The HOLIVAR programme seeks to bring together European scientists interested in climate variability over the last 11,500 years (the Holocene period). The scientists, principally include palaeoclimatologists, climate historians and climate modellers. The over-arching research questions of the programme concern how and why climate has varied naturally on different time-scales (annual to centennial) during the Holocene and how an understanding of past variability can be used to improve the performance of climate models. Although HOLIVAR is a free-standing programme it is also a contribution to the PAGES/CLIVAR intersection, a joint project sponsored by the International Geosphere Biosphere Programme (PAGES) and the World Climate Research Programme (CLIVAR).

Holocene Climate Variability (HOLIVAR)

An ESF scientific programme

Evidence for Holocene climate variability comes from several sources. Instrumental and documentary data are available for the recent past but natural archives of climate information, such as tree rings and peat bogs, are needed to extend the time-scales further into the past. However, the reconstruction of climate history from these proxy records depends upon a thorough understanding of all the processes involved in their formation and preservation, and to provide regional scale climate reconstructions it is necessary to combine the data from the different archives, a process that demands accurate dating and the use of multi-proxy databases.

The HOLIVAR community is particularly interested in Holocene climate modelling, how the models can be further improved and how in turn they can be used to understand past climate change. A key issue is specifying the external climate forcings to be used in the models and the extent to which proxy methods can be used to identify past variability in forcings. Improved time-series of solar irradiance is especially needed.

Data–model comparisons for the entire Holocene will not be possible for many years. However, progress can be made by focussing on time periods within the Holocene of known rapid change using models of intermediate complexity (EMICs) and on the last millennium in particular using fully coupled atmosphere-ocean general circulation models (AOGCMs).

The ultimate HOLIVAR objective is to engage with historians and archaeologists in studies of past climate-human society interactions both to examine the role of climate change as a potential cause of changes in human activity in the past, and to gain an insight into how humans might respond to climate change in the future.

The European Science Foundation acts as a catalyst for the development of science by bringing together leading scientists and funding agencies to debate, plan and implement pan-European initiatives.

Introduction

The ESF HOLIVAR programme seeks to bring together European scientists interested in climate variability over the Holocene period, broadly the last 11,500 years of earth history. The scientists involved in the programme include palaeoclimatologists, palynologists, palaeolimnologists, glaciologists, geochemists, oceanographers, climate historians, archaeologists and climate modellers. The over-arching research questions are:

- how and why has climate varied naturally on different time-scales (annual, centennial and millennial) over the Holocene period?
- how can an understanding of past variability improve the performance of climate models, leading to an improved prediction of future climate change?
- how can climate models help to explain past climate change?
- how has climate variability and the nature of human society interacted during the Holocene?

Although these are questions relevant for the world as a whole, the HOLIVAR programme focuses mainly on research in Europe, and is allied closely to the aims and objectives of the Past Global Changes (PAGES) PEP-III project *(http://www.pages-igbp.org/)* that is concerned with climate change along a pole to pole transect through Europe and Africa.

Scientific rationale

There is increasing evidence that greenhouse-gas forcing is becoming one of the dominant, though not the only process driving global warming. Consequently, future climate change will be the result of interactions between the effects of human-induced changes and the effects of natural variability. There is therefore an urgent need to understand these interactions, to document and identify the characteristics of natural climate variability and to improve the performance of climate models that seek to predict future climate change.

Natural variability, whether associated with mechanisms external or internal to the earth system, is expressed on interannual, decadal, and century time-scales. Data for only the most recent part of the historical record can be derived from instrumental measurements and, therefore, there is a need to extend the instrumental record backwards in time using documentary records and proxy records contained in naturally occurring archives such as lake and marine sediments, peat bogs, tree rings, speleothems and ice cores *(Figure 1, cover page)*.

