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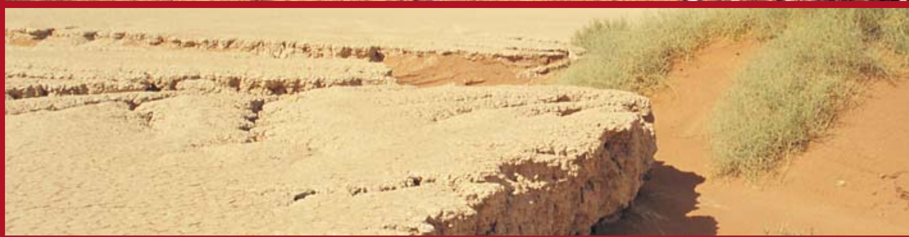
Climate Change -

the 'stone tape'

Earth sciences for society



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Prospectus for a key theme of the International Year of Planet Earth

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What is this brochure for?

This brochure is a prospectus for one of the main scientific themes of the International Year of Planet Earth 2005-2007.

It describes, in terms accessible to the informed layperson, why the research that the Year hopes to support under this theme is of such vital importance to our understanding of the Earth System, and to society at large.

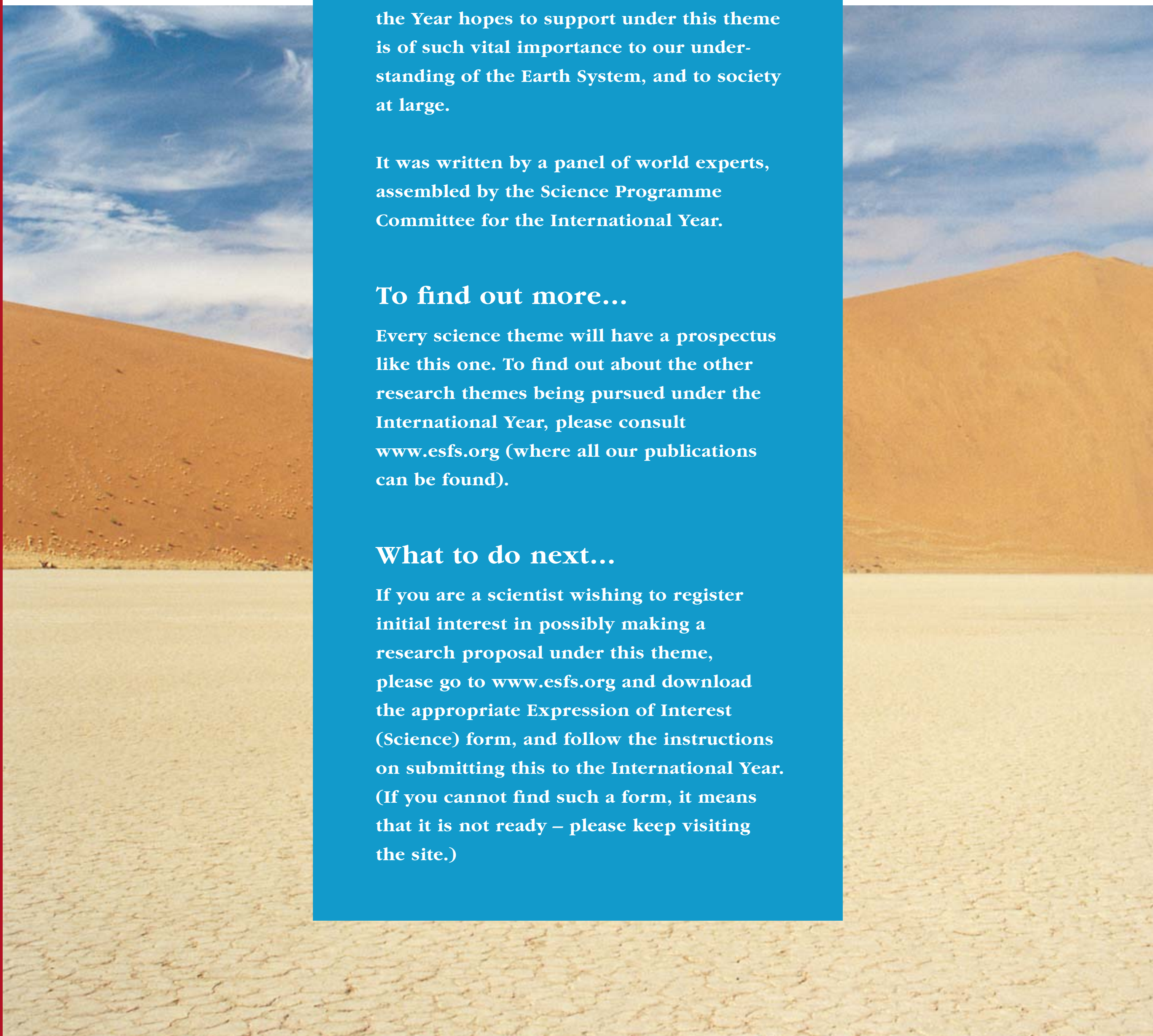
It was written by a panel of world experts, assembled by the Science Programme Committee for the International Year.

