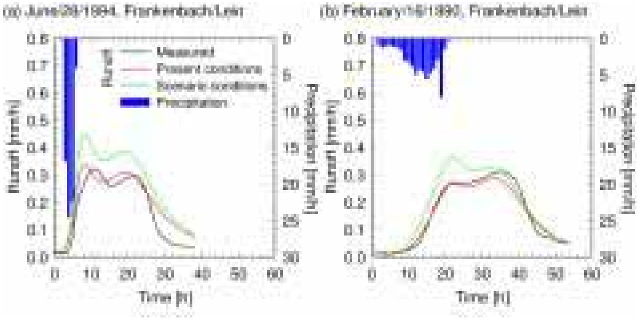


Fig. 9: Flood-discharge simulations for two storm events in the Lein catchment, illustrating the impact of the scenario shown in Figure 8; (a) convective storm event, (b) advective storm event.

Hydrological modelling is performed using a modified version of WaSiM-ETH, which was originally designed to quantify the impact of climate changes on the hydrological regime. In order to improve the representation of land use and thus the description of storm-runoff generation, the following mechanisms have been added to the model:

(1) A macropore module allows for rapid penetration of water into the soil through preferential pathways like cracks, root channels or earthworm channels.

(2) Siltation is simulated as a decrease in permeability of the soil surface depending on precipitation intensity and actual vegetation coverage.
(3) Subgrid variability and the impact of sewerage systems are taken into account with regard to the impervious portion of grid cells.
A comparison of flood events simulated for present and scenario conditions (Figure 9) clearly shows that even moderate urbanisation leads to markedly higher runoff peaks and quicker responses to heavy rainfall.

EUROTAS
PIK contribution leader: Axel Bronstert

The German part of the Elbe river basin (approximately 100000 km²) is one of the five designated catchments chosen to study issues associated with flood risk within the EU-funded EUROTAS project. The three-year project aims at developing an integrated approach to hydrological modelling and risk assessment. The tools and the expert knowledge generated during the project will be encapsulated in a decision-support system in order to evaluate catchment-specific management strategies for the reduction of flood risk.
The semi-distributed, conceptual HBV-D model (a hydrological model developed in the Swedish Meteorological and Hydrological Institute) is used for a proper simulation of flood runoff within the macroscale Elbe catchment. Continuous simulations using HBV-D on a daily time step show good results in terms of river discharge for the various sub-basins and the Elbe river as a whole. This is especially true during flood events.
For the *climate-change impact studies* HBV-D is repeatedly applied in order to model discharge with observed and simulated climate input. First, climate measurements are used for the hydrological simulations. The expanded downscaling method (EDS) is then used to downscale observed/reanalysed atmospheric circulation fields to provide regional climatic boundary conditions for the hydrological model. In a third step, the coupled atmosphere-ocean general circulation model ECHAM4 delivers atmospheric circulation fields for the period 1860 to 2100 which are then downscaled using EDS. An increase in temperature and a simultaneous decrease in precipitation totals as well as extreme rainfall events are predicted. Accordingly, flood risk within the investigated sub-catchments in the southern part of the Elbe basin is simulated as being lower within the next century (Figure 10).

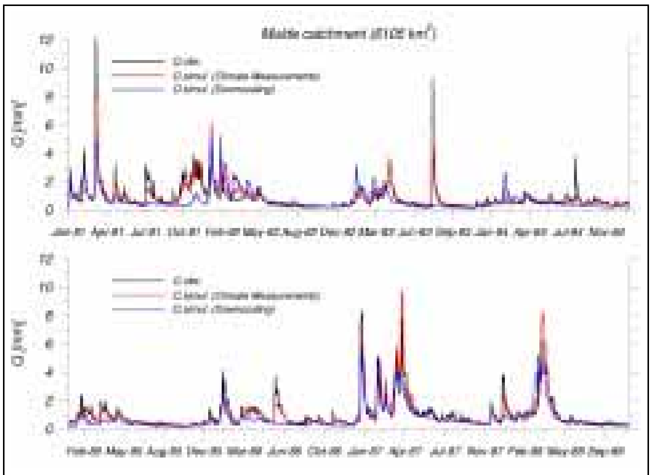


Fig. 10: Comparison between daily observed discharge, daily simulated discharge using HBV-D with climate measurements, and daily simulated discharge using HBV-D and the local climate from observed and downscaled Atmospheric Circulation Fields. Example application for the Mulde basin, a subcatchment of the Elbe.

For the *assessment of land-use change* on the hydrological regime of river basins, realistic land-use change scenarios with a proper representation of the spatial complexity of the landscape need to be available. For this purpose LADEMO (Land-Use Development Model) has been developed within the framework of the EUROTAS project. It is a user-supported model for the development of land-use scenarios. The whole procedure consists of two main parts. The first part of the LADEMO model is designed as a GIS-based (Geographical Information System) interactive tool for a user-supported evaluation of the landscape in order to integrate catchment-specific expert knowledge. The second part of LADEMO is an automated procedure which generates a dynamic evolution of land-use patterns based on the user-defined scenario target as described above for LUCK.

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

Project Leader: Friedrich-Wilhelm Gerstengarbe

From left to right:
Peter C. Werner, Uwe Böhm, Detlef Hauffe, Maarten Krol, Jörg Krywkow, Martin Kücken, Andreas Güntner, Annekathrin Jaeger, Ursula Werner, Friedrich-Wilhelm Gerstengarbe, Gerd Bürger

Introduction
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.

	Piauí	Ceará
Area	250.934 km²	148.016 km²
Inhabitants	2.616.900 (10/km²)	6.626.235 (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. 1: Characteristics of the selected federal Brazilian states.

Fig. 2: Investigation area, Piauí and Ceará in Brazil.

General Goals
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.

As an example of semi-arid regions the Brazilian states Piauí and Ceará (Figure 1, Figure 2 and Figure 3) 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 towards investigating the interactions between natural, social and economic systems are necessary (Figure 4). The challenge is to combine the results of all disciplines in an overlying level "integration". Integration is pursued through the representation of dynamic processes in modelling, analysis of spatial data in landscape ecology, and construction of scenarios of regional development. These scenarios will serve to assess options for the sustainable management of natural resources and development potentials of societal systems.

Fig. 3: Small reservoir (Açude) in north-eastern Brazil during the dry season.

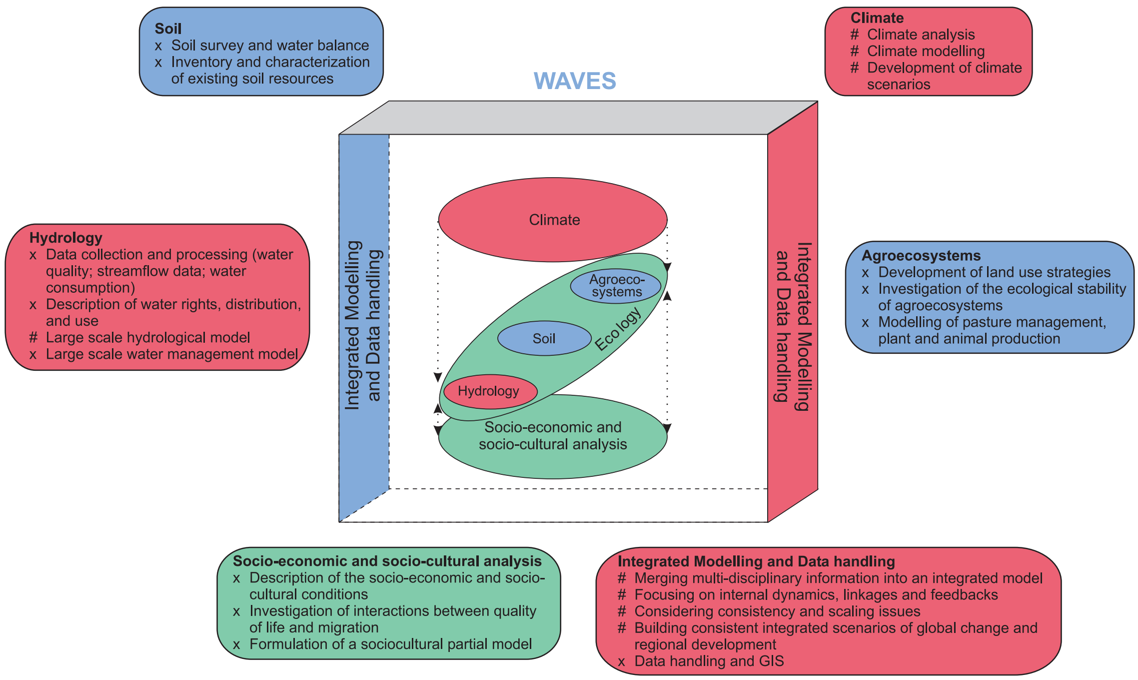


Fig. 4: Relations and goals of the disciplines. Disciplines included: climatology, hydrology, agricultural and social sciences, landscape ecology. # - PIK related tasks; x - tasks of the cooperation partners.

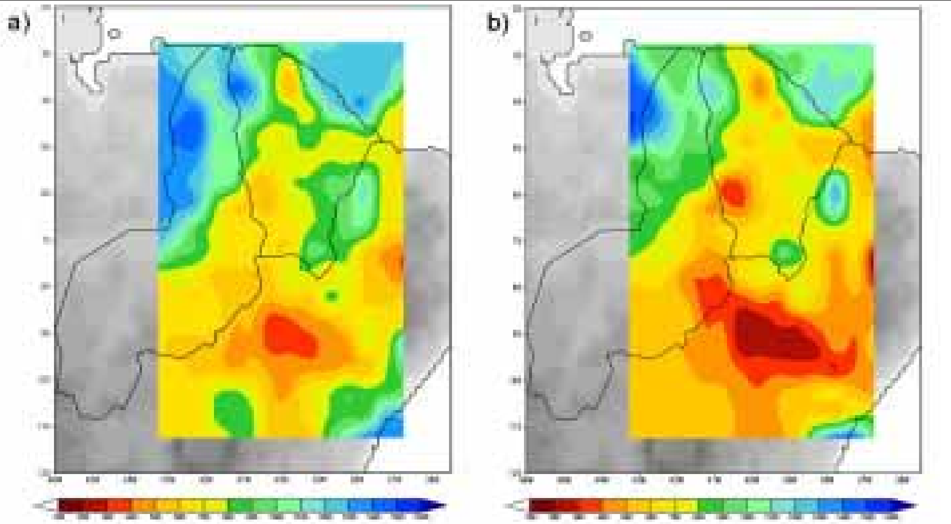
Climate Analysis and Modelling

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

Scenario Development

A special scenario model was created to assess the most probable climate development to be expected for Piauí and Ceará. The idea of this model is to couple information of large-scale climate developments calculated on the basis of global climate model simulations with long-term observation data of the region under investigation. The model is able to guarantee the temporal, spatial and physical consistency of the meteorological parameters used.

Fig. 5: a) Gridded precipitation Northeast Brazil; basic scenario 1921 - 1980 - annual sum (mm); b) Gridded precipitation Northeast Brazil; scenario for 2041 - 2050 - annual sum (mm).



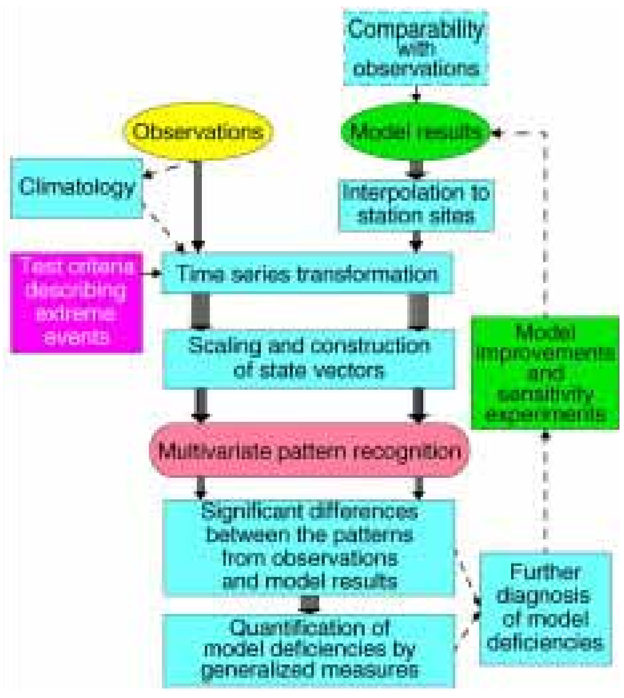


Fig. 6: Principal structure of the developed validation algorithm.

Depending on the meteorological reference values used, the main idea of this model consists in either employing an extended cluster-analysis algorithm or a specially adjusted analogue procedure. For the scenario of future climate development until 2050, the presently observed increase in CO_2 (business as usual) will continue. The large-scale precipitation behaviour was assessed on the basis of model simulations carried out at the Max Planck Institute for Meteorology in Hamburg (MPI). Taking precipitation as the reference value, it was then possible to calculate the future scenario in a small-scale resolution. The evaluation of the results shows that precipitation is expected to decrease drastically, in some areas by as much as 50%. This trend is shown in Figure 5a and Figure 5b. Such strong tendencies could not be observed for temperature, air humidity and radiation. These results enable hydrology, agriculture, landscape ecology and socio-economy to better estimate these tendencies in their respective fields.

Climate Modelling

On the one hand, knowledge about the quality of climate models is important for the evaluation of the model results themselves; on the other hand, it provides information on how to improve the model. For these reasons, a validation algorithm has been developed that for the first time allows to assess the quality of climate models as to application-oriented parameters (Figure 6). This scheme was successfully used for the first time to assess yield losses of typical agricultural products in the investigation area on the basis of MPI's Regional Climate Model REMO that is used at PIK.

Large-Scale Hydrological Modelling

Water availability is a key factor within the system of climatological, ecological and socio-economic interactions in the semi-arid northeast of Brazil. Issues of water resources in WAVES have been studied by three working groups: the assessment of water quality and of management strategies (Hydroisotop GmbH), large-scale modelling of water use and water management (University of Kassel), and large-scale hydrological modelling (PIK).

A quantitative description of the hydrological cycle covering the whole WAVES study area was required. The model which has been developed for this purpose accounts for water availability in terms of river runoff, reservoir storage, soil moisture and groundwater recharge. It was adjusted to the specific conditions of northeastern Brazil. They can be characterized from the hydro-meteorological point of view as a pronounced semi-arid climate with almost all of the annual rainfall during the rainy season of about five months duration. From the operational-hydrological point of view, the large study area of about 400000 km^2 is characterized by more than 7000 large (>50*10^6 m^3 storage capacity), medium-sized and small private reservoirs and generally scarce data.

The model works in a deterministic, spatially distributed mode with a daily time-step. One version of the model is based on river basins, another version is based on administrative boundaries (using municipalities as discretisation units). This latter version is compatible to be incorporated into the Semi-arid Integrated Model (see below), providing the necessary information on physical water availability for adjacent sectors, in particular water management and agro-ecosystems. An innovative concept for delineating modelling units has been developed. *Landscape units* (level 2 in Figure 7) are defined as terrain patches with similar characteristics for the generation of *lateral* water fluxes, i.e., similarity of the major landform, general lithology, soil associations and toposequences. Each landscape unit is composed of terrain components (level 3 in Figure 7), representing upland areas, slopes and valley bottoms, respectively. Lateral surface and subsurface water flow between these components is explicitly represented in the model. In summary, this hierarchical scheme allows to link vertical and lateral hydrological processes at their respective dominating scales, ranging from the basin scale to the point scale of a soil profile (Figure 7). Spatial information on topography, soils and land use is taken into account.

Model simulations of generated runoff (Figure 8a) primarily reflect the spatial patterns of rainfall (e.g. higher amounts in coastal mountains in Ceará) and of soil characteristics (mainly related to crystalline or sedimentary bedrock). Running the hydrological model with the climate scenario until 2050 (see above) while assuming that all other natural and water-management factors remain constant, the simulations reveal an extreme decrease in the future availability of surface water (Figure 8b). The simulated reduction in river runoff is generally more severe than the expected decrease of rainfall volumes (e.g. for Ceará, spatial average values are -25% and -52%, respectively).

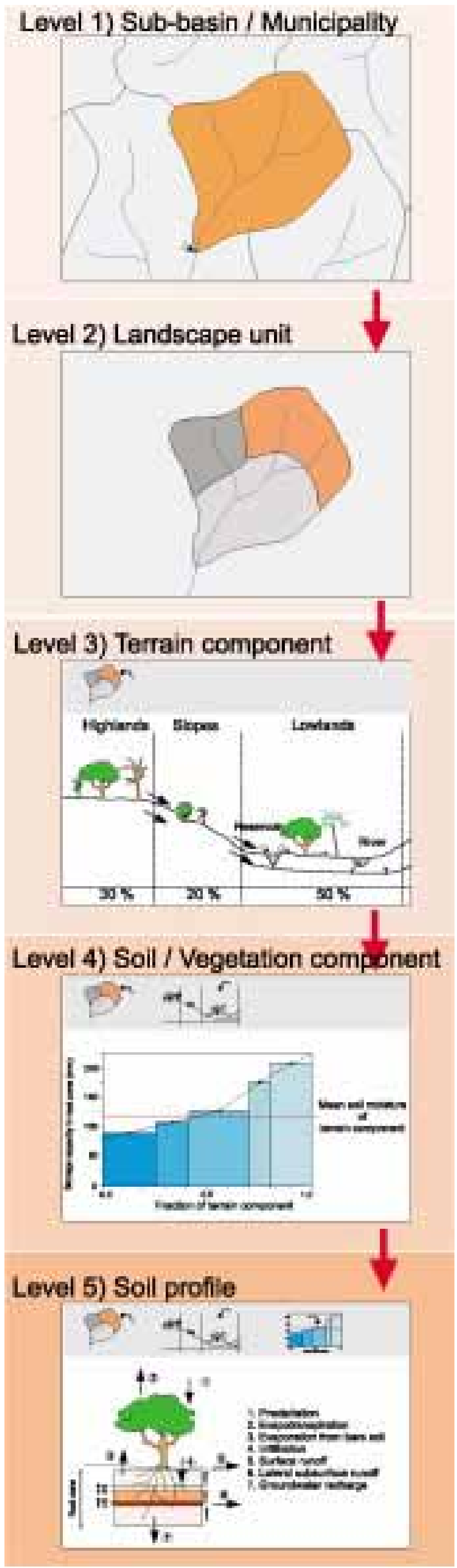


Fig. 7: Hierarchical disaggregation scheme for delineation of modelling units at different spatial scales in the large-scale hydrological model.

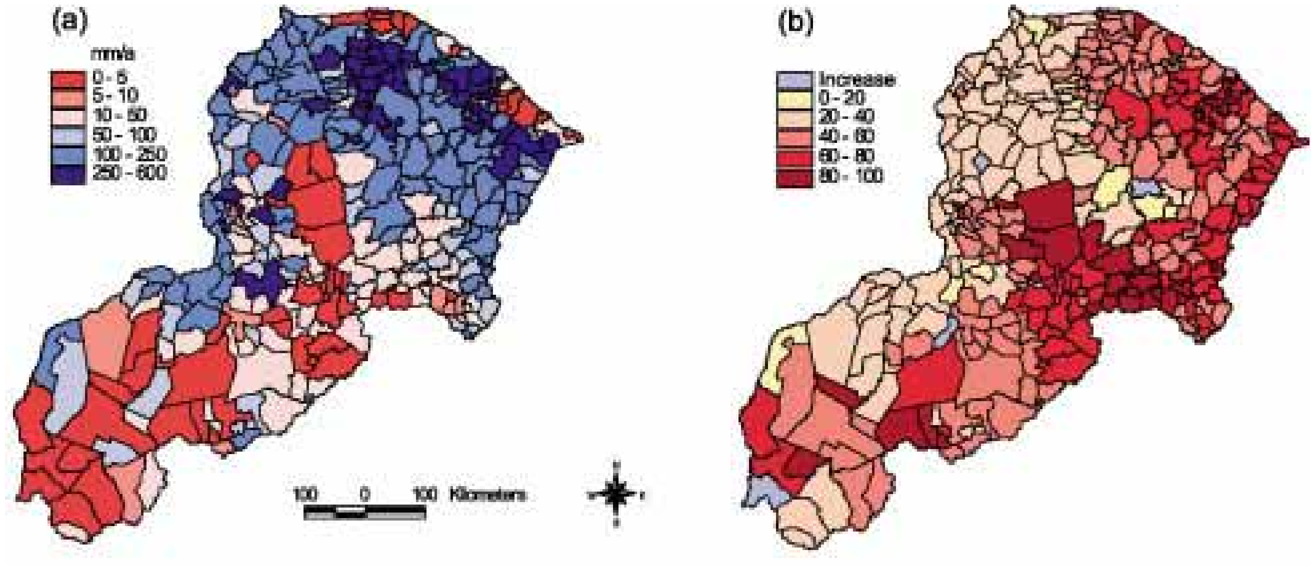


Fig. 8: (a) Mean annual generated runoff (mm) at the scale of municipalities, WAVES study area Piauí and Ceará, simulated period 1921 - 1980; b) Decrease of mean annual runoff (%) between reference period 1971 - 1980 and scenario period 2041 - 2050.

