Special Issue on Past Global Changes

Past Global Changes and their Significance for the Future

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The majority view of informed scientists is that human activities, by increasing the concentration of greenhouse gases in the atmosphere, will have a discernible influence on global climate in the next century. The magnitude and nature of this impact is still hard to estimate, but whatever the impact, it will develop within the context of natural variability as revealed in the record from the past. Even if our future climate is less modified by human activity than is currently anticipated, it will not remain constant. Natural climate variation has occurred and will continue to occur on all timescales. It affects people and their livelihoods in ways that are still hard to predict and plan for. Research designed to document and understand the course of past climate variation, its causes, regional expression and consequences is thus of fundamental importance.

Among the needs of decision makers concerned with future global changes and their impacts on human society are the following:

- a range of possible future scenarios that are consistent with both empirical evidence and theory. These scenarios need to be articulated at global, regional, and preferably national and local levels so that they can form a framework for decision making;
- an increasingly realistic assessment of the balance of probabilities within the range of scenarios presented;
- some indication of the potential rates of change under realistic forcing and feedback conditions;
- a robust framework within which to assess the possible future resource implications both of predictable trends and of changes in the magnitude and frequency of extreme events such as severe droughts or floods.

None of these needs can be met without recourse to the past. This issue of *The Globe* provides readers with an overview of the variety of ongoing research activities that contribute to our knowledge of palaeoclimatic conditions and examines their relevance to future predictions.

PAGES (Past Global Changes)

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PAGES (Past Global Changes) is one of the core projects of the International Geosphere-Biosphere Programme (IGBP). PAGES seeks to obtain and interpret a variety of palaeoclimate records and to provide the data necessary to validate predictive models. PAGES has identified specific criteria for its activities and it applies these to evaluating and prioritising research within two *time-streams:*

- The main focus is on continuous, high resolution records, with annual to decadal time resolution for Stream I studies (the last 2000 years), and decadal to century scale resolution for Stream II studies (the last 200k years).
- All studies using proxy records emphasise chronology, in order to obtain the most complete, accurate and precise dating control possible for each data set.
- Proxy records for palaeoclimate must be calibrated as rigorously as possible so as to provide unambiguous, and wherever possible, quantitative reconstructions. This implies linking palaeo-research to contemporary monitoring and experimentation.
- Wherever possible, multi-proxy studies should be carried out, both to maximise the information retrieved from a site and to provide mutually independent constraints on palaeoenvironmental inferences.
- Priority is given to research on sites most likely to provide diagnostic evidence for changes in large-scale sub-systems of climate; increasingly, global syntheses and insights into global processes arise from the demonstrable coherence between diverse and widely separated palaeo-environmental archives.
- Where appropriate, special attention is given to the influence of human activity on the environment, especially where the combination of anthropogenic impacts and climate change have created vulnerable habitats, or where the challenge of disentangling human from natural effects is of critical importance.
- Special attention is be paid to the requirements for rigorous data-model intercomparisons.
- All PAGES data will ultimately be archived in the World Data Center for Paleoclimatology in order to provide access to and interchange of information to interested scientists.

The goals of the focussed research agenda growing out of the priorities outlined above include:

- **reconstructing the history of natural climate forcing mechanisms and their effects.** Links between forcing mechanisms such as solar variation and volcanic activity and the responses they generate in the Earth's climate must be established through studies of past events, as well as modelled and explained in theoretical terms. These natural forcing processes will interact with any anthropogenic effects. We need to know much more about how natural forcing mechanisms have affected past climate before we can assess their future significance.

- **documenting the internal dynamics and feedbacks that modulate climate changes on the timescales of seasons to centuries.** These too will interact with and modify any human-induced changes that may occur. They often involve complex leads and lags that can only be explored in the evidence from sources such as tree rings, corals, ice cores and sediments that allow us to reach beyond the short time span of instrumental records. They affect the way in which we interpret present day trends and they will strongly affect the course of future changes. To predict their future impacts, we need to greatly improve our knowledge of their patterns and amplitudes in the past.

- **providing data for developing, testing and validating climate models.** Model simulations of the Earth's climate system often highlight particular areas and processes of key importance for improving their validity and predictive power. This in turn requires that evidence from the past be refined in order to test the models against reconstructed past conditions. Models form one of the major links between science and decision making. To be fully effective in simulating future climates, models need testing under boundary conditions unlike those of the present. Unless models can achieve an adequate level of realism in simulating past climate conditions, their performance in predicting future conditions will remain less certain than decision makers would like. Working with the modelling community is one of the key roles of PAGES. Many past climate changes are global in their effects and can be traced as simultaneous responses in both hemispheres and from the equator to the poles; but the way these changes are expressed varies greatly from place to place. The challenge for PAGES is to understand the global mechanisms and document the regional effects. Both are vital for model development and validation, hence for reducing uncertainties in future prediction.

- **refining our knowledge of the past role of greenhouse gases during rapid warming episodes.** The parallel trends in past global temperature, atmospheric carbon dioxide and methane concentrations, as revealed in ice core records, provide one of the most dramatic arguments in favour of future greenhouse gas warming, but the precise phasing of and the processes reponsible for the parallel changes in temperature and gas concentractions need to be more fully understood before the future implications can be confidently established. Only the historical record contains the evidence needed to resolve these crucial issues.

- **estimating the probability of major instabilities in the Earth system under warm climate conditions.** It is now clear that the Earth's coupled ocean-atmosphere system has been highly unstable in the recent geological past, with massive swings of ocean circulation and associated dramatic changes in climate taking place over the space of a few decades at most. Even though such dramatic *'switches'* are more typical of cool, glacial times, there is growing evidence that they cannot be excluded from the range of future possibilities in a warming world. Many lines of evidence from sources as diverse as tree rings and sediments show that even during the warm period since the last glaciation - *the period we live in now* - climate varied over a much greater range than instrumental records would lead us to believe. There is also growing evidence for sudden, major changes in climate during the warm period before the last glaciation, the Eemian Interglacial. All these warm climate fluctuations need much fuller investigation, since they may hold part of the key to estimating the likelihood of similarly dramatic changes in the near future, changes that would have human consequences well beyond the range of recent experience.

- **documenting the impact of past environmental changes on human resources and activities.** The record of the past contained in historical documents, sediments, peats and the like is rich in illustrations of the ways in which climate change and human activity have been closely interwoven. It is not a simple story, for the impact of climate variation through extreme events for example, is often in part a function of the pattern of human resource use at the time. Human activities create the canvas upon which climate variation expresses its consequences for people, their welfare and their very survival. One of the responsibilities of PAGES is to improve our understanding of these interactions so that future resource management and environmental policy can learn from the lessons of the past.

These areas of PAGES science will be addressed in the forthcoming PAGES Open Science Meeting to be held in the UK in the University of London, Senate House, April 20 - 23 inclusive, 1998. Goals of the Meeting are to present the 'state-of-the-art' in these vital research areas, to identify the most urgent future challenges for all those involved in PAGES activities and to optimize the response of PAGES-related Science to the needs of decision makers, especially in the areas of natural hazards, environmental planning and resource management.

Academic co-sponsors of the Meeting are the Environmental Change Research Centre, University College London and the Centre for Quaternary Research, Royal Holloway, University of London.

Further information and updates on plans for the Meeting are available from:

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What can we learn from the last episode of rapid global warming (at the Pleistocene-Holocene transition) about the mode of operation of global climate changes?