To find out more...

Every science theme will have a prospectus like this one. To find out about the other research themes being pursued under the International Year, please consult www.esfs.org (where all our publications can be found).

What to do next...

If you are a scientist wishing to register initial interest in possibly making a research proposal under this theme, please go to www.esfs.org and download the appropriate Expression of Interest (Science) form, and follow the instructions on submitting this to the International Year. (If you cannot find such a form, it means that it is not ready – please keep visiting the site.)



Introduction - the stone tape

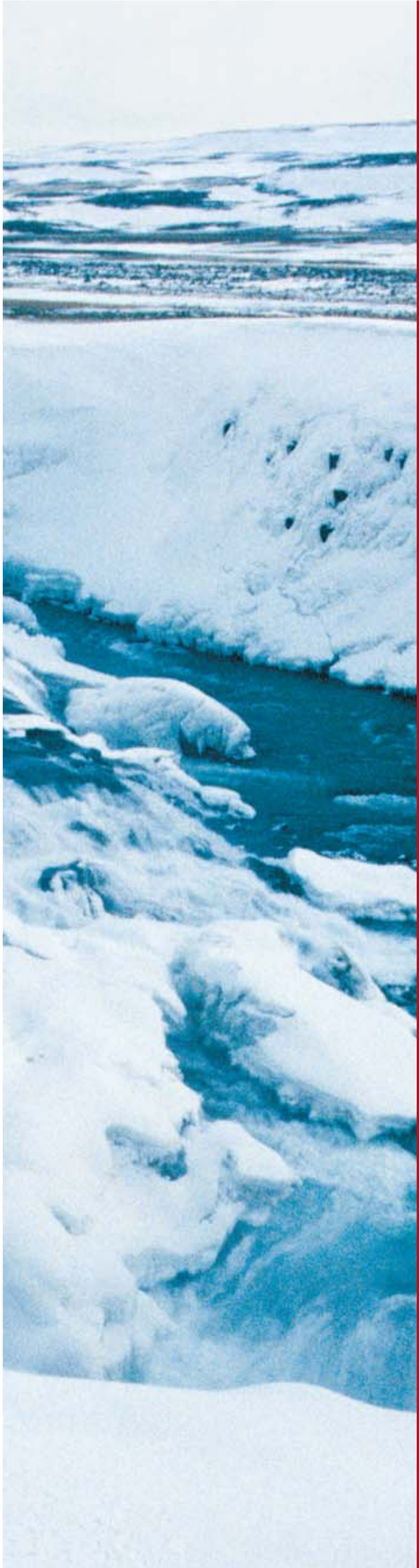
Ancient changes in Earth's climate system are 'written in stone'. The nature and properties of dust and ice accumulations, lake and ocean sediments, the size, shape and position of dune fields and river terraces, sequences of fossil plant and animal assemblages, ancient shorelines, growth lines in corals, tree rings and carbonate cave formations, and in the archaeological and the written records of ancient societies all contain elements of the story.

The history of the human race and its cultures owes much to past climate variability. Understanding past climates is one step towards understanding how we came to be who we are. No doubt the shape of our future will be strongly influenced by climate.

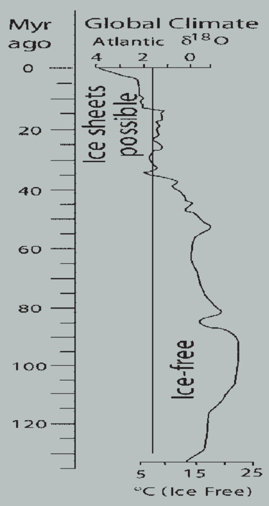
Scientists who research the dynamic Earth System know it is complex and undergoes constant adjustment. Now, for the first time, one species, *Homo sapiens*, has become a major agent in altering the Earth System and climate patterns. Humans are also becoming better at observing and understanding the way in which we alter these patterns, on scales relevant to the regions and societies in which people live. To do this effectively we need to understand the difference between both natural variability and that variability due to human influence – sometimes called "anthropogenic" variability. However, this apparently neat distinction will become increasingly blurred as time goes on.

Historical records reveal how important are the linkages between ocean, atmosphere and changes in land-cover. Our few hundred years of direct climate measurements contain only a small range of climate variability. Our ability to read the stone tape - records from the geological past - increases with advances in science and technology. It is vital however that representative examples of the best natural archives are kept safe for consultation by future scientists, who will come armed with deeper understanding and better technologies than we have today.

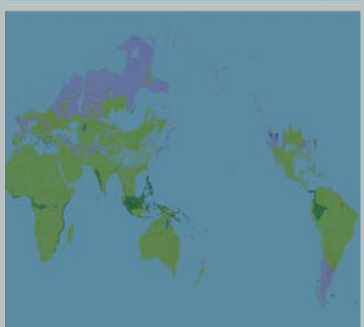
This document sets out a framework of questions that show how the Earth sciences contribute to a better understanding of climate change and suggests where future research will best contribute to the wellbeing of society.



The Earth has experienced several ice and greenhouse episodes in the past



Source M. Coffin, IODP



Key questions

What is the "big picture" of climate change patterns over the last four glacial cycles?

