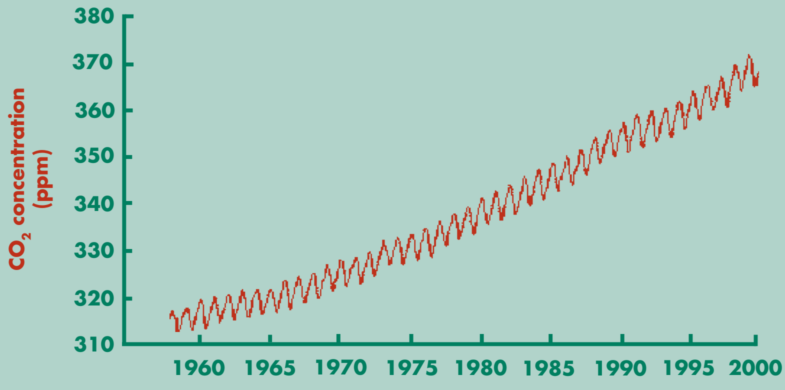
ESF Forward Look Report 1

The ESF Scientific Forward Look on Earth System Science:

Global problems, global science – Europe's contribution to global change research



Keeling curve of atmospheric carbon dioxide

May 2003

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It maintains close relations with other scientific institutions within and outside Europe. By its activities, the ESF adds value by cooperation and coordination across national frontiers and endeavours, offers expert scientific advice on strategic issues, and provides the European forum for science.

The ESF Scientific Forward Look on Earth System Science:

Global problems, global science – Europe's contribution to global change research

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Editors: Tony Mayer and John Marks

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Foreword

When ESF initiated its new Action Lines, the importance of Scientific Forward Looks was quickly recognised as a key element in planning activities in a particular area of science at both a European and a national level. Forward Looks should stimulate new actions in terms of research and also provoke discussion on how best to organise ourselves to deliver the identified research aims. Within the ESF context, Forward Looks are likely to develop proposals for EUROCORES and will impact on the whole range of our activities and on those of our Member Organisations.

I particularly welcome the Forward Look on Global Change Research as it is not only the first Forward Look but it has developed a set of recommendations which demands action from scientists and research organisations. Furthermore, without the major contributions to the finance and organisation of this Forward Look by ESF Member Organisations, this exercise would not have been possible. It, thus, shows the benefit of the ESF "internal partnership" way of working.

The Forward Look has demonstrated the need for Europe to optimise its investment and take leadership in this multidisciplinary topic. It also has thrown down a challenge for researchers themselves. The need to bring together the natural and social sciences is one of the most important recommendations. We have all paid lip service to this in the past, but the Forward Look demands that we take action.

The recommendations need to be taken forward not only by ESF but also by many other bodies, including our own Member Organisations and the European Commission. What ESF will do is to commit itself to work towards the implementation of this report, which is based on carefully prepared reviews and in-depth discussion involving many leading European scientists. It thus provides a voice from the scientific community to which we must all pay heed.

This full report, including the scientific "assessments" of European global change research, provides the basis for extensive debate and the development of new research initiatives in Europe in order to strengthen the continent's contribution to global programmes and enable it to gain a position of leadership in the future.

Enric Banda
ESF Secretary General

Section 1:

The Forward Look

1.1 Introduction and rationale

The ESF Scientific Forward Looks

It is becoming increasingly apparent that both the science community in general and funding agencies at both the national and European level need to be aware of the likely direction that research will take in the future, especially as traditional disciplines combine to produce new and exciting multidisciplinary areas of study. In looking ahead, agencies are also able to better plan their resources to meet future demand, including the development of new facilities and infrastructure, which may have a considerable lead time before becoming available. Additionally, such foresight will help the development of pan-European approaches between national agencies as well as informing European institutions such as the European Commission and the ESF itself.

In its Plan 2002–2006, the ESF committed itself to promote a series of scientific Forward Look activities as part of its role in serving the needs of the European research community and ESF's Member Organisations – for the most part the national research funding agencies. The aim is that the ESF should consolidate partnerships between itself and its Member Organisations, and join forces with other institutions involved in a particular topic.

This requires bringing together the best ideas and capabilities. Such a gathering of Europe's key scientific players in any given topic must aim at producing assessments and recommendations of the highest scientific quality that will be accepted by their scientific peers. At the same time, this should not inhibit adventurous forward thinking and sometimes "thinking the unthinkable"; rather it should provide a means for exploring all ideas and new directions in research.

Such an activity needs to balance assessments of state-of-the-art with looking forward. The nature of research is that it is unpredictable but, within reason, a Forward Look for the next five or more years can provide a useful guide for everyone concerned in monitoring the health of European science.

The Forward Look on Earth System Science: Global Change Research

Scientific research in global change is, by its very nature, an international endeavour, yet its funding is predominantly the responsibility of individual national funding agencies. This situation has worked relatively well as long as collaboration is a matter for individual scientists in different countries, although travel money and sometimes visa and other problems create barriers. Today, the scale and complexity of scientific questions related to global change require an unprecedented global collaboration of scientists from a broad range of disciplines both in the natural sciences and in the social sciences. At the same time, the requirements for infrastructures for global change research increasingly extend beyond the capabilities of a single nation; therefore science funding mechanisms transcending national boundaries are becoming even more necessary. In parallel, the regional dimension is becoming ever more important in global change research. This calls for effective funding structures in Europe in order to promote a strong coordinated contribution of European scientists to the global research effort. The ESF and the EU have important, partly complementary, but rather different roles to play, along with national funding bodies.

The international scientific community developed a set of four global research programmes, known as the Earth System Science Partnership (ESSP), in response to the scientific challenges of the complex issues of global change:

- the World Climate Research Programme (WCRP) deals with understanding the physical climate system, its evolution, variability and predictability;
- the International Geosphere-Biosphere Programme (IGBP) addresses the biogeochemical and ecological aspects of global change;
- the International Human Dimensions Programme on Global Environmental Change (IHDP) has developed a research agenda on the role of humans in causing global changes and how they are affected;
- the International Programme of Biodiversity Science (DIVERSITAS) was created to address the causes and effects of the loss of biological diversity in an interdisciplinary way, and to design tools for a more sustainable use of biological diversity.

The essential role of developing countries was realised early on and as a result the Global Change System for Analysis, Research and Training (START) has been initiated by IGBP, IHDP and WCRP. The START project helps to build endogenous capacities in developing regions so that they can participate effectively in research projects of the international programmes. START also promotes interdisciplinary research at the regional level through its regional networks.

Characteristic of these programmes is their large scale and multidisciplinarity, and their light central scientific management structure. They are very resource efficient because they build on a large body of existing and planned global change research at the national and regional levels, to which they add considerable value by:

- providing a framework for priority setting through an internationally agreed coherent research agenda;
- providing a framework for efficient allocation of scarce resources (for example, ship time, buoy arrays);
- stimulating scientific network building;
- developing common methodologies and experimental protocols;
- organising model intercomparisons and data standardisation;
- promoting the development of research observation networks, some of which may become fully-fledged operational monitoring systems;
- executing synthesis and integration of individual research project results;
- providing essential inputs into the international policy process dealing with key environmental issues, for example through key contributions to the Intergovernmental Panel on Climate Change (IPCC) assessments and through the transfer of results to the public at large.

The total amount of funding for global change research is not the main issue. However, mechanisms for research funding, both national and regional, should be reviewed in order to stimulate the development of a strong European contribution. Unnecessary barriers should be removed. In addition, there is a need for more stable mechanisms to support value-adding activities, requiring less effort in fundraising for the scientific management of these global programmes. The aim of the Forward Look is to overcome barriers of all types and at all levels and to provide a template for more effective collaboration and coordination leading to a more effective use of research money in Europe and a strengthening of the European leadership in global change research.

1.2 Summary and conclusions of the Forward Look symposium

The Forward Look symposium took place in Stockholm from 30 January to 1 February 2002 in partnership with the FORMAS (the Swedish Research Council for Environment, Agricultural Science and Spatial Planning), the Swedish Research Council and with additional support from the NWO (Netherlands Organisation for Scientific Research).

Introduction

In his keynote speech Professor Bert Bolin of Stockholm University and former Chair of the Intergovernmental Panel on Climate Change, placed Earth System science in the context of sustainable development, that is the scientific knowledge necessary to lead to sustainable developments in various domains of society. At the same time, Earth System science is exciting frontline science. It requires a long-term perspective and commitment; it requires research of the highest quality; and it requires a re-thinking of traditional science production beyond disciplinary boundaries. In order to achieve the ambitious goal of understanding the Earth's systems and the way they are being influenced by human activities, it is crucial to support scientists who have the appropriate interests, expertise, and desire to cross disciplinary boundaries and to stimulate gifted young people to develop their talents in this direction. The relevance to society makes it mandatory that the scientific community take an active role in communicating the results to the wider public and contribute to the integration and synthesis of the results to benefit policy making. It is essential to create a dialogue between the scientific community and the representatives of society.

The international programmes of the Earth System Science Partnership (WCRP, IGBP, IHDP and DIVERSITAS) demonstrated that they have done an impressive job in integrating results across all four programmes. Many exciting scientific results have been obtained, as shown by articles in the leading scientific journals, and as was demonstrated in the first Global Change Open Science Conference held in July 2001 in Amsterdam. The ESSP merits support from the scientific community and from the science funding agencies. The next phase in ESSP research will involve a set of fully integrated joint projects, addressing issues such as water, food and fibre, and carbon. Integrated regional research will be an important component of these joint projects. Specific multidisciplinary questions such as climate variability and predictability, industrial transformation, and the role of the coastal zones will continue to be emphasised in their own right but will also contribute to this fully integrated approach.

The approach to the Forward Look symposium

Six small teams of leading European scientists were invited to contribute to the ESF Forward Look by providing an insight for their area of science into what Europe could contribute to the global research effort, based on strengths and available infrastructure; how this could be organised; and what barriers need to be overcome in order to realise the European contribution. The areas chosen were not meant to be all-encompassing, but rather to be illustrative of what Europe could contribute. It is expected that the case study papers will serve as seeds for initiatives in the scientific community and for action in the funding community.

Outcomes of the discussion on the case study papers

A common element in many of the case studies was the observation that Europe has considerable strengths to offer to global change science. There are excellent groups in each of the case study areas and there is a rich diversity in scientific approaches and study sites. In particular, the diversity in both cultures and landscapes was mentioned. The EU accession countries have a lot to offer in this context. In many areas of modelling, such as the interplay between the social system and the environment, Europe is recognised as the world leader. However, sub-optimal use is being made of these European resources mainly because of how research is planned nationally, based on a variety of national priorities that are insufficiently integrated at the European level. This could be rectified by a more coordinated planning of future projects (individual as well as joint) at a European level and by more communication about national priorities. There was a call for a strong science-driven coordination of global change research in Europe. In this context an open competition for funds across borders on the basis of quality was proposed, which should not be restricted solely to the policy goals of the EU. A European role in the scientific coordination by the global research programmes requires a small but stable and easy to access budget for value-adding activities. To date, these funds are insufficient and dispersed. The gap between the natural sciences and the social sciences was seen to be a major problem in most of the case studies. For all areas, monitoring and long-term datasets are increasingly essential; the continuity of the *in situ* component of monitoring was especially considered to be in jeopardy.

Better use of existing instruments for supporting global change research

There are a number of players within Europe with an interest in global change research, most of whom operate at the national level. The overview of mechanisms and instruments for supporting Earth System science at the European level in the ESF, in the EU Framework Programme, and in other organisations, demonstrated that a wide range of mechanisms is already available. Also the presentations of national research showed that many national instruments supporting global change research already exist; most of these also encouraged and supported international collaboration. Maximum use should be made of these instruments in the design of collaborative programmes. Barriers to their effective use in supporting integrated Earth System science programmes should be analysed and recommendations on how to improve their usefulness should be addressed to the appropriate bodies. A wide range of programmes addressing various aspects of Earth System science is already ongoing in several European countries. These programmes vary considerably in size and in design; some only bring together research supported in a responsive mode by the funding agencies, whilst in other countries there is a fully coordinated activity from the outset. As a first step to European integration, the potential for linking these programmes should be explored in depth. The presentations and the ensuing discussion gave the sense that there is willingness in the national science funding structures to explore such linkages and the ESF was seen to be an appropriate forum for such discussions.

Data and monitoring

Monitoring is an essential tool for Earth System science. It requires an integrated system with remote sensing (especially from space) and *in situ* components, and with associated data handling, distribution, and storage. The problems related to the development and maintenance of such a system were illustrated, in particular, by reference to ocean monitoring. The synergy between monitoring requirements for research and those for operational policy and commercial purposes was clearly demonstrated. The cost of operational systems cannot and should not be funded from science budgets. This calls for partnerships. In Europe, the Global Monitoring for Environment and Security (GMES) initiative of the European Commission, already endorsed at a high political level, should develop into an important mechanism in this respect. An effort to develop new technologies is essential for reducing the cost of monitoring in order to meet new emerging needs. The ESF could play a leading role in stimulating the development of such technologies through its EUROCORES scheme. The availability and access to data are other key factors for frontline science. Responsibility for storage, interoperability of databases, and data policies requires attention at the European level.

Links between science and policy

Finally, the links between science and policy were considered. There is still a gap between the scientific community and the policy community in appreciating and understanding each other. The new Earth System science has a lot to contribute to developing a scientific basis for a sustainable society. The EU plays a key role in this area at the European level. The EU requires a firm scientific basis for its policy directives, which in turn drive the priorities in the Framework Programme. The EU should look to the ESF to provide the scientific platform to develop science plans for Europe and to bring together and support European research groups that can contribute to policy-relevant advice to the European Commission.

1.3 Recommendations

1• **Th**e European scientific community is encouraged to initiate the development of flagship projects that address the challenges of the science agenda of the Earth System Science Partnership programmes in a bottom-up manner. Projects such as these should make a strong European contribution to the global programmes, making maximum use of European intellectual strengths, other scientific and technical facilities and capabilities, including the relevant available research infrastructures. The projects must be open for the participation of the best research groups in Europe and if necessary provide the basis for the definition of new European research infrastructures. Such projects must make maximum use of the existing mechanisms of the ESF, and of its Member Organisations, of the EU, as well as opportunities offered by other organisations such as ESA, EUMETSAT and ECMWF. Projects should aim at fully integrating into the global research effort. Integrated projects of research in the Arctic and sub-Arctic Basin and in the Mediterranean Basin (some programme proposals for aspects of the Mediterranean are already under discussion) were identified as flagship projects which could constitute major European contributions to international global change research within the context of the ESSP. Such an approach must ensure the full integration of the social and natural sciences from the very start.

2• **Th**e concept of the European Research Area (ERA), proposed by the EU Commissioner for research, Philippe Busquin, points to the need for a full integration of scientific efforts across

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the whole spectrum of European science, not limited to the mission-orientated policy goals of the EU Framework Programme. The application of this concept to Earth System science requires the setting up of a European global change board. This board would provide a platform that could bring together all the relevant European players, including the ESF and the EU. Given that such a body must be science driven and policy relevant, it is appropriate that this should be organised by the ESF, but the European Commission and the EU Framework Programme would have major roles to play; thus, it would be seen as a fully collaborative effort. The main tasks of this board would be:

- to act as a platform to stimulate the development of European flagship projects addressing the agenda of the ESSP, making maximum use of existing mechanisms. Advantage must be taken of ESF instruments, in particular, EUROCORES. This recently established instrument is well suited to bring together national funding agencies in a funding partnership for European cooperation in research without the need to transfer national money and without the need for new structures. Also the new instruments in the EU Sixth Framework Programme, Large Integrated Projects and Networks of Excellence, as well as the collaborative programmes of national research councils should be used effectively for such flagship projects;

- to develop efficient mechanisms to stabilise and increase the European contribution to the budgets for the value-adding activities of the ESSP programmes, building on existing mechanisms within the ESF;

- to identify barriers and complexities imposed by national and European funding mechanisms which prevent the full development of the potential of international scientific research collaboration and to propose harmonisation measures;

- to propose, in exceptional situations where existing instruments clearly fail, to the ESF, its Member Organisations, and to the EU, new instruments for European collaborative programmes;

- to identify the potential for better coordination of, and more collaboration between, national scientific infrastructures and to propose new research infrastructures required by the European effort in Earth System science.

The proposed board should be composed of representatives of the ESF Member Organisations; the European Commission; the international programmes of the ESSP and other agencies in Europe, both at the national and European level, involved in supporting global change research; and scientific leaders in the field. Criteria for membership of the board should be the preparedness to discuss and act on structural issues and their financing consequences as well as the capacity to understand the science involved.

3• The Forward Look addressed four specific themes which are essential for programme development in Earth System science: (a) the collaboration between the natural and the social sciences; (b) the interface between the science and the policy domains; (c) the requirements for monitoring and data; and (d) capacity building. The most important agreed recommendations are as follows.

a. Collaboration between the natural and the social sciences

In nearly all domains of Earth System science, the role of humans is a key factor as a driving force, as a subject of impacts, and as an agent in mitigating impacts. Collaboration can take shape only if programmes are developed in a side-by-side collaboration of natural and social scientists from the very start. The new approach to Earth System science in which the global system is addressed by synthesising fully integrated research (both on a global and a regional scale) on key themes such as water, carbon, and food and fibre production and consumption systems, offers an excellent potential for collaboration initiatives at the European level. The ESF has an important role to play in breaking down the institutional barriers that hamper collaboration between the natural and the socio-economic sciences. These barriers also hamper the engagement of leading social scientists in global change research. Examples of such barriers include the way in which the peer review system operates and is organised at present, the publication culture, the funding structures and the mutual suspicion that exists between the two communities. There has to be a willingness to plan projects together from the start, taking into account the different traditions in the various disciplines. The proposed European global change research board should play a leading role in identifying and analysing such barriers and in proposing solutions to overcome or remove them. The relevant bodies of the ESF should be closely involved. In particular, the ESF Standing Committee for the Social Sciences should be invited to stimulate key communities to become active in this area.

b. The interface between the science and the policy domains

Earth System science is an area of integrated scientific effort to resolve frontline scientific questions about the functioning of our planet. At the same time, problems in society related to a sustainable use of the Earth's resources and the development of a sustainable society, require a much better insight into the Earth's fundamental processes and in the way humans act in relation to sustainable futures. From now on the results of Earth System science must also feed into the policy domain. On the other hand, society has very specific questions for the scientific community regarding these issues. The proposed European global change research board could play a role in organising the input of science into regional assessments at the European level. While the clear lead role lies with the EU, the proposed board could act by creating a directory of Earth System science; a clearing-house of information and available expertise. Finally, scientists should accept that they have a responsibility, both individually and as a community, to communicate their research results to the wider public and to inform policy makers and politicians, and also to build this into research activities as part of the general dissemination of results. This requires the creation of methods for dialogue between the scientific community and the general public.

c. Requirements for monitoring and data

Science provides the basis for the design of operational systems for environmental monitoring for policy and commercial purposes. In turn, Earth System science is

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crucially dependent on monitoring from space and *in situ*. Once an operational phase is reached, the responsibility for the monitoring systems should be transferred to operational entities and should not remain within the research setting.

This calls for partnerships between the scientific community, science funding agencies, and operational monitoring entities. At the European level such partnerships should be created involving the European Commission, ESF (and its constituent parts), ESA, and EUMETSAT. Other players such as EuroGOOS and ECMWF should also be involved. It requires long-term commitments from governments to invest in the infrastructure needed for operational monitoring for policy, science, and private sector applications. In this context, it is necessary to create an awareness in government ministries and agencies of the importance of monitoring and of the need for a coordinated effort in its investment. At the same time it should be realised that some of these ministries may play only a small role in monitoring. A special effort is required to create awareness of the importance of the *in situ* observations, as these often receive the least attention.

The European effort in this area should form part of the Integrated Global Observing Strategy (IGOS). The proposed European global change research board could promote the active participation of Europe in the approved activities of the already established IGOS partnerships. The new EU initiative on GMES offers a potentially powerful mechanism to organise and focus the European effort. The proposed board could develop a close relationship or – better still – be acknowledged as a key player in the GMES structures, as representing one of the principal user communities.

The next generation of monitoring systems must be much more cost effective. This will require new science and technology. The ESF should promote the development of this next generation technology in close collaboration with European partners and EUROCORES should be explored as a mechanism for this collaboration.

Efforts need to be made to develop databases for social science research within Earth System science.

Increasingly, the cost of obtaining, archiving and providing available and accessible data is becoming a significant problem. Publicly funded data has to be made available to researchers without a commercial charge. Funding of data acquisition and storage systems should allow the provision of data at no, or little, charge to bona fide scientists undertaking public good research. The science funding agencies should take an active role in ensuring that frontline Earth System science research is not inhibited by data problems as European researchers are seriously disadvantaged when faced with charging systems based on full-cost recovery.

d. Capacity building

Insufficient human capacity is a – if not the – primary factor preventing Earth System science research from achieving its full multidisciplinary breadth. A major accomplishment of the ESSP programmes has been the education of a new generation of scientists capable of making significant contributions to the integrated multidisciplinary science effort. However, an increased and sustained effort is needed. The European science funding agencies should support this effort by stimulating multidisciplinary science projects for promising young scientists. In addition there is an obligation on the EU and on national agencies to develop multilateral efforts to aid capacity building in the developing world, including the support of young researchers. This will also help to favourably influence funding decisions taken by international bodies such as the World Bank or through the Global Environmental Facility (GEF).

A second issue in capacity building is that there are large untapped resources in the EU accession countries and in the developing world. In addition to the importance of supporting science as an instrument for sustainable development, there is the simple necessity that if we really want to study as well as monitor the Earth's systems in a comprehensive global manner then we need to develop partnerships. This in turn implies an obligation to help build capacity. Partnerships between science funding agencies and the development assistance agencies should be promoted to support this.

Section 2:

Setting the Stage

Earth System science is part of a wider scientific effort to contribute to achieving a sustainable development of our global society. Ambassador Bo Kjellén of Sweden, in his welcome address, put this in the context of the preparations for the World Summit on Sustainable Development in Johannesburg in September 2002. In his Keynote speech, Professor Bert Bolin further developed this close link between Earth System science and the science necessary for sustainable development. Professor André Berger, the winner of the 2001 ESF European Latsis Prize, showed the need to put sustainable development into the context of astronomical and geological settings of the Earth and its likely future condition.

1.1 Welcome address

Ambassador Bo Kjellén
Ministry of the Environment of Sweden

On behalf of the Swedish Government, I wish to welcome you most warmly to this important conference. Our Minister of the Environment, Mr. Kjell Larsson, would have liked to be here himself, but he has had to take a couple of months leave for medical reasons; however, he has asked me to convey to you his warm greetings and wishes for the success of the conference. We are all gratified that the European Science Foundation has accepted the invitation to hold in Stockholm this major symposium on global change.

The Swedish Government has taken a number of initiatives to ensure that the objectives of sustainable development are taken into account in decision making over the whole range of public and private activities in this country, at the national, regional, and local levels. The ambition of integrating the ecological, social, and economic aspects of the concept has been highlighted; this is of course in line with the way in which the international discussion on sustainability has been moving since the Rio de Janeiro Conference in 1992.

It is a major step to agree that these three components of sustainability have to be compatible and mutually supporting, and the importance of this progress in thinking should not be underestimated. No doubt the confirmed existence of global environmental threats such as climate change, ozone depletion, widespread desertification, and increasing water stress have demonstrated that mankind is faced with new challenges which will require new responses, not least in the field of multilateral diplomacy. And the follow-up to Rio has shown that governments are taking these threats seriously; the Marrakech Agreements on climate a couple of months ago proved the point. And as Europeans, I think we should all feel satisfied with the way in which the European Union played the leading role in this process.

Nevertheless, my own experience as an international negotiator in the field during this period and as a concerned citizen has confirmed to me that we need to go beyond the generalities of the discourse on sustainability. It is necessary to try to clarify in a more precise way how the new concerns for the environment at all levels impact on other societal processes. This requires a conscious multidisciplinary approach in a global perspective.

In 2000, the Swedish Government, after extensive debates in the research community and in Parliament, decided on a new structure for the research councils that finance an important part of Swedish research. On their boards, the research community has the majority. Eleven research councils were merged into four; and the issues closely linked to sustainability were concentrated in the Research Council for the Environment, Agricultural Sciences and Spatial Planning (FORMAS). I have the privilege to chair the FORMAS Board.

FORMAS has been operative for a year and we now have to strengthen the instruments at our disposal for supporting well-designed multidisciplinary research on sustainability. And speaking as a representative of the Swedish Government, it is also essential that the links to international and national action on all these problem areas are fully explored. As the UN Secretary-General pointed out in his recent report on sustainable development, there is an obvious link between ecosystem health and human health.

In this context, I also wish to refer to the paper on food and fibre. The authors at one point state: "The development of new, interdisciplinary research approaches requires more than just networking and synthesis. New thinking is required to develop and implement a research agenda that is both relevant to the policy formulating process and to the scientific community." To me, this captures the essence of what we are all aiming at.

As a practitioner, it has struck me that the response of multilateral diplomacy to the new global threats has been driven to a large extent by the natural sciences, but that on the other hand the results of our negotiations will only be fully operative with the full contribution of the social sciences and the humanities. The reason for this is that global sustainability will require changes in our societies that will certainly not be easy to achieve, neither at the societal nor the personal level. And we have to be open to critical reflection on the way in which our systems work, such as that provided by Ulrich Beck with his concept of the "risk society".

Just to take the example of climate change: reductions in the emissions of greenhouse gases will affect the very heart of our industrial civilisation – energy and transport. Action on climate change will increasingly be part of economic and social policy and touch on the central areas of democratic decision making. The Intergovernmental Panel on Climate Change is indeed so far the outstanding example of an efficient contribution of science to an international negotiating process, and I have no doubt that similar methods need to be applied in other areas as well.

No doubt these issues will appear in the preparations for the World Summit on Sustainable Development in Johannesburg in September 2002, to which the Swedish Government attaches great importance. This major conference comes thirty years after the first UN Conference on the Human Environment, here in Stockholm, and ten years after the Conference on Environment and Development in Rio de Janeiro. We have learnt a lot during thirty years and important progress has been made, but when we look around the world we realise that there has been only a very limited success in the fight against poverty – our intragenerational challenge – or in the efforts to achieve long-term sustainability – the intergenerational objective of the Brundtland report.

In preparing, negotiating, and following up Johannesburg, the European Union has to be a strong driving force. We are well equipped to take up this responsibility. The Sixth Environment Action Programme and the Sixth Framework Programme, both concluded during the Swedish Presidency, establish a firm basis for action in the areas that will be tackled during the Stockholm Conference, and also establish a structure for long-term support for sustainable development by the research community. So does the creation of the European Research Area and the EU Strategy on Sustainable Development, as adopted by the Göteborg summit in 2001. Together these central documents set an agenda that will have a major impact on the efforts of the European Union to make a lasting contribution to the long struggle for global sustainability, facing the world of nine billion people in which our children and grandchildren will live around 2050. We must never forget that we are the first generation that can influence the living conditions of future generations globally.

Decision makers will not be able to face this responsibility without the help of science: independent, imaginative, multidisciplinary science. As we are calling for still more cooperation across the boundaries of disciplines, I am sure that many think of C.P. Snow, who in 1959 wrote his famous book *The Two Cultures*[1]. The debate has continued since then, but it may well be that the combined concepts of sustainability and global change are modifying the basis for this debate. However, C.P. Snow one year later held a series of lectures at Harvard University, called "Science and Government", which in fact addresses the *problematique* so brilliantly described in Uno Svedin's contribution to this symposium. Speaking from the Government side today, and in relation to Uno Svedin's paper, it seems pertinent to quote some of the Snow's words, where Snow pleads for the contribution of science to policy making. He notes that: "Scientists have it within them to know what a future-directed society feels like, for science itself, in its human aspect, is just that." Whereas he feels that: "Administrators are by temperament active men. Their tendency … is to live in the short term, to become masters of the short-term solution." And to conclude, Snow said: "We are immensely competent; we know our own pattern of operations like the palm of our hands. It is not enough. That is why I want some scientists mixed up in our affairs."

And that is why I, as a representative of the Swedish Government, feel so privileged to address this European Science Foundation symposium devoted to global change research. I am confident that this conference will make a major contribution to the further thinking on these central problems and to the Forward Look.

[1] C. P. Snow (1959). *The Two Cultures*. Cambridge University Press, 1993.

1.2 Keynote address: Science for sustainable developments

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Global change and sustainable development

The definition of "global change" includes detection, analysis, and interpretation of the observed variability and changes in the Earth's systems on global scale. An important aspect is to determine the role of human activities in explaining the ongoing changes, and to develop models that would help us to project possible changes caused by future human activities. However, we are not able to predict human behaviour, nor the future development of a global society; we therefore cannot "predict" changes in the global environment in the real sense of the word. But we can develop sets of possible and internally consistent scenarios, although we cannot exclude surprises. If used properly, such scenarios may be of great help in determining the range of possible future changes. In view of these facts and in order not to be misinterpreted in the communication and applications of scientific findings, the word "prediction" should be used with great caution.

Because of expected future changes in the global environment the issue of how to secure a sustainable future for humankind has arisen. The expression "sustainable development" has been coined and has come to mean the search for how a future structure of the global society might be organised and to what extent our exploitation of natural resources might have to be limited in the light of the constraints that nature imposes.

Science for sustainable development will of necessity require close cooperation between researchers in the fields of natural and socio-economic sciences beyond what so far has usually been the case. Contributions in this context will require the development of dynamic models of how human activities affect the environment and the reverse; namely: What will be the response of people and society to environmental change? Necessary or desirable modification of human behaviour might require setting new priorities.

Efforts to formulate ways and means to achieve this have just about begun. It might also be appropriate to take a reverse approach and ask the question: What development pathways would *not* be sustainable beyond a decade or two, as well as in the long-term, and accordingly should be avoided? (Schellnhuber et al.1997). This is also relevant because there is not just one approach to sustainable development as people wish to shape their own future based on personal preferences, for example cultural values. Therefore, sustainable development must be anchored in the socio-economic and humanistic sciences, and such efforts should be a major part of a European programme for global change research.

It is interesting to note that the detection as well as the description of the major environmental threats now in the forefront of attention have been science driven. The scientific community has also been quite successful in safeguarding its integrity in communicating its scientific findings in a balanced and well thought through manner to politicians, stakeholders, and the general public. The initiatives to take preventive measures have sometimes been successful, as for example in stopping the depletion of the ozone layer, but less so in other cases particularly with regard to a slow down of human-induced global climate change. An effort is now required, with the social sciences in the lead, and with natural scientists providing information on the environmental constraints that nature imposes.

The need to pay increased attention to sustainable development

Scientific research addressing the issue of sustainable development has so far been modest. Few countries have adopted clear strategies on how to deal with sustainable development in spite of the threats that are becoming increasingly clear. Environmental destruction is rapidly getting worse in developing countries, but developed countries will also have to find ways to secure their sustainable future. We are all becoming increasingly dependent on each other. The limitations of the carrying capacity of the land and its possible decrease, particularly in developing countries, may upset the basis for peaceful coexistence of people and nations and be a major source of conflict. The rapid change in the global society and the increasing use of natural resources is worrying, similarly so the stress that people are exposed to and the conflicts that therefore may arise. The likely increase of the world population by two to three billion people during the first half of this century will probably almost exclusively occur in the major cities in developing countries. Sustainable development is obviously at stake. What does this imply?

As the ESF is addressing the issue of global change in terms of a Forward Look, it seems essential not that primarily interdisciplinary research projects involving natural sciences *or* socio-economic sciences be supported – as I feel is still often the case, as evidenced by the papers prepared for this symposium – but that integration of *all* relevant research disciplines is needed in order to learn about the functioning of the Earth's system as a whole. More equity will have to be achieved between developed and developing countries as well as rich and poor people within countries fifty years from now, when the global population may well have increased by 50%. This will require the availability of more food, water, energy, and raw materials without the deterioration of the environment and loss of fertile lands and waters as a result of increased exploitation. This is indeed a challenge.

The Stockholm Environmental Institute (2002) is just about ready to publish a study, which addresses a number of issues that will arise in this context. More research will be needed to address these issues adequately.

The need for early action

Even if the major threats to the environment are recognised by most people and politicians, no real urgency for action can be noted. Negotiations between countries are still much governed by their efforts to get by with the least possible commitment. The reason is partly the difficulty in describing more vividly, but still accurately, the implications of global environmental change; for example, it is clear that in global climate change the occurrence of extreme events might be more disastrous than a gradual change in average temperature or rainfall. How can the impacts of such events be better captured? Not only the environmental disturbances need to be described but specifically their societal implications. How to bring in the concepts of "risk" and "vulnerability" into the analysis more systematically? Where will the most damaging changes take place and how quickly might such "hot spots" develop?

The global system, its environmental as well as human components, is a chaotic system. How meaningful would it be to search for features of expected changes that might cause drastic societal changes? For example, droughts in the sub-tropics might well become more frequent (IPCC 2001) and countries in these parts of the world are often poor and therefore more vulnerable. Analyses are needed about how these countries would cope with major changes in their region as a consequence of global change?

The possible long-term (50–100 years) global changes in the climate have been analysed by many and the long-term features of the climate system that deserve attention have been elucidated. However it will be difficult to reduce the uncertainty of such analyses and present results that are more robust and reliable because of the problem of validation. The confidence in model projections is fundamentally dependent on how convincingly they can be validated against observed changes as a global environmental change emerges. As yet, rather few of the observed major extreme events in recent times can be ascribed to being part of human-induced global change. Can progress be made in this regard?

In addition, long-term integrations hardly convince politicians that early preventive actions are needed; they are seldom able to envisage the significance of changes beyond a decade or two, and there is a lack of more detailed analyses of the changes that are likely to occur during the next 10–20 years, and in particular what their implications might be. Which *early* actions might be needed to ease long-term threats? For example, how quickly must the energy supply system be changed in order to avoid an increase of atmospheric carbon dioxide concentrations to 500–550 ppmv, if measures were delayed 10–20 years rather than being begun immediately? It should then be recalled that the lead time for building new major electricity-producing units is at least 10 years and it will take much longer to change the system as a whole. The issue of urgency needs increased attention.

Developed and developing countries

The most obvious controversy in the global context concerns the role and responsibilities of developing countries during the next few decades. It is often argued that the threat of climate change is primarily the result of past emissions of greenhouse gases by developed countries and that they therefore should take the lead in mitigation efforts. The Framework Convention on Climate Change and the Kyoto Protocol certainly make this very clear. Future "permissible" emissions of carbon dioxide by developed and developing countries respectively (derived on the basis of the IPCC stabilisation scenarios; IPCC 2000) through to 2050 (Bolin and Kheshgi 2001) but expressed in terms of emissions per capita, are shown in Figure 2.2.1. At present the per capita carbon emissions by USA and Canada are more than 5 tonnes per year, and by other OECD countries about half that amount, while developing countries on average emit merely 0.55 ton per capita and year. A requirement to stabilise atmospheric carbon dioxide concentrations below 550 ppmv implies that developing countries would not be able ever to emit more than about 1.3 tonnes of carbon annually, even if developed countries were to drastically reduce their emissions, say by 50–75 % or even more, during this century. To some extent, but probably only temporarily, an enhancement of the terrestrial sinks might ease the situation. These conclusions are rather robust and call for major efforts by developed countries to provide non-carbon emitting energy resources.

Can other conclusions be extracted from the IPCC (2000) *Special Report on Emission Scenarios* (SRES) or other research efforts related to sustainable development? It is strange that only half a page of the SRES is devoted to analyses of the importance of the possible occurrence of regional "catastrophic" developments (in the sense of chaos theory) of the supply systems for fossil fuels. It should be noted that within a decade or two the supply of oil and gas will come from only a few regions of the world primarily outside the OECD countries. What will this imply and how would such a situation be modulated by the availability of new forms of primary energy?

Some specific foci for a European programme

Fundamental research is best pursued by gifted individuals through the cooperation that naturally develops in this age of excellent communication facilities and networking. This is presumably best supported by funding from national research agencies and foundations in recognition of the importance of these new emerging fields of scientific endeavour. It is important that adequate funding is available for such work, particularly as support for cooperative European efforts, which is the subject of this symposium.

The large international research programmes, namely WCRP, IGBP, IHDP and DIVERSITAS are organising the global research efforts. Europe should accept these programmes as the starting point for formulating joint European efforts in this context. European scientists already play a leading role in these truly global undertakings.

There is a great need for international cooperation concerning: data collection; assimilation and analysis; the development of the Earth's system models, especially the integration of global and regional environmental models; and socio-economic models. This is the kind of work that is of most immediate interest for the development of strategies for sustainable development and accordingly of prime interest in the political context.

How then can Europe best contribute? What are the European interests and where is competence to be found? Which priorities should be set? In particular, what efforts will require European coordination and what should rather be left for the individual research teams to address as part of their projects back home? These are important issues, which will have to be decided by the scientists themselves.

However, in order to be of best use in general, and in the context of sustainable development in particular, it is essential that a constructive dialogue be maintained between the scientific community and society at large. Too many scientific reports have been put on the shelf without having been considered adequately. In this regard lessons have been learned from the efforts relating to global climate change. Finally, at this stage it is rather more important to set priorities and decide on projects than to aim for comprehensive overviews. The latter has actually already been accomplished in the global context.

Global models of the environmental system and its changes must build on regional models that capture the special features found in different regions and that govern the socio-economic responses to ongoing and future changes. These should be interlinked in order to incorporate the large-scale interplay between the environmental and socio-economic systems. There are numerous conceivable projects that deserve attention, but I will restrict myself to two important examples of particular interest to Europe:

The Mediterranean region

The Mediterranean region is probably the region that might be most vulnerable to climate change. A proposal for a concerted effort has been worked out by a good number of European scientists. I cite the introductory paragraph of that document.

> "The Mediterranean Basin, being the Mediterranean Sea and the contiguous regions, is characterised by the vulnerability of its water resources to climate variability and the actions of man. Climate change is a potential hazard with regional and global dimensions. Dry spells in the summer promote wildfires, loss of harvests, and ecosystem damage. On the other hand, abnormal storm and flash floods recently affected North Africa and Spain. The sensitivity of its energy and water cycles to atmospheric conditions, locally and through teleconnections to the North Atlantic Oscillation and Indian Monsoon is exacerbated by the over-exploitation of ground water resources owing to desertification and population-growth related processes. Regionally, a drastic decrease of ground water levels is associated with the disappearance of wetland habitats. The consequent saline water intrusion into vital coastal aquifers has led to water-resource loss, associated with high pollutant concentrations from agricultural practices. In addition, the stress on the environment has rapidly increased through an increase in the atmospheric particulate load (aerosols) that affects both human health and the water cycle. The Basin has increasingly become affected by air pollution, not only through local wildfires and industry, but also via long-range transport from other parts of Europe."

The Arctic Sea and adjacent land areas

No specific proposal is available, but the WCRP has set up a special committee (ACSyS, Arctic Climate System Study) to plan and coordinate activities. It is obvious that the enhanced global warming that the Arctic region may experience, and that actually already has begun, may have far-reaching repercussions on the North European scene, and the North Atlantic is an area of profound importance for global ocean circulation. The North Atlantic Oscillation, the reduction of the ice coverage in the Arctic Sea, particularly in summer and autumn, a slow reduction of the intensity of the Gulf Stream and its penetration into the North Atlantic and the Arctic Sea, may be related to a changing climate and are of immediate concern for Europe. Changes such as enhanced precipitation at northerly latitudes, the formation of less saline water in the Arctic Sea, and a possible future reduction of the deep water formation are key features that need careful attention. The socio-economic implications of major environmental changes in the north are also interesting because of the presence of the indigenous populations in the area. Collaboration with North American and perhaps Russian Federation scientists would be desirable. It should be noted that an assessment of present knowledge about the climate and climate change in the Arctic region has been initiated with participation by all circumpolar countries. The final report is expected by 2004.

Initiatives are required to make a European global change programme visible in order to attract adequate funding. It is important to point out that even though some of these efforts are of an applied nature, the development of Earth's system models is a necessity in order to be able to address fundamental problems in the environmental as well as the social sciences. The difficulties in developing core programmes in the IHDP are related to the limited past efforts to consider regional, and in particular global, societal issues of this kind. It is important that this difficulty be overcome.

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2.3 The astronomical theory of palaeoclimates: does it matter for sustainable development?

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Summary

From the insolation view point and from data and model results a better analog than the Eemian for the future is isotopic stage 11 (around 400 000 YBP). Actually, the orbital forcing for the present and next tens of thousands of years is almost unique, the predicted CO_2 concentrations for the next centuries (and already the present ones) are unprecedented and finally, according to our modelling results, the present Holocene interglacial will, most probably, last exceptionally long, with no counterpart over the last million years. In this context, the anthropocene of Crutzen and Stoermer might be the end of the Quaternary and the transition towards the Quinternary, a new geological period with much less ice on the Earth.

Future insolation

The major characteristics of the insolation of the next 130 kyr is the small amplitude of its variations (Berger 1978). This amplitude is slightly increasing with time, but is far less than the amplitude at isotopic stage 5. For example, over the next 50 kyr, the amplitude of insolation at 65°N in June is less than 30 Wm^2. Consequently, from the point of view of insolation only, the Eemian can hardly be taken as an analogue of the next thousands of years, as it is often assumed.

This kind of weak insolation variation from 5 kyr BP to 60 kyr AP is really exceptional and only five intervals, in particular from 405 to 340 kyr BP, were found to be highly correlated to this reference insolation pattern.

This almost unique characteristic of insolation over the next 100 kyr is actually a result of being in a minimum phase of the 400-kyr cycle of eccentricity. The transition between the last and the next 400-kyr cycles is characterised by a short cycle (at the 100-kyr frequency) with a low amplitude. This considerably damps the amplitude of the variations of precession (which reinforces the role of obliquity), but it also shortens the length of the precession cycles.

Modelling past climates

Different experiments using the LLN 2-D climate model have been made to analyse the response of this model to both insolation and CO_2 forcings. This model (Berger, Loutre and Gallée 1998) links the northern hemisphere atmosphere, ocean mixed layer, sea ice, ice sheets, and continents. It is a sectorially averaged latitude-altitude model that reproduces well the present-day climate.

Forced by both the insolation and the Vostok CO_2 reconstruction, this model also simulates the long-term variations of the northern hemisphere ice volume in agreement with the SPECMAP isotope record (Berger, Loutre and Gallée 1998). It simulates the entrance into glaciation around 2.75 Myr BP, the emergence of the 100-kyr cycle around 900 kyr BP and the late Pliocene-early Pleistocene 41-kyr cycle (Berger, Li and Loutre 1999). Besides the forcings, modelling results indicate that some processes and feedbacks play a very important role, in particular the albedo-temperature feedback, including its relationship with the land cover and vegetation, the water vapour feedback and the ice sheet-isostatic rebound.

Predicting the future

In order to investigate the response of this model to future forcings, three constant CO_2 concentrations were used in addition to the

[1] André Berger is the winner of the ESF European Latsis Prize 2001: http://www.esf.org/esf_pressarea (item 16).

insolation: a low value (210 ppmv); a high value (290 ppmv); and a medium value (250 ppmv) corresponding to an average concentration for, respectively, glacial, interglacial, and intermediate times. It must be stressed that the present-day level of atmospheric CO_2 is already 370 ppmv, 30 % above the interglacial level and about twice as much as during the glacial maximum.

Over the next 130 kyr northern summer insolation is high everywhere and no ice sheet can develop with a high CO_2 concentration (290 ppmv). However, when CO_2 is low (210 ppmv), the ice volume increases up to 58 kyr AP where it reaches 32 x 106 km^3 and the following glacial maximum is reached at 101 kyr AP with this same amount of ice.

During the whole interval from 20 to 110 kyr AP, the difference between the ice volumes generated under a 210 and a 290 ppmv forcing is very large. This reflects a higher sensitivity of the model to CO_2 when the insolation variations are small (now and in the future) than when they are large (Eem). This conclusion, if confirmed by experiments with more sophisticated models, maybe very important in the framework of the intensification of the greenhouse effect due to human activities.

But past CO_2 concentration has undergone large variations (Jouzel et al. 1993) and there is no reason why it should not be the case in the future. Using these values as a natural scenario, the ice volume simulated by the LLN 2-D model, starting with the present-day Greenland ice sheet, leads to an interglacial that is exceptionally long. The peak of this interglacial lasts ~ 55 kyr (from 5 kyr BP to 50 kyr AP), which is rather unusual when compared to the more traditional 10 to 20 kyr found in geological records. This characteristic is related to the small changes in insolation described above and a CO_2 concentration that remains larger than 270 ppmv over the next 15 kyr. Starting at 50 kyr AP, there is a global trend of growing ice sheets with a short reversal that lasts roughly 10 kyr. The first maximum of ice occurs at 63 kyr AP with 22 x 106 km^3, a maximum that is partly due to the important decrease of CO_2 that starts at 57 kyr AP. It is followed by a secondary minimum at 71 kyr AP with 20 x 106 km^3 of ice and a maximum of 33 x 106 km^3 at 100 kyr AP, before deglaciation begins.

Using a CO_2 scenario based upon Shackleton et al. (1992) leads to ice volumes similar to the "natural" experiment just described. However, the melting of the ice sheets at 120 kyr is much more important with the Shackleton scenario than with the Jouzel values. This is because in the Shackleton scenario insolation and CO_2 increase approximately in phase, leading to a severe melting of the ice sheets, while with Jouzel values insolation and CO_2 play opposing roles. This shows the extent to which CO_2 concentration can either reinforce or damp the effect of insolation.

With all the precautions required by the quite arbitrary nature of the CO_2 scenarios and by all the hypotheses of the model, it was decided to test the sensitivity of this natural evolution to the anthropogenic increase of greenhouse gases over the next few centuries to millenia.

The possible human impact

Let us first note that, according to the reconstructed CO_2 concentration over the last two glacial–interglacial cycles, 290 ppmv is reached only during very limited periods. Most of the time, the CO_2 concentration is situated around 225 ppmv (between 210 and 250 ppmv). Assuming a constant CO_2 concentration of 250 ppmv over thousands of years (as we did; see above) there is already a very strong forcing of the climate system, if we refer to the last 400 000 years. This is why two other long-term CO_2 scenarios were constructed, during which high CO_2 values will be kept over much shorter times. They are based upon the IPCC scenarios leading respectively to a stabilised CO_2 concentration of 750 and of 550 ppmv between the 22nd and the 23rd centuries (Loutre and Berger 2000). Currently, it is assumed that the CO_2 concentration: will increase from the unperturbed level (assumed to be 296 ppmv in the model) to 750 or 550 ppmv over the next 200 years; will decrease to 300 ppmv over the following 450 or 300 years; will reach linearly the 1 kyr AP concentration of the natural scenario; and will then follow this scenario up to 130 kyr AP.

The responses of the northern hemisphere ice sheets to these scenarios are very different. In the 550 ppmv experiment, a slight melting of the northern hemisphere ice occurs only over the next 1 000 years and it is very difficult to see any difference with the results from the natural scenario based upon the Vostok data. For 750 ppmv, the impact is far more pronounced, a complete melting of the Greenland ice sheet being simulated between roughly 10 and 14 kyr AP. These results seem to indicate that there is a threshold value of CO_2 above which the Greenland ice sheet disappears in the LLN 2-D model. The simulated ice volumes in the 750 ppmv scenario are almost the same as in the natural scenario after 40 kyr AP. After 100 kyr AP, the natural (the 550 and the 750 ppmv) scenarios lead to more or less similar results. It seems therefore that 40 kyr at least are required for the climate system to be no longer sensitive to what could happen over the next few centuries.

Conclusions

All the experiments done with the LLN 2-D model show that we are facing an exceptionally long interglacial. Except for scenarios where the CO_2 concentration is kept constant below 215 ppmv, our Holocene interglacial is predicted to last up to 50 kyr AP. The next significant glacial would happen at ~ 60 kyr AP with a total northern hemisphere ice volume which depends upon the CO_2 scenario: 32, 15 and 2 x 106 km^3 of ice for constant CO_2 of 210, 250 and 290 ppmv respectively and ~ 20 x 106 km^3 in the natural Vostok, 550 and 750 ppmv scenarios. The following glacial maximum is reached at 100 kyr AP with 32 x 106 km^3 of ice in the 210 ppmv, natural-Vostok and the human-perturbed scenarios. This glacial maximum is followed by a warming around 120 kyr AP that cannot yet be identified in our experiments as an interglacial.

On the basis of the past limited evidence available, Berger, Gallée and Mélice (1991) first concluded that, after a period of warming due to an anthropogenic increase in greenhouse gases, the next glaciation will just be delayed and less severe. However, the experiments described here show that the future climate is very sensitive to greenhouse gas concentrations and to their changes over time. According to these new results, the enhanced greenhouse warming might weaken the positive feedback mechanisms which transform the relatively weak orbital forcing into global interglacial–glacial cycles, so that the initiation of future glaciations will be delayed (namely the cooling trend towards the next ice age will be retarded by tens of thousands of years). In such conditions, a kind of so-called “irreversible greenhouse effect” could become the most likely future climate. At least our result confirms the prediction of J. Murray Mitchell Jr in 1972: “The net impact of human activities on the climate of the future decades and centuries is quite likely to be one of warming and therefore favourable to the perpetuation of the present interglacial.” It can even be anticipated by Crutzen and Stoermer (2000) that the anthropocene would be a transition between the Quaternary and what might be called the Quinternary, the next geological period characterised by the total disappearance of the Greenland and west Antarctic ice sheets (and a subsequent 12 m rise of sea level!).