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The recent publications of the **IPCC** (Intergovernmental Panel on Climate Change) have raised awareness about the sensitivity of the Earth's climate to natural internal and external influences, the role of humans in altering the delicate, balance of atmospheric gas ratios, and likely scenarios of the way global climate may change over the next 50 to 100 years (*Houghton et al.*, 1995). While not ignoring the longer-term perspective, the focus of the IPCC's attention has nevertheless been fixed mainly on the short-term climate variability of recent centuries, and on the modelling of these variations under present-day global *'boundary conditions'*. The need for a longer temporal perspective, however, is vital, for climate changes in the past have often been exceedingly abrupt, and the history of global climate change in the recent past is much more complex than was realised even a decade ago.

We live in an*'interglacial'* geological episode, a period of relative warmth that has persisted for at least 10,000 years. It is the latest in a series of interglacial stages which, over the past two million years or more, punctuated much longer episodes of generally cold conditions, termed *'glacial'* stages. The gradual, cyclical fluctuations are best explained by the *'Milankovitch Hypothesis'*, which is the notion that long-term global climatic changes are driven by variations in solar radiation received by the Earth, which in turn are caused by the gravitational motions of the Sun and planets. In recent years, however, and particularly within the last decade, there has been a growing conviction among the scientific community that more frequent and much shorter-term climate *'pulses'* have also occurred, certainly within the last 130,000 years, as irregular phenomena superimposed on the more gradual Milankovitch trends. Evidence obtained over the last decade or so from deep-ice cores from the polar ice caps, as well as from high-resolution ocean sediment cores recovered from the floor of the Atlantic Ocean, suggests that global climate can *'flip'* quite suddenly between markedly cold conditions and conditions akin to those of the present day, occasionally within less than a century. Such changes, referred to as *'Sub-Milankovitch variations'*, since they cannot be explained by the known astronomical (gravitational) effects, vary in duration between approximately 500 and 2,000 years.

The duration of interglacial stages that preceded the present one appears to have averaged between about 10,000 and 14,000 years, and thus there has been much speculation about how much longer the present interglacial will run. Two other fundamental questions are presently giving rise to vigorous debate. First, do interglacial stages wane gradually, to usher in cold, *'glacial'* stages, or can they terminate abruptly? Some scientists argue for the latter, and point to the possibility that, even during an interglacial period, global climate can jump to a different mode of operation within less than a century (*eg, Broecker*, 1997; *Adkins et al*, 1997), with potentially disastrous consequences. Secondly, what scale of climate variability is possible during an interglacial episode? Until very recently it was generally believed that interglacials were fairly stable climatic episodes, subject only to minor fluctuations. This view is increasingly being challenged, at least as far as those interglacials that pre-date the present one are concerned. These appear to have experienced dramatic, very short-lived cold spells, much more extreme than anything detectable in the record for the present interglacial (*GRIP*, 1993; *McManus et al*, 1994). It seems, therefore, that we live in an atypical period, and there is much speculation as to whether the subdued climate variability of the past 10,000 years reflects human intervention in, or modulation of, natural chemical cycles, which, in turn, affect global climate variations.

Two of the biggest challenges the scientific community now has to meet are: (i) establishing the causes of sub-Milankovitch climatic variations, and

(ii) determining the degree to which they are predictable.

These are daunting tasks, however, for two reasons. *First*, a number of processes are thought to have had an influence on such abrupt climatic variations, including *for example*, oceanic circulation, the dynamics of the polar ice sheets, atmospheric gas ratios and dust content, the biomass of the oceans and continents, volcanic activity and solar output. Changes affecting several, or all, of these processes are likely, of course, to operate in close harmony and to be co-dependant, and hence determining which, if any, of these mechanisms was the primary *'trigger'* initiating abrupt climate changes may prove to be an arduous exercise. Secondly, the rate of climatic change that appears to have operated during some of the sub-Milankovitch events is beyond the resolving power of most of the common geological dating methods, with a few exceptions, where exceptional circumstances prevail.

It is therefore difficult to establish the precise *'order of play'* of changes affecting, inter alia, ice sheets, oceans, global biomass, the atmosphere and the global climate system. The *'chicken-and-egg'* dilemma pervades the literature that is concerned with this topic.

The period that offers the best opportunity for resolving some of these issues is the period of transition between the last glacial stage and the present interglacial, known as the Pleistocene-Holocene transition, which dates approximately to between 18,000 and 10,000 years ago. During that period, and as a consequence of a significant rise in global temperature, the surface of the world changed dramatically, with a substantial reduction in the volume of polar ice, a rise of sea level of the order of 120m or more, and major redistributions of terrestrial biomes, as well as adjustments in global biomass. These changes were not unidirectional, however, but were subject to a number of feed-back loops. *For example*, global warming would have led to shrinkage of the polar ice caps, but the sudden influx of cold meltwater resulting from this process would have cooled ocean surface waters, at least temporarily. This, in turn, may have induced more widespread cooling and even (almost paradoxically) to temporary expansions of the ice masses. It is possible to reconstruct such feed-back loops, and to examine the inter-connectivity between the oceans, atmosphere, continents and global climate, in much more precise detail for the Pleistocene-Holocene transition than for any other geological period. That is why a number of major, international research initiatives have been launched which focus especially on the Pleistocene-Holocene transition. UK scientists are playing leading roles in these initiatives, of which two are cited below as examples.

- The Natural Environment Research Council's (NERC) North East Atlantic Palaeoceanography and Climate Change (NEAPACC) Special Topic was launched in 1992 to examine the pivotal role that the North-east Atlantic appears to have played in the *'oceanic conveyor system'*, which is one of the mechanisms thought to be responsible for at least some sub-Milankovitch climatic perturbations. Some of the results of this programme will be presented at the GEOSCIENCE '98 Conference to be held at Keele, UK in April 1998 and at the International Conference on Satellites, Oceanography and Society to be held in Lisbon, Spain in August 1998 (*see Diary Dates this issue of The Globe for more information*). This programme forms a major contribution to the international effort directed to an understanding of the role of the oceans in the global climate system. Details of the NEAPACC Special Topic can be obtained from:

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- NERC has also sponsored the TIGGER Special Topic, which focused on climatic variability on the continents, and especially those affecting the British Isles. A brief outline of the TIGGER project follows this article. The results of both the NEAPACC and TIGGER Special Topics which have a bearing on events that occurred during the Pleistocene-Holocene Transition are also being fed into the INTIMATE project, one of the major projects of the International Union for Quaternary Research (INQUA) Palaeoclimate Commission. The remit of this project is the synthesis of ice-core, marine and terrestrial data which span the Pleistocene-Holocene transition, the object being to improve our understanding of the nature of climate variability in the North Atlantic region during that period. Results of this program will be presented at the INQUA Congress to be held in South Africa in 1999. Details of the INTIMATE project can be obtained from:

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For general background:

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TIGGER - An Overview

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If we want to understand what the climate will be like in the future, we need to understand how it has changed in the past. The geological record of environmental change over the last two million years helps us to understand the processes driving such changes, and the rate at which they happened in the past. Over the past four years, a Natural Environment Research Council (NERC) programme known as TIGGER has been looking at the geological dimension of environmental change. TIGGER studied geological aspects relevant to NERC's TIGER (Terrestrial Initiative in Global Environmental Research), hence the extra G in its name. This article describes the four elements of TIGGER.

Sahel

The sub-Saharan Sahel savannah is uniquely sensitive to climate change, and of course particularly to changes in rainfall. Since the late 1960s it has suffered one of the most persistent droughts in the entire global meteorological record. Three aspects of the region formed the core of the research:

- a study of groundwater and its chemical and isotopic composition:
- research on lake sediment cores; and
- research on wind-borne sediments.