The Earth, which is about 4600 million years old, has experienced several ice and greenhouse episodes in the past. Since the 1960s it has been possible to say that there were many ice expansion episodes in only the last two million years or so. The most recent ice maximum – a mere 21,000 years ago - was one of the severest, and vast areas of North America, northern Europe and high mountain regions were covered by ice. High dry areas, such as the Tibetan Plateau had patchy ice cover at best.

Recent advances in reading and dating of records from the ocean, ice cores, and dust and fossil soil sequences from Central China reveal that the main climate events affected the whole Earth simultaneously. The best explanation for this is variations in the Earth's orbit around the Sun.

Scientists' attention has now shifted toward understanding how ice sheets build and collapse, and on the recent discovery that there have been many rapid and often short-lived events (on timescales of 100 to 1000 years). These cannot be related to orbital variations – they must relate to other Earth System processes. Such rapid and intense changes would cause major disruption to societies and economies if they recurred today.

New efforts are being directed to searching for the connections between phenomena. For example, how do events that start in the north Atlantic also seem to have effects in eastern Asia? What is the relationship between the various monsoon systems? How might change in one alter the dynamics of others?

Each ice maximum was associated with much lower global sea level than we see today. In some cases vast shelf areas became exposed and presented new migration routes for plants, animals and people, as well as obstructing flow of sea water between the Indian and Pacific oceans. The exposed continental shelves also increased the area available for production of (natural) greenhouse gases. Interpretation of the archaeological record and spread of humans certainly must take account of the sea-level story.

Recognizing the patterns across the most recent glacial cycles is essential background for understanding how climate systems work on a broad scale and (in the last two cycles) the development and spread of human societies.

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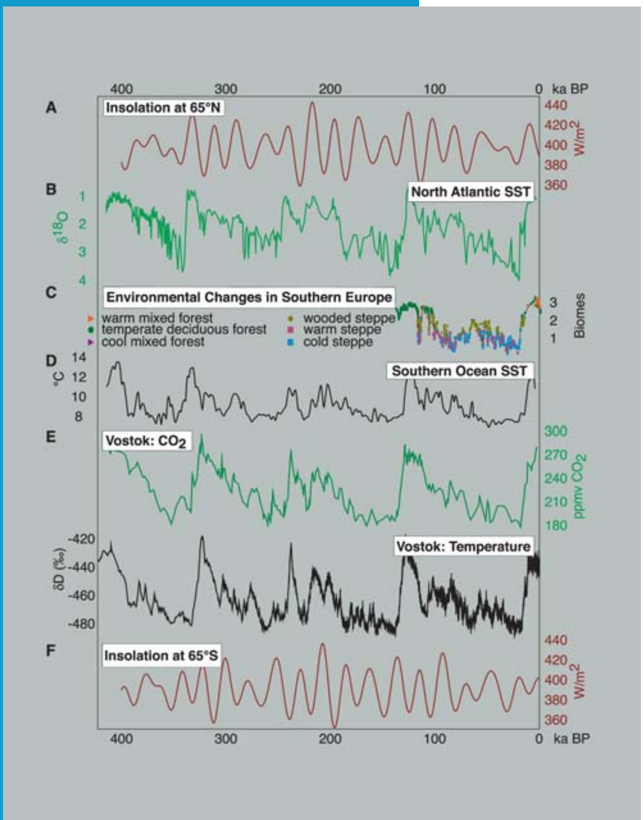
What has been the variability in climate over the last 1000 years?

This graph shows several records indicating synchronous climate changes from the last four glacial cycles (Alverson et al. 2003).



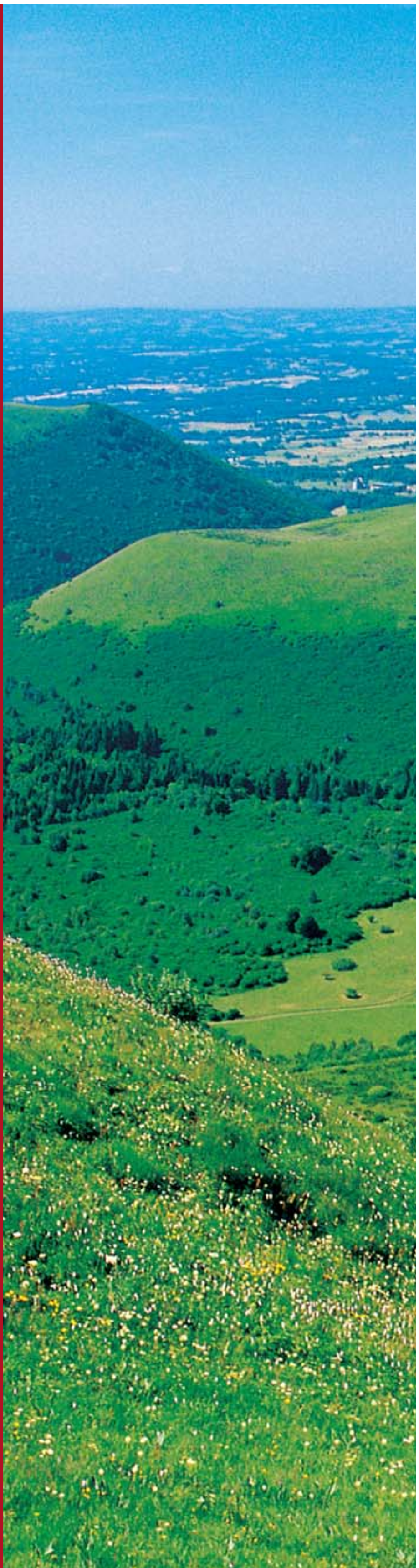
Climate varies in temperature, precipitation and the frequency of extremes such as drought, storms and floods. These impinge on productivity of natural and agricultural systems, bushfire frequency, water quality and damage to property and infrastructure.