Landscape Ecology

The working group landscape ecology, at the Technical University of München, Weihenstephan, studies strategies for sustainable land use. The tool used is a Geographic Information System (GIS), matching the key processes of the natural and anthropogenic components of the landscape system.

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.

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 University of Applied Sciences, Köln. Socio-cultural analyses focus on how social and environmental conditions affect human behaviour. 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 potential of development under current and changed conditions, e.g. climate, water infrastructure, market.

Integrated Modelling

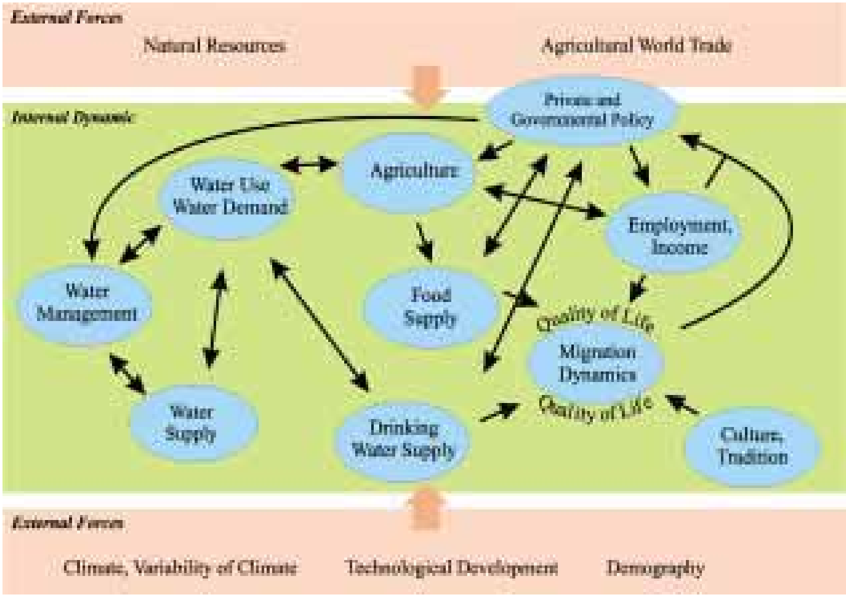
The purpose of integrated modelling in WAVES is to make a dynamic representation of how the regional system of natural resources and society functions, based on existing and newly generated knowledge on the problem. PIK is responsible for this integrative task.

Generally, two of the most important problems in making integrated assessments are the mutual intelligibility of information between different scientific disciplines, and the manifold 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 explicitly inside the model, allowing for the analysis of feedbacks, which can hardly be achieved by other approaches.

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

Fig. 9: Flow diagram of the integrated model: main causal chains and main linkages among the different modules. Arrows denote important processes connecting the main variables (one- or two-way).



of sustainable development in semi-arid regions, and in the extent of scientific disciplines explicitly covered in a regional integrated model.

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 internal processes and to identify the important external forces driving the system, and a bottom-up approach to refine process knowledge and the parameterisation of the processes.

Semi-Arid Integrated Model

The Semi-Arid Integrated Model (SIM) resulted from analysing the central problem from a systems-theory perspective. Hypotheses on what is relevant in describing the dynamics of the system steered the selection of variables and processes to be represented internally in the model and of driving forces, such as Global Climate Change, to be captured in integrated scenarios. The model (Figure 9) illustrates the main causal chains, the main linkages between scientific disciplines and the main, external, driving forces to be captured in integrated scenarios. In the model, migration from the rural areas is represented as adaptive behaviour of inhabitants reacting to worsening living conditions, represented by an indicator for the "quality of life". Employment and income from subsistence farming play a dominant role, in quality of life 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.

Model Structure

SIM exhibits a modular structure, with the following thematic contributions:

Climate: represented mainly by scenario inputs for precipitation and other meteorological variables, completed with an evapotranspiration model.

Water: a large-scale hydrological model (HYMO-WA) simulates soil humidity, surface flows and surface storage in small and large reservoirs; water use in the various economic sectors is described in a water-use and management model (NoWUM).

Agriculture: the FAO model CROPWAT describes the agricultural production of the main regional crops, rainfed and irrigated, and an agricultural economy model (RASMO) simulates the actual land use, farm income and employment.

Socio-economy: gradients in the value of an indicator for the quality of life, depending e.g. on agro-economic variables, drive the migration between municipalities in a push-pull type of model (MIGFLOW), linked to a standard demographic model.

All modules are defined at the spatial scale of the municipalities, partly using finer scale geographic information.

Model parts were constructed by or in collaboration with the various German and Brazilian project partners. In the current model version, some modules are represented by versions that need further development but results of SIM already show quite satisfactory integrated representations of water availability and interesting simulations of impacts of possible climate change (Figure 8b, Figure 10 and Figure 11).

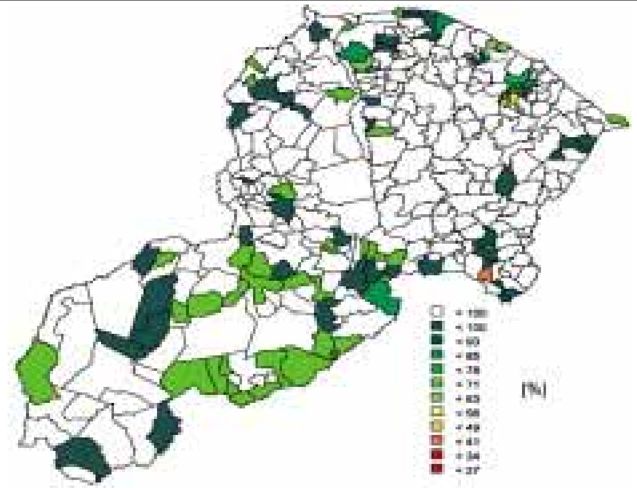


Fig. 10: Relation between water use and water demand for the dry period in the simulation year 2024. Reduced water use caused by insufficient water availability (the percentage of water demand being supplied is shown).

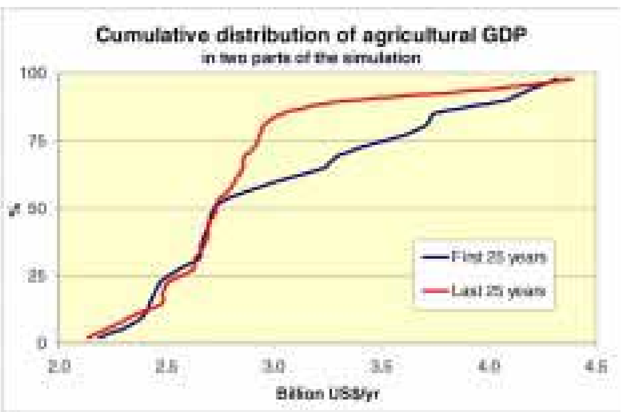


Fig. 11: Cumulative distribution of annual agricultural GDP in Ceará and Piauí for the climate-change scenario for the first and second half of the simulation period, showing an adverse change in the range of medium to good agro-economic returns.

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 a range from a few hours to months or seasons. Moreover, the geographic units or discretisation principles applied, common for spatial simulations, can be very different among disciplines. 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 for all scientific disciplines but even more so for integrated modelling as scaling issues automatically emerge at the interfaces between the individual disciplines.

A scaling study on the modelling of evapotranspiration concluded that upscaling of the formulation used from the finest data level (10 minutes) to the level of daily evaluation is valid without reparameterization.

Co-operations

WAVES is a joint contribution by 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 was carried out between 1994 and 1996. The main phase of the project started in 1997 and will last until 7/2000.

Main Collaborating Institutions

Germany

- Technical University München-Weihenstephan
- University Stuttgart-Hohenheim
- University Kassel
- Potsdam Institute for Climate Impact Research
- Hydroisotop GmbH Schweitenkirchen
- University of Applied Sciences, Köln

Brazil

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

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

EUROPA
European Network Activities on Global Change

Project Leader: Manfred Stock

Scientific cooperation and exchange, internally and externally, nationally and internationally, is a major driving force for research and hence a backbone of PIK's research programme. To give that goal a further push, a number of individual projects, most of them externally financed by the European Union, were bound together to form EUROPA, a kind of "concerted action", as it were, within PIK. The main objective of this activity has been to intensify international contacts, to adjust PIK's research within the European framework and to obtain impulses for PIK's other core projects. In future a new research project, EUROPE, will replace these network activities, taking over some of its goals and tools.

EUROPA comprises several externally funded projects listed in Table 1. Its components are either concerted actions (CAs) or research projects (RDs). Figure 1 illustrates the relationships between these components of EUROPA and other PIK core projects. Most of the topics are closely connected to other core projects and these are reported elsewhere. Here, we concentrate our reporting on four examples:

- A Concerted Action Towards the Improved Understanding and Application of Results from Climate Model Experiments in European Climate Change Impacts Research (ECLAT-2)
- Climatological Change of Hydrographic Parameters in the North Sea and the Baltic Sea (KLINO)
- Regional Integrated Climate Change Assessment – RICC (an internal PIK RD)
- Weather Impacts on Natural, Social and Economic Systems (WISE)

ECLAT-2
PIK Contribution Leader: Wolfgang Cramer

The EU-funded ECLAT-2, a "Concerted Action Towards the Improved Understanding and Application of Results from Climate Model Experiments in European Climate Change Impacts Research" has the goal of assisting climate-impact research in its search for a consistent strategy of applying climate-model output to impact assessments. For this purpose, in all four projects workshops are being organised on various topics related to the problem addressed. Each of them focuses on a small set of keynotes given by specialists from the field (not only Europeans), and then a set of working groups discusses the keynote presentations in greater detail. Results are published as EU Reports.

At PIK in October 1999 the second ECLAT-2 workshop was held on the subject of "Climate scenarios for agricultural, forest and ecosystem impacts". Keynote presentations were given on agricultural and forest assessments, on downscaling techniques and on global feedbacks between the biosphere and the atmosphere. The workshop brought around 40 participants to Potsdam and was considered highly useful not only as a platform for discussion but also as a tutorial for scientists looking for guidance in their respective impact-assessment studies. The report of the workshop will be published during the year 2000.

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

The KLINO project, embedded in the national research framework "Climate Change and Coasts", focused on changes of the spectral wave data in the Atlantic, the North Sea and the Baltic Sea. The measured wave data from the North Atlantic indicated a significant increase in the mean significant wave height of 1-2% per year from the 1960s to the 1990s but no corresponding increase in the mean wind speed. This finding initiated systematic model studies of the sensitivity of the wave data to different properties of the wind data. The first step was to determine a spectral wave climatology over 13 years (1981-1993) with the WAM wave model driven by the Re-Analysis Wind Fields of the European Centre for Medium-Range Forecasts (ECMWF).

Acronym	European Network Activity	Core project
ACACIA	A Concerted Action Towards a Comprehensive Climate Impacts and Adaptation Assessment for the EU (CA)	EUROPA
CLD	Modelling the Effect of Land Degradation on Climate	→ POEM
CLIMPACT	Regional Climate Modelling and Integrated Global Change Impact Studies in the European Arctic (CA)	EUROPA
DART	Dynamic Response of the Forest-Tundra Ecotone to Environmental Change (RD)	→ CHIEF
ECLAT-2	A Concerted Action Towards the Improved Understanding and Application of Results from Climate Model Experiments in European Climate Change Impacts Research (CA)	EUROPA
EFIEA	European Forum on Integrated Environmental Assessment (CA)	EUROPA
ETEMA	European Terrestrial Ecosystem Modelling Activity (RD)	→ POEM
EUROTAS	European River Flood Occurrence and Total Risk Assessment System	→ RAGTIME
KLINO	Climatological Change of Hydrographic Parameters in the North Sea and the Baltic Sea (RD)	EUROPA
LTEEF-II	Long-Term Regional Effects of Climate Change on European Forests: Impact Assessment and Consequences of the Carbon Budget (RD)	→ CHIEF
MAGEC	Modelling Agroecosystems Under Global Environmental Change	→ AGREC
Millennia (terminated)	Numerical Simulation and Analysis of Climate Variability on Decadal and Centennial Time Scales (RD: results were used to improve ocean models)	→ POEM
MOUNTAIN	Environmental and Societal Changes in Mountain Regions (CA)	EUROPA
RICAMARE	Research In Global Change in the Mediterranean: A Regional Network (CA)	→ RESOURCE
RICC	Regional Integrated Climate Change Assessment (PIK-internal RD)	EUROPA
Sub-Saharan	Freshwater Resources in Sub-Saharan Africa with Emphasis on Regional Scale Interactions of Land Use and Climate (CA)	→ RESOURCE
ULYSSES	Urban Lifestyle, Sustainability and Integrated Environmental Assessment (RD)	EUROPA
WISE	Weather Impacts on Natural, Social and Economic Systems (RD)	EUROPA

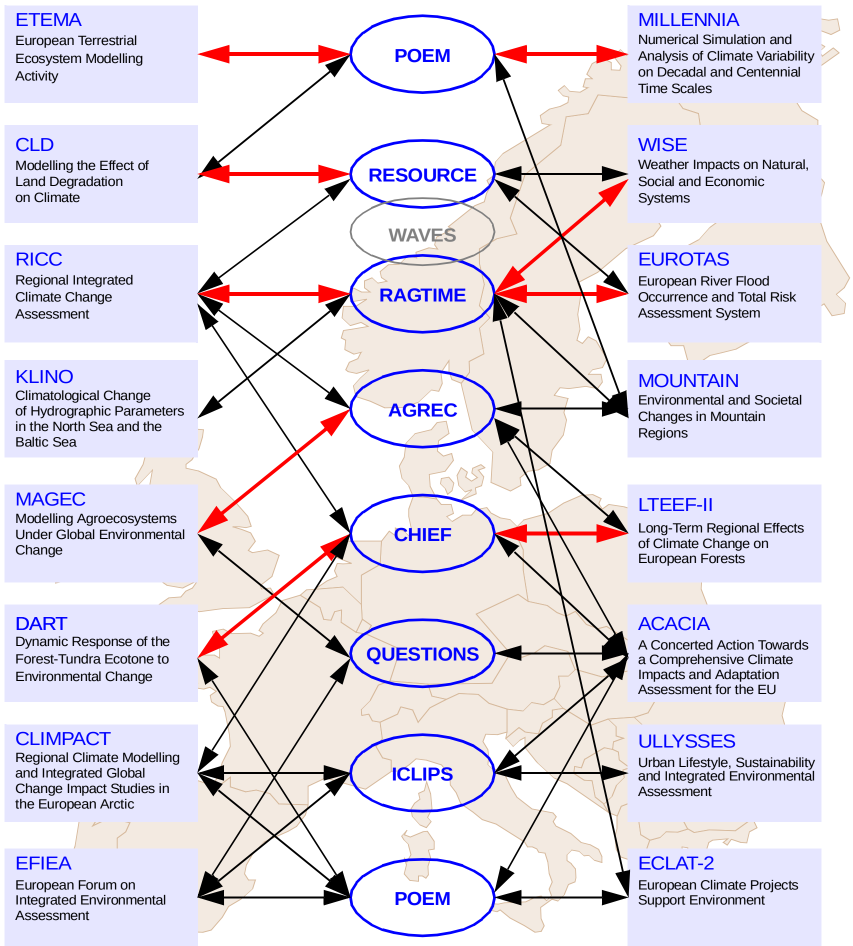
Table 1: List of project activities under EUROPA or other core projects (→ see there).
Project types: CA = Concerted Action, RD = Research and Development.

The time series of the model data were found to compare sufficiently well with ocean weather ship and buoy data to study the effect of wind variability on the wave data. The response of the wave data to changes in wind variability can be summarized for three different scales of variability:

- First, an increase in the large-scale North Atlantic Oscillation (NAO) leads to higher waves in the eastern north Atlantic.
- Second, an increase of the duration of the storms (synoptic scales) produces higher waves in the unsaturated regions of the storm track.
- Third, an increase in high-frequency wind variability (gustiness) results in an increased probability of extreme waves.

In practice, the response of the wave data cannot easily be reduced to a change in a single property of the wind data because the response may consist of a superposition from different non-linear effects with different regions of origin. We conclude from the present studies that changes in wind variability alone, such as storm frequency changes, are insufficient to explain the above-mentioned increase in wave height. For predictions of wave heights induced by global changes the most relevant information is provided by changes in the large-scale wind fields (e.g. NAO) and in the synoptic scale variability (e.g. storm properties). These wind field properties are also highly relevant for wave predictions in coastal regions, which are necessary for coastal zone management.

Fig. 1: Scheme of scientific co-operation and exchange with other European partners working on Global Change. The outlined darts represent the relation to PIK's core project structure either as existing (red) or additionally prospected.



Regional Integrated Climate Change Assessment – RICC
Responsible: Manfred Stock

As a result of the regional pilot project called "Brandenburg Study", methods and tools have been further improved and developed throughout other core projects like AGREC, CHIEF, RAGTIME, QUESTIONS and WAVES. These provide a good basis for regional assessments of global change impacts or even for building Regional Simulators. One example is given in the following summary of TRAIN (model for the calculation of evapotranspiration, mainly based on the simulation of transpiration and interception evaporation).

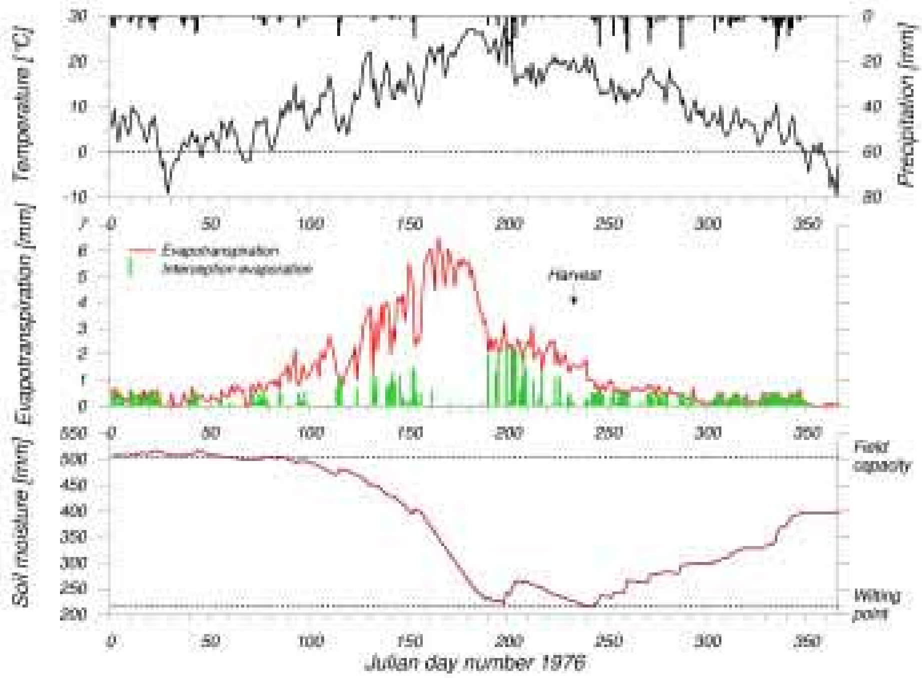
Modelling the regional water availability with TRAIN
(Contribution from RAGTIME by Lucas Menzel)

The physically based SVAT (Soil Vegetation Atmosphere Transfer) model TRAIN has been designed to simulate the spatial pattern of evapotranspiration and groundwater recharge in order to quantify the impacts of climate and land-use change on water availability. Pilot applications of TRAIN serve to improve the model's capability to properly reflect land-cover responses to various natural conditions (Figure 2). The model is envisaged as a tool for the evaluation of water use and water-use efficiency in natural and agricultural systems within a European framework. This will be especially necessary for regions with critical (sparse) water resources like the eastern Mediterranean. Evapotranspiration and agricultural productivity will be coupled for a regional impact assessment of water-related changes and the development of adaptation and mitigation strategies.