Peltier and Vettoretti (2001), using the Canadian climate general circulation model, showed that under the present insolation regime and pre-industrial CO_2 concentration no glacial inception is possible, contrary to what they are able to simulate at the transition between isotopic stages 5e and 5d. All these modelling results increasingly confirm that the pattern and range of global climatic conditions likely to be experienced over the future will be close to those experienced during some Quaternary warm phases, the late Pliocene or even at the Palaeocene-Eocene boundary. It is therefore more than necessary to use the reconstructed record of past climates to test our model understanding of the behaviour of the climate system and as a guide to future conditions.

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Section 3:

Future Directions for European Global Change Research

The approach to the Forward Look

Eight small teams of leading European scientists were invited to contribute to the ESF Forward Look by providing an insight for their area of science into what Europe could contribute to the global research effort based on strengths and available infrastructure, how this could be organised and what barriers need to be overcome in order to realise the European contribution. The areas chosen were not meant to be all-encompassing, but rather to be illustrative of what Europe could contribute. It was expected that the case study papers would serve as seeds for initiatives in the scientific community and for action by the funding community.

3.1 Global carbon cycle science

Colin Prentice[1], Liliane Merlivat[2], Philippe Ciais[3], Martin Heimann[1], Karin Lochte[4]

Context and background

The global carbon cycle has been a subject of intense scientific interest ever since the first high-precision measurements of atmospheric carbon dioxide (CO_2) concentrations in the late 1950s demonstrated a rising trend. These observations also revealed a clear seasonal cycle, which was proof that atmospheric CO_2 concentrations are influenced by biological processes. Subsequent research confirmed that the rising trend can be attributed to fossil fuel burning, but that about half of the CO_2 thus released dissolves in the ocean. The role of the terrestrial biosphere took longer to clarify. We now know that the terrestrial biosphere can be a net sink or a net source of carbon depending on land-use dynamics and other processes such as CO_2 "fertilisation" that can influence the balance of photosynthesis and re-oxidation of carbon at the whole-ecosystem level. But very many questions about the carbon cycle remain unanswered, including fundamental questions about the causes and consequences of land-use change, and the influence of terrestrial and marine ecosystem processes on atmospheric CO_2 and climate.

The global carbon cycle has meanwhile greatly increased in political and public visibility, because of the growing evidence that anthropogenic releases of CO_2 are contributing to global climate change. Hence the Kyoto Protocol and subsequent international negotiations that

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have evoked a worldwide interest in the problem of how to influence the future development of the carbon cycle and the social and economic consequences of doing so. The means are diverse and include emissions-permit trading, geo-engineering schemes, non-carbon energy technologies, biofuels, and planting forests. The scientific community studying the global carbon cycle accordingly faces a challenge of a new order. We need not only to understand the past and present dynamics of the carbon cycle, but also to make credible forward projections of CO_2 concentrations over a century or longer in a world in which the climate, economy, and society are all changing at unprecedented rates. And we need to understand the conditions for and the consequences of different types of actions to manage the global carbon cycle. Therefore, questions as to which instruments are available to society and how effective they will be now of central importance.

This short report is designed to provide an initial basis for discussion of the potential for a broadly based, coordinated European programme to increase scientific understanding of the global carbon cycle and its relation to climate change. We have interpreted this theme as covering timescales from the sub-daily timescale of surface carbon-exchange processes, through the decadal timescale of recent global observation programmes and most immediate policy relevance, to the geological time frame of the evolution of the Earth's atmosphere. The report is complementary to the international Global Carbon Project (GCP) science plan that is under development by the International Geosphere-Biosphere Programme (IGBP), the World Climate Research Programme (WCRP) and the International Human Dimensions Programme (IHDP). The GCP is an umbrella activity whose actual implementation requires engagement by the scientific communities and funding agencies of the participating nations. The GCP plan is being developed by a worldwide consortium with a strong representation of European scientists. The present report embodies an independent European perspective that may also be a first step towards shaping a future European contribution to the GCP. It builds partly on two more detailed documents produced by the US carbon cycle community in response to specific funding agency initiatives (the US Carbon Cycle Science Plan and the North American Carbon Program), as well as on the current draft of the GCP plan.

One aspect in which we deviate from the GCP and the US reports is that we include explicit consideration of geological timescales. The perspectives offered by geological observations are highly relevant because of what they can teach us about earlier states of the Earth in which high CO_2 concentrations and warm climates existed (Figure 3.1.1), about the origins of the fossil fuels themselves, and about the nature and possible climatic role of some extremely large stores of fossil carbon (such as methane hydrates). On the other hand, we have restricted ourselves principally to the part of the carbon cycle that goes through CO_2. Thus we do not deal with atmospheric chemistry research designed to better understand and manage atmospheric concentrations of the two next most important greenhouse gases (methane, CH_4 and ozone, O_3), even though these gases are also climatically highly relevant, and although their abundances are also partly controlled by biogeochemical processes.

The scope of the proposed programme is substantially broader than that of the intensive research activity on terrestrial carbon processes and land–atmosphere interactions that is currently funded by the EU within the framework of the CarboEurope cluster of projects. These projects focus on quantifying and understanding the present-day distribution of carbon fluxes in Europe and adjacent regions. That work is vital, but it represents only a part of the research needed to understand the workings of the global carbon cycle and, thereby, the possible future evolution of atmospheric CO_2. European Union support for carbon cycle research also includes a strong component of global marine carbon research, with current projects ranging from the

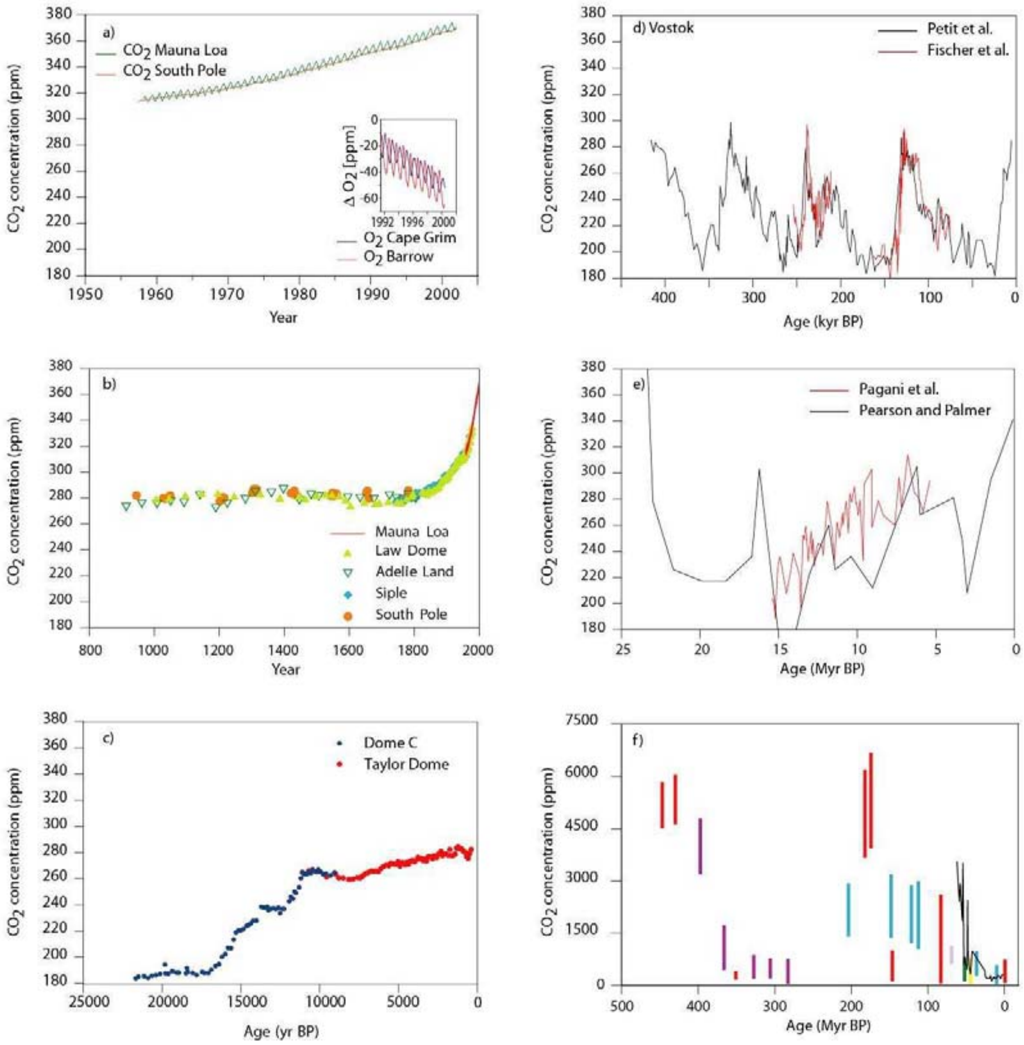

Figure 3.1.1. Variations in atmospheric CO_2 concentration on different timescales

use of merchant ships and fixed stations collecting intensive data across the North Atlantic (CAVASSOO, ANIMATE) to studies of nutrient dynamics and its interaction with carbon cycling in the coastal zone and open ocean (EUROTROPH, IRONAGES), and modelling of marine carbon cycle processes and variability (ORFOIS, NOCES). These European-level activities are possible only because major investments have been made by individual nations in broadly based carbon cycle research and the disciplines that underlie it.

The status of carbon cycle research in Europe

Two defining characteristics of carbon cycle research are:

- ***Its extremely interdisciplinary nature***
  Carbon cycle research today draws on physics, chemistry, meteorology, oceanography (physical and biological), terrestrial ecology, physical geography, geology, economics, human geography and the other social sciences.

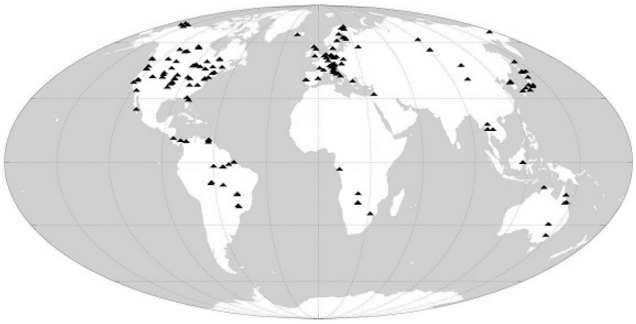

Figure 3.1.2. Global distribution of CO_2 flux measurement sites

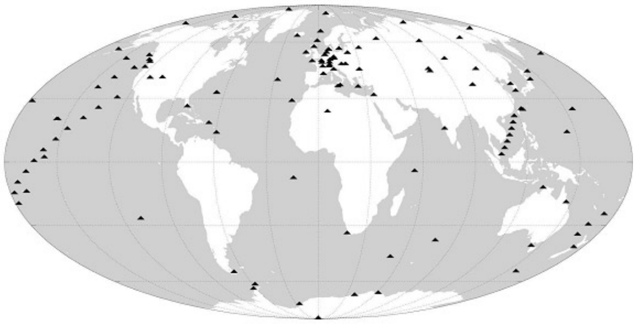

Figure 3.1.3. Global distribution of CO_2 tropospheric concentration measurements (which are located either in the marine boundary layer, or at high elevations, or on "tall" towers removed from local influences on the PBL).

- ***The major requirement for infrastructure for global observation purposes***
  Carbon cycle research depends on research ships and aircraft, marine and atmospheric observing stations, towers instrumented for flux measurements, marine and ice sheet coring operations, high-technology analytical instrumentation for high-precision concentration and isotopic determinations, unique experimental technologies for *in situ* field experiments (for example CO_2 fertilisation of forests and Fe fertilisation in the open ocean), supercomputers (for regional and global modelling), and satellites equipped with specialised sensors. Carbon cycle research also involves periodic large field campaigns that frequently have to take place in remote and/or logistically difficult regions.

Both of these characteristics, for different reasons, imply a need for transnational coordination: the first because it is very difficult, especially for smaller nations, to achieve a critical mass of expertise in all of the required fields; the second because of the high costs that restrict what individual nations can afford.

Europe taken as a whole is already a major player in global carbon cycle research; indeed Europe leads in several areas. European scientists have pioneered the deployment of several key technologies: coupled climate–carbon cycle modelling; terrestrial carbon-flux measurements from towers (Figure 3.1.2); ice core drilling and precise analysis of CO_2 concentration in ice; space-based measurements of vegetation properties; and attempts to measure column-integrated CO_2 abundance (with the recent successful deployment of the SCIAMACHY sensor aboard ENVISAT); and *in situ* experiments in fully grown forests and in the open ocean. More generally, European scientists are involved in all fields of carbon cycle observation, experimentation, and modelling, especially terrestrial and marine biogeochemistry. The USA leads globally in remote tropospheric concentration measurement programmes for CO_2 and other carbon cycle tracers, but European scientists also are engaged in such measurement programmes in Europe, Siberia and the Arctic (Figure 3.1.3).

European Union Framework Programme funding for projects such as the European Study of Carbon in the Ocean, Biosphere and Atmosphere (ESCOBA), for ice core drilling in Greenland and Antarctica (EPICA), and recently for CarboEurope and a range of marine carbon cycle projects, have had a highly beneficial effect on the strength of European carbon cycle research. Carbon cycle science in Europe has also benefited from national funding supporting international initiatives in marine science (JGOFS and WOCE for contemporary observations, and ODP for palaeodata recovered from deep sea sediments). A generation of highly talented young scientists has been recruited to the field, partly in response to these funding opportunities from the early

1990s onward. New opportunities have also been created for work in the human sciences addressing global change as a topic of relevance for society. Nevertheless, in the carbon cycle research community there is a widespread feeling that more could be achieved, and clear international leadership established or maintained, given the remarkable human resources that we now have in Europe. In brief, there would be substantial benefits from:

- a more balanced participation of different nations;
- greatly improved coordination of large observational, experimental and modelling programmes across nations (including observational programmes in and around Antarctica, where several European nations are stakeholders);
- greatly improved coordination of major investments in infrastructure – not only satellites, but also research ships, aircraft, remotely operated underwater vehicles, and supercomputers;
- better organised systems for the dissemination of data, especially data gathered separately by national agencies (for example, crop data, soil survey, forest inventory, socio-economic, and demographic data);
- free and open access to such data, and to other relevant data assembled by European agencies;
- increased readiness by national agencies to support interdisciplinary and international research that does not fit the traditional subject moulds, including research spanning the boundaries of natural science, socio-economic sciences, and technology;
- a coherent European science planning framework for global change research in general.

In summary, there is an impressive commitment to carbon cycle science in Europe. Numerous world-leading projects are underway, in part with EU support. Yet the distribution of carbon cycle-related research programmes across European nations remains patchy and fragmented. The science base for this endeavour could be further strengthened by greatly improved coordination. Currently, major programmes are still being developed largely independently by different nations, there are significant gaps in the expertise of most or all nations, interdisciplinary research in many nations is still hampered by traditional disciplinary compartmentalisation in universities and funding agencies, and scientists from the less wealthy nations in particular continue to have limited opportunities for participation. If the kinds of mechanisms listed above came into being, these problems could be overcome in a highly cost-effective manner.

Key questions

1. Why does the Earth's atmosphere have its present composition, and how has the abundance of CO_2 been controlled during the history of the Earth?
2. What interactions between climate and biogeochemical cycles have determined the co-variation of CO_2 concentration and climate change on glacial–interglacial and millennial timescales?
3. How have the sources and sinks for anthropogenic CO_2 evolved during the industrial period?
4. Where are the sources and sinks of CO_2 in the land and ocean today, and how are they affected by climate variability?
5. What are the characteristic response times of different processes of CO_2 uptake on land and in the ocean, and how do these processes interact with climate change?
6. What are the conditions for, and consequences of, different instruments and technologies for CO_2 emissions reduction and carbon sequestration, and how can they be deployed effectively to stabilise atmospheric CO_2?

These six questions represent an attempt to frame the major issues in global carbon cycle science. The questions are ordered roughly in terms of timescale, namely from long geological timescales, through the timescales of historical and recent observations, to consideration of the immediate present and the future. The order also reflects a gradient from what would usually be considered the most “fundamental” to the most “applicable” or “strategic” science, but this is not a firm distinction. Fundamental research related to the Gaia hypothesis, as implied by the first question, has importance for understanding the tolerance range of the global environment to human perturbation. Conversely, research on the fate of fossil fuel CO_2 emissions and their interactions with climate has yielded fundamental insights into the workings of the Earth’s system. Human dimensions enter strongly with the third question and dominate the sixth question, pointing to a pressing need for closer links between the natural and human sciences in answering questions about the contemporary carbon cycle.

1. Why does the Earth’s atmosphere have its present composition, and how has the abundance of CO_2 been controlled during the history of the Earth?

The chemical evolution of the atmosphere and oceans over millions of years is controlled by a combination of tectonic, biological, and sedimentological processes. Many of these processes influence global climates by inducing slow changes in atmospheric CO_2 concentration. “High-frequency” climate changes in a geological perspective, including the glacial–interglacial cycles, are generated by variations in insolation induced by orbital forcing (namely by changes in the tilt, phasing, and eccentricity of the Earth’s orbit around the Sun that are caused by gravitational interactions among the planets and are predictable over a timespan of a few million years). These astronomically induced changes oscillate about a climate mean that varies, more slowly, in response to gradual changes in terrestrial boundary conditions: land–sea distribution and orography, ocean gateways, bathymetry, and the atmospheric concentration of CO_2.

The key driver for most of these boundary conditions is plate tectonics, but the atmospheric composition is also strongly influenced by the cumulative long-term effects of biological processes. For example, the high concentration of molecular oxygen (O_2) in the Earth’s atmosphere is a legacy of billions of years of photosynthesis, resulting in the sequestration of organic carbon (a small fraction of which, as fossil fuel, is now being re-oxidised, causing a small but measurable annual decrease in atmospheric O_2 concentration). The concentration of CO_2 over millions of years is primarily regulated by the geochemical carbonate–silicate cycle: CO_2 is consumed in the weathering of silicate rocks while only half of the CO_2 thus consumed is released during the formation of carbonate sediments in the sea. Metamorphic reactions ultimately transform the marine carbonates and regenerate the remaining CO_2, which is released by volcanoes. Disequilibrium in this cycle can be caused by factors affecting any of its components, including factors affecting weathering rates (weathering is promoted by plant growth and by orogeny, which increases erosion) and factors affecting volcanic activity.

A major cause of the transition from the “greenhouse” world of the early Cenozoic to the more familiar world of the past few million years, in which ice has always been present in greater or lesser amounts, is believed to be a reduction in the concentration of atmospheric CO_2. However, the explanation of this reduction is controversial due to poor quantification of changes in the various components of the carbonate–silicate cycle. For example, according to one hypothesis, the uplift of the Himalayas and the Tibetan plateau was the decisive factor; on the other hand, drawdown of atmospheric CO_2 due to enhanced weathering in one region would be expected to reduce weathering rates elsewhere, resulting in a stabilisation of atmospheric CO_2. The lowering of atmospheric CO_2 concentration is also likely to have triggered the major expansion of plants using the C4 photosynthetic pathway (which includes most of the extant tropical grasses) during the Miocene. A comprehensive analysis of carbon cycle changes during the Cenozoic is lacking, yet these processes are fundamental to understanding the Earth's present state and the reactions of the biosphere as atmospheric CO_2 concentration approaches levels that have not been seen for the past 20 million years.

Dramatic excursions in atmospheric CO_2 concentration may have been caused during the Cenozoic by the catastrophic release of methane (CH_4) hydrates from the sea bed. Methane hydrates are stable at the temperatures and hydrostatic pressures characteristic of the continental slope today. Their origin is largely unknown, yet they account for a very large carbon store, more than the conventional fossil fuels. It has been suggested (based on stable carbon isotope evidence) that the Palaeocene warm event, which had major consequences in terms of species extinctions and geochemical changes, was caused by a catastrophic release of CH_4 from hydrates. The direct greenhouse effect of this release would have been small, but the amount involved would have been sufficient to cause a substantial increase in atmospheric CO_2 concentration over a timescale of tens of thousands of years. Further, it has been suggested that global warming and a rising sea level could trigger catastrophic CH_4 release in future. Such "low probability, high impact" events need to be far better understood and provide an additional rationale for intensified study of the coupling between climate change and biogeochemical cycles on a timescale of millions to tens of millions of years – the timescale that is accessible through the geochemical analysis of deep sea sediment cores.

2. What interactions between climate and biogeochemical cycles have determined the co-variation of CO_2 concentration and climate change on glacial–interglacial and millennial timescales?

Palaeodata from the Quaternary period, derived from polar ice cores and terrestrial and marine sediments, have provided uniquely detailed information about the natural variability and linkages of biogeochemical cycles and climate, especially during the 420 kyr spanned by the longest of these records (from Vostok, Antarctica). The key drivers for global change on this timescale are orbital changes. In order to understand the longer-term consequences of the anthropogenic perturbation, it is essential to make use of palaeodata that record the consequences of astronomical perturbations. Such data provide the evidence for major global changes that have actually occurred. They provide the only way to test the performance of models outside the recent, relatively narrow range of variation in atmospheric composition and climate that is covered by direct observational records.

Ice cores from Antarctica and Greenland are a key resource and continue to yield a wealth of climatic and biogeochemical information. Antarctic cores have provided a reliable history of changes in atmospheric CO_2 concentration (although there are still uncertainties concerning precise timescales, and about some important parameters that are at the limit of measurement, such as the $\delta^{13}C$ of the CO_2). Over the past 420 kyr, CO_2 concentrations have bounced between glacial-maximum values around 190 ppm and interglacial values of around 280 ppm, with additional periodicity at the Milankovitch obliquity frequency (41 kyr) and more muted variability at millennial timescales. The CO_2 increase appears to be close to synchrony with Antarctic warming at the end of glaciations, but the CO_2 decrease delays Antarctic cooling after the start of glaciations by several thousand years.

The major mechanisms involved are still unknown, and our current inability to hindcast

CO_2 concentration on these timescales reflects poorly on the predictive power of current models. The problem of explaining glacial–interglacial cycles of CO_2 concentration could be more coherently tackled by a combination of data analysis and modelling involving both palaeodata and modelling specialists. For example, deployment of spatially extensive palaeodata (such as $\delta^{13}C$, SST, dust accumulation rates, and export production proxies in marine sediments) may help confirm or reject hypotheses about the control of atmospheric CO_2 by providing multiple constraints on the results of high-resolution coupled models for key times, such as the last glacial maximum. The problem raises several issues about the present and past workings of the ocean which require further observation and analysis: notably, the mechanisms controlling the thermohaline circulation and the importance of aeolian dust as a source of Fe for marine ecosystems in different regions; quantifying changes in the composition and function of open ocean ecosystems between glacial and interglacial periods; quantifying changes in aeolian and riverine fluxes of N, P, Fe, Si and alkalinity; and understanding the processes governing the sinking of particulate matter from the euphotic zone.

3. How have the sources and sinks for anthropogenic CO_2 evolved during the industrial period?

The history of atmospheric CO_2 concentration and certain associated tracers, such as $\delta^{13}C$ and O_2, is known from direct measurements over the past decades (>50 years for CO_2, 10–20 years for $\delta^{13}C$ and O_2). For the decades and centuries before direct observations began we rely on high-resolution ice core records from the upper layers of the Antarctic ice and firn. Where they overlap, the two sources of information closely agree. They demonstrate that CO_2 concentration variations were limited to about a 20 ppm range between the early Holocene (ca 11 kyr BP) and the Industrial Revolution. The early part of the CO_2 rise after the beginning of industrialisation cannot be explained fully by fossil fuel burning alone; changes in land-use (especially deforestation) played an important role up to about 1900, when fossil fuel burning became the key driver.

We need to understand the evolution of atmospheric CO_2 over the pre-industrial and industrial periods, including the causes of fluctuations in the pre-industrial period, in order to be confident of our understanding of the present-day carbon cycle; in order to initialise models of the carbon cycle as applied to more recent periods; and in order to more completely attribute the geographic origins of the excess CO_2 in today's atmosphere. Attempts to model this evolution have begun, but they have focused almost exclusively on the natural science aspects. Yet there are large uncertainties in current reconstructions of past land-use (even during the most recent decades), and of energy-production systems prior to 1900. A sustained effort will be required to improve and reconcile spatially explicit land-use histories, using multiple documentary sources, including attempts to model land-use systems mechanistically. This effort will necessarily involve both natural scientists and social and economic historians.

Carbon cycle modelling further depends on assumptions about the magnitude of CO_2 and N fertilisation and the sign and magnitude of climate change and land-use effects on net ecosystem exchange. Reliable representation of these effects in models requires a continued effort in whole-ecosystem experimentation (with experiments continued for long enough to include acclimatory responses), and above all, a strengthened cooperation among ecosystem modellers and experimentalists.

4. Where are the sources and sinks of CO_2 in the land and ocean today, and how are they affected by climate variability?

The existence of land and ocean carbon sinks is evident from analysis of time series of the concentration of atmospheric CO_2 and other tracers. Global networks of atmospheric observations have also established the existence of a 4–5 ppm north-south interhemispheric gradient in CO_2 concentration. This is smaller than the gradient that would be generated by the fossil fuel source alone (5–6 ppm) implying the existence of a sink in the northern extratropics. Several lines of evidence, including O_2 and $\delta^{13}C$ measurements, suggest that this sink is caused at least in part by terrestrial carbon uptake in the northern mid-latitudes. On the other hand, the tropical lands appear to be roughly carbon-neutral, indicating that CO_2 emissions from tropical deforestation must be roughly balanced by net carbon uptake into other ecosystems in the tropics. The existing global network of CO_2 concentration measurements is, however, barely adequate to infer more detailed patterns. Further, as the rate of increase of atmospheric CO_2 concentration varies enormously between years, a sustained global monitoring effort (which has built up over the past decades) has been essential and will need to continue if we are to reliably distinguish long-term trends from interannual variability.

Both the scientific goal of understanding the contemporary carbon cycle, and the practical goal of attributing CO_2 sources and sinks to different regions and political entities, call for major improvements in our ability to monitor the changing net carbon balance of different land and ocean regions. It is likely that further progress will be made through a combination of different technologies: remote sensing (including improved interpretation of existing data in terms of land-cover characteristics and the emerging technologies for sensing CO_2 concentrations from space); flux measurements on land; ΔpCO_2 measurements at sea; an enhanced network of CO_2 concentration measurement stations; and advanced numerical techniques for data assimilation to integrate these different kinds of data into an operational inverse modelling framework.

Confidence in the attribution of terrestrial sinks based on atmospheric measurements would be further improved if consistency with inventory data could be established. Conventional forest inventories are restricted in scope and do not give information about changes in the largest terrestrial carbon store, in the soil, whose dynamics differ considerably from those of tree growth. Therefore, new approaches are needed for bottom-up carbon accounting, taking into account the major influence of a management regime on carbon storage.

5. What are the characteristic response times of different processes of CO_2 uptake on land and in the ocean, and how do these processes interact with climate change?

The basic mechanisms by which CO_2 is taken up by ocean and land are reasonably well established. They span a range of timescales that have been estimated by various approaches including measurements of the natural "radiocarbon age" (from ^{14}C content) of vegetation, soil and ocean water reservoirs, and measurements of the penetration of "bomb ^{14}C" and other tracers of recent human activities including chlorofluorocarbons (CFCs) and tritium (^{3}H). The consequences of climate change and variability for each process are much less well established. But it is already clear from atmospheric CO_2, stable isotope and O_2 measurements, and measurements on carbon in the marine system that the effects of climate on CO_2 exchange between the atmosphere and surface reservoirs both on land and in the ocean are large. These effects account for interannual variations in the rate of increase of the atmospheric CO_2 concentration, especially associated with the El Niño-Southern Oscillation (ENSO), which are as large as, or larger than, the background trend (due to fossil fuel emissions) on which the fluctuations are superimposed.

Model projections further suggest that climate change will have sustained effects on carbon uptake, with the overall effect of warming (both on land and in the ocean, for different reasons) being a tendency to reduce uptake, and thus to increase atmospheric CO_2 content more rapidly. Additional, poorly understood effects on carbon uptake are likely because of the anthropogenic modification of nutrient cycles, including reactive

N deposition and increases or decreases in the transport of different nutrients from land to sea by dust deflation and river transport. There are large differences in the long-term (multidecadal) projections of different models, indicating that the models themselves need to be more rigorously evaluated and improved with respect to their ability to reproduce key observational and experimental results. This requirement in turn puts the spotlight on process studies in both the terrestrial and marine realms. Studies of central relevance include CO_2 enrichment and artificial warming experiments on land, and Fe fertilisation experiments in the ocean. Modelling studies are required to assess how short-term observed responses in a single place translate into long-term responses on a global scale. Long-term time series of observations such as *in situ* biogeochemical measurements that have been made at sampling sites in the ocean, and long continuous time series of land and ocean colour (representing photosynthetic activity), are key data for model evaluation. Terrestrial and marine ecosystem experiments also point to the significance of biodiversity, especially the different responses of functional groups of organisms, in determining biogeochemical processes in a changing climate. Substantial further development of process-based models is needed; for example, representation of different phytoplankton functional groups in regional and global carbon cycle models is a top priority, and terrestrial carbon models require major improvements in the representation of drought responses, competition processes, disturbance regimes, and nutrient cycling.

Progress in answering the fourth and fifth questions is essential if we are to project with any confidence the magnitudes and locations of carbon sources and sinks in the future. This will require a far more synergistic approach to the design of models, and the planning of observational and experimental programmes than has been the norm in the past. And coupled models of climate and the carbon cycle, whose recent development has been pioneered by European modelling groups, need to take into account a sufficient set of physical and biological processes to allow robust and well-founded projections of the fate of anthropogenic CO_2.

6. What are the conditions for and consequences of different instruments and technologies for CO_2 emissions reduction and carbon sequestration, and how can they be deployed effectively to stabilise atmospheric CO_2?

The question could be rephrased as: “What pathways to a sustainable, non-carbon fuelled energy system are biophysically, socially, and economically feasible?” This is a huge challenge. First of all, we need to understand the conditions for and consequences of different approaches to emissions reduction and for each approach we need at least a semi-quantitative understanding of its technological feasibility, economic viability, social acceptability, effectiveness, trade-offs (for example, the competing claims on land of arable cultivation, forestry, and biofuel plantations), and collateral impacts on other economic sectors and the environment. Similar information is needed on the various methodologies proposed to sequester carbon or to preserve existing carbon stocks, taking into account potentially important second-order effects (such as warming-induced loss of soil carbon from forest plantations) and the potential for fossil fuel substitution. There are many unanswered questions here even in the biophysical realm, such as the relative effectiveness of afforestation versus conservation of old-growth forests as carbon sinks. And finally, as assessment of different emission scenarios and mitigation options will require comparison of different degrees of climate change impact on the environment and society, it will be necessary to analyse the feedbacks from climate change via various economic and resource sectors on population and economic growth. This will require a serious reappraisal of methodologies for climate impact research to include human activities and responses as an integral part of the climate system.

The means to influence purposefully the global carbon cycle include legal, economic, and political instruments such as emissions trading and environmental taxes and regulations. The human consequences of applying such instruments also vary greatly across regions and nations, thus raising fundamental issues of equity and economic development. To begin to answer these questions will require fundamental research that cuts across the boundaries between the natural and human sciences. The components of such research include an extension of fundamental observational research and numerical modelling: for example, flux measurements to quantify carbon uptake by forests and croplands as a function of time under different management regimes; and models to analyse the consequences of land-use changes for the global carbon balance. We will need a new synthetic approach to data, linking aspects of the biophysical and socio-economic systems and facilitating the modelling of interactions between the systems. And we will need to further develop the nascent science of integrated assessment, including an increased emphasis on techniques for model comparison and objective evaluation against data. Such research must include the development of CO_2 emission scenarios in which climate policy instruments are explicitly included. It will then be possible to begin to explore the multidimensional space of possible joint trajectories of climate, human dimensions, and energy systems and to seek trajectories fulfilling the requirements of sustainable development.

Some cross-cutting topics

Underlying the major questions outlined above is a multitude of interdisciplinary problem areas (examples of which are listed below) where the current state of knowledge is seriously inadequate. These issues must be tackled from an interdisciplinary perspective because few individual European nations possess the critical mass of either resources or expertise required to tackle them effectively.

Coupling of carbon and nutrient cycles

Biological productivity both on land and in the ocean requires the availability of light and CO_2 for photosynthesis and a supply of various nutrients. The interactions among these limitations are surprisingly poorly understood. A few facts are established, such as the Fe limitation on primary production in the eastern equatorial Pacific and the Southern Ocean, and the N limitation of vegetation growth in cold climates on land. But fundamental issues such as the relative roles of limitation by N and P, the controls on the fixation of N_2 from the atmosphere, the role of "pollution" by reactive N, and the extent to which nutrient availability constrains the response of primary productivity to changing CO_2 levels, are still controversial (both on land and at sea). Possible approaches to disentangling these problems may include increased use of time series information on marine biogeochemistry and a wider range of *in situ* experiments on land and in the ocean.

Environmental controls on remineralisation

Remineralisation is the conversion of organic carbon to CO_2, which is carried out by heterotrophic organisms and also (on land) by combustion. Remineralisation has received far less attention than photosynthesis although both are equally fundamental. The long-term response of soil heterotrophic respiration to temperature has emerged as a major and inadequately understood determinant of the projected evolution of atmospheric CO_2 concentration. The interactions of soil moisture and temperature in determining heterotrophic respiration rates are inadequately studied, yet they are essential to project climate change effects on carbon storage in water-limited regions. The processes and timescales of remineralisation in the ocean and their response to changes in ocean circulation are also poorly understood. Long-term field experiments (for example, soil warming experiments) are part of the solution. Creative uses of accelerator mass spectrometry (AMS) for ^{14}C determination will be required to empirically determine the "recalcitrance spectrum" of soil carbon on land, and dissolved organic carbon (DOC) in the sea.

Mesoscale physical processes with implications for the carbon cycle

The dynamics of the lowest layers of the atmosphere (the planetary boundary layer, PBL) are not mechanistically represented in most global atmospheric models. Yet PBL processes are fundamental to the understanding of land–atmosphere carbon and water exchanges, and to the reconstruction of land–atmosphere carbon exchanges from atmospheric measurements. In the ocean, too, mesoscale processes have global consequences: they are involved in the processes of deep water formation in the North Atlantic, and both deep water formation and upwelling in the Southern Ocean. The physics of the Southern Ocean are poorly understood, partly due to a dearth of measurements; yet it is vital to model this region correctly both for understanding present ocean CO_2 uptake and for understanding the possible role of Antarctic sea ice in the regulation of atmospheric CO_2 content on glacial–interglacial timescales. Research requirements include redesigning ocean circulation models with more explicit representation of physical processes at the ocean bottom, and a major effort to improve our knowledge of the present-day physics and biogeochemistry of the Southern Ocean. Improved understanding of air–sea gas exchange is also vital, especially at high latitudes with strong winds.

Land–ocean interface

Biogeochemical fluxes between land and ocean, involving transfers of inorganic nutrients and organic substances from land to ocean via rivers and via aeolian transport of dust, and their metabolism in estuaries, coastal seas and shelf sediments, are simultaneously among the most vital and least studied aspects of the entire Earth system. We require far more information on the fluxes of carbon and nutrients involved, on vertical mixing and biogeochemical transformations in the coastal zone, and on export and burial of terrigenous material on the continental slopes and in the deep sea. This information is necessary both for understanding and prognostic modelling (the current representation of the land–ocean interface in ocean models being quite trivial), and for the correct inference of land and ocean CO_2 sources and sinks from atmospheric CO_2 concentration or atmosphere–sea surface concentration difference (ΔpCO_2) measurements.

Controls on biodiversity and the distribution and abundance of major functional groups of organisms

Changes in the distribution and abundance of biological functional groups can have major effects on the carbon cycle. On land, climate changes may cause regional dieback of forests and CO_2 release because the specific climatic tolerances of dominant tree species are exceeded, and intensive land-use could exacerbate such effects. Climatically induced shifts in the distributions of phytoplankton functional groups could modify ocean biogeochemistry both locally (altering the strength of the “biological pump” which removes CO_2 from surface waters and thus lowers the CO_2 concentration in the atmosphere), and globally by modifying the nutrient profile of circulating water. Models include these effects to some degree but there are still major uncertainties, for example about the control of coccolithophorid versus diatom blooms or the susceptibility of boreal trees to heat stress, which result in large inconsistencies between current models. Models need to better quantify the characteristics of major functional groups, and additional field observations and experiments may be required to provide information on the environmental tolerances of species.

Carbon chemistry in the biosphere and atmosphere

The terrestrial biosphere emits carbon to the atmosphere not only as CO_2 but also in the form of chemically reactive substances such as carbon monoxide (CO), CH_4, and volatile organic compounds (VOCs). The fluxes of some of these substances are large enough to complicate the inference of sources and sinks from CO_2 concentration measurements, and to cause errors when CO_2 flux measurements are used to analyse ecosystem carbon balance. The fluxes of trace gases from the land are strongly influenced by fires, both natural and human-set. The marine biosphere is also a minor source of CH_4 and CO, and of the climate-influencing aerosol precursors dimethyl sulphide (DMS) and carbonyl sulphide (COS). Additional CO2 is taken up by the ocean over long timescales through $CaCO_3$ dissolution and probably also reduced $CaCO_3$ production by calcifying micro-organisms, but the global controls on the $CaCO_3$ cycle are understood only in general outline, and the consequences of the changing pH of ocean water are poorly understood.

Policy dimensions of the carbon cycle

Far too little is known about the mechanisms that could realistically lead to stabilisation of atmospheric CO_2 concentration. Economic, legal, and political instruments designed to reduce CO_2 emissions, and/or to encourage carbon sequestration, are open to many questions about their physical effectiveness, economic efficiency, and social acceptance. Policy makers are therefore working somewhat in the dark, as the post-Kyoto negotiations made clear. There is an urgent need for carbon cycle science to address issues relevant to policy makers through research that considers not only the first, but all three of these dimensions. This will require an exceptional degree of interaction between the natural sciences, human sciences, and technology. Addressing these issues will also call for a whole-system perspective on the consequences of specific actions, considering trade-offs among different societal requirements (for example between carbon sequestration and biodiversity conservation), and analysing collateral economic and environmental effects such as the possible consequences of ocean carbon sequestration for marine ecosystems and fisheries.

Data and infrastructure requirements

Research on the contemporary carbon cycle is underpinned by coordinated, highly accurate and precise monitoring of key variables; time-limited intensive observational campaigns focusing on particular regions; and large-scale manipulative experiments such as free-air carbon dioxide enrichment (FACE) studies on land and Fe fertilisation experiments in the open sea. Progress towards a comprehensive understanding becomes possible only through a combined analysis of data obtained from disparate sources, including satellites, ships, aircraft, land-based observatories (such as flask sampling stations and instrumented towers) and coastal or sea-based observatories (such as marine research stations, research vessels and ships-of-opportunity, unmanned underwater vehicles, buoys and floats). The amount of data involved also requires reliable systems for electronic archiving and provision of data to the community, and time and effort to synthesise and standardise large volumes of data. Research on past changes in the carbon cycle, analogously, depends on: the synthesis and analysis of multiple data sources and has major requirements for infrastructure, including advanced analytical facilities able to process very large numbers of samples; the means to carry out major drilling campaigns in polar ice, marine sediments and lakes; and actively maintained data archives. Modelling is a major component of carbon cycle research on all space- and timescales, and generates a need for advanced computational resources.

Since many of the data required are from regions of key importance located in the tropics, there are excellent opportunities for capacity building and for the effective involvement of scientists based in developing countries. This is already starting to happen, for example through Brazil's leadership of the Large-Scale Biosphere Experiment in Amazonia (LBA), which engages many European scientists.

The following paragraphs illustrate some of the key data requirements for rapid progress in carbon cycle research during the next five to ten years. The list is not intended to be comprehensive, nor is it prioritised. In some cases activities of the kind listed are already coordinated to some degree through mechanisms in the EU's Fifth Framework Programme, or through European agencies such as the European Space Agency (ESA) and the European Forest Institute (EFI). In other cases no such coordinating mechanism exists. In all cases there is a need for more effective concerted action by European scientists and funding agencies to ensure that the requirements are met.

Global palaeodata collection and synthesis

The raw material for understanding past changes in the global carbon cycle consists of:

- direct measurements of CO_2 and other tracers of the carbon cycle in ancient air trapped in polar ice, which has so far yielded a record extending back to 420 kyr at Vostok and higher-resolution records for more recent periods; and
- a large amount of geochemical and biological information derived from marine and terrestrial sediments, and concentration measurements of numerous biogeochemically relevant species from ice cores in Antarctica, Greenland, and tropical mountain ice caps. Such information includes proxies for CO_2 concentration that allow a CO_2 record to be constructed back through the Cenozoic (Figure 3.1.1), and approaches global coverage for some variables (such as various indicators related to sea-surface temperature in marine cores, and pollen evidence for ecosystem changes in terrestrial cores) over more recent periods.

Ice core drilling remains a limiting factor; for example the precision of the record of $\delta^{13}C$ in past atmospheric CO_2 is limited by the volume of available ice from suitable sites. Continuation of the European ice core drilling effort is a top priority. Marine sediment cores with satisfactory temporal resolution are still sparse or non-existent in many regions of the ocean and long cores extending through the Cenozoic are few. Marine sediment drilling activities have been largely coordinated through the ODP (Ocean Drilling Program), and European participation in the second phase of ODP is also a top priority. Continental drilling on a small scale (typically for records of the past 10–30 kyr) is feasible with modest resources, and a large amount of palaeovegetation data has been assembled for certain key time periods by the BIOME 6000 project with extensive participation from scientists from the former Soviet Union and developing countries. The prospect of obtaining longer records from deep lakes is beginning to be explored.

Scientific coordination among the communities working on ice, marine sediments, and (especially) terrestrial sedimentary archives is currently weak. Accelerated progress in understanding the dynamics of the coupled Earth System on palaeo timescales will require substantial improvements in data archiving (above all for terrestrial data), open data access (for marine and terrestrial data), coordination of marine and terrestrial branches, and interaction between data experts and modellers. The information content of the archives is also being continually improved through the development of new measurements and proxies. Specific efforts are needed to improve and evaluate proxies for marine ecosystem composition and productivity, and to develop robust globally applicable methods of inferring land climates.

Surface-based carbon dioxide observing system

Continued, regular measurements of atmospheric CO_2 and associated tracers are an essential underpinning for the study of the contemporary carbon cycle.

- Simultaneous eddy-correlation measurements (Figure 3.1.2) of energy, water, and CO_2 flux are now providing pointwise information to evaluate and improve terrestrial models. The current network is heavily biased to northern forests; more stations are needed in the dry, seasonally wet, and wet tropics where much of the world's terrestrial primary productivity is located. Flux measurements from chronosequences (forest stands differing in age only), croplands, and pastures are a priority to clarify the influence of disturbance and management regimes on carbon uptake.

- Flask sampling stations (Figure 3.1.3) ideally measure concentrations not only of CO_2 but also its major stable isotopic forms ($^{13}CO_2$ and $C^{18}OO$), CH_4, CO, hydrogen (H_2), sulphur hexafluoride (SF_6) and O_2. The additional species are "tracers" of various processes that contribute to determining atmospheric CO_2 concentration. Global coverage is still inadequate and suitable continental sites, especially, need to be exploited. The coverage of observations is still inadequate to verify international treaty commitments, even when the aim is to quantify total fluxes at the scale of the European continent.
- Continuous CO_2 analysers (Figure 3.1.3) allow spatial differences in concentration to be resolved at a particular point in time under defined synoptic weather conditions. A more widespread deployment of this technology, especially on tall towers with a sub-continental-scale footprint, would greatly improve our ability to attribute source and sink regions for CO_2. The technology itself requires further development, especially with a view to reducing analytical costs.
- Measurements of ΔpCO_2 are a key resource for characterising the patterns of air–sea fluxes of CO_2 needed to construct physically consistent CO_2 budgets on a whole-basin scale. Ships-of-opportunity provide the possibility for multiple repeated measurements along standard tracks; these need to be supplemented by campaigns and the deployment of automated instruments in undersampled regions. Measurements in the Southern Ocean are a high priority because this region is one of the most important in relation to the global carbon cycle, yet is the least well sampled in almost every respect.

Three-dimensional biogeochemistry of the ocean

A better understanding and modelling of ocean carbon cycling on all timescales urgently requires an enhancement of information on key biogeochemical variables in the ocean as a function of location and depth, including improved knowledge of processes in the twilight zone. Complementary approaches include:

- extending the use of Argofloats (unmanned devices that move up and down in the ocean and simultaneously record temperature, salinity, and the current position of the device), and remotely operated underwater vehicles to measure biogeochemical quantities such as chlorophyll fluorescence, nutrients, and dissolved CO_2 and O_2 at a range of depths;
- extended deployment of strategically located, permanent time-series measurement stations with the capability to record vertical profiles of physical and biogeochemical quantities down to 1 000 metres;
- shipboard measurements including vertical profiles of dissolved and particulate organic carbon and O_2 concentration (as an indicator of remineralisation).
- further development of accurate, low-powered sensors to facilitate routine measurements of biogeochemical variables from any of the above platforms.

Priority regions for the deployment of these approaches must include: the North Atlantic, extending northward into the Nordic Seas and Arctic Ocean and including the European marginal seas; and the Southern Ocean. Although several European nations are stakeholders under the Antarctic Treaty, monitoring efforts in the surrounding seas are logistically complex and expensive and have suffered funding problems that could in principle be overcome by better coordination among these nations' Antarctic research efforts.

Inventories

Inventories, which several countries perform at approximately decadal intervals in order to assess economic forestry resources, have also been used to provide information about the patterns of change in aboveground forest carbon storage in the boreal and temperate zones. A more comprehensive analysis of the terrestrial carbon cycle could be achieved given more extensive inventories in various ecosystems (on a global scale and not only forests). We need more accurate determinations of the carbon density of different vegetation types (which is still subject to large uncertainty) and especially, to determine the size of the less commonly measured pools (understory vegetation, below-ground biomass, litter). Improved global data on soil carbon and nutrient densities in different ecosystems are also needed, using a systematic approach to take account of fine-scale heterogeneity and depth dependence. Such data will enable the development of full regional carbon balances (to verify the balances inferred from atmospheric measurements), and the monitoring of rates of change in total-system carbon in response to environmental and management changes. In particular, all kinds of inventory data are lacking for most tropical countries; this deficiency can practicably be remedied only by space-based methods (see below), supplemented by "ground truth" studies as required to calibrate the observations made from space.

Operational remote-sensing data products

These need to be produced through cooperation between the space agencies and the research community. The recently launched joint EU-ESA initiative Global Monitoring for Environment and Security (GMES) may provide a focus for such activities. However, GMES aims primarily at providing an operational monitoring capability by 2008, in a narrowly defined context. Complementary, science-driven activities will be needed. The following are among the potentially important space-based measurements for carbon cycle research.

- ***Atmospheric column concentrations of CO_2***
  Several initiatives are underway to sense atmospheric column concentrations of CO_2 from space. The achievable precision will be an order of magnitude less than that of *in situ* observations, but this limitation will be offset by the benefits of dense, repetitive sampling, potentially allowing the uncertainty of surface fluxes to be reduced by an order of magnitude. Two spectral domains can be used for CO_2 sensing: thermal infrared (which is measured by existing instruments but is biased towards the middle and upper atmosphere); and solar infrared (which is more sensitive to near-surface concentrations but is also more subject to interference by aerosols, clouds, and the surface reflectance). The CO_2 signal in thermal infrared measurements could in principle be detected from observations on the TOVS series of satellites, although better accuracy should be obtainable from instruments with higher spectral resolution such as AIRS (NASA), and IASI and (ESA). The CO_2 signal in reflected solar infrared radiation is the basis for the current application of the SCIAMACHY instrument (on ENVISAT) to CO_2 sensing, but this has major problems with cloud contamination and does not provide reliable data over the ocean. Two purpose-built sensors have greater potential: the Orbiting Carbon Observatory (OCO, recently selected by NASA); and a European system, CARBOSAT, which has been proposed to ESA.

- ***Vertical profiles of CO_2 concentration***
  Technologies for active remote sensing of vertical profiles of CO_2 concentration using space-based lidar have also been suggested, but need further conceptual development.

- ***Land and ocean spectral reflectances***
  The mainstay of remote sensing applications in carbon cycle research up to now has been the land and ocean spectral reflectances provided by AVHRR operational weather

instruments operated by NOAA. New sensors with much improved precision have recently become available: MODIS and SeaWiFS (NASA), and VEGETATION and MERIS (ESA). A key to understanding temporal changes in biospheric activity will be the existence of long-term, continuous, properly calibrated, and intercomparable biophysical data products derived from spectral signatures across satellite platforms.