The emerging view from the long-term climate record is important to modern societies because it provides a basis for understanding recent trends and their potential causes. The beginning of the Holocene (approximately the last 10,000 years) was a period largely free of human influence on climate systems. It is also the time when agriculture arose, apparently in several places (e.g. the Levant, Yangtze and Yellow River valleys). By about 5-6000 years ago agricultural systems were widespread in the east and west of the Eurasian continent. By 3000 years ago extensive areas were under cultivation elsewhere. The geological record tells us that all these changes were accompanied, the geological record tells us, by widespread forest clearing, increased burning patterns, and usually by increased erosion rates as well as the building of small scale engineering works to trap or divest landscapes of excess water.

Humans had by this time become a serious influence on landscape processes at regional scales - but probably not to the extent that climate modification was taking place. The mid-Holocene expansion of wetland agriculture may have led to the release of the greenhouse gas methane, a key launching point for human impact on atmospheric chemistry, changing its heat and water-holding capacity.

High resolution records of the recent past can be obtained from growth rings of long-lived trees, ice cores (which reveal layers equivalent to annual snowfall) and laminated lake sediments. All are sensitive at annual scale (or better) for reconstructing climate changes. The data sets for this are few, the best known being reconstructions of mean temperature for the last 1000 years for the mid to high latitudes of the Northern Hemisphere overleaf. Coverage is poor for the tropics and Southern Hemisphere during this time but the potential is there to discover it.

Many great civilizations have collapsed for a variety of reasons

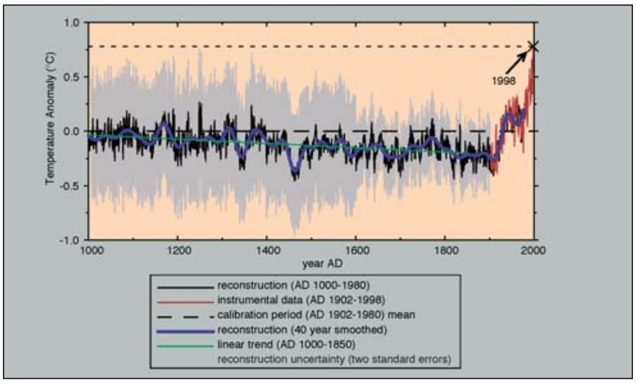


The Northern Hemisphere record shows relatively mild temperatures during the late 11th and 12th Centuries, and in the early and late 14th Century. Mean temperatures were cooler than present from the early 14th to 19th Centuries. These periods are generally supported by historical data, and are often referred to as the Medieval Warm Period and Little Ice Age respectively. Historical records show these had significant effects on societies. In warm periods wheat production occurred further north, and wine production was possible earlier in the season. In the Little Ice Age illness rates and agricultural decline in marginal areas was significant. In many cases the temperature anomalies were no more than 0.2 to 1˚C from those in the earlier part of the 20th Century. These small changes in mean temperature and their impacts are a telling point for sceptics who write off any significance for the 1-5˚C changes that are projected for the next 50 to 100 years. The second half of the 20th Century stands out as a particularly warm period.

What caused these changes? There is some suggestion that solar variability caused some of the long-term trends, but the recent warming is unprecedented. Many data series, such as they are, show that global climate is moving into territory unseen during the last 10,000 years and probably much longer. Variability in the energy output of the Sun, in the amount of volcanic gases and ash in the atmosphere and changes in ocean circulation have all been invoked to explain some of the trends seen in the last 10,000 years, none can explain the upward trend of the last half century. The idea that there is a strong human imprint on recent climate change is now compelling, with forest clearing, building and man-made gas emissions all having a strong influence on Earth's warming.

Despite this we still need to understand the relative importance of human versus natural influence on climate systems if we are ever to understand where the observed variability is coming from. Climate variation has a significant impact on people's lives. Research into such natural variations as El Niño and volcanic dust and gases in the atmosphere must have high priority, as it will help reveal the mechanisms by which climate variability occurs on timescales that are directly relevant to human societies.

Northern hemisphere temperatures for the last millennium Mann et al (1999), from Alverson et al. 2003.