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

The EU project "Weather Impacts on Natural, Social and Economic Systems (WISE)" has analysed impacts of current climate variability in Germany, The Netherlands, the UK and Italy to evaluate the sensitivity of

Fig. 2: Modelling evapotranspiration and soil moisture for a loess-rich soil cultivated with spring wheat in the upper Rhine valley (Rheinland-Pfalz, Germany). The daily data refer to the year 1976, which was characterized by a dry and hot summer with severe losses in agricultural yields due to limited water availability. A drastic reduction in total evapotranspiration can be recognized as a consequence of soil moisture decrease down to the wilting point. During this period the main source of evapotranspiration was interception evaporation.



today's society to extreme weather. Unlike studies of anticipated impacts of climate change, WISE did not rely on scenarios and projections, but on existing and newly collected data. The research involved:

(i) the statistical modelling of meteorological and sectoral time series, aimed at quantifying the impacts of changing weather variables on sector output;

(ii) a population survey aimed at investigating public perception of and behavioural response to unusually hot and dry summers and mild winters; and

(iii) a management survey, aimed at gaining an insight into managers' awareness and perception of the importance of extreme weather on their operations.

The three activities provided a useful insight into the contributing countries' sensitivity to and perception of extreme weather events. Sectors that were analysed included agriculture, outdoor fires, water supply, human health, electricity and gas consumption and tourism. Additionally, the effect of wind storms on insurance claims for property damage was studied using statistical storm-damage models. It appears from the statistical modelling that extreme weather can have impressive impacts on all sectors, especially when expressed in monetary terms.

However, weather variability is generally considered a manageable risk, to which sectors in Germany appear reasonably well-adapted. The population and management surveys reveal both positive and negative impacts of extreme weather. People generally respond to these impacts by adjusting their activities. The utilities (electricity, gas and water) indicate that they are quite capable of handling the current level of weather variability and do not consider climate change an important threat to their operations. The tourism sector experiences impacts but typically takes a reactive approach to adaptation, although it is also developing weather-insensitive products.

Results of the statistical analyses did not always correspond to the perceptions of the public and managers. For example, while people state that they (try to) use less water during hot and dry spells, both the statistical analyses and the management survey suggest that they use more. Such discrepancies are particularly interesting from a policy perspective because they may undermine public or managerial acceptability of adaptation or mitigation measures, depending on which perception prevails when the measures are designed (for more information on WISE, see page 21).

Most of the activities in the core-project EUROPA are funded by the European Community.

Sectoral Modelling and Assessment

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

Project Leader: Frank Wechsung

From left to right:
Hannes Reuter, Frank Wechsung, Peggy Michaelis, Gerd Bruschek, Martin Wattenbach

Not present:
Meike Blum, Jan Gräfe, Thomas Kartschall

Introduction

Wheat is the dominant crop on the world's farmlands. Its central role as an agricultural commodity is based on its wide range of usability. In 1998 590.8 mill t wheat were produced, with China (109.7 mill t), the 15 current EU members (103.9 mill t), the USA (69.3 mill t) and India (65.9 mill t) as the main producers. The Food and Agriculture Organisation (FAO) expects that the demand for wheat will further increase as a result of its substitution for coarse-grain cereals as incomes rise in developing countries and the world's population becomes more urban.

Climate impacts on wheat yield and trade are good indicators of the general climate sensitivity of crop productivity and agricultural trade. Higher-order effects of changing crop productivity on the regional scale have been jointly evaluated with the RAGTIME project. Major results of this cooperation are reported in the RAGTIME section of this report (see page 59).

In AGREC we have focused on wheat and continued to analyse the sensitivity of the agricultural sector to regional and global climate change.

Research Goals and Results

The sensitivity of wheat production to climate change and climate fluctuation was analysed on the field scale for the federal state of Brandenburg and for Europe. In addition, the consequences of possible yield shifts for the international wheat trade were analysed. Finally, an effective adaptation measure to yield fluctuations in Morocco was developed in order to reduce vulnerability to climate change in northern Africa.

Mechanistic Model Solutions

Several performance studies have been carried out in order to verify the mechanistic model solutions developed within the FACE (Free-Air Carbon Dioxide Enrichment) experiment. The improved mechanistic descriptions can be extrapolated to other spatial and temporal scales. This scalability was seen as a precondition for reliable climate-impact simulations based on few detailed experimental results from single test sites. It was possible to show that the photosynthesis description in the "demeter" crop-soil model, originally developed and validated using data from the FACE Wheat experiment in the Sonoran desert (USA, Arizona), could be used to reproduce the short-term photosynthesis characteristics of triticale (wheat-rye hybrid) leaves in the LITFASS project (Figure 1). LITFASS ('Lindenberg Inhomogeneous Terrain - Fluxes between Atmosphere and Surface: a Long-term Study) is an interdisciplinary research project of the German Weather Service. The scientific objective of LITFASS (1995-2001) is to determine and model/parameterize the area-averaged turbulent fluxes of momentum, heat, water vapour (and other trace constituents) over a heterogeneous landscape around Lindenberg Meteorological Observatory.

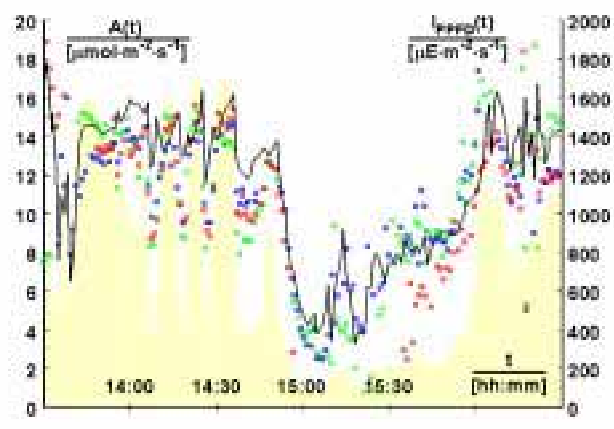


Fig. 1: Observed (o o o) and simulated (-) flag leaf photosynthesis A(t) in one minute time steps for triticale (18 June 1998 Lindenberg) corresponding to the in-coming photosynthetic flux density I_{PPFD} ( ) .

Brandenburg's Wheat Production May 'Cool Off'

Large parts of Europe enjoy climate conditions that are very suitable for intensive agricultural production. However, these conditions are dependent on the mild winters ensured by the warm water transport from the Gulf of Mexico to the northern European coasts with the North Atlantic thermohaline circulation as the underlying transport mechanism. As recent simulations have shown, climate change may destabilize and finally shut down this circulation. In order to explore the consequences of the associated climate cooling for crop production, a simulation study was carried out for the impact of such a scenario on the wheat yield. Simulations were restricted to Brandenburg (Figure 2).

The consequence of a total collapse of North Atlantic ocean circulation for monthly temperatures and the precipitation regime in Brandenburg was derived from Climber 2 simulations at PIK (see page 37). The simulated climate-change signal was used to create a scenario for severe and moderate cooling. For the former (i.e. severe cooling), the current climate was changed by 100% of the simulated difference signal. In addition,

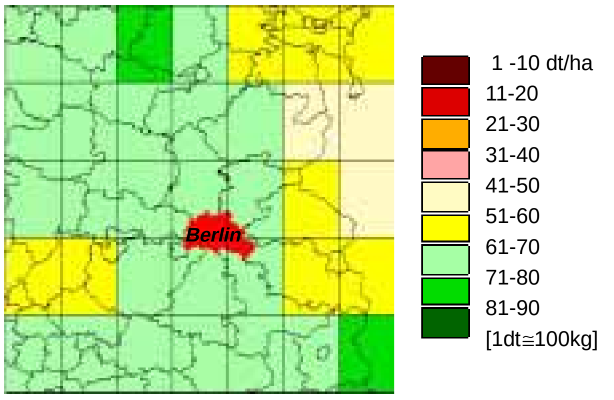


Fig. 2: Simulated spatial pattern of potential Brandenburg wheat yield around Berlin under current climate conditions for the period 1981-1990 ignoring technological constraints.

a moderate cooling scenario was produced by applying only 50% of the simulated changes to the current climate.

The impact of severe and moderate cooling on Brandenburg's wheat yield was simulated using the PIK version of the FAO model, which was adapted to Brandenburg's soil and climate conditions. In particular, the modelled yield sensitivity to water stress was decreased. All yield simulations were based on the FAO soil map and climate data (1981-1990) from the Climatic Research Unit (CRU) of the University of East Anglia.

Besides the systematic overestimation of current yields due to the exclusion of technological constraints, the model simulations followed the yearly yield changes from 1981-1990 with an accuracy of about 80%. Moderate cooling caused yield reductions by 18%. Strong cooling reduced the simulated wheat yield by about 50%. Cooling decreased yields because of temperature limitations for photosynthesis (Figure 3).

Higher CO_2 Counteracts Yield Losses

Many negative impacts of future global warming on wheat yield may largely be offset by the stimulating effects on growth and yield of the parallel increase in atmospheric CO_2. However, the magnitude of this effect is still a subject of debate. It depends on the validity of current hypotheses on the large-scale impact of higher CO_2 on crop yield. Using the PIK version of the FAO crop model, the potential wheat yield (free of technological constraints) in European non-mountainous areas was simulated for current climate (Figure 4, top) and for warmer European climate (Figure 4, bottom and Figure 5).

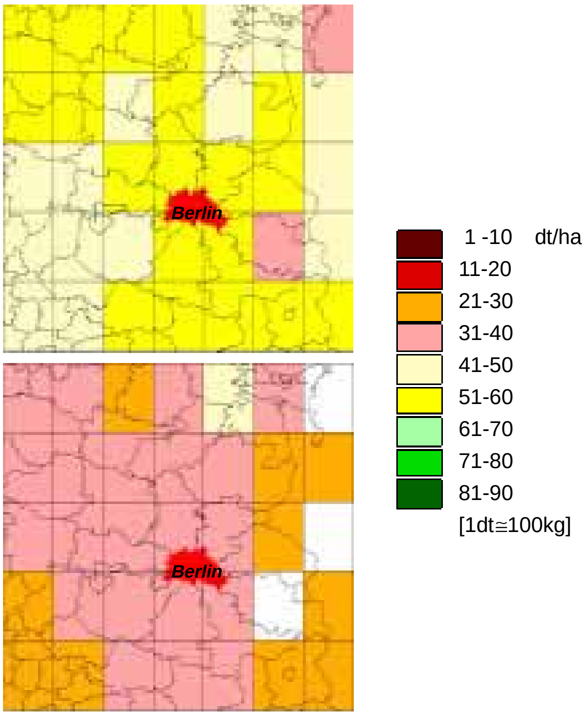


Fig. 3: Potential Brandenburg wheat yields around Berlin for cooler (top: -2.3 °K, bottom: -4.6 °K) and drier climate (top: -12%, bottom: -24% precipitation) as a consequence of a (partial) shutdown of North Atlantic thermohaline ocean circulation.

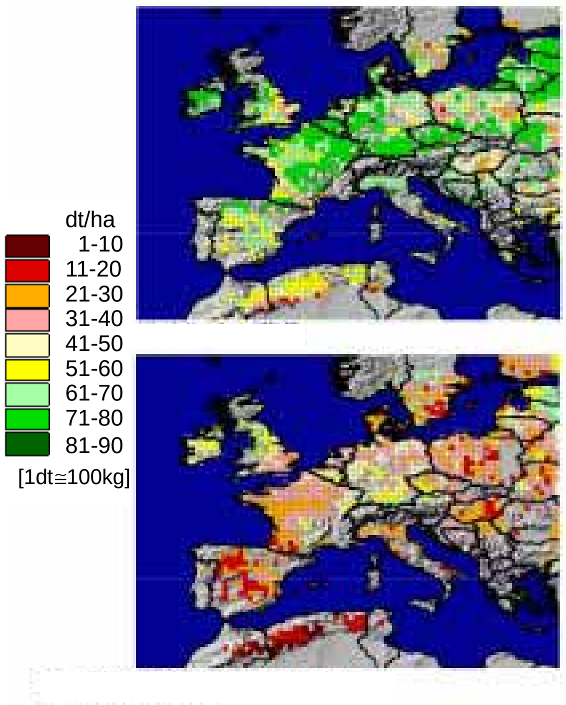


Fig. 4: Simulated spatial wheat-yield distribution over Europe for current climate conditions (top) and for the ECHAM3-T42 climate-change scenario (bottom, (+3°K, -14% precipitation), disregarding technological yield constraints and the effect of higher atmospheric CO_2.

Particular emphasis was placed on the sensitivity of simulations for different hypotheses regarding the impact of higher CO_2 on photosynthesis and transpiration.

Yields were simulated in a 0.5 by 0.5 grid scale based on the FAO soil map, the CRU Norwich climate data set (1961-1990) and a 2x CO_2 climate scenario from the ECHAM3-T42 Global Circulation Model supplied by the Max Planck Institute for Meteorology. Mountainous areas were excluded using an algorithm based on an available digital elevation model of 30 arc seconds (approximately 1 kilometre) from the U.S. Geological Survey. A shaded relief map of the world was used for the validation of the algorithm. The FAO crop model was modified in order to account for daily changes in water supply and the future increase in atmospheric CO_2.

The impact of higher CO_2 was modelled externally. A temperature-dependent correction factor for photosynthesis (α) accounts for the impact of higher CO_2. The correction factor α was calculated using a regression derived from a Farquhar photosynthesis model. Potential transpiration under higher CO_2 was reduced by the factor β, which was directly derived from the α-factor. Yield simulations for the climate-change scenario were repeated under three different assumptions regarding the partial effect of higher CO_2 on photosynthesis and regional transpiration:

1) no effect (Figure 4, bottom);
2) stimulation of photosynthesis, but no reduction in transpiration because of a regional acclimation in the vapour-pressure gradient between vegetation and atmosphere (Figure 5, top); and
3) increase in photosynthesis and reduction in regional transpiration (Figure 5, bottom).

The assumed climate change (+3 °K temperature, -14% precipitation) leads to severe yield losses (-40%) across Europe under (1). Higher CO_2 limits the yield decrease (-8%) under (2) and leads to yield increases (+13%) under (3). Simulated wheat production across Europe is quite sensitive to different hypotheses regarding the regional impact of higher CO_2. This underlines the importance of further studies to explore the regional impact of higher CO_2 on crops and vegetation.

Wheat Deficits in Latin America, Africa/Near East

Very often, the regional impact of climate change on crop production may not correlate directly with the regional yield impact. The simultaneous changes in crop productivity in other regions could have a significant feedback on local crop production by changes in commodity prices and trading streams. Therefore, in a joint research initiative the Institute of Agricultural Pol-

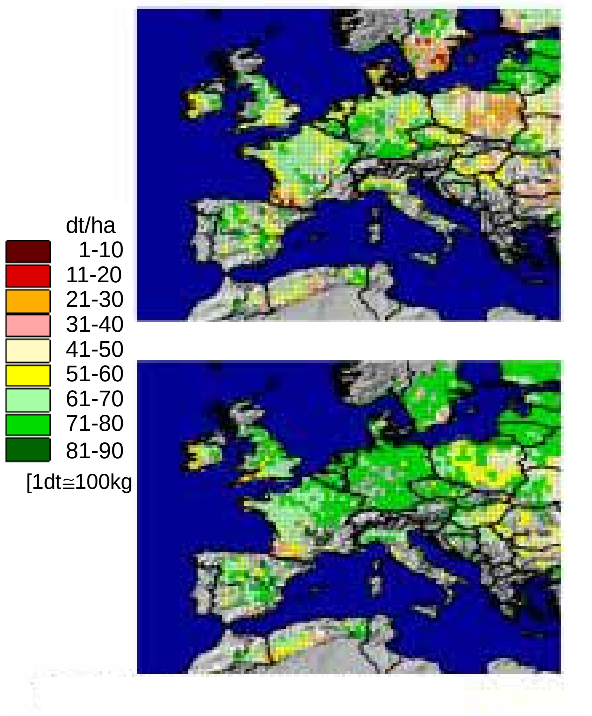


Fig. 5: Simulated wheat-yield distribution over Europe for the ECHAM3-T42 climate-change scenario (+3 °K, -14% precipitation), taking into account a physiological CO_2 effect on photosynthesis (top), assuming a physiological CO_2 effect on both photosynthesis and transpiration (bottom). All technological yield constraints are ignored.

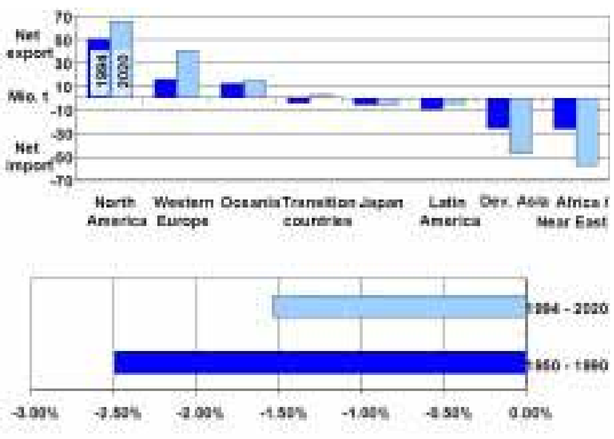


Fig. 6: Net wheat trade (top) and average change in world wheat prices (bottom) in 1994 and the baseline scenario for 2020 (source: WATSIM database and simulation runs, IAP Bonn 1999).

icy at Bonn University (IAP) and PIK evaluated the impact of a range of climate-change scenarios for 2060 on a projection for the agricultural commodity market in 2020.

For this simulation the World Agricultural Trade SIMulation Modelling System (WATSIM) was used, a multi-region/product model. WATSIM considers 15 global regions and 29 agricultural products. It allows a detailed representation of shifts in land availability, crop yield, feed efficiency, population, urbanization and real income. Several policy options are taken into account such as tariff controls, intervention prices, "set-asides" and export restrictions.

The baseline simulation for 2020 without climate change assumes no major changes in current agricultural policy, but shifts towards livestock and other high-value products in developing countries. The consequences of these changes for the net wheat trade and the average change in world wheat prices are depicted in Figure 6. The impact of climate change on this reference projection was studied for scenarios supplied by the Goddard Institute for Space Studies (GISS) of NASA in New York (USA), the Geophysical Fluid Dynamics Laboratory (GFDL) in Princeton (USA) and the United Kingdom Meteorological Office (UKMO). The corresponding yield shifts were taken from the literature and PIK's own simulation studies. Incorporating the estimated yield shifts into the WATSIM reference projection resulted in a drastic increase in wheat deficits in Africa/the Near East and Latin America across all used climate-change scenarios (Figure 7).