However, none of these archives alone is adequate to capture the temporal and spatial variability needed for regional comparisons with climate model output. Consequently the primary requirement is to combine and harmonise palaeoclimate data from the different records and archives and to develop the use of multi-proxy databases that enable data to be manipulated and translated into formats that facilitate comparison with climate model simulations *(Figure 2)*.

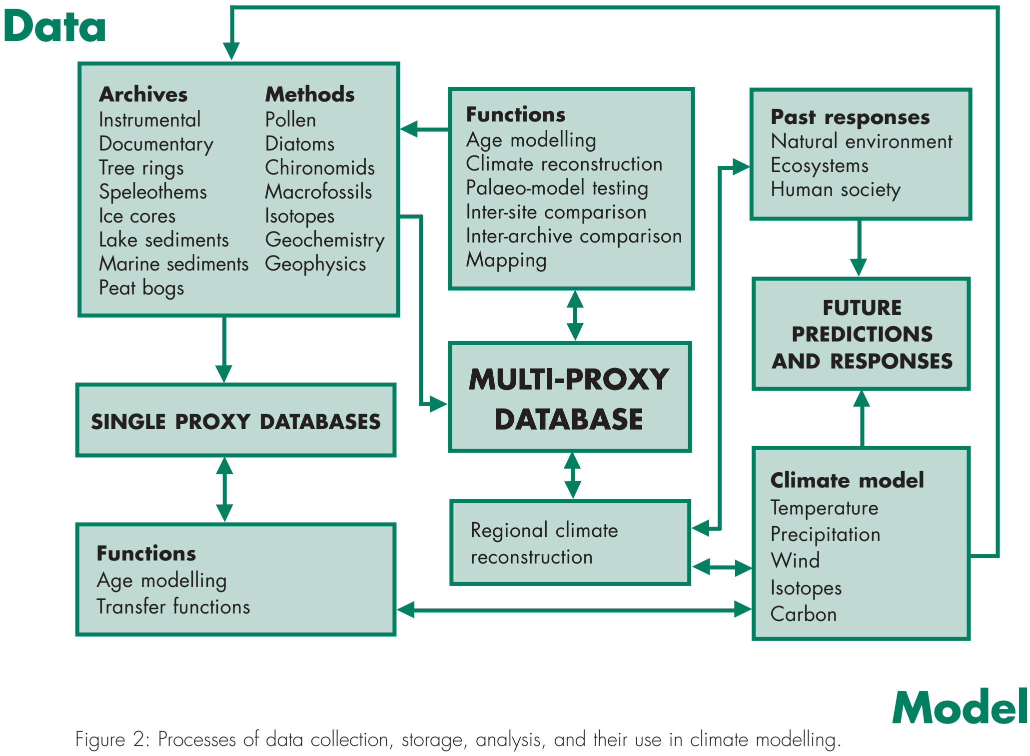

Figure 2: Processes of data collection, storage, analysis, and their use in climate modelling.

Instrumental and documentary climate records

Continuous instrumental records of temperature, precipitation and other climate-related variables are available for the last one to two centuries. They are insufficiently long to capture centennial-scale variability but, especially after homogenisation, are of fundamental value in providing verification for model results and as a means of calibration for proxy records.

Documentary sources cover a longer period, though they tend to be discontinuous in time and space, and are often difficult to quantify. They are particularly valuable, however, as sources of information on extreme events, such as floods, droughts and severe frosts.

Extending instrumental records using proxies from natural archives

Natural archives such as tree rings, speleothems (cave stalagmites), lake and marine sediments, peat bogs, and glacier records preserve environmental responses to climate change.

Some are annually banded *(Figure 3)* allowing calendar ages to be derived, others have no in-built seasonal or annual structures but can be dated, albeit with less precision, using radiometric methods such as radiocarbon dating. In this case radiocarbon years can be converted into calendar years using a tree-ring based calibration or ^{14}C wiggle-matching.