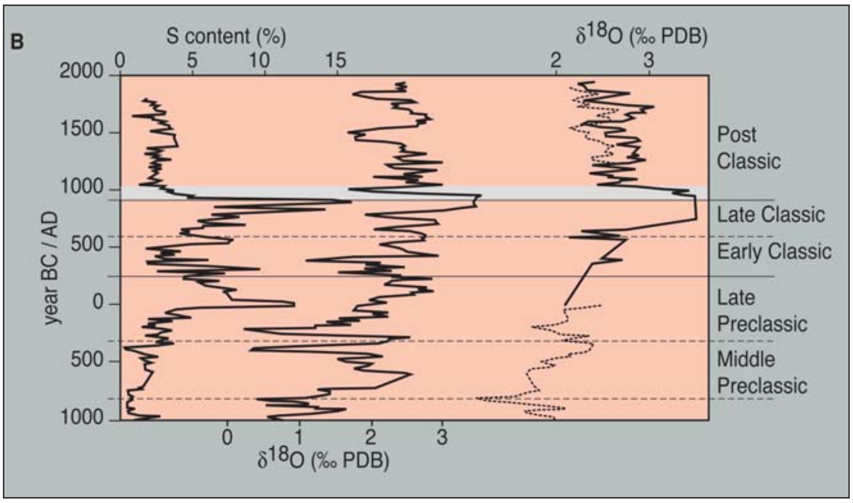
What impact has past climate change had on societies?

Many great civilizations have collapsed for a variety of reasons, including climate. Drought may have been responsible for the collapse of the Harrappan culture of northwest India, the Maya of Central America and the Hohokam of Arizona.

In other parts of the world too much water has been a problem. Peak water flow in the Yangtze, for example, occurs when run-off from the Tibetan Plateau coincides with summer monsoon rain. Serious floods occur every few years causing loss of life, crops and property – though these same floods bring fresh nutrient-rich sediments. During the Holocene people have battled rising waters with engineering works and where these failed the failure of rice crops has led to great hardship. Meanwhile in the Yellow River valley a combination of climate variability and pressure of land use has led to desertification in the north west and retraction of settlement towards the south east. Desertification continues today and the Chinese Government continues to relocate people and livestock.

Bringing together the great data sets of environmental change and history of societies will inform debates on technological innovation, early nation states, and may even help us understand some of the long-standing animosities between peoples in the Middle East, east Africa and elsewhere.

Climate and associated cultural changes (from Alverson et al. 2003).



Human activity has resulted in changes to atmospheric chemistry and land cover, and caused serious decline in biodiversity

Who is behind the International Year?

Initiated by the International Union of Geological Sciences (IUGS) in 2001, the proposed International Year of Planet Earth was immediately endorsed by UNESCO's Earth Science Division, and later by the joint UNESCO-IUGS International Geoscience Programme (IGCP).
The main aim of the International Year - to demonstrate the great potential of the Earth sciences to lay the foundations of a safer, healthier and wealthier society - explains the Year's subtitle: Earth sciences for society.

How will it work?

To achieve maximum political impact, the IUGS-UNESCO team aims to have the International Year proclaimed through the UN system, targeting 2006 as the Year itself. Its ambitious programmes cannot, however, be implemented in twelve months. We expect the Year's activities to begin in 2005 and culminate in 2007.

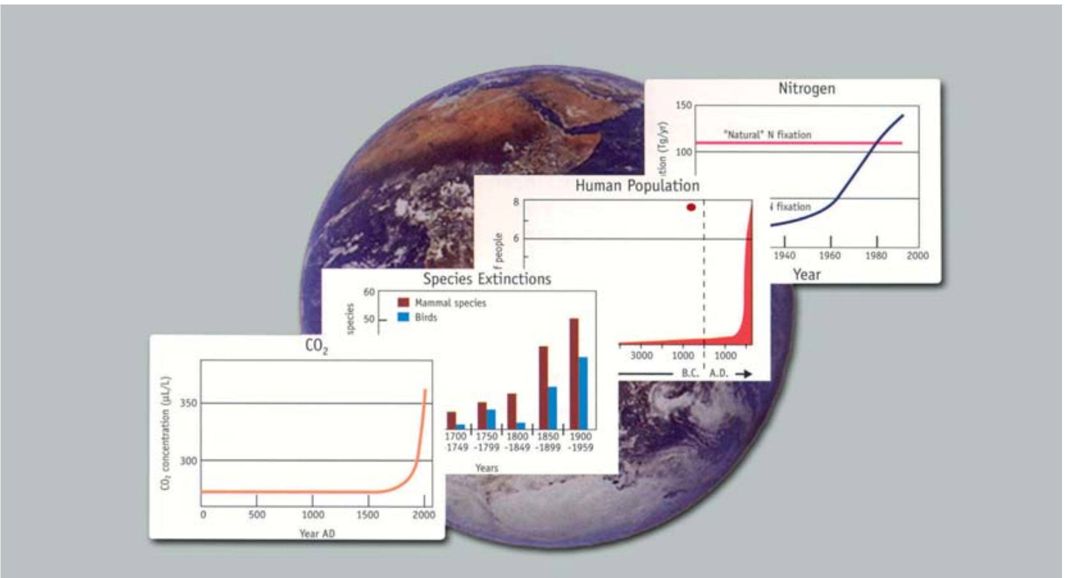
Modifying biogeochemical cycles leads to complex feedbacks

What is the role of human activities in climate forcing?