In contrast, net exports from the northern hemisphere, particularly from the USA and eastern European transition countries, increased. World-market prices for wheat were slightly higher for GISS and GFDL (+4 and 4.8%) than in the reference projection. The price increase was quite dramatic for the UKMO scenario (+80.4%), partly offsetting the impact of decreasing yields on regional net trade.

Managing Wheat Deficits in Northern Africa

Like other north African countries, Morocco depends greatly on wheat imports. 2.55 mill t of wheat, representing a value of 468.22 mill US-$ had to be imported in 1995, while only 1.09 mill t of wheat were produced. However, early yield predictions may enable Morocco´s agriculture to adapt the wheat planting area to fluctuating climate conditions and therefore to lower its vulnerability for climate shifts towards less favourable growth conditions. It also allows a shift in import contracts from more costly short-term to less costly long-term ones. Integrated climate measures such as circulation modes like the North Atlantic Oscillation (NAO) and sea-surface temperatures were shown to be very useful for describing predictable climate variations such as ENSO (El Niño, Southern Oscillation) and resulting yield impacts.

Wheat-yield fluctuations for Morocco were evaluated in respect of possible correlations with the North Atlantic Oscillation (NAO) and Atlantic Sea-Surface Tem-

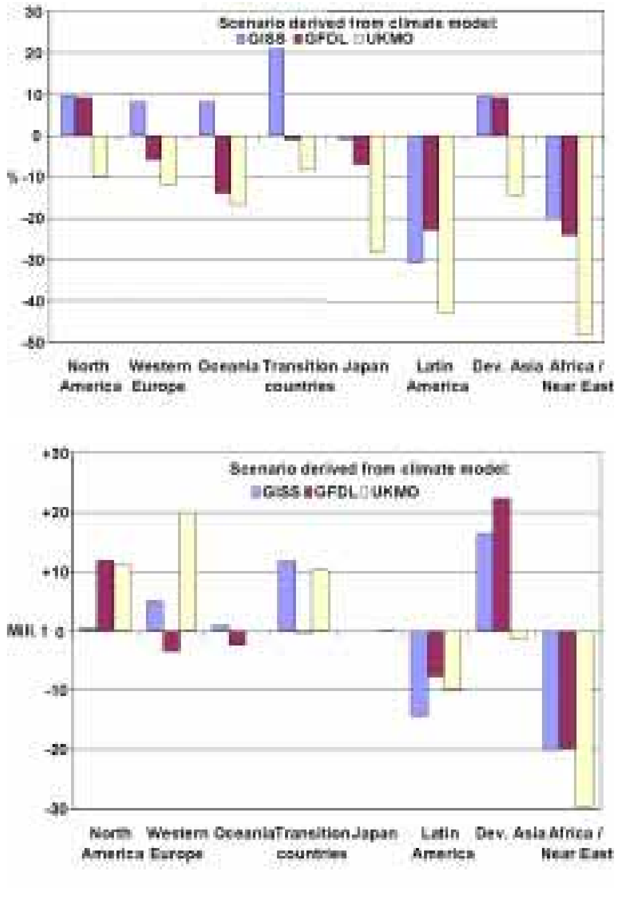


Fig. 7: Climate impact on average wheat yields in% (top, source: PIK calculations and Rosenzweig & Iglesias, 1994) and simulated impact of the yield shifts for the GISS, GFDL and UKMO scenarios on net wheat trade against the baseline scenario, 2020 (bottom, source: WATSIM simulations IAP, Bonn).

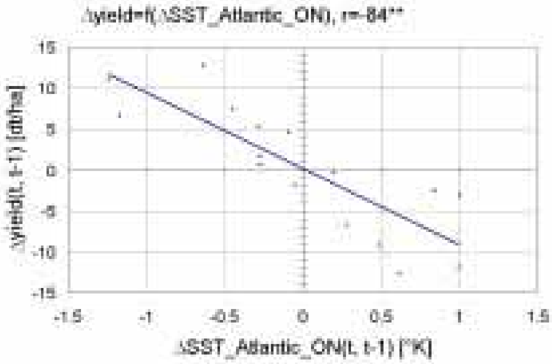


Fig. 8: Linear regression between the year-to-year change (t, t-1) of Moroccan wheat yield (Δyield) and Atlantic sea-surface temperature (ΔSST_Atlantic_ON) for the period 1982-1997.

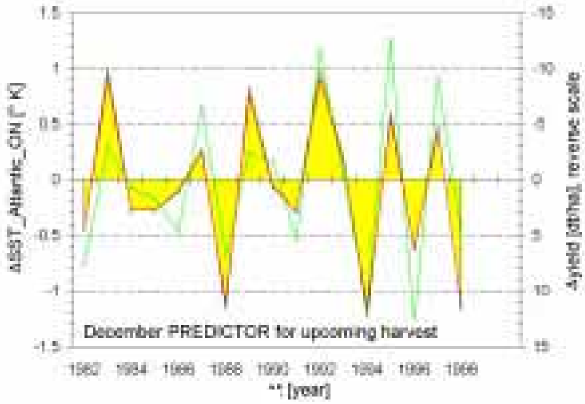


Fig. 9: Observed yield fluctuation (green line) and simulated yield volatility (red line) for 1982-1997, using the regression model from Figure 8 based on ΔSST_Atlantic_ON observations (yellow) and a comparison of observed and predicted yield (dashed red line) for 1998.

peratures (SST). Correlations were analysed for hydrological (November-April, May-October), meteorological (spring, summer, autumn, winter), agricultural and monthly periods. In order to eliminate non-climatic technological yield factors like changes in production techniques, use of fertilizers, pesticides, herbicides and structural crises, not absolute yield and climate measures were compared but the volatility of these values, i.e. changes from the preceding year and period, respectively (Δyield (t, t-1), ΔSST (t, t-1)).
The period 1982-1997 was characterised by wheat yields between 5.5 dt/ha and 18.7 dt/ha in Morocco (1dt ≅ 100 kg). The year-to-year yield volatility, however, ranged from -12.6 dt/ha to +12.9 dt/ha.

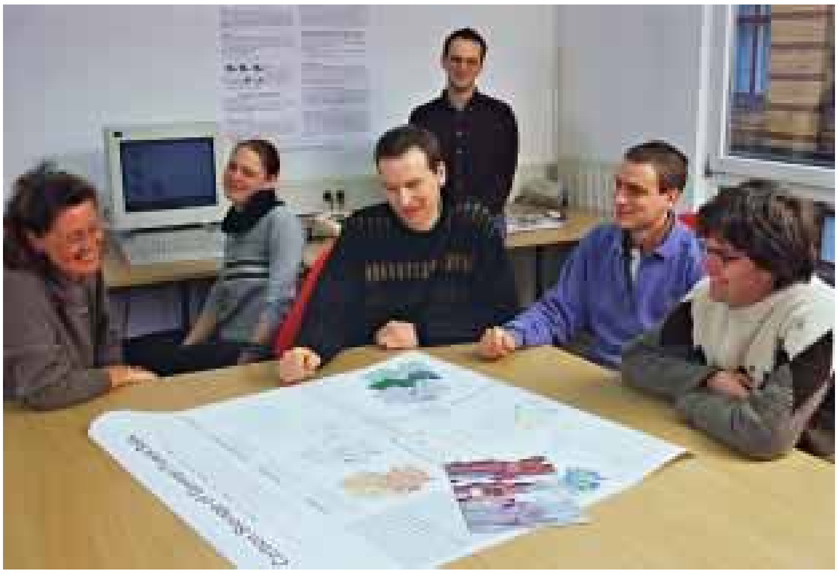
The yield volatility correlated closely with the volatilities of the monthly NAO summarized over the period October-February and the sum of monthly Atlantic SST for October and November (ΔSST_Atlantic_ON). A regression model based on the latter correlation allows yield predictions 8 months in advance of the upcoming harvest (Figure 9). This study underlines that, besides possible negative effects of climate change on northern Africa, there is still a great potential for adaptation. However, it has to be taken into account that the regression used here for early yield prediction is an empirical model with only limited suitability for extrapolations. Further research is necessary to explore the underlying climatic processes.

CHIEF
Global Change Impacts on European Forests

Project Leader: Petra Lasch

From left to right:
Felicitas Suckow, Ylva Hauf, Marcus Lindner, Markus Erhard, Jörg Schaber, Franz Badeck

Not present: Petra Lasch



Introduction

Beyond their timber value forests are of utmost importance in providing recreational areas, wildlife reservoirs, protected water areas and, in some regions, protection against landslides or floods. Globally, forests play an active role in the carbon cycle and therefore influence the development of the Earth system. Forests hold a large fraction of the terrestrial carbon stock. 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, 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 life times of these ecosystems, it is important to estimate the likely range of possible developments of forests over the next few decades or even centuries.

Land-use changes of considerable extent have occurred in the recent past and are still taking place at the present time. These changes range from the transformation of forests into industrial, urban or traffic land-use types, to changes in species composition and the planting and regrowth of forests on land that is no longer used agriculturally. All these changes are fundamentally constrained by the climatic boundaries of each tree species of interest.
In the densely populated regions of central Europe, the social benefits of forests go beyond their direct economic value. This must be accounted for by an assessment of the impacts of Global Change on forests, either by including monetary interests of industries or public bodies depending on such values as tourism and catchment management or by including non-monetary interests of other uses like recreation and wildlife. To analyse the effects of future environmental conditions on forest structure, functioning simulation models of forest ecosystems, which respond realistically to changing environmental conditions such as the deposition of nutrients and other pollutants, the ambient concentration of CO_2 and climate, are needed.

Major Research Goals

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, forest economics, and social benefits of forests. These issues are addressed at three different scales and at different levels of detail: the European, the German and the regional scale.

To achieve 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. Implementation of the project includes the following tasks:

- development of a new forest model for assessing the ecological impacts of Global Change, which is applicable to both managed and unmanaged forests;
- evaluation of different forest functions related to biodiversity, groundwater recharge, carbon storage;
- model validation and application on different temporal and spatial scales; and an
- integrated impact assessment for the forest sector.

Development of a New Forest Succession Model

Various models of forest succession dynamics have been in use over the last 20 years. Their basic underlying assumption is that tree growth is determined by site conditions such as climate and soils, and by competition between trees 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 seed dispersal, are formulated as functions of site conditions and competition. Because of our limited knowledge of the basic physiological processes, only some of the most important processes were incorporated deterministically. Other factors, which may be driven by the heterogeneity of the landscape or weather variability, are simulated as stochastic processes.

These forest succession 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. Yet, ecological and physiological research have made considerable progress over the past few years. Particularly in the fields of global-scale biogeochemical and patch-scale eco-physiological modelling, invoking ecological and evolutionary theory about the functioning of plant communities has led to considerable progress. We believe that it is now possible to synthesize this current knowledge in a way that will allow a new generation of forest succession models to be formulated which are mechanistic and able to respond to the changing environmental conditions without being too complex.

General new features of such a forest succession model 4C (Forest Ecosystems in a changing Environment) which is currently under development in CHIEF, are:

- modelling of establishment, growth and mortality of tree cohorts on patches of 200 m^2;
- assumption of horizontal homogeneity but vertical heterogeneity of the patches;
- application of three discrete time steps: *a) daily* for soil dynamics and phenology, *b) one to two weeks* for net primary productivity (NPP), and *c) annual* for tree growth (allocation), population dynamics;
- calculation of soil water balance, carbon and nitrogen turnover and soil temperature for a layered soil;
- simulation of net primary production by the canopy and allocation of assimilates into tree organs/tissues,
- representation of mortality by a stress-related mortality based on carbon balance and an age-dependent mortality; and
- potential to start simulation runs from a given stand structure and simulation of forest management interventions.

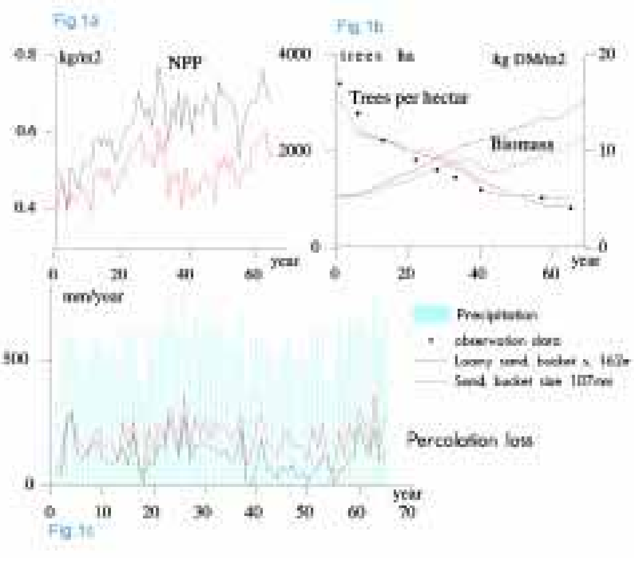


Fig. 1: 4C simulation at Hyytiälä (Finland) site with different soil conditions. a) net primary production (NPP), b) number of trees per hectare and biomass, c) precipitation and percolation to groundwater. Black lines: simulation result with the soil which can be found at the site. Red lines: simulations results for which another, sandy soil with lower water holding capacity has been used. Black dots in 1b: observed tree numbers per hectare.

4C thus comprises closed cycles of carbon, nitrogen and water and can be applied to unmanaged and managed forests. Currently species-specific parameters are given for four of the main European tree species: beech (Fagus sylvatica), oak (Quercus petraea), pine (Pinus sylvestris), and spruce (Picea abies). It can be applied for the simulation of growth and water balance in forest stands comprising these species. Extension to the full range of classical forest succession model applications, i.e. dynamics of competition of all European forest tree species, will be achieved with future work.

European forests have been managed for timber production over several centuries and therefore forests with a natural species composition are very rare. Thus long-term observations of natural forest dynamics in Europe are scarce, but we do have data sets on the development of managed forest stands of the economically important species. These data sets are very valuable for model testing and validation.

Up to now the model has been validated and applied at different sites with mono-specific stands using observation data. In the following examples we show one of these tests with forest-inventory data, as well as several case studies which demonstrate how trends of enhanced growth potential in European forests and sensitivity to climatic change can be analysed with the 4C model.

Figure 1 shows results of these type of tests performed for a pine forest in Finland. The black curve in Figure 1b shows the modelled tree number per hectare which can be compared to the observed values (black dots). The corresponding annual net primary production and input of percolation water to the groundwater can be seen in Figure 1a and Figure 1c respectively. The model's sensitivity to soil quality is demonstrated with a simulation for this pine stand, where the loamy sand is replaced by a sandy soil. Increasing percolation water losses lead to higher water limitation and decreasing productivity. In a dry period (simulation year 38) mortality is increased in the sandy soil run. The resulting loss in production is compensated by enhanced growth of the leaf area of the remaining trees in the following decades.

Effects of Increased Atmospheric CO_2 on Biomass Production

For the same stand the modelled effects of increasing atmospheric CO_2 partial pressures is demonstrated in Figure 2. The curves show percent changes in net primary production relative to a simulation run for which the atmospheric CO_2 content was held constant at the level of 1924. The black line represents the stand development with the historical increase of CO_2. An increased production by about 7 percent around 1980 is predicted due to the CO_2 fertilization effect as a contribution to the observed increases in growth trends in European forests. The red curve represents a simulation run in which CO_2 was increased to 1990 values right from the start.

A step-change scenario (green line) serves to decompose the CO_2 response into different components. NPP responds rapidly to increased atmospheric CO_2. This response can be decomposed into the instantaneous increase in assimilation and a further increase in NPP due to increases in leaf area in the following years (data not shown). Thus, all three increased CO_2 regimes result in higher NPP compared to the non-change scenario.

Sensitivity to Changes in Temperature and Precipitation

Another set of growth simulation runs was performed for a pine forest in Brandenburg (Kienhorst, stand included in the European forest monitoring programme Level II). Simulations start with the 90-year-old stand as characterized by a forest inventory.

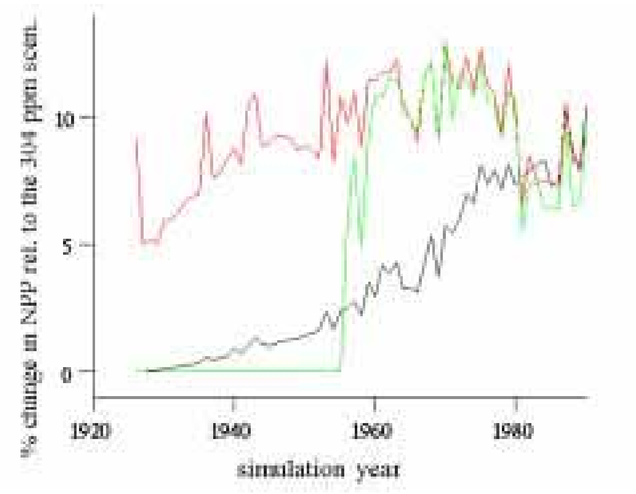


Fig. 2: Percent change in net primary production (NPP) of a constant CO_2 scenario (354 ppm, red line), the continuous historical increase (from 304 to 354 ppm, black line), and a step change from 304 to 354 ppm at simulation year 1956 (green line) relative to a non-change scenario (304 ppm).

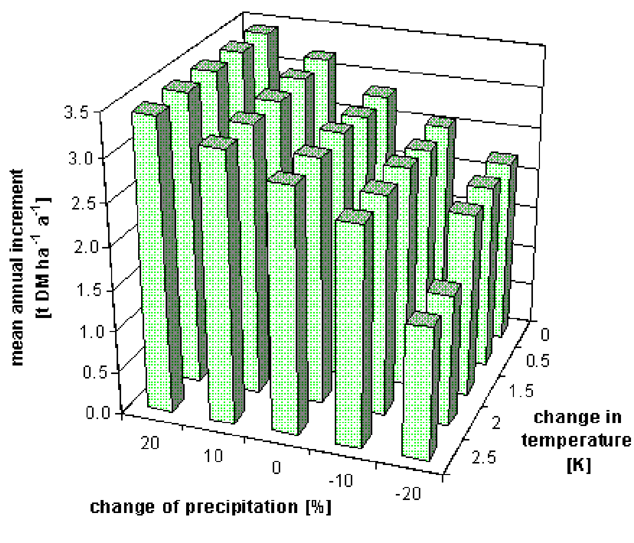


Fig. 3: Mean annual wood increment of the pine stand at Kienhorst site (Germany) under different climate-change conditions (change in temperature on the y-axis, change in precipitation on the x-axis).

Simulations run for 40 years (weather data 1951-1990 from a nearby station). The sensitivity of growth and mortality with respect to climatic change were investigated by repeated runs for which step-wise increases in temperature and defined percent changes in precipitation were applied to all input data.
Figure 3 shows the mean annual stem wood increment of the stand. A distinct decrease in growth with decreases in precipitation is predicted, while higher temperatures have little impact on growth with the exception of the results obtained for a 20% decrease in precipitation. At temperature increases of between 1.5 and 2.0 degrees, increase in temperature growth not only is strongly reduced but is also accompanied by increased mortality. The low impact of temperature for the current precipitation regime contradicts intuition. Increased temperatures are expected to lead to increased transpiration and thereby to an earlier occurrence of water deficits in summer.

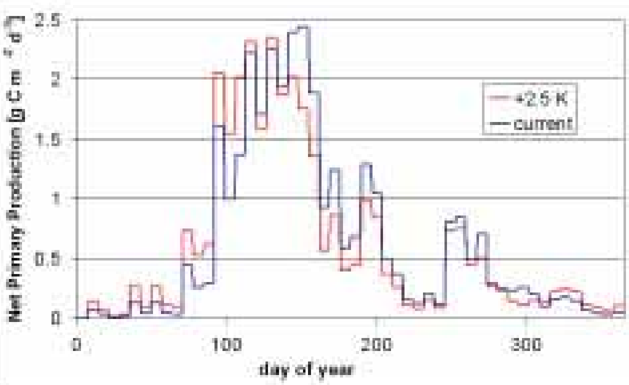


Fig. 4: Net primary production at Kienhorst site (Germany) for current climate and increased temperature climate during the course of the year. In a warmer climate net production is increased in winter and spring and decreased in summer and autumn relative to the production under current climatic conditions.