These three records of change combine to give a sobering picture of events over the last 2000 years.

TIGGER has shown that the present drought is not unique. A major shift to a more drought-ridden regime around 1,500 years ago led to a severe drought, between 1,200 and 1,000 years ago, and appears to coincide with a similar drought in Central America which led to the collapse of the agricultural economies of that region. Lowering of the water table near Lake Chad results from extracting *'fossil'* water, largely accumulated before the last ice age and not adequately restored during wet phases of the last 10,000 years. Obviously engineering projects which extend this *'water mining'* do not offer a long term solution to water supply in the Chad area.

The Sahel project involved workers in seven British universities and two NERC institutes. The project was led by Professor A Street-Perrott (Swansea University, UK) and Dr W M Edmunds (British Geological Survey).

Britain

Because we cannot measure past climate directly, we rely on a variety of *'proxy'* climate measures. A second element of TIGGER tested how well these indicators record environmental change in Britain over the last 2,000 years. Proxies range from lake sediment - and microscopic plant and animal fossils contained in them - to the nature and composition of upland peats. Peat contains a record of the water table, which controls the decay rate of dead plant material as the peat accumulates. Peat profiles, like the very different environment of Sahel lakes, record the balance between precipitation and evaporation in the past.

This project focused on refining methods for past climatic interpretation, and testing their accuracy by relating them to the relatively short-term instrument record of the past 200 years. But a number of direct new indicators of climatic change also emerged. Temperature records are similar between sites within the British Isles, whereas precipitation records are not. It looks as though proxy climate methods should concentrate on temperature if we are to recognise regional patterns.

This part of TIGGER was led by Professor R Batterbee (University College London) and Dr K Barber (University of Southampton, UK) with collaborators in four other universities, three NERC institutes and the UK Natural History Museum.

Rapid change

One of the most significant and rapid climatic oscillations occurred as the last ice age was ending. The way that ecosystems responded to that period of rapid climate change (roughly 14,000 to 8,000 years ago) was studied in two Scottish sites, with data from several sites in England and Ireland. It appears that microscopic plant fossils, such as diatoms, and fossil insect larvae in lakes respond faster to abrupt climate changes than plants on land. However, terrestrial plant fossils might help use to distinguish precipitation and temperature changes - an important distinction in understanding the ecological impact of climate fluctuations. One group has been measuring the present-day requirements of a number of plant species that occur commonly in the fossil record, in order to infer the climate at sites where those plants grew in the past. Another indicator comes from fossil beetles, which can migrate rapidly if the temperature changes. Combining these records may provide sensitive proxy climate signals over a range of temperature and rainfall.

This element of TIGGER was led by Professor John Lowe (Royal Holloway, University of London) and Dr Tim Atkinson (University of East Anglia, UK), with collaborators from several other institutions.

The next ice age

Since we are manifestly living in a warm *'interval'* in the mainly glacial phase of the last two million years, geologists want to know when we might return to icy conditions. The geological record of the last two million years seems to make this inevitable, despite the current preoccupation with global warming! How might we recognise the onset of a new ice age, and how rapid might the process be? A TIGGER consortium set out to investigate four Mediterranean sites, to find out what happened the last time we entered a glacial phase, which lasted from 100,000 to 10,000 years ago. In Mallorca the team found a complex interplay of sea-level with the deposition of sand and gravel by rivers and wind during that phase of climatic transition. It is becoming clear that the Mediterranean landscape and vegetation were highly sensitive to climate change during the last interglacial sequence.

New questions

The TIGGER programme has certainly thrown light on many of the questions implicit in its four core projects. But it can fairly be said that it has raised as many new questions as it has answered. The events of the past two million years still represent the best key that we have to understanding the pattern and process of climate change. It is a challenging but promising field for further research.

Final TIGGER review meeting

A final TIGGER review meeting was held at the Geological Society in London, in March 1997. Full papers are due to be published in a thematic volume of the Journal of the Geological Society. A full set of summary papers presented at this meeting is available from:

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The Palaeoclimate Modelling Intercomparison Project (PMIP)

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Past climate change presents a challenging test of our understanding of climate, and our ability to simulate climate using computer models. These models have been developed in the context of present day climate and are used to predict future climate change. However, even the most complex of these models are highly simplified representations of the true climate system. It is vital that they are tested on climate regimes that are different to the present. Past climates are essential parts of this testing, they give us a unique opportunity to evaluate the sensitivity of climate to different forcing processes. If these models can simulate past climates, then it gives us extra confidence in their ability to predict the future. There is a long history of palaeoclimate modelling and many successful simulations. It was noted that in some regions, different models could give different predictions of past climate change. In part, this was because the model simulations frequently used slightly different scenarios of the climate forcing (such as different reconstructions of land ice sheet conditions). It was therefore difficult to fully evaluate why the models were giving different answers.

The PMIP was designed to answer some of these problems. Its aim is to compare the results from climate models, driven by exactly the same palaeoclimate forcing. This will help us to better understand the mechanisms of climate change and to test the ability of the models to reproduce past climatic conditions. PMIP is co-ordinated by S Joussaume and K Taylor and has been endorsed by both IGBP/PAGES and WCRP/WGNE. 17 modelling groups are participating in the project. The project complements the Atmospheric Modelling Intercomparison Project (AMIP) which is evaluating the ability of climate models to correctly simulate our current climate. A good simulation of present day climate is a pre-requisite for reliable model predictions but it is also important to test their sensitivity to changes. PMIP will be able to evaluate this question.

For the PMIP simulations, each modelling group uses exactly the same boundary conditions and so differences between simulations must reflect differences in model structure and parameterisations. The model intercomparisons are designed to:

(a) identify similarities and differences in the simulated climates, and

(b) isolate the mechanisms responsible for the differences.

Performing model-data comparisons allow us to evaluate the climate model, and to identify which components of the models are reliable and robust. In its initial phase, PMIP has focused on two time periods. The Mid-Holocene (6,000 years ago) was seasonally warm, caused by changes in the Earth's orbital parameters. The PMIP experiment changed the orbital parameters appropriately and the atmospheric CO_2 concentrations were reduced to pre-industrial levels. However, an important limitation of the simulation is that the sea surface temperatures are prescribed to be the same as present. Thus this simulation is a simple experiment to examine the effect of changes in the seasonal and latitudinal distribution of insolation. The emphasis is on model-model comparisons, although model data validation is also being performed. The second time period being considered is the Last Glacial Maximum (21,000 years ago). All PMIP models change the sea surface temperature, the orbital parameters, and the atmospheric CO_2 concentration is lowered to those found in ice core data. In addition, the North American and Scandinavian continents were covered in large ice sheets.

All models have completed their simulations and the project is now in the process of analysing the results. To aid in this process, a number of sub-projects have been formed to focus on particular regions. Examples of this are changes in the monsoons during the mid-Holocene, mid-latitude changes at the Last Glacial Maximum, and studies of the mass balance of the ice sheets.