We know that human activity has resulted in changes to atmospheric chemistry and land cover, and caused serious decline in biodiversity. In addition thousands of new synthetic chemical substances have been produced whose role in the biosphere is not fully understood. Many lake systems, for example, have become acid as a direct consequence of industrial gas emissions over the past 150 years. Modifying biogeochemical cycles leads to complex feedbacks into key elements of climate systems and hence into economic activity and water and food security.

One of the ways we can monitor climate modulation by humans is to estimate the greenhouse gas emissions resulting from human activities. We can estimate the amounts but we cannot identify where they all end up. Are they trapped in the soil, incorporated into forest cover? Has the ocean absorbed much of them, or are all these - and maybe more - factors involved? Figure 7 attempts to separate human and natural factors in driving recently observed climate change.

The relative climatic contributions of land-cover change and changes to the chemistry of the atmosphere still remain to be worked out. Research priorities in this area require process-studies in biology, soil science (pedology) and oceanography, involving automatic monitoring, remote sensing and “ground-truthing” – in other words, the necessary reality check of actual field studies. In addition, studies of sediment chemistry in high deposition rate settings will also add detail.

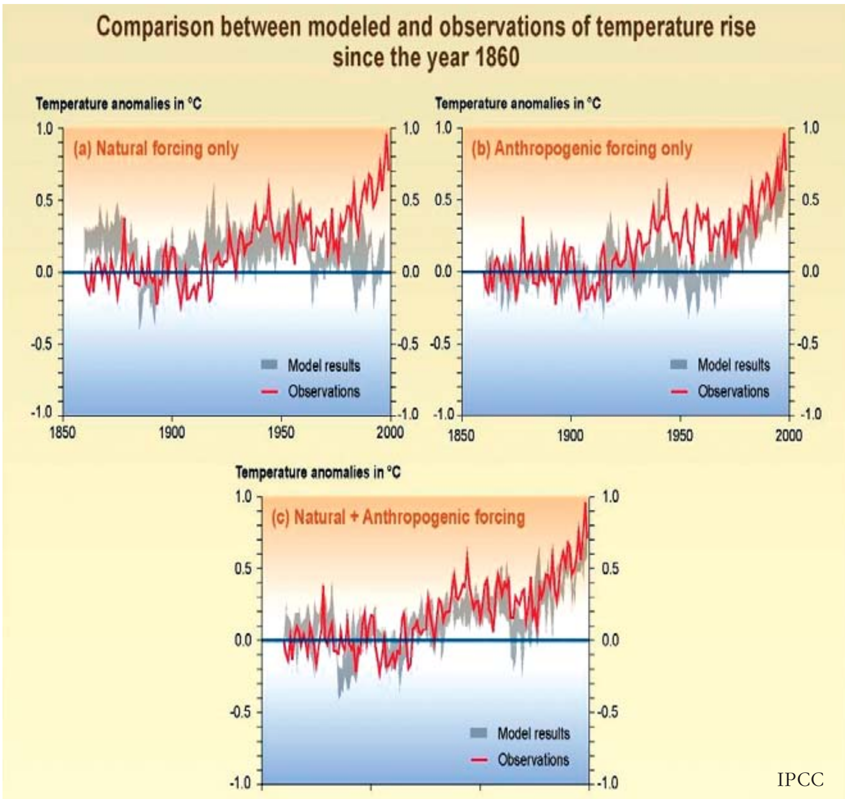


IGBP

What is the role of models in predicting future climate and how can we assess their merit?

Simulation models seem the best way forward for climate prediction. These use mathematical equations to describe the physical world and the dynamic feedbacks between ocean, atmosphere and land cover dynamics. The value of the model's output is compromised by our understanding of Earth systems, the degree to which reality can be described by mathematical functions and the power of computers to carry out the necessary calculations. Over 25 global climate simulation models are commonly used today. When these are run they often generate forecasts that differ to a smaller or greater degree. This reflects the difficulties of integrating the physical elements in a meaningful way, and the sensitivity of many elements of the system where small changes can be greatly magnified, as the geological record shows.

In recent times integrated systems have been developed linking climate, economic, demographic, industrial emission output, agricultural and natural ecosystem models. The better systems allow "feedback loops" among the various modules so that changes in one part of the system can be followed



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Simulation models seem the best way forward for climate prediction

Science programme

A panel of 20 eminent geoscientists from all parts of the world decided on a list of nine broad science themes - Groundwater, Hazards, Earth & Health, Climate, Resources, Megacities, Deep Earth, Ocean, and Soils.

The next step is to identify substantive science topics with clear deliverables within each broad theme. A 'key-text' team has now been set up for each, tasked with working out an Action Plan. Each team will produce a text that will be published as a theme prospectus like this one.

A series of Implementation Groups will then be created to set the work under the eight programmes in motion. Every effort will be made to involve specialists from countries with particular interest in (and need for) these programmes.