Figure 4 shows that this is the case. Net primary production in the warmer climate-change scenario is decreased in late summer relative to the current climate scenario due to higher water deficits. Yet gains in winter and spring, when increased temperature stimulates photosynthesis, compensate for these drought induced losses in carbon assimilation.

Phenology
In order to study the effects of phenology (seasonal timing of life-cycle events) on stand development the weather sensitive bud burst (BB) model of 4C has been tested in a 120-year simulation of a beech stand in southern Germany.
Evaluation of net primary production (NPP) for the days before the latest simulated day of BB in the 120 year record shows a 1% increase in yearly NPP per day of advancement of BB. Roughly speaking, a dominant deciduous tree produces 10% of its yearly NPP during the first 10 days after BB. The difference between earliest and latest day of BB in 120 years was 45 days. This demonstrates the significance of a realistic phenology model.

Level II - Application of 4C
Within the scope of the Pan-European Programme for Intensive and Continuous Monitoring of Forest Ecosystems (Level II) six sites in Brandenburg have been selected. Together with the State Forest Service at Eberswalde the forest succession model 4C was applied on these sites to describe the dynamics of the forest development under different climate scenarios. Furthermore, because of the very detailed and complex measurements of soil and stand data they are a good basis for model validation.
As a first step, the 4C submodels of soil water and soil temperature were tested with observations from these Brandenburg Level II sites at two soil depths. The model reproduces the general pattern of changes in soil water content as well as the minima and maxima. However, the comparison of measurements and model results during high precipitation (more than 15 mm), shows the need for further improvements in percolation modelling and a more detailed description of the vertical root distribution profile.
The validation of the soil model and other 4C-submodels with the Level II data set will be continued to ensure the quality of model results.

Climate Impacts on Forests in Brandenburg
A new focus of the regional forest impact study in the federal state of Brandenburg was the investigation of the possible consequences of climate change on forest management and the evaluation of the implications of vegetation changes for other forest functions. The majority of forests in the federal state of Brandenburg were managed intensively in the past. At present large areas of Brandenburg's forests are dominated by pure stands of Scots pine, but current forest management practice aims at increasing the share of deciduous and mixed forests. We have used the succession model FORSKA-M, which was improved and enlarged by a multi-layer soil percolation model, a modified height growth function and a management model during the last years. The model operates with daily time series of climate data and is able to simulate the dynamics of trees on small forest patches. The model was applied to simulating natural potential vegetation, which would grow without human interference, and the dynamics of managed forests. In order to analyse the possible con-

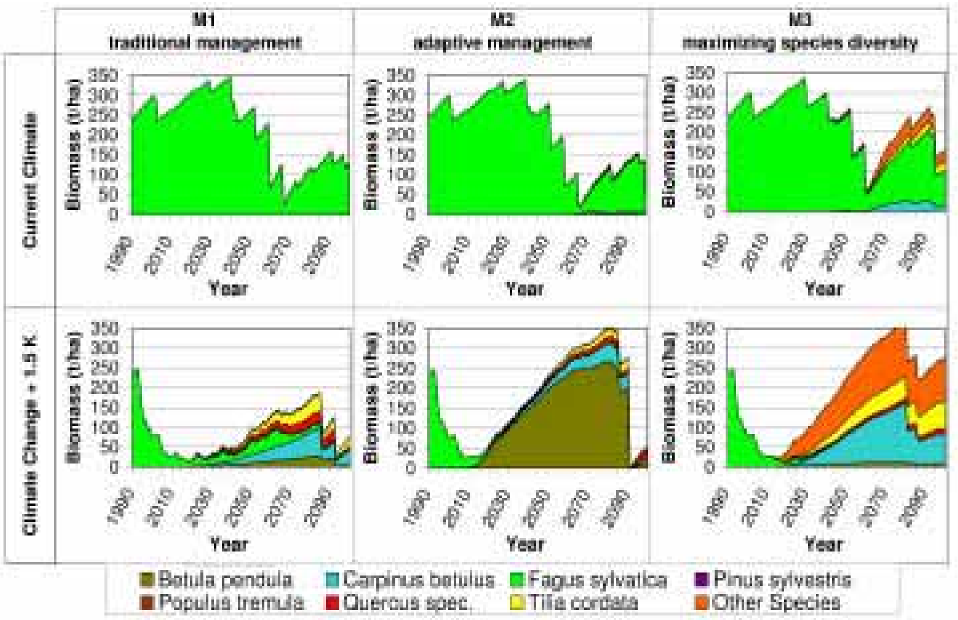


Fig. 5: Application of the FORSKA model at a site in northeast Brandenburg. The beech forest was not sensitive to the applied management under current climate. Beech (Fagus sylvatica) was dominant under all management scenarios but the simulated biomass at the end of the simulation period was lower than at the beginning. With a temperature rise of 1.5 °C and reduced precipitation beech lost competitiveness. Under climate-change conditions other tree species like birch (Betula pendula; M2) or hornbeam (Carpinus betulus; M3) were preferred which are more productive at this site.

sequences of climate change on forest management, forest inventory data of Brandenburg were used to initialize FORSKA-M with representative forest stands. Simulation experiments were run with three different adaptive management strategies (Figure 5):

M1 - traditional management, favouring economically important species,
M2 - adaptive forest management, favouring the climatically best adapted species, and
M3 - maximizing of species diversity.

To study the effects of climate change two climate scenarios were used. The current and climate-change scenarios (1,5 °C temperature increase which is combined with a precipitation decrease varying from 40 to 140 mm) were produced using a statistical method developed by the climate department of PIK for 40 meteorological stations in and around Brandenburg. Figure 5 shows the results of transient simulation runs at one selected forest-inventory site. The model simulated at this site a beech forest under current climate, which was harvested after 80 years and a new beech forest was planted. Under climate-change conditions beech was not able to grow and other tree species like birch (M2) or hornbeam (M3) were preferred, which are more productive at this site.
The regional impact assessment corroborated the high sensitivity of natural forests in the region to the projected climate change and it underlined the importance of adaptive management strategies to help forestry cope with climate change. To evaluate the impacts of climate change on non-timber forest functions mathematical measures of species diversity and habitat diversity were applied. Impacts on groundwater recharge of natural and managed forests were analysed by functions developed for forests using experimental data in the federal state of Brandenburg and the soil water balance model of FORSKA-M. The results indicate that the simulated shifts in the species composition would be associated with a reduction in biodiversity and habitat value. Furthermore, groundwater recharge (Figure 6) and carbon storage both decreased under the climate change scenario. Hence, the total impact of climatic change may be much more extensive than vegetation changes alone.

LTEEF-II Project
The focus in the LTEEF-II project ("Long-Term Regional Effects of Climate Change on European Forests") is on carbon fluxes between the forests and the atmosphere, and on long-term carbon budget of the forest sector. Regional level impacts of climate change on forest growth are assessed with process-based models and these responses are then scaled up to country and European level with national forest inventory data in a large-scale scenario model. The results will be compared with data from remote-sensing based calculations of carbon budgets and global vegetation modelling of the other LTEEF partners.
A GIS-based (Geographical Information System) analysis was performed to select sites of the most common tree species in different climatic zones. Forest cover, tree species distribution, elevation, soil type, and average climate conditions were used as selection criteria.

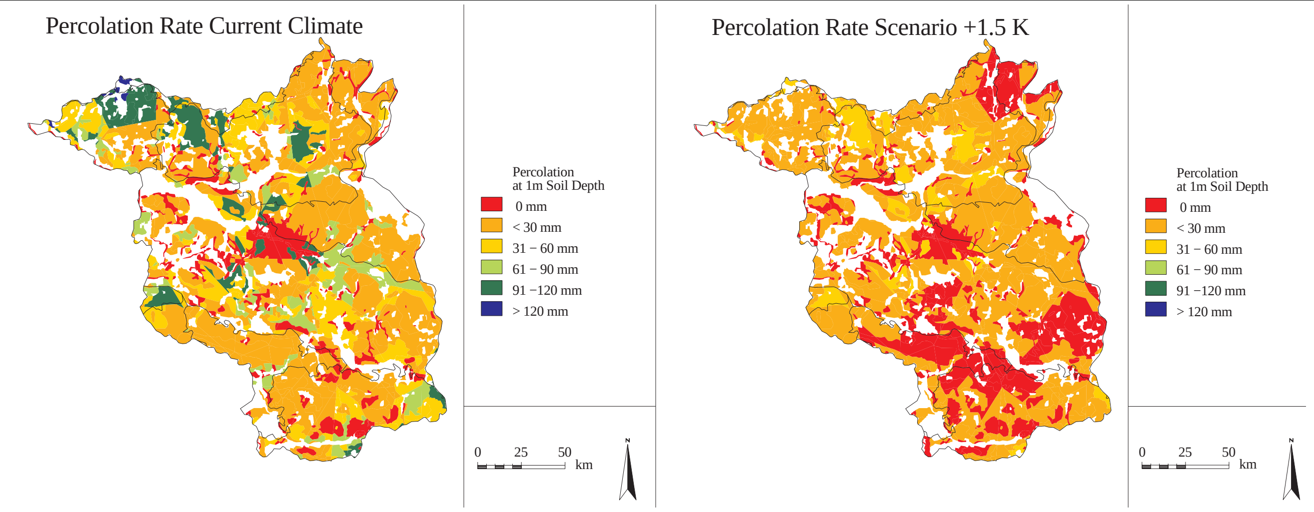


Fig. 6: Brandenburg: Groundwater recharge calculated by FORSKA-M with current climate and climate change scenario. The figure demonstrates the difference in groundwater recharge below simulated potential natural vegetation in Brandenburg. In the case of the climate change scenario a strong decrease in groundwater recharge was simulated with an increase in areas without any groundwater recharge.

For each site long-term time series of daily weather data (1831 - 2100) were generated. For the years 1901 - 1990 monthly values of interpolated climate data could be used. For the rest of the period the output of a General Circulation Model (GCM) was downscaled and related to the climate data set. The time series of monthly values were then disaggregated to daily values using a weather generator. The results of the project will be available at the end of the year 2000.

German Forest Sector Under Global Change

The aim of this national case study is to assess the nature and extent of possible impacts of climate change on forests and the forest industry in Germany. Several simulation models have been linked to simulate and assess possible consequences of different management and climate scenarios on forest development and wood production in a virtual forest enterprise which consists of representative forest stands reflecting average national forest conditions. The project integrates a broad range of impacts of climate change (see Figure 7). PIK co-ordinates this collaborative effort with 7 partner institutions from German forestry faculties and forestry research institutes and is responsible for (i) the systems analysis and (ii) an assessment of effects of climate change on species competitiveness. The focus of the project activities in 1998/1999 was on the development of the research methodology including the generation of regionally interpolated climate data and scenarios.

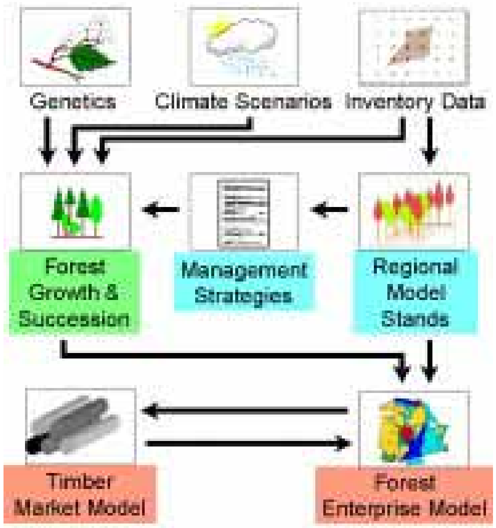


Fig. 7: Representation of major components in the German Forest Sector under Global Change project.

The CHIEF project is externally funded by the European Union (LTEEFII), the German Ministry of Education and Research (German Forest Study, Carbon Budget Project), DAAD (co-operation with Finnish institutes), and the Deutsche Forschungsgemeinschaft DFG (NIMA workshop).

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

Acting Project Leader: Manfred Stock

Introduction

Water plays a crucial role in the livelihood and the sustainable development of many regions in the world. The cultural and social dimensions of freshwater are related to its essential importance for human survival and well-being, but it is also of great importance for the economy, especially for agriculture.

Water-related problems have become critical in many parts of the world. This situation is expected to become even more serious under climate and other global change impacts.

Research Fields and Tasks

The value and price of freshwater largely depend on the social and cultural dimensions of its use. The RESOURCE project therefore focuses primarily on these socio-economic aspects of water use. The objective of RESOURCE is to perform an integrated analysis of Global Change effects on water resources and socio-economic impacts in particular in the eastern Mediterranean. The Mediterranean has been selected as target 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.

The goal is to develop options for mitigating the impacts of climate change, or else for adapting to these. Pursuing this goal also means taking account of the interactions with the natural dimensions of availability or scarcity.

In the last few years the RESOURCE project has contributed to an assessment of water-scarcity problems through research in three fields:

- development of climate-change scenarios based on the climatology of the Mediterranean;
- development of tools for a regional integrated modelling of water prices in the eastern Mediterranean; and
- regional vulnerability and risk assessment of water scarcity for the Mediterranean.

In the 1998 - 1999 period only a limited number of project activities were carried out. These included:

- participation in the ongoing EU-project RICAMARE;
- assessment of wheat deficits in northern Africa (see page 82)
- scientific exchange with partners in the Mediterranean, in particular in Israel; and
- the investigation of water-related conflicts.

The reduced activity was due to the fact that the priority given to socio-economic aspects should accord with the main foci to be defined by the new head of PIK's socio-economic department. This position will now be filled by the end of May 2000, and it is envisaged that the objectives, tasks and the project structure of RESOURCE will be redesigned under the new perspectives of the department.

Research In Global Change in the Mediterranean: A Regional Network (RICAMARE)

RICAMARE is a "concerted action" within the ENRICH (European Network for Research into Global Change) programme of the European Union. Its main task is to provide an inventory of present research on Global Change impacts in the Mediterranean and to intensify the transfer of knowledge in this area. Several workshops are planned to achieve this objective but no support is given for additional research.

The work is organized in the following scheme of activities and tasks, with PIK involved mainly in Task I.3:

- Activity I: Development of the Global Change research agenda:
  - Task I.1: Land-use, land-cover changes and water.
  - Task I.2: Global Change, biodiversity and conservation.
  - Task I.3: Integrated assessment of the costs of Global Change in the Mediterranean.
  - Task I.4: Development of a concerted data assessment, assimilation and validation for the Mediterranean.
- Activity II: Training and capacity building.
- Activity III: Promoting the diffusion of research results and increasing awareness of Global Change and its implications.

In Task I.3 a workshop is scheduled for February 2001, where PIK is involved in the organization jointly with Israeli and Italian partners.

Another "concerted action" EU project is being undertaken by PIK on a related topic: "Freshwater resources in Sub-Saharan Africa with emphasis on regional scale interactions of land use and climate". A workshop was organized and held in Nairobi from 26th to 30th October 1999. A follow-up workshop will be held in May 2000.

Socio-Economic Dimensions of Water Resources Under Global Change in the Eastern Mediterranean
PIK is collaborating with several partners in the Mediterranean, in particular with partners from Israel. The research focus of this collaboration is on Global Change effects on water resources and subsequent assessments of the socio-economic impacts of these changes, in particular with regard to natural and agricultural vegetation changes.

These joint activities are based upon co-operation agreements between PIK and a number of Mediterranean research institutions. A number of joint workshops were held and joint proposals developed during the 1998-1999 period.

The Mediterranean research at PIK concentrates on climate, hydrology, land use, integrated modelling and socio-economic impact assessments with the following activities:

- Climatic conditions in the Mediterranean, in particular spatial and temporal characteristics as well as trends in temperature and precipitation, are analysed and high-resolution climate scenarios developed.
- Linkages between Mediterranean climate and larger-scale atmospheric circulations are elaborated. Particular emphasis is placed on the description of extreme events, i.e. droughts, which play an important role in subsequent impact assessments.
- At PIK a new regional dynamic climate model has recently been developed which is currently being tested for the Mediterranean region.
- Land-use scenarios have been developed, providing a basis for assessing the role of a changed land surface in future climate. Coupled modelling reveals bidirectional interactions between changing vegetation and climate and feedbacks with the hydrological cycle and water resources.
- In this joint project with partners in Israel emphasis is placed on the assessments of bioproductivity for current and scenario situations. Again the focus is on droughts.
- At PIK the TRAIN model (see page 77) has been developed, which uses available soil moisture and evapotranspiration data for providing inputs to crop and other productivity models.
- The socio-economic component of the integrated modelling framework provides developments in population and economy for scenarios of future water use. In collaboration with partners in Israel socio-economic costs of climate change are evaluated.

PIK, furthermore, collaborates with research partners from Israel and Germany in a project to demonstrate the applicability of remote sensing (radar data) to the retrieval of soil-moisture information for the semi-arid northern Negev. Soil moisture, a crucial component of the hydrological cycle and the energy exchange at the land surface, may be severely affected by environmental changes in the Mediterranean. Continuous spatial and temporal monitoring of these changes, using remote sensing, can help to better understand related processes and drivers in semi-arid regions.

What Might Cause Water-Related Conflicts?
There is continuing debate on whether environmental degradation may lead to conflict. In 1998 NATO's Committee on Challenges of Modern Society (CCMS) finished a pilot study on this issue, which came to the conclusion that:

"The relationship between environmental stress and conflict is characterized by

- Multi-causality: environmental stress contributing to conflict almost always interacts with other political, social and economic factors and evolves through various multi-stages before it results in conflict;
- Reciprocity and feedback loops: the relationship between environmental stress and conflict is recursive; because just as environmental stress can lead to conflict under unfavourable contextual factors, conflict can lead to more environmental stress;
- Consequences of environmental stress: poverty, food insecurity, poor health conditions, displacement (migration or refugee movements) and disruption of the social and political institutions are regarded as the most important consequences of environmental stress, which then contribute to conflict under a certain set of unfavourable contextual factors."

These conclusions call for an integrated approach which is able to take into account these various aspects. In co-operation with the QUESTIONS project at PIK, the office of the German Advisory Council on Global Change and the Heidelberg Institute of International Conflict Research (HIIK) developed a new approach of this type which merges the syndrome concept (see QUESTIONS) with concepts of conventional conflict theory.

As a first step, the relationship between shortages of freshwater and conflicts has been investigated over the last two years. The issue of "water as a cause of conflict" is one of the central issues in the general discussion on environment and security.

In contrast to conventional approaches, which focus on conflicts that have actually taken place in the past, we started our analysis with a global assessment of "mutual water dependence". This assessment was based on a global model to estimate (annual averages of) surface runoff and river discharges. Using methods of fuzzy-logic as in QUESTIONS, the water exchange between two neighbouring countries as computed by the model was evaluated with regard to the level to which each country depends on this particular amount of water. According to this idea the water exchange between two countries is assumed to be critical if water scarcity can be assessed in one or even both countries without the water being exchanged. To obtain a first, tentative measure for water scarcity we have generalized the idea of Falkenmark that an amount of less than 666 m^3 per year and capita corresponds to a highly critical situation, whereas for more than 1000 m^3/(yr * cap) no scarcity can be diagnosed.

Table 1: Situations of critical water exchange, i.e. the two countries depend critically on shared water resources, ranked according to the degree of criticality. In the right column "water conflicts" as specified within the KOSIMO database of the Heidelberg Institute of International Conflict Research are marked.