- ***Vegetation density and heterogeneity***
  Vegetation density and heterogeneity, especially in forests, are linked to biomass and disturbance regime in terrestrial ecosystems. New approaches for sensing these properties exploit combined spectral and angular signature measurements. Data may be obtained from MISR (NASA, for medium resolution) and possibly, later this decade, from the planned SPECTRA mission (ESA, high resolution). Deployed with high resolution, these techniques should be able to perform forest inventories at greatly reduced cost, including tropical areas where currently no large-scale inventory exists.

- ***Functional groups of plants***
  Functional groups of plants on land and in the ocean (phytoplankton) can in principle be characterised by exploiting various combinations of spectral, temporal and angular signatures measured from space. Improved land-use detection, which is important for characterising the direct human impact on terrestrial carbon cycling, will rely on similar approaches. Wetland ecosystem distribution could in principle be derived from active microwave space-borne sensors, in particular SAR; such observations have been available for almost a decade from the ERS platforms (ESA).

- ***Soil moisture and sea-surface salinity***
  Soil moisture and sea-surface salinity are key variables in land and ocean models respectively. Both can be measured using microwave radiometry. The proposed European instrument SMOS (Soil Moisture and Ocean Salinity) would provide this capability.

The definition of carbon-cycle data products from space-borne measurements, and their calibration and testing to yield improved algorithms for use in operational analyses, represent major scientific and technological challenges that would most effectively be pursued through mechanisms involving more intensive interaction between the institutional players (GMES, ESA and national space agencies) and the user communities.

Regional field campaigns

Given that long-term, globally comprehensive surface-based monitoring of all variables of interest for carbon cycle research is not a practical possibility, regional field campaigns of one to several years duration represent a catalyst for major steps forward in understanding. The general approach for terrestrial regions is to measure land–atmosphere fluxes together with aircraft-based measurements of the vertical profile of atmospheric composition (standard flask measurements) through the PBL, in an attempt to close the budgets for land–atmosphere exchanges at a larger spatial scale. For oceanic regions, the equivalent data are pCO_2, temperature and salinity measurements as a function of time, location and depth. For both terrestrial and ocean studies, remotely sensed data and meteorological observations provide the context. Such campaigns should focus on regions of key importance for the global carbon cycle and climate, such as West Africa, Amazonia (where LBA provides an excellent model), Siberia, the North Atlantic Ocean (defined broadly to encompass the Nordic Seas), and the Southern Ocean.

Socio-economic data and space-time dynamics of anthropogenic components in the carbon cycle

Refinement of current knowledge of human perturbation will call for several currently missing or inadequately characterised data sets to be assembled, including: geographical data on historical changes in demography; industry and land use; data on the seasonality and regional breakdown of fossil fuel use; present and historical data on forest management regimes; and data on interregional and international trades in food and wood products, which make a significant contribution to the geographic distribution of sources and sinks of CO_2. Several organisations such as the World Bank, FAO, UNEP and CIESIN compile global data on specific variables such as crop yields, demography, and wealth, but generally only at coarse (national level) resolution. Greater spatial specificity is important and could be achieved, for example drawing on the expertise available in EuroSTAT.

High-performance computing

The development of coupled models of climate and the global carbon cycle is a top priority, and one that is extremely challenging both intellectually and in terms of computing infrastructure. Existing models are compromised by the limitations of currently available supercomputing capacity in any European nation. In Japan, this has been recognised in the development of the Earth Simulator project and the associated Frontier Research System on Global Change. Something comparable will be required as a European facility if Europe is to maintain its lead in Earth System modelling. Enhanced links with operational weather forecasting models are also needed in order to perform a comprehensive re-analysis of CO_2 observations and, ultimately, to develop a fully operational real-time data assimilation system for CO_2.

Data management

Finally, a European data centre should provide archiving, quality assurance, maintenance, and re-gridding as required for major global data sets relevant to carbon cycle research. This activity does not, as far as we are aware, form part of the remit of any existing European agency. At present, European scientists rely mainly on the work of US organisations for this service. And in many areas there is no effective system for assembling observations; for example, terrestrial palaeodata and marine biogeochemical observations.

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3.2 Food and fibre

John R Porter[1], Ken Green[2], John Ingram[3], Jill Jaeger[4]

Introduction

The provision of food and fibre is central to the well being of humans. From our current vantage point of ample sufficiency in Europe of both food and fibre we run the danger of forgetting the historical importance that food and fibre has played in the social and political development of the continent. At the time of the Napoleonic wars in the first years of the 19th century, the price of a tonne of wheat in the UK peaked at five times the price it is today. Food riots and famine stalked Europe long before and after "dropsy" of the potato either starved to death or sent into emigration half of the eight million population of Ireland. Today more than 75% of the land area of Europe is cultivated for food, grassland, or forestry production. In Europe the effects of agriculture and forestry on biodiversity and the cycles of carbon, nutrients, and water are seen as the critical agricultural issues. Cultivation is perhaps the most important human practice to influence these meta-agricultural issues. Therefore many of the questions posed in this European Science Foundation Science Forward Look concerning biodiversity and the water and biogeochemical cycles have their foundation in the human practice of cultivating the land.

Globally, the picture is different from that seen in Europe. In Europe we have a stable overall population with an ageing population structure and with some European countries experiencing negative population growth. In many parts of the developing world and, particularly in South-East Asia, populations are expanding but fortunately at a decreasing rate. There are causes for optimism that even with a population of 9 to 10 billion, the world, on average, will be able to feed itself. However, the average conceals the fact that the relative gap between the richest and the poorest people in the world is getting larger. In 2001, the *Economist* magazine reported that the Gini coefficient, an index of income inequality, had risen from 0.60 to 0.63 since the 1980s. Within the western world alone, the Gini coefficient varies from 0.20 to 0.35. In absolute terms the global poor may be getting richer but not as fast as the already affluent are getting even richer. The issues for the developing world in terms of food and fibre provision are balanced between the biological issues of food and fibre production and the economic and social issues of accessibility to resources. This interface between the biological and the social is the key area for research in the future as far as food and fibre are concerned.

The purpose of this paper is to assist the ESF in its stated desire to identify what needs to be done in global change research relating to food and fibre production from a European perspective. With this in mind, we start by summarising what has been achieved to date in food and fibre research, then look at what is currently achievable but which is limited due to lack of resources and/or lack of networking. We take these first from the viewpoint of agroecology and then from that of human dimensions. We then discuss approaches that require "new thinking" before attempting a synthesis leading to conclusions and recommendations. An appendix to this paper provides responses to the questions asked by ESF.

Methods

In order to canvas opinion from a broad range of European scientists on the relevant research issues for the provision of food and fibre under global environmental change, the ESF questionnaire was sent to scientists in 11 European countries. These colleagues were identified via the GCTE Focus 3 membership[5]). Replies were received from scientists in five countries (Austria, Denmark, France, the Netherlands, and the UK) and their comments are given in the appendix to this paper.

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[5] http://mwnta.nmw.ac.uk/GCTEFFocus3/

The agroecology viewpoint

Focus 3 of GCTE is entitled Agroecology and Production Systems and comprises research groups from 40 countries, including 17 member countries of ESF. Although by no means inclusive of all the European or global research in agroecology, Focus 3 does contain most of the relevant aspects of research in the sense that it includes the factors affecting the production of single commodity crops, pests and diseases, and soils, and is now looking to encompass farming systems. The GCTE Focus 3 emphasis is on the biological aspects of food and fibre productivity but with a clear recognition that there is a need to link biological and biophysical studies with those relevant to food systems (Figure 3.2.1).

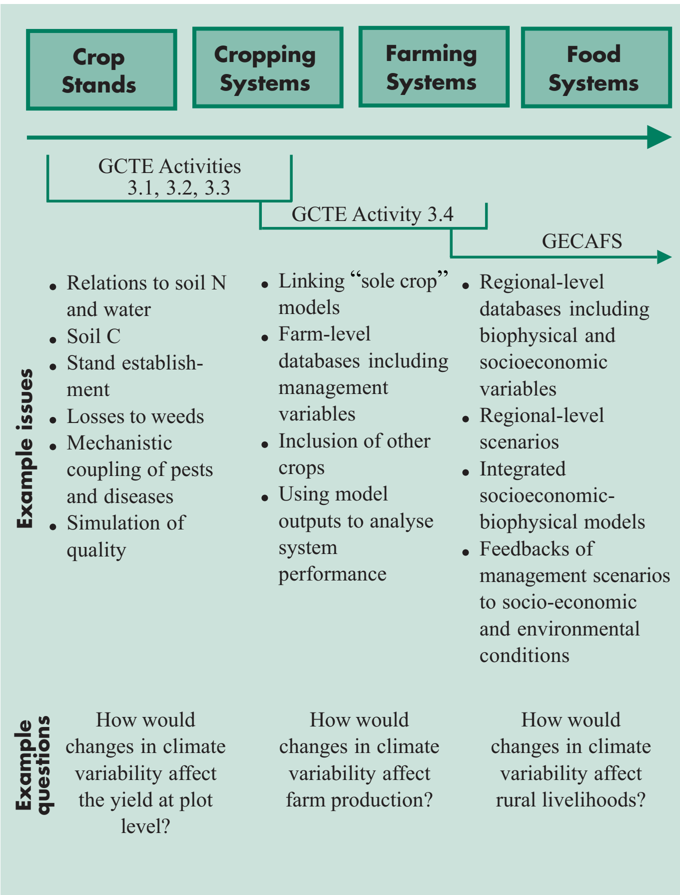

Figure 3.2.1. The division of topics within GCTE Focus 3 (Agroecology and Production Systems) and the link to research on environmental change and food systems (GECAFS). GCTE Activity 3.1 covers food, forage and fibre crops; Activity 3.2, pests and diseases; Activity 3.3, soils; Activity 3.4, production systems.

Achievements to date in agroecological research

It is fair to say that we have made considerable progress in understanding and modelling the responses of monoculture crop stands to changes in CO_2 concentration and temperature. The main human staple crops of wheat, rice, and maize, have received more attention than others that have more relevance for the world's poor, such as sorghum and millet – but the methods are transferable. The effects of interactions of factors such as nutrition and/or drought in combination with elevated levels of greenhouse gases have also been studied and detailed and Europe-wide comprehensive land-cover and land-use databases are available. Soil carbon models have also been developed, compared, indexed, and classified and are currently very important in studies of the sequestration of C into agroecological and forestry systems. Experimentally, measurements of changes in C stocks and an emerging network of sites aiming to measure greenhouse gas fluxes at a range of spatial scales can also be added to the "done" or "in progress" column of scientific activities in relation to global change. Understanding of the importance of non-linearity of responses and thus the relevance of changes in climatic variability for crop production has also been recognised. Finally, fibre and tree crops for energy or other non-food uses have also been the subject of national and EU research programmes. In summary, much has been achieved within Europe and elsewhere to the point where questions such as: "What is the impact of climate change on x, y, or z; for example wheat yield?" are no longer felt to be necessary. The scientific debate has moved forward conceptually within its own terms and beyond them by recognising the need to include issues at other scales and levels in the hierarchy of organisation that links the molecular to the societal.

Conceptually "do-able" agro-ecological research

There is a need to develop better mechanistic understanding of the links between the various components that determine harvested rather than potential yield. This could include linking soil C models to crop and vegetation models. Modelling deficits are reciprocal in soil and crop models but their integration is "do-able" given present knowledge and skills, requiring only time and energy. Modelling the effects of pests and diseases on crops also requires attention but the intellectual machinery is in place in that we now recognise that many of the environmental factors that drive the growth and development of crops also have strong influences on the life cycles and epidemiology of plant diseases and pests. Again, advances in this area mostly require the mix of people, time, and a relatively modest amount of money. The key conclusions from agroecology are that we are able to predict the performance of single crops on small scales. We are making progress with modelling and measurement of carbon fluxes but we have not yet come to grips with biotic interactions or complex agroecosystems.

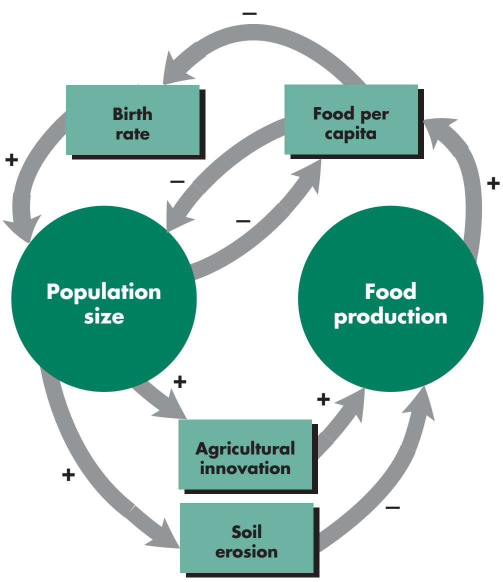

Figure 3.2.2. A diagram showing the positive and negative interactions between human drivers of food production and some of the biophysical processes involved. (Conway, 1997)

The human dimensions viewpoint

To paraphrase the compiler of the prototype English dictionary, Dr Samuel Johnson on the state of the Church in Scotland in 1773, most biologists regard the social sciences as "doing a service to imprecision and lack of critical rigour". Thus many agrobiologists feel that whilst their subject deals with hard facts and is quantitative, the social sciences are plagued by constructivist angst and political correctness leading to research of little insight or value. However, it is human social and economic activity that is changing the world's climate and environment. Therefore, any integrated analysis of environmental change has to identify the causal connections between the socio-economic drivers of change and the changes themselves, and study the means to deal with them via mitigation, adaptation, or the acceptance of damage. An example (Figure 3.2.2) of this linkage comes from Conway's book (1997) on the need for a second green revolution. It shows the qualitative direction of the links between human activities and biophysical change and is notable for the conclusion that human activity does not, by definition, always lead to negative changes. However, there does come a point when the pressures from global environmental change (GEC) additionally affect food provision and vulnerability, the adaptation possibilities and their social and economic consequences. This likely-to-be-non-linear reckoning of the marginal (in the sense of extra) effects of global environmental change on the provision of food and fibre is what we will point to as the area of food and fibre research that requires "new thinking" (Conway 1997). What is important about Figure 3.2.2 – which could be criticised for missing a few arrows, for instance a negative one between soil erosion and food production – is that it may be the case that predicting qualitative (that is, plus and minus) as opposed to quantitative effects of global environmental change is as good as we can do this kind of integrated "biosocial" analysis. Though, by combining social science insights on socio-economic development with more quantitative models derived from the biophysical sciences, some progress could be made in providing more refined qualitative predictions. The value of these qualitative results can be much enhanced, for policy makers in particular by the use of the various scenario techniques that biophysical and social scientists have been developing.

As with the topics from agroecology highlighted above, specific issues provide a focus for the human dimensions aspects of food and fibre provision to humans. In this regard, four key ideas have come from the International Human Dimensions Programme (IHDP) that need to be integrated with agroecology and production systems.

The first idea from IHDP is that social institutions play important roles as determinants of human–environment interactions. The roles that institutions play are reflected in our understanding that institutions: are systems of rules; are decision making procedures and programmes that give rise to social practices; assign roles to the participants in these practices; and guide interactions amongst the players in the particular roles.

Identifying the role that institutions play focuses on their causal links to global environmental change as well as the comparative performance, effectiveness and design of institutions in mitigating or adapting to global environmental change. Entitlement and access to food and fibre are not only questions of access to these resources but of people's ability to make effective use of them. Applying this perspective to food systems leads us to ask the main *science* question: "What role do institutions play in determining the responses of food production and consumption systems to global environmental change?" To this may be added subsidiary questions such as: "How much of any change in food systems may be attributed to institutions such as land tenure, access to credit, and markets?" "Why are some environmental policies and institutions more effective than others in sustaining or enhancing food system security?" The *design* question is: "How can environmental and trade regimes be developed to reduce social vulnerability to changes in the food system, and enhance adaptive capacity of social groups in different societies or regions?"

Another identified and significant human driver in food and fibre provision is the change in global food consumption patterns. Wider international trading of food has environmental effects at the national, regional, and local levels. Household consumption patterns change with affluence and although technological developments, such as biotechnologies, provide opportunities for cleaner agricultural practices and new "designer" foods, they are also disputed. The main question here concerns the interactions between changes in food production and consumption, and changes in global environmental change. Specific questions include how changes in patterns of food consumption will be reflected in regional differences in global environmental change and vice versa. Also, what are the implications of a switch from extensive agricultural production to intensive agricultural production in developing countries as consumption patterns change, including developments in biotechnology and organic systems of food production?

"Vulnerability", in particular social vulnerability, is an overarching concept encompassing the capacity of individuals and rural and urban communities to anticipate, cope with, resist, and recover from perturbations such as global environmental change. Interestingly, human dimensions research directly shares the notion of vulnerability with community plant and animal ecology. Here the interest is on the properties of natural ecosystems that make them resistant to invasion or able to recover following damage. As within community ecology, vulnerability is seen as a property of the system and not a residual of global environmental change. Vulnerability is inherently dynamic and responds to socio-economic factors such as economic restructuring or globalisation that can alter either exposure levels to threats such as global environmental change as well as the ability and capacity to cope with, recover from, and adapt to, the perturbation. From the ecological perspective, climate and abiotic factors can be seen as introducing the higher-order dynamics that globalisation brings about in the human context. Human coping usually refers to shorter-term adjustments that are undertaken within the context of the prevailing social system via temporary relief measures. Adaptation includes longer-term modifications in practices such as land management and diversification, and structures such as institutions regulating access to credit: for "ecology", read carbon, water, and nutrients. These modifications are made in an attempt to reduce social vulnerability in ways that any negative impacts stemming from global environmental change are moderated.

As an issue, "vulnerability" includes the lessons that can be learnt from existing vulnerability assessments of food systems and how the social vulnerability of food systems to global environmental change is affected by other stresses on the system. Methodological questions encompass the need for adequate theory, well-studied cases, and data. A starting point may be to examine the congruence between the human and the ecological use of the concept of vulnerability.

Interactions between food systems and global environmental change are inherently scale-dependent. Particular communities or livelihood systems have a different vulnerability from that of a national economy and dealing with such questions on a global scale is extremely difficult. It is not possible to simply add local vulnerabilities to give national or global estimates. Thus, local community-level concerns about the impacts of global environmental change might focus on the risks of experiencing hunger, while national concerns might focus on impacts on the national products and on import requirements. There are historical precedents for this. At the time of local food scarcity during the Irish potato famine, Ireland as a country was exporting corn to the UK. Thus the main question with respect to scale is: "How do the interactions between food consumption and production systems and global environmental change vary across different space- and timescales or, at which spatial and temporal scales and in which ways are food consumption and production systems vulnerable to global environmental change?"

In summary, the overriding food and fibre issues from the standpoint of IHDP involve the effects of institutions, changes in food consumption patterns, analysis of vulnerability and adaptation capacity, and the influence of scale on the interactions between global environmental change and scale.

Synthesis and "new thinking"

Earlier sections of this paper indicate that agroecological research has concentrated on the issues of food and fibre productivity per unit area and, to some extent, production from regions. At the same time, social sciences have been highlighting aspects such as institutional flexibility and vulnerability. However, there is a need to develop research on the issue of "provision". Provision includes notions of availability and access to food and fibre, so the interactions between global environmental change and food and fibre provision involve many complex issues spanning natural, social, and climate sciences. Research over recent years has traditionally been within the above broad disciplines. However, working independently, these disciplines are not able to design and undertake a strategic research programme to address the interdisciplinarity at the heart of the broader issue.

The development of new, interdisciplinary research approaches requires more than just networking and synthesis. New thinking is required to develop and implement a research agenda that is both relevant to the policy formulating process and to the scientific community. Concepts, such as vulnerability, could be shared in the development of this interdisciplinarity. One example of such a programme is the newly launched joint project of IGBP, IHDP, and WCRP entitled Global Environmental Change and Food Systems (GECAFS). Its goal is to determine strategies to cope with the impacts of global environmental change on food provision systems and to analyse the environmental and socio-economic consequences of adaptation. GECAFS is being developed to answer three fundamental questions of interest to science, development, and society:

- Given changing demands for food, how will GEC additionally affect food provision and vulnerability in different regions and among different social groups?
- How might different societies and different categories of producers adapt their food systems to cope with GEC against the background of changing demand?
- What would be the environmental and socio-economic consequences of such adaptations?

These questions give rise to research themes (Figure 3.2.3) that are currently being developed within the context of case studies. A key research aspect of GECAFS is to determine how best to develop the research agenda that builds effectively on disciplinary studies, while maintaining both disciplinarity and interdisciplinarity.

Given strengths in all three disciplines and an interest in developing new areas of policy-relevant research, Europe is well placed to help develop new interdisciplinary paradigms, and to take a leadership role in advancing this research in the international arena.

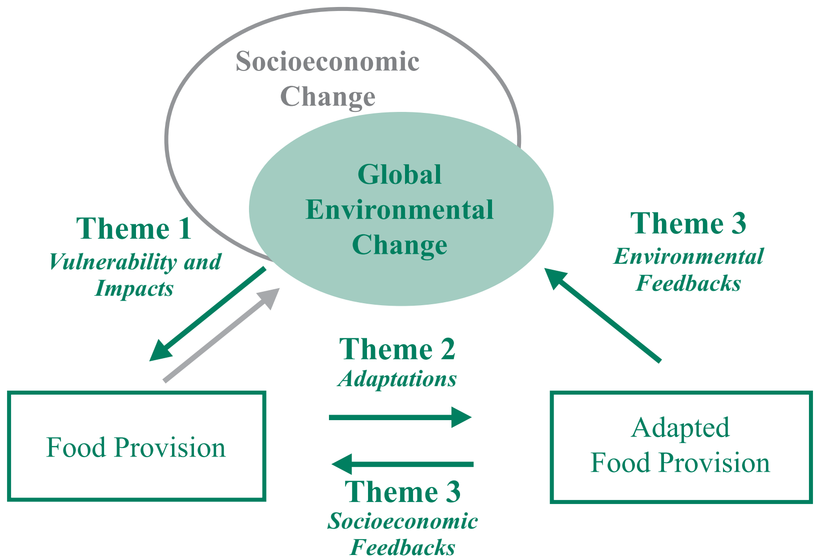

Figure 3.2.3. A diagrammatic representation of the three GECAFS science themes with respect to GEC and food provision systems. Green text and arrows show the main features of GECAFS while ongoing socio-economic change and feedback of current food provision systems to GEC are shown in grey.

Conclusions and recommendations for the ESF

Certain general points emerge from the above discussion. The first is that there are important differences between Europe and the developing world in the concerns and questions connected with the provision of food and fibre and GEC. The negative effects of GEC are likely to be most severe for the already marginalised and climatically extreme areas of production; relevant questions for Europe concern food quality and the influence of land-use on issues such as biodiversity, water quality and the C and N cycles. The insights from human dimensions are that the provision of food and fibre is not solely a question of production but involves the roles that institutions play, food system vulnerability, and the fact that food provision and security are scale-dependent phenomena. Finally, concepts of analysis and expression may overlap between the ecological and the social sciences.

We do not see ESF as, or becoming, a major funder of research in the food and fibre area. However, we can identify four very useful activities for the ESF to engage in which would be a positive contribution to the development of GEC research in Europe:

- The promotion of COST-like actions and workshops where scientists can come together and discuss ongoing and planned research. As detailed in the appendix to this paper, intra-European integration of research in GEC has been one of the great successes of the EU Framework Programmes. It is often the case that the seed of a research network starts at such workshops.

- Running international networks such as GCTE and IHDP involves administration in terms of maintaining memberships, updating web-pages and organising conferences. Universities and research institutions often fund the scientific leadership of these networks, but they are less willing to support secretarial functions. Thus, "glue funding" is needed for secretarial functions and the support of this activity by the EU or the ESF would be well accepted by the scientific community who benefit from membership of the international networks.

- Putting together integrated projects on the provision of food and fibre requires new and considered thinking. However, it is often the case that research plans and programmes are hatched at 2 to 3-day workshops and the rush and time pressure can mean that projects look good on the surface but have little scientific substance because they are not properly thought through. We would recommend that the ESF establish research fellowships, particularly to bring non-European scientists to Europe. These would have the function of giving an acknowledged expert in an area time to study and plan. A similar scheme has been launched by the Royal Society in the UK with the condition that the person appointed should be completely free from administration and teaching. The skill will be for the ESF to identify the areas where new thinking is needed.

- Many scientists have heard of the ESF and see it as an organisation relevant to their interests and concerns. Therefore one useful function for the ESF would be to find out what are the issues that scientists think important in GEC research in Europe and convey this to the national research councils and the European Commission.

For example, many scientists have found the interdisciplinary requirement for projects within the Fifth Framework Programme has not been borne out in practice. This is because the reality of the project-evaluation procedure has not laid sufficient weight on the horizontal as opposed to the vertical integration of the science as a selection criterion. This is an example of a concern that needs to be presented to the European Commission and the national research councils from a body representing European scientists such as the ESF.

Acknowledgements

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Appendix

Strengths and Weaknesses of European Global Change Research on Food and Fibre

As we were asked a series of specific questions about global change research, we thought it best to respond to those questions. In this process we have consulted researchers in 11 European countries in global change research and the answers below are an amalgamation of their and our views.

1. As a brief introductory starting point, provide a personal overview of where global change research in the topic you are writing about is going in relation to the general evolution of global change research, as witnessed in the research agenda of WCRP, IGBP, IHDP and DIVERSITAS. Identify what aspects of the topic that will benefit from European cooperation between research groups are well addressed across Europe, and those aspects where there is weakness.

There has been a series of projects on global change as it affects food and fibre starting in the late 1980s in both the natural sciences and, to a lesser extent, the social sciences. The emphasis of global change research has been mainly in the following areas.

- Modelling and experimental studies of the impacts of climate change on agriculture and ecosystems – water, forests, and grassland
- Future research on climate change and agriculture will have to deal with some unknown aspects that because of their complexity have not yet been studied in detail. These include the effect on secondary factors of agricultural production (for example, soils, weeds, pests and diseases), the effect on the quality of crop and animal production, the effect of changes in frequency of isolated and extreme weather events on agricultural production, and the interaction with the surrounding natural

ecosystems. Studies should also investigate combined effects of adaptation and mitigation strategies, and include assessments of the consequences on current efforts in agricultural policy for a sustainable agriculture that also preserves environmental and social values in rural society.

- It is very helpful to think about land surface in the context of global change and its mitigation. This involves considering soils and vegetation whether used for agriculture, forestry or semi-natural habitats and taking account of as many factors as possible regarding land–atmosphere interactions and comparing various different management possibilities. Scientists from different backgrounds are not interacting enough, especially those in agriculture and other land-uses. Anything to help this, for example through ESF workshops, would be useful.
- More research focus should be put on reductions of net greenhouse gas emissions from agriculture. Research has already shown large potentials for agriculture to reduce emissions of CH_4, N_2O and CO_2. However, most studies have assumed that farmers are willing and able to implement the measures. None of the measures have consciously been implemented or tested at the farm scale. The major challenge for research in collaboration with policy makers is to propose and implement effective, efficient, and verifiable abatement measures and policies. In terms of emission reductions, priority needs to be given to chain-oriented methods that seek to increase carbon, nitrogen, water and energy-use efficiencies in the whole food chain.
- The interaction of climate change with other environmental stresses such as ozone damage and drought.
- There has been a focus on research and development of renewable non-fossil fuel energy sources as mitigation strategies.
- On “vulnerability”, that is the capacity of individuals and communities, both rural and urban, to anticipate, cope with, resist and recover from perturbations due to environmental changes; this includes work on adaptation practices in, for example, land management and new institutional structures, and on scale issues (short versus long; local versus regional versus national).
- On “industrial transformations”, examining the complex socio-technical and institutional systems that make up agricultural production, food processing, food distribution and consumption patterns.

In general the various IGBP and related activities are helpful in bringing people and ideas together, for example work on soil C has benefited greatly. However, there also is a tendency for the different members of a network to get too concerned with their own areas of research.

Strengths

Very strong collaboration has developed between European groups as an essential element under EU research programmes. This has forced European collaboration and has given a much stronger pan-European focus to global change research than was the case prior to the 1980s. A significant budget from the EU has helped to fund and add value to national work in Europe of global importance – although funding is not at the level seen in the USA.

Weaknesses

The use of consortia under the Fifth Framework Programme and Centres of Excellence under the Sixth Framework Programme constrains the funded projects to those already aligned at the pre-proposal stage; this can discriminate against highly innovative projects from research partnerships with less EU experience or contacts than others. This can lead to the appearance that EU funding is controlled by a small group of researchers who are “in the know”.

Under the current Framework Programme it is not possible for the EU to call for a project in a very specific area; thus the EU can end up with too many projects in one area and none in another, leaving very large gaps in essential, policy-supporting areas.

In Europe there is a danger that we focus too much on the high-tech carbon-observing systems such as flux towers. This is not to argue that they are not needed, indeed they are very important for understanding the carbon cycle. However, these projects are often portrayed as if they could provide a basic support for national greenhouse gas inventories or the Kyoto Protocol, which they do not. In UNFCCC negotiations, as in The Hague and Bonn, it became quite apparent that other countries (for example, USA, Canada, Australia) are focusing more on inventory-based systems for monitoring carbon in terrestrial ecosystems, and this seems to be lacking in Europe.

European monitoring programmes on CO_2 and N_2O fluxes have been dominated by studies in forests and natural ecosystems. However, agriculture in some form is a dominating land-use in Europe. Therefore there is an urgent need to set up a European monitoring programme of greenhouse gas fluxes from agricultural ecosystems, in particular for arable farming systems. Such a monitoring programme will also need to include effects of crop and soil management, as this may be of overriding importance for emission estimates and be used in policy making.

It is important to emphasise the role of the social and human sciences in studies of both mitigation and adaptation. Whilst agricultural production will be adapting to environmental changes, there are other dynamics that will have a stronger impact on food supply and/or demand than the environmental dynamic, namely changing global economic and trade developments, changing household food consumption patterns, and new technological developments (throughout the chain from farm to factory to shop to plate). More work on these dynamics is needed at the European level, especially with respect to the expansion of the EU.

2. How can we build on strengths and overcome weaknesses from a European perspective? It is desirable to address this issue with a view to creating win-win situations with regard to strengthening European research in this area and making an important contribution to global programmes.

It should be possible to target very specific projects that are identified as essential to policy needs, put them to open tender and re-think the centres of excellence idea. However, this would concentrate all the research money on those projects already funded and may stifle innovation and work in other areas.

There has been much national investment in looking at effects of climate change on crop productivity. A better coordinated effort is needed to consider implications of this on production overall; this needs better links to research on current and projected amounts and on the distribution of arable and grassland. Another area relating to food, of relevance to Europe, is the interaction between climate change and food quality. This is a very under-researched area both in Europe and globally; so far it has been food quantity and not quality that has attracted research support. In food-sufficient Europe the main concern should be with food quality.

We need to link pests and diseases to crop models. A related topic is pest-risk analysis that has direct policy implications related to quarantine legislation and trade agreements and has unfortunately sharpened in focus following the possible emergence of bio-terrorism.

We need also to have more studies of changing patterns of food consumption in European households (including those of accession countries) in response to events of the last ten years such as challenges to the food chain hygiene, the movement to organics, and the opposition to GM foods.

3. What actions are needed at the national level and at the European level? Please address the following items in this context:

a. Is special attention needed on infrastructures and monitoring? If so, what?

Monitoring aspects of the environment and ecosystem functioning is very important; it is the only way to get real data on change. Such work is in itself boring and difficult to attract research-type funding. Any stimulation for monitoring or use of existing data sets would be welcome. In the UK there is the Environmental Change Network (ECN) in which a set of variables is monitored regularly using common protocols, and the results coordinated. There are about 12 terrestrial sites and more recently a large number of freshwater sites. Again, ESF might be able to encourage this sort of activity.

b. What European coordination is necessary between organisations responsible for supporting this research in terms of, for example, developing joint programmes, setting up joint infrastructure or mechanisms for sharing infrastructure, or "glue funding" for the central structures of the research programmes?

As a case study we feel that the COST programme has shown the value of coordination on a European-wide basis and linking to the international global change agenda. It has been well appreciated by researchers since it has been relatively flexible in its organisation and has not taken too much time to administer. Good examples are COST 619: Elevated CO_2 and Grasslands, now over but which included two significant joint meetings with GCTE; and COST 623: Soil Erosion under Global Change, which has provided a hitherto lacking coordination mechanism, and which is directly related to the Global Change and Terrestrial Ecosystems (GCTE) soil erosion network.

Given the national funding problems in Europe for environmental research there is a gap in the funding profile for the provision of infrastructure to maintain global networks of researchers in global change. Also, there is no EU mechanism for providing funds to run global change networks that span the globe. The funds for running network offices are about 112 thousand euros per year. We stress the need for the ESF to find infrastructure funds for European-sited offices that can both help European coordination and link this to the international scene. The international leverage resulting from such an infrastructure investment can be seen in the soil erosion network of GCTE. Had the GCTE office not been in existence to help develop the COST proposal and agenda in line with the international (namely GCTE) agenda, we doubt that this valuable global coordination exercise would have happened.

c. Is there sufficient interchange and collaboration between individual researchers and laboratories? How could this be improved?

We feel that there are very good EU programmes for interchange between researchers and laboratories within Europe as a whole. Where a gap exists, it is in the difficulty in inviting and accommodating global change researchers from outside Europe. The establishment of ESF Travelling Fellowships for non-European personnel to visit European laboratories and policy studies institutes and to cooperate in global change research would help a great deal.

Links to developing countries is especially important in the context of global change research since it is in these areas that the negative effects of higher temperatures and altered rainfall patterns are going to be felt most acutely. As an example, the EU INCO project on Southern African rangelands has both been developed upon, and helped to further strengthen, existing European collaboration. A core project of the IGBP programme (GCTE) was instrumental in getting this together, and it is an example of how improved European collaboration can help jointly address critical issues where bi-lateral links would be deficient. IHDP research on food systems is starting to be more strategically coordinated; European researchers have a potentially vital role to play in providing the underpinning for this work.

4. What will be needed to establish European leadership in this aspect of global change research?

Better European coordination through ESF could give a clearer picture of scientific priorities. The ESF is well placed in preparation for an expanded European Community as it already works with many European nations outside the current EU membership. An example is the development of urban and peri-urban science.

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3.3 Water: the resource challenge of the 21st century

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Introduction

Water is a key resource challenge. On the global scale, withdrawal and net consumption of water is expected to grow substantially during the next 50 years, owing to an increase in population, food production and an improved quality of life. In addition, even if the trend of a decrease in net consumption continues in several of the most developed countries, the global increase of water use by 2025 is expected to be in the range of 25–50%, according to several development scenarios (Cosgrove and Rijsberman 2000).

The aim of this paper is to briefly review the behaviour of the terrestrial water cycle as a part of the Earth system, and to reflect the current and future European research agenda on water. This paper does not attempt to re-invent the science agenda, but to look at Europe's strengths and weaknesses, including possible new provision of organisational and research infrastructures.

Water cycles and energy cycles are closely linked and future climate change will cause major changes in regional water availability, affecting food security and social security, ecosystem vulnerability, and therefore the overall sustainability agenda. For European research, water and climate present a particular challenge. Along with a need to enhance physical and biogeochemical aspects of water research, new integrated methodologies to address interactions between hydrology, climate, and water management need to be developed. These need to be based on interdisciplinary and participatory approaches. A dialogue between basic climate and hydrology science and a more applied water forecasting and management strategies, needs to be intensified and made more effective.

In the future, European research should be better positioned to address issues of vulnerability to the increasing frequency of hydro - meteorological extremes such as floods and droughts. European research on water cycle and water resources management needs to address global water issues more effectively and in a less fragmented way. Europe must maintain and consolidate its present position as a leading partner in several international global change, water research, and observational programmes.

Water resources, the hydrological cycle and the environment

In essence, renewable water resources are finite, as they are limited by the flux of freshwater brought to, and withdrawn from, the continents by the processes of the hydrological cycle. Nevertheless, it is generally accepted that the available water resources are not equivalent to the sum of the annual river flows to the oceans. Floods compose a large proportion of the flows and when they occur as extreme events, they manifest as a disaster rather than a beneficial resource. River flows are very unevenly distributed with time; almost everywhere on Earth river regimes show a strong seasonal variability. In areas such as the sub-tropics, or in Mediterranean-type climates, flows are often ephemeral and at times limited to a few weeks of the year. In cold regions, winter flows may be reduced significantly as a result of the retention of water in the forms of snow and ice.

The spatial variability of surface flows is also striking. In the rural areas of developing countries the travel distance and time required for accessing and collecting the water can be long. Depending upon geological features, groundwater may be a convenient water supply option. However, a groundwater source is often unusable, either because of the make-up of its natural chemical constituents (for example, salt or arsenic) or because of anthropogenically induced pollution (for example, nitrates). In addition, shallow aquifers may not withstand harsh dry seasons and as a consequence groundwater resources, as well as surface flows, may dry up.

In order to adapt to the variability of water resources in time and space, water supply and reticulation systems have been developed (for example, dams, transfers of water by canals and pipes). However, the required investment in labour and/or capital implies the grouping of users around, or in, cities or market towns. Nevertheless, a sizeable proportion of the world's population still lives in scattered rural habitats and these people depend on the availability of water in its "natural" form for satisfying their basic needs such as drinking, cooking, sanitation, livestock watering, and agriculture. In different climate regimes (for example, sub-tropical, semi-arid, Mediterranean-type), such "natural" availability of water is highly variable within a given year and between one year and the next. Any reduction in the amount of water resources or minor changes in their distribution in time will lead to serious impacts for these communities if they are not supplied with potable water from external sources.

Freshwater is an essential driver of terrestrial and aquatic ecosystems. The state of equilibrium in the distribution of terrestrial ecosystems results from a balance between climatic conditions and the ecosystem's resilience in the face of variations in those climatic conditions. Any change in the variability of climate, or any trend in any one of its components, may lead to latitudinal and altitudinal shifts in the distribution of terrestrial ecosystems (for example, rainforests, savannas, steppes). In a given catchment or basin these changes might have tangible effects on the water budget and thus on the availability of water resources.

Freshwater ecosystems (such as ponds, lakes, wetlands, and rivers channels) are essential components of the natural environment. They provide support for the existence of aquatic and terrestrial wildlife, environmental goods (for example water and foods) and services (such as flood attenuation, depletion of organic pollution). In many regions fish are a key element in the social and economic organisation of human communities and are the major source of proteins, and sometimes the only one, especially for the poor. Further issues on the importance of the environment in water resources, considering only present climatic conditions and not any further repercussions of enhanced warming or variability, are expanded upon in the Box.

Unfortunately, and especially in developing countries, water is also associated with specific diseases. There are several ways in which water is involved in transmission of disease, including water-borne diseases resulting from the contamination of water, as well as water-dispersed diseases, such as Legionella.

With regard to water-related diseases, aquatic ecosystems are extremely sensitive – both positively and negatively – to any changes, including those related to climate change (for example, changes in water temperature, water depth, velocity of water in streams etc.).

Although figures show that at the global level the increase of water demand and use appears as being the determinant driver in what can be considered as a looming crisis, it must be pointed out that the relationship of humans with water is largely defined at the local level, with water being considered either as a resource or as an ecosystem (Kabat et al. 2002). Global and even national indicators hide the obvious fact that for all beings, scarce water means bare survival and no water at all means death within a few days. In many stressed environments, the resource component in the demand/supply balance may, indeed, become the key issue if the resource is modified in total amount or in its temporal or spatial distribution by, for example, changes to mean climates and climatic variability.

With a water crisis facing many countries, it seems an immense task just to manage water so that there is enough for domestic supply, agricultural, and industrial uses. Therefore, providing water to other users, such as the "environment" is often given a low priority. Indeed, the situation is often presented as a conflict of competing demand, as though it was a matter of choice between water for people and water for wildlife. However, since the UNCED Conference in Rio in 1992, it has become increasingly recognised that the "environment" means far more than just wildlife, although the need to conserve biodiversity is widely accepted. Functioning ecosystems perform vital functions such as flood reduction, groundwater recharge, and low flow augmentation, and important products such as fish, pastureland, reeds, medicines, and timber (Acreman 1998). Thus for the millions of people worldwide, particularly the rural poor who depend directly on natural resources or benefit from ecosystems, providing water for the environment and for people are one and the same (Acreman 2001).

The Dublin Conference in 1992 (a preparatory meeting for UNCED) concluded that "since water sustains all life, effective management of water resources demands a holistic approach, linking social and economic development with protection of natural ecosystem". For example, upstream ecosystems need to be conserved if their vital role in regulating the hydrological cycle is to be maintained. Well-managed headwater grasslands and forests reduce runoff during wet periods, increase infiltration to the soil and aquifers, and reduce soil erosion. Downstream ecosystems provide valuable resources, such as fish nurseries, floodplain forests or pasture, but these must be provided with freshwater and seen as a legitimate water user. At the UNCED Conference itself, it was agreed that "in developing and using water resources, priority has to be given to the satisfaction of basic needs and the safeguarding of ecosystems" (Agenda 21, Chapter 18, 18.8). Thus whilst people need access to water directly to drink, irrigate crops or supply industry, providing water to the environment means using water indirectly for people. The declaration from the Second World Water Forum in The Hague in 2000 highlighted the need to ensure the integrity of ecosystems through sustainable water resources management. South Africa is one of the countries that has taken a lead in implementing this concept. Principle 9 of the 1998 National Water Act of South Africa states that "the quantity, quality and reliability of water required to maintain the ecological functions on which humans depend shall be reserved so that the human use of water does not individually or cumulatively compromise the long-term sustainability of aquatic and associated ecosystems". The 1996–2001 Fifth International Hydrology Programme of Unesco included an ecohydrology project that included ecosystem management to improve water quality, particularly in the form of buffer strips to ameliorate the impacts of agricultural pollution. The World Commission on Dams (2000) recommended the release of environmental flows from dams to support downstream ecosystems and their dependent livelihoods.

Water resources under climate variability and climate change

A significant proportion of the solar energy received by the Earth is utilised in driving the hydrological cycle, that is for evaporating vast quantities of water of which 40 000 km^3 are moved and precipitated over the continents every year. The increase of greenhouse gas concentrations in the atmosphere will lead to an increase of the available energy on the surface of the Earth and thus, according to the basics of thermodynamics, an "intensification" of the hydrological cycle will occur. On the global scale, all global climate model simulations have verified this.

The oceans play a major role in climate as they are able to store and to release sizeable proportions of the incoming energy. Experience and the most advanced knowledge on climate processes are consistent in the prediction that the expected intensification of the hydrological cycle will not be experienced merely as a smooth linear trend, but rather in the form of oscillations in the variability of climate. The oscillations may be more frequent than in the past and the amplitude of the variability may also increase over some areas (Kabat et al. 2003).

Most of the geochemical and biochemical characteristics of water are acquired during its travel from the clouds to the rivers, through the biosphere, the soils, and the geological layers. Changes in the amounts, or patterns, of precipitation will alter the route and the residence time of water within the catchment and change its quality in ways that the resource might be lacking, not because of the quantity, but because its newly acquired quality may have rendered it unsuitable for the required use. For example, there are real risks that an increase in the concentration of dissolved salts may occur as a result of an increase in evaporation under higher temperatures. The risk of increased salinity might also be associated with excesses of water. Under such conditions the water tables that were previously kept at a given distance under the surface, may rise and reach soil horizons, which may then be salinised or contain agrochemicals or industrial wastes. The water from these shallow aquifers may eventually drain into the river network and reduce the quality of the water further downstream.

Looming data crisis

To be able to assess any changes in river flows, aquifer levels or freshwater ecosystems and to predict their behaviour in the future, the following two conditions need to be met:

- we need to have ready access to sufficient and reliable local data and information to address issues of changes in hydrological responses for a given basin or region; and
- we need to have the capacity to model hydrological processes realistically.

Contrary to climate information, which is generally collected for scientific purposes, most information on hydrology and water resources is collected for management purposes. The consequence is an institutional fragmentation of the collection process, country by country and even within a single country, where different water-use sectors (for example, energy, navigation, agriculture, domestic supply) may operate their own specific networks and use different procedures for the collection, storage, and retrieval of data. Moreover, while there is a long tradition of exchanging or freely disseminating atmospheric information at the global level, the free availability of water-related data remains, in many cases, a sensitive issue as it applies to an economic resource. Several initiatives, including Resolution 25 (Cg-XIII) adopted by the World Meteorological Organisation (WMO), are advocating the sharing of hydrology-related data. However, there is still a long way to go to match the effectiveness of the World Weather Watch of the WMO.

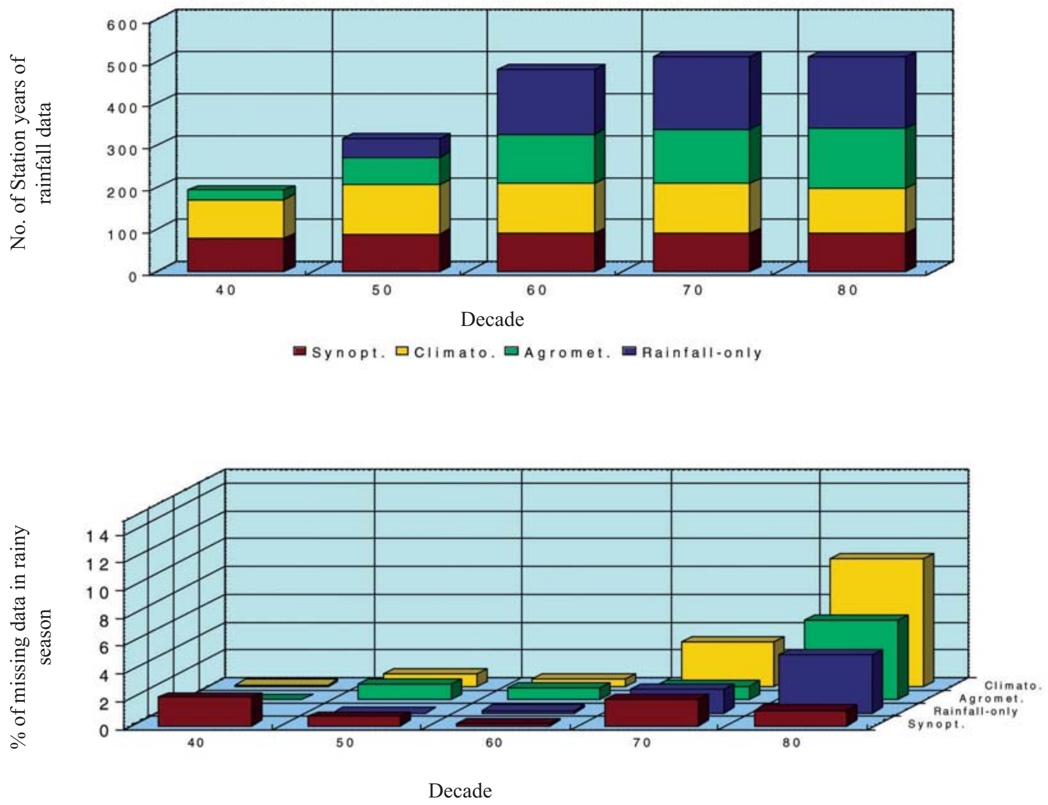

Figure 3.3.1. Example of the retrogression of the quality of hydrometeorological data in a country of sub-Saharan Africa (source: World Bank 1991).

The cutting-back of many national meteorological and hydrological services, and consequently of the maintenance and operation of their networks and field stations, are other very serious causes for concern. The governing concept seems to be that any water crisis is, in the first instance, a management crisis or a supply side-issue rather than a resources crisis. However, political interest in, and financial support for, the monitoring of weather and water resources has been shrinking markedly in most countries. The effects of such a rationale are definitely jeopardising our capacity for addressing some major issues of water resources under conditions of current climate variability and of possible future change, as well as for forecasting and accurately monitoring water-related disasters, and for planning the equitable share of the benefits of water in large transboundary river basins.

The retrogression of data collection varies. In some instances the number of stations has declined, while in others the number of stations may have been maintained but the quality of the data (that is its accuracy or continuity over time) might have regressed to the extent they become unusable. Figure 3.3.1 shows an example of the latter case for a country of sub-Saharan Africa. Although the number of rainfall stations has remained steady, the frequency of observation gaps has increased dramatically, thus rendering unusable the time series from a number of rainfall stations. Figure 3.3.2 illustrates that the decline in monitoring activities is not necessarily limited to the developing countries.

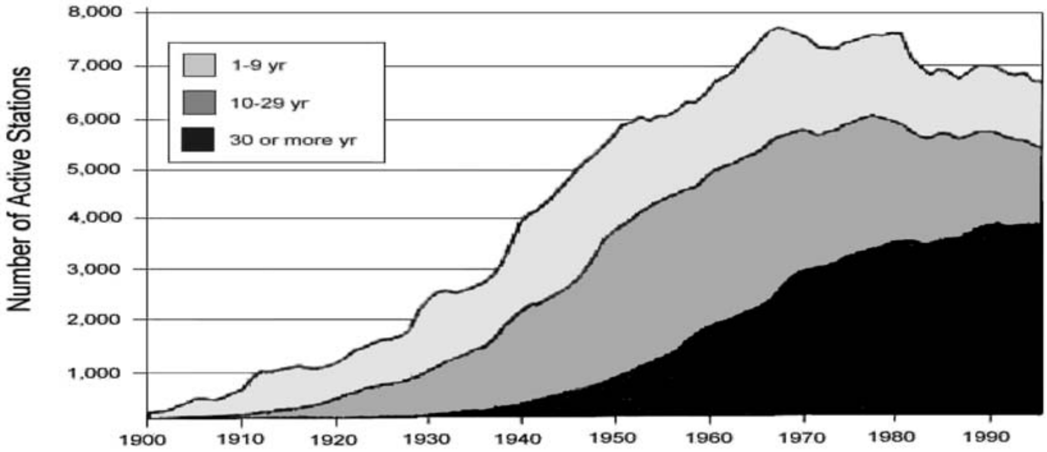

Figure 3.3.2. Number of active discharge monitoring stations in the USA from 1900 to 1996 (Figure contributed by J.M. Fritch, WMO).