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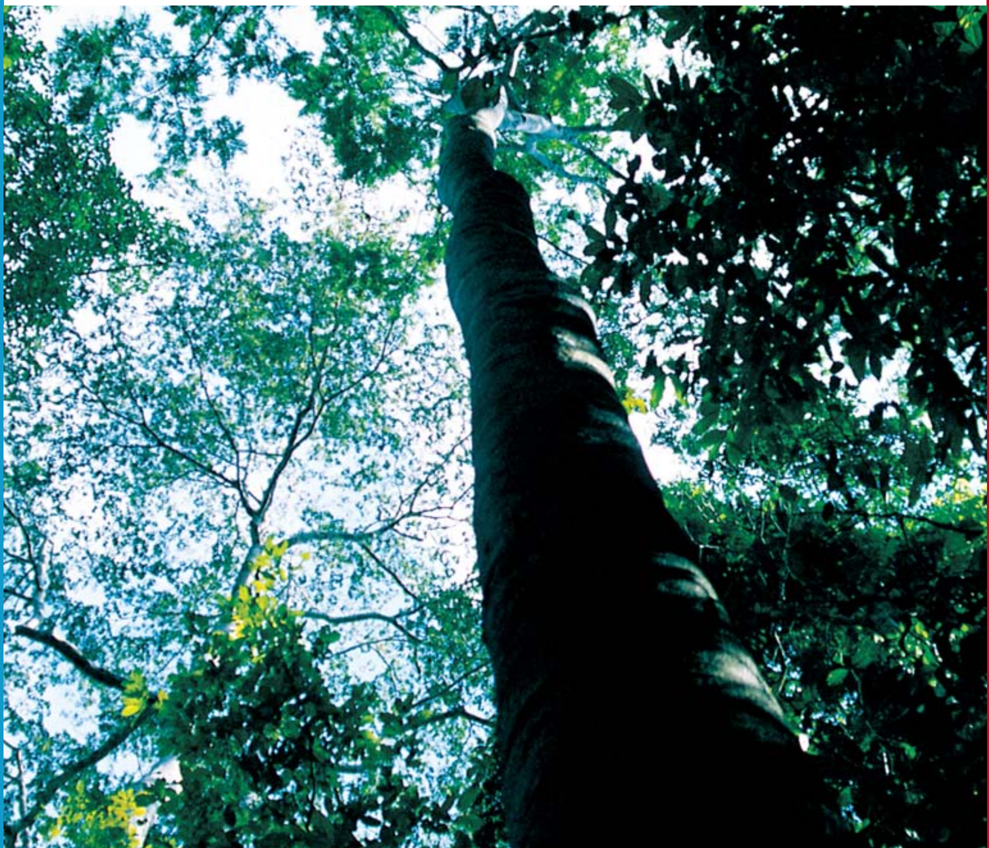
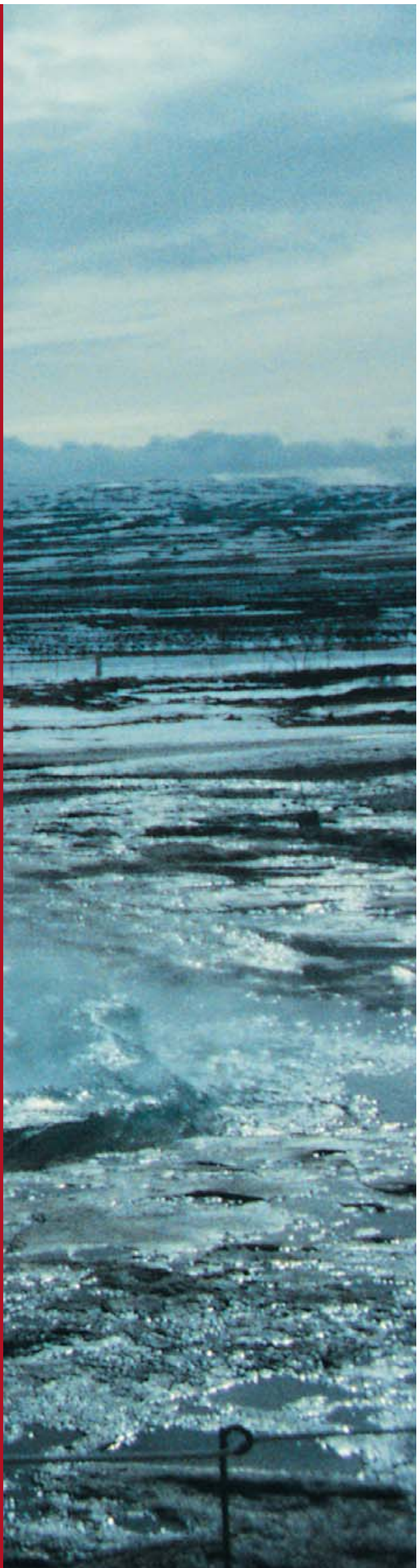
dynamically to other systems. A great strength of models is their ability to integrate data from various sources and assist our move toward a better understanding of Planet Earth. We should do our best to make models fit reality since the benefits of getting these systems functional will be a giant step in developing sensible planning approaches and something approaching sustainability of human activity.