Country 1	Country 2	Criticality	Water Conflict
Israel	Jordan	1.184	X
Ukraine	Moldova	0.655	
Algeria	Tunisia	0.637	
India	Pakistan	0.500	X
Afghanistan	Pakistan	0.500	
Sudan	Egypt	0.500	X
Turkey	Syria	0.473	X
Germany	Czech Republic	0.373	
Afghanistan	Uzbekistan	0.368	
Oman	United Arab Emirates	0.353	
India	Bangladesh	0.312	X
Belarus	Ukraine	0.308	
North Korea	South Korea	0.269	
Austria	Czech Republic	0.238	
Syria	Iraq	0.236	X
Saudi Arabia	United Arab Emirates	0.209	
Russia	Ukraine	0.197	
France	Germany	0.189	
Turkmenistan	Iran	0.181	
Austria	Germany	0.164	
Oman	Saudi Arabia	0.138	
Armenia	Iran	0.119	
Russia	China	0.114	
Saudi Arabia	Jordan	0.070	
Saudi Arabia	Yemen	0.043	
China	North Korea	0.034	

According to this analysis there are in all 26 bilateral situations of critical water exchange (see Table 1). The most critical water situation was found between Israel and Jordan, followed by Ukraine/Moldova, Algeria/Tunisia and India/Pakistan. Common sense already tells us that in the latter case as well as in the case of Israel/Jordan water plays a significant role within broader conflicts. It should be stressed that neither these additional factors nor the issue of groundwater depletion is taken into account here. The latter is known to play an important role within the peace process in the Middle East.

In order to place the common-sense knowledge about existing conflicts and their causes on more objective ground, we made use of the KOSIMO database of HIIK. This data set contains systematic details on a total of 693 (violent and non-violent) conflicts since World War II (as of 1999), among which "resource conflicts with water aspects" are particularized. These entries in the database are specified in the right column in Table 1. It can be seen that "water conflicts" are generally found in critical situations.

Yet, we note situations with critical water exchange in which until now no violent or non-violent conflict has occurred. This may be due to two reasons:

- the states involved were able to resolve the critical situation by peaceful means; or
- further factors leading to conflict were missing within the multi-causal relationships between environmental stress and conflicts.

It is advisable, however, to regard at least some of these situations not as "resolved" but rather as potential trouble spots in future.

In summary, we can confirm the conclusions of the NATO-CCMS pilot study. There is no such thing as *the* wars over water; yet water might well play a significant role within a wider set of causes for a violent or even non-violent conflict - in the past, in our present time as well as in the future.

Appendix

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External Funding

Projects

Project Name	Acronym	Reference No.	Sponsor	Total Funding	Period of Funding	Project Leader
Integrierte Abschätzung von Klimaschutzstrategien: Methodisch-naturwissenschaftliche Aspekte	ICLIPS	01LK9605/0	BMBF/DLR PT-USF	DM 2,249,737	01.04.1996 - 30.06.2000	Tóth
Nationale Koordinierungsstelle des deutschen IGBP	IGBP	01LG9503/9	BMBF/DLR PT-USF	DM 1,716,578	01.01.1996 - 31.12.1998	Fosberg
Ökologische Forschung in der Stromlandschaft der Elbe	ELBEÖKO	339577	BMBF PT BEO Berlin	DM 1,313,200	01.01.1997 - 31.05.2001	Becker
BAHC "Internationales Kernprojektbüro für das IGBP-Kernprojekt Biosphärenaspekte des Wasserkreislaufs" - Verlängerung	BAHC	BAHC9901	BMBF	DM 1,303,838	01.01.1999 - 31.12.2001	Hoff
Einrichtung eines "Deutschen Forschungsnetzes Naturkatastrophen" (DFNK)	DFNK	01SF9970/1	BMBF	DM 1,053,358	01.01.2000 - 31.12.2002	Schellnhuber / Menzel
Integrierte Abschätzung von Klimaschutzstrategien: Sozialökonomische Aspekte	ICLIPS2	29641815	BMU	DM 1,020,640	01.07.1996 - 31.08.1999	Tóth
Wasserverfügbarkeit im semi-ariden Nordosten Brasiliens - Analyse und Modellierung	WAVES-K	01LK9712	BMBF/DLR PT-USF	DM 750,400	01.08.1997 - 31.07.2000	Gerstengarbe
Wirkung von Klimaänderungen auf Vegetation: Entwicklung eines Modells für die Klimafolgenforschung	VEGEKLIM	01LK9408/2	BMBF/DLR PT-USF	DM 699,057	01.07.1995 - 30.10.1998	Cramer
BAHC "Internationales Kernprojektbüro für das IGBP-Kernprojekt Biosphärenaspekte des Wasserkreislaufs" - Verlängerung	BAHC	01LG9503/9	BMBF/DLR PT-USF	DM 684,800	01.03.1997 - 31.12.1998	Lütkemeier
Wasserverfügbarkeit im semi-ariden Nordosten Brasiliens - Integrierte Modellierung	WAVES-I	01LK9713	BMBF/DLR PT-USF	DM 652,450	01.08.1997 - 31.07.2000	Bronstert / Krol
Untersuchung der Auswirkung erhöhter atmosphärischer CO_2-Konzentrationen innerhalb des Free-Air Carbon Dioxide Enrichment-Experiments: Ableitung allgemeiner Modellösungen	FACE2U	01LK9535	BMBF/DLR PT-USF	DM 444,243	01.04.1996 - 31.08.1998	Kartschall
Europäische Ökosysteme 1989 - 1998: Quantitative Analyse unter Verwendung von Satellitenfernerkundungsdaten	Europ.Ökos.	01LA9828/0	BMBF/DLR	DM 420,807	01.11.1998 - 31.10.2000	Cramer

Project Name	Acronym	Reference No.	Sponsor	Total Funding	Period of Funding	Project Leader
Klimatologie und Prognose klimainduzierter Änderungen hydrographischer Größen in Nord- und Ostsee; Teilprojekt A: Seegangsberechnungen zur Gewinnung einer spektralen Seegangs-Klimatologie	KLINO	03F0185A	BMBF/KFA Jülich	DM 401,541	01.11.1996 - 31.10.1999	Claussen
Wasser- und Stoffrückhalt im Tiefland des Elbeeinzugsgebietes	WASTOR	0339585-TP3	ZALF	DM 359,741	01.10.1997 - 30.09.2000	Becker
Simulation der langfristigen Variabilität im Klimasystem des Holozäns mittels eines gekoppelten Atmosphäre-Ozean-Biosphäre-Modells mittlerer Komplexität	Holozän	01LG9906	BMBF/DLR	DM 337,742	01.10.1999 - 30.09.2002	Claussen
Deutsche Waldstudie; Teilprojekt 2: Natürliche Waldentwicklung	WALD2	01LK9528/2	BMBF/DLR	DM 312,225	01.07.1997 - 30.06.2000	Cramer
Quantifizierung des Einflusses verschiedener Maßnahmen auf den Verlauf von Hochwasserereignissen	FLAT	29724508	UBA	DM 310,200	01.10.1997 - 30.09.2000	Bronstert
Sequentielle indikatorbasierte Regelungsstrategien im Rahmen des Leitplankenansatzes in der integrierten Klimaschutzanalyse	Regelungsstrategie	II/76186	VW-Stiftung	DM 297,480	01.03.2000 - 28.02.2003	Bruckner
Vom Eem ins Holozän: Modellierung des letzten Warm-Kaltzeitzyklus mit Hilfe eines Klimasystemmodells mittlerer Komplexität	ZYKLUS	CL 178/2-1 CL 178/2-2	DFG	DM 294,200	01.01.2000 - 31.12.2002	Claussen
Asymptotisch adaptive Verfahren zur Simulation von Mehrskalenproblemen der Strömungstechnik	Simulation	KL 611/6-3 KL 611/6-4	DFG	DM 288,000	01.10.1999 - 30.09.2002	Klein
CLIVAR marin; Teilprojekt: Untersuchung der thermohalinen Atlantikzirkulation in einem hocheffizienten globalen Ozean-Atmosphären-Modell	CLIVAR	03F0246H	BMBF/KFA Jülich	DM 281,561	01.03.1999 - 28.02.2002	Rahmstorf
Untersuchungen zur Verwendung von Ergebnissen verschiedener Klimamodelltypen als Antrieb in Ökosystemmodellen	Unters. Modelle	01LK9325/8	BMBF/DLR	DM 276,000	01.09.1995 - 31.03.1998	Werner
Analyse und Modellierung der Wasserverfügbarkeit im Elbegebiet und die Hochwasserabflußbedingungen im Odergebiet in Abhängigkeit von Klima und Landnutzung	Abflußbed. Oder/ Elbe	01LA9810	BMBF/DLR	DM 263,206	01.03.1999 - 28.02.2001	Becker

Project Name	Acronym	Reference No.	Sponsor	Total Funding	Period of Funding	Project Leader
Grobrasteranalyse zu den Möglichkeiten für umweltentlastende Landnutzungsänderungen infolge des globalen Wandels	RASTER	II/75141	VW-Stiftung	DM 259,600	01.10.1999 - 30.09.2002	Cramer
Regionale Auswirkungen des anthropogen bedingten Treibhauseffektes in Nordrhein-Westfalen: Die Anfälligkeit in Nordrhein-Westfalen für einen möglichen Klimawandel	RANK	VB5-8818.3.11	MURL	DM 209,720	01.10.1997 - 31.03.1999	Block / Reusswig
Abschätzung der regionalen Kohlenstoffbilanz von mitteleuropäischen Wäldern unter dem Aspekt des globalen Wandels	REGKO	01LA9876/0	BMBF/DLR	DM 197,200	01.07.1999 - 30.06.2001	Suckow
HSP III - Evolutionsmodelle des Systems Erde (Fortsetzung)	HSP III	24-04/035-2000	MWFK	DM 187,000	2000	Franck
Kleinskalige Instabilitäten als Bausteine der turbulenten Energiekaskade	Instabilitäten	KL611/10/1	DFG	DM 171,000	01.11.1999 - 31.10.2001	Klein
Elastizität der Selbstregulation in einfachen Erdsystemmodellen	Erdsystemmodelle	Fr910/9-3	DFG	DM145,000	01.01.1999 - 31.12.2000	Franck
HSP III - Evolutionsmodelle des Systems Erde (Fortsetzung)	HSP III	24/2599-0435-1998	MWFK	DM 140,100	1998	Franck
HSP III - Evolutionsmodelle des Systems Erde (Fortsetzung)	HSP III	24-04/035-1999	MWFK, ESF	DM 140,100	1999	Franck
Modellgestützte Erforschung der lateralen Abflüsse	Laterale Abflüsse	Be1575/4-1	DFG	DM 128,000	01.08.1998 - 31.07.2000	Becker
Extreme hydrologische Ereignisse in Mitteleuropa seit 1500 - Prozesse und Wirkungen	EXEME1500	WE2356/1-1	DFG	DM 106,900	01.01.1999 - 31.12.2000	Werner
Third Assessment Report of IPCC	MPI	01LG99016-PO	MPI-BGC Jena	DM 87,829	01.08.1999 - 31.07.2001	Schellnhuber
Kongreß Japan	CONF-JAP		IGBP/GSF	DM 54,709	May 1999	BAHC
Elastizität der Selbstregulation in einfachen Erdsystemmodellen	Erdsystemmodelle	Fr910/9-1	DFG	DM 45,100	01.01.1998 - 31.12.1998	Franck
Machbarkeitsstudie über die Formulierung systemanalytischer Indikatoren für integrierte Strategien einer nachhaltigen Entwicklung in Deutschland	LAND	315/20116401/I TAS	Forschungszentrum Karlsruhe	DM 44,940	01.04.1999 - 30.06.1999	Block / Reusswig
Synthese Workshop Südtirol	WS-SYN		IGBP	DM 43,352	March 1999	BAHC

Project Name	Acronym	Reference No.	Sponsor	Total Funding	Period of Funding	Project Leader
Workshop FLOOD 2000	FLOOD	4851/74/00	DFG	DM 37,500	01.11.2000 - 03.11.2000	Bronstert
EMIC-Workshop	EMIC		GSF	DM 33,000	15.06.1999 - 16.06.1999	BAHC
National and regional climate change impact assessments in the forestry sector - Workshop	NIMA	4850/208/99	DFG	DM 25,900	03.11.1999 - 06.11.1999	Lindner
Roots - Workshop	ROOTS	422-63723-1 BAC 9901/0	IGBP	DM 20,000	30.09.1999 - 02.10.1999	Hoff
Arbeiten zur Verdunstungskarte Rheinland-Pfalz	Verdunstungs-karte	1.-4.03.00 1572/98	Landesamt für Wasser-wirtschaft Rheinland-Pfalz	DM 12,000	1998/1999	Menzel
Ermittlung von Hochwasserwahrscheinlichkeiten für Teilabschnitte der Nuthe	NUTHE	W8-2Su v. 26.5.98	LUA	DM 10,280	01.06.1998 - 20.11.1998	Becker
Living with floods - Antrag auf Erstattung der durch die Koordination eines EU-Antrages entstandenen Mehraufwendungen	EU FLOODS	07 SK GSF1/1	BMBF/DLR	DM 9,692	2000	Bronstert
Wissenschaftlich-technologische Zusammenarbeit mit Polen	WTZ	POL-199-96	DLR	DM 8,104	01.01.1998 - 31.12.2001	Franck
Vorhaben: Regional agricultural model application	RAMA	BCT0559-58	BMBF/KFA Jülich	DM 8,000	01.06.1999 - 30.11.1999	Kartschall
DAAD-Austauschdienst	DAAD	313/SF-PPP-pz	DAAD Bonn	DM 6,971	1999-2000	Lindner
Einladung eines tschechischen Wissenschaftlers	TSE	436TSE17/1/99	DFG	DM 6,300	1999-2000	Werner
Quantifizierung des Einflusses der Landoberfläche und der Ausbaumaßnahmen am Gewässer auf die Hochwasserbedingungen im Rheingebiet	LaHoR	3/DU/1/002	IRMA	Euro 576,520	01.12.1998 - 31.12.2001	Bronstert
A concerted action towards a comprehensive cli-mate impacts and adaptation assessment for the European Union	ACACIA	ENV4-CT97-0531	EU	Euro 384,000	32 months	Schellnhuber
European terrestrial ecosystem modelling activity	ETEMA	ENV4-CT95-0052	EU Environmental and Climate Program	Euro 291,000	01.05.1996 - 30.04.2000	Cramer
Dynamic response of the forest-tundra ecotone to environmental change	DART	ENV4-CT97-0586	EU	Euro 268,700	01.04.1998 - 31.03.2002	Cramer

Project Name	Acronym	Reference No.	Sponsor	Total Funding	Period of Funding	Project Leader
Modelling agroecosystems under global environmental change	MAGEC	ENV4-CT97-0693	EU	Euro 214,000	01.04.1998 - 31.03.2001	Cramer
Weather impacts on natural, social and economic systems	WISE	ENV4-CT97-0448	EU	Euro 195,564	01.11.1997 - 31.10.1999	Flechsig
European river flood occurrence and total risk assessment system	EUROTAS	ENV4-CT97-0535	EU	Euro 174,980	01.01.1998 - 31.12.2000	Bronstert
Freshwater resources in Sub-Saharan Africa with emphasis on regional scale interactions of land use and climate	Sub-Sahara	ENV4-CT98-0771	EU	Euro 145,000	01.11.1998 - 31.10.2001	Fosberg
Numerical simulation and analysis of climate variability on decadal and centennial time scales	MILLENNIA	ENV4-CT95-0101	EU Environmental and Climate Program	Euro 130,000	01.03.1996 - 28.02.1998	Rahmstorf
Modelling the effect of land degradation on climate	CLIMATE & LAND DEGR.	ENV4-CT98-0696	EU	Euro 120,000	01.05.1998 - 30.04.2001	Claussen
Strategic integrated assessment of dynamic carbon emission reduction policies	SIADCERO	EVK2-CT-1999-00002	EU	Euro 117,800	01.04.2000 - 30.09.2001	Tóth
Urban lifestyles, sustainability and integrated environmental assessment	ULYSSES	ENV4-CT96-0212	EU Environmental and Climate Program	Euro 110,000	01.04.1996 - 31.07.1999	Tóth
Long-term regional effects of climate change on European forests: Impact assessment and consequences for carbon budgets	LTEEF-II	ENV4-CT97-0577	EU	Euro 97,625	01.01.1998 - 30.06.2000	Cramer
European climate support environment: Network for the coordinated provision of scientific and technical advice for applying climate change data	ECLAT2	ENV4-CT98-0734	EU	Euro 16,079	13.10.1999 - 15.10.1999	Cramer
Hochwasserkonferenzen	RIBAMOD	ENV4-CT98-6216	EU	Euro 14,000	1998/1999	Bronstert
Modelling and parameterization of the "air-vegetation-snow-soil"	AIRVEG	INTAS-96-1935	INTAS	Euro 5,000	01.02.1998 - 31.03.2001	Claussen
An analysis of interregional and international water distribution and conflict problems	CONFLICT	1214-047068.96/1	Schweizer Nationalfond	SFR 24,715	01.10.1996 - 31.09.1997	Schellnhuber
James S. McDonnell Foundation	McDonnell	99-5 CF-SPE.03	James S. McDonnell Foundation	US$ 1,000,650	01.04.1999 - 31.03.2005	Rahmstorf

Co-operation

Institution/Location	Type of co-operation	PIK contact
Australia		
Australian National University, Centre for Resources and Environmental Studies (ANU-CRES), Canberra	Scientific information and data exchange: Developing Global Climate Surfaces	Cramer
Global Change and Terrestrial Ecosystems (GCTE-CPO), CSIRO Division of Wildlife and Ecology, Lyneham, Canberra	Scientific information and data exchange: co-operation in the framework of the GCTE-CPO and development of a DGVM (Dynamic Global Vegetation Model)	Cramer
	Development of common science and data plans IGBP Transect Initiative	Hoff
Climatic Impacts Centre, Macquarie University, North Ryde	EU project: Land-Surface Processes and Climate Response	Claussen
University of New South Wales, Sydney	Scientific information and data exchange: ocean modelling	Rahmstorf
Austria		
Universität für Bodenkultur, Institut für Waldbau, Wien	Modelling of forest succession and model validation: core project CHIEF	Badeck
Österreichisches Institut für Nachhaltige Entwicklung	climate sensitivity and adaptation of VINE	Stock
	co-operation agreement	Schellnhuber
International Institute for Applied System Analysis (IIASA), Laxenburg	Supervisory board / Co-operation agreement: IGBP Core project LUCC	Claussen Toth
	Research and development project: core project ICLIPS	Toth
	EU project ULYSSES	Toth
Belgium		
Institut d' Astronomie et de Géophysique, Université Catholique de Louvain, Louvain-la-Neuve	Scientific Information and data exchange	Claussen
Brazil		
Center for Weather Forecasting and Climate Studies (CPTEC-INPE), Cachoeira	Research association LBA - Large-Scale Biosphere-Atmosphere Experiment in Amazonia	Hoff
Funedação Cearense de Meteorologia e Recursos Hídricos (FUNCEME), Fortaleza	Project agreement, core project WAVES	Gerstengarbe
Universidade Federal da Bahia, Salvador de Bahia	Project agreement, core project WAVES	
Universidade Federal Do Ceará, Fortaleza, Ceará	Project agreement, core project WAVES	Gerstengarbe
Departamento de Hidráulica	Scientific information, data exchange, joint model development on large-scale hydrology and erosion: core project WAVES	Bronstert Krol
Canada		
Canadian Forest Service, Integrative Climate Change Modelling , Edmonton, Alberta	Scientific information and data exchange	Lindner
China		
Chinese Academy of Sciences, Dept. of Hydrology, Beijing	Chinese BAHC Programme	Hoff
Czech Republic		
Institute of Atmospheric Physics, Dept. of Climatology, Prague	Scientific information and data exchange: model validation	Werner
Department of Geography, Masaryk University, Brno	Scientific information and data exchange: climate analysis	Gerstengarbe