Current international coordinated research efforts

The key research project dealing with the physical aspects of the global water cycle is WCRP's Global Energy and Water Cycle Experiment (GEWEX) that has established a number of Continental Scale Experiments (CSEs) in which all facets of the water cycle in a major river basin are investigated with the aim of understanding, modelling and predicting the water and energy cycle on timescales of days to months, and to project the future water cycle given a climate change scenario. In GEWEX's Co-ordinated Enhanced Observing Period (CEOP), ending in 2004, all CSEs will jointly establish enhanced data sets allowing the teleconnection in the water cycle to be deciphered, and which will test the future observing system (high level reference sites with in situ measurements and ground-based vertical profiling plus global coverage from operational and pre-operational satellite sensors) that would allow the transfer of interactively coupled models from CSE basins to any other large basin. One of the CSEs is a European activity called BALTEX, which covers the Baltic Sea catchment, with contributions from all countries having a major territory in the Baltic Sea catchment area.

There are still some major gaps (often also in the implementation plans) in the projects relating to the physical aspects of the water cycle. These are:

- groundwater recharge and variability;
- measurement of upper soil wetness from space;
- pre-operational flood forecasting.

Single European countries and sub-groups of EU Member States are comparably advanced concerning hydrological research and hydrological services, and are leading the forecasting of precipitation. However, there is a lack of coordination and an emphasis on water cycle-related research in the Mediterranean Basin, although it is the most vulnerable European area with respect to climate variability and change; the water cycle in this basin may already be altered by regional pollution and ongoing climate change. With regard to water pollution, European countries can point to major successes in its political measures as environmental research on the quality or diminished quality of inland waters has clearly shown how to remedy the situation.

Another internationally coordinated research activity related to water, in which a European contribution predominates, is the IGBP core project Biological Aspects of the Hydrological

Cycle (BAHC) that has quantitatively dealt with the links between the water cycle and the terrestrial biosphere. The new interprogramme projects on Water and on Food and Fibre can build on the results of BAHC and GEWEX as well as of GCTE in IGBP.

In some European countries transdisciplinary research dealing with water is already under way, namely stakeholders such as farmers and water-resource managers are involved. A good example is the research programme GLOWA in Germany having initiated such projects for European and African river basins.

With regard to European cooperation, we can point to the Rhine Commission that links scientific findings with international policy making.

At the international (multi-agency) level, The International Dialogue on Water and Climate[1] was established in 2001 as a platform to bridge the information gaps between the water and climate sectors in order to improve our ability to cope with the impact on water management of increasing climate variability and change. The goals of the dialogue are to develop a knowledge base, generate widespread awareness, identify policy and management options that build such capacities, learn from the experiences throughout the world, and make this knowledge available to the most affected communities.

The International Dialogue on Water and Climate recognises that the implications of climate variability and climate change have not been fully considered in current water policy and decision making frameworks. This is particularly true in developing countries where the financial, human, and ecological impacts are potentially the greatest, and where water resources may be already highly stressed, but the capacity to cope and adapt is the weakest. The dialogue itself has different components where the water-resource management and climate-scientist communities are engaged in a process of building confidence and understanding, identifying options and defining strategies which are applicable at regional, national, and river basin levels. The envisaged final outcome are policies and actions that create conditions where more effective coping and adaptation mechanisms for dealing with water and climate vulnerability are developed and applied at the international, national, and community levels.

[1] http://www.waterandclimate.org

What are the areas relating to water where European research could make a difference?

Characteristics of existing research on the water cycle

1. European researchers are among the leading groups because they have been strongly involved in coordinated international programmes from their inception. However, most of the large-scale or global data sets with a European contribution have been issued and consolidated by institutions in the USA.
2. Many national funding agencies and the European Commission are still hesitating to ear-mark funds for large-scale projects of the established Global Environmental Change Research Programmes (such as WCRP, IGBP) in contrast to USA and Japan. This leads to a partial lack of coordination of European research projects, which can therefore only partly contribute to the coordinated programmes of IGBP and WCRP, and as a rule, suffer from lack of long-term continuity. Exceptions in some countries are WOCE, parts of CLIVAR, BAHC, JGOFS, and GLOBEC.
3. Concerning multi- and transdisciplinary research needed in the new interprogramme global environmental change projects, some European countries may have a comparative advantage as they have already initiated this kind of research for water and carbon.
4. There is a lack of research on the long-term threat to groundwater originating from

agriculture, acid rain and fertiliser deposition from the atmosphere, and industry.

5. Except in meteorology there is no “culture” of international cooperation via near real-time exchange of data related to the water cycle (soil moisture, ground water, river runoff or stream flow, water quality).
6. Despite of a wide recognition of the importance of the biogeochemical cycles in the climate system, the European climate research community is only incidentally connected to a community of the biospheric and biogeochemical sciences.
7. Climate and hydrological research in Europe is still very much driven by the top-down science agenda, and less by the needs of water planning and water management communities. This is a handicap in terms of, for example, the development of scientifically sound flood and drought forecasting and warning systems.

Directions for future research and observing activities

1. Development of integrated and adaptive flood forecasting for all major river basins in all European countries by better integration of hydrological services and hydrological research in European countries and closer links to the meteorological community (researchers and services). This could be the first GMES success story. This needs the establishment of a real-time river flow network as a test bed for flood forecasting and also the improvement of aerial precipitation measurement by integration of radar networks with rain-gauge networks controlled by high accuracy reference sites.
2. Groundwater modelling with the goal to avoid over-exploitation thereby linking the focus on Water with the focus on Food and Fibre theme. This research needs exchange of groundwater level and quality data between all countries.
3. Extension of long-term weather forecasting into seasonal precipitation prediction and dissemination to users. It has to be based on a global coupled model (European Centre for Medium Range Weather Forecasts) and nested regional models, with an emphasis on droughts. This research needs the implementation of the Argo observing system, upper soil wetness data from the ESA Soil Moisture and Oyster Salinity mission, in addition to all other *in situ* and satellite data available now. It also needs research efforts to disseminate the appropriate prediction to the different user groups, for example hydropower companies and farming associations.
4. Regionalisation of changes in water availability due to climate change. Useful regionalisation of climate change is often not yet available because it needs correct global and regional forcing and rigid climate model tests. We need a rather long-term strategy and major international cooperation. The strategy has to include rigorous model intercomparisons and validation, a multitude of possible forcing scenarios (including aerosols and land-use changes) and careful diagnosis. It must become an EU topic, for example focusing on the Mediterranean and Africa.
5. Consolidation of long-term data series on past and current climate variability across Europe, and a statistical analysis of these series in order to understand the extremes (floods, droughts) due to natural climate variability. One must ask whether the frequency as well as magnitude of these extremes is increasing across Europe, and what is the role of anthropogenic climate change in exacerbating future extremes?

European research infrastructure

For these new research activities on Water, European research infrastructure (including funding and institutional structure) needs to be up-graded in the following areas.

1. Interactive regional modelling platforms with emphasis on the water cycle comprising atmosphere, marginal seas, soils, vegetation, runoff at several research centres, and services.
2. Compliance of hydrological services with Resolution 25 of the World Meteorological Congress 1999 regulating the free and open exchange of hydrological data, similar to Resolution 40 of the World Meteorological Congress 1995 for meteorological data.
3. Budget lines of European funding agencies for the focus on Water, especially in the EU Sixth Framework Programme, as this would also help European countries that lack national coordinated programmes for IGBP, IHDP and WCRP to establish these.
4. European network of centres of excellence for Earth System modelling with the appropriate computing infrastructure and joint model runs preferably in ensemble mode.
5. Improved evaluation of proposals to the European Commission through the involvement of, for example, the ESF in the selection process for reviewers.
6. Agreement between the ESA and the EU on the financing of an Earth Watch Programme, including a European contribution to a global precipitation mission.
7. Establishment of single national committees for all four global environmental change programmes (DIVERSITAS, IGBP, IHDP, WCRP).
8. Encouragement and full integration of social sciences, with a focus on participatory approaches, in all countries by enhanced funding comparable to the natural sciences domain.
9. Encourage public-(semi) private research partnerships in the area of Water, and remove bureaucratic barriers in funding this kind of partnerships.

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3.4 Industrial transformation

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Introduction

The threats of global environmental change pose important challenges to environmental and socio-economic research. These challenges no longer primarily concern discovery and confirmation of environmental problems, but rather involve an improved understanding of society, its changes, and its relation to nature in order to develop sustainable strategies for a changing society. It has become increasingly obvious that traditional environmental research, which has been (and still is) dominated by natural science and technology, is inadequate in this context. Increased collaboration, cross-fertilisation and possibly integration between different disciplines, perspectives, scales and methods are central for coping with the challenge of global environmental change. During the recent decades this challenge has formed the background for the growth of environmental research in social science and humanities, and of integrated research under headings such as ecological economics, eco-restructuring, industrial ecology, sustainability science or industrial transformation. It also forms the background to the International Human Dimensions Programme on Global Environmental Change (IHDP) and its project on Industrial Transformation. This report presents an overview of this project, and takes a look at its research foci from a European perspective and discusses European research strengths, weaknesses, interests, challenges and priorities in the context of IHDP and the Industrial Transformation project and its research agenda.

The IHDP Industrial Transformation (IT) project

While there are many international research programmes dealing with the natural science of global environmental change, the IHDP provides a unique forum for global environmental research focusing on human aspects of environmental change. Within this programme, the Industrial Transformation (IT) project focuses particularly on production and consumption systems and "seeks to understand the complex society-environment interactions, identify driving forces for change, and explore development trajectories that have a significantly smaller burden on the environment" (Vellinga and Herb 1999, p. xi). The main focus of the IHDP-IT agenda "is a new way of organizing research, which aims at understanding the societal mechanisms and human driving forces that could facilitate a transformation of the industrial system toward sustainability" (IHDP Annual Report 1998-1999). The IT project is based on the assumption that there will be a need for important changes in production and consumption systems for meeting future human needs and the goal of sustainable use of resources. One should emphasise that "industrial" in this context refers to the industrial society or economic system, which is a lot broader than the industrial sector. The project is further based on a systems approach and it is multidisciplinary, built on foundations of both social and natural sciences, and it has ambitions to combine, challenge and integrate different research perspectives (Vellinga and Herb 1999, pp. 4-6). The four general characteristics, which have been defined to delimit Industrial Transformation research, include that the research should:

- deal with the relationship between societal, technological, and environmental change;
- focus on systems and system changes of relevance to the global environment;
- relate producer and consumer perspectives, including incentives and institutions that shape these;
- be international in scope (Vellinga and Herb 1999, pp. xi and 2).

The project focuses on system changes on various levels; some macro-trends such as economic liberalisation and globalisation might be rather general, but perhaps the most interesting outcome of the research plan development process through regional preparatory workshops, is the recognition of the different developments, problems and challenges in various parts of the world.

Five research foci have been selected (Table 3.4.1): Energy and Materials Flow; Food; Cities (focus on Transport and Water); Information and Communication; and Governance and Transformation Processes. These foci have been further developed by the acceptance of the IT project under various headings. There are presently 18 IT projects These projects vary significantly in scope, scale, ambition, length, and the range of participation. Most of the projects fit in the

Table 3.4.1: Key research questions for Industrial Transformation research

Research focus	Key research questions
Energy and Materials Flows	● From geographical, sectoral, and company levels, what are the strengths and the nature of the relations between energy and material use, technological change, and economic performance? ● How will international trade in energy, investments in energy infrastructure (production and distribution), and the related flows of energy and materials be affected by international treaties, e.g. the Framework Convention on Climate Change and related protocols, and the WTO? ● What are the technical, economic, and social driving forces for the private energy sector towards the development of low carbon technologies and markets? ● What is driving and/or pulling consumer needs and preferences in the field of energy and materials use, and what institutional, socio-psychological, and technical arrangements would influence purchasing, investment, and lifestyle to have a significantly lower level of environmental impact?
Food	● What is the feasibility of "de-linking"? Is it possible to meet growing needs and changing preferences while simultaneously reducing environmental impacts? ● What are the regional variations in sustainability of different FCPSs (food consumption and production systems), and what role do FCPSs play in regional development? ● What are the global trends and what solutions can be envisaged? ● Which measurement tools can be used/developed to measure progress in the sustainability of the FCPS? ● How do regional policies affect the contribution of FCPSs to global environmental change and how could they be redesigned?
Cities (focus on Transport and Water)	● What are the opportunities and constraints to "de-link" transport from the carbon cycle? ● Why is the transport-carbon budget different from one city to another? ● How can systems be re-designed to minimise negative effects both locally and remotely, seen from technological, spatial, and institutional perspectives? ● How can the need for water be "de-linked" from effects on the hydrological cycle? ● Why do these effects differ from city to city? ● How can the re-design of technological, spatial, and institutional systems help to reduce the negative effects on the environment of water use?
Information and Communication	● What is the role of global environmental change in the strategic decisions of leading companies in the electronics, information, and communication technology sector? ● In what ways can the new technologies alter the overall system of production and consumption to raise living standards while contributing to materials efficiency and reducing burdens on the global environment? ● How will information and communications technology influence society and lifestyle and, through this, alter the way environmental resources are used? ● To what extent do changes in information and communication technology enable the development of an international society that supports international and local discourses on global environmental change and its effect on society, the scientific community, and policy and decision makers?
Governance and Transformation Processes	● How does systemic change in society-environment relations occur and what processes shape the relation between socio-economic activity and the natural environment historically and in the contemporary period? ● What contemporary transformation processes might be harnessed to the goal of systemic change in society-environment relations? ● What are the most powerful supranational and non-state driving agents for global environmental change? ● What is the role of the state in a globalised context in promoting global environmental change? ● What are the examples of successful models of policy intervention, where special attention has been paid to the societal context?

general research foci's remits, but there are only a few projects that seem to be on the right level to really be able to contribute to the major objectives of the project. The most obvious weakness of these projects is the limited geographical spread of the major research partners. Most projects are Dutch, some American, one is Japanese but the rest are European.

It is rather early to evaluate the influence and the quality of these activities in any detail, but the mere establishment of this research programme and its connected activities has many positive contributions and may be viewed as an important step in the right direction.

The establishment of this international research programme:

- reflects the need to change the paradigms of human behaviour because of the seriousness of the global environmental and economic problems;
- reflects the fact that transformation to more sustainable systems is only partially a matter of technology; economic, socio-cultural, and institutional changes play an equally important role (Vellinga 2001). This presents a challenge and an invitation for socio-cultural and economic research to contribute to global change-industrial transformation research;
- stimulates communication and research efforts across national borders and traditional disciplines. This is particularly important for involving the social sciences in global change research. It is evident that there is a much greater need to develop networks and stimulating analysis on international levels in social sciences and humanities;
- offers a challenging context for many of the new interdisciplinary fields in environmental research such as human ecology, ecological economics, materials flow analysis, industrial ecology, cleaner production, and political ecology. These fields share many goals, ambitions, and activities, and many of the researchers in IT circles are also active participants in more than one of these fields.

IHDP and its programmes try to encourage research with a strong connection to decision making, and assist and complement the natural scientific analysis of global environmental change and thus play a more important role in this context. It also tries to stimulate innovative research that may contribute to the development of theories and methods in social science and humanities.

The IT project is rather special and different in relation to the emerging new interdisciplinary research fields in environmental research. Among other things, this is because of:

- the explicit connection with global change issues;
- the fact that the IT project takes a more global view, for example by stressing the differences in various parts of the world. This reflects the participation of “non-westerners” in the development of the research agenda;
- the focus on environmentally “de-linked” economic development, which is a challenge for much of the ongoing integrated environmental research, and an implicit invitation to development research (for example, regional economic, urban, rural, and industrial development studies) to contribute. So far, this kind of research has surprisingly seldom considered the environmental aspects, and it has been absent in other environmental research contexts, but it is definitely needed for reaching the goals of the IT project;
- the emphasis on the importance of human players and consumers and their social context. This should be viewed as an invitation for a more active and broader participation of social, economic, and cultural research in global environmental change research;
- the explicit ambition to involve industry (more generally the industrial economic system) in the development of the research, which has been an important and unique element in the development of the research plan.

All these points indicate perspectives and connections that are poorly developed in the dominating integrated environmental research and can be summarised as the challenges that the IT project tries to tackle. The first step is to understand the mental model that forms the basis of present economic thinking.

European strengths, weaknesses, and challenges in relation to the IT research foci

There is no doubt a large, widespread and growing body of research in Europe with a potential to contribute to industrial transformation research. To a large extent this research can be found within environmental research in traditional disciplines such as economics, technology, biology, geography, and sociology or the new emerging interdisciplinary research areas of ecological economics, industrial ecology (for example, energy and materials flow analysis, cleaner production) and political ecology (for example, governance and policy studies). This interdisciplinary environmental research has grown dramatically in northern and central Europe where it is strongly linked to national policy agendas and different international networks, but it is much less developed in southern and eastern Europe. These research communities have been heavily involved in the development of the industrial transformation research agenda, which is clearly visible in research planning and particularly in connection with the five research foci, and even more in the IT projects. However, the most interesting aspect of the research plan is that the key research questions developed in connection with the five research foci point very clearly to a need to strengthen areas other than those currently dominating industrial ecology or ecological economics. But such areas still remain to be addressed in the real life of most economies, such as the need to establish economic values for natural capital stocks and flows (Sejak 1999).

Energy and materials flow

Energy systems analysis has long been an established field throughout Europe, while materials and product flow analysis has perhaps been the most visible research in the development of industrial ecology, and grew dramatically in the 1990s. This type of research is given particular importance and influence in the Netherlands, Scandinavia, and the German-speaking region. What is particularly emphasised among the key questions are aspects that so far have been rare in the research; for example, geographical differences in wealth, production and consumption, international trade, technological change, and improved linkages to driving forces, institutions, policies, consumer behaviour, human needs, and development of infrastructures. Flow analysis research is very strong in Europe, and in many ways it is dominating industrial transformation research; all the other research foci have important materials flow analysis components. But judging from developments over the past five years, when actually not very much happened in tackling the limitations of these analyses (exemplified by the areas above, see also Anderberg 1998, and Anderberg et al. 2000), this research area would definitely need some extra impetus to meet such challenges.

Food

The Food research focus is mainly concerned with the global food system: de-linking production and environmental impact, global trends and solutions, and regional policies and indicators in relation to global environmental change. The environmental problems connected to this focus include, for example, the fact that human activities are causing the loss of 750 tonnes of topsoil per second worldwide and 5 000 acres of forest-cover per hour (Hawken et al. 1999, p.149). A more subtle decline than physical soil loss, but no less dangerous, is the loss of the soil's organic richness. After a century of farming in Iowa, the place with the world's highest concentration of prime farmland, what is left is half dead with the life burned out of it by herbicides, pesticides, and relentless mono-cropping (Hawken et al. 1999, p.193).

This focus involves many research areas that are well established and well addressed internationally, for example, through the IHDP-IGBP Land-Use and Land-Cover Change project. The particular challenges of the IT project are, in this context, to improve understanding of the consumption aspects, and of the linkages between different parts of the food chain. Important research is being done on national, EU and international levels in this field in many European countries that are connected to international networks and projects. It is definitely well motivated as a key area for global industrial transformation research, but it is more difficult to say whether this research focus should be particularly encouraged from a European angle. The challenges of strengthening and integrating analysis of consumption change, international linkages or chemical flows could motivate such particular attention.

Cities

The research focus of Cities attempts to stimulate comparisons of water and transport flows in large cities all over the world and poses questions about how the systems can be re-designed to minimise resource use and environmental effects. More detailed comparisons of cities in a global context might be interesting, but this research focus seems to be much more limited and less innovative than the other foci. It centres around materials flow and transport analysis, but seems to have a very limited perspective on cities as a flow concentration and an environmental problem, and is only indirectly concerned with the city itself; for example social aspects and driving forces for the development of cities and the present transformation of different kinds of cities in various parts of the world. In Europe, the growing research on the environmental impact of cities, urban ecology, and sustainable cities (see for example EEA 1996; EC 1996; Breuste, Feldman and Uhlmann et al. 1998) is much broader than the IT research focus, including analysis of flows, effects, management, planning methods, visions for sustainable urban development and a critique of the "urban civilisation". There are numerous analyses of energy, water, and materials flow and related emissions in different big-city regions in Europe similar to that which the IT focus wants to undertake. These approaches describe and problematisise the flows in the cities and may encourage increased efficiency, but they present difficulties in handling the complexity, giving practical advice and connecting to broader development issues (Anderberg 1999). Attempts at evaluating and comparing policy efforts and the environmental situation in different urban areas also show that this is still very difficult because of non-standardised reporting and non-comparable situations (The Third European Conference on Sustainable Cities and Towns, the Hannover Conference 2000). Urban ecology and research on the city environment is particularly strong in Europe and should perhaps warrant some extra interest in relation to this research focus. On the other hand, this is an area that already attracts attention in the EU and one may also question the choice of focus, and the global relevance of research on European cities.

Information and communication

Information and Communication focuses on the electronics, information and communications technology sector and its relations to global change: the effects of new technologies on production and consumption systems, lifestyles and civil society that might be important for global change. The new technologies relate to an important development in present-day society, which is thrilling because we can still not foresee the consequences. This research forms part of a broader technology assessment and research that increasingly addresses the consequences of introducing information technology into different societal contexts. This type of research is mostly undertaken in advanced parts of Europe that have a substantial penetration of information technologies, but we have not a sufficient overview of this field to tell how important its connections with environmental or global issues are. In the IT context, this research focus links to the Erasmus University project on Industrial Transformation of the Electronics Industry. It might be strategically important to strengthen this type of research, which probably can be found only in the USA, Japan and Europe. On the other hand, Information and Communications research seems a bit weak and isolated in this context and would perhaps gain from being more integrated into some of the other foci such as Governance and Transformation Processes.

Governance and transformation processes

Governance and Transformation Processes is perhaps the most central research focus for the whole IT project, since it deals with some of the most important questions on systemic change, driving agents, the role of the state, and successful policy intervention. Regional, sectoral, and comparative studies of firms, industries, and product studies are mentioned in the research planning as possible contributions. In this research focus there is, as in the energy and materials focus, an explicit goal to enlarge the perspective on production and consumption systems and to focus on their change and governance. The aim to connect to regional and industrial development research is evident. This research area is well-established throughout Europe but with foci other than environmental development. So far, with only a few exceptions (for example, Porter 1990), this focus seems of limited interest in terms of environmental and global environmental change issues, though it is very much concerned with globalisation processes and their effects and dynamics. An obvious challenge for this research focus, as well as for the whole IT project, is to mobilise and involve economic development research. This should definitely be encouraged!

In general terms, the strengths of European global change research can be identified in the ability of the European research community to develop multinational research networks on global Earth problems and in the ability of European funding institutions to support important projects in this context. European research in the relevant fields is varied and dynamic and often actively responds to new social trends, problems, and policy concerns, but in the emerging area of industrial transformation the existing networks cover only parts of the necessary expertise and perspectives. There are very few research initiatives that try to tackle the wider and more ambitious goals of this research programme and that have a sufficient breadth in the participation. Another advantage that Europe has is that of being in the forefront of technological development and economic transformations. The transition of eastern Europe, which can be viewed as an enormous social experiment, represents in many ways a unique opportunity for studying transformation processes.

A significant weakness of European research in the fields relevant to industrial transformation and global environmental change is that the focus for research is predominantly at the national and sub-national levels. With the development of EU and research cooperation in Europe, comparative studies and analysis at the European level have increased, but projects or other research activities with a large-scale focus are still very rare within social science and humanities; international networks and collaborative projects are much less developed than in the natural sciences. The valuable aspect of local and national orientation and the various research agendas in social science and humanities throughout Europe is that there is a broad collection of different research and national experiences on transformation issues of potential relevance to the IT research themes.

Currently, there are many disciplines and research areas that are very little involved with global environmental change research, and which should have a potential to contribute or are even vital in order to allow industrial transformation to reach some of its ambitious goals. One good example is regional, urban, or industrial development focusing on the processes and effects of globalisation. Environmental research in “softer” social sciences and humanities (history, political science, psychology, and to some extent sociology and human ecology) is often present, but plays only a marginal role in the emerging research fields of society-environment interactions. Integrating these rarely represented perspectives and expertise in interdisciplinary environmental projects is perhaps the most important and difficult challenge for industrial transformation research, but it is crucial to come close to the research goals.

Problems in connecting with integrated global change research

With the radicalisation of environmental politics and the establishment in the 1990s of the goal of sustainable development, the gap between what politicians and administrators expect from research and what research is able to provide has grown and thus strengthened the demand for integrated research. As a consequence, natural scientific research shows an increasing interest in involving social science for widening the focus and producing more relevant and influential results. But cooperation between the natural and social sciences is not easy and the results are seldom very close to the expressed goals, even if there may be interesting and relevant outcomes.

The basic problem is that there is insufficient collaboration between the different disciplines. Social science and humanities should be able to both strengthen the linkages to societal development and enlarge the perspectives within environmental projects - and this is definitely obvious in relation to industrial transformation, which has as its goal to understand and even to influence societal change. A second problem is that for many interdisciplinary projects there is insufficient interaction (collaboration/confrontation) between participants, or adaptation to the project by all involved (compromise), or creativity and an active search for new solutions and insights. Problems of lack of integration in interdisciplinary projects between natural and social scientists are primarily because of differences in perspectives (research cultures), and the particular set-up of the project in terms of resources, the players, and disciplines involved, and the power structures of the project (Anderberg 2001).

Traditionally, there has been a clear division between these two scientific communities, but there are also deep cultural or paradigmatic differences on both sides of the divide. Questions, concepts, what is considered as interesting and researchable, do not have much in common. One side often has difficulties in understanding the relevance of the other's research and the problems being struggled with. This is because of specialisation in scientific disciplines, which has resulted in completely different scientific languages that are not mutually comprehensible, and we do not even have interscience dictionaries that could translate the language of other scientific disciplines. Deep specialisation in selected research fields enables researchers to increase their knowledge but at the same time it prevents them from constructing interdisciplinary cognition bridges. One example of this is the short-sightedness of professional economists that prevents them incorporating ecology into economics. Up to now, standard neo-classical economic theory remains separate from other social sciences and remains negligible in global change research, although economic activities are repeatedly identified as the main driver of non-sustainability.

An important problem, which often is neglected in the large-scale analysis, is that social science, even if it has some understanding of certain social, political, and economic relationships, is hardly able to specify the interrelationships between such systems for application in more complex models of social change (Mannion and Bowlby 1992).

From a social science perspective, natural science is often difficult to collaborate with. Fundamental problems include the position of natural science in environmental research. Natural science traditionally “owns” environmental problems and natural scientists dominate the environmental research establishment and tend to decide the frames for collaborative efforts. This means that natural science components are almost always considered necessary in any environmental project, and that interdisciplinary research is often evaluated with natural science criteria. More practical problems include the fact that natural scientists tend to be unwilling to transcend their specialist roles. The power, prestige, and confidence of natural scientists also create problems in that they give social and political analysis little more than a complementary function in many collaborative projects.

Fundamental difficulties and problems are also found within the social sciences and humanities, themselves. For example, these include attitude and motivation, perspectives, questions, tools and styles of analysis, pedagogical and strategic abilities and the lack of international networks and orientation. Environmental problems are still a rather peripheral topic in most disciplines and motivation to engage in environmental and interdisciplinary research is relatively low. In comparison with the natural sciences, research in the social sciences and humanities is also disadvantaged by having less experience in large collaborative projects, less developed international networks, and a much more national orientation in research focus and reporting. This makes large projects that focus on international large-scale issues foreign to many social scientists. Therefore, international interdisciplinary efforts and networking activities that involve social scientists, such as the IHDP, are even more important.

Many social scientists approach environmental issues with radically different questions and perspectives. For example, about thoughts, attitudes and strategies of people in a particular context, and with qualitative and narrative methods of analysis, and may have problems finding a place within or even communication linkages to large-scale, systems-oriented, quantitative and nomothetic project. Social scientists often have far too much respect for conventional environmental analysis. To be able to contribute to interdisciplinary projects with natural scientists, social researchers must improve their ability to define and explain their areas of competence, and more actively try to "sell" their problems and to overcome language and paradigm barriers.

How can we build on strengths to overcome weaknesses? Which actions?

In summary, the strength of European research is that there exists a wide and varied research of potential relevance for the analysis of global industrial transformation; the weakness is that only parts of this potentially interesting research have any connection to global environmental change research or to international development issues. The challenge in this context is to mobilise the relevant research that is as yet not involved with global environmental change research, to encourage the integration of environmental aspects in economics and social science in general, and to encourage the integration of international perspectives in research with a local or national orientation. International networking and communication are central in relation to these challenges. The IHDP and the Industrial Transformation project offer unique fora for addressing the human and social aspects of global environmental change, which are central for meeting the challenges that this poses to the global society. For example, IHDP and IT should be used for mobilisation of research on international and regional economic development and transformation, and strengthening connections between various nationally and locally oriented research on the analysis of global industrial transformation. This can be done in several ways:

Support for the activities of the IHDP and IT programmes

The weakness of research and international networks in human global environmental change research makes it vital to secure these programmes. Strong and stable programmes are necessary to continue interesting and attractive activities.

Improvement of communication between IHDP and national research communities

National committees should be formed that can stimulate research and contacts with the different IHDP projects, workshops, and other activities. This is particularly important for small countries doing very limited research from the international perspective.

Support for one or several of the IT foci

Several of the research foci pose important and interesting challenges and have an established body of research on which to build further. Our opinion is that the research foci Energy and Materials Flow, and Governance and Transformation Processes, with the central challenges of integrating flow analysis and economic development research in different scales, should have priority.

Support of research in topics of particular relevance

Many of the research foci have topics that are worth particular attention in European research, because of their potential for understanding change and transformations. For example:

- the global influence of the development of recycling and new environmental standards in Europe;
- the development of a European food system from a global perspective;
- the Information Society and global environmental change;
- the industrial transformation of central and eastern Europe.

Encouraging development of linkages between key research communities and research areas

Implicit in the choice of research foci is a wish to link research on flows and environmental effects and broader social and economic developments. These broader areas can also be stimulated by making particular efforts in established fields such as encouraging integration of environmental aspects in regional economics or economic geography or putting increased emphasis on industrial change and management problems in industrial ecology.

Support for education and research milieus with particular relevance to IT and exchanges with these institutes

Tackling the research challenges in connection with IT also demands development and maintenance of new competences in the form of new combinations of specialisms. Therefore, linkages between research projects and doctoral programmes should be emphasised. On a national level there are often problems of maintaining and using experience and competence in connection with large and relatively unique research projects. This should often be an all-European interest. To develop competence and stimulate linkages to global change research in smaller countries, it is essential that institutes with major roles in global change research are actively used for different exchanges: long- or short-term visits, workshops, and course participation etc.

Reflections on the Forward Look

Global environment change research (WCRP, IGBP, IHDP, DIVERSITAS) was recently induced by growing global tensions caused by insatiable human wants that limit and reduce the life-supporting capacity of the Earth. Global change research is dominated by natural science but there should be more concern regarding the questions of how society works and on how society and nature interact. Therefore, IHDP research should be given higher priority in European research because it is the only part of global environmental change research that integrates natural and social sciences and addresses societal driving forces. Within IHDP research, the IT programme is focused on the main causes of non-sustainability:

Analysis of *energy and materials flow* shows that 80% of these flows are consumed in advanced economies by only 20% of the world's inhabitants. Central and eastern European economies in transition that are emulating the same consumption patterns have an even greater flow-consumption divide.

Although *food* is the most important source of energy to sustain human life, farmers comprise the poorest sector of the human community.

Ever-growing *cities* and urban agglomerations are non-sustainable, as is their energy, materials, and transport base.

Information society and communication technologies are negating the traditional labour concentrations and traditional labour division.

Governance and transformation processes can address the most difficult anthropogenic causes of current non-sustainability.

The lack of cooperation from social scientists was criticised by several participants at the Forward Look symposium. This lack of cooperation is partly caused by the fact that social sciences and especially mainstream economics have been, up-to-now, practically untouched by the vision and principles of sustainable living. Market systems of the current world that are the main reason for non-sustainability have a global dimension and must be addressed in a similar way that global change research is addressing environmental problems. There is a need for interdisciplinary education that will integrate natural and social sciences. There is also a need for re-evaluating the theory and practice of world trade with respect to the natural environment.

There are important socio-cultural and economic research communities that are focusing on topics of utmost relevance to global environmental change, such as globalisation and regional economic development. But this research is not sufficiently integrated into the environmental analysis and often not in the right format for being integrated into global environmental change research. To increase interdisciplinary cooperation and participation of social scientists in global environmental change research, it is necessary to:

- have a greater sharing of the problems between natural and social scientists;
- increase the status of interdisciplinary research;
- encourage the enlargement of perspectives and synthesis work in key areas;
- properly use good experiences in collaborative work;
- improve the evaluation of interdisciplinary efforts.

The ESF should be able to make an important contribution to these challenges in the European context, for example by:

- stimulating interdisciplinary competence by supporting interdisciplinary projects on topical subjects, for example integrated assessments of regional vulnerability;
- encouraging exchanges of experiences in interdisciplinary global change research;
- helping to secure the IHDP and Industrial Transformation programmes.

If the ESF is considering the establishment of a new committee for dealing with these challenges, we believe that a systems analysis committee would be better than a global environmental change committee for mobilising socio-economic research and enlarging the global environmental change research community.

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3.5 The European contribution to international biodiversity research

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Summary

Over the last ten years the Convention on Biological Diversity has been ratified by most European countries and the European Union, reflecting the increasing awareness of the magnitude of the biodiversity crisis worldwide. In current political thinking and in much of legislation, biodiversity is considered as a resource requiring conservation and sustainable exploitation. Moreover, there is still considerable uncertainty concerning the importance of biodiversity in sustaining goods and services delivered by ecosystems. Many national and international agencies and the Framework Programmes of the EC now support biodiversity research, but the scientific knowledge on which nature conservation and the sustainable use of biodiversity must be based is still weak and the scientific capacity in Europe is still much fragmented. Therefore, what is needed are research programmes that increase our basic knowledge of biodiversity addressing the correct scales of space and time, and that include evaluation of the role of biodiversity in producing goods and services that support human health and living conditions. What is also needed is a much better understanding of the complex interactions between environmental and societal dynamics that depend on many psychological, ethical, political, and economic issues. Biodiversity science must develop into a truly multidisciplinary science and become an integrated part of the Earth System approach, in which biology, ecology, and biogeochemistry are intrinsically linked to the human dimension (economy, sociology, ethics, etc.). Bringing together the scattered expertise around well-formulated research priorities will be a major challenge for the ESF in the coming years.

Introduction

The biological richness of our planet, its biodiversity, is rapidly changing as the human species transforms the biosphere at an unprecedented rate and scale. Worldwide, over several millennia, the landscape has been altered to fit human needs that have gradually shifted from basic the requirements for water, food, and shelter to sophisticated multiple usage of the land for agriculture, industry, urban development, transport, and leisure. Within only a few hundred years, intense pollution, eutrophication, and intensive fisheries have dramatically changed Europe's rivers, lakes and even large marine ecosystems such as the North Sea and the Baltic Sea.

On the global scale, humans are now using over 40% of the land for all primary production, leaving less and less space for other species, which are squeezed into marginal areas – too small for the long-term survival of many species – and consequently doomed to extinction in a very short time in a “business as usual” scenario. Also, large areas of the seas and oceans have changed, especially because of intensive fishing practices and climate change, and many species are now at risk. Species extinction is a natural phenomenon but it is at last dawning on human society that many values that depend on biodiversity are seriously threatened, and that any loss will be irreparable.

And there is more at stake than species extinction alone. The main biogeochemical cycles on Earth are driven by biology as much as by physics and chemistry. When species are important for the basic functioning of the biosphere, the biodiversity crisis may have lasting consequences for our own welfare and perhaps even survival.

Humans “manage” the planet but they are also part of the biosphere and are important drivers of global ecology and biogeochemical cycles. As an example, human-driven nitrogen fixation is now exceeding nitrogen fixation from all other biota on Earth taken together. The behaviour of humans, as individuals and as societies, is therefore a crucial aspect to understanding the ecology, biogeochemistry, and biodiversity of the Earth. Therefore, biodiversity is, first of all, an environmental question, that is to say the result of interactions between social and natural dynamics.

The European dimension of the biodiversity crisis

The presence of mankind in Europe has transformed the landscape over thousands of years. Today there is nowhere in Europe below 2 000 metres that has not been moulded by humans in one way or another. European ecosystems are thus part of the continent's culture and heritage and, at the most fundamental level, ecosystems provide (in whole or in part) the basic needs of societies.

European society has been actively engaged in the biodiversity debate since its earliest stage. The realisation that an extinction crisis is imminent has led to increased support for the conservation of species and the protection of the remaining “wild” areas of Europe and worldwide. Further concern has been voiced about the disappearance of a number of species and species communities in Europe because of their commercial interest or public appeal.

Preservation of species and conservation and restoration of ecosystems are accepted societal objectives and have been incorporated into the legislation of all European countries. Further, the EU and its Member States are major and decisive players in the definition of the international legal or regulatory framework on biodiversity or biodiversity-related issues (for example the Convention on Biodiversity, the Framework Convention on Climate Change, CITES, etc.). However, conservation and restoration are relatively minor activities in Europe. Very often, they rapidly come into conflict with more established uses of the environment, as has for example been proved during the implementation of the NATURA 2000 network of protected areas.

These conflicts indicate a need to clarify what is the value of biodiversity to society, including direct benefits from using biodiversity (for example, food and chemicals but also tourism and even religion) and what the possible effects are of the changed ecosystems on the continued delivery of a number of goods and services that are important to individual and economic health. Many people in Europe believe in the role of man as the steward of nature, but for the majority of society, day-by-day behaviour is not yet guided by such ethical principles.

The key to change this situation and the role of biodiversity science in that process will probably require some of the following arguments.

- Unless the general public can be shown that biodiversity matters, changes in people's perception, attitude and behaviour will not necessarily follow from better knowledge and information.
- In order to succeed, conservation of biodiversity and restoration of nature will have to be justified on social and ethical grounds as well as by scientific argument.
- Valuation of ecosystem function(s) has made it clear that the costs of replacing goods and services provided by them and mediated by biodiversity would be extremely high.
- The perception exists that “managed” ecosystems perform well or even better in terms of important economic objectives, such as food production, despite the threats that exist (for example loss of genetic diversity and resistance to pests). It is therefore necessary to establish scientifically how changing biodiversity will change the capacity of the Earth System to support human and other life. For that, the logical prerequisite is to show what the interactions between biodiversity and human societies are and how they have changed over the centuries.

Strategic priorities for biodiversity research in Europe

Support for existing large European environmental initiatives

There are a large number of players in biodiversity science and assessment in Europe and internationally with European partnership, including:

- institutions and agencies, such as ETC-Nature or EEA;
- research consortia, established under Framework Programme activities such as BIO-ASSESS, EPIDEMIE, BIOMARE;
- coordinated groups, such as BIOFORUM, and European Network Marine Research Stations (MARS);
- biodiversity science policy making networks, such as EPBRS-BIOPLATFORM and MARBENA;
- NGOs (or GINGOs) such as EUROSITE or SAVE.

Furthermore, there are national entities for biodiversity (the National Platforms or Networks for Biodiversity), and there are international science programmes, for example DIVERSITAS and the IGBP.

Each of these players has a clearly defined action plan, priorities, and strategy. Coordination of this potential, support for the integration of existing but poorly known expertise in central and eastern European countries, and the development of regional cooperation appear to be strategic goals for the development of biodiversity science in the next few years.

The European Union and its Member States play a leading role on the international scene in promoting a coherent legal framework for environmental protection where biodiversity issues occupy a core position. Besides the institutional basis, technical facilities for observation and data gathering, funding mechanisms, and knowledge building are also promoted and largely supported by the EU.

On the European scale, the biodiversity policy elements that are of interest for the ESF's biodiversity strategy are related to the following major developments:

- The adoption of the principle that environmental/biodiversity-relevant measures should horizontally cross all production sectors (for example, agriculture, forestry, tourism, etc.). This is clearly mentioned in the major policy documents of the EU such as the Community Biodiversity Strategy, the Sixth Environment Action Programme for the Green Papers on Sustainability and/or Innovation, major directives (for example those on Habitats, Birds, Water Framework), etc.
- The proposed enlargement of the EU will extend the territory of application of these policies, but at the same time will create new challenges related to the increase of the EU's biotic and societal diversity, and new transnational opportunities for action. On a Europe-wide scale, with 44 member states, the Council of Europe's European Landscape and Biodiversity Strategy can be an important platform of operation in the coming years.
- Regarding science strategy per se, the EU has developed within the Sixth Framework Programme the concept of the European Research Area that marks a break with the approaches of the last decade(s). Biodiversity is clearly included in one of the thematic priority areas, along with sustainable management and global change issues, where networks of excellence and large "umbrella" integrated projects are expected to be funded.

Promotion of interdisciplinary research programmes on biodiversity and human societies

A major challenge to the understanding of biodiversity dynamics is to promote a long-term integrated approach to environmental problems that includes biodiversity. Human communities and cultures are strongly influenced by the natural resources available. The last 10 000 years have seen a fundamental shift in the balance between natural and anthropogenic dynamics. The co-evolution of biotic communities and human societies has resulted in an extraordinary richness of cultures including traditional methods of exploiting biotic resources. Other cultural aspects, such as art and religion, also co-evolve with natural resources. This balanced co-evolutionary process has been disrupted through the development of modern technology, and population growth.

We can no longer separate the "natural" from the "social", and even in the most remote parts of the continent one can speak only of "socio-natural" systems and "socio-natural" dynamics. Therefore, the fate of biodiversity is closely linked to the needs of societies, the use of appropriate technologies, and the values (patrimonial, economic, ethic, aesthetic, etc.) of biodiversity to societies. We need to develop an appropriate, integrated approach to the study of socio-natural systems, a component of which is their biological diversity. Excellent examples of such large-scale programmes are the DIVERSITAS Transversal Research Network, namely The Global Invasive Species Programme, The Global Mountain Biodiversity Assessment and Greening Agriculture.

Data acquisition and dissemination

A major problem relates to data acquisition and dissemination. As far as acquisition is concerned, we are badly lacking in long-term monitoring programmes not only for biodiversity itself but to understand changes in systems in relation to global (climate) change and local impacts. Only by collecting long-term data can one find a perspective by which to understand trends at the appropriate scales (which go beyond the three years of data collection needed for a PhD thesis). Scenarios and predictive models can be validated only against real data. Such data must describe the state and dynamics of the ecosystem because biodiversity is part of that system and we have to understand the system as a whole to understand the dynamics of biodiversity. Very few long-term ecological programmes have been implemented in Europe and a system equivalent to the US Long Term Ecological Research Network is long overdue.

The ultimate objective of data dissemination should be to give direct access to the real data to scientists and other stakeholders in the biodiversity issue. This will require an entirely different strategy from the current one for collecting, linking, and making available information. We propose to study the links with the Global Biodiversity Information Facility (GBIF) and for the marine environment with Ocean Biogeographical Information System (OBIS), which is now being developed for the Census of Marine Life. Many existing data centres are either simply collecting and keeping data from projects, which are accessible only to the project participants and tend to become invisible once the project is finished, or collect information on what information is kept in other databases. Institutes should do a much better job in making known and making available the data from their researchers and research projects. Journal editors could have a major role in this.

Another problem is that much existing information is not easily available and even hidden. In general, the availability of the data can be considered to be poor. Increasing data availability must be a top priority for all biodiversity research. All ongoing research should make data available on the Internet and submit data as a routine to an established agency (such as GBIF). An important additional effort is required to save historical data and update taxonomic and biogeographic information in an electronic form.

New conceptual tools are needed, such as indicators of biodiversity and ecosystem health that allow an evaluation of the impact of environmental policies. Realistic scenarios for predicting the future development of biodiversity, and the development of a modelling strategy that would allow the evaluation of functional biodiversity in biogeochemical cycling, and the incorporation of socio-economic developments are necessary.

Research needs for implementation of the above priorities

Inventorying genes, microbes and macroscopic species, and habitats

With the advent of molecular methods it is now possible to establish the biodiversity of microbes that are crucial for ecosystem functioning. A major European and international effort in this field is timely. Surveys of microbiota and cryptic or poorly known habitats in Europe should be part of an exploration – a voyage of discovery – and made known to the European public.

Measurement of biodiversity at the genetic, specific, and landscape level has to be increasingly based on new technologies allowing for quick but reliable assessment of the degree of biodiversity. Such methodologies include molecular methods for genetic diversity and rapid assessment of species diversity, markers, tagging, remote sensing (including technology for the marine underwater landscape), on-line data acquisition and dissemination, etc.

Although the state of knowledge on larger, macroscopic species and habitats in Europe is more advanced than in most other areas of the world, major efforts are still required to establish the state of biodiversity, certainly in marine areas. For instance, in the North Sea more than 40% of all benthic copepod species found in a 1986 survey were new to science. One recent initiative that has started in the USA but has worldwide goals and scope is the Census of Marine Life. This decadal effort already involves several projects led by European scientists.

Europe is still strong in taxonomy but some traditional taxonomic knowledge is being lost with the switch of interest to molecular methods. There are no specialists left for some marine invertebrate groups, and for some areas there are only one or two specialists remaining. The knowledge on plants and animal species that is preserved in many national faunas and floras should be updated, geo-referenced and combined into regional (biogeographical) faunas and floras and made available to the public. There are still many, even young, amateur scientists interested in species identification of certain taxonomic groups (birds, shells, fish, plants, butterflies, beetles etc.). They can be part of a collective effort of data collection, for example on phenology, on distribution, on early warning for invaders, provided that an international framework and scientific supervision is created.

Studying rate and consequences of changing biodiversity

Changes in biodiversity occur on spatial and temporal scales that are beyond what is usually funded in normal scientific programmes. We are therefore unable to reliably estimate changes in abundance and distribution of species. Of special importance is the alarming increase in the transport, by man, of exotic or invading species everywhere around the world. The possible consequences of introducing genetically modified organisms into the environment also require attention.

A coordinated effort of long-term and large-scale studies, which are essential if some of the major changes in the environment are to be monitored and understood, is lacking. A system of long-term ecological research networks coupled with the monitoring efforts of national governments and guided by academic, governmental, and EU bodies should be put in place. Some efforts have already been made, mostly sponsored by the ESF and the EU. The ESF Marine Board has published a series of documents and an action plan for the marine environment that are currently being implemented through the concerted action BIOMARE, which is part of the International Biodiversity Observation Year (IBOY). This concerted action aims at the establishment of a network of European biodiversity flagship sites that are connected to the European Network of Marine Research Stations (MARS).

Only a very few institutes are capable of supporting long-term observations of the environment and they are mostly operating in isolation (or lack coordination). They are also suffering from the increased emphasis on short-term publishable projects required for the career of individual scientists and the funding of institutes. For these reasons we are unable to answer basic questions concerning the magnitude of biodiversity loss (genes, species, habitats); the rate of adaptation to changing environmental conditions, especially those driven by humans; and the large-scale patterns and long-term trends of changes in biodiversity due to natural causes and global climate change. The establishment of a network of long-term ecological research stations is essential for this purpose, with guaranteed funding for a sufficient number of years.

The functional role of biodiversity

The functional role of biodiversity, namely the way ecosystem-level functions and processes are mediated by interacting organisms such as genotypes sequentially organised into diverse ecological entities, has received increasing attention during the last decade. Although important progress in theory and experimentation (especially for terrestrial ecosystems through the development of techniques of building plant-constructed communities in the field or laboratory microcosms) has been made, the so-called "diversity debate" on whether species are important for ecosystem functioning remains open. This fact sets the foundations for identifying important research priorities:

- to develop an epistemology for functional biodiversity and explore and exploit its potential for developing unifying concepts to study the functioning of nature;
- to develop appropriate techniques (and support funding and collaboration frameworks) enabling the study of the functional role of biodiversity in the major terrestrial and aquatic ecosystem types in Europe;
- to develop theoretical and experimental methods to address the effects of biodiversity variations on ecosystem performance, including species extinctions and invasions and uncontrolled spread of GMOs, on larger spatial and temporal scales meaningful to global change drivers and mechanisms;
- to connect the above with Earth observation research and global system modelling in order to study the relationship between local variation(s) in diversity and large scale evaluation of sinks and sources of climate change drivers.

The role of biodiversity in the large biogeochemical cycles on Earth (carbon, nitrogen, phosphorus, silicon) must be clearly established through concerted efforts as explained, for example, in the Marine Science Plan of the ESF Marine Board. This requires a link between ecology and biogeochemistry that must include the study of adaptation (molecular and population genetics) and should be based on appropriate experimentation.