The climatic information in these archives is stored in the form of physical, chemical and biological properties referred to as proxy climate indicators or climate proxies *(Figure 4)*. Each of the major archives contains a range of climate proxies (e.g. stable isotopes, diatoms), and some proxies occur in more than one type of archive. The exact relationship

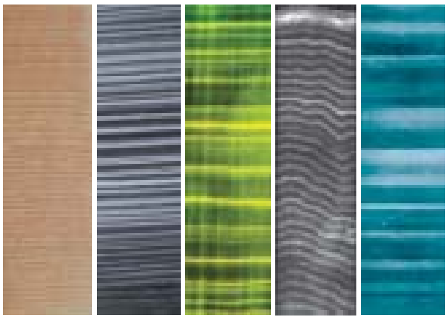

Figure 3: Annually banded archives: (from left to right) tree rings of Huon pine from Tasmania (E Cook); varves from Lake Holzmaar, Germany (B Zolitschka); speleothems from Rana, Norway (J Kihle); coral from Papua New Guinea (S Tudhope); ice from GISP2, Greenland (A Gow)

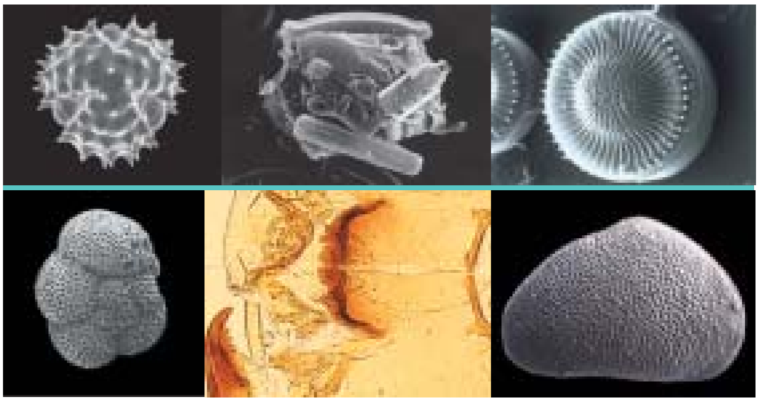

Figure 4: Microfossils used as climate proxies: (clockwise from top left): pollen (*Aster linosyris*) (H Halbritter); testate amoeba (*Difflugia bacillariarum*) (D Charman); diatom (*Cyclostephanos tholiformis*) (C Sayer); ostracod (*Sarscypridopsis aculeata*) (R Jones); chironomid (*Heterotrissocladius subpilosus*) (S Brooks); foraminifera (*Neogloboquadrina pachyderma*) (UCL)

between climate proxies and climatic variables such as temperature, rainfall, or wind can be indirect and complex. Reconstruction of climate history from proxy records therefore depends on a thorough understanding of the processes governing the formation of the proxy climate signals, their incorporation into the archive, and the preservation of their integrity over time.

Climate proxies can be calibrated by developing transfer functions which describe the relationship between a climate proxy and climate across the modern-day environmental gradient and are validated by comparing their recent record with historical climate data. Because each climate proxy has its own particular strengths and weaknesses, the reliability of climate reconstructions can be further improved by integrating data from different proxies and across archives. Consequently, one of the aims of HOLIVAR is to encourage this multi-proxy, multi-archive approach *(Figure 1)*.

Combining data to provide regional scale climate reconstruction

Combining data from different archives is not a trivial task. It requires both scientific and institutional commitment. Scientifically the key issue is to improve the accuracy and precision of dating techniques and to increase the robustness of the age models that are used in making independent comparisons between data from different sites. Institutionally combining data requires scientists to be willing to contribute data to common databases using a harmonised approach that allows database queries across data types to be processed swiftly and efficiently. HOLIVAR stresses the need to develop a central, multi-proxy data system of this type to bring proxy climate data together and ultimately to enable regional climate reconstruction through the Holocene.