It is too early to summarise the conclusions from the work but there are already some interesting results. For instance, all models show that enhanced summer insolation during the mid-Holocene results in increased summer warming of the Northern Hemisphere land. Due to this amplified land-ocean temperature contrast, the monsoon circulation is enhanced and penetrates further north into the continents. As a result, the monsoon rainfall over South Asia and North Africa is increased. However, there are some large variations in the magnitude of the change. Additionally, in the N. African region all of the models show too little variation in the hydrological conditions. This may be due to the limitations of the simulations because the sea surface temperature and the land surface conditions have been held fixed. The analysis of the PMIP results will continue for some time. The UK has considerable involvement in this project, both on the data side and the modelling side (through the UK Universities Global Atmospheric Modelling Programme, UGAMP, and the Hadley Centre). Detailed analysis of model-model and model-data comparisons will help us to interpret the behaviour and robustness of the models and will, we hope, increase our confidence in the models used to predict future climate change.

Past carbon dioxide levels and proxy indicators

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The concentration of carbon dioxide (CO2) in the Earth's atmosphere has fluctuated markedly over geological time. Analysis of air trapped in Vostock polar ice (Barnola et al, 1987) exposed a glacial-interglacial fluctuation in CO2 concentration for the past 160,000 years, with levels of 180 to 200 ppm, occurring during glacial periods and 280 to 300 ppm during interglacials. Beyond the ice core record however there are no direct means of estimating CO2 levels, which is why a number of modelling techniques and proxy indicators (ie indirect signals of past CO2 levels) have been employed. The pattern of CO2 fluctuations on geological time scales were first revealed by modelling of the long-term geochemical carbon cycle for the last 600 million years. The model revealed a general trend of declining CO2 levels over geological time, with significantly large fluctuations superimposed. The pattern of long-term CO2 decline has been attributed to an increase in the amount of solar radiation available *(Oglesby and Marshall,* 1992) for the weathering of silicate minerals from rocks, an important sink for atmospheric CO2. Representative reactions are:

Atmospheric CO2 + CaSiO3 (rocks) CaCO3 (precipitated in oceans) + SiO2

Atmospheric CO2 + MgSiO3 (rocks) MgCO3 (precipitated in oceans) + SiO2

The Berner models have been tested and the combined approaches of modelling and proxy methods have provided a good picture of global CO2 changes for the last 600 million years. Broadly speaking, CO2 levels of 14 to 18 times the pre-industrial level (PIL) of 300 ppm existed between 600 and 400 million years ago (Mya). These extremely elevated atmospheric levels were followed by a sharp decline from about 12 times PIL, 420 Mya, to 1.5 to 2 times PIL about 300 Mya. This significant decline in atmospheric CO2 may have contributed to a global palaeo-climatic shift from non-glacial to fully glacial conditions during the Permo-Carboniferous glaciation. Such a marked decline in atmospheric CO2 has been attributed largely to the colonisation and the proliferation of land plants during this interval (400 to 360 Mya), which would have removed CO2 from the atmosphere via biomass accumulation and burial, and via accelerating the chemical weathering of silicate minerals from rocks and soils (*Lovelock & Whitfield*, 1982; Berner, 1997). The very low CO2 world of the Carbo-Permian glaciation (300 to 280 Mya) was succeeded by a gradual rise in atmospheric CO2 levels up to about 4 to 5 times PIL between 250 to 150 Mya, followed by a gradual decline to pre-industrial times. On geological time scales therefore, the current ambient CO2 concentration of 360 ppm is relatively low, however the rapidity of the rise in CO2 over the last 200 years, due to the burning of fossil fuels and land use change, is unprecedented in the recent geological past.

Proxy indicators which have been utilised to reconstruct past CO2 levels include ratios of the two stable isotopes of carbon (d13C) in fossil soil carbonates and organic matter (*Mora et al*, 1996) and marine sediments (*Freeman & Hayes,* 1992) and stomatal characteristics of fossil plants (*McElwain & Chaloner,* 1995, 1996,*McElwain, in press*). The stable carbon isotopic ratios of fossil soils have been measured from fossil soil horizons spanning the last 450 million years. The rationale of this method is based on a diffusion-reaction model for the stable carbon isotopic composition of soil carbonates, developed by Cerling (1991). The model indicated that in the absence of C4 vegetation and under favourable climatic conditions, the carbon isotopic composition of fossil soil carbonates would provide a good indication of the atmospheric CO2 concentration in which they developed. However, this method has received criticism (*Wright & Vanstone,* 1991) based on the assumption that plants with the C4 photosynthetic pathway were unimportant before the Miocene (about 25 Ma). There is circumstantial evidence that C4 photosynthetic pathways may have evolved a number of times in the fossil record before this time (*Wright and Vanstone,* 1991). The use of stable carbon isotopic composition in the marine system is based on the assumption that fractionation of carbon isotopes in marine phytoplankton is directly related to the CO2 concentration dissolved in the oceans in which they lived and hence indirectly an indicator of past atmospheric CO2 levels. Analysis of phytoplankton preserved in marine sediments has provided a near continuous record of CO2 levels for the past 160 Ma. However, *Tortell et al*. (1997), have shown that some marine phytoplankton actively uptake bicarbonate ions from the oceans, enabling rapid growth despite low dissolved CO2 availability. This is assumed not to occur in the interpretation of the marine carbon isotopic record, but rather the phytoplankton take up dissolved CO2 by diffusion. This proxy method has an advantage over the fossil soil method in providing near continuous records of past CO2 levels, however, over shorter absolute time periods, as unlike the fossil soil record, marine sediments beyond about 160 Mya are unreliable due to post-burial changes in their chemistry.

Use of the stomatal characteristics of fossil plants, including the stomatal density (the number of stomata on the leaf surface) and the stomatal index (a ratio of the number of stomata to the total number of cells on the leaf surface) as proxy indicators of CO2 levels in the past, is a relatively new technique. The stomatal pore controls two of the most important physiological functions of the plant; the intake of CO2 during the process of photosynthesis and the loss of water through the stomatal pore during the process of transpiration. This method utilises a well documented inverse relationship between stomatal characteristics and atmospheric CO2 concentration (*Woodward,* 1987, *Beerling et al*, 1993) as a proxy indicator of the CO2 concentration in which the plant developed. During periods of elevated CO2, fewer stomatal pores are required by the plant to achieve the same carbon gain for photosynthesis, and as a direct result of fewer pores, the plant improves its water use efficiency by losing less water through transpiration. This method provides a signal of past CO2 concentrations from plant leaves which are in direct contact with their atmospheric environment and highly sensitive to changes. Both stable carbon isotopic methods of detecting past CO2 levels are a step removed from the atmospheric environment and must first estimate the CO2 concentration of the rhizosphere in the case of fossil soils and the ocean in the case of the marine carbonates. However, there are limitations to the stomatal proxy method, as the fossil plant record is by no means continuous over the whole of geological time and many biological factors which influence stomatal characteristics, such as light, water availibility and microclimate must be taken into account before quantitative estimates of past CO2 levels can be made.

In conclusion, both the modelling and varied proxy methods for reconstructing CO2 levels in the past are so far in very good agreement, despite the differences in their implementation, which gives confidence in reconstructed changes in CO2 over geological time. Together with proxy climate indicators and palaeontological data, further high-resolution reconstructions of past CO2 changes are required to improve our understanding of the interactions of the biosphere-geosphere-atmosphere system in the past. It is these fundamental interactions which are at the crux of current greenhouse induced global change issues.

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Why study past climates in marine sediments?

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The title of this article contains two intrinsic questions. Firstly, why study past climate and secondly, why do it using marine sediments? The answer to the first question has been reviewed by Frank Oldfield (*this issue*) but can be summarised as using the past as a key to understanding future climate change. What I hope to achieve in this article is an answer to the second question by demonstrating that marine sediment records are an essential part of both past reconstructions and future estimates of global climatic change.