Institution/Location	Type of co-operation	PIK contact
Water Research Institute, Prague	Scientific information and data exchange: EU project EUROTAS	Bronstert Menzel
Denmark		
Danmark Farmaceutiske Hojskole (DFH), Institute for Environmental Chemistry	Scientific information and data exchange: core project BBM/GAIA - Thermodynamic criteria for validation of global model	Svirezhev
Danish Hydraulic Institute (DHI), Water Resources Division, Hørsholm	Scientific information and data exchange: EU project EUROTAS	Bronstert Menzel
Danish Meteorological Institute (DMI), Copenhagen	EU project MILLENNIA	Rahmstorf
	EU project: Land-Surface Processes and Climate Response	Claussen
National Environmental Research Institute	BMBF project KLIMÖKO	Bürger
Nils Bohr Institute (NBI), Copenhagen	EU project MILLENNIA	Rahmstorf
Finland		
European Forest Institute, Joensuu	EU project LTEEF II	Cramer
Finnish Forest Research Institute, Vantaa	Scientific information and data exchange: core project CHIEF	Lindner
University of Helsinki, Dept. of Forest Ecology, Helsinki	Scientific information and data exchange: core project CHIEF	Lasch
France		
French Institute of Agricultural and Environmental Engineering Research, Lyon	Scientific information and data exchange: EU project EUROTAS	Bronstert Menzel
Centre d'Etudes Spatiales de la Biosphère (CESBIO), Toulouse	Scientific information and data exchange: Global Primary Production Data Initiative (GPPDI)	Cramer
	Scientific information and data exchange: Remote sensing data assimilation for ecosystem models Joint project	Cramer
Ecole Normale Supérieure (ENS), Laboratoire d'Ecologie, Paris	EU project ETEMA	Cramer
Laboratoire d'Ecophysiologie végétale, Université de Paris-Sud XI, Orsay	Scientific information and data exchange	Badeck
Laboratoire de Météorologie Dynamique (LMD) du CNRS (Centre National de la Recherche Scientifique), Paris	EU project: Land-Surface Processes and Climate Response EU project: Climate and Land Degradation	Claussen
	EU project MILLENNIA	Rahmstorf
Laboratoire d'Oceanographie Dynamique et de Climatologie (LODYC), Paris	EU project MILLENNIA	Rahmstorf
Météo-France, Toulouse	EU project: Land-Surface Processes and Climate Response	Claussen
MEDIAS France, Toulouse	Multilateral agreement: Northern Africa Initiative	Hoff
	EU project RICAMARE	Stock
UNESCO-IHP (International Hydrological Programme), Paris	Support of various projects, workshops, etc.	Becker
Germany		
Akademie für Raumforschung und Landesplanung (ARL), Hannover	Arbeitskreis "Raumorientiertes Risikomanagement"	Stock
Akademie für Technikfolgenabschätzung, Baden-Württemberg	Scientific information and data exchange: core project QUESTIONS, BMBF project "Syndromdynamik"	Petschel-Held
Alfred-Wegener-Institut für Polar und Meeresforschung (AWI), Bremerhaven and Potsdam	Scientific information and data exchange: core project BBM/GAIA	Svirezhev

Institution/Location	Type of co-operation	PIK contact
Bayreuther Institut für Terrestrische Ökosystemforschung (BITÖK), Bayreuth	Scientific information and data exchange: core project QUESTIONS, BMBF project "Syndromdynamik"	Petschel-Held
Bayrisches Landesamt für Wasserwirtschaft, München	Large-scale hydrological modelling ARC/EGMO, ASSGI, SWIM	Becker
Büro für Angewandte Hydrologie (BAH), Berlin	Scientific information and data exchange: BMBF project: "Elbe-Ökologie" Core project RAGTIME	Becker
	Program development and application	Lahmer
Bundesamt für Gewässerkunde, Koblenz and Berlin	Influence of land use and river training measures on the Rhine basin (EU project LAHOR)	Bronstert
	Co-operation within the BMBF-funded project "GLOWA Elbe"	Wenzel
Bundesanstalt für Geowissenschaften und Rohstoffe, Berlin und Hannover	Scientific information and data exchange: Expo 2000	Stock
Bundesforschungsanstalt für Forst- und Holzwirtschaft, Institut für Forstökologie und Walderfassung, Eberswalde	BMBF project: "Wälder und Forstwirtschaft Deutschlands im Globalen Wandel" Core project CHIEF	Cramer
Institut für Ökonomie, Hamburg	VW foundation project MESSAGE	Wechsung
Institut für Forstgenetik, Großhansdorf	BMBF project: "Wälder und Forstwirtschaft Deutschlands im Globalen Wandel" Core project CHIEF	Cramer
Geodatenintegration und Analyse, Berlin	Development of GIS tools Core project RAGTIME	Lahmer
Deutscher Wetterdienst (DWD), Offenbach/ Potsdam	Framework agreement for collaboration in the area of meteorology Exchange and transfer of data and models Joint national and international research projects Scientific information and data exchange	Stock
	Data acquisition for PIK's data bank system	Oesterle
	RECLIM project (Improved Dynamical Techniques for Deriving Regional Climate Informations)	Gerstengarbe
	Regional climate model application	Böhm Kücken Gerstengarbe
Deutsches Elektronen-Synchrotron - Institute for High Energy Physics (DESY-IfH), Zeuthen	HPSC-Forum Berlin-Brandenburg	Kramer
Deutsches Institut für Ernährungsforschung, Potsdam	MAN-Vertrag (Metropolitan Area Network)	Kramer
Deutsches Institut für Wirtschaftsforschung (DIW), Berlin	Scientific information and data exchange Core project RESOURCE, core project ICLIPS	Toth
Deutsches Klimarechenzentrum GmbH (DKRZ), Hamburg	Discussion and agreement on co-operation: - El Niño: scientific information and data exchange - Regionalization: scientific information and data exchange - Network project "Wissenschaftliches Rechnen"	Claussen
	CERA: Development of a meta database (preliminary contract for the accession of PIK to the DKRZ and Scientific Computing in Climate Research)	Toussaint
Deutscher Verband für Wasserwirtschaft und Kulturbau (DVWK)	Membership of Scientific Commission	Stock
Europäische Akademie Bad Neuenahr/Ahrweiler	Arbeitskreis "Klimavorhersage und -vorsorge"	Claussen
Fachhochschule Brandenburg	MAN-Vertrag (Metropolitan Area Network)	Kramer
Fachhochschule Potsdam	MAN-Vertrag (Metropolitan Area Network)	Kramer

Institution/Location	Type of co-operation	PIK contact
Fa. Hydromod, Wedel/Hamburg	Mantle project KLINO (BMBF project)	Claussen
Fernuniversität GH Hagen, FB ESGW / ökologische Psychologie	Scientific information and data exchange: Core projects: QUESTIONS, RESOURCE, ICLIPS	Toth
Forschungzentrum Jülich, Programmgruppe Systemforschung	Core project RAGTIME Collaboration in BMBF project "Elbe-Ökologie"	Becker
Forschungsstätte der Ev. Studiengemeinschaft, Heidelberg	Scientific information and data exchange + network project proposal BMBF Core project RAGTIME	Wenzel
Freie Universität Berlin	Co-operation in teaching and research, joint appointments (gemeinsame Berufungen): a) C4: Modelling of global environmental systems (D&C department) b) C3: Theoretical Climatology (Climate Research department)	Claussen
	Research and Development proposal: preparation and supply of NOAA-AVHRR satellite data	Cramer
Institut für Geographie	Scientific information and data exchange	Claussen
GeoForschungsZentrum (GFZ), Potsdam	Telegrafenberg user association	Stock
	Deutsches Forschungsnetzwerk Naturkatastrophen (DFNK)	Menzel
	Information exchange on data and meta data management	Flechsig
	Potsdam-MAN contract (Metropolitan Area Network)	Kramer
Gesellschaft für Technische Zusammenarbeit (GTZ), Berlin	Scientific information and data exchange	Stock
Gesellschaft für Wasserwirtschaftliche Planung und Systemforschung mbH (WASY), Berlin-Bohnsdorf	Software systems, development and application	Becker
GKSS-Forschungzentrum Geesthacht GmbH	Scientific information and data exchange	Claussen
Hellriegel-Institut e.V., Fachhochschule Anhalt, Bernburg	Bernburg Study 1997 Execution of a comparative study on the FACE Wheat Experiment Maricopa (BMBF-sponsored project) Joint research and development project (BMBF-sponsored): Validation and regional application of agro-ecosystem models	Kartschall
Hochschule für Film und Fernsehen, Potsdam	MAN-Vertrag (Metropolitan Area Network)	Kramer
Humboldt-Universität zu Berlin	Establishment of a special research area (Sonderforschungsbereich) Scientific information and data exchange Execution of joint projects	Schellnhuber
	Project agreement Mantle project FACE (BMBF project)	Kartschall
IBM Deutschland Informationssysteme GmbH, Stuttgart	Co-operation agreement: "Wissenschaftliches Rechnen" University chair (Stiftungsprofessur)	Rupert Klein
Institut für Agrartechnik Bormin e.V.	MAN-Vertrag (Metropolitan Area Network)	Kramer
Institut für Gewässerökologie und Binnenfischerei (IGB), Berlin	Collaboration in BMBF project "Elbe-Ökologie" Area water and nutrient budgets Core project RAGTIME	Becker
	Co-operation within the BMBF-funded project "GLOWA Elbe"	Wenzel
Institut für Ökologische Wirtschaftsforschung (IÖW), Berlin	Scientific information and data exchange + BMBF network project proposal Core project RAGTIME	Wenzel
Institut für Ökologische Wirtschaftsforschung, Wuppertal	Scientific information and data exchange: social dimensions of Global Change	Reusswig
Institut für Regionalentwicklung und Strukturplanung (IRS), Berlin	Scientific information and data exchange: city development	Stock

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Institut für sozial-ökologische Forschung GmbH, Frankfurt/M.	Scientific information and data exchange: social dimensions of Global Change	Reusswig
Konrad-Zuse-Zentrum für Informationstechnik, Berlin	Co-operation agreement with FUB: "Wissenschaftliches Rechnen"	Schellnhuber
	HPSC-Forum Berlin-Brandenburg	Kramer
Landesanstalt für Forstplanung Brandenburg, Potsdam	Scientific information and data exchange: core project RAGTIME	Flechsig
Landesanstalt für Wasserwirtschaft Rheinland-Pfalz, Mainz	Elaboration of an evaporation map for the German state of Rheinland-Pfalz	Menzel
Landesforstanstalt, Eberswalde	Scientific information and data exchange	Suckow
Landesumweltamt Brandenburg (LUA), Potsdam	Scientific information and data exchange: core project RAGTIME Water and nutrient budgets of river basins (Stepenitz, etc.)	Flechsig
Max-Planck-Institut für Biogeochemie, Jena	Scientific information and data exchange	Cramer
Max-Planck-Institut für Meteorologie, Hamburg	Co-operation agreement Scientific information and data exchange	Claussen
	Modelling and numerical experiments for Baltex (BMBF project - subproject: "Wasserkreislauf")	Claussen
	BMBF feasibility study: El Niño	Claussen
	Research and development project: core project ICLIPS	Toth
	EU project MILLENNIA	Rahmstorf
	EU project ETEMA	Cramer
	BMBF project KLIMÖKO	Bürger
	Core project WAVES	Gerstengarbe
	Core project QUESTIONS, BMBF project "Syndromdynamik"	Petschel-Held
	BMBF project: "Expertise zu CO_2 Quellen und Senken"	Cramer
Münchner Projektgruppe für Sozialforschung	Scientific information and data exchange: Core project QUESTIONS, BMBF project "Syndromdynamik"	Reusswig
Münchener Rückversicherung, Forschungsgruppe "Geowissenschaften"	Scientific information and data exchange	Schellnhuber
Niedersächsische Energieagentur, Hannover	Scientific co-operation on EXPO 2000 (theme park)	Stock
Niedersächsische Forstliche Versuchsanstalt, Göttingen	BMBF project: "Wälder und Forstwirtschaft Deutschlands im Globalen Wandel" Core project CHIEF	Lindner
Rheinisch-Westfälisches Institut für Wirtschaftsforschung (RWI), Essen	Scientific information and data exchange: core project QUESTIONS, BMBF project "Syndromdynamik"	Petschel-Held
Statistisches Bundesamt	Scientific information and data exchange: core project QUESTIONS, BMBF project "Syndromdynamik"	Petschel-Held
Technische Fachhochschule Wildau	MAN-Vertrag (Metropolitan Area Network)	Kramer
Technische Hochschule Darmstadt	Scientific information and data exchange: Project proposal to the DFG in 1997: "Inlandeismodellierung"	Claussen
	EU project ULYSSES	Toth

Institution/Location	Type of co-operation	PIK contact
Technische Universität Berlin Institut für Landschaftsentwicklung Institut für Management in der Umweltplanung Institut für Ökologie und Biologie	Hydrological analyses in the upper Stör basin Core project RAGTIME	Lahmer
	VW foundation project MESSAGE	Wechsung
	Co-operation within the BMBF-funded project "GLOWA Elbe"	Wenzel
	Projekt der Volkswagenstiftung: "Grobrasteranalyse zu den Möglichkeiten für umweltentlastende Landnutzungsänderungen in Folge des Globalen Wandels"	Wechsung
Technische Universität Braunschweig, Institut für Geographie und Geoökologie (IfGG)	Co-operation agreement: Modelling the area water and nutrient budgets of river catchments	Lahmer
Technische Universität Cottbus, Fakultät Umweltwissen-schaften	Scientific information and data exchange	Flechsig
Lehrstuhl für Hydrologie und Wasserwirtschaft.	Scientific information and data exchange: social dimensions of Global Change	Wenzel
Technische Universität Dresden, Institut für Hydrologie und Meteorologie	DFG focus programme "Regionalisierung in der Hydrologie" Water and nutrient budgets, large-scale modelling	Becker
Technische Universität München, Forstwissenschaftliche Fakultät, Lehrstuhl für Bioklimatologie und Immissionsforschung Lehrstuhl für Waldwachstumskunde und Lehrstuhl für Forstpolitik und Forstgeschichte, Weihenstephan Institut für Landespflege und Botanik, Weihenstephan	Integriertes Messprogramm (Mikrometeorologie, Atmosphärenchemie, Physiologie) zu Auswirkungen der Totalen Sonnenfinsternis am 11.8.1999 in der Region München/Freising/Weihenstephan	Kartschall
	BMBF project: "Wälder und Forstwirtschaft Deutschlands im Globalen Wandel" Core project CHIEF	Cramer
	Project agreement: core project WAVES	Gerstengarbe
Thüringer Landesanstalt für Umwelt, Jena	Collaboration in framework of BMBF project "Elbe-Ökologie"	Klöcking
Umweltbundesamt (UBA), Berlin	Co-operation and advisory discussions; integration of WBGU; ICLIPS research results Scientific information and data exchange	Schellnhuber
Umweltforschungszentrum Leipzig- Halle GmbH (UFZ), Sektion Agrarlandschaften und Abt. Angewandte Landschaftsökologie	Scientific information and data exchange core projects QUESTIONS, HGF Project "Sustainable Global Development - Perspectives for Germany"	Schellnhuber Reusswig
Abteilung für Ökonomische Ökologie und Umweltsoziologie	Scientific information and data exchange: core project RAGTIME	Flechsig
	Co-operation within the BMBF-funded project "GLOWA Elbe"	Wenzel
Universität Bayreuth, Abteilung Mikrometeorologie Institut für Pflanzenökologie	Integriertes Messprogramm (Mikrometeorologie, Atmosphärenchemie, Physiologie) zu Auswirkungen der Totalen Sonnenfinsternis am 11.8.1999 in der Region München/Freising/Weihenstephan	Kartschall
	BMBF project: "Expertise zu CO_2 Quellen und Senken"	Cramer
Universität Bonn	EU project MILLENNIA	Rahmstorf
	Co-operation agreement: Climate analysis and climate diagnosis	Gerstengarbe
	Project agreement, core project WAVES	Gerstengarbe
Institut für Agrarpolitik, Marktforschung und Wirtschaftssozio-logie	BMBF project KLIMÖKO	Bürger
	VW foundation project MESSAGE	Wechsung
Universität Bremen, Fachbereich Geowissenschaften	Scientific information and data exchange; Project proposal to the DFG in 1997: "Inlandeismodellierung"	Claussen
Universität Dortmund, FB Raumplanung	Scientific information and data exchange: core project QUESTIONS, BMBF project "Syndromdynamik"	Petschel-Held

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Universität Düsseldorf, Juristische Fakultät	Scientific information and data exchange: core project QUESTIONS, BMBF project "Syndromdynamik"	Petschel-Held
Universität Frankfurt/M.	Co-operation agreement: Climate analysis and diagnosis	Gerstengarbe
	Scientific information and data exchange: social dimensions of Global Change	Reusswig
Universität Freiburg, Institut für Kulturgeographie	Scientific information and data exchange: core project QUESTIONS, BMBF project "Syndromdynamik"	Petschel-Held
Universität Gesamthochschule Kassel	Scientific information and data exchange: core project QUESTIONS, BMBF project "Syndromdynamik"	Petschel-Held
	Co-operation within the BMBF-funded project "GLOWA Elbe"	Wenzel
	Scientific information and data exchange: core project WAVES	Gerstengarbe
	Research and development project: core project ICLIPS	Toth
Universität Gießen	BMBF project: "Expertise zu CO_2 Quellen und Senken"	Cramer
Universität Göttingen, Institut für Bodenkunde und Waldernährung	Core project QUESTIONS, BMBF project "Syndromdynamik"	Petschel-Held
Universität Halle, Institut für Acker- und Pflanzenbau	Project agreement: BMBF project Mantle project FACE	Kartschall
Universität Hamburg, Institut für Meereskunde	Network project in the framework of a co-operation agreement Scientific information and data exchange: mantle project KLINO (BMBF-sponsored project)	Claussen Bauer
Meteorologisches Institut	Network project in the framework of a co-operation agreement Scientific information and data exchange: mantle project KLINO (BMBF-sponsored project)	Claussen
	Common research on statistics and climate analysis	Gerstengarbe
Universität Hohenheim, Institut für Bodenkunde und Standortlehre	Project agreement: core project WAVES	Gerstengarbe Werner
Universität Jena, Arbeitsgruppe Meteorologie	Scientific information and data exchange	Werner
Universität Kiel, Institut für Meereskunde	BMBF project: "Expertise zu CO_2 Quellen und Senken"	Cramer
Institut für Weltwirtschaft	Research and development project: Core project ICLIPS	Toth
Projektzentrum Ökosystemforschung,	Scientific information and data exchange: hydrological analyses in the Oder catchment, water and nutrient budgets (BMBF project "Elbe-Ökologie")	Becker
	Scientific Advisory Board (Chair)	Cramer
Universität Köln	Scientific information and data exchange: core project WAVES	Gerstengarbe
Universität Magdeburg, Institut für Psychologie	Proposal in framework of BMBF project "Nachhaltiges Wirtschaften" Scientific information and data exchange	Linneweber
Universität Marburg, FB Wirtschaftswissenschaften	Scientific information and data exchange: Core project QUESTIONS, BMBF project "Syndromdynamik"	Petschel-Held
Universität München, Institut für Geographie	Laterale hydrologische Flüsse in komplexen Landschaften	Bronstert
Universität Münster	DFG focus theme "Regionalisierung in der Hydrologie": Data banks, development of GIS tools	Lahmer
	BMBF network project "Wasserkreislauf" Meta databases on Global Change	Flechsig