Impacts of biodiversity on human and livestock health

There is an increase awareness of the dependency of human life on the health of other species and on the integrity of ecosystems. Different topics are particularly relevant to this issue:

- medicines as natural sources;
- ecosystem disruption, biodiversity, and human infectious diseases;
- the role of species in medical research;
- adaptation to anthropogenic constraints: resistance of vectors to pesticides, antibiotic resistance in bacteria, utilisation by vectors on newly created ecological niches, etc.
- world transport and the spreading of species (vectors, diseases, etc.)

Conservation and restoration

The issue of restoration is very different on land than in the seas. The exploitation of marine resources is mainly still the hunting-gathering strategy that , on land, has been overtaken by cultivation for the past 10 000 years. The dramatic collapse of fish stocks makes this only too apparent. A whole new science of marine conservation has to be established, based on knowledge of marine ecosystems and not just by borrowing ideas from terrestrial ecology. The concept of a precautionary approach to fisheries which has been proposed by the UN's Food and Agriculture Organization may be useful; it suggests an ecosystem approach to fisheries taking into account the dynamics of the aquatic systems under the constraints of all human activities.

The conservation of biological diversity in relation to human activities is now known as sustainable development. It is an operational science that is increasingly focusing on the restoration of ecosystem components and functions. It relates clearly to biological conservation, which is the use of scientific knowledge for operational purposes. The questions that arise are: "What do we know? What can we transfer? What do we have to investigate?" The sharing of knowledge, and transfer of experience and expertise in ecological engineering are required.

A new biodiversity science

The primary cause of biodiversity erosion and loss is human activity related to models of economic development. Therefore, solutions for the biodiversity crisis are to be found in the attitude of society with regard to its natural environment. The future of biodiversity does not rely on a technical approach only, but will depend on how people perceive the living world, what its value is for society, what the priorities are with respect to development, etc. Therefore, the human dimension is not something that has to be added to a biodiversity research programme, it is at the heart of the issue.

In a period where both nature and science are under attack, it is of utmost importance to identify what are the coming scientific issues in biodiversity, what kind of mismatches exist between the need for sound environmental and biodiversity protection policies and the scientific priorities, and what questions are posed by the social, economic, and management sciences that are relevant for successful conservation planning.

The need for scientific tools to support biodiversity planning and management as well as the need to understand how changes in biodiversity will affect aspects of human life that until now have been considered independent of environmental determinism (for example, health, economy, social justice, and even security), mean that biodiversity science should acquire some new qualitative traits:

- it has to become more predictive;
- it has to enlarge its potential application by involving a variety of stakeholders and interest groups to define research priorities and implement the results;
- it has to become more contingency-oriented by considering a richer menu of research options and a creative mix of alternatives;
- it has to use risk assessment and improve approaches to estimate the uncertainty of the effects of global change on biodiversity, and in general develop and apply methods to quantify the trade-offs involved in any decision making process.

Europe's contribution to DIVERSITAS and IGBP

The new DIVERSITAS science plan is intended to promote integrated biodiversity science, linking biological, ecological, and social disciplines in an effort to produce socially relevant new knowledge, and to provide a scientific basis for understanding biodiversity loss and its implications for conservation policies and sustainable use of biodiversity. It is structured around three core projects:

Core project 1	Understanding, monitoring and predicting biodiversity changes.
Core project 2	Assessing impacts of biodiversity changes.
Core project 3	Developing the science of conservation and sustainable use of biodiversity.

Core project 1 will provide the basic knowledge that is required to assess the impacts of biodiversity changes (core project 2) and to develop strategies for the conservation and sustainable use of biodiversity (core project 3).

Discussion on future priorities within the IGBP had not been finalised by the time of this symposium. There are elements of biodiversity within many IGBP programmes, especially in GCTE and the Global Ocean Ecosystem Dynamics (GLOBEC) and to a lesser extent in SOLAS and LOICZ.

The role of the ESF

Within this very complex environment, a challenge for ESF is to help create and/or successfully implement a European vision, a strategic plan, and an action plan for biodiversity science free from preconceived perceptions on "policy-relevant" research and that could assist the major national and international funding agencies in prioritising their research activities.

European scientists should be encouraged to better use the mechanisms that ESF has at its disposal, such as networks, exploratory workshops, and EURESCO conferences. The ESF should probably establish a new committee on biodiversity science or at least global change science in order to achieve this because of the interdisciplinary nature of what is required.

The scientific priorities formulated in this paper and the contribution to DIVERSITAS and perhaps some of the IGBP projects can be supported through the EUROCORES programme of ESF, which seems particularly suitable for contributions to core project 1 of DIVERSITAS. The European role in biodiversity research may be strengthened by stimulating networks, exploratory workshops, and EURESCO conferences.

Another mechanism may be for the EU to finance the coordination of national projects by invoking the Article 169 procedure of the Maastricht Treaty; substantial funding could be made available for this activity in the Sixth Framework Programme.

European countries or associations of European countries (for example, the Benelux countries, the Nordic countries, the Baltic countries) may support certain elements of the DIVERSITAS science plan, as has been done in IGBP, by establishing small project offices at selected, high-quality institutes which should be responsible for catalysing further development of the science plan. These offices should take care of logistics, administration and public relations.

3.6 Climate change and variability

Brian Hoskins[1] and Jürgen Willebrand[2]

Summary

Organisation

Climate change and variability research involves the study of the behaviour of the climate system relevant to timescales of seasons and longer, and of the predictability of this behaviour. For many years it has been associated with the International Associations of Meteorology and Atmospheric Sciences (IAMAS) and of the Physical Sciences of the Ocean (IAPSO), respectively, which are part of the International Council of Scientific Unions (ICSU). Since the early 1980s a more focused international collaboration in the area of climate research has been organised through the World Climate Research Programme (WCRP). One of the strengths of WCRP has been its co-sponsorship by ICSU and the World Meteorological Organization (WMO), and more recently the Intergovernmental Oceanography Commission (IOC) of UNESCO, thereby enabling the involvement of both government and non-government scientists. Subsequently, the International Geosphere Biosphere Programme (IGBP) was formed by ICSU to provide a focus for research on the wider, biogeochemical aspects of global change. The Global Climate Observing System (GCOS) was established in 1992 to ensure that the observations and information needed to address climate-related issues are obtained and made available to all potential users. It is co-sponsored, in addition to WMO and IOC, by the United Nations Environment Programme (UNEP) and by ICSU. The stated role of the Intergovernmental Panel on Climate Change (IPCC), set up by the UN, has been to assess the threat of anthropogenic climate change and the possible responses to it. Through its three assessments, there is no doubt that it has also stimulated research and helped set the scientific agenda.

WCRP research is currently structured into five major projects: CLIVAR, WOCE, GEWEX, SPARC and ACSYS/CLIC.

The Climate Variability and Predictability (CLIVAR) study aims to understand the physical processes responsible for climate variability and predictability on seasonal, interannual, decadal, and centennial timescales, including the response of the climate system to increases of radiatively active gases and aerosols, and to extend the range and accuracy of seasonal to interannual climate prediction through the development of global coupled predictive models.

The World Ocean Circulation Experiment (WOCE) will end in 2002, with some of its research on the ocean's role in climate continuing in CLIVAR. Much of the research on sub-grid-scale physical parameterisations required by the climate models is carried out within the Global Energy and Water Cycle Experiment (GEWEX).

GEWEX includes programmes on the land surface, radiative transfer, cloud and precipitation processes and provides the link between field programmes and the modelling community. Its focus on processes means that GEWEX timescales are generally seconds to days whilst its spatial scales range from the cloud scale to the global scale.

The Stratospheric Processes and their Role in Climate (SPARC) has been the focus for middle atmospheric research relevant to climate.

The Arctic Climate Systems Study (ACSYS) has been the focus for Arctic research but this is now moving on to the broader Climate and Cryosphere Project (CLIC).

Apart from project numerical experimentation groups within the major WCRP programmes, there are two such additional WCRP groups. The Working Group on Numerical Experimentation (WGNE) provides a strong link to the weather services and Numerical Weather Prediction (NWP) research as well as supporting the assessment of the atmospheric component of

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climate models. The Working Group on Coupled Modelling (WGCM) provides a similar link to the climate prediction centres and provides the forum for assessment of coupled climate models.

Many IGBP projects have strong relationships to the broader aspects of climate variability and change and there are links between the IGBP projects BAHC, IGAC, PAGES and GAIM and the WCRP projects GEWEX, SPARC, CLIVAR and WGCM in the areas of hydrology, chemistry, palaeoclimate and climate system modelling, respectively. The PAGES project has led in the assembly of palaeoclimate indicators and collaborated with CLIVAR in the modelling of past climates. Integrated modelling of the Earth System is performed in GAIM that has links with WGCM. The oceanic carbon cycle has been studied in the JGOFS project that has close connections to WOCE.

The future

IGBP is undergoing a total review of its programme, and new projects are emerging. Apart from WOCE and ACSYS, the WCRP projects are generally expected to continue for some years. However, new emphases and directions can be anticipated.

The twin aims of WCRP as spelt out in its 1997 conference are to understand and enable the prediction of climate variations on the timescales of seasons and years and of climate changes on human activity. The, albeit limited, success in predictions relating to the 1997 El Niño has been evidence of progress on the first of these. The well-accepted conclusion of the IPCC Third Assessment that climate has changed due to human activity and can be expected to change significantly in the future is a testament to progress on the latter.

This progress sets the scene for new agendas in the next decade or so.

- Improving the understanding and modelling of climate variability and change so that regional predictions of both near- and far-future climate can be given in probability form.
- Widening the scope of interactive processes in models so that biogeochemical processes become more fully interactive in them, enabling predictions of climate change.

Despite some successes in understanding and predicting El Niño and climate change, there is much still to be learned about climate processes and variability. For example, the representation of clouds and radiation in models has been highlighted for many years as a vital problem and remains so. The tropics has a major variation of convection on intraseasonal timescales associated with the Madden Julian Oscillation, yet this is simulated poorly, if at all, in models. The Asian Summer Monsoon and its variability are in general not well represented. Getting the annual cycle in Pacific sea-surface temperatures and the El Niño both well represented in models is still a problem. Little is known about the predictability of climate variations on decadal and longer timescales. The nature of the North Atlantic Oscillation and other modes of variability that directly affect Europe, and the roles of the stratosphere and ocean in them are obscure at the moment. The frequency and length of blocking events in the western North Atlantic/West European sector determines, to a large extent, the severity of the winter or warmth of the summer in Europe but the determinants and predictability of this are not understood. The cause of variations in the intensity and distribution of North Atlantic storms is another related feature of great importance and much ignorance. The ocean components of climate models are currently under-resolved so that central elements of the ocean circulation such as the Gulf Stream, and also ocean eddies, are misrepresented. Warm to cold water conversion by localised deep convection in the Labrador and Greenland Seas, and the overflows over the narrow sills between Greenland and Scotland and its mixing with other waters are all very crudely handled in climate models, although these processes have a strong influence on ocean heat transport. The fate of the Atlantic thermohaline circulation in a global warming scenario is still unclear.

This discussion highlights the reason why seasonal forecasting for Europe and elsewhere should be seen as being in its infancy. We do not yet know what useful results may be achieved. It also highlights the fact that the results from models of climate change can, at present, be trusted only to give a broad-brush picture. Detailed scenarios for local and regional climate change can be obtained using regional models embedded in climate models. These are very useful for analysing the possible impacts of climate change. However, they can be considered only as illustrative. When there is more confidence in the ability of models to handle the range of variables in the climate system then there will be more confidence in looking at the regional behaviour in those models. Even then the prediction will only be probabilistic. Obtaining a distribution of such probabilities will almost definitely involve performing an ensemble of simulations with perturbations in the representation of the physical processes as well as in aspects of the initial conditions. Climate change simulations will then be seen as an initial value problem with predictions on all timescales up to a century or more.

Increasingly, there will also be attempts to liaise more closely with those who use the predictions so that the knowledge of this final use influences their presentation and the user is aware of how the results may be interpreted.

The vegetation on the land surface and the chemical composition of the atmosphere are two vital aspects of climate change simulations that have until recently been imposed on the models. Increasingly over the next decade, in a partnership between WCRP and IGBP, they will be determined by fully interactive components of the climate models. The surface biosphere, the chemistry of the atmosphere and land surface, and the chemistry and biology of the ocean are hugely complex topics. The compromises between having enough complexity for realism and yet permitting time integrations for relevant periods that will be necessary when including them in climate models will clearly vary according to the focus of the particular model. For example, a model whose focus is the future chemical climate may have less complexity in the physical climate components though they must still be sufficiently realistic for the purpose. For simulations of an Ice Age cycle, less complexity may be used in the physical and chemical components but an interactive ice sheet model will be required. New modes of variability may be expected with the increased degrees of freedom in these models. The exploration of these will help determine the representations used in the various components of them.

In both these future developments, to improve the understanding of processes, verify models, provide the initial conditions for them, and to monitor the state of the climate system will require a range of space- and surface-based observational systems. Realisation is increasing that there is a need to design the observing system specifically for climate purposes rather than merely using data from observations mostly collected for other reasons, such as weather forecasting. For climate purposes it would be preferable if corrections were made to satellite orbits to keep them in the same position with respect to the Earth and if there was an overlap in time for instrument replacements so that cross-calibration could be routinely performed. In future there will also be a requirement that these observations, as well as being studied on their own, are all assimilated in state-of-the-art climate models including a full range of the relevant processes, as in the data assimilation process routinely performed in Numerical Weather Prediction.

One very important test of our understanding of climate and of the models that are to be used for future prediction is to use the same models for simulation of palaeoclimate variations and changes. The focus should be on a reconstruction of climate evolution and relevant forcing factors during the last millennium, including the various glacial-interglacial periods, and should include changes in the biogeochemical system. A better understanding of the rapid climate changes, which have been identified in the record, is also required. Again it will be necessary to improve the observational database and to employ a range of increasingly complex models run over various epochs. Progress will occur through combining the results of model simulations with more and better palaeoclimate indicators.

With respect to future assessments of climate change by the IPCC, it is to be hoped that a better integration of IPCC requirements with the research performed in WCRP projects can be achieved, and that future IPCC assessments can be made less time-intensive for the scientists, given that it is mostly the same scientists involved in WCRP and the Scientific Working Group 1 of IPCC.

The European dimension

Europe has played and continues to play a leading role in international climate research through all the various participants but in particular through WCRP. The current Chair and Vice-chair of the Joint Scientific Committee of WCRP are Europeans, as is also the Director. WOCE, CLIVAR, CLIC and SPARC all have European co-chairs and their international project offices are situated in Europe. WGCM is also chaired by a European. European scientists are extremely active in the science of WCRP, as they have been in IPCC, the Scientific Working Group of which has also been co-chaired by a European.

In climate modelling, European groups have generally been seen as being international leaders over the last decade. The multiple efforts in Europe appear to have thrived on diversity and competition. Europe has also been to the fore in efforts to understand climate processes through model experimentation and diagnosis of them and of observations. Through ESA and also EUMETSAT, Europe has contributed well to the space observations relevant to climate. It has also provided ships and aircraft to make *in situ* observations for process studies and monitoring.

Europe has played a leading role in obtaining and interpreting palaeoclimate indicators and in the modelling of palaeoclimates. However there are some weaknesses that have been apparent or that are increasingly becoming so.

The US WCRP-related organisation and funding structure has a strong influence on the lines of research that WCRP poses and executes. This is not paralleled by the more disparate structures in Europe where individual European countries often have their WCRP-related organisation but there is little such organisation at a European level. The EU programmes are organised with a view to policy requirements rather than to international global change programmes, and are arguably less driven by scientific excellence.

The future scientific directions discussed above will require the running of very high-resolution climate models. It will need ensembles of runs of them. It will require models that have a much wider range of fully interactive components. At the same time, these models and their simulations need to be analysed in detail. These activities will necessitate vast increases in computer power. The success of the European effort in climate modelling has been enabled by the provision of computer power at a competitive level. However there is currently no European equivalent of the Earth Simulator that is near completion in Japan and the Accelerated Climate Prediction Initiative in the USA that will provide the leap in computer power necessary for the new research themes.

One disadvantage of the diversity of climate modelling frameworks in Europe is that it has tended to inhibit the active exchange and comparison of model components. There are recent welcome efforts through PRISM to try to overcome this. Some efforts have also been made in Europe to make climate models available to the community. However there is always an understandable tension between this and the desire to capitalise on the effort required to develop the models.

The data from the huge range of model-runs performed is in general not readily accessible. An obvious weakness of the science in Europe and on its influence in the world is because of the general requirement of its governments that data be charged for, even though this is often at a low rate for scientific requests. For example, the re-analyses of past data by ECMWF are widely agreed to be of the highest quality; however, relatively little use is made of them around the world compared with those from the USA which are freely available electronically.

The expertise required as climate system models become more inclusive and develop into Earth System models will be very broad. Sometimes such expertise will not be available in the European country of the climate modelling centre, and therefore extremely good cross-Europe collaboration will be essential.

The general discussion of the weakness in climate observations because they are mostly collected for other purposes applies in Europe in terms of satellite and *in situ* data. Because the latter are often collected in national programmes whose funding depends on the nationally viewed primary requirement, they are particularly vulnerable if their wider climate importance is not given full weight. Further, EU funding is not available for projects that wish to continue measurements as may be required for a climatically useful record.

Building on strengths and overcoming weaknesses in Europe

Actions required

1. The primary requirement for the continued strength of European research in climate variability and change is for high level funding of excellence at both national and European levels. The EU Framework programmes must be seen as additional to national funding.
2. There should be a move towards less bureaucratic and more scientifically knowledgeable ways of working at a European level. US funding programmes have managers who understand the science and nurture the scientists who may produce it. Managers of European funding programmes should be required and given the opportunity to regularly interact with the scientific community in workshops etc. in order to stay familiar with the scientific issues.
3. The European profile in WCRP and the hosting of its international project offices is excellent. However, it is not clear that this feeds back into the programme in Europe. For example, there could be a much stronger link between the project offices and the programmes in Europe and in its countries.
4. Discussion at a European level on the continued support of the international project offices would be beneficial.
5. In order to promote a European influence on the WCRP's scientific programme comparable to that of the US funders and scientific community Europe must have mechanisms to coordinate a European view/ high-level strategy and to express it better than at present. Care should however be taken to avoid increasing bureaucracy and appearing to act in an overly political manner. One attempt to formulate European strategies in EuroCLIVAR was very successful and produced many benefits.
6. The strength through the diversity of the various climate modelling efforts in Europe must not be lost. However, the synergy between them can be enhanced by building on the work already started, for example in PRISM, to standardise model frameworks.
7. To get the maximum benefit from the vast range of data produced by the models argues for analysis and diagnosis of them by the wider community in Europe. The aim should be to make the data rapidly available electronically to that community.
8. Standard, up-to-date versions of the models themselves should be made available and supported as community models.

9. The problems caused by the European approach to accessing data and charging for it must be tackled. It is certain that it leads to a reduction of science based on European data. It is arguable that it is inefficient as a financial mechanism, leading to a transfer of funds that does not pay for itself.

10. Present attempts to produce a coordinated plan to get a supercomputer system for climate modelling in Europe that is competitive with the Japanese and US developments must be supported. This is essential if Europe is to maintain a position anywhere near the top in climate modelling. However this must not be at the expense of national computer support, which is essential for the wide range of experimentation and process studies that need to be done.

11. Europe should play a leading role in the international move to design and obtain a climate observing system that will enable the necessary monitoring and prediction capabilities as well as process studies. The advanced environmental satellite missions of ESA form a vital part of the system that has already been planned. The need to make continued satellite-based observations more suitable for climate purposes should be considered and acted upon. Participation in new observing systems such as Argo to observe climate change within the oceans should be supported.

12. The use of ships and aircraft for process and monitoring studies has increasingly been coordinated at a European level. Their availability and this coordination must continue and be developed.

13. Mechanisms must be found for taking a European level climate perspective on nationally funded observation systems, particularly those funded primarily for other purposes.

14. The EU should allow the funding of continued climate-related observations.

15. The data analysis that must be an integral part of the climate research and prediction programme is presently being treated in a rather *ad hoc* manner. There is a real opportunity for Europe to take the lead here by forming an EU climate data assimilation centre. This would build on the proven ability of a number of institutions to maximise the information content of diverse data streams through analysing them together in the context of a model that predicts the relevant parts of the system.

16. The mobility of scientists in Europe and the collaboration of climate researchers and their institutes have all improved markedly in the past decade. However, the new research directions will demand even more progress in this area and may require new funding mechanisms to be instituted.

17. One of the aspects of the world programme in climate research and prediction that is clearly deficient and in which Europe is well placed to take a leading role is related to developing countries. Routine observations are needed from all countries but are often not available from many developing countries. The results of seasonal predictions could be valuable in developing countries but there can be insufficient knowledge and lack of mechanisms to make use of them. Action on climate change will be needed in all countries but this will require understanding of the science in those countries. The agenda of the international programmes does not necessarily reflect the needs of all countries. One response to these problems has been the creation of START, sponsored by IGBP and WCRP as a focus for regional training. With its historical ties, Europe could consider producing a coherent programme of education and training, and funding to help obtain routine observations and to enable the use of short-range climate predictions.

Mechanisms

The formation of an ESF panel with a relevant agenda would be a suitable way to progress and monitor most of these required actions. Initial actions on item 9 could be pursued directly by the ESF. Many of the actions, but in particular items 2, 14, 15, 16, and 17, could be referred directly to the EC. Actions are already underway on items 6 and 10.

3.7 The role of monitoring in global change

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Summary

We need to monitor the Earth System to describe what is happening, to test our theories about why it is happening, and to initialise models designed to predict future change. Monitoring is the process by which observations are collected systematically on a long-term basis and assimilated into dynamical models to produce useful information. The cost of global monitoring is known from major international experiments in GARP, WCRP and IGBP. It is beyond the means of the agencies that fund scientific research. Global monitoring of the atmosphere depends largely on data collected by operational services to meet the needs of paying customers in government or industry. We explore how that strategy can be adopted in monitoring the ocean. It is shown that although most paying customers are concerned with small-scale problems in coastal waters the service providers will depend on both local and global monitoring. The latter will have to be funded by governments as a public good, perhaps with a European centre for ocean monitoring. That will involve substantial investment in observing systems including satellites and robotic systems inside the ocean. Investment is also required to develop new technology (for modelling as well as observing) to improve the performance and reduce the costs of monitoring. Monitoring the ocean ecosystem is necessary to generate many of the products demanded by end-users. Ecology and the small Rossby radius give ocean simulations much greater computational complexity than weather forecasting. The high computational complexity of climate modelling arises from the ocean component; so monitoring the ocean will be the prime user of petaflops computers when they come available.

Introduction

Monitoring is the process by which observations are collected systematically on a long-term basis, and assimilated into dynamical models to produce useful information. It has three roles in global change: (1) to document what is happening; (2) to stimulate and test theories for why it is happening; and (3) to initialise models designed to predict future change.

The specification (what to monitor, where, and at what intervals) is different for each of those three roles. But all three present substantial technical and organisational challenges because of the wide ranges in space and timescales to be monitored for global change.

Monitoring is expensive and it involves long-term commitments that are difficult to guarantee. While the scientific community may best understand what monitoring is needed for global change research, they seldom have the funding, management, and logistics to implement it. The solution adopted in meteorology is to analyse data collected for operational weather forecasting. In the future that option will also become available in oceanography. The transition is being fostered by spending science funds to adapt models and instruments used in oceanographic research, and testing them in pre-operational field trials. This strategy of leveraging science budget to stimulate monitoring by operational agencies and businesses will yield the massive data sets needed for global change research. The European Science Foundation is contributing to that process through its Marine Board, by specific activities such as EuroWOCE, and by advising the European Commission. The strategy is being led by EuroGOOS, a creation of the ESF-EC European Committee for Ocean and Polar Sciences (Hempel 1995).

The strategy has proved successful in the USA, where NOAA translated experience gained in the one-shot scientific experiment TOGA into permanent monitoring of ENSO (El Niño-Southern Oscillation). Others are planning to convert WOCE (the World Ocean Circulation

Experiment) (Siedler, Church and Gould 2001) into a permanent Global Ocean Observing System (GOOS). The full economic cost of WOCE was 3 billion euros over ten years. It achieved 97% of the first goal: a global snapshot of the circulation, but the available resources were insufficient to address the second goal: showing how the global circulation changes. That demanded an unaffordable "WOCE every month". However, investing science budget on developing innovative technology such as Argo and Autosub (see below) will make that affordable. So we give high priority in global research to developing technology that will reduce the cost of monitoring: cash, manpower, and management. Robotic systems – satellites, unmanned autonomous vehicles, undulating floats and drones – will dominate monitoring in the 21st century.

However, even with the best technology, the prerequisite for monitoring is a customer willing to pay. Governments agreed to fund the great experiments of the WCRP as one-shot costs justified by public concern about climate change. That does not apply to an open-ended commitment to monitor the Earth System for global change. So a discussion of monitoring in global change must address three interlinked questions: What to monitor and why? What technology can do it cheaply? Who is the customer and how will it be managed? This paper will address all three questions.

What is being measured now?

There have traditionally been three sources of long-term measurements: (1) statutory activities of governments (in relation to defence, transport, agriculture, fisheries, pollution, weather forecasting, etc.); (2) commercial operations (for example, in support of offshore oil and gas industry); and (3) initiatives of the research community. All three sources grew rapidly during the second half of the 20th century. However, the Earth System is so complex that all the data archived in the last century (and many observations were not) represent a very thin sampling, with the attendant problems of aliasing. Under-sampling forces us to treat with caution our conclusions about what is happening and why. Uncertainties in observations used to initialise forecast models limit their value.

The bewildering complexity of the Earth System demands substantial investment in monitoring if the three roles are to be satisfied. Although some valuable time series of measurements can be funded within the budgets of individual scientific institutions and funding councils (for example the monitoring of atmospheric CO_2 at the Mauna Loa observatory in Hawaii), many are so expensive that they have long been the subject of international collaboration (for example, ICES monitoring of fish stocks). Finance ministries are always reluctant to make the kind of long-term commitment that is the quintessence of monitoring, unless there is a political driver (climate change, biodiversity), or statutory commitments (defence), or international treaties (pollution). And the first of these, the political driver, can evaporate as fast as it arises. Nevertheless, politics has led to substantial funding for the scientific community to collect observations aimed at the second role, understanding global change. Since the International Geophysical Year 1957-1958, the scientific community has joined forces internationally to attack global change in a series of increasingly ambitious programmes, GARP, WCRP and IGBP. These have benefited from the political response to growing public concern about the risks of global change. They have been designed largely in the spirit of basic Earth System science to resolve ignorance rather than meet statutory or treaty obligations.

In other cases, governments have been prepared to spend on monitoring in the expectation of economic benefit. For example, 2 billion euros a year is spent worldwide on weather forecasting, for benefits that are many times greater. The OECD analysed the economic case for ocean monitoring and services based on them (Tindermans 1994). The economic case was made successfully for monitoring the tropical Pacific Ocean in support of predicting El Niño-Southern Oscillation events. Similar pragmatism exists in the world of commerce. Monitoring paid for by the private sector in support of commercial operations (such as offshore energy and aquaculture) is increasing rapidly, and it may become an important source of data for research on global change. However, commerce is as volatile as government and cannot be expected to sustain long-term observations merely because they have proved useful to a secondary user, scientific research.

Global Monitoring for Environment and Security (GMES)

It is with this background, that there is so much excitement in the global change community about the EU decision to launch GMES. Here is the first opportunity to develop a European rationale for sustained monitoring of key aspects of the Earth System, without the chopping and changing that characterised funding for monitoring in the past. The prospect of substantial, reliable funding for monitoring raises the questions of priorities and efficiency. What should be monitored? And what technologies should be adopted to get best value for money?

These questions will raise a major debate in the scientific community. How should GMES allocate its resources between the three roles of monitoring: describing, explaining, and predicting? There seem to be two pre-conditions. The first is that monitoring the whole globe is most cost-effective from space, so satellites will play a substantial role. That will help to stabilise the non-mandatory Earth observation programme of ESA by providing a permanent customer. The second prerequisite is that GMES monitoring must be useful. It must be designed to serve clearly identified end-users: "European citizens at home and abroad", to quote from an early description of GMES aims. That introduces the challenge of how to link global change to the end-user, whose problems are inevitably local.

Local response to global change

In the last century, the priority of global change research was to detect global warming by the greenhouse effect (Houghton 2001). Most agree that has now been achieved. In the 21st century the main challenge will be to discover how global warming will affect the local climate, how the ecosystem will respond locally, and what are the hazards for society. The IPCC scenarios for changing global atmospheric temperature are of little practical value in themselves. It depends on heat storage in the ocean, which involves an uneven distribution of surface temperature and sea level change. We need to know how that regional rise in sea surface temperature will cause the death of coral, reducing the tourist income of affected countries. Or how rising sea level will cause more frequent coastal flooding. Or how the decline of sea ice will affect the climate of Northern Europe, and what opportunities it will offer for trade (it promises to cut ten days off shipping a container from Europe to Japan).

Other local environmental problems

There will be a change in priorities for monitoring when the focus turns from global average conditions (which have no direct impact on the quality of life of European citizens) to the regional climate (which is important for the ecosystem and human activities). The space- and timescales, and the kind of observations, overlap those needed to address other local problems that exist whether or not climate is changing. For example, fisheries scientists have long noted correlations between fish stocks and indices of regional climate change, which must be taken into account in planning European policy for fishing. Storm surges, which can cause devastating coastal flooding (Grieve 1959), are created by the combination of tide, wind, and waves, but their frequency will increase with higher sea level due to global warming. Negative storm surges disrupt ship movement at ports. One can think of many other examples. The point is that when one turns to the end-user, one discovers a variety of practical problems that depend only peripherally on climate change. Many of them are more sensitive to natural climate variability, such as the North Atlantic Oscillation (Europe's equivalent of ENSO). The point is that monitoring designed to meet GMES objectives can also help to address other environmental problems in Europe. That provides a richer portfolio of end-users to justify public investment in monitoring.

Dealing with emergencies

One of the most important applications of ocean monitoring is dealing with emergencies such as oil pollution from shipwrecks or accidents on oilrigs, coastal flooding, or rescue from sinking yachts. The requirement is for a mobile system with high-resolution models and associated observations that can be quickly deployed in remote locations. An example of what can be achieved is provided by the rapid response during the Gulf war to the world's greatest oil pollution event. Starting from scratch, a forecasting system was made operational in five days. It correctly predicted that the oil would come ashore before reaching its target, the desalination plants in Bahrain and Saudi Arabia.

The open ocean boundary condition

Most end-users are concerned with what happens locally in coastal seas. (The main customer in the open ocean is defence.) In order to meet their needs, service providers run models and make observations in their customers' theatres of operation. For short timescales (Nowcasting) the products of those local services are not seriously contaminated by changes along the open ocean boundaries, but such changes become important on longer timescales. In order to predict changes along the open ocean boundaries of coastal models, the service providers need information about the open ocean. The best way to get this is from a global model that assimilates observations collected globally. Thus, even though the end-user is concerned only with local conditions in coastal seas, the service provider requires global monitoring.

There is a debate in Europe about the division of responsibilities between the public and private sectors. Commercial service providers can afford to pay for local monitoring, but expect governments to pay for global monitoring as a public good. That is because it has to be done only once to serve all service providers, but it is difficult to create a global consortium to pay for it commercially. There is also a debate about data policy; should Europe adopt the US policy of making available, free of charge, all data collected as a public good? It will take some time to agree on a satisfactory data policy. The most effective solution may be to establish a publicly funded European centre for ocean monitoring akin to the European Centre for Medium Range Weather Forecasting. Whatever the outcome of these debates, the point remains that most end-users are concerned with local problems, but serving those paying customers will involve global as well as local monitoring. That will provide data for scientific research on global change.

UN Convention on the Law of the Sea

Local services require global monitoring, so arrangements must be made for it to take place freely anywhere in the world ocean. Many of the ocean features to be monitored, such as the Gulf Stream, pass through the Exclusive Economic Zones (EEZs) of coastal states. One interpretation of the UN Convention on the Law of the Sea would allow coastal states to deny the deployment of foreign observing systems in their EEZs. That would have severe consequences for global monitoring. The Intergovernmental Oceanographic Commission (IOC) is investigating protocols for global monitoring in EEZs, but progress is slow. Europe has a special need to address this problem in the Mediterranean Sea, where Atlantic water flows in along the North African coast, and the deep return flow is formed in the Levant. All of the Mediterranean lies within EEZs. The EC has funded a programme called MAMA to foster collaboration of all Mediterranean states to agree on rules for monitoring. The IOC hopes to use this as a model in GOOS for other regions of the world.

Choosing what to monitor and how

A monitoring scheme designed to meet the priorities of GMES will have two parts. The first part is global and will employ cost-effective observations from space. It will serve all three roles: documenting global change, providing data for testing theories about its causes, and initialising integrations of forecast models. The second part will focus on the needs of end-users. It will involve local as well as global observations, and will be concerned with how they are linked. If we are clever it should be possible to economise by specifying local observations that will also serve end-users who are not preoccupied by global change.

The design of monitoring systems will draw on experience gained from scientific experiments, notably WCRP and IGBP. To illustrate how this will be done I shall concentrate on the challenge of designing a monitoring system for the sea. Like the atmosphere, the ocean is a globally connected fluid, so the global aspect is fundamental (Woods 1994). But from a European perspective our history has been shaped largely by our coastal seas, whether the Mediterranean and Black Seas (Braudel 2001), the Atlantic seaboard (Cunliffe 2001), the North Sea, Baltic or Arctic. Today we can think of these European home waters extending across the EEZ's permitted by the UN Convention on the Law of the Sea, a vast area exceeding that of the European land mass. We have international treaties designed to control pollution in those seas, and European policies and directives relating to transport, pollution and fisheries. Much of our oil and gas comes from offshore, with important new fields on the outer edges of our continental shelf.

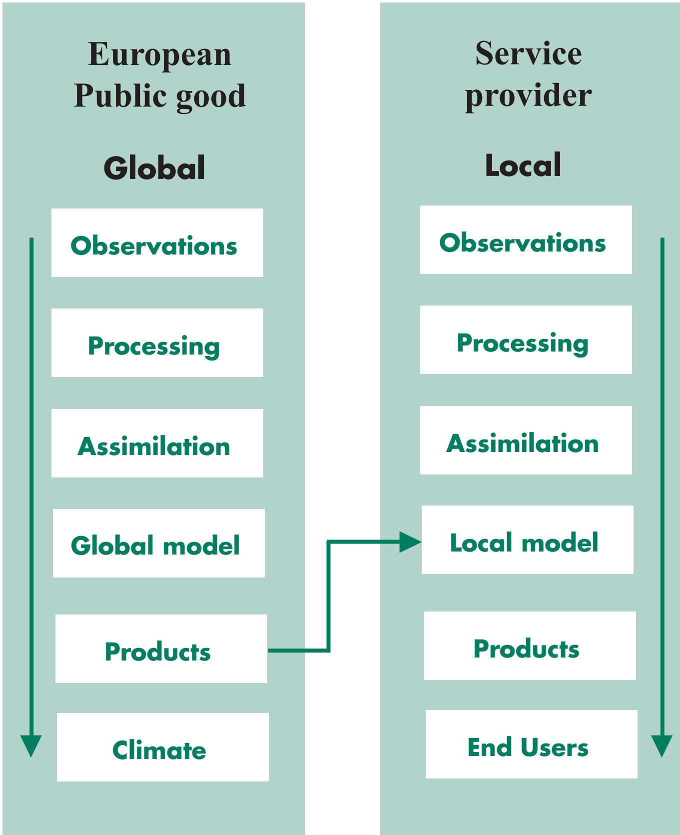
So the European Seas provide ample scope for monitoring aimed at satisfying commercial interests and governmental obligations arising from polices, statutes, and treaties.

Monitoring global heat transport

There is direct linkage between the European Seas and the global ocean. Two hundred years ago, Rennell (1793, 1832) suggested that the climate of Europe was influenced by changes in the Gulf Stream during the Little Ice Age. Today we know that our climate is affected by the Atlantic circulation as a whole. Ocean currents transport a petawatt of heat northward and release it to the atmosphere upwind of Europe, at the astonishing rate of hundreds of megawatts per square kilometre. This massive natural radiator, which keeps Europe warm in winter, draws on solar heat gathered as far away as the Indian and Pacific Oceans. Monitoring the fluctuations in that global circulation of heat is a high priority for Europe. Observations from space (altimeter, scatterometer, radiometer) will contribute. But it is also necessary to measure the flow at all depths, which demands deep hydrographic measurements. The direct way to monitor the deep ocean would be to use unmanned autonomous vehicles to repeat every month the trans-Atlantic sections made by research ship during WOCE. But perhaps the fluctuations of the heat transport can be determined indirectly as an emergent property of global ocean circulation models that assimilate satellite and in situ measurements, such as Argo drifting buoys (Wilson 2000). These modelling and observing technologies will be discussed below.

Monitoring European seas

Monitoring the seas around Europe has a long history. Systematic monitoring of the tides in support of port management started in the 19th century (Cartwright 1999). The European wind-wave climate was documented in the 20th century for the offshore oil industry, and wave forecasting became global in the 1990s (Komen et al 1994; Biblot and Hansen 1997). An important step towards European collaboration came in 1994 with the formation of EuroGOOS, a consortium of 30 national agencies in 13 countries, who are working towards joint operations (Woods 1997, 2002). The EuroGOOS publication series provides an in-depth analysis of the relevant science and technology, and analyses the special problems and opportunities in each regional sea; *see http://www.eurogoos.org.*



Elements of ocean monitoring

Monitoring the ecosystem

The needs of many end-users can be satisfied by monitoring and modelling physical variables (sea level, currents, temperature). But others involve the ecosystem: fisheries and aquaculture, water quality, and the hazards of toxic blooms and eutrophication. Furthermore, the ocean ecosystem provides positive feedback in the global carbon system, which influences the ice age cycle and the rate of global warming in the 21st century. European policies and international treaties provide a large potential base for future monitoring of the ecosystem that will provide data of great value for global change research. That potential is being unlocked by investment of science budget in experiments such as JGOFS and GLOBEC, which are acquiring the essential scientific understanding of the ecosystem, and developing innovative technologies for modelling and observation.

Three contemporary problems indicate the flavour of this research. (1) Is the ecosystem chaotically unstable like the weather and, if so, how does that limit predictability? (2) How to design monitoring procedures that will cope with mesoscale patchiness, which has plagued biological oceanography with aliasing; and (3) development of acoustic and optical (hologram) instruments that can monitor plankton biodiversity. Monitoring from ships-of-opportunity towing continuous plankton recorders provides a unique mapping across the Atlantic and North Sea. There is an urgent need to complement that infrequent spatial monitoring with high frequency time series at a mid-ocean monitoring site, complementing the existing coastal site at the Canaries; the Azores offers many advantages compared with the US-JGOFS site at Bermuda.

Innovative technology for monitoring

Operational service providers will deliver the volume of data needed for global change research. Existing services are progressively updated by incorporating technical advances developed mainly in universities and national research laboratories. There are three targets for new technology: (1) reducing aliasing errors by increased sampling rate; (2) reducing costs thereby making new services economically viable; and (3) permitting new kinds of services. New tools first prove their worth as prototypes in scientific experiments; then they are re-engineered for operational use and demonstrated in pre-operational trials such as those promoted by EuroGOOS. European innovation in ocean technology is world famous, but a skill shortage and lack of investment has slowed the development of innovative models and instruments for operational use. As a result, many European service providers have imported rival technologies from the USA. That is incompatible with the GMES aim to establish an autonomous capability in Europe. The EU Framework Programme has been addressing the skill shortage by fostering collaboration and training through MAST and its successors.

Observing technologies

Monitoring involves making routine observations that are assimilated into models. The sampling strategy is ideally based on OSSEs (Observing System Simulation Experiments). Scientific research uses observations to stimulate and test theories that are expressed in models to simulate the ocean and coastal seas. Theories are tested by comparing emergent properties of these simulations with observations of the same phenomena using the ecological Turing test (Woods 2002a). The new understanding and tools produced by scientific research are used progressively to update operational monitoring. Here we highlight some of the technologies used in scientific research that offer promise for future operational monitoring.

Satellites

Monitoring from space provides the primary data flow for global change research. It depends on paying careful attention to calibration and inter-mission continuity. Satellite observation was the prerequisite for WOCE. Global monitoring of the surface pressure field by radar altimeter mapped the open ocean tides and the uneven distribution of storms in the ocean interior, a critical test of circulation models. European operational models such as Foam and Mercator depend on assimilating altimeter data. This remarkable instrument still has more to offer and demands ongoing research and development. Other instruments on ocean observing satellites include radars to monitor wave and sea ice, and radiometers to monitor surface temperature and colour (for sediments and plankton).

High Frequency (HF) radar

Coastal HF Radar, which can provide frequently updated maps of wind-waves and surface currents, promises to do for ocean operations what weather radar has done for Nowcasting in the atmosphere. Successful trials in Bergen and elsewhere have shown how it can revolutionise the provision of safe ship movement in congested waterways and ports. Radar provides the frequency of observation needed for local wave forecasting; satellite passes are too infrequent. A vigorous development programme within GMES could see an operational network of radars covering all the European EEZ within 20 years.

Autonomous Unmanned Vehicles (AUVs)

The adoption of autonomous unmanned vehicles is revolutionising scientific research (Griffiths 2002). Data collected by AUVs cost an order of magnitude less than by research ship. One long-range deep-going vehicle, the Southampton Oceanography Centre's Autosub, has logged over 300 successful missions in the Atlantic and Mediterranean and under ice in the Arctic and Antarctic. Its missions have included a wide range of science, from duplicating ship-based fish stock surveys, to mapping turbulence in the benthic and sea surface boundary layers. Communicating by satellite, these AUVs can make physical measurements (including current profiles) on demand at remote locations where lack of data is limiting the skill of ocean forecasting models. This conditional sampling will complement the sparse observations provided by Argo, which will have a mean spacing that is an order of magnitude coarser than the width of the Gulf Stream and storms inside the ocean. Carrying half a tonne of instruments these AUVs will also monitor chemical and biological properties of the ocean interior that cannot be observed from space.

Unmanned Airborne Vehicles (UAVs or drones)

Aircraft complement satellites by making more frequent observations and flying under clouds. They are particularly important for monitoring coastal seas, and feature in the routine operations of the UK Environment Agency. The development of fast, long-endurance drones for military reconnaissance promises to revolutionise operational monitoring of the European Seas in the way that Autosub is doing underwater. Airborne instruments include CASI (high resolution spectrometers for mapping sediments and plankton) and lidar altimeters (for precision mapping of inshore waters). Lidars can also provide underwater profiles of plankton pigments and sediments.

Acoustics

One of the legacies of the cold war is the know-how to exploit long-range sound transmission through the ocean for scientific research and, in the future, cost-effective monitoring. Two techniques have been demonstrated successfully by the US, and subsequently applied in European seas. The first is acoustic tomography (Munk, Worcester and Wunsch 1995), which can monitor the variation of ocean weather (fluctuations in permanent currents such as the Gulf Stream and in transient, quasi-geostrophic eddies, the ocean equivalent of storms). The second is acoustic thermometry, which can detect small changes (order milliKelvin) in the mean temperature along megametre rays - one way to monitor changes in the global heat content of the ocean.

Ships-of-opportunity

It is not appropriate to use research ships for monitoring, although they have a valuable role to play in experiments, such as WOCE, that pave the way to monitoring. The future of monitoring lies with robotic systems in space, in the air, and in the sea. However, ships-of-opportunity have an ongoing role for low-cost monitoring. Merchant ship observations play an important role in weather forecasting, and in monitoring interannual variation of plankton and related environmental variables measured with the continuous plankton recorder. The EuroGOOS Ferry box programme will greatly expand this cost-effective monitoring in European seas.

Modelling

As in meteorology, dynamical models lie at the heart of ocean monitoring. The best way to extract information from observations is to assimilate them into a model. The FRAM project demonstrated how the Southern Ocean circulation could be determined from the archive of measurements collected sporadically during the 20th century. The design of monitoring systems will increasingly be based on OSSEs (Observing System Simulation Experiments). An international experiment, GODAE, is being planned to investigate how much the Argo system of undulating drifters will contribute to the performance of operational ocean models. Future designs will include conditional sampling, by which measurements are made by AUVs at locations that provide the greatest increase in forecast skill. Modellers have already highlighted the fact that they do not yet have an adequate map of the shape of the sea floor; urgent attention is being given to remedying this deficiency by designing a global bathymetry project.

The global models used today in operational oceanography (Foam, Mercator) were derived from codes developed for atmospheric forecasting. Their regular meshes do not map well onto the complex topography of the ocean floor, with its mid-ocean ridges and narrow channels through which water flows from one basin to another (for example, the overflow of dense Arctic water into the Atlantic). Unstructured, adaptive meshes developed for engineering applications have recently been adapted for ocean circulation modelling. Initial results show that they better describe the response of flow to topography, which is handled badly by existing operational models. Unstructured adaptive grids also offer economies by increasing resolution dynamically only at locations, such as transient jets and associated fronts, where there is important action. The hydrostatic assumption used in all existing operational models can lead to significant errors in modelling the ecosystem, which is sensitive to vertical motion. Non-hydrostatic models simulate vertical motion more realistically. They cost more to run, but they will be engineered for operation applications.

At present, different models are used for the open ocean and coastal waters. The latter have higher resolution (less than one kilometre) and are often nested in the coarser global models. The introduction of unstructured adaptive meshes offers the prospect of using the same model to describe the global ocean and changes close inshore, even into estuaries and lagoons, with some grid elements drying out at low tide. Techniques are now being developed to assimilate data into such models. They are likely to become the standard for operational purposes within twenty years.

Ecosystem modelling is still in its infancy. Models of the global carbon cycle incorporate simple representation of biological processes occurring in the plankton. Advanced model codes that simulate the growth of individual organisms are being developed for scientific research. They are more stable and do better in simulating the competition that underpins biodiversity, but their computational complexity is much greater than the simple models used for operations today (Woods 2002a). However, within twenty years the availability of petaflops computers will permit the operational use of individual-based models.

Computing

The computational complexity of ocean simulations far exceeds that of weather forecasting. In climate modelling the high computational complexity is due to the ocean component of the coupled system. Oceanography and climatology will be the prime users of petaflops computers (billions of sums every microsecond) when they become available in a dozen or so years. Meanwhile, scientific research and pre-operational trials will continue to proceed more slowly than in the USA if European oceanographers do not have access to the most powerful computers available at each stage. There is a strong case for the EC to invest in a computing centre and a high-speed network for ocean and climate modelling. This will have to be continuously upgraded over the next fifteen years during the transition from teraflops to petaflops. At each stage it will provide computing power that is an order of magnitude greater than is available for ocean modelling in the EU Member States.

Conclusion

The GMES will provide a framework for planning a coherent monitoring system to meet the needs of operational service providers whose customers range from commercial offshore operations to government agencies meeting commitments arising from European directives and policies, national legislation, and international treaties. This operational monitoring will provide a data stream that is far richer than can be funded on science budgets. Although commercial operators and government agencies operating commercially will increasingly dominate the downstream operations, there will be a continuing need for public good monitoring at the global scale. Public funding will also be needed for scientific research and development of new technologies to improve existing services and make new services possible. Public investment will also be needed for the very large computers and high-speed networks needed to get value for money in monitoring. This might best be achieved through a European centre for ocean monitoring. The strategy is to achieve synergy between the needs of operational service providers working commercially, on the one hand, and the scientific community of the other. That is the way to maximise monitoring for global change research.

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3.8 Sustainable development and R&D policy: the European context

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Summary

In order to address the topic of how the policy world relates to research, with special emphasis on sustainable development, it is reasonable to give some flavour of European Sustainable Development (SD) policy and then try to relate that to specifics of the corresponding research attempts in the same domain. In the case of European policy for SD we are in the lucky position that the Göteborg Summit in June 2001 provided an interesting frame and a visionary outlook. The policy that was finalised in Göteborg, including measures agreed upon for onward implementation, may thus form the basis for future planning. After that the characteristics of a science in support of SD will be indicated. Using a comparison between the SD policy for Europe and the specificity of the necessary R&D we consider the “match” between the two and what it means in terms of demand for European R&D tools and how they could be used. In this context, "tools" means something broader than those indicated in the Sixth Framework Programme (FP6), or the European Research Area (ERA). Some of the more general issues in bridging the gap between general policy and R&D policy will also be touched upon.

EU Sustainable Development (SD) policy

Since the Göteborg Summit of 15 and16 June 2001 it has become much easier to define what the priority elements are than previously, when only a limited number of aspects were consolidated. Now we can clearly say that the strategic aim is that EU citizens shall be granted economic stability, social supporting conditions, and a clean environment.

We can definitely say that the SD policy is based on all the three pillars, or dimensions of the SD concept, namely that all new major suggestions for decisions have to be judged against their effects with regard to economic, social, and environmental outcomes. These pillars should be seen as mutually reinforcing.

Structurally, in the frame of EU agreements, this means that the environmental dimension has to be added to the Lisbon Strategy that basically related to the social and economic development dimensions.