The Importance of the Oceans

Climate is caused by differential latitudinal solar heating ie, the tropics are hot and the poles are cold. Energy is, therefore, constantly transported from the equator towards the poles. There are two transporters of this energy, the atmosphere and the oceans. The atmosphere responds to change on the scale of days, months or a few years. The oceans, however, have a longer response time. The surface ocean can change over months to a few years, but the deep ocean takes decades to centuries. This causes a major problem when trying to reconstruct or predict climate change as there will always be a lag between the response of the two main controls of global energy redistribution. Moreover the long response time of the ocean, means that historic records are too short to provide an adequate base line for the ocean system prior to human intervention. Because marine sediments provide continuous climate records at a range of time scales, they can be used to reconstruct the stability and natural variability of the ocean system before possible anthropogenic influences. They can also help in the estimation of the delay between the response of the atmosphere and ocean to climate forcing.

The study of marine sediments has shown that ocean processes are highly variable and that they can have a major impact on global climate. Examples of two such key oceanic processes are given here. The first is deep water formation in the Nordic Seas. At present warm and salty subtropical water formed in the Caribbean is carried via the Gulf Stream to the high latitudes. This water cools sufficiently as it moves northward to sink, beginning the global deep ocean conveyor system. This conveyor system can be seen as the regulating '*heart beat*' of global climate as it maintains the steady heat transport to the high latitudes of the Northern Hemisphere. It also keeps the climate of Europe nice and mild throughout the year! We know that during the last ice age, this deep water thermohaline ocean circulation was reduced, due to alterations in atmospheric circulation and the input of fresh water from melting icebergs. Moreover, it also collapsed completely during short 100-1000 year glacial events called Heinrich events, having a catastrophic affect on global climate. One is left questioning what will happen to deep water formation in a Greenhouse World?

The oceans also have a major impact on the carbon dioxide in the atmosphere. One of the main processes is ocean productivity, when CO2 is extracted by marine organisms to form organic matter via photosynthesis. This biological material can rain out of the surface waters and the trapped carbon is sequestered in marine sediments. We know that ocean productivity has been highly variable in the past. At present we are trying to estimate from marine palaeo-climate records how much the ocean productivity varied in the past, particularly in the upwelling zones off the western coasts off South Africa and South America, and its affect on atmospheric CO2.

The Importance of Palaeoceanography

It is essential to study ocean history so we can produce a more thorough understanding of past and future climate change. What time-scales do palaeoceanographers look at? It has been argued by *Hay et al* (1997) that the Holocene (the last 10 ka) is unsuitable in many ways as the geochemical system is not in steady state and the physical geological processes are operating at unusually high rates. They argue that the Late Cretaceous which had four times the present day atmospheric CO2 content would provide an analogy for the future. Unfortunately, the further back in geological time the harder it is to make reliable high resolution climate reconstructions. This causes a problem as the Earth has been undergoing global cooling, not warming, for the last 100 Ma. So we do not have a good recent analogy to a longer term warmer future. There are, however, two interglacial periods, at 420-390 ka and 130-115 ka which were slightly warmer and possibly higher than pre-industrial levels of atmospheric CO2. I have complied these along with other important periods of climate change which are presently being studied.

The majority of the key periods studied are when rapid global climate change occurred, so we can understand both the causes and how the system responds. Heinrich events are a good example of rapid '*human scale*' events. During the last glacial period the North American ice sheet failed periodically (~10 ka), possibly initiating in only a few years, pushing out huge Armadas of icebergs into the Atlantic. This injection of meltwater shut off deep water formation and chilled the global climate. The Heinrich events also have little brother events call the Dansgaard-Oeschger cycles, which are warming and cooling cycles occurring every 1.5 ka. What is remarkable is that these cycles did not just occur in the last glacial period, they occurred throughout the Holocene period (*Bond et al, 1997*).

Conclusion

Marine palaeo-climate records provide long continuous records of climate at a resolution ranging from annual to thousands of years. It is obvious that palaeoceanographers are studying a wide set of global climatic changes, the more we understand about our oceans and how they have reacted to global change the better we will be able to understand what they might do in the future.

To conclude:

1) Oceans are important in global climatic change;

2) Studying past oceanic changes using marine sediments is essential to understand past climate change and will enable us to understand possible future change;

3) It is necessary to have an integrated approach using all palaeo-climate records to understand how climate changes and how it is caused; and,

4) Palaeo-climate records provide essential data with which to test global circulation models, which eventually provide us with climate estimates for the future (*see Paul Valdes, this issue*).

Marine sediment palaeo-records have brought to light many surprises which have confronted both oceanographers and climatologists, and has made them re-think how climate reacts to change (*Maslin and Berger, 1997*). I am sure this will continue into the future!

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Coral indicators, climate change and the El Ni¤o Southern Oscillation

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Introduction

In late 1997, wildfires swept through huge swathes of normally moist and verdant rain forests in SE Asia, resulting in life-threatening air pollution, and capturing the headlines of the global press. This extremely unusual event may have been exacerbated by poor commercial logging practices, but the real underlying cause was a severe drought which had dried-out old timber and fallen vegetation. Although catastrophic in it's own right, the drought-related fires in SE Asia were only one manifestation of a near-global disturbance of atmospheric circulation and climate related to the development of an exceptionally severe El Ni¤o Southern Oscillation (ENSO) event, one which continues to build at the time of writing.

Nature and Consequences of ENSO

ENSO is the term coined to describe a periodic reorganisation of atmospheric and surface ocean circulation centred on the Pacific region which occurs every 2-7 years. During these events the trade winds fail, the atmospheric low pressure which usually brings heavy rainfall to SE Asia weakens and moves eastward to the central Pacific, and anomalously warm water conditions develop in the central and eastern equatorial Pacific.

Amongst some of the major climatic repercussions of this reorganisation of circulation patterns are severe droughts in Australia, SE Asia and in southern Africa, cyclones and flooding in the central Pacific, heavy rainfall and flooding in northwestern South America, and severe winter storms in the southern USA. ENSO also impacts significantly on the climate of Europe, although in a less predictable manner. Severe ENSO events, such as the one in 1982/83 (which was the strongest for over a hundred years, but which itself looks like being surpassed by the current event), can cause billions of £ of damage through loss of property, livestock and agricultural revenue, and catastrophic loss of life due to floods, cyclones and drought. Consequently, a huge, interdisciplinary and international research effort, is focusing on developing an understanding of the causes of ENSO and other forms of interannual-centennial timescale climate variability. The ultimate goal is to develop a predictive capability. This collaborative venture is embodied in both the Climate Variability and Predictability Study (CLIVAR) of the World Climate Research Programme and the Past Global Changes (PAGES) project of the International Geosphere-Biosphere Programme.

Understanding ENSO

Although the last decade has seen major advances in our understanding of the way in which ENSO events develop through the generation and propagation of slow-moving waves within the upper layers of the tropical oceans, the reason why some ENSO events are much stronger than others remains obscure, as does the reason why the frequency of ENSO events varies from about 2 to 7 years. *For example,* most of the current generation of computer models developed for ENSO prediction failed to forecast the severity of the current 1997/98 event.

One way forward for research in this field is to examine the history of past ENSO events to look for patterns which will give insights into the mechanisms responsible for variations in strength and periodicity. Unfortunately, reliable instrumental records of climate from the key tropical oceanic regions are seldom more than a few decades in length, which is insufficient to allow assessment of this component of the climate system. Consequently, it is necessary to look for and exploit natural archives of climate information. This is the specific goal of a recent initiative of the PAGES project entitled Annual Records of Tropical Systems (ARTS). ARTS is bringing together oceanographers, climatologists, modellers and those working on extracting records of past climates from natural archives such as annually-banded corals, annually-banded trees, and annually-banded ice-cores. Of these natural climate recorders, corals appear to provide the best potential for revealing the long-term behaviour of the crucial oceanic component of ENSO.