An independent testing regime needs to be developed to identify the better models and ways of making them even better. One way of doing this is to initialise models with boundary conditions for selected time "windows" in the past. These include Earth orbital parameters, greenhouse gas concentration, atmospheric aerosol load, shoreline and sea-level, ice cover etc., as read from the "stone tape" – the geological record itself. Climate simulations for the selected time windows can then be generated and compared with regional palaeodata sets that have been used to infer past climate conditions.

Research priorities must include building better data series with a better geographical coverage, especially in the Southern Hemisphere and the Tropics; in the first instance they might focus on the more climatically sensitive regions. This will enhance the science of both modelling and palaeodata science, and raise the confidence of society in meaningful prediction of global climate.



Earth scientists have a distinguished record of studying past climates



What about the future and likely future climate trajectories?

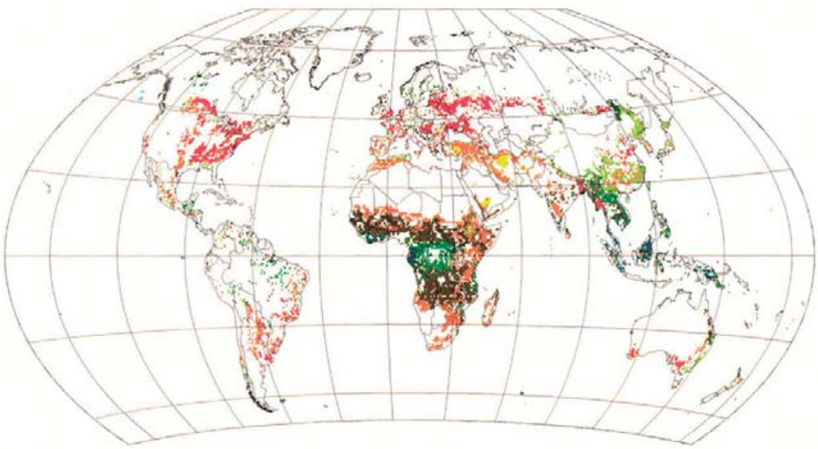
The future climate will impact on food security and agriculture, water supply and quality, storm and cyclone frequency, shoreline stability, biodiversity and the future of biological resources. Developing climate models will reduce the degree of uncertainty in regional climate prediction. However only the geological record can reveal the full range of Earth System variability and in the first instance remains a test bed for whether simulations are likely to be reasonable.

Earth scientists have a distinguished record of studying past climates and Earth systems, often studying the relationship between the two. Society may well ask them to focus part of their research agenda on identifying how a variety of scenarios, which directly affect the life chances of people, will play out through those systems. Good leadership will lead to informed decision making and prudent planning. Earth scientists might be asked to forecast any potential abrupt or environmental surprises. A sound knowledge of the Earth System will improve the chances of achieving this.

It might be fitting to remember an old Chinese proverb:

Things will be different FROM today…and we will do things differently…thus it has always been and ALWAYS will be.

This embodies ideas both about the Earth and those who live on it.



- Temperate forests
- Grasslands
- Deserts
- Savanna
- Tropical seasonal forest
- Tropical moist forest
- Wetland, mangrove etc.
- Agricultural land
- Ice
- Tundra
- Boreal forests

IPCC diagram showing possible changes in vegetation under a 2x CO_2 atmospheric scenario.

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Summary of Research Agenda

- Increasing our knowledge of the patterns in climate and environment over the last 2 glacial cycles.
- Identification of how glacial conditions develop and decline.
- Identification of the frequency and causes of abrupt events in the geological record.
- A better spread of high resolution data series, especially in the tropics and Southern Hemisphere.
- Better understanding of the tropical heat engine and on how it links to climate variability in temperate zones
- Targeted palaeoenvironmental studies where there are high quality archaeological records, especially those where cultural changes have taken place.
- Process studies in biology, geology, pedology and oceanography (involving monitoring, remote sensing and ground-truthing through field studies where appropriate) to identify the relationship between climate and change in systems. These studies should include a focus on variability in carbon flux since this may be helpful in understanding whether or not climate will change back into a glacial period.
- In order to throw light on global warming and possible future sea-level rise, locations in the world influenced by subsidence and uplift should be identified for comparative study.
- Foster research co-operation between model and palaeodata scientists.
- Technical advances in chronology methodologies.
- Analysis of instrumental and biophysical data to discover linkages, sensitivity, inertia and lags in systems across regions today.
- Several key researchers should be invited to a workshop to prioritise and develop the research agenda further.

Only one Earth

The human race needs its planet. We depend on it completely, because we evolved from it, remain forever part of it, and can exist only by courtesy of the self-sustaining Earth System.

The more we learn, the more we understand that we must nurture the Earth as we would our children, for their sake.

Earth science – key to sustainability

Earth scientists have unravelled many of the Earth's secrets and have made great progress in understanding how our planet works.

However, this information is often not properly used. We often build in the wrong places and exploit resources unsustainably, despite now being able to forecast many kinds of natural hazard with considerable accuracy.
We act as though we are still ignorant, when the key to a better life sits in our hands.

Earth scientists worldwide are ready and prepared to assist society arrive at a safer, healthier and wealthier environment for all.

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