Institution/Location	Type of co-operation	PIK contact
Universität Oldenburg	Co-operation in the framework of analysis of socioeconomic and sociocultural conditions in NE-Brazil Formerly in the framework of the Project WAVES-SOLAM (BMBF project)	Leimbach
Institut für Chemie und Biologie des Meeres	Joint project work and proposal: BMBF project KLIMÖKO	Bürger
	Co-operation agreement and scientific information and data exchange on: pattern recognition and systems analysis with neural networks, vulnerability of ecosystem complexes (mud-flat sediments), description of biotic induced weathering processes	Kropp
Universität Osnabrück, Fachbereich Sozialwissenschaften	Scientific information and data exchange: core project QUESTIONS, BMBF project "Syndromdynamik", expert opinions	Petschel-Held
Universität Potsdam	Joint teaching and appointments (Berufungen) Co-operation agreement Sonderforschungsbereich 555 "Komplexe Nichtlineare Prozesse"	Schellnhuber Bronstert Rahmstorf
	Potsdam-MAN contract (Metropolitan Area Network)	Kramer
Wirtschafts- und Sozialwissenschaftliche Fakultät	Common DFG project proposal: Integration in times of social change	Reusswig
	Co-operation agreement; project proposal: "Selbstregulation im globalen Ökosystem Erde" Ecosystem research	Block
Universität des Saarlandes, FB Sozial- und Umweltwissen-schaften; Saarbrücken	Scientific information and data exchange: Northern summer/ Brandenburg Study	Toth
Universität Stuttgart, Institut für Wasserbau	Regionalization of flood processes (EU project LAHOR)	Bronstert
Universität Würzburg, Geographisches Institut	DFG project Extreme - 1500	Werner
Wissenschaftlicher Beirat der Bundesregierung Globaler Umweltveränderung (WBGU), Geschäftsstelle am Alfred-Wegener-Institut für Polar- und Meeresforschung, Bremerhaven	Chairman Scientific information and data exchange with the advisory board members and their institutes Core project QUESTIONS, BMBF project "Syndromdynamik"	Schellnhuber
Wissenschaftszentrum Berlin (WZB)	Scientific information and data exchange SAB (Prof. Simonis)	Schellnhuber
Wuppertal Institut für Klima-Umwelt-Energie	Scientific information and data exchange Execution of joint projects and workshops	Schellnhuber
Zentrum für Agrarlandschafts- und Landnutzungsforschung (ZALF), Müncheberg	Research and development project: Mantle project GRANO Scientific information and data exchange: core project AGREC Network project in framework of BMBF project Elbe-Ökologie	Wechsung
	Co-operation within the BMBF-funded project "GLOWA Elbe"	Wenzel
	Scientific Advisory Board	Cramer
Greece		
National Technical University of Athens, Department of Geography and Regional Planning	EU project ULYSSES	Toth
Department of Hydraulics	Scientific information and data exchange: EU project EUROTAS	Bronstert Menzel
Hungary		
Budapest University of Economics	Scientific information and data exchange: core project ICLIPS	Toth
Central European University (CEU), Budapest	Research and development project: "EEFSU Socioeconomic and Environmental Data"	Toth
Israel		
Blaustein Institute for Desert Research, Sede Boker	Scientific information and data exchange: core project RESOURCE	Sprinz

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Ministry of Science and Technology (MOST)	Scientific information and data exchange	Schellnhuber
University of Haifa	Scientific information and data exchange: core project RESOURCE	Sprinz
University of Tel Aviv	Scientific information and data exchange: regional climate modelling, climate scenarios	Gerstengarbe
Italy		
Centro Interuniversitario dell'Italia Nord Orientale per il Calcolo Automatico (CINECA), Bologna	EU project MILLENNIA	Rahmstorf
Fondazione Eni Enrico Mattei, Milano	EU project WISE	Flechsig
Istituto per lo Studio delle Metodologie Geofisiche Ambientali (IMGA), Modena	EU project MILLENNIA	Rahmstorf
Istituto Sperimentale per le Colture Industriali, Bologna	EU project MAGEC	Wechsung
Joint Research Centre, Institute for Remote Sensing Applications, Ispra	EU project ETEMA	Cramer
Joint Research Centre (JRC), Institute for Systems Engineering and Informatics, Ispra	EU project ULYSSES	Toth
Università di Padua	Scientific information and data exchange: EU project EUROTAS	Bronstert Menzel
Università di Venezia, Dept. of Environmental Sciences	INTAS project: Modelling of point and nonpoint pollution in watersheds	Krysanova
Università di Viterbo, Dept. of Forest Sciences	BAHC core research contribution: Fluxnet - List server administration	Hoff
Japan		
Institute for Global Environmental Strategies, Hayama, Kanagawa	Scientific information exchange; visiting researchers; memberships in boards	Schellnhuber Petschel-Held
Netherlands		
Alterra - Green World Research, Wageningen	Modelling of forest regeneration and model validation: core project CHIEF	Lasch
	EU project LTEEF II Core project CHIEF	Cramer
	Multilateral agreement: Northern Africa Initiative BAHC administration	Hoff
	EU project: Climate and Land Degradation	Claussen
Commission for Hydrology of the river Rhine (CHR), The Hague	Influence of land use and river training measures in the Rhine basin (EU project LAHOR)	Bronstert
DLO Research Institute for Agrobiology and Soil Fertility (AB), Wageningen	EU project MAGEC	Wechsung
Erasmus University, Rotterdam	Scientific information and data exchange	Sprinz
National Institute of Public Health and Environmental Protection (RIVM), Bilthoven	EU project ETEMA	Cramer
	Scientific information and data exchange: IMAGE 2 - network EU project ULYSSES	Wenzel
Research Institute for Agrobiology and Soil Fertility, Haren	EU project MAGEC	Cramer
University of Utrecht, Department of Geography	EU project IRMA/SPONGE	Bronstert

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Wageningen Agricultural University, Department of Theoretical Production Ecology, Wageningen	Project agreement: mantle project FACE (BMBF project) Scientific information and data exchange: AGRAR/ GCTE Wheat Network Core project RAGTIME	Kartschall
	EU project Climate and Land Degradation	Claussen
Waterloopkundig Laboratorium (WL), Delft Hydraulics	Scientific information and data exchange: EU project EUROTAS	Bronstert Menzel
Vrije Universiteit Amsterdam, Institute for Environmental Studies	EU project WISE	Flechsig
Nigeria		
University of Lagos, Faculty of Environmental Sciences, Lagos	Multilateral agreement: Northern Africa Initiative	Hoff
Norway		
Norsk Institutt for Naturforskning, Trondheim	Scientific information and data exchange: Developing Regional Ecosystem Model Applications	Cramer
Poland		
Warsaw Agricultural University, Dept. of Silviculture	Agreement on co-operation: data exchange and modelling of pristine forest succession: core project CHIEF	Badeck
Warsaw University, Institute of Geophysics	Scientific co-operation (WTZ project) in dynamic earth-system modelling	Franck
Russia		
All-Russia Research Institute of Hydrometeorological Information, World Data Centre, Obninsk	Data exchange contract	Werner
Moscow State University	INTAS project (International Association for the promotion of co-operation with scientists from the independent states of the former Soviet Union): Moscow Global Biosphere Model (MGMB)	Schellnhuber Svirezhev
Russian Academy of Sciences Computer Centre, Nowosibirsk	INTAS project: "Air-Vegetation-Snow-Soil"	Claussen
Russian Academy of Sciences, Institute of Forest Sciences, St. Petersburg	BAHC core research / IGBP initiative: Northern Eurasian Study	Hoff
Russian Academy of Sciences, Institute for Physics of the Earth	Scientific information: projects COEM and TRIPEDES	Franck
Russian Academy of Sciences, Moscow	INTAS project (International Association for the promotion of co-operation with scientists from the independent states of the former Soviet Union): Moscow Global Biosphere Model (MGMB)	Schellnhuber
Russian Hydrometeorological Service, St. Petersburg	INTAS project: "Air-Vegetation-Snow-Soil"	Claussen
Spain		
Consejo Superior de Investigaciones Cientificas, Instituto de Estodios Sociales Avanzados, Barcelona	EU project ULYSSES	Toth
Laboratorio Ecología, Facultad de Medio Ambiente, Universidad Castilla-La Mancha, Toledo	Scientific information and data exchange	Thonicke
Universidad de Castilla-LaMancha, Instituto Desarrollo Regional	EU project: Climate and Land Degradation	Claussen
Universidad de Complutense de Madrid, Dept. Geofisica y Meteorologia	EU project: Climate and Land Degradation	Claussen

Institution/Location	Type of co-operation	PIK contact
Sweden		
International Geosphere-Biosphere Programme (IGBP), Stockholm	Support of various projects, workshops, etc.	Hoff
	IGBP Transect Initiative Development of common science and data plans	
Lund University	EU project ETEMA	Cramer
	Scientific information and data exchange: core project CHIEF	Badeck
	INTAS project: "Air-Vegetation-Snow-Soil"	Claussen
Stockholm Environment Institute	EU project ULYSSES	Toth
Stockholm University, Department of System Ecology	EU project: Baltic Basin Case Study (BBCS)	Cramer
Switzerland		
Eidgenössische Anstalt für Wasserversorgung, Abwasserreinigung und Gewässerschutz (EAWAG), Dübendorf	EU project ULYSSES	Toth
Eidgenössische Forschungsanstalt für Wald, Schnee und Landschaft, Birmensdorf	Scientific information and data exchange, modelling of forest succession and model validation: core project CHIEF Data provision contract: "Sturmschäden im Ural: Ursache und Bewertung" (STURMURAL)	Badeck
Eidgenössische Technische Hochschule Zürich (ETHZ), Departement für Forstwissenschaften	Modelling of forest succession and model validation: core project CHIEF	Badeck
Graduate Institute of International Studies, Geneva	Co-operation agreement: International Responses to Global Climate Change (SOAR) Co-operation agreement Core project RESOURCE	Sprinz
Universität Bern, Historisches Institut	DFG project Extreme - 1500	Werner
Institut für Geographie	DFG project Extreme - 1500	Werner
	BMBF project KLINÖKO	Bürger
Physikalisches Institut	Scientific information and data exchange	Sitch
United Kingdom		
ADAS, Wolverhampton	Scientific information and data exchange: Large-scale modelling of hydrology and water quality	Krysanova
Cranfield University, International Ecotechnology Research Centre	Scientific information and data exchange: core project BBM/GAIA Modelling human responses to Global Change	Svirezhev
European Centre for Medium Range Weather Forecasts (ECMWF), Berkshire	Scientific information and data exchange: Regional climate model	Böhm
Hadley Centre, Meteorological Office, Bracknell	EU project: Land-Surface Processes and Climate Response EU project: Climate and Land Degradation	Claussen
Hydraulic Research Ltd, Wallingford	Scientific information and data exchange: EU project EUROTAS	Bronstert Menzel
Institute of Hydrology (IH), Wallingford	EU project: Climate and Land Degradation	Claussen
	Multilateral agreement: Northern Africa Initiative	Hoff
Institute of Terrestrial Ecology, Edinburgh Research Station	Exchange of scientific visitors and joint venture research on geophysical modelling	Schellnhuber von Bloh
Jackson Environment Institute, University College, London	Research and development project: core project ICLIPS	Schellnhuber Toth
Middlesex University, Flood Hazard Research Centre	Research and methodological development for coastal vulnerability assessment and adaptation	Richard Klein

Institution/Location	Type of co-operation	PIK contact
National Environmental Research Council (NERC), Institute of Terrestrial Ecology, Penicuik	EU project ETEMA	Cramer
Research Methods Consultancy (RMC), London	EU project ULYSSES	Toth
Soil Science Department, IACR Rothamsted, Harpenden, Hertfordshire	EU project MAGEC	Cramer Wechsung
University College London, Department of Geomatic Engineering, Department of Geography	Global satellite land surface data for biophysical modelling	Lucht
University of Durham	Scientific information and data exchange EU project DART	Cramer
University of East Anglia, Climatic Research Unit, Norwich	EU project WISE	Flechsig
University of Essex, Dept. of Biology, Colchester	Project agreement: mantle project FACE (BMBF project)	Kartschall
University of Lancaster, Centre for the Study of Environmental Change, Lancaster	EU project ULYSSES	Toth
University of Oxford, Environmental Change Unit, Oxford	Mountain Regions/ Global Change EU project ENRICH	Becker
University of Reading, Dept. of Meteorology, Reading	EU project: Land-Surface Processes and Climate Response	Claussen
University of Sheffield, School of Biological Sciences, Sheffield	EU project ETEMA	Cramer
USA		
Battelle Pacific Northwest National Laboratories, Washington	Research and development project: core project ICLIPS	Toth
Boston University, Center for Remote Sensing, and Department of Geography	Production of global biophysical remote-sensing data (MODIS)	Lucht
Brookhaven National Laboratory Biosystems Division, Upton, Long Island	Project agreement: mantle project FACE (BMBF project)	Kartschall
Center for Environmental and Estuarine Studies, University of Maryland	Scientific information and data exchange: Integrated modelling of water and biogeochemical cycles	Krysanova
Center for Political Studies, Institute for Social Research, University of Michigan, Ann Arbor	Scientific information and data exchange	Sprinz
Electric Power Research Institute, Palo Alto, CA	Scientific information and data exchange: core project ICLIPS	Toth
Geophysical Fluid Dynamics Laboratory (GFDL), Princeton	Scientific information and data exchange: Ocean modelling (informal co-operation)	Rahmstorf
Georgia State University, Athens, Georgia	Scientific information and data exchange: BBM/GAIA	Svirezhev
Goddard Space Flight Center, NASA, Greenbelt, Maryland	Research Network LBA - Large-Scale Biosphere-Atmosphere Experiment in Amazonia	Hoff
International Global Atmospheric Chemistry (IGAC-CPO), Cambridge, MA	Development of common science and data plans Core project of the IGBP Transect Initiative	Hoff
International Geosphere-Biosphere Programme IGBP-START, Washington	Support of various projects, workshops, etc.	Hoff
John Hopkins University, Baltimore, Maryland	Projektbezogener Personenaustausch mit den USA (NFS-DAAD-Programm): "Numerical simulation of complex flows using asymptotic-based schemes"	Rupert Klein
Lawrence Berkeley Laboratory, Berkeley, California, Ann Almgren	"Multiple scales asymptotics and numerics of atmospheric flows"	Rupert Klein
Lawrence Livermore National Laboratory, Global Climate Research Division, Livermore	Project agreement: mantle project FACE (BMBF project)	Kartschall
Massachusetts Institute of Technology (MIT), Joint Program on the Science and Policy of Global Change, Cambridge	Exchange of scientific information, joint organisation of forums	Schellnhuber Toth

Institution/Location	Type of co-operation	PIK contact
State University of New York, College of Environmental Sciences and Forestry, Syracuse	Mountain Hydrology and Ecology	Becker
United States Department of Agriculture (USDA), Agriculture Research Service, U.S. Water Conservation Lab., Phoenix, Arizona	Project agreement: mantle project FACE (BMBF project)	Kartschall
United States Department of Agriculture (USDA), Agricultural Research Service, Grassland, Soil and Water Research Lab., Temple, Texas	Scientific information and data exchange: Catchment modelling with GIS, SWAT and SWIM models	Krysanova
University of Maryland, Geography Department, College Park	Scientific information and data exchange: Global Primary Production Data Initiative (GPPDI)	Cramer
University of Montana, School of Forestry, Numerical Terradynamics Systems Group, Missoula, Montana	NATO Collaborative Research Grant "Environmental Thresholds"	Sprinz
University of New Hampshire, Complex Systems Research Center, Durham, New Hampshire Institute for the Study of Earth, Oceans and Space	Scientific information and data exchange: Comparing Global Biosphere Models for NPP Macroscale hydrological modelling	Cramer
	Scientific and logistic co-operation within IGBP Task Force GAIM	Schellnhuber Claussen Cramer
US Dept. of Energy, Oak Ridge National Laboratory, Tennessee	Scientific information and data exchange: Global Primary Production Data Initiative (GPPDI)	Cramer
Usbekistan		
Central Asian Hydrometeorological Research Institute, Glavgidromet Sanigmi, Tashkent	Scientific information and data exchange: project preparation (Aral Sea)	Österle

Scientific Events

Event	Place and Date	Scientist(s) in charge
Workshop "Wasser- und Stoffhaushalt der Elbe und ihres Einzugsgebietes" *("Water and nutrient dynamics of the Elbe river and its catchments")*	Potsdam, 10 February 1998	Alfred Becker
Workshop "Climate change & arctic biomes: structure, function and modelling"	Potsdam, 2 - 8 April 1998	Wolfgang Cramer
Planning Meeting "Global Change research in mountain regions", with IGBP, core projects BAHC, GCTE, LUCC, PAGES	Pontresina, Switzerland, 16 - 18 April 1998	Alfred Becker, Harald Bugmann
European expert meeting on the Oder flood in summer 1997	Potsdam, 18 May 1998	Axel Bronstert
Workshop on "Climate impact response functions"	Potsdam, 2 - 4 September 1998	Ferenc Tóth
Signing of co-operation agreement between the University of Potsdam and PIK	Potsdam, 15 September 1998	Manfred Stock
WISE Project Meeting	Potsdam,11 - 12 January 1999	Michael Flechsig
Workshop "Modelling in WAVES"	Potsdam, 13 - 14 January 1999	Axel Bronstert, Maarten Krol
DFG Workshop "Integration Methodology for Global Change"	Frankfurt/Main, 23 - 24 January 1999	H. J. Schellnhuber (co-organizer)
Workshop TERI-CA "Ecosystems in the landscape"	Potsdam, 14 - 16 March 1999	Wolfgang Cramer
Workshop ATEAM (Advanced terrestrial ecosystem modelling and analysis)	Potsdam, 17 - 18 March 1999	Wolfgang Cramer
Session "Integrated Scenarios" during the "Bilateral Project Workshop of WAVES"	Fortaleza, Brazil, 8 April 1999	Maarten Krol
IDNDR-Workshop on "Zukünftige Bedrohungen durch (anthropogene) Naturkatastrophen" *(Future threats caused by (anthropogenic) natural disasters)*	Potsdam, 29 - 30 April 1999	Fritz Reusswig, H. J. Schellnhuber
Workshop on "Differential inclusions and qualitative reasoning in Global Change research: theory and practice"	Potsdam, 18 - 19 May1999	Thomas Bruckner, Gerhard Petschel-Held, Ferenc Tóth
Workshop "Power-user and supercomputer"	Berlin, 19 - 20 May 1999	Rupert Klein
IPCC, WG III, Chapter 10, Last Meeting	Potsdam, 20 - 21 May 1999	Ferenc Tóth

Event	**Place and Date**	**Scientist(s) in charge**
International WE-Heraeus-Workshop (217th seminar) on “Facets of universality in complex systems: climate, biodynamics and stock markets”	Rauischholzhausen, 7 - 10 June 1999	H. J. Schellnhuber (co-organizer)
Workshop on “Earth System Models of Intermediate Complexity” (EMIC), together with IGBP	Potsdam, 14 - 16 June 1999	Martin Claussen, Wolfgang Cramer
IPCC-TAR Meeting for WGII, Chapter 19 Authors	Potsdam, 1 - 3 July 1999	H. J. Schellnhuber
Meeting of partners in preparation of an R&D proposal for the EU 5th Framework Programme “Dynamic and interactive assessment of national, regional and global vulnerability of coastal zones to climate change and sea-level rise” (DINAS-COAST)	Potsdam, 13 - 14 September 1999	Richard Klein
Workshop on “Extreme hydrologische Ereignisse in Mitteleuropa seit 1500 - Prozesse und Wirkungen” *(Extreme hydrological events in Central Europe since 1500 - processes and impacts)*	Potsdam, 7 - 8 October 1999	Friedrich-Wilhelm Gerstengarbe, Peter C. Werner
ECLAT-2 EW-2 Workshop “Climate scenarios for agricultural, ecosystem and biological impacts”	Potsdam, 13 - 15 October 1999	Wolfgang Cramer
Workshop “National and regional climate impact assessment in the forestry sector” (NIMA)	Belzig/Wenddoche, 10 - 13 November 1999	Marcus Lindner
International Conference “Understanding the Earth System”	Bonn, 24 - 26 November 1999	H. J. Schellnhuber (co-organizer)
Vorstandssitzung der Deutschen Meteorologischen Gesellschaft (*Board meeting of the German Meteorological Society)*, together with Deutscher Wetterdienst *(German Weather Service)*	Potsdam, 26 - 27 November 1999	Martin Claussen
IGBP-DIS Steering Committee Initial Meeting	Potsdam, 30 November - 2 December 1999	Wolfgang Cramer

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