Climate Records from Corals

Reef-building corals are colonial organisms which construct hard skeletons of lime (calcium carbonate). Individual colonies of some species may live for several centuries during which time they construct massive dome-shaped skeletons several metres in diameter. Coring down through the skeletons of such corals reveals a pattern of growth which includes annual growth rings broadly analogous to annual rings in trees. Critically, from the point of view of climate reconstruction, the chemistry of the skeleton laid down by the coral animal varies systematically according to the environmental conditions prevailing at the time of growth. Specifically, the ratio of two forms of oxygen (d16O and d18O) varies with changes in sea surface temperature and with rainfall, and a number of trace elements (strontium, magnesium and uranium) vary with changes in temperature. Therefore, by sampling down through coral cores, and performing geochemical analysis on these samples it is possible to construct records of past variations in rainfall and temperature with a temporal resolution of ± 1-2 months over several hundred years. In addition, since coral skeletons may be dated by radiometric techniques including 14C and uranium-series, analysis of ancient (dead) corals may be used to investigate variability in ENSO and other aspects of tropical climate over the past hundred thousand years thereby providing a truly long-term perspective.

Achievements to Date

Although the reconstruction of past climates from analysis of coral skeletons is a relatively young science, some notable contributions to date include:

- identification of major changes in the strength and periodicity of ENSO on multi-decadal timescales related to rapid near pan-tropical climate reorganisation;

- further evidence for the nature of the linkages between the Indian Monsoon system and the Pacific ENSO;

- evidence for unexpectedly large changes in tropical sea surface temperature during the most recent major build-up of large high-latitude ice sheets (the last glacial which peaked about 20,000 years ago); and,

- evidence to suggest that ENSO may have been a persistent mode of tropical climate variation over the past 130,000 years. However, the evidence to date also suggests that the strong, regular 3-4 year frequency of ENSO experienced from the 1960's to 1990 may be somewhat unusual.

Future Goals for Coral Climatological Studies

Specific goals for future research in this field can be divided into investigation of variations during periods when global climates were broadly similar to those of today (*'within climate regime'*), and variations during periods of Earth history when global climates are known to have been very different to those of today (*'between climate regime'*). Specifically:

Within Climate Regime:

- Extend the continuous record of past sea surface temperature and rainfall by 100-200 years through analysis of cores from living corals at a network of sites through the tropical oceans. Identification of *'key'* climatological regions, in terms of perceived source areas of variation (for example the far western equatorial Pacific and Arabian Sea regions) should be made in consultation with oceanographers, climatologists and modellers. Such a network of records will permit analysis of between-ocean and within-ocean variations, including phase leads and lags. In turn, this should aid identification of *'source areas'* of different forms and wavelengths (interannual-decadal-centennial) of climatological/oceanographic variation, as well as facilitating recognition of the mechanisms of signal propagation.

- Investigate the nature of tropical climate variability during intervals over the past few thousand years and during the last interglacial (ca. 125,000 years before present) when global climatic conditions were similar to, or slightly warmer than those of today. Results of these studies will give an indication of the variability which may occur over the next few decades/centuries under a variety of Greenhouse warming scenarios.

Between Climate Regime:

- Investigate the nature of tropical climate (mean conditions and nature and extent of interannual variability) during times when global climatic boundary conditions were very different to those prevailing today, for example, during the last glacial period when high latitude temperatures are known to have been > 10 C cooler than those of today. These studies are important because they allow an assessment of the sensitivity of ENSO climate dynamics to changes in mean sea surface temperature and to latitudinal temperature gradients. Once again, these studies should provide insights into the underlying processes controlling ENSO.

To *conclude*, coral studies have the potential to make a major contribution to the international and interdisciplinary research effort focused on understanding the causes of climate variability on seasonal to thousand year timescales. Such an understanding of the physics of climate variation is crucial for the successful development of a predictive capability to guide both short term contingency planning (*eg*, choice of crops in drought-prone areas) in the face of individual ENSO events, as well as long term international policy decisions in the context of predicted global Greenhouse warming.

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Evidence of climate change from loess/palaeosol sequences in North Central China.

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Introduction

A key objective of Quaternary research is to retrieve past climate data from geological proxy data recorded in sediments. Ideally, the retrieved palaeoclimate data will be in a form readily comparable with output data from General Circulation Models; the reliability of these models, which are commonly used to predict *future* climate changes, can thus be tested against *past* changes in climate. Long sedimentary records from the deep oceans have so far been the major focus of palaeoclimatic work. However, the thick and extensive loess/palaeosol sequences of North Central (NC) China have recently and justifiably received intense scientific attention. They span the last ~2 million years of Earth's history and preserve the longest and most detailed record of Quaternary climate change yet found on land.

The Loess Plateau of NC China consists of thick sequences of loess (windblown dust), which bury the underlying topography and form a wedge of sediment, thickest (~350m vertical extent) near the eastern edges of Mongolia and Tibet, around 150m thick in the central area, and thinning out towards the southern and eastern cities of Xian and Beijing. The dust was blown by winter monsoon winds from desert source areas, such as the Gobi, and from glaciated uplands of the Tibetan Plateau, where rock has been shattered by frost action into fragments sufficiently small to be picked up and transported. Transport and subsequent deposition of the loess was maximised during cold, dry climate conditions. Interbedded *within* the paler, 'buff'-coloured loess are numerous ancient buried soil layers (palaeosols), which can be traced over many kilometres as near-horizontal, reddened beds. These formed during warmer and wetter climate conditions, when successive loess surfaces were vegetated and subjected to enhanced weathering and soil formation. Alternation of cool periods (with loess deposition) and warmer and wetter periods (with enhanced soil formation) produced the thick, interbedded sequences we see today, often exposed in the steep walls of erosional gullies. Retrieval of *quantitative* palaeoclimatic data from these remarkable natural archives is an important and timely scientific task, given the prospect of future changes in monsoonal activity and resultant rainfall patterns in this densely populated region of Asia.

The loess/soil sequences carry a very detailed magnetic record of climate change. The soils contain higher concentrations of strongly magnetic iron oxides (magnetite and maghemite), of distinctively ultrafine grain size (< ~0.05µm); the less weathered loess layers contain much less of this material. These differences can be easily and rapidly quantified by measuring the *magnetic susceptibility* of the sediments; the soils have susceptibility values 2-5 times higher than the loess layers. Since the pioneering work of *Heller & Liu* (1982, 1984), which first demonstrated the magnetic recording of climate in these sediments, worldwide interest has resulted in generation of very detailed susceptibility data (eg at 5 -15cm spacing over stratigraphic sections >150m) for sites spanning the present climatic gradient from the semi-arid west to the more humid south and east. Strong correlation exists between the loess/soil magnetic record and the deep-sea oxygen isotope record: high susceptibility values, associated with the palaeosols, correlate with lighter dO18 values (reduced global ice volume); low susceptibilities, associated with the loess units, match heavier dO18 values (increased global ice volume). Thus, the Asian monsoon systems are clearly linked with environmental changes at higher latitudes in the northern hemisphere.