Holocene climate modelling

The earth's climate is a system of immense complexity, incorporating numerous sources, sinks and transports of material and energy, with complex feedbacks operating between different parts of the system. Changes in the climate system over time can be simulated using models of varying types and complexity. These include comprehensive coupled atmosphere-ocean general circulation models (AOGCMs), earth system models of intermediate complexity (EMICs) and more simple energy balance models (EBMs). AOGCMs have the advantage of high spatial resolution and include representations of many key processes in the system but the disadvantage that long time-scale simulations are expensive and slow to run. However, simulations of the last 250-500 years are becoming available and the HOLIVAR community has a special interest in data-model comparisons over this time period that spans the intersection between instrumental, documentary and proxy record availability and that covers a known period of relatively rapid climate change from the "Little Ice Age" to the recent period of warming. The less complex EMICs have the advantage of speed and allow experiments and sensitivity testing to be carried out over longer time periods on centennial to millennial time-scales *(Figure 5)*. HOLIVAR will in particular encourage simulations of events that are well known from palaeoclimatic data.

Understanding climate forcing in the Holocene

Climate models, whether GCMs or EMICs can be used to perform control runs that simulate the inherent variability in the climate system or forced runs that simulate the response of the system to changes in external forcings. External forcings, in turn, may be either natural, e.g., changes in insolation from orbital variations, solar activity or volcanic aerosols *(Figure 6)* or anthropogenic e.g. changes in land cover, greenhouse gases or sulphate aerosols.

Whilst the timing and magnitude of some of the these forcings are reasonably understood over the very recent period (last 100 years) uncertainty increases with age and currently limits the usefulness of expensive GCM simulations over periods longer than the last few centuries. For Holocene simulations improved time-series of solar irradiance variations are especially needed. The extent to which such information can be provided from the record of cosmogenic isotopes (such as ^{10}Be and ^{14}C) in natural archives is a key issue for the HOLIVAR community.

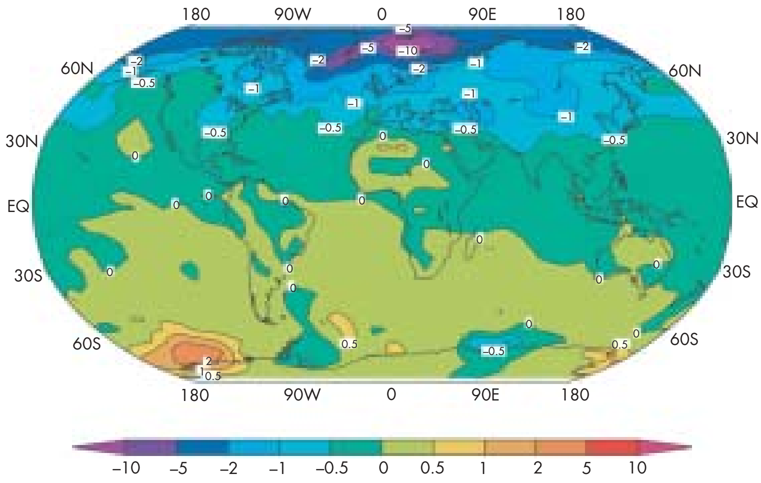

Figure 5: Annual mean surface temperature anomaly for the 8.2K event simulated by an EMIC (from Renssen, H,H Goosse, T Fichefet, and J M Campin, *Geophysical Research Letters* 28, 2001)

Comparing model output with palaeoclimate data

One of the key objectives of HOLIVAR is to encourage the comparison between model simulations and palaeoclimate data, using data to test and improve model performance on the one hand, while using model experiments to investigate the causes of past climate variability on the other hand. Data-model comparisons are not straightforward, however, because the characteristics of model output and palaeodata are very different, especially with respect to scale and uncertainty. Proxy records integrate climatic information only locally over space, but often over longer time periods (seasons to decades, or more), as if climate history has passed through a low-pass filter. They also respond to non-climatic drivers, making their climatic interpretation imprecise. In contrast, numerical models simulate climate at larger spatial scales, not resolving variations at scales near to or less than their resolution (typically hundreds of kilometers). Matching the two approaches consequently requires the use of scaling techniques. In the inverse approach, climate is reconstructed from the proxy data, usually with some spatial aggregation to a scale appropriate for comparison with the climate model simulation, whereas the forward