The Sixth EU Environment Action Programme (EAP) is very important in that it points the way to how the environmental dimension of European SD should be interpreted. But it is not just the 6th EAP that needs to be taken into account; the European Commission Strategy Document, including its design for implementation processes is the other part of the picture. Here we may find general goals and strategies for the integration of environmental concerns in the various EU policy sectors.

The reference in this document to the need to “build an effective review of the SD Strategy” is very clear. It links the operational issues to different policy areas and sector strategies for environmental integration. The emphasis on “the global dimension” is very explicit, stressing issues of global environmental governance, such as the trade-environment nexus.

The follow up to Göteborg also includes a special set of goals:

- at least 22 % of electricity from renewables by 2010;
- environment-friendly transport;
- a new chemicals strategy;
- agricultural policy and ecologically sustainable production methods.

Of the highest importance is the first set of priority areas:

- climate change ("yes" to the Kyoto Protocol);
- transport (combating volume, crowding, pollution etc);
- health (in relation to the chemicals policy; contagious diseases; and the establishment of – a food safety authority);
- natural resources (agriculture and fishing production policies).

In detail each prioity includes the following:

Climate change

- the Kyoto Protocol is important in that it sets national and European commitments in a global context;
- targets for electricity from renewable energy sources are set for 2010 (see above);
- the European Investment Bank is asked to address the issue.

Transport

- the volume of traffic and congestion have to be addressed;
- de-linking of transport growth from GDP growth is needed;
- a shift from road to rail/water/public passenger transport is necessary;
- infrastructure investment for SD transport is needed;
- a better pricing policy for transport should be developed.

Public health

- safety and quality of food to be addressed (for example, through the establishment of a European food safety authority);
- use of chemicals is of increasing importance;
- outbreaks of infectious diseases and resistance to antibiotics have to be combated;
- European surveillance and early warning networks should be developed.

Natural resources

there is a need to:

- change the relationship between economic growth (that is, the consumption of natural resources) and the generation of waste;
- maintain biodiversity;
- preserve ecosystems;
- avoid desertification;
- add SD objectives to the Common Agricultural Policy;
- review the Common Fisheries Policy in the same context;
- implement the EU Integrated Product Policy.

As we are dealing with connections to research it is interesting that there is a clear reference to the Sixth Framework Programme, especially with regard to the thematic domains of energy, transport, and the environment.

In summary, we can say that the EU sustainable development policy has, as it now stands, the following key features. It

- is multidimensional and systemic in nature;
- emphasises the policy process (including review and feedbacks);
- deals with multilevel governance as essential to the design;
- is consultative and participatory in nature;
- provides not only a European but also a global context;
- has provided a priority sequence and a set of themes.

Characteristics of sustainable development research

What can be said about the characteristics of research in support of sustainable development? This has been broadly debated and there is no clear consensus at the moment. It would be fair to say that the following points would come high on many suggested lists of actions:

- systems features
  - interdisciplinarity
  - cross sectors approaches needed
  - contextual embedding (including the

integration of socio-economics in any assessment)

- long-term (as well as medium-term) actions
- multiscales (issues of "matches" of different phenomena; for example, natural phenomena and socio-economic-cultural phenomena at different scales, as seen in watershed management)
- items related to "risk"/danger, but also to ranges of options
  - several paths
  - avoid non-sustainable directions
  - avoid pitfalls due to the inherent path dependence of technology (create "forward look" mechanisms
- players' presence
  - upstream presence in the R&D agenda
  - "practice orientation"
  - allow for unexpected R&D directions
- governance embedded

Within the research domain, developments should be emphasised with regard to increasing the level of integration into the domain of "global change" research; the increased interest by the research community of the micro-macro connection; and the increased understanding of the importance of the science-policy relationship.

Integration

The important issue here is the need to connect still unconnected domains of knowledge through weaving disconnected perspectives together; developing further the link between natural science and social science/humanities; and pursuing further issues related to systemic complexity (for example, resilience).

This means that R&D efforts have to address the full range of multidisciplinary to transdisciplinary approaches; complexity, but in often new and creative ways so as to meet various holistic challenges;and the situations in which the need to act materialises in parallel to further R&D investigation, and to use the inflow from that action as a continuous input into the R&D process.

The micro-macro connection

Facing globalisation in a world of local existence introduces a number of analytical challenges: for example, the move from global level aggregates only to regional (and also more local) understanding as the basis for modelling; governance expressed as a multilayered institutional and political power reality; and the role of lifestyles of individuals in a world of market sensitivity.

The science-policy relationship

There is definitely a gap that has to be addressed. However, the sustainability themes encourage ways to bridge the gap, vital to meet the challenge of sustainability. This means: understanding the differences in the logic of the two "sides"; appreciating that this is a common task; and finding practical means and institutional ways of meeting these challenges.

Tools to approach the linking of SD policy to R&D capacities

What is described above is the landscape of two territories: The SD policy territory and that of R&D policy and implementation. How can these two become better connected? We need to have tools for:

- combining policy domains (for example R&D policy and innovation policy, but also investment policy);
- stakeholder involvement ("participatory involvement in R&D agenda setting");
- creating conditions for R&D activities ("institutional design")
  - financial mechanisms
  - implementation mechanisms;
- feedback and synthesis mechanisms in connection to policy ("precautionary tasks mechanisms");
- quality control;
- result dissemination.

But different tools have different characteristics:

- the long-term characteristics of the issues calls for tools with substantial duration;

- the need for step-by-step practical experience calls for investment not only in research, but also in novel technology;
- the potential path-dependency calls for contextual sensitive parallel approaches combined with comparisons inbuilt in the strategies, and a readiness for the costs involved in keeping options open;
- the many possible alternative SD end-states call for tools to be flexible to encourage diversity;
- the participatory challenges call for tools that provide agenda-defining mechanisms.

We could also frame these considerations in terms of a set of questions.

- What specific requirements emerge from "governance" embedding? (that is regarding the tools related to the science-policy interface)?
- What specific demands emerge from the "player" relevance? (namely the tools related to participating mechanisms especially upstream in the definition of the agendas, including the need to balance the roles of the stakeholders involved)?
- What specific demands arise from the systemic nature of the issues? (for example early connections between differences in the unconnected domains; specific mechanisms for this to be designed and encouraged, including interdisciplinary institutional platforms).

These questions in turn can be connected to suggested institutional tools within the future EU R&D machinery:

- How could the first steps within the ERA be made, which would still keep a variable geometry of styles open, but which at the same time would be able to make forceful advances at an early a stage as possible?
- What are the very first steps? Spearheading test cases? Which thematic realms? Which players should be involved?
- How should the Article 169 option to be regarded in this context? Is it only to be confined to the Sixth Framework Programme, or is it broader?
- How should we regard the suggested tools in terms of their functional characteristics, namely in their capacity to provide networks, financing mechanisms, synthesis mechanisms, and evaluation mechanisms?

We must take note of the differences between tools in relation to their application, the varying thresholds that need to be overcome in order for new activities to take place at all, their time distribution of effects, and the depth of their impact. We also have to take note of the direction in terms of their respective support of a limited, European, sustainability approach or an approach that stressed - like the Göteborg Summit - the involvement of Europe in a global context. The degree to which this broader view is emphasised has implications on the design of the tools.

All these items have to be further elaborated upon now we are discussing research in Europe to support of sustainable development. There has to be a wider movement and willingness by the research community to approach these challenges.

On bridging the gap

Do we operate in Europe with a gap between SD policy and supporting R&D efforts? I think it is fair to say that the gap – in terms of differences in points of interest as well as in how issues have been addressed – has been there, but that there also is a visible move towards convergence. First, the relatively new interest in convergence at the highest political level is encouraging. Cross-references between the two domains are increasing. One example is that of the movements during the autumn of 2001 when the references to the Sixth Environmental Action Programme were built into the Sixth Framework Programme. That is not the only case. In fact, the design of the so-called

"Priority 8" in the Sixth Framework Programme relates to the same concern. So there is movement.

However, the relationship between policy and the R&D is not easy. The dynamics are driven by different types of constituent and the corresponding logic may also vary considerably. What in the R&D field may seem to be a reasonable degree of critical assumption in a width of approaches may be seen in the policy domain to be entirely outside a realistic political window, and thus not so interesting. On the other hand, a heated topic in the political domain close to a breakthrough in real time may not be sufficiently appreciated in the R&D world because the "novelty" and degree of research appeal may not be seen as sufficient. In this sense what may with one pair of eyes be seen as crucial, may from another perspective be an issue only of timing.

The needed synergies between the two fields have not yet reached maturity. That holds true for the policy world where sector integration is the name of the challenge. The challenge of coping with increasingly complex systems in a truly interdisciplinary way may also be true in the research arena. We are definitely not close to the solution.

The interplay between the various levels in the local, regional, national, and global contexts is also a topic that needs to be further addressed in the policy arena and in the R&D domain. The outcome of Göteborg illuminated at the highest political level in Europe that a sustainable development that takes into consideration only a European world will fail to see the fundamentals of future sustainability. Here the connections between activities devoted to European problems and those that deal with global and planetary connotations, for example the major international research programmes such as IGBP, WCRP, IHDP and DIVERSITAS, will be of utmost importance.

It would be very naïve to think that the connections between general policy in such a wide domain as sustainability and that of the R&D response can be quickly and easily overcome. But it is also true that we have come a long way from the Stockholm UN Conference on the Environment in 1972 and that there is a strong international desire to address this issue. Therefore, we can say that we are moving into an era of having a stronger precautionary approach to policies and activities. However, much more remains to be done.

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Section 4:
Putting the Forward Look into a Broader Context

The international programmes of the Earth System Science Partnership (WCRP, IGBP, IHDP and DIVERSITAS) are developing a set of fully integrated joint projects addressing issues such as water, food and fibre, and carbon. At the same time specific multidisciplinary questions such as climate variability, industrial transformation, or the role of the coastal zones will continue to play an important role in these programmes. This enables the Forward Look to position itself within global developments on the global scale.

The development of the European Research Area and the scientific requirements following on from the policies of the EU, as formulated in the Sixth Framework Programme, clearly lead to another set of reference points for this Forward Look.

Finally, the infrastructural contributions by European organisations in the area of space-based observations and operational monitoring are an important asset for the European research effort.

4.1 Earth System science: a partnership of global change programmes

Will Steffen[1], Peter Lemke[2], Jill Jaeger[3], Anne Larigauderie[4]

Introduction

Four international, interdisciplinary programmes coordinate research worldwide on various aspects of global environmental change: the World Climate Research Programme (WCRP); the International Geosphere-Biosphere Programme (IGBP); the International Human Dimensions Programme on Global Environmental Change (IHDP); and the International Programme of Biodiversity Science (DIVERSITAS).

This paper provides an overview of recent research achievements and of plans for future research. The programmes are increasingly working together in joint projects.

The Earth System Science Partnership: a strategy for integrative global change research

Scientific underpinning

The science of global change has made enormous progress during the past decade, and our understanding of the Earth's environment and the ways in which human activities are affecting it has increased significantly. The research has highlighted the importance of biological processes in helping to control fundamental Earth System processes, described in much more detail

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as the nature of human-driven changes to the planet, and begun to unravel some of the consequences of these changes. A summary of this work, carried out in increasing collaboration among DIVERSITAS, IGBP, IHDP and WCRP, has been produced in the IGBP Science Series (Science 4). The so-called "big-picture findings" of Science 4 provide the rationale for a more formal collaborative effort among the four global change programmes the Earth System Science Partnership (ESSP), and generate, in broad terms, the questions that will guide the research of the partnership over the next decade:

The Earth is a system that life itself helps to control

Biological processes interact strongly with physical and chemical processes to create the planetary environment, but biology plays a much stronger role than previously thought in keeping Earth's environment within habitable limits.

Global change is much more than climate change; it is real, it is happening now and it is accelerating

Human activities are significantly influencing the functioning of the Earth System in many ways; anthropogenic changes are clearly identifiable beyond natural variability and are equal to some of the great forces of nature in their extent and impact.

Human enterprise drives multiple, interacting effects that cascade through the Earth System in complex ways

Global change cannot be understood in terms of a simple cause–effect paradigm. Cascading effects of human activities interact with each other and with local- and regional-scale changes in multidimensional ways.

The Earth's dynamics are characterised by critical thresholds and abrupt changes. Human activities could inadvertently trigger changes with catastrophic consequences for the Earth System.

Indeed, it appears that such a change was narrowly avoided in the case of depletion of the stratospheric ozone layer. The Earth System has operated in different quasi-stable states, with abrupt changes occurring between them over the last half million years. Human activities clearly have the potential to switch the Earth System to alternative modes of operation that may prove irreversible.

The Earth is currently operating in a no-analogue state

In terms of key environmental parameters, the Earth System has recently moved well outside the range of the natural variability exhibited over at least the last half million years. The nature of changes now occurring simultaneously in the Earth System, their magnitudes and rates of change are unprecedented.

The ESSP Mission

To meet the challenge of global change, the ESSP partnership must be guided by a clear mission statement. The evolution of the vision and mission began in 2000 with a statement developed at the scientific committee meetings of the programmes of the ESSP: "IGBP, IHDP, DIVERSITAS and WCRP will build on our existing understanding of the Earth System and its interactive human and non-human processes through time in order to: (i) improve evaluation and understanding of current and future global change; and (ii) place on an increasingly firm scientific basis the challenge of sustaining the global environment for future human societies."

The current mission statement is: "To deliver scientific knowledge to help human societies develop in harmony with Earth's environment."

Research strategy of the ESSP

Figure 4.1.1 presents the overall structure of the ESSP and provides the context in which the four global change programmes are now carrying out their work. The centre of the structure is the fundamental Earth System science carried out by the partnership itself. A major task of the partnership is, through collaborative activities, to develop the frameworks and approaches required to achieve the higher level of integration needed to address the big Earth System questions outlined in IGBP Science 4. There are three types of approach that the Partnership is developing.

This initial strategy is centred on joint work of the Working Group on Coupled Modelling (WGCM) of the WCRP, and the Global Analysis, Interpretation and Modelling (GAIM) project of the IGBP; and collaboration between IGBP and IHDP in the form of a joint working group exploring ways of integrating social and natural science research approaches and methodologies in the context of Earth System science. These initial activities will be expanded in the near future to include DIVERSITAS.

The joint projects on global sustainability

At present there are three such projects: global carbon cycle, food systems, and water resources. The aim of each joint project is to address a critical issue of human well-being that depends strongly on the dynamics of the Earth System. The intent of these projects is to draw on the fundamental Earth System science being carried out within the IGBP, IHDP, WCRP and DIVERSITAS programmes as well as on projects at the national and regional (for example, European) levels, and to apply them to the particular global sustainability question. The approach is to develop a framework to integrate the contributions of existing and planned research projects, rather than initiating parallel or competing research projects.

Integrated regional studies

A proposed third approach to integration is based on geographical regions rather than global sustainability issues or the Earth System as a whole. The overall aim here is to study the region as an integrated whole, perhaps organising the set of regional studies around Earth System "switch and choke points". The research approach is similar to that of the joint projects on global sustainability: to develop a framework to integrate more focused individual projects from a variety of sources. It is likely that, rather than competing with the IGBP projects or the joint projects on global sustainability, the integrated regional studies will bring new scientists,

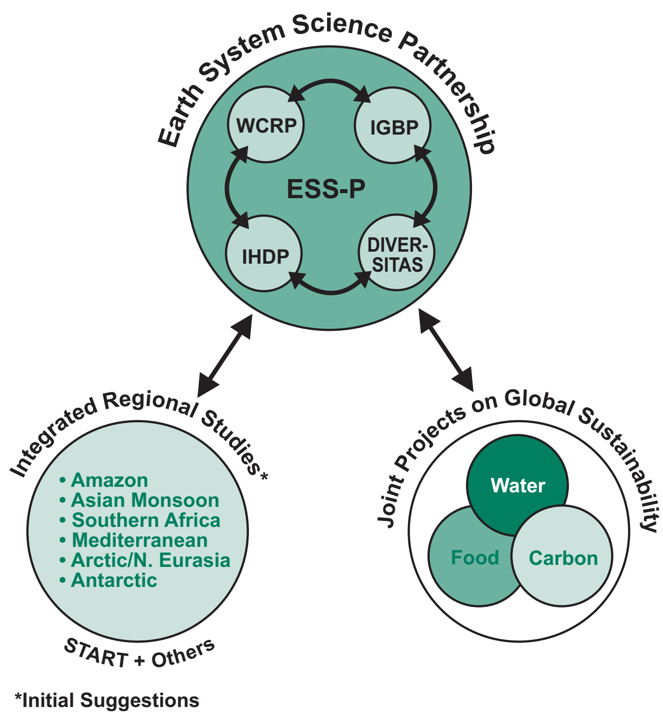


Figure 4.1.1. The Earth System Science Partnership and its activities. An overall structure for Earth System science at the international level based on the global change programmes. The internal structure of IGBP is shown as an example; any of the other three global change programmes could also be shown in similar detail.

research communities, and funding sources into the international effort on Earth System science. LBA (Large-scale Biosphere-Atmosphere Experiment in Amazonia), which is already a recognised IGBP-level project, is the most advanced model of an integrated regional study at present. START (the Global Change System for Analysis, Research and Training), itself co-sponsored by IGBP, IHDP and WCRP and thus an activity of the ESSP, will take a lead role in facilitating the set of integrated regional studies.

DIVERSITAS[5]

[5] http//:www.icsu.org/diversitas

The biodiversity crisis

During the long history of life, Earth has experienced several periods of mass extinction. But the current extinction "crisis" differs from the previous ones in that it is occurring at an unprecedented rate, and is the direct result of human activities. Erosion of biodiversity occurs at various levels, from the genetic diversity of many natural and domesticated species to the diversity of our planet's ecosystems and landscapes, through the tremendous richness of species. Current human-induced rates of species extinction are estimated to be about 1 000 times greater than past background rates. Biodiversity loss is a matter of concern, not only because of the aesthetic, ethical, or cultural values attached to biodiversity, but also because it could have numerous far-reaching, often unanticipated, consequences for our life-support system. The capacity of natural and managed ecosystems to deliver ecological services such as production of food and fibre, carbon storage, nutrient cycling and resistance to climate and other environmental changes, could be reduced. Assessing the causes and consequences of biodiversity changes, and establishing the bases for the conservation and sustainable use of biodiversity, are major scientific challenges of our time.

The past decade has seen the birth of the Convention on Biological Diversity, of many conservation programmes aimed at protecting biodiversity, as well as many national research programmes dedicated to developing biodiversity science. Scientific efforts, however, need international coordination to address the complex scientific questions posed by the loss and change of biodiversity globally, as well as a research framework integrated across disciplines. DIVERSITAS provides such an international framework.

What is DIVERSITAS?

DIVERSITAS is a global environmental change programme, sponsored by ICSU (International Council of Scientific Unions), SCOPE (Scientific Committee on Problems of the Environment), IUBS (International Union of Biological Sciences), IUMS (International Union of Microbiological Societies) and UNESCO (United Nations Educational, Scientific and Cultural Organization), which was first launched in 1991. These sponsors launched a second phase of DIVERSITAS in March 2001 and opened an international secretariat in Paris. In May 2002, the Scientific Committee of DIVERSITAS endorsed a new science plan.

The mission of DIVERSITAS is to:

- promote integrative biodiversity science, linking biological, ecological and social disciplines in an effort to produce socially relevant new knowledge;
- provide the scientific basis for an understanding of biodiversity loss, and to draw out the implications for policies for conservation and sustainable use of biodiversity.

DIVERSITAS achieves these goals by synthesising existing scientific knowledge, identifying gaps and emerging issues of global importance, promoting new research initiatives, building links across countries and disciplines, investigating policy implications of biodiversity science, and communicating these to policy makers and international conventions.

Scientific goals and structure

The science plan of DIVERSITAS is articulated around three core research projects (Figure 4.1.2).

Core project 1: Discovering Biodiversity and Predicting its Changes

To understand and predict the consequences of changes in biodiversity for natural ecosystems and human societies, it is first necessary to know how much biodiversity there is on Earth, how it is changing and why.

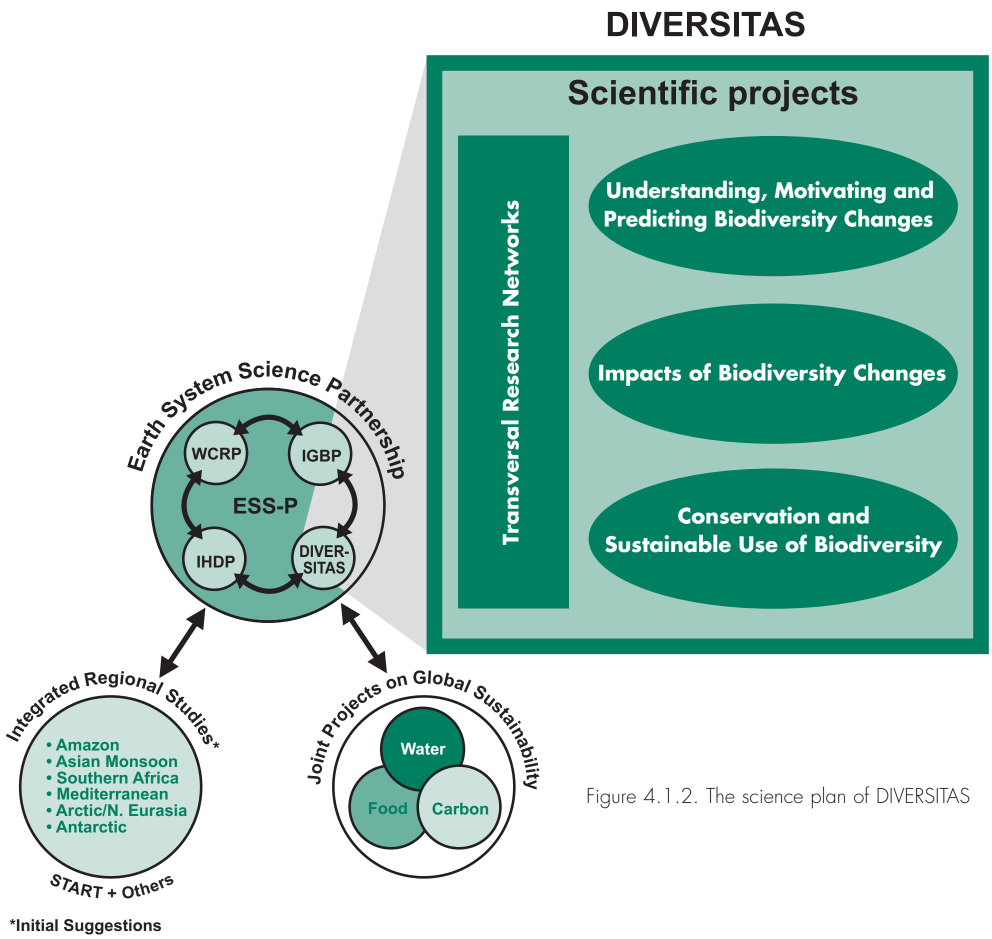


Figure 4.1.2. The science plan of DIVERSITAS

1. ***How much biodiversity is there? (Focus 1.1)***

Despite the growing interest in biodiversity during the last decades, our knowledge of the true diversity of life that inhabits our planet is still very limited and fragmentary. This focus is designed specifically to promote research on poorly known organisms, and on habitats and geographic areas that have received insufficient attention. Of special importance are micro-organisms, including, bacteria, archaea, and many protist and fungal lineages. Most of these organisms have not been cultured in the laboratory, and are therefore effectively unknown, yet they play a fundamental role in sustaining the biosphere, especially in global biogeochemical cycles. Moreover, in view of their extraordinary metabolic diversity, microbes are of enormous biotechnological value, and their discovery promises economic dividends in areas such as medicine and bioremediation.

2. ***How and why is biodiversity changing? (Focus 1.2)***

The assessment of the state and change of biodiversity requires monitoring at the relevant scales of space and time. These scales can vary from days to years and from fractions of a metre to thousands of kilometres. Monitoring is essential to evaluate the success or failure of conservation and restoration measures (for example in the framework of the Convention on Biological Diversity) and to calibrate and validate models and scenarios and thereby improve their performance. The objective of this focus is to develop the scientific basis for monitoring biodiversity, as well as the tools for monitoring and the use of these tools. It also aims to promote the integration of biodiversity monitoring and monitoring tools into global networks of observatories that are being developed by other programmes.

3. ***How can we predict biodiversity changes? (Focus 1.3)***

The aim of this focus is to improve our capacity to predict and hence to respond to biodiversity loss. This focus will:

- foster research into the anthropogenic drivers of change in biodiversity in terrestrial and aquatic systems;
- develop theoretical, experimental and empirical knowledge of the ecological and evolutionary processes that have shaped biological diversity in the past;
- develop an understanding of the impact of changes in the pattern and intensity of human resource use on ecological structure and processes, and the implications of this for biodiversity at multiple spatial and temporal scales;
- and contribute to the capacity to predict and evaluate the consequences of biodiversity change for the provision of ecological services, in order to support conservation and the sustainable use of biodiversity at appropriate spatial and temporal scales.

Core Project 2: Assessing Impacts of Biodiversity Changes

The goals of Core Project 2 are to understand the consequences of biodiversity changes on ecosystem functioning and goods and services (Focus 2.1). This core project will actively promote the development of research in this area, building on the existing collaboration between DIVERSITAS and IGBP-GCTE. Its goals are to:

- extend current knowledge on plant-based processes in temperate grasslands to other organisms, other trophic levels, and other ecosystems;
- assess impacts of biodiversity changes at larger temporal and spatial scales in interaction with other environmental changes, in particular land-use changes;
- identify the impacts on the provision of ecosystem goods and services of relevance to human societies.

A particular emphasis, within the context of ecological services, will be placed on impacts of biodiversity changes on human health (Focus 2.2). Approaches to the study of emerging diseases in humans have focused on treating infectious agents and producing medicines to combat them. These approaches have not generally placed infectious agents (such as virus, parasites, microbes) in their ecological context, nor examined the complex factors leading to emergence of diseases. The ultimate goal of this ecological approach is to contribute to developing a broader, predictive science of infectious diseases.

Core Project 3: Developing the Science of Conservation and Sustainable Development

The Focus 3.1 of this core project, “Effectiveness of current conservation measures and regulation”, has two objectives: the scientific evaluation of the effectiveness of existing conservation measures; and the identification of the socio-economic causes of the failure of conservation measures. Focus 3.2 will establish scientific approaches for optimising multiple uses of biodiversity, considering possible trade-offs between economic and environmental goals, and the uncertainty associated with novel developments.

In addition to the three thematic core projects, a few integrated cross-cutting networks, which embrace issues addressed in all the core projects, will be developed around particular topics or ecosystems. One such network, the Global Mountain Biodiversity Assessment (GMBA), is currently ongoing. It has published the first global assessment of mountain biodiversity, and is providing scientific advice to the Convention on Biological Diversity and its Subsidiary Body on Scientific, Technical and Technological Advice, in the context of the International Year of the Mountain.

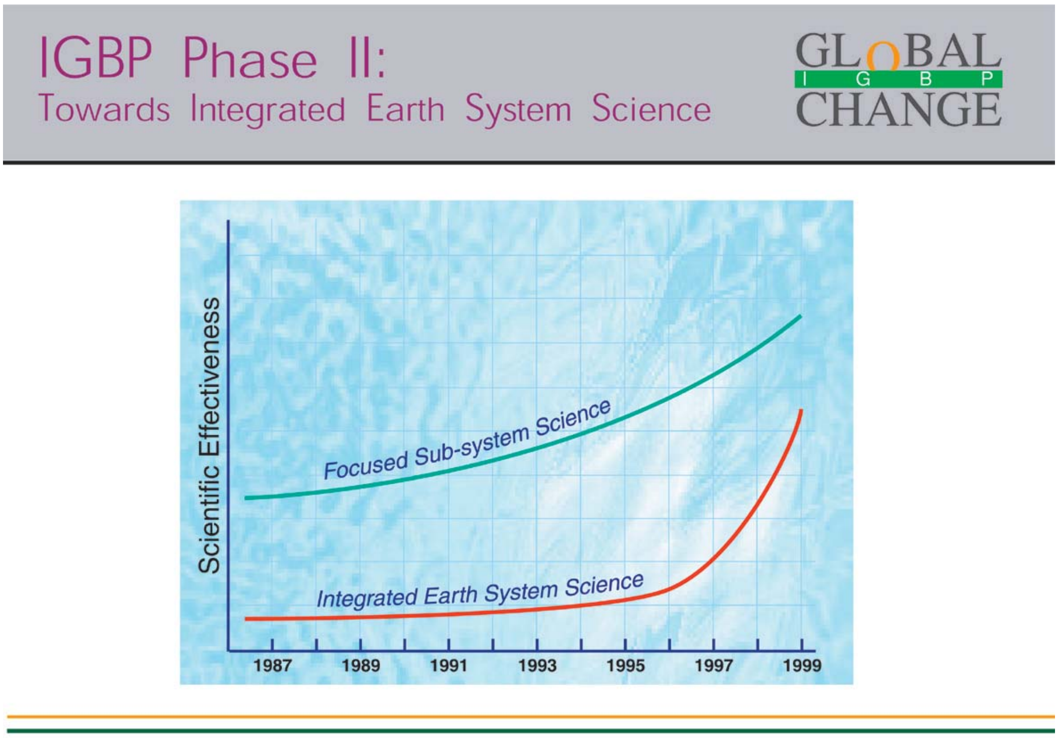


Figure 4.1.3. The changing relationship between focused sub-system science and integrative Earth System science.

IGBP II[6]: a second decade of international research on global biogeochemistry

The challenge of sub-system science and integration

Nearly all of the science carried out in the first decade of IGBP has been conducted at the sub-(Earth) system level – atmospheric chemistry, ocean biogeochemistry, terrestrial ecology, etc. – in the core projects. However, by the late 1990s, there was a growing recognition that many of the big challenges of global change could be met only by a much more integrated approach, in which several sub-system level areas of expertise are brought to bear on a single question (Figure 4.1.3). Increasingly, the emphasis in Earth System science is on the connectivity of compartments of the Earth System, of scientific disciplines, and of scientific progress across the natural and social sciences. Thus, a central goal of IGBP II is to develop a substantive science of integration, putting the pieces together in innovative and incisive ways towards the goal of understanding the dynamics of the planetary life support system as a whole.

It is essential to recognise that the two approaches – sub-system "disciplinary" research and integrated Earth System science – are complementary and both are required for IGBP II to meet its objective. An understanding of global change cannot be achieved by either approach alone. The new emphasis on a systems-level approach must be grounded strongly in the wealth of detailed, quantitative understanding of components of the system (namely, in the work of the IGBP projects), but it must also seek new approaches to bring these pieces together in effective ways to address the big issues of global change science. One of the most important challenges to IGBP II is to build effective linkages and synergies between the projects, working on parts of the Earth System, taking a

[6] http://www.igbp.kva.se

more globally integrated perspective. An even bigger challenge is to make sure that the global networks of IGBP II work strongly across the "digital divide" of developed and developing countries, working in concert with START and with other capacity-building and scientific networking organisations. Finally, the challenge of integration must also be met in close collaboration with IGBP's partners within the framework of the Earth System Science Partnership, described above.

Thus, the necessity of both focused sub-system science and of integrating activities, and the relationship between them, lies at the heart of the IGBP II strategy and the structure of the international approach to Earth System science adopted by IGBP and its partner global change programmes.

Mission and objective of IGBP II

As one of the members of the ESSP, IGBP shares the overall vision and mission statement described above for the partnership. In addition, IGBP has an overall specific scientific objective aimed at improving our understanding of global biogeochemistry and the changes that are occurring in these cycles:

To undertake a systems analysis of planetary composition and dynamics, focusing on the interactive biological, chemical and physical processes that define Earth System dynamics, the changes that are occurring in these dynamics, and the role of human activities in these changes.

Structure of IGBP II

Although the increased emphasis on integration in global change research is evident, there is no doubt that the vast majority of IGBP research will continue to be carried out in the new and ongoing projects. In fact, without this fundamental, focused, detailed research, and comparable research in the projects of WCRP, IHDP and DIVERSITAS, there will be no possibility of successfully addressing the larger, more integrative questions that have now gained more prominence in Earth System science.

Figure 4.1.4 shows the conceptual structure of IGBP II, which has evolved over the past two years through discussions at the 2000 and 2001 meetings of IGBP's Scientific Committee and much work between these meetings. In this version of the structure, the more integrative work carried out by GAIM and PAGES is shown within IGBP II although, as noted above, it could equally be seen as central to the Earth System Science Partnership as a whole. The structure of the six projects (excluding GAIM and PAGES) is both simpler and more integrative from an Earth System perspective than the IGBP I structure. It also addresses explicitly the increasing emphasis on the interfaces between the major Earth System compartments, which (apart from LOICZ) were not well addressed in IGBP I.

Integration within IGBP II is centred on global analysis, interpretation and modelling (GAIM), aimed at a fundamental understanding of the composition and dynamics of the Earth System, and on a comprehensive understanding of the past dynamics of the Earth System (PAGES), which helps to understand the contemporary period and project Earth System behaviour into the future. As noted in the description of the Earth System Science Partnership, both GAIM and PAGES are rapidly growing beyond their "IGBP-centric" roles in IGBP I and undertaking significant collaboration with the other global change programmes. Examples include the PAGES-CLIVAR intersection (CLIVAR is WCRP's project on climate variability and change) and the collaboration between GAIM and WCRP's Working Group on Coupled Modelling. A key issue yet to be resolved is the programmatic relationship of GAIM and PAGES to each other, to the IGBP II projects, and to the other programmes.

The key role of the six projects in IGBP II (and their counterparts in IHDP, WCRP and

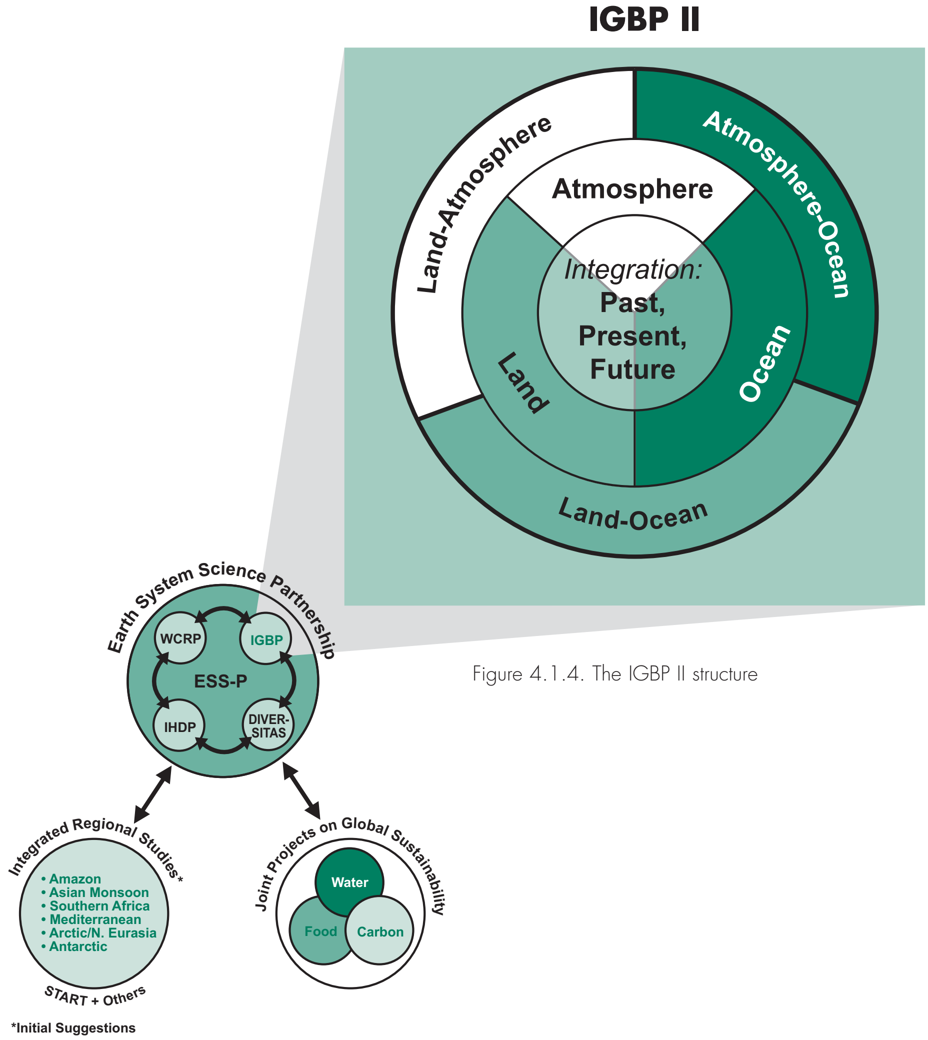


Figure 4.1.4. The IGBP II structure

DIVERSITAS) is to carry out focused research in their sub-systems and to contribute to higher levels of integration, both by working across the boundaries of neighbouring projects (and programmes) when the scientific question demands it and by contributing to the three types of integrating activity outlined for the ESSP. The emphasis within IGBP will continue to be on the biology, chemistry, and physics of the Earth's biogeochemical system, with the partner programmes focusing on the physical climate system (WCRP), the human dimensions (IHDP), and biological diversity (DIVERSITAS). However, it is impossible and counterproductive to completely separate components of the Earth System.

The new structure will increasingly place challenges on the individual networks and research groups that contribute to projects. By the very nature of the structure of IGBP II and the scientific questions it will address, there will need to be more connectivity among the projects and it will:

- provide a unique opportunity to open new research ground beyond traditional boundaries;
- extend and empower networks and research groups that contribute to them;
- bring more flexibility by facilitating the contributions of a particular network to multiple integrating frameworks; and
- facilitate more sharing of expertise and networks across the project boundaries.

IHDP[7]

[7] http://www.ihdp.org

The International Human Dimensions Programme on Global Environmental Change (IHDP) was initially launched in 1990 by the International Social Science Council (ISSC) as the Human Dimensions Programme (HDP). In February 1996, the International Council for Scientific Unions (ICSU) joined ISSC as co-sponsor of the IHDP, and the secretariat was moved to Bonn, through a generous grant from the German Government. IHDP is an international, interdisciplinary, non-governmental science programme dedicated to promoting and coordinating research. Its aims are to describe, analyse, and understand the human dimensions of global environmental change. IHDP'S programme is designed around its three main objectives of research, capacity building, and networking.

Research on the human dimensions of global environmental change is concerned with the causes and consequences of people's individual and collective actions in terms of the ways in which human activities affect the environment, the socio-economic impacts of global environmental change, and the individual and societal responses to those changes. This research requires collaboration from a wide range of disciplines and studies encompassing the local, regional, and global scales.

Increasingly these activities are carried out in collaboration with the partner international programmes on global environmental change: the International Geosphere-Biosphere Programme (IGBP), the World Climate Research Programme (WCRP), and the International Programme of Biodiversity (DIVERSITAS).

Overarching questions

All IHDP research activities and joint projects are guided by four overarching questions:

1. What factors determine the capacity of coupled systems to endure and produce sustainable outcomes in the face of social and biophysical change?
2. How can we recognise long-term trends in forcing functions and ensure orderly transitions when thresholds are passed?
3. How can we steer tightly coupled systems towards desired goals or away from undesired outcomes?
4. How can we stimulate social learning in the interest of managing the dynamics of tightly coupled systems?

IHDP's core research projects

IHDP has four core research projects, one of which (Land-use and land-cover change, LUCC) is co-sponsored by IGBP. The projects are a key mechanism used to identify and generate new IHDP research activities in priority areas, promote international collaboration, and link policy makers and researchers.

LUCC (Land-Use and Land-Cover Change, co-sponsored with IGBP)

LUCC's objectives are to obtain a better understanding of land-use and land-cover changes (for example, deforestation, degradation, desertification) and of the physical and human driving forces behind these processes. LUCC helps to define links between land-use and land-cover change and other critical GEC issues such as climate change, food production, health, urbanisation, coastal zone management, transboundary migration, and availability and quality of water.

GECHS (Global Environmental Change and Human Security)

The main goal of the GECHS project is to advance interdisciplinary, international research and policy efforts in the area of human security and environmental change. Human security is achieved when and where individuals and communities have options necessary to end, mitigate, or adapt to threats to their human, environmental, and social rights; to actively participate in attaining these options; and to have the capacity and freedom to exercise these options.

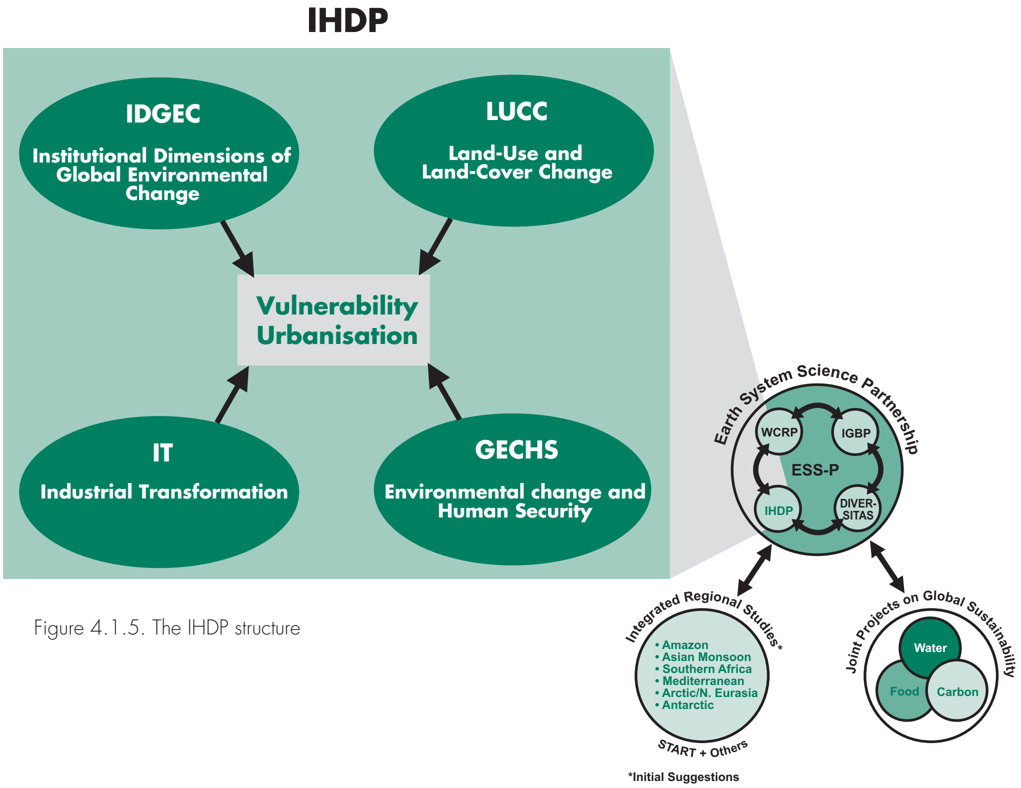


Figure 4.1.5. The IHDP structure

The project is tackling the following questions:

- What types of environmental change threaten human security?
- How does environmental change threaten human security?
- What regions are the least/most secure?
- How do individuals and communities cope with the insecurities linked to environmental change?
- Why are some individuals, communities and regions more vulnerable than others?
- Why are some strategies more effective in one situation than in others?
- Can we predict future insecurities?

IDGEC (Institutional Dimensions of Global Environmental Change)

The IDGEC project analyses the roles that social institutions play as determinants of the course of human–environment interactions. Institutions (collections of rules, decision making procedures, and programmes) are drivers of both systemic and cumulative environmental problems. Faulty institutional structures of property rights, for example, can lead to severe depletions of stocks of living resources or to excessive uses of ecosystems for the disposal of toxic wastes. Institutions constitute a cross-cutting theme. The priority science questions posed by IDGEC are:

- What roles do institutions play in causing and responding to global environmental changes?
- How effective are institutional innovations that are designed to respond to global environmental change?
- What are the prospects for (re)designing institutions to confront environmental challenges?

The project has developed three flagship activities designed to address these questions, dealing with global carbon management, the political economy of tropical and boreal forests, and the performance of exclusive economic zones.

IT (Industrial Transformation)

The Industrial Transformation research agenda focuses on the relationship between changes in the industrial systems and changes in the environment. It aims to analyse how manufactured goods and services are being produced and consumed, the natural resource and energy transformations associated with these activities, their environmental impacts, and the consequences of these impacts on the quality of life. The overall goal of the project is to discover ways to enable a transformation of the industrial system towards sustainability, or, in other words: ways to decrease the environmental impacts of industrial activities.

The science plan of the LUCC project was published in 1995. The science plans of the other three projects were published in 1999. The completion of a science plan is the first major step in developing an international and interdisciplinary core project. The success of the project as a whole depends on the science plan attracting the support of highly qualified researchers willing to integrate their ongoing and past research activities under the umbrella of the project, as described in the science plan. It is also important that researchers prepare and submit new research proposals in order to carry out the new research priorities identified in the science plans. As noted in the IDGEC Science Plan:

> "[The Science Plan] leaves ample scope for individual researchers or research teams to decide where to cut into the overall *problematique* and how to frame specific questions and hypotheses for sustained analysis. But it also provides a road map that should ensure that these individual efforts have enough in common to make it possible to compare and contrast their findings and to develop a body of propositions dealing with the institutional drivers of global environmental change and with efforts to (redesign) institutional arrangements as part of the larger process of coming to terms with large-scale environmental problems."

Cross-cutting themes

The science plans of each IHDP core project were designed to provide direction for, and to shape the content of, an international research programme extending over a period of five to ten years.

The above four projects will remain the core of IHDP's scientific programme. However, as they develop, it is important to look at linkages between the projects as well as topics that are also of interest to the other international global environmental change research programmes.

One particular topic that is of interest to all the IHDP core projects is "vulnerability". The first discussions on this cross-cutting theme of IHDP research were held in 1999. In May 2000 a workshop was held in the USA, co-sponsored by IHDP, in which representatives of the LUCC and GECHS communities and the IHDP secretariat participated (Clark et al. 2000). The workshop illustrated that the conceptual framework for vulnerability analyses provides a strong basis for integrative studies of the human and environment systems. This was followed by another workshop in May 2001, again co-sponsored by IHDP, and organised by the Stockholm Environment Institute. IHDP will continue to develop this theme in and between the projects.

A new research topic, of interest to the core projects and partner programmes, is "urbanisation". An international research project within the human dimensions community aimed at improving the scientific understanding of urban systems, processes and dynamics is more than overdue. Not only IHDP's position within the human dimensions research community, and its physical proximity to German and international research institutes dealing with aspects of urbanisation, but also its extensive networks in developing countries, put the research programme in a prominent position initiate and establish an interdisciplinary research project on urbanisation, with a special focus on developing countries. In the first stage a scoping report will be developed, which will describe the central research questions for the human dimensions research community. In order to draft this report, IHDP will conduct a two-week workshop in Bonn in June 2002 with leading scientists from all the regions and young scientists from developing countries. The workshop will start with presentations from the participants on their own research activities. On the basis of the presented material, a state-of-the-art report will be compiled listing the most important research foci of the human dimensions research community as well as identified research gaps. In a second step the central research questions and demands for future research activities will be identified.

WCRP[8]

Objectives

The major objectives of the WCRP are to determine to what extent climate can be predicted and assess the extent of human influence on climate. To achieve these objectives WCRP carries out fundamental research into understanding the basic behaviour of the physical climate system, in particular to:

- improve our knowledge of global and regional climates, their temporal variation, and our understanding of the responsible mechanisms;
- assess the evidence of significant trends in global and regional climates;
- develop and improve mathematical models capable of simulating and assessing the predictability of the climate system over a range of space- and timescales;
- investigate the sensitivity of climate to possible natural and human-induced stimuli and to estimate the changes in climate likely to result from specific disturbing influences.

These objectives and research aims were reaffirmed at the Conference on the WCRP: Achievements, Benefits and Challenges, held in Geneva in August 1997, with the overall research priorities for the next decade being to:

- assess the nature and predictability of seasonal to interdecadal variations of the climate system on global and regional scales, and to provide the scientific basis for operational predictions of these variations for use in climate services in support of sustainable development;
- detect climate change and attribute causes, and project the magnitude and rate of human-induced climate change, regional variations, and related sea level rise (as needed for input to the IPCC, the United Nations Framework Convention on climate Change, UNFCCC, and other conventions).

WCRP has a broad-based multidisciplinary science strategy offering the widest possible scope for investigation of all important physical aspects of climate and climate change, with emphasis on providing practical deliverables of global and regional relevance, importance and value, and specific reference to sustainable development.

WCRP core research projects

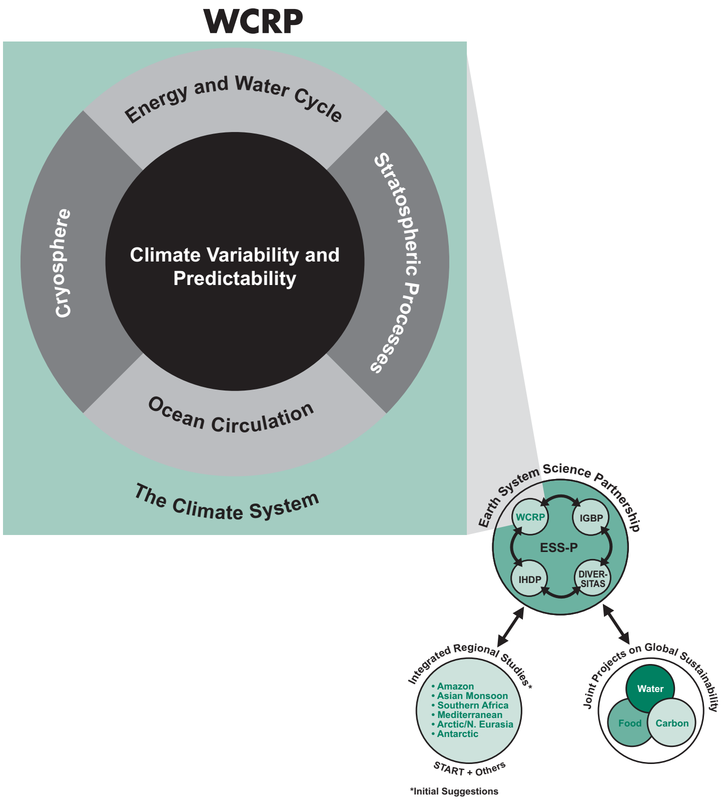
Global Energy and Water Cycle Experiment (GEWEX)

GEWEX is the scientific focus in WCRP for studies of atmospheric and thermodynamic processes that determine the global hydrological cycle and energy budget and their adjustment to global changes such as the increase in greenhouse gases. High priority continues to be given to assembling the unique global climatological data sets providing information on radiation, cloud, water vapour, aerosols, and rainfall, blending the best available observations from satellites and operational meteorological networks. GEWEX also aims to promote interdisciplinary cooperation between the atmospheric and hydrological sciences, in order to characterise energy and water budgets on the scale of continents.

Stratospheric Processes and their Role in Climate (SPARC)

SPARC has the objectives of investigating the influence of the stratosphere on climate and the

[8] http://wmo.ch/web/wcrp/wcrp-home.html



coupled chemical and dynamical radiative processes that control changes in the stratospheric circulation and composition, particularly including ozone depletion and increased penetration of ultra-violet radiation into the troposphere. A new topic deals with the effect of atmospheric chemistry on climate.

World Ocean Circulation Experiment (WOCE)

WOCE has collected basic data needed to understand and predict changes in the world ocean circulation, volume and heat storage, which would result from changes in atmospheric climate and net radiation. This work has already provided unprecedented insight into the circulation and ventilation of the deep ocean, and is revealing significant changes in the spatial structure of deep ocean temperatures and salinity. The concluding phase of WOCE is focusing on the synthesis of the measurements gathered to provide a dynamically consistent description of the global ocean in the 1990s, as well as the development of improved models that accurately reproduce the ocean circulation.

Climate variability and predictability (CLIVAR) study

CLIVAR is focused on the natural variability of the coupled climate system comprising atmosphere, ocean, land-surface and ice masses and the changes in response to natural processes and human influences. It is composed of three parts with activities relating to Global Ocean-Atmosphere-Land System (GOALS), Decadal to Centennial Variability (DecCen) and Anthropogenic Climate Change (ACC). Implementation is under way, including regional studies such as the Variability of the American Monsoon System (VAMOS); the Asian-Australian Monsoon System; and African climate variability. Another priority is the validation and refinement of the models needed for extending effective predictions of climate variations such as ENSO and NAO. Efforts are being made to ensure that all nations can get the maximum benefit from improved climate predictions, and that results are disseminated as widely as possible.

Arctic Climate System Study (ACSYS) and Climate and Cryosphere (CLIC) project

The scientific goal of ACSYS is to ascertain the role of the Arctic in global climate. This activity started in 1994 and will terminate at the end of 2003. It will be succeeded by CLIC, which will be a coordinated study of the role of all components of the cryosphere in the global climate system. ACSYS will continue for a further few years as an important element of CLIC.

Climate modelling

The unifying theme running through the WCRP is the development of comprehensive global models of the full climate system, building on scientific and technical advances in the other main WCRP projects. These models are the fundamental tools for understanding and predicting natural climate variations and providing reliable estimates of anthropogenic climate change. The results produced by these activities in WCRP have been a key input to the IPCC Third Assessment Report.

Development of regional climate research capability

WCRP has continued to promote the involvement of scientists worldwide in its activities in order to meet its scientific challenges and to deliver research results relevant to the entire global community. In particular, WCRP continues to seek to develop local climate research interests and capabilities through the global change System for Analysis, Research and Training (START), which it sponsors jointly with IGBP and IHDP. In particular, WCRP has maintained a strong interest in the implementation of the Climate Prediction and Agriculture (CLIMAG) project, which is exploring the use of predictions of climate variability for agriculture.

Achievements to date

Sustainable development requires, amongst other things, adequate and informed environmental governance, management, and decision making based on a sound understanding and forecasting of conditions with and without the inclusion of human influences. Global environmental research programmes such as WCRP are therefore essential to initiate and set up the relevant databases (prior to these being taken up by more operational programmes) and to coordinate the research that is necessary to achieve the predictive goals. In general terms, WCRP contributes to:

- detection of changes in the environment;
- better understanding of the causes of these changes;
- better ability to understand and represent in modelling all involved processes and more accurately predict weather, weather-related phenomena, short-term (that is, seasonal to interannual) climate, climate change, and its components such as the water cycle.

All these are indirect contributions to the quality of life and its development, sustainable or otherwise. The following examples of WCRP's achievements to date have such implications.

Climate forecasting

The Tropical Ocean and Global Atmosphere (TOGA) project (1985–1994) established the physical basis for the understanding and predictions of El Niño temperature signals and associated changes in the global atmospheric circulation from a season to a year in advance. This was a major breakthrough in (operational) seasonal forecasting.

Climate change assessments and projections

The improved understanding of key climate processes gained through WCRP has led to significantly improved climate models, and also to operational weather and ocean forecasting models. Coordinated data analyses and climate model simulations provide the basis of our understanding of natural climate variability. In particular, improved modelling of the coupled physical climate system through systematic model diagnoses and intercomparisons has provided increasingly accurate simulations and predictions of natural climate variations, giving more confidence in models and their projections of human-induced climate change. Such results feed directly into the scientific assessments of the IPCC and have contributed significantly to the conclusion in the Third Assessment Report that: "there is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities". In turn, the IPCC assessments provide the most authoritative, up-to-date scientific advice needed to inform the UNFCCC. In this way, WCRP has helped provide the direct scientific underpinning of the political process.

WCRP will continue to play a most important role in helping to provide climate change scenarios and making them (and their likely consequences) immediately available by various means to decision makers, the media, and the general public. These are critical inputs to determining a sustainable path.

Observations and global data sets

Comprehensive field measurements are a major component of all WCRP projects. Some of these have evolved into new operational climate observational and data collection systems. In particular, the buoy array in the tropical Pacific is crucial for monitoring and for initialising model predictions of ENSO (El Niño-Southern Oscillation) events; systematic observations of the ocean's three-dimensional structure, combined with satellite altimetry have provided the basis for establishing key elements of a Global Ocean Observing System (GOOS). WCRP has also assembled essential global and regional climatological data sets; in particular for radiative fluxes, clouds, water vapour, the hydrological cycle, and the oceans.

Stratospheric ozone

A major achievement has been a careful assessment of temperature trends and of changes in the vertical distribution of ozone in the stratosphere and their relationship. This type of basic information is vital for any future scenarios and decisions, especially in the light of the experience in relation to the ozone hole.

Public awareness

It is important to stress that it was the international community of physical scientists who alerted the world to the reality of global warming and the prospect of anthropogenic climate change. It is this same community that has determined the most likely causes of the recent global warming and which has the capability to provide increasingly reliable climate change scenarios, which are crucial for many aspects related to sustainable development. WCRP has helped raise the level of scientific, governmental, and public appreciation of the importance of climate issues, and fostered much greater cooperation between hitherto distinct scientific disciplines in understanding the whole climate system.

Outstanding future questions

Outstanding future questions associated with the activities of the WCRP are:

- What are the dominant processes in the hydrological cycle, and is an acceleration of the process due to warming possible?
- What is the optimal way to model and predict clouds, radiation, and precipitation?
- How much will sea level rise due to glacier/ ice sheet melting?
- Is an abrupt climate change possible due to regime changes in the cryosphere?
- What are the mechanisms of natural climate variations?
- What is the optimal strategy to combine models and observations (present/past) for climate prediction?
- What are the effects of atmospheric composition on climate?

- What are the anthropogenic impacts?
- How is the biosphere to be included in climate models?
- What are the effects of biogeochemical cycles on climate?

In order to solve these problems the following tools and infrastructure are required:

- Earth System models (physics, biogeochemistry);
- improved modelling infrastructure;
- operational climate prediction centres;
- operational climate observing centres;
- integrated assessment for management, policy, and development.

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4.2 Policy relevance and policy support in the EU Framework Programme

Christian Patermann
European Commission, Directorate General Research

Links between policy and research

If one speaks about the policy relevance of the EU Framework Programme at a conference focusing on global change issues, it is the EU's Sixth Environmental Action Programme (EAP) that immediately springs to mind. In a very recent co-decision of the European Council and Parliament this connection between the two programmes has been strengthened, as it is requested to "ensure that the environment, in particular the priority action fields identified in the present EAP, constitute an important priority in the Community research programme". In this context, a better interaction between the players in environmental policy, research, information, and training has to be set up.

Furthermore, the decision calls on the European Commission to ensure a better coordination of the Member States' research activities in this field in order to improve the application of the results. This recognises the shaping role that the European Research Area and the Sixth Framework Programme play in European research policy.

In addition to mentioning the EAP, one should refer to the Göteborg conclusion of 2001 on the Sustainable Development Strategy, which «asks the Council to take due account of energy, transport, and environment in the Sixth Framework Programme for Research and Development». The EU strategy presented by the Commission also points out the crucial role of scientific research for the necessary knowledge relating to, for example, the critical thresholds or impacts and damages of pollutants. The Framework Programme for Research will thus strengthen the implementation of sustainable development in the energy and transport sectors and have a strong element on global change.

Examples from the Fifth Framework Programme (FP5)

Political relevance of European research actions and input to national and EU policies in Europe are not inventions of the last year; policy relevance has been an issue in previous Framework Programmes. Three out of the five major criteria used to evaluate FP5 proposals concern the policy relevance of the proposed RTD action:

- Community added value and contribution to EU policies;
- contribution to Community social objectives;
- economic and science and technology prospects.

Without achieving a minimum score in these criteria no action can be implemented. In fact, a significant number of scientifically excellent proposals have been rejected over the years because of insufficient policy relevance. This approach has clearly strengthened the support provided by European research actions to policy decisions in the EU and its Member States.

There are examples where the long-lasting research efforts supported by the European Commission have had a significant impact on international politics:

- the Climate Change Convention and debate;
- the stratospheric ozone problem;
- the biodiversity conventions and policies.

In the past, scientists, mainly through the IPCC (Intergovernmentall Panel for Climate Change) process, have raised public awareness regarding a number of global environment problems, which could have a significant impact on Europe, such as ozone depletion and climate change. This increased public sensitivity to environmental issues based on research results has played a crucial role in forcing policy makers to act and finally to conclude a number of international environmental conventions and treaties, such as the Convention on Climate Change and the Montreal Protocol.

The Convention on Climate Change and debate

The IPCC assessment reports, compiled by leading international scientists with a strong contribution from Europe, became standard works of reference for policy makers and other experts. In particular, research carried out by European networks supported through previous Framework Programmes was very successful in shaping the reports. The demands of the Kyoto Protocol in the European context made it necessary to develop a fully integrated European carbon research programme within the key action: Global Change, Climate, and Biodiversity of the current Environment and Sustainable Development Programme. It is called CarboEurope and has special built-in links to the negotiating policy bodies. Building on previous European networks, the size and dimension of this research cluster adds up to 20 million euros of EU funding, involving 80 institutions from 20 countries in Europe and elsewhere.

The steering committee and secretariat of the CarboEurope "cluster" build the main interface for all projects and act as contact and consultation points for both research and policy bodies (for example, DGs Research, Environment, and national ministries). A unique feature is the establishment of a rapid response mechanism on specific policy-relevant issues posed by the European Commission services, which has been used by DG Environment on different occasions during negotiation of international agreements (Kyoto Protocol, Conference of the Parties, COP6, COP6-bis) (specific questions regarding definitions, scientific literature supply, etc.). Clearly, the scientific community has come closer to the process of political negotiation and is working on establishing an independent carbon reporting and verification system for Europe by 2010, which is the first commitment period specified by the Kyoto Protocol.

The stratospheric ozone problem

European research programmes have contributed strongly to the present state of knowledge of the ozone layer and have influenced policy by providing new and relevant scientific results. These results have helped to provide the scientific basis for the EU position in the Montreal Protocol negotiations, which have resulted in effective international regulations so that future stratospheric ozone depletion and ultra-violet radiation enhancement can be minimised. Recent policy issues have included the speed of recovery of ozone amounts and ultra-violet radiation levels as the halogen loading declines, and the revision of regulations covering HCFCs and bromine-containing gases. The latter are of continuing importance to certain industrial sectors; for example, the use of methyl bromide in agriculture.

European stratospheric research has made important contributions to the IPCC (1999) special report. The importance of contrails and additional cirrus formation to climate change is now widely recognised. The improved quantification of their effects in relation to other aircraft impacts and the possible reduction of the effects of aircraft emissions remain important areas of research. The results and discussions contribute to the formulation of a sustainable European transport policy and have influenced the International Civil Aviation Organisation regulatory process of the atmospheric effects of aviation.

The biodiversity projects and policies

In the topic of biodiversity, the Environment Directorate within DG Research was responsible for managing the final months of several important Fourth Framework Programme projects. Many of these projects had interesting results for policy, including the following.

BioDepth

This project was a pan-European experiment that was a finalist for the 2001 Marie Curie awards for scientific excellence. It demonstrated that decreased biodiversity damages ecosystem function. With fewer plant species growing in a field, there is a decrease in harvest yield and quality, and a decrease in the abundance of insects. Nutrients are recycled less efficiently and the community is less able to resist weeds and plant diseases. This experiment has enormous significance for the Common Agricultural Policy.

In addition, the Environment Directorate has actively stimulated international collaboration in the field of biodiversity. Here we may take three examples:

ENBI (European Network for Biodiversity Information)

The European Network for Biodiversity Information is currently under negotiation. This large network of 64 partners is the European Commission's contribution to the Global Biodiversity Information Facility, a hugely ambitious worldwide project in which Europeans play a leading role. ENBI pre-figures the new FP6 networks of excellence.

CBD (Convention on Biological Diversity)

In the international arena, DG Research supports the EC head of delegation in the negotiations of the UN Convention on Biological Diversity and its SBSTTA, using information from existing projects to defend the scientific basis of the Community's negotiating position.

EPBRS (European Platform for Biodiversity Research Strategy)

The EC has established the European Platform for Biodiversity Research Strategy, a forum for scientists and policy makers to discuss and provide direction for European biodiversity science. This platform brings together delegates from across the EU, the newly associated states and the EFTA countries, and is the first effort of its kind. It focuses not only on the successive Framework Programmes, but also on Europe's scientific effort in support of various international multilateral agreements, including the CBD.

Summarising, we can say that the aims of FP5 are ambitious, as they are directed towards an effective science policy support. Developing options and providing input to political negotiations requires a number of new instruments (the "cluster" approach, integrated projects) and also a closer collaboration between key scientists and the negotiating bodies. This has been well established in a number of flagship activities, for example CarboEurope and the Biodiversity Platform. This approach needs to be continued in FP6 making use of these and some new instruments.

Sixth Framework Programme: Priority 6

Continuation of the type of research just described is ensured, since global change is one of the central topics in the FP6 thematic priority: Sustainable Development: Global Change and Ecosystems. This priority combines research on sustainable energy systems, sustainable surface transport, global change questions, and ecosystem functioning. More than 2.1 billion euros are foreseen for this priority, of which 700 million euros will be spent on Global Change and Ecosystems.

Without going into all the details of this priority but concentrating on what is relevant in respect to global change, one may mention the following.

- Impact and mechanisms of greenhouse gas emissions and atmospheric pollutants on climate, ozone depletion, and carbon sinks (oceans, forests, and soil). The objective is to detect and describe global change processes, associated with greenhouse gas emissions and atmospheric pollutants from all sources, including those resulting from energy supplies, transport, and agriculture.

- Water cycle, including soil-related aspects: to understand the mechanisms and assess the impact of global change, and in particular climate change, on the water cycle, water quality and availability.
- Biodiversity.
- Mechanisms of desertification and natural disasters: to understand the mechanisms of desertification and natural disasters, including their links with climatic change.
- Strategies for sustainable land management, including coastal zones, agricultural land and forests.
- Operational forecasting and modelling, including global climate change observation systems: the objective is to make systematic observations of atmospheric, terrestrial and oceanic parameters including those of climate so as to improve forecasting of the marine, terrestrial and atmospheric environment; consolidate long-term observations for modelling and in particular prediction; establish common European databases; and contribute to international programmes.

Sixth Framework Programme: Priority 8

The policy relevance of the Framework Programme becomes even more strongly apparent in its so-called "Priority 8", which has the objectives to underpin the formulation and implementation of Community policies, to explore new and emerging scientific and technological problems and opportunities, to encourage small and medium enterprises (SMEs) to get involved in collective and cooperative research; and finally to help open up the ERA to the rest of the world through specific measures of international cooperation.

The overall budget for this activity as it is indicated in the Common Position on FP6 of the European Council and Parliament is 1.32 billion euros.

Priority 8 has three parts:
(1) supporting policies and anticipating the EU's scientific and technological needs (570 million euros); (2) horizontal research activities involving SMEs (450 million euros); and (3) specific measures in support of international cooperation (300 million euros).

I will concentrate on the first part: supporting policies and anticipating scientific and technological needs: These activities will assure flexible and efficient conduct of research important for the Community objectives, by underpinning the formulation and implementation of Community policies, bearing in mind also the interests of future members of the Community and associated members, and by exploring new and emerging scientific problems and opportunities, when these needs cannot be satisfied under the thematic priorities. A part of the budget targeted for this activity will be allocated at the beginning of the FP6 (in the order of 350 million euros); the remaining part will be allocated during the course of implementation of the specific programme.

Policy oriented research

Policy oriented research will in particular provide support for the Common Agricultural and Fisheries Policies (CAP, CFP), to sustainable development objectives and to other Community policies such as health, regional development, trade, development aid, gender equality, education, culture, and consumer protection. Activities under this heading will also provide support for Community policy objectives deriving from the political orientation given by the Council with regard to economic policy, the information society, and enterprise.

The initial research priorities of this heading were grouped in the following lines of action:

Sustainable management of Europe's natural resources

Research under this heading will respond to policy requirements related to the modernisation and sustainability of the CAP and CFP, and to the promotion of rural development including forestry. It also focuses on environmental assessment of soil, water, air, and noise, including the effects of chemical substances.

Providing health, security, and opportunity for the people of Europe

Research under this heading will respond to policy requirements arising from the implementation of the European Social Agenda, public health, consumer protection, and the creation of an Area of Freedom, Security and Justice. It also includes a focus on the impact of environmental issues on health.

Underpinning the economic potential and cohesion of a larger and more integrated EU

This heading will respond to the needs of a series of policies concerned with competitiveness, dynamism, and integration of the European economy, in the context of globalisation, enlargement, and Europe's commercial relations with the rest of the world. It includes a focus on sustainable development, the development of tools, indicators, and operational parameters for assessing sustainable transport and energy systems, forecasting and developing innovative policies for sustainability in the medium- and long-term and the protection of cultural heritage.

Research to explore new and emerging scientific and technological problems and opportunities

The research to be carried out under this new heading is intended to respond flexibly and rapidly to major unforeseeable developments (for example: BSE), emerging scientific and technological problems and opportunities as well as needs appearing at the frontiers of knowledge. Well over 100 million euros will probably be available for this element over the next four to five years and a constant monitoring will ensure that the funds are made available for the most urgent needs not covered by other parts of the Framework Programme.

Of course the question arises as to how these priorities are defined While final decisions have not yet been taken, it is foreseen that the choice of topics, areas, and research themes will be made by a Commission-internal user group involving services other than DG Research, and which will base its decisions on the advice provided by an independent consultation of high-level scientific and industrial experts. In addition, a permanently open call for Expressions of Interest is under consideration to constantly harvest ideas from the scientific and industrial world. Policy requirements from the other Commission services will also play an important role. The work programme that will thus be adapted annually will be approved in the usual process involving the opinion of the Member States in the Programme Committee.

This short overview of the EU's approach to employing research and technological development for a sound support of policy making in the Member States, the European Union and indeed worldwide, shows how close the research projects in global change are to daily decision making in politics. The new Framework Programme takes this even further and provides, for the first time, the possibility to respond flexibly and quickly to newly emerging research and information needs from the political sphere of our society. In this way Europe can play a leading role in the world's global change policy.

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4.3 EUMETSAT (European Organisation for the Exploitation of Meteorological Satellites) Programmes

David Williams
EUMETSAT, Darmstadt, Germany

EUMETSAT is an intergovernmental organisation that establishes and maintains operational meteorological satellites for 18 European states. These are Austria, Belgium, Denmark, Germany, Finland, France, Greece, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey and the United Kingdom. There are also 5 Cooperating States: Slovak Republic, Hungary, Poland, Federal Republic of Yugoslavia, and Croatia. The images and data from its satellites make a significant contribution to the forecasting of hazardous weather throughout Europe and neighbouring continents, particularly Africa.

The EUMETSAT satellite operations' centre is in Darmstadt, Germany. This centre is linked to a Primary Ground Station in Fucino, Italy, and data up-link stations in Bracknell (UK), Toulouse (France) and Rome (Italy). Data from the satellites are distributed in real time from Darmstadt through the EUMETSAT data dissemination network. For the current satellites this means all data is processed and transmitted within 30 minutes of the observation up to 48 times per day depending upon the product.

The EUMETSAT geostationary satellite programme is funded until 2015 and includes the continuation of the current Meteosat system until at least the end of 2003 when a new generation of satellites known as Meteosat Second Generation (MSG) takes over. A EUMETSAT polar satellite system (EPS) is under development within ESA with the launch of the first satellite (Metop-1) scheduled in 2005. This satellite series will greatly enhance the range of observations made by EUMETSAT, particularly in support of climate and environment monitoring and is expected to provide observations until 2019.

The EUMETSAT data are intended primarily to support the National Meteorological Services (NMS) of Member States. The NMS in turn undertake analysis utilising the imagery, and distribute both the image data and analysis to other end-users – for the public most notably through the provision of weather forecasts on television. Through this particular distribution system it could be said that most of the population of Europe makes direct use of EUMETSAT imagery.

In addition to the primary use there are many other users. Universities and research institutes rely on Meteosat data for research and education. Commercial organisations also use the systems, either as end-users (such as airlines) or as service providers (television stations and commercial weather forecasting firms). Smaller reception facilities are installed in schools, flying clubs, and marinas and in addition are set up by many private individuals. In all, several thousand systems, located in over 100 countries, are installed for the direct reception of EUMETSAT image data.

Improvement in the service to its users is a key objective of EUMETSAT and in this context GMES is seen as a significant initiative. Within the concept of GMES, EUMETSAT is a service provider and it delivers data, products, and services to a user community. Within meteorology, the role of EUMETSAT in the operational system is shown in Figure 4.3.1, and indeed the general model is applicable to GMES. There are three important factors in this system. The first is that an operational system does not need to be entirely within one institution. For meteorology, the information delivery and processing centres are with the national weather services, whilst ESA, national agencies, and industry develop the technologies.

The second is the role of the scientific community at all stages of the operation.

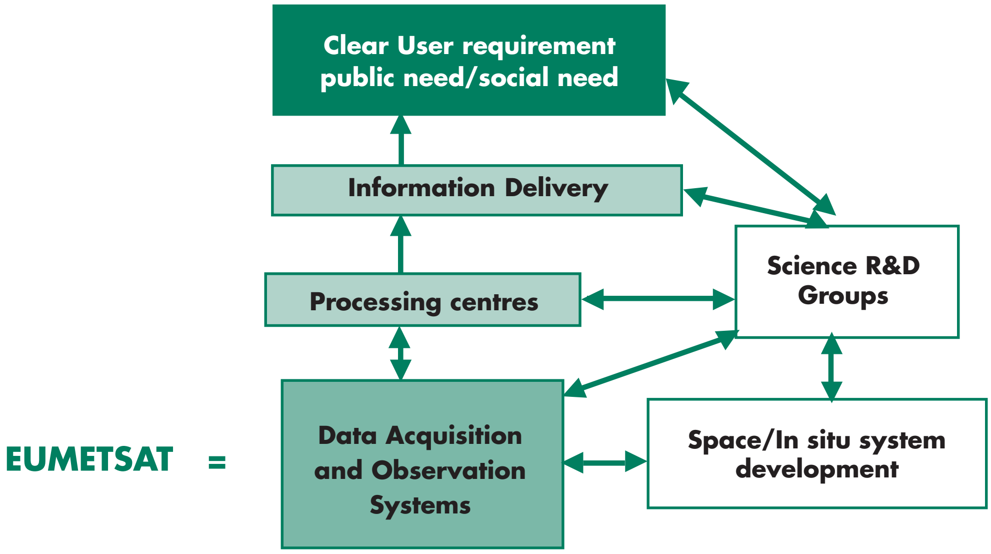


Figure 4.3.1. Steps in an operational system

The third and perhaps most important is that there is a clear societal need for weather forecasts. Without this the operational system would not exist, regardless of how good a job it undertook. Recognition of these issues, and in particular the need for a clear public and/or social need is crucial for applications developed in the GMES initiative.

A long-term goal for GMES is to ensure that the observational system is in place to support the myriad of application areas that will be developed in the short term. This is neither a simple nor inexpensive goal. At present, the primary operational satellite services are funded by the national weather services within the framework of EUMETSAT, and at a national level for the *in situ* data. The need and hence the case for further operational services can be made only in the framework of GMES. Whether any new funds flow through national support of agencies such as EUMETSAT, or directly via the EU is an open issue.

In the short term, and particularly up to 2003, the GMES initiative will focus on developing applications that will demonstrate the role of satellite data in specific areas. The choice of demonstrations is open, but all activities will need to be able to demonstrate that there is a societal need. Without this they will fail to translate to operational services. Within EUMETSAT there is a specific initiative to develop new products and services through the concept of the Satellite Application Facilities (SAF). These facilities are jointly funded by EUMETSAT and EU Member States, and the remit is to develop new products and services, based primarily but not exclusively, on data from existing and future EUMETSAT satellites. The developments themselves may be either products or software modules. In the latter case the module may be self-standing or feed into a larger system such as a numerical weather prediction model.

A key feature of the developments in all the SAF is the involvement of scientists from several Member States. One agency in one Member State acts as the lead for a particular SAF, and coordinates the activities of all involved through a virtual network. A second key feature is that the driver for the SAF is the development of products and/or services that will be implemented in an operational environment. For each SAF there is an overview by the EUMETSAT Council, and all services and products developed will become part of the EUMETSAT catalogue and be available to the community at large. At the present time there are eight SAF in the development phase. The range of products and services being developed is wide ranging but for the four SAF most closely associated with climate and environment is shown in Figure 4.3.2.

In summary, EUMETSAT has a significant programme of existing and planned satellite observations in support of meteorology, climate, and environment. For these missions, steps are already being taken to develop a range of products and services. However, a further significant effort is still needed to ensure maximum exploitation of the operational missions planned. In addition there are a large number of areas where new product developments are needed and where long-term operational observations are still not guaranteed.

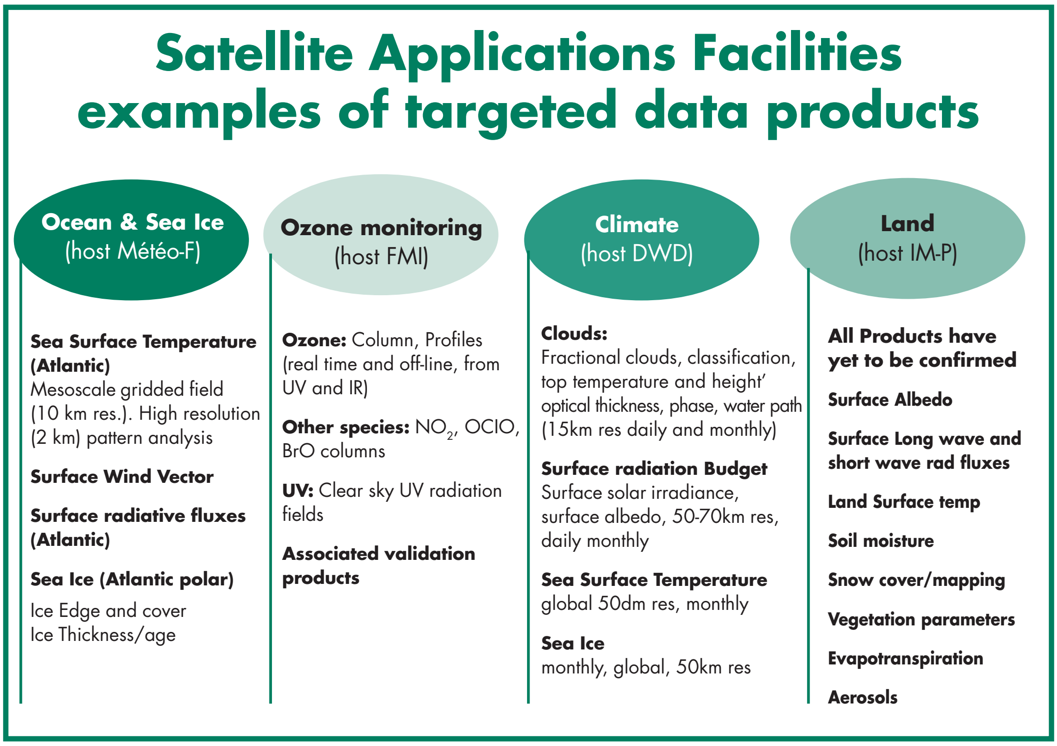


Figure 4.3.2. Targeted products from four SAF

4.4 ESA's contribution to global change research

Overhead Presentation

Eine-Arne Herland
Division of Earth Sciences, European Space Agency, the Netherlands

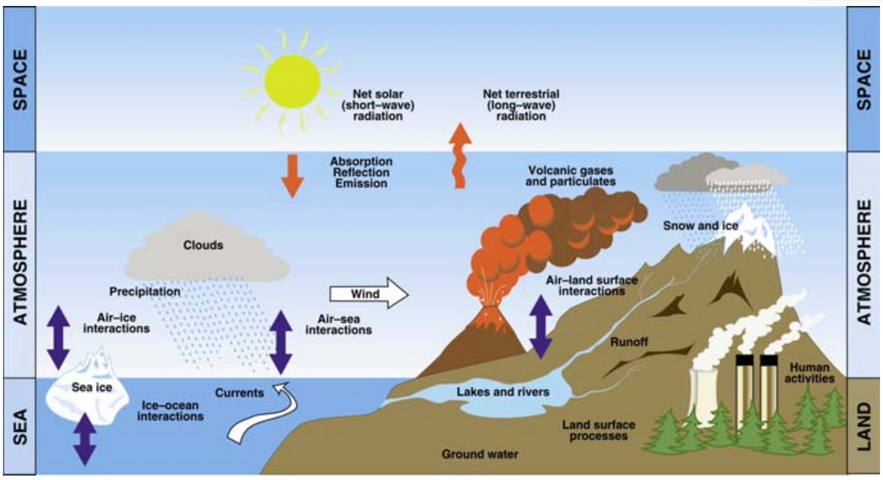
The ESA Living Planet Programme
Underlying Rationale

- Four key

- The need to address public concerns about the Earth, its environment and mankind's impact on it.
- The Earth is a complex (and evolving) system which is not properly understood.
- Data required to improve knowledge of the processes involved, to develop and validate models.
- Space has a role to play in the helping to ensure the provision of the requisite data.

ESF Forward Look, Stockholm, Jan 30-Feb 1, 2002

The Earth System



See *Earth Explorers: Science and Research Elements of ESA's Living Planet Programme* (ESA SP-1227)

ESF Forward Look, Stockholm, Jan 30-Feb 1, 2002

The Four Themes

Four fundamental themes underly ESA's Earth Observation Science and Research Element of the 'Living Planet' Programme (ESA SP-1227), namely:

• Theme 1 - Earth Interior including marine geoid, gravity and magnetic field at various scales, from local or regional to global.

• Theme 2 - Physical Climate System spanning the time scales from fast (days to weeks) via medium term (seasonal to interannual) to long term (decadal to centennial).

• Theme 3 - Geosphere-Biosphere including carbon, energy and water cycles, bio-chemical cyles and the productivity of the different ecosystems.

• Theme 4 - Atmosphere and Marine Environment and anthropogenic impact comprising composition changes by human activity, chemical processes in troposphere and stratosphere and marine pollution.

The four Themes span the full Earth System and recognise the need for the detailed treatment of interactions between the regimes.

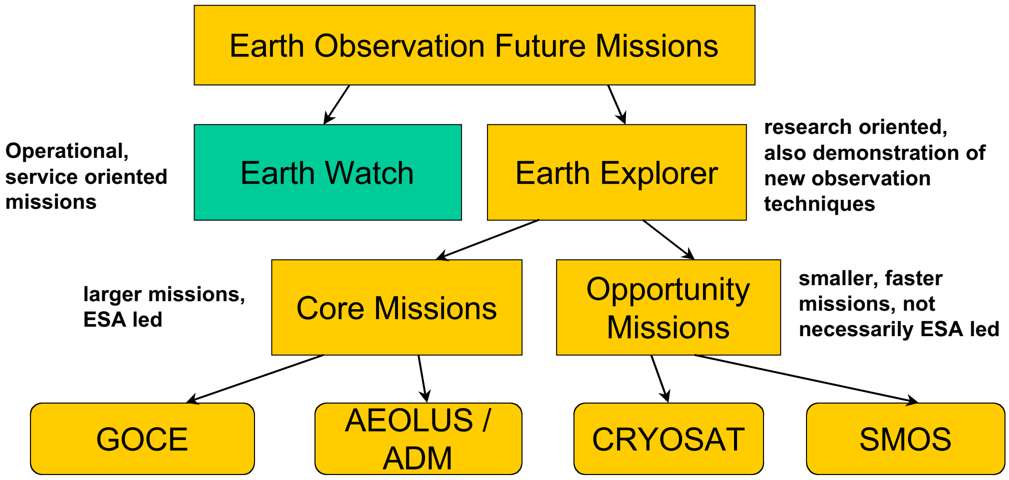
The Earth Explorer Missions

- Means of addressing objectives (see ESA SP-1227)
- Regular flight opportunities funded under the Earth Observation Envelope Programme
- Objectives of Earth Explorer Missions - research and development focussing on specific topics/techniques
- Two complementary types of Earth Explorer missions, namely:

  Earth Explorer Core Missions - larger research/demonstration missions led by ESA.
  Earth Explorer Opportunity Missions - smaller research and demonstration missions not necessarily ESA led.

- Complemented by Earth Watch - thematic pre-operational missions focussing on specific emerging Earth Observation application areas

The Overall Scenario



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Satellite missions

- ERS-1/2
- Envisat
- MSG – with Eumetsat
- Metop – with Eumetsat
- GOCE – first Core mission
- CryoSat – first Opportunity mission
- Aeolus – second Core mission
- SMOS – second Opportunity mission
- EarthCARE – Phase A for next Core mission selection
- SPECTRA – Phase A for next Core mission selection
- WALES – Phase A for next Core mission selection
- SWIFT – instrument on GCOM-A1

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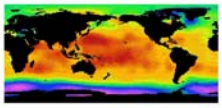
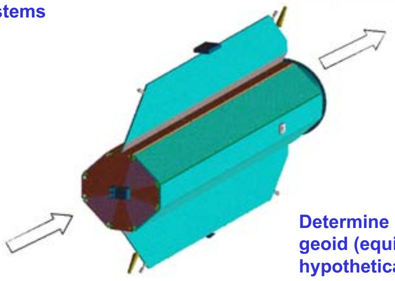
GOCE Mission Objectives

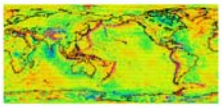
Studies in:

- Solid Earth Physics - anomalous density structure of lithosphere and upper mantle
- Oceanography - dynamic ocean topography and absolute ocean circulation
- Ice Sheet Dynamics - ice sheet mass balance
- Geodesy - unified height systems
- Sea Level change

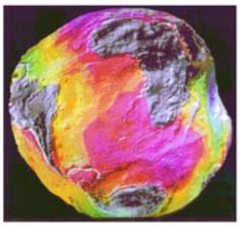
Geoid







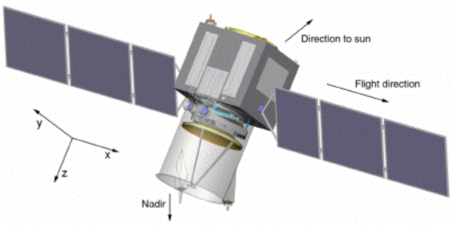
Gravity Anomalies

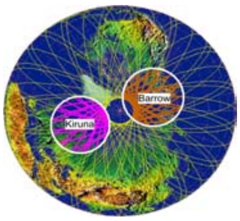


Determine Earth's gravity field and its geoid (equipotential surface for a hypothetical ocean at rest):

- high accuracy (1 mgal and 1 cm)
- fine spatial resolution (~ 100 km)

Aeolus-ADM Mission Objectives





Measures atmospheric winds in clear air to:

- Improve parameterisations of atmospheric processes in models
- Advance climate and atmospheric flow modelling
- Provide better initial conditions for weather forecasting

Using:

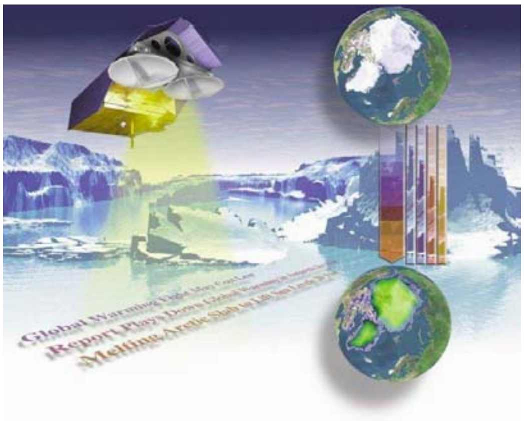
- A Doppler Wind Lidar operating in the UV (355 nm)
- Two channel receiver to detect aerosol and molecular backscatter signal

see <http:/www.estec.esa.nl/explorer/>

ESF Forward Look, Stockholm, Jan 30-Feb 1, 2002

CryoSat Mission Objectives

- Research goals:
  - Study of mass imbalances of Antarctic and Greenland ice sheets
  - Investigate the influence of the Cryosphere on global sea level rise
  - Use of sea ice thickness information for advances in Arctic and global climate studies
- Measures variations in the thickness of the polar ice sheets and thickness of floating sea ice
- Uses a Ku-band radar altimeter:
  - conventional pulse limited mode
  - synthetic aperture processing along track (over sea ice)
  - Interferometric processing across track (over ice sheets)



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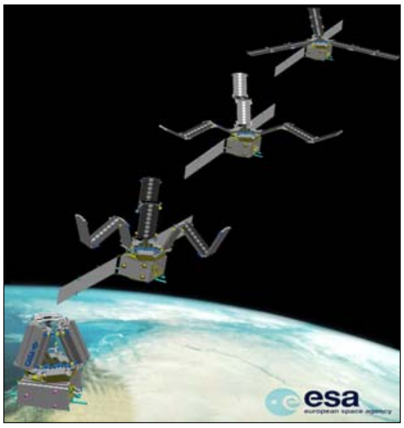
SMOS Mission Objectives

- To demonstrate the use of L-band 2-D interferometry to observe:
  - *salinity over oceans,*
  - *soil moisture over land*
  - *ice characteristics*
- To advance the development of climatological, hydrological and meteorological models.



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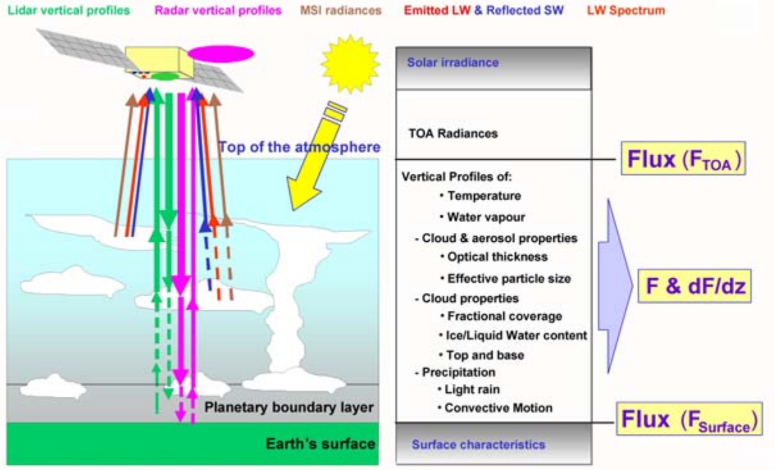
The EarthCARE mission

Approach

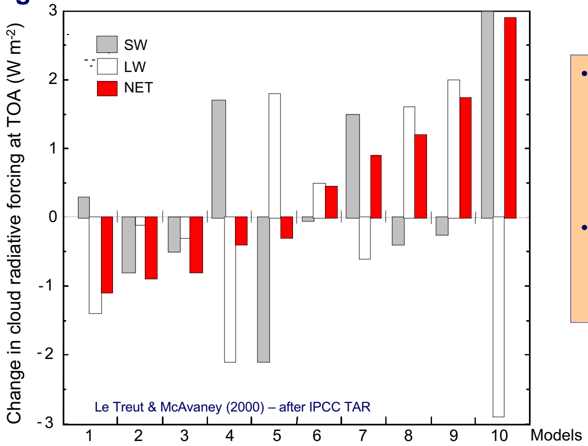


Requirement is to measure the vertical profiles with an accuracy such that the instantaneous TOA flux is derived within ±10 W m^{-2}

EarthCARE - the Challenge

Cloud Radiative Forcing (CRF)

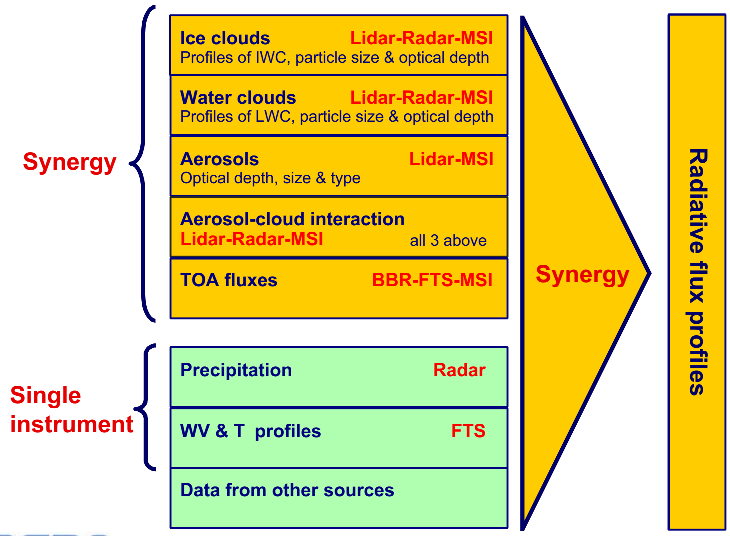
Change in TOA fluxes in 10 models due to clouds for CO_2 doubling



- more aerosol and low cloud cool the climate by reflecting more sunlight to space
- more high clouds warm the climate by reducing the IR loss to space

dispersion of the predictions ⇨ similar to IPCC external factors

EarthCARE
Instrument synergy



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SPECTRA
Scientific Objectives

- ***Scientific goal***
  - Describe, understand and model the role of terrestrial vegetation in the global carbon cycle and its response to climate variability under the increasing pressure of human activity.

- ***Specific research objectives***
  - **Provide detailed observations of key properties of terrestrial biomes** that can be assimilated by dynamic vegetation models at the regional scale.
  - **Generate biome–specific parameterisations** to improve climate models at the global scale.

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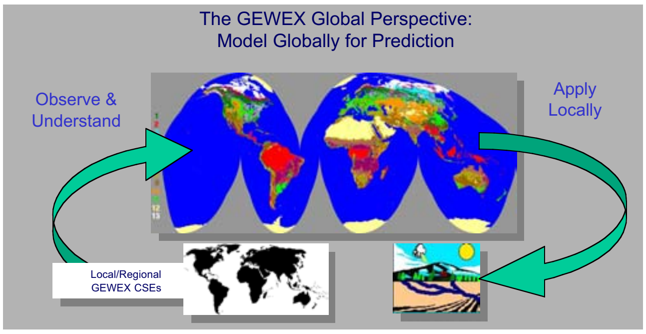
SPECTRA
Mission Concept

- The response of **terrestrial vegetation** to **climate variability** and the **terrestrial carbon cycle** are major issues in climate understanding.
- **Sampling** all **terrestrial biomes** leads to better understanding and prediction of the response of terrestrial vegetation.
- Our land observing mission will sample terrestrial biomes by using a **global distribution of regions** as a reference**.**



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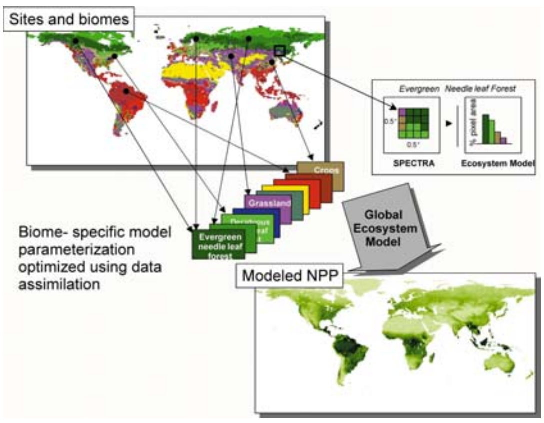
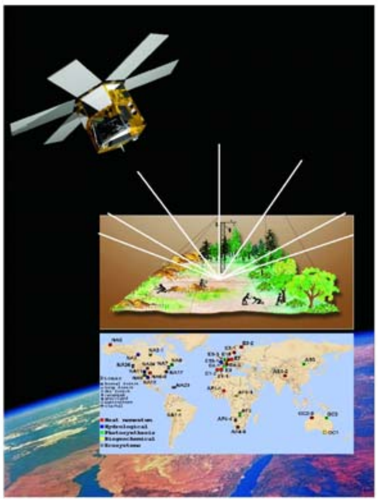
The role of SPECTRA for GEWEX / ISLSCP





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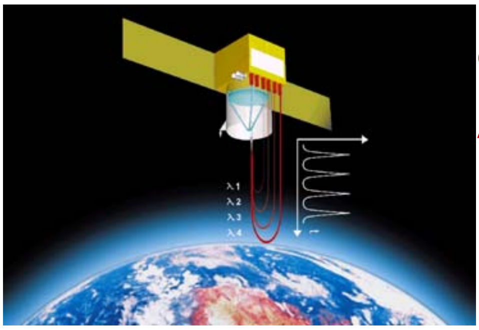
The WALES Mission

WALES – Water Vapour Lidar Experiment in Space

Mission goal: To determine profiles of water vapour accurately and at high vertical resolution from space with global coverage



CORE ELEMENT:
Nadir-viewing water vapour DIfferential Absorption Lidar (DIAL) System

First active humidity profiler in space

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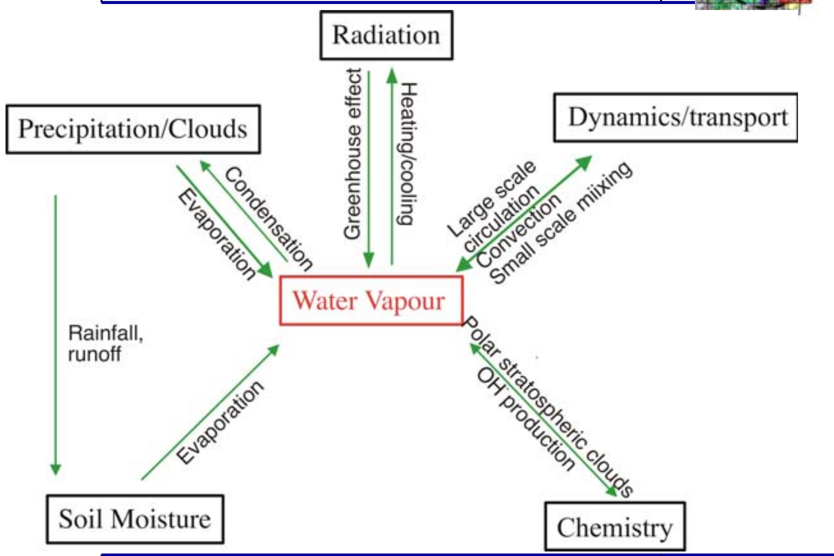
WALES - scientific justification

The Role of Water Vapour



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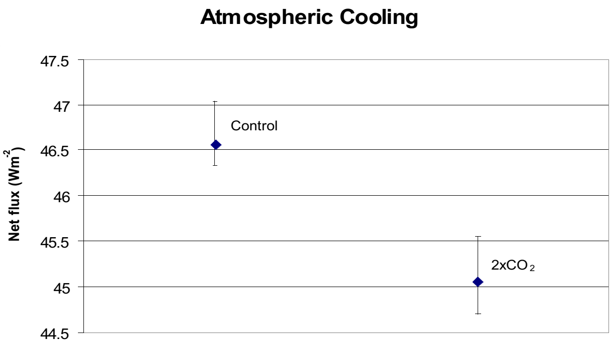
Impact Study
Climate Impacts

Radiative transfer studies show that WALES data meet the low-bias requirements needed

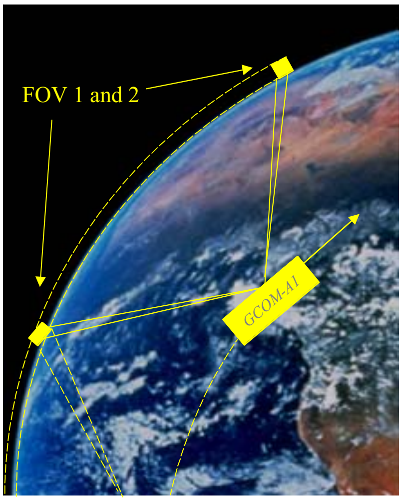
- to infer humidity anomalies at monthly or longer time scales
- to minimise systematic errors in climate change simulations

EXAMPLE

- doubling CO_2 traps more radiation (1.5 Wm^{-2})
- the low uncertainty in WALES observations is equivalent to small error bars on atmospheric radiation (just 0.5 Wm^{-2}, around 1%)



SWIFT – Stratospheric Wind Interferometer for Transport Studies



Viewing geometry:

Image field ~1 degree x 2 degrees (50 km x 100 km) made up of 80 x 160 pixels each 0.63 km high. Stratospheric coverage from 15km to 65km with measurement resolution of 3 pixels or 1.9km vertically

- **650km orbit has tangent distance of ~2860km.**
- **69° inclination achieves full global coverage.**
- **Yaw maneuver required.**
- **Orthogonal FOVs resolve full horizontal wind vector**
- **Spacecraft velocity means ~9 minute delay between orthogonal components**

NASDA

CSA ASC

Conclusion (1)

- ESA's Living Planet strategy gives the Agency a clear mandate to support global change research
- ESA is currently implementing and planning a series of missions that will contribute significantly to global change research
- ESA and the EC have agreed on a common European Strategy for Space with GMES as a central element
- ESA is starting the GMES Service Element as part of the Earth Watch programme, in close cooperation with the EC
- ESA maintains international links with other space agencies and international research programmes
- close interaction with the scientific community is needed from mission definition through implementation and data exploitation

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Conclusion (2)

- close cooperation needed with operational entities in planning and implementation of operational and long-term monitoring
- global change research is crucially dependent on cooperation between research, development and operational entities through well calibrated long time series, model development and trend analysis

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Section 5:

The Forward Look Discussions

5.1 Overview of the working group discussions

Chris Rapley
British Antarctic Survey, Cambridge, UK

Having considered the nature of global change, and having been informed of the associated international research efforts, the conference turned its attention to the role that Europe might play in ensuring effective and rapid advances. Three working groups were each tasked to address a specific problem area identified beforehand by the steering committee. The working groups were requested to summarise the key issues, to identify measures to alleviate the problem, and to indicate what actions by European scientists or by European funding agencies at the national or international level would be helpful.