Magnetic susceptibility and rainfall *Liu et al* (1992) first identified a positive linear relationship between modern rainfall values and the susceptibilities of individual loess and palaeosol units across the Loess Plateau. It is unlikely that such a relationship could arise by chance, or by individual site-specific factors (such as disturbance). Magnetic data and analysis by electron microscopy (*Maher & Thompson,* 1992) show that the source of the higher susceptibility values in the palaeosols is ultrafine-grained magnetite (~0.01 - 0.05µm, often oxidised towards maghemite). Such fine-grained material can be formed efficiently via the action of iron-reducing bacteria (*Lovley et al*, 1987). Magnetotactic bacteria can also contribute smaller amounts (per bacterium) of magnetite particles. Magnetotactic bacteria produce magnetite particles directly; the Fe-reducers release Fe2+ extracellularly, where it may, upon subsequent re-oxidation of the soil, react with Fe3+ oxides to form magnetite (*Taylor et al*, 1987). It is probable that both groups of bacteria functioned when local oxygen-poor conditions occurred within the soil micro-environment. It seems logical that such bacterial activity will be greater in soils which undergo more frequent wetting and drying cycles. These pathways of magnetite formation during soil development can thus account for the observed relationship between rainfall and magnetic susceptibility.

Retrieving palaeorainfall from magnetic susceptibility

a) **Heller et al (1993)** used the present-day rainfall and the susceptibility of the youngest palaeosol (S0) to calibrate palaeo-rainfall calculations from the palaeo-susceptibility variations at Luochuan. However, they used not susceptibility but susceptibility fluxes (ie susceptibility x sedimentation rate), on the basis that deposition of loess occurs continuously, even during soil-forming periods.

b) **Maher et al (1994)** examined the relationship between modern climate and the pedogenic susceptibility of modern soils (ie not S0, but younger soils developed on erosion surfaces within the Plateau). They found strong positive correlation between susceptibility and annual rainfall and calculated a simple mathematical relationship between them. If the susceptibility of the buried soils formed rapidly enough to reflect the rainfall at the time of soil formation, this calculated rainfall/susceptibility relationship can be transferred to the *palaeo*-susceptibility values of the buried soils, to calculate the *palaeo*-rainfall at each soil-forming stage. For the last glacial/interglacial cycle, *Maher et al* (1994) identify significantly higher rainfall (and hence more intense summer monsoons) in the early Holocene and the last interglacial, especially in the presently semi-arid western Plateau. During the last glacial, rainfall was reduced across the whole Plateau region, especially in the south-east.

Multi-proxy studies

Other proxy climate indicators contained within the loess/soil sequences include particle size and carbonate content. For example, the strength of the winter monsoon winds, responsible for much of the dust transport to the Loess Plateau, may be gauged from variations in the maximum grain size of the quartz grains deposited in the sequence (*Xiao et al*, 1995). Since these grains are not affected by weathering and soil formation, larger maximum grain sizes (~90-120µm) may indicate periods of increased wind strength and smaller sizes (~65-85µm) periods of decreased winter monsoon intensity. Carbonate content, in contrast, may be sensitive to variations in summer monsoon moisture supply, reflected in dissolution and remobilisation of detrital carbonate and its reprecipitation in illuvial soil horizons. High-resolution studies of the loess/soil sections in the western Loess Plateau, where the sequences are at their thickest, indicate decoupling of the behaviour of the summer and winter monsoons during the last glacial cycle. From ~70-50k years, both the summer and winter monsoons were weak and varied little; from ~50-30k years, the summer monsoon was generally strong but variable, whilst the winter monsoon was weak; and from ~30-12k years, the winter monsoon was strong and the summer weak (*Chen et al*, 1997). Given such high-resolution sequences and sampling (*eg* at intervals of ~200 years), it should be possible to make precise comparison and correlation between the loess records and both deep-sea records (eg the sequence of Heinrich layers in the N Atlantic) and ice-core records, and hence identify leads and lags and possible causal links between the climate system components. However, accurate absolute dating of the loess sequences presently remains a problem beyond the radiocarbon age limit. (Dating by correlation with the deep-sea oxygen isotope record can on occasion induce circularity of argument when the resulting chronology is treated as an independent age model). Ongoing developments in optically-stimulated luminescence dating techniques offer some prospect of improved accuracy in this regard.

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Third Assessment Report of the IPCC

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Preparations are now beginning for the Third Assessment Report (TAR) of the Intergovernment Panel on Climate Change (IPCC). The Report is expected to be completed by the end of the year 2000 and published in 2001. Over the next few months the IPCC will be choosing authors and editors for the Report and defining in detail its contents. Governments have been asked to nominate scientists and other experts who may be able to contribute. As the UK's official contact for the IPCC I am seeking specialists who would be prepared to draft parts of the report or to act as reviewers.

The success of the IPCC to date has depended on the voluntary participation of scientists, economists, engineers and other specialists worldwide, who have given of their own time to provide written material and review documents. I believe researchers and technical specialists can benefit greatly from participating in the IPCC process. They are able to participate fully in a lively worldwide debate on different technical aspects of global warming and gain much satisfaction in seeing the wider application of their research work.

However, it would only be fair to point out that those who wish to be involved in the preparation of IPCC reports will need to be prepared to put in considerable time and effort and be prepared to meet strict deadlines. They or their employers may also need to allocate the necessary resources in terms of time and money.

By far the most onerous burden falls on those chosen by the IPCC to be Lead Authors. They need to be prepared to spend at least one month, possibly two, per year during the preparation of the Report and to travel to meetings to draw together and edit documents and prepare executive summaries with other Lead Authors. In view of the demands placed upon them those nominated by the UK and accepted as Lead Authors by the IPCC may be provided with support for travel and subsistence, though funds will be limited and cannot be guaranteed.

The IPCC has also agreed to introduce Review Editors to help finalise the Reports and they will also receive support to travel to meetings. Unfortunately, contributing authors will not receive additional support, however in general they will not be expected to travel to meetings.

The IPCC reports will be organised as follows: *Working Group I* will assess the scientific aspects of the climate system and climate change, *Working Group II* will assess the scientific, technical, environmental, economic and social aspects of the vulnerability to climate change of , and the impacts on, ecological systems, socio-economic sectors and human health and *Working Group III* mitigation of climate change and the methodological aspects of cross cutting issues such as equity, discount rates, and decision making frameworks.

If you would like to find out more about participating in the IPCC Third Assessment Report and an application form, please contact:

Theo Holdbrook
Department of Environment, Transport and the Regions
B256, Romney House, 43 Marsham Street
London SW1P 3PY, UK

Tel: 0171 276 8313
Fax: 0171 276 8509
E-mail: theo@globatmo.demon.co.uk

Please note that nominations need to be returned to IPCC by the end of February so you should aim to return them by **13 February 1998.**

ARCICE - 'Arctic Ice and Environmental Variability'

A three year programme called ARCICE - 'Arctic Ice and Environmental Variability', and funded with £3 million by the UK Natural Environment Research Council (NERC), has started. It aims to enhance our understanding of, and capacity to predict, variations in the Arctic cryosphere relevant to climate and sea level change in North West Europe.

Collaboration with other thematic programmes, research councils, Government Department and commercial interests is being encouraged.

Further information on the Programme can be found at http://www.cecs.ed.ac.uk/arcice
or by e-mailing the Programme Manager, Dr Andrew Kerr, at arcice@ed.ac.uk

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UK Climate Impacts Programme (UKCIP)

The Programme

In April 1997, the UK Government launched a programme to co-ordinate an integrated assessment of climate change impacts in the UK. The UK Climate Impacts Programme seeks to provide a *'stakeholder-led'* assessment of climate change impacts on the UK. The Programme aims to bring together those from the public and private sector with responsibilities for accommodating the effects of climate change to undertake sectoral- and regional-based impact assessments within an integrated national framework.