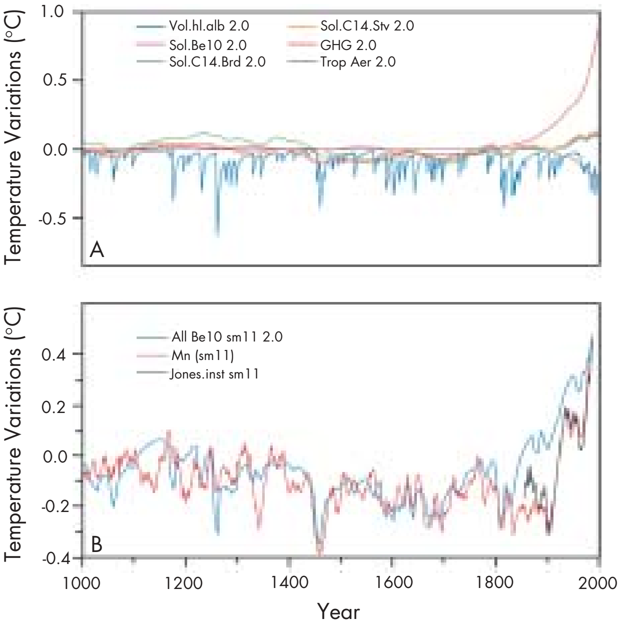

Figure 6: (A) Northern Hemisphere temperature forcing over the past 1000 years attributable to documented volcanic eruptions (blue), solar variability (magenta, green and orange), anthropogenic greenhouse-gas emissions (red) and air pollution (brown), as calculated with an energy-balance climate model.
(B) Comparison of the combined temperature effect of these four natural and anthropogenic climate-forcing mechanisms (blue) with the instrumental temperature record (black; AD 1860-1993) and an integrated Northern Hemisphere temperature reconstruction based on natural archives with annual resolution and age control (red; AD 1005-1993) (from Crowley, T J, *Science* 289, 2000)

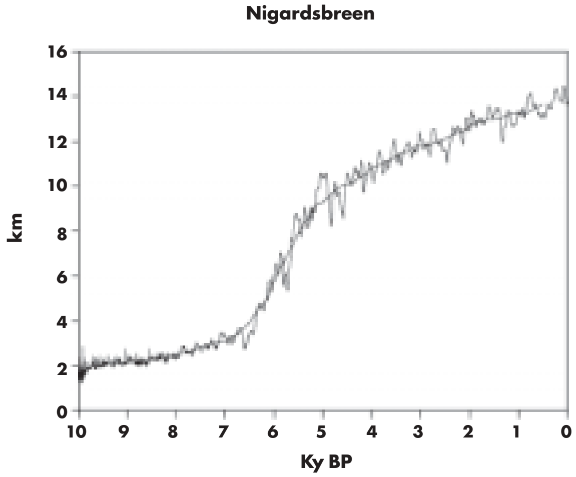

Figure 7: Glacier length (in km) for Nigardsbreen as a function of time (in kyr BP) showing a phase of rapid expansion and high variability during the mid-Holocene. Length of records are generated using a process-based glacier model coupled to the climate model ECBilt, which is driven by orbital forcing (from Weber, S L, and J Oerlemans, *The Holocene*, 2003)

approach involves the comparison of actual proxy data with simulated proxy time series generated by process-based or empirical models that are driven by climate model output that has been downscaled to the proxy site (Figure 7). HOLIVAR seeks to encourage the development of both approaches. The inverse approach can be facilitated by harmonising and combining proxy data at the