Working Group 1: Natural sciences–social sciences interfaces and collaboration

(Chair: Leen Hordijk; Rapporteur: Karin Lochte)

Global change research requires a highly interdisciplinary approach. Much progress has been made in this respect. Indeed, the rapid growth of interdisciplinary teams has been one of the great successes of the international global change research programmes. In spite of this, it has proved difficult to establish the necessary active linkages between the natural and social sciences.

Working Group 1 identified the following as the key barriers to progress and causes of failure:

- research questions being formulated by natural scientists or social scientists separately, resulting in an unbalanced emphasis on particular aspects or issues, and a lack of "ownership" of the problem or approach by one group or the other;
- institutional barriers such as:
  - funding structures ("silos") which inhibit social science-natural science joint projects;
  - evaluation procedures which militate against interdisciplinarity;
  - teaching practices and disciplinary "academies" which develop narrow outlooks and "tribal" prejudices;
  - career aspects which reward conservatism;
- a lack of shared concepts, tools, goals, and products;
- different scales of interest and operation, different ways of prioritising, and different languages;

- a lack of awareness and an associated "blinkered" outlook;
- a low interest by leading social scientists in Earth System science.

Conditions for improved collaboration were seen as:

- joint design and implementation of common projects from the start;
- the adoption of a common scale of approach – namely regional;
- problem-oriented research as a basis for joint work.

The group recommended that ESF should:

- be instrumental in developing true interdisciplinarity in the Earth System Science Partnership (ESSP) projects on food and fibre, water, and carbon;
- develop flagship areas building on existing good collaborations;
- help to foster education on interdisciplinary science.

Working Group 2: Infrastructure and monitoring

(Chair: Anders Lindroth; Rapporteur: Dave Williams)

Observing and understanding global change requires the development, deployment, and operational maintenance over long periods of time involving expensive infrastructure.

Working Group 2 noted the following:

- there is a lack of common knowledge on the detail of existing infrastructure and monitoring activities;
- there is a consensus on needs in nearly all areas;
- the ESF could potentially play a major pan-European role in assimilating information and coordinating European effort.

Priority infrastructure areas were identified as:

- supercomputing power needs, to match or leapfrog initiatives such as those being taken in Japan;
- a need to utilise existing and future data sets: key issues include charging policy, access to meta-data, the use of standard formats, and the need to articulate the specific needs of global change research, including relevant social science data.

Working Group 2 recommended that ESF should promote the distribution of data at marginal cost, but recognised that for large data sets there is a significant infrastructure cost that would need to be met. It was noted that the "free" exchange of scientific data was one of the fundamental tenets of the International Council of Scientific Unions (ICSU), and consequently that it would be worthwhile enlisting ICSU's support on this issue.

Regarding monitoring, Working Group 2 noted that:

- monitoring includes the acquisition, transmission, quality control, storage, custodianship, dissemination, and assimilation of large data sets;
- social science data should be included as well as natural science;
- surface data are required from sites over a wide geographic area and that this has implications regarding human capacity building;
- the necessary long-term funding commitments have often proved elusive;
- the science community needs to confront and agree the proper balance between expenditure on observations and expenditure on the custodianship and exploitation of the data;
- there is significant duplication of *in situ* monitoring effort in Europe;
- the international bodies GTOS, GOOS, GCOS, IGOS have addressed the issue at the global level but there is a role for a European

body to play in providing coordinated input to these;
- there is a need for a sustained investment in new technologies since these provide part of the solution.

Recommendations to ESF were to:

- gather, summarise, and make available information on what monitoring is being carried out within Europe;
- seek to harmonise European activities to eliminate unnecessary duplication;
- act as a source of input to the international coordinating bodies for global change monitoring;
- define European roles and needs in developing new technologies.

Working Group 3: Research–policy interface

(Chair: Mike Hulme; Rapporteur: Pier Vellinga)

The motivation for global change research is not merely intellectual curiosity, but the need to guide human behaviour at the collective and individual levels to achieve a sustainable world society. The interaction between scientists, policy makers, and society at large has proved problematical, partly because of the different cultures, motivations, and outlooks involved, but also through a general lack of experience.

Working Group 3 made the following points and recommendations:

- the classic "linear" view of the interaction between science and society, in which research leads to understanding, assessment, and policy formulation, is flawed, and a participative, interactive approach is necessary;
- the ESF should formally adopt the four global change programmes (ESSP) and should endorse their research plans;
- the ESF should establish a broad global change committee with membership drawn from the four programmes, thereby giving Europe a focal point and voice for global change issues. The proposed ESF global change committee should:
  – actively seek to solve the problem of the value added funds needed to support the international programme offices and networking activities of the four international programmes
  – establish task groups to address issues that are on the political agenda for strengthening research (for example, the Global Monitoring for Environment and Security initiative - GMES)
  – stimulate strategic assessments on issues such as energy supply and water
  – seek to align research programmes within Europe at the national and international levels, through the use of existing and new instruments (such as EUROCORES)
  – develop the means to provide targeted briefings and a "yellow pages" service to improve science-policy interaction within Europe.

Working Groups 4, 5, 6: Programme development on a European scale: institutional barriers to a European approach and the roles of European organisations, including ESF

(Chairs: Arne Jernelöv, Jose Moreno-Rodriguez, Eckart Ehlers; Rapporteurs: Chris Ritz, Paul Leadley, Karin Refsnes)

Following the plenary discussion, the three parallel working groups were asked to consider:

- the issue of programme development at the European level;
- institutional barriers to a European approach;
- the roles of European organisations including ESF.

They were asked to provide building blocks for:

- the development of strategic actions by the scientific community to develop research programmes addressing the new ESSP global change agenda, but with priorities based on European strengths and existing infrastructure;
- actions by the national and European funding agencies to facilitate the strategic actions through the optimum use of existing instruments and the development of new instruments, and the removal of barriers, especially those that inhibit cooperation between funding agencies.

There was much common ground in the reports of the working groups, which can be summarised as follows:

- Europe must address global issues; global change is pervasive and a regionally constrained approach is insufficient;
- the ESF should indeed endorse the four international programmes (ESSP) and establish a global change committee;
- the purpose of the proposed global change committee should be to place global change research centre stage and to be, for Europe, the primary, authoritative, independent, expert point of contact on global change research and policy issues;
- since such a body will depart significantly from ESF's existing disciplinary-based organisational structure, careful consideration will be necessary in order to realise this goal;
- the proposed global change committee should be responsible for ensuring appropriate linkage between the ESSP, national funding bodies, international funding bodies (primarily the EU), and the policy sector, especially the European Parliament.
- whilst many of the national research agencies are ESF Member Organisations, the largest budgets on environmental issues are generally those of government departments and agencies. The proposed global change committee should therefore seek to promote key research issues within these bodies;
- tasks for the proposed global change committee in addition to those identified in the earlier working group sessions included the requirement to:
  - stimulate new, regional, or topical European research activities which directly support or complement the international research agendas;
  - help formulate the EU research agenda and maximise the impact of EU funds;
  - ensure the provision of less complex and more stable European GC funding sources;
  - ensure that participation in research supporting the international programmes is seen as positive by national funding agencies;
  - proactively influence ESF Member Organisations to raise intellectual critical mass, especially in the social sciences, through new funding instruments, the removal of barriers and the support of flagship projects;

- ensure science quality;
- liaise closely with ICSU and others to address specific impediments to progress in the areas of data charging and interdisciplinarity;
- develop mechanisms to support young scholars from all regions of Europe;
- encourage the participation of non-OECD countries.

Barriers to progress were identified as:

- current lack of awareness of global change programmes and activities within ESF and the ESF Member Organisations;
- gaps between national and international objectives;
- the need to increase research capability within Europe.

Actions for the science community in Europe were identified as to:

- actively pursue joint natural science-social science definition and implementation of common projects from the start;
- adopt a common scale of approach (that is, regional) for natural science-social science projects;
- address problem-oriented research as a basis for joint work;
- exert and maintain bottom-up pressure on ESF Member Organisations for research and value added funding;
- contribute to integrated assessments and science and society initiatives.

Actions for the four international programmes were to:

- continue to enhance and crystallise vision, priorities, plans, and synthesis activities;
- adopt an audacious, time-limited, practical goal to provide a focus and a challenge against which progress can be judged.

5.2 Summaries from the working group discussions

Working Group 1: Natural sciences–social sciences interfaces and collaboration

(Chair: Leen Hordijk; Rapporteur: Karin Lochte)

It is generally recognised that good cooperation between social and natural sciences is essential for Earth System science since most issues addressed by global change research are of human origin. However, many social science fields have no traditional links to natural sciences and vice versa. Barriers and problems in the collaboration between both fields of science are well known and need to be overcome in order to achieve significant progress in global change research. This session addressed in three steps the causes of failure, ways to improve collaboration, and recommendations to the ESF.

Barriers and causes of failure

Global change research has in the past been driven primarily by the natural sciences that have observed in recent decades man-made changes in the natural system with potentially extensive consequences for society. Research questions were mainly formulated only by the natural sciences. Under these conditions the social sciences did not recognise this type of research as relevant to their field of activity. The consequences are that global change research has not attained enough importance in the social sciences and that many leading scientists in that field have not become involved. This barrier was considered the most serious reason for the failure of collaboration.

Institutional barriers also represent major obstacles for collaboration between the social and natural sciences. The structures for funding are generally different for the two domains, which renders joint funding of projects difficult. Researchers belong to different scientific academies and publish in different journals, hence there is no knowledge of each other's type of research. Evaluation of joint projects presents a problem because of a lack of suitable reviewers and standards. Academic teaching does not include aspects of global change, and career prospects for young scientists working in global change research may be less promising than for traditionally oriented researchers. These barriers are caused by the present organisation of science in academies and faculties.

The scientific "culture" in both fields differs substantially. Problem-definition and the pathway to knowledge in social sciences are very different from those in natural sciences. For instance, social sciences tend to ignore the importance of "reliable" natural ecosystems for human societies, while the natural sciences consider humans only as an impact on the environment, if at all. Therefore, it is difficult to agree on joint approaches and to obtain data that can in any way be compared. Lack of shared concepts, lack of joint tools, different opinions about common goals or final products represent major barriers. Different ways of setting the priorities for research topics and different scientific languages add further problems to the development of joint global change research. It has to be noted that considerable differences also exist between the major social science disciplines (and to a lesser degree amongst natural science disciplines). Therefore, the task of developing joint global change research is not limited to merely a better cooperation between the natural and social sciences. While multidisciplinary approaches and projects are already underway, comprising different disciplinary sub-projects formally linked to a joint topic, genuine interdisciplinarity is rare and extra efforts are needed to establish it in Earth System science.

Global change research in natural and social sciences is often conducted on different spatial and temporal scales. While natural sciences tend to concentrate on global scales, social sciences are more concerned with regional problems. This scale problem has to be solved relative to the investigated issue.

The above-listed problems and barriers have inhibited development of successful collaborative Earth System science. As a consequence, this type of science has a low reputation especially amongst social sciences, and many leading social scientists are not inclined to participate in global change research even if funds for such research are available. Under these conditions integrated research cannot be expected to flourish and to attain high scientific standards.

Conditions for improved collaboration

The first condition for the development of joint projects is an equal participation of the disciplines at all stages of the research. Projects have to be designed jointly by natural and social scientists from the start. Since global change is essentially an anthropogenic problem, research should be defined in the first place from the human dimensions aspect. This will narrow the focus of research leaving enough space for disciplinary research. Interdisciplinary concepts and approaches, joint tools, common goals and products have to be developed. This requires additional effort and time, which need to be acknowledged and provided for by funding authorities.

As a second condition, the basis for joint work has to be problem-oriented research. Addressing a joint problem, such as outlined by the international joint projects on carbon, water, food and fibre, would provide a focus uniting different disciplinary approaches and different perceptions of the scientific issue. There are already some good initiatives (for example, projects at the Institute of Islamic and Arabic Sciences in America, the ProMed proposal) that could serve as templates to develop, in a European context, problem-oriented global change science.

The third condition is an agreement on a common scale of approach. In many cases, the most promising seems to be the regional scale, although this will be partly determined by the topic to be investigated. When working in this common frame of reference, scientists can carry out disciplinary research and still link their data.

Collaboration between social and natural sciences can be improved if the above conditions are met. However, institutional barriers, as outlined above, cannot be removed by these measures. To overcome such hindrances for interdisciplinary global change research, which are rooted in the present organisation of science, a conscious effort on the part of the funding authorities and the academic institutions has to be made.

Recommendations to the ESF

In order to improve collaboration between the natural and social sciences in the frame of global change research the following specific recommendations were made for the role of ESF in this process.

The ESF should be instrumental in developing fully interdisciplinary projects within the joint topics of the global Earth System Science Partnership (ESSP): carbon, water, food and fibre. This limitation to the internationally agreed joint topics is considered necessary, as it seems unlikely that more topics can be accommodated at present. It involves the organisation of explorative workshops to start up these projects in an interdisciplinary way, providing a coordinating platform bringing together the right group of scientists from different disciplines and helping to identifying a specific European frame for these general topics.

The ESF should develop flagship areas for regional joint projects. This effort should build on already existing good collaboration. Two geographic regions of specific importance for future environmental and societal changes were identified: the Mediterranean and Arctic/boreal regions.

The ESF should help to foster interdisciplinary education. It was felt important that students should be first trained in their specific subject before they are given opportunities to get involved in interdisciplinary global change science. The ESF should provide support for dedicated interdisciplinary global change training courses at post-graduate level involving all relevant social and natural sciences. Furthermore the development of a network of young researchers in global change science may help to focus more attention on this field of science. An information platform for young researchers for jobs in global change research and for relevant science programmes (for example Nato science programmes) may also be helpful.

In addition, a general role of ESF as a coordinating body was identified. This may involve a directory of researchers and projects in global change research, including information about nationally funded projects.

Working Group 2: Infrastructure and monitoring

(Chair: Anders Lindroth; Rapporteur: David Williams)

Working Group 2 met to discuss a number of issues concerning the need for infrastructure and monitoring with respect to global change. Whilst there was clearly a lack of common knowledge of the overall set of activities being undertaken, there was a good degree of consensus on the major issues that need to be addressed. There was also a view that ESF could play a significant role in concerting a European position.

Infrastructure issues

Computing

The need for dedicated supercomputing power at a European level was noted. At present the majority of climate modelling is based on the computing capacity of the weather services and as such is a secondary user. Specific capacity dedicated to climate, ocean and land modelling would be of significant benefit.

Data handling and management

Meta-data to enable the data quality to be identified and to allow long time-series of consistent data to be held must be stored with the data itself.

Data sets must be stored in identified formats and on media and in structures that allow access. Even now some data sets are stored in such a way that they cannot be accessed.

Data charging was still seen by some as a barrier to utilisation. The approach adopted by ESF should be to recognise that data should be available for research at no cost, or the cost of fulfilling the order. The latter case recognises that for significant volumes of data there is a real additional cost of fulfilling a request. For a combination of the above reasons the existing data sets are not always fully utilised.

Surface-based observations are an essential complement to satellite data. There is a need to build capacity in this area through, for example IGOS, GCOS, GCOS and GOOS, and ESF could play a role in this.

Monitoring issues

There is an essential need for long-term observations both to underpin research and to enable monitoring. The ESF could assist in the articulation of the observational requirements. At present there are a range of activities being pursued, but an overall European position has not been developed.

The activities of monitoring should cover the acquisition, transmission, quality assessment, storage, and assimilation of data. They should also cover the human and social issues and not just geophysical observations. This bringing together of the two scientific communities was seen as a major plus for the Forward Look symposium.

The ESF could provide, through appropriate actions, an overview of what is being done and monitored in Europe by European entities. Much of this would involve linking with what is being undertaken by bodies such as IGOS and CEOS.

The ESF could also assist in defining European roles in developing new technologies and working with the relevant agencies at both national and European levels to ensure the funds are available.

Finally, long-term monitoring requires long-term funding. The science budget has to determine what effort it is able to devote to these activities at a European level. In addition there is a need to identify those agencies responsible for long-term issues (national and European) and work with them to ensure that they devote resources to the issue. The ESF could have a valuable role in this activity.

Working Group 3: Research–policy interface

(Chair: Mike Hulme; Rapporteur: Pier Vellinga)

The parallel session was opened by Mike Hulme, Director of the Tyndall Centre at the University of East Anglia. Pier Vellinga, Dean of the Faculty of Earth and Life Sciences of the Vrije Universiteit Amsterdam, rapporteur wrote the report presented below.

The discussion started with a short introduction by each of the participants. In this round many of the participants expressed the need to strengthen cooperation among European researchers in the field of global environmental change and the need to develop adequate institutions to discuss and shape the European input into the four major global change programmes: WCRP, IGBP, DIVERSITAS and IHDP.

The ESF is recognised by the participants as the most suitable organisation in Europe to facilitate the discussion about, and the coordination of, the input of European researchers and their organisations at the national and local levels into the four international global change programmes.

To enhance the efficiency and the effectiveness of the input of European researchers in the global change programmes and ultimately in global change policy development and implementation, the following eight issues and recommendations were put forward by the group.

1. The mental model of the science–policy interface

Most of the participants spoke in favour of a model where there are relatively clear distinctions between what is research, what are research programmes, what is assessment and what is policy formulation and implementation (see Figure 5.2.1).

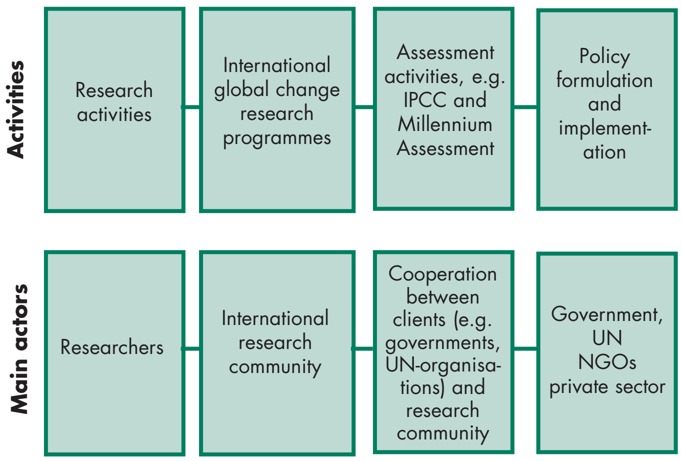

Figure 5.2.1

The participants of the parallel session recognised that a linear process of research to policy and direct interaction between the top researchers(s) and the top policy makers should be considered with scepticism. In a democratic system, policy makers are advised by their broader constituency, including the public at large, NGOs, the private sector, policy makers in adjacent fields, etc. It is the role of the research community to actively inform all relevant stakeholders. If required, targeted sessions with policy makers could be organised to create a dialogue between those who do research or who plan research, and policy makers that use research. However, such sessions should be structured with care and they should be transparent in terms of the broader community of researchers and stakeholders. Formal, open and transparent assessment procedures such as IPCC is the preferred mechanism.

Assessments in which governments and other important policy players have a stake may well produce a list of relevant research questions; however, it is up to the (more) independent research community and their research planning bodies to translate such research questions into research plans.

2. ESF endorsement of the four major international global environmental change research programmes: WCRP, IGB, DIVERSITAS and IHDP

The participants expressed the need to establish a more formal relation between the four programmes and the relevant research, research funding and research-users organisations. Preferably DG Research should officially recognise the four international programmes and their organisations as organisations that have a role in helping to shape the global change research programmes of the EU and its Member States.

To organise such a link with DG Research it was agreed that official endorsement by ESF would be an important first step. The next step is described below under item 3.

3. Setting up an ESF standing committee on global environmental change research

The participants of this session expressed the need to set up an ESF standing committee on global environmental change research, consisting of ESF high-level representatives, representatives of its national Member Organisations (especially the research funding organisations), DG Research and DG Environment representatives, representatives of the four global change EU research programmes, in particular the key European members of these organisations.

Such a standing committee should discuss and shape the input (in terms of research planning) of European researchers and their funding organisations into the international global change research programmes.

The committee would help in creating some kind of coordination mechanism among the most important research funding organisations in Europe, at EU-level, and at the level of the Member States and the EU accession countries.

4. "Glue funding"

The ESF should provide (or help to provide) "glue funding" (added value money) for research cooperation, research planning and research findings dissemination to be carried out by the organisations of the four global environmental change programmes. In particular the International Human Dimensions Programme and the DIVERSITAS Programme and the International Project Offices of the Core Projects have a critical shortage of funds. These organisations, of necessity, direct much of their energy to fundraising for individual short-term activities, as there is no formal mechanism for funding these organisations. The ESF can make a major difference in this field.

5. Special committees

If and when considered useful, the ESF should set up special committees for the implementation of specific topical goals as formulated by the EU and its Member States. The GEMS is an example that benefits from such a structural and transparent input by ESF and its Member Organisations.

This recommendation was particularly stressed by the participants of the parallel session that are engaged in the ESF Marine and Polar Boards.

6. Developing mechanisms

The ESF and the proposed standing committee on global environmental change should develop mechanisms through which the role of European researchers in international assessment activities can be encouraged. The ESF could also play a role in the process of setting priorities for and initiating formal assessments on global environmental change issues that are particularly relevant for the European Union. The participants recognised the latter as a second priority. First priority is setting-up the standing committee mentioned under recommendation 2.

7. Planning of global environmental change research

The ESF, through the proposed standing committee, could help the DG Research in aligning the planning of global environmental change research at the level of the Member States and the level of the EU DG-Research.

8. Facilitating and/or organising specific/targeted briefings

The ESF could consider facilitating and/or organising specific/targeted briefings for EU policy makers and EU-level NGOs (private and public sector NGOs) on scientific issues related to global environmental change policy development and implementation. This should be organised as a transparent process. This recommendation was motivated by a number of statements with anecdotal evidence that over the last few years such policy briefings have occurred in a haphazard way and scientists were selected mainly on the basis of personal networks of the policy makers in Brussels. A systematic overview/database of researchers («yellow pages») would also help to identify the range of expertise available in the EU.

Working Group 4: Programme development on a European scale: institutional barriers to a European approach and the roles of European organisations, including ESF

(Chair: Arne Jernelöv; Rapporteur: Karin Refsnes)

Global programmes

Working Group 4 saw the large global programmes as key players also in the future. However, further integration is needed between them.

Global programmes need participation and funding from as many countries as possible. Better interaction with national funding agencies is needed regarding national research funding priorities, funding of international projects offices, and “glue funding”.

Integrated impact assessment

Concerning integrated impact assessment, it is important to take a much broader approach than that of only environmental research. Increased focus on interdisciplinary research is needed between the natural and social sciences, between different disciplines of natural sciences, and between different disciplines of social sciences.

Within the framework of integrated assessment the concept of “vulnerability” might be exmined. In this respect policy relevance, adaptation and mitigation measures, extreme conditions and multiple stresses are important matters to be considered in depth. Societal aspects are very often drivers, therefore it is necessary to have a sufficient emphasis on social science. Because of different conditions in different regions, a regional approach might be more appropriate (for example, the Mediterranean, Arctic etc.). The participation of researchers from countries that are more “vulnerable” should be facilitated.

The more integrated the research is, the more time is needed for planning and implementation.

Important questions are: (1) What amount of resources is needed for integrated global research? (2) How could European countries and organisations contribute?

Cooperation between funding agencies and researchers

Significant barriers are:

- complexity of the different national peer review processes;
- different funding priorities;
- national research councils fund mainly national researchers.

General measures for stimulating international collaboration:

- overseas fellowships;
- fellowships for visiting researchers;
- give priority to projects with international collaboration in several programmes;
- give grants for networking and formulation of EU-proposals.

European region

It is very important that the European region has enough research capacity to participate in global programmes. Furthermore, it is necessary to have capacity to carry out high quality independent assessments, namely to assess the reliability of estimates and claims from other actors.

The ESF instrument, EUROCORES, may also be a promising mechanism for funding global change research.

Basic research must be considered in a flexible way, this means that strategic problem-solving and policy-related research in many cases might be relevant.

The following questions need to be considered: (1) What power do we want to give to ESF? (2) What are the benefits of working internationally?

A member of the group came up with the idea that a European strategy for sustainable development should be developed. In this respect, the following questions are interesting: How to translate the general aspects of sustainable development into concrete recommendations, actions and requirements? If such a strategy were to be developed, a thorough discussion between researchers and policymakers would be necessary. The group did not pursue this idea beyond this.

There is a need to develop new mechanisms for regional collaboration between funding agencies regarding priority setting and mechanisms for joint programme funding (for example, putting money into a common pot).

International cooperation, such as participation in international programmes or cooperation on a bilateral basis, should be regarded as a positive in national funding decisions. A mechanism is needed to convince national agencies that participation in international programmes is a high quality proof. It should be mentioned that the Research Council of Norway, Division of Environment and Development, makes international cooperation one of the criteria when taking the final decision on a project.

ESF could be used as a platform for discussion and creation of new ideas.

Working Group 5: Programme development on a European scale: institutional barriers to a European approach and the roles of European organisations, including ESF

(Chair: Eckart Ehlers; Rapporteur: Christoph Ritz)

Background

At the Rio Conference the policy makers recognised a series of pressing global change issues. The key threats can be addressed only on a global scale for two reasons: first because of the complexity of the problems; and second because the impact is global and often little dependent on an individual country's contribution to the cause of the threat.

The science community has initiated several Earth System science research programmes to address these global problems. The most important international research programmes are the World Climate Research Programme (WCRP), the International Geosphere-Biosphere Programme (IGBP), the International Human Dimensions Programme on Global Environmental Change (IHDP) and the International Programme of Biodiversity Sciences (DIVERSITAS).

General barriers

The national and continental structures focus primarily on their specific country or region and are thus generally not well suited to address overarching issues in a coordinated way. At present in Europe there is no active intermediate body to bridge the national or regional interests and the global view. Based on such arguments Working Group 5 suggested the following actions.

The ESF and the international programmes and data providers

Europe must be concerned and take on responsibility for global change issues. The ESF is recognised as an independent body both by the national agencies and the European Union. It is thus a perfect European structure to act as platform between national, EU, and international structures.

1. The ESF should formally endorse the four international Earth System sciences research programmes WCRP, IGBP, IHDP and DIVERSITAS.

2. The ESF should form a dedicated global environmental change committee to:

- interact with the international programmes;
- interact on a regional level within Europe;
- make a bridge between research and users on a European scale.

Being aware of the deep changes that such a committee poses for the ESF structures, we suggest an intensive study as to how such a key committee can be realised. It is very clear that such a committee cannot be integrated into the existing disciplinary structures of the ESF.

The ESF and national research councils and the European Union

European research on global change and its regional impact must be strengthened.

3. The ESF should play a coordinating role and act as a mediator between existing European funding structures:

- by bringing together research council members of the individual countries in a forum where they can informally discuss issues of common interests;
- to inform about ongoing programmes and activities. The ESF could play an active role as an information platform (regional assessments and synthesis activities on specific topics, workshops on specific topics involving scientists and users etc.);
- to enhance cooperation and coordination;
- to stimulate new, complementary regional or topical programmes. Global environmental change research is moving strongly in the direction of integrative, place-based

(regional) studies and these programmes are typically not confined by national boundaries.

What are the institutional barriers for an active ESF performance?

The largest budgets on environmental issues are spent by governmental agencies.

4. The ESF should interact with government agencies at the EU or national level to:

- promote key research issues on global change;
- help to formulate the EU research agenda;
- ensure the scientific quality. The scientific quality of integrative projects is difficult to evaluate, since many disciplines are involved. The ESF should assess appropriate evaluation mechanisms jointly with the EU and the national funding structures.

5. The ESF should stimulate cooperation between European researchers, as the quality of integrative research projects strongly depends on the scientists involved.

Other issues

Capacity building

Young scientists and researchers from the eastern Europe and developing countries must have a medium- or longer-term perspective in conducting research on global change issues.

6. The ESF is urged to develop mechanisms to support and incorporate young researchers as well as scientists from the eastern Europe and developing countries into global change research activities such as:

- summer schools, workshops;
- participations in longer-term research projects (for example, integrated regional activities, and flagship activities).

Regional assessments

7. The ESF should conduct place-based scientific assessments on a regional scale to complement global assessments such as the IPCC Ozone and Biodiversity Assessments.

Working Group 6: Programme development at the European level: institutional barriers to a European approach, and roles for European organisations, including ESF

(Chair: José Moreno; Rapporteur: Paul Leadley)

Working Group 6 identified a number of ways in which the ESF and other European organisations could facilitate global change research:

1. The ESF should find a way to help coordinate and/or promote European "glue funding" for the international global change programmes. The lack of coordinated funding for the global change programmes in Europe (namely, WCRP, IGBP, and especially for IHDP and DIVERSITAS) poses considerable problems in fundraising. Currently, there appears to be a number of obstacles to greater ESF participation:

- a lack of awareness of global change programmes in the ESF;
- "glue funding" for global change programmes is often seen as an overhead; namely, money that would be better spent on research. It was noted that the percentage of money spent in this way on global change programmes was a very small fraction of the total amount of funding on global change research;
- significant gaps remain between national and international objectives concerning global change research.

Several concrete measures could improve the visibility of global change programmes in the ESF and perhaps lead to coordinated funding.

- There was strong agreement that the ESF should set up a standing committee on global change. This would improve the visibility of global change research within the ESF and provide a framework within which coordinated European efforts on global change research could be discussed.

- "Glue funding" should perhaps be re-named "added value" funding to help overcome the idea that money spent on global change programmes is an overhead. While this change may appear cosmetic, the idea that funding of international coordination of global change research adds considerable value to individual national research programmes is expressed very poorly by the term "glue funding".
- The ESF should play a more active role in promoting dialogue between national funding agencies, the EU, and the four global change programmes.

2. The ESF and other European organisations should help to establish major integrative global change research projects; namely, develop transdisciplinary studies that link research on climate, biogeochemical cycles, biological diversity, and the role of man in global change. It was suggested that integrative research could be fostered by bringing together experts from various fields of research to study global change problems within a given location. For example, regional global change studies of Mediterranean ecosystems and Arctic/boreal ecosystems fit the objectives both of the global change programmes and the EU Framework Programme. For the EU such programmes could help to bridge North-South gap (by bringing European researchers together to study the Mediterranean region) and East-West gaps (by bringing European researchers from these areas together to study the Arctic/boreal region). In addition, regional programmes would build on existing European research initiatives (for example, the RICAMARE programme for the Mediterranean Basin). One possible mechanism by which the ESF could promote this kind of research would be to take the ESF European Social Survey Programme as a model.

3. The ESF and other European organisations should strive to increase the stability of funding and to reduce the complexity of funding instruments.

- Global change research requires stable, long-term funding because many of the questions being asked can be answered only by long-term observations and long-term experiments. Large gaps in funding, especially at the EU level, pose serious problems in maintaining high quality research programmes
- The ESF and, in particular, the European Commission should think about ways to significantly reduce the number and complexity of existing funding instruments. While some new instruments may be necessary, considerable caution should be exercised before launching new instruments.

4. The ESF should make efforts to increase the involvement of non-OECD countries in global change research. One possible mechanism would be to strongly reinforce and, perhaps, re-think programmes such as ENRICH.

5.3 Overview of national programmes

Rapporteur: Tony Mayer
European Science Foundation

This section is based on a series of brief statements about global change research architecture and programmes taking place at the national level, principally through ESF Member Organisations. Contributions covered the situation in the Czech Republic, Denmark, Estonia, Finland, Germany, Italy, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

Europe has a considerable diversity in its research funding structures that is reflected in the various support mechanisms for global change research. Given the links to policy development, global change research is also supported directly by ministries in addition to that funded by grant agencies and national research organisations (the ESF Member Organisations).

For the most part, global change research is funded through the normal mechanisms available to those agencies, usually through competitive, peer-reviewed, responsive mode mechanisms. However, in some countries and agencies, specific thematic programmes have been created with earmarked funding (in which the competitive, peer-review selection takes place). There are examples of overall national programmes bringing together all interested agencies and ministries, for example Finland. In other cases, there may be declared agency initiatives that may also encompass activities in other agencies in the same country, for example the UK.

The foci for the research effort are also rather diverse. Naturally, there is a regional emphasis in many programmes. For example, countries in Scandinavia tend to concentrate on Arctic and sub-Arctic phenomena, including Greenland. In the Nordic case, there is also a regional coordination developed through the Nordic Council mechanism.

Interdisciplinary programmes are generally difficult to plan and implement even in the case of multidisciplinary agencies, such as those in the Netherlands and Germany.

The degree of coherence and national focus is highly variable although all the European countries have either overall global change committees or national committees contributing to the overall coordination efforts of the global programmes organised through the ESSP.

There are also significant investments by national agencies in the international project offices of the major global programmes although there is no overall coherent European approach to such support. Each project office is supported in accordance with national or agency priorities. There is a considerable infrastructure investment through research vessels, satellite instrument development, aircraft, polar facilities (both Arctic and Antarctic), long-term monitoring sites, and databases. However, such investment is again determined by national priorities, including, in the case of polar studies, political priorities.

The picture that emerges is one of a substantial total investment in all aspects of global change research involving national research organisations and the universities. Where there is research investment planning, funding decisions are taken in response to local (namely national) priorities or are left to the regular responsive mode competition system.

Appendix 1:

ESF Forward Look on Global Change Research

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- **Bert Bolin**
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- **David Carson**
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- **Uno Svedin**
  FORMAS, Sweden
- **Hansvolker Ziegler**
  BMBF, Germany, representing the International Group of Funding Agencies (IGFA)
- **Tony Mayer**
  European Science Foundation (Secretary)

Appendix 2:
Forward Look symposium programme

Session I

09.00 **Welcome and Opening** by Host Country representatives
Professor Enric Banda – ESF Secretary General
Ambassador Bo Kjellén, Ministry for the Environment, Sweden and President of the FORMAS Board
Professor Lisa Sennerby-Forsse – FORMAS
Professor Pär Omling – SRC

09.35 **Outline of the programme and expected outputs**
by Dr. John Marks, Chair of the Forward Look Steering Committee
Chair: Enric Banda

09.50 **Keynote address: Science for Sustainable Developments**
by Professor Bert Bolin
Discussion *Chair*: Enric Banda

Session II

11.00 **Presentations of the science cases**, by "writing teams"
Chair: Jean Jouzel
Carbon: Colin Prentice and Liliane Merlivat
Water: Hartmut Grassl and Pavel Kabat
Food and Fibre: John Porter, John Ingram and Jill Jaeger
Industrial Transformation: Stefan Anderberg and Josef Sejak

14.00 Presentations of the science cases (cont.), by "writing teams"
Chair: Eckart Ehlers

Biodiversity: Carlo Heip, Christian Levêque and Andreas Troumbis
Climate Variability and Change: Brian Hoskins and Jürgen Willebrand
Role of Monitoring in Global Change: John Woods
Linking research and policy development: Uno Svedin

16.10 *Policy relevance and policy support in the EU Framework Programme:* Christian Patermann
European Space Agency (ESA): Einar-Arne Herland
European Centre for Medium-Range Weather Forecasts (ECWMF): David Burridge
European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT): David Williams *Chair*: Tony Mayer

17.15 General Discussion

18.00 **Invited Lecture: The astronomical theory of palaeoclimates: does it matter for sustainable development?** by Professor André Berger, European Latsis Prize winner 2001 *Chair*: Tony Mayer

Session III

Presentations by European Institutions and Organisations

Thursday 31 January 2002

Session IV

09.00 *Presentations of the international programmes by World Climate Research Programme (WCRP):* Peter Lemke

International Geosphere-Biosphere Programme (IGBP): Will Steffen

International Human Dimensions Programme on Global Environmental Change (IHDP): Jill Jaeger

International Programme of Biodiversity Science – DIVERSITAS: Anne Larigauderie

Chair: Marie-Lise Chanin

Session V

11.30 Development of an Integrated Research Plan for Europe - Working Groups 1, 2, 3

Natural sciences–social sciences interfaces and collaboration: Chair: Leen Hordijk

Infrastructure and monitoring Chair: Anders Lindroth

Research–policy interface Chair: Mike Hulme

Session VI

14.00 Plenary: Report from Working Groups1, 2, 3 Chair: Chris Rapley

14.30 The institutional and structural requirements for implementing a European integrated effort and possibilities for meeting these requirements. Panel chaired by J. Marks with a representative of the international global change programmes and of EC, ESF and other institutional capabilities (Anver Ghazi, Tony Mayer, Will Steffen)

15.00 Working Groups 4, 5, 6: all three addressing programme development on a European scale: institutional barriers to a European approach and the roles for European organisations, including ESF

Chairs: Arne Jernelöv, Eckart Ehlers and José Manuel Moreno

17.00 Plenary: Report from Working Groups 4, 5, 6 Chair: Chris Rapley

Friday 1 February 2002

Session VII

09.00 Presentations from national programme managers of national programmes on current national activities and mechanisms for internationalisation of national programmes and from Euro IGFA *(To date: Czech Republic, Finland, Germany, Italy, the Netherlands, Norway, Portugal, Sweden and the UK)* Chair: Hansvolker Ziegler

Session VIII

11.30 Final plenary discussion: summary, conclusions, actions and closure

Chair: John Marks

Appendix 3:
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Appendix 4:

List of acronyms

ACC _______ Anthropogenic Climate Change
ACSYS _____ Arctic Climate Systems Study
AIRS ______ Atmospheric Infra-Red Sounder
AMS _______ Accelerator Mass Spectrometry
AUV _______ Automated Unmanned Vehicles
AVHRR _____ Advanced Very High Resolution Radiometer
BAHC ______ Biological Aspects of the Hydrological Cycle (IGBP)
CarboEurope Cluster of projects to understand and quantify the ESA mission to monitor the carbon balance of Europe
CARBOSAT _ ESA mission to monitor the carbon cycle
CAVASSOO Carbon Variability Studies by Ships Of Opportunity
CBD _______ Convention on Biological Diversity (UN)
CEOP ______ Co-ordinated Enhanced Observing Project
CIESIN _____ Center for International Earth Science Information Network
CITES ______ Convention on International Trade in Endangered Species of Wild Fauna and Flora
CLIC _______ Climate and Cryosphere Project
CLIMAG ____ Climate Prediction on Agriculture
CLIVAR _____ Climate Variability and Predictability Study (WCRP)
COST ______ European Co-operation in the field of Science and Technology Research
CRYOSAT __ ESA radar altimetry mission to measure ice sheet thickness
CSE _______ Continental Scale Experiments
DecCen ____ Decadal to Centennial Variability
DIVERSITAS _ International Programme of Biodiversity Science
DOC _______ Dissolved Organic Carbon
EAP _______ Environment Action Programme (EU)
EarthCARE __ Earth Clouds, Aerosols and Radiation Explorer (ESA)
EC ________ European Commisssion
ECMWF ____ European Centre for Medium-range Weather Forecasts
ECN _______ Environmental Change Network
EEZ _______ Exclusive Economic Zone
EFI ________ European Forest Institute
EFTA _______ European Free Trade Association
ENBI _______ European Network for Biodiversity Information
ENRICH ____ European Network for Research in Global Change
ENSO ______ El Niño -Southern Oscillation
ENVISAT ___ ESA Advanced polar orbiting Earth observation satellite
EPBRS _____ European Platform for Biodiversity Research Strategy
EPICA ______ European Project for Ice Coring in Antarctica (ESF)
EPS _______ EUMESTAT Polar Satellite
ERA _______ European Research Area
ERS _______ European Remote Sensing (ESA)
ESA _______ European Space Agency
ESCOBA ___ European Study of Carbon in the Ocean, Biosphere and Atmosphere
ESF _______ European Science Foundation
ESSP ______ Earth System Science Partnership
EU ________ European Union
EUMESTAT __ European Organisation for the Exploitation of Meteorological Satellites
EuroCLIVAR _ European Climate Variability and Predictability Study
EUROCORES ESF Collaborative Research Programmes
EuroGOOS _ European Global Observing Systems
EUROSTAT __ Statistical Office of the European Communities
EUROTROPH Nutrient Cycling and the Trophic Status of Coastal Ecosystems (EC)
EuroWOCE _ European component of the World Ocean Circulation Experiment
FACE ______ Free Air Carbon Dioxide Enrichment
FAO _______ Food and Agriculture Organization (UN)
FCPS ______ Food Consumption and Production Systems
FORMAS ___ Swedish Research Council for Environmental, Agricultural Science and Spatial Planning
FOV _______ Field Of View
FRAM ______ Fine Resolution Antarctic Model
GAIM ______ Global Analysis, Interpretation and Modelling (IGBP)
GARP ______ Global Atmospheric Research Programme
GBIF ______ Global Biodiversity Information Facility
GCC _______ Global Change Committee (proposed)
GCOS _____ Global Climate Observing System
GCOS _____ Global Observing System for Climate
GCP _______ Global Carbon Project
GCTE ______ Global Change and Terrestrial Ecosystems
GEC _______ Global Environmental Change
GECAFS ___ Global Environmental Change and Food Systems
GECHS ____ Global Environment Change and Human Security
GEF _______ Global Environmental Facility
GEWEX ____ Global Energy and Water Cycle Experiment (WCRP)
GLOBEC ___ Global Ocean Ecosystem Dynamics (IGBP)
GLOWA ____ Global Change in the Hydrological Cycle
GM ________ genetically modified
GMBA _____ Global Mountain Biodiversity Assessment
GMES _____ Global Monitoring for Environmental Security
GOALS ____ Global Ocean-Atmosphere-Land Systems
GOCE _____ Gravity Field and Steady-State Ocean Circulation mission (ESA)
GODAE ____ Global Ocean Data Assimilation Experiment
GTOS _____ Global Terrestrial Observing System
IAMAS ____ International Association of Meteorology and Atmospheric Sciences
IAPSO ____ International Association of Physical Sciences of the Ocean
IASI _______ Infrared Atmospheric Sounding Inferometer (ESA)
IBOY ______ International Biodiversity Observation Year

ICAO	International Civil Aviation Organisation
ICES	International council for the Exploration of the Sea
ICSU	International Council of Scientific Unions
IDGEC	Institutional Dimensions of GEC
IGAC	International Global Atmospheric Chemistry (IGBP)
IGBP	International Geosphere-Biosphere Programme
IGOS	Integrated Global Observing Activity
IGOS	Integrated Global Observing Strategy
IHDP	International Human Dimensions Programme on Global Environmental Change
IIASA	International Institute for Applied Systems Analysis
INCO	Industrial cooperation Component of the EU Framework Programme
IOC	Intergovernmental Oceanography Commission (UNESCO)
IPCC	Intergovernmental Panel on Climate Change
IPO	International Project Office
IRONAGES	Iron Resources and Oceanic Nutrients. Advancement of global Environment Simulations (EC)
ISLSCP	International Satellite Land-Surface Climatology Project (GEWEX)
ISSC	International Society of Scientific Councils
IT	Industrial Transformation project (IHDP)
IUBS	International Union of Biological Sciences
IUMS	International union of Microbiological Societies
JGOFS	Joint Global Ocean Flux Study
LBA	Large-scale Biosphere-Atmosphere experiment in Amazonia
LOICZ	Land–Ocean Interactions in the Coastal Zone
LUCC	Land-Use Land-Cover Change (IGBP)
MAMA	Mediterranean network to Assess and upgrade Monitoring and forecasting Activity in the region
MARS	Marine Research Station
MAST	Marine Science and Technology programme
MERIS	Medium Resolution Imaging Spectrometer
MetOp	Meteorological Operational satellite (ESA)
MISR	Multi-angle Imaging SpectroRadiometer
MODIS	Moderate Resolution imaging Spectroradiometer
MSG	Meteosat Second Generation
NASA	National Aeronautics and Space Administration
NGO	Non-Governmental Organisation
NMS	National Meteorological Services
NOAA	National Oceanic and Atmospheric Administration
NOCES	Northern Ocean Carbon Exchange Study (IGBP)
NWO	Netherlands Organisation for Scientific Research
NWP	Numerical Weather Prediction
OBIS	Ocean Biogeographical Information System
OCO	Orbiting Carbon Observatory
ODP	Ocean Drilling Program
OECD	Organisation for Economic Cooperation and Development
ORFOIS	Origin and fate of biogenic particle fluxes in the ocean and their interaction with atmospheric CO_2 concentration as well as the marine sediment
OSSE	Oriented Scintillation Spectrometer Experiment
PAGES	Past Global Changes (IGBP)
PBL	Planetary Boundary Layer
PRISM	Parameter-elevation Regressions on Independent Slopes Model
SAF	Satellite Application Facility
SBSTTA	Subsidiary Body on Scientific, Technical and Technological Advice
SCIAMACHY	scanning imaging absorption spectrometer for atmospheric instruments on ENVISAT
SCOPE	Scientific Committee on Problems of the Environment
SD	Sustainable Development
SeaWIFS	Sea-viewing wide field of view sensor (NASA)
SEI	Stockholm Environmental Institute
SME	Small and Medium Enterprise
SMOS	Soil Moisture and Ocean Salinity
SOLAS	Surface Ocean Lower Atmosphere Study
SPARC	Stratospheric Processes and their Role in Climate (WCRP)
SRES	Special Report on Emission Scenarios
SST	Sea-Surface Temperature
START	Global Change System for Analysis, Research and Training
SWIFT	Stratospheric Wind Interferometer for Transport Studies (ESA)
TIROS	Television Infrared Observational Satellite program (NASA)
TOA	Top Of the Atmosphere
TOGA	Tropical Ocean and Global Atmosphere project
TOVS	TIROS Operational Vertical Sounder (NOAA)
UAV	Unmanned Airborne Vehicles
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
VAMOS	Variability of the American Monsoon System
VOC	Volatile Organic Compound
WALES	Water Vapour Lidar Experiment in Space (ESA)
WCRP	World Climate Research Programme
WGCM	Working Group on Coupled Modelling (WCRP)
WGNE	Working Group on Numerical Experimentation
WMO	World Meteorological Organization
WOCE	World Ocean Circulation Experiment

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