Climate Change will Affect the UK

A review of how climate change will affect the UK was recently completed by the Climate Change Impacts Review Group (CCIRG). The Group concluded, on the basis of one possible scenario of climate change, that the impacts will be mixed, but that adverse effects will outweigh positive effects.

Why Integrated Impact Assessment?

The effects of climate change are likely to be felt across sectoral, regional and national boundaries. The water sector, *for example,* will not only be affected by altered temperature and precipitation patterns, but will also have to respond to changes in demand for water by other sectors such as agriculture, industry and the domestic sector. Previous assessments have examined the impacts of climate change on specific sectors. The ability of one sector to respond to climate change impacts may be constrained by competing demands of another.

Individual sectors need to work together in an integrated manner to obtain a more realistic assessment of climate change impacts. This will enable appropriate adaptation strategies to be developed which take account of impacts and interactions across sectors and regions. The need for collaboration between sectors and among stakeholders requires that integrated and co-ordinated impacts assessments should be undertaken.

Informing Policy

Stakeholders in the public and private sector need access to the best available information in order to make informed decisions to adapt to the potential effects of climate change. Assessments conducted under the UK Climate Impacts Programme aims to provide Government and private sector decision-makers with better information to inform adaptation strategies. The Department of the Environment, Transport and the Regions (DETR), which has the policy lead on climate change issues within Government, will draw on these findings to inform Government policy on the need to mitigate and adapt to climate change. It is important that stakeholders from the private and public sector are involved in this assessment and influence this process of policy formulation. The assessment will inform stakeholders in the private and public sector responsible for taking decisions to accommodate climate change impacts from the company to the regional level.

The Structure of the Programme

The UK Climate Impacts Programme seeks to facilitate close links between the impacts research community, stakeholders and end-users. The UK Climate Impacts Programme is guided by two advisory panels. *The Science Advisory Panel* offers independent advice and expertise to the Programme. *The User Forum* represents stakeholders participating in the assessment as well as end-users affected by climate change impacts. Its role is to ensure that information from assessments is provided at temporal and spatial scales meaningful for decision-making. The Programme is guided by a top level Steering Committee.

Modular regional and sector-based impact studies are conducted within a national, integrated framework. Common datasets and scenarios will be used to facilitate integration both within and across modular studies.

The Programme Office

The role of the Programme Office is to:

- Identify interactions between sectoral groups and common research priorities.
- Facilitate integration within and between modular studies.
- Offer expertise on impacts assessment.
- Offer independent advice on the most appropriate methodologies and research approaches to impacts assessment.
- Communicate results from the assessments to a wide audience to provide the best possible information on which to base decision-making.

The Programme Office is located in the Environmental Change Unit (ECU), University of Oxford and is jointly managed by the ECU and Environmental Resources Management (ERM), Oxford.

New Newsletter

The UKCIP recently launched a newsletter which aims to distribute information regularly between stakeholders, researchers and the Programme Office. Copies of the newsletter are freely available from the Programme Office.

Further information on the Programme may be obtained from:

Programme Co-ordinator
UK Climate Impacts Programme
Environmental Change Unit
1a Mansfield Road
Oxford, OX1 3TB, UK

Tel: (+44) 1865 281192
Fax: (+44) 1865 281188
e-mail: ukcip@ecu.ox.ac.uk
Internet: http://www.ecu.ox.ac.uk/ukcip.html

European Science Foundation launches new networks

The European Science Foundation (ESF) recently announced that it had launched a total of eight new scientific networks by the end of 1997. The aim of these networks is to foster collaboration between European scientists and research institutes on a variety of topics including:

- **Alpine Biodiversity;**
- **Regional climate modelling and integrated global change: impact studies in the European Arctic.** The European Arctic is a particularly sensitive part of the global system. Through a series of three workshops, this network will bring together two important research communities - regional climate modellers and impact researchers. It aims to develop Europe's capacity to carry out regional integrated impact studies, combining both the natural and the socio-economic aspects of global changes impacts on a regional level.

The new networks, which will run for the next three years, bring the ESF's portfolio of current networks to 21. They all share a common aim of building bridges between relevant scientists, research institutes and universities in different European countries, by making use of a variety of networking arrangements including workshops and exchange visits. Another major objective of the scheme is to encourage multidisciplinary and interdisciplinary approaches to complex research problems.

The ESF is an association of more than 60 major national funding agencies devoted to basic scientific research in over 20 countries. It represents all scientific disciplines. Its two main aims are to bring together scientists in its programmes, networks and conferences; and, the joint study of issues of strategic importance in European science policy.

For more information, please contact:

ESF Communications Unit
The European Science Foundation

1 quai Lezay-MarnŽsia
67080 Strasbourg Cedex, France

Tel: +33 (0) 3 88 76 71 00
Fax: +33 (0) 3 88 37 05 32
Internet: http://www.esf.org

Source: ESF Communications, no 37

Internet News

World Data Center-A for Palaeoclimatology in Boulder, Colorado, USA has archives of palaeoclimatic data derived from tree-rings, ice cores, pollen, marine and terrestrial sediments, and a wealth of other sources are available for downloading: http://www.ngdc.noaa.gov/paleo/paleodat.html

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Plant Fossil Record Database (International Organisation of Palaeobotony): This database includes descriptions and occurrences of many thousands of extinct plants. Names, places and ages can be searched and the occurrences are instantly plotted on palaeogeographic maps. Patterns of migration and evolution through geological time can be clearly examined to help better understand the history of climatic and environmental change: http://ibs.uel.ac.uk/ibs/palaeo/pfr2/pfr.htm

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Climate Change: Scientific Certainties and Uncertainties: The Natural Environment Research Council (NERC) recently issued its statement on Climate Change: Scientific Certainties and Uncertainties based on information gathered from a wide range of sources. The document is now available on the Web: http://www.nerc.ac.uk/climate.html

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Special Briefing on Climate Change: The Economic and Social Research Council (ESRC) Global Environmental Change (GEC) Programme has recently published a Special Briefing titled After Kyoto: Making Climate Policy Work to coincide with the Kyoto conference on climate change. The briefing is edited by Owen Greene and Jim Skea, and is based mainly on contributions drawing on research carried out under the GEC Programme. It also includes contributions from other ESRC Centres and Programmes in the UK. These are: the recently completed Transport and Environment Programme; the Centre for Social and Economic Research on the Global Environment (CSERGE), University of East Anglia and University College London; and the Centre for Science Technology, Energy and Environment Policy (STEEP), Science Policy Research Unit, University of Sussex.

Areas covered by the briefing include: implementing climate agreements; targets for emissions reduction; green taxes; cities and demand management; transport; regulating the energy sector; renewable energy; regulation; the business contribution; climate change and changing lifestyles; small and medium-sized companies; and the politics of climate change. The Briefing can be downloaded from the GEC Programme web site (the file is in PDF format, so Adobe Acrobat is required to view it): http://www.sussex.ac.uk/Units/gec/sbriefs.htm

(For information on how to obtain a hard copy of the report, please contact the Programme Office, fax: 01273 604483; e-mail: gec@sussex.ac.uk)

Future Issues of *The Globe* & copy dates

Issue 42, 9 March 1998, *Focus on Global Change and Human Health*

Issue 43, 5 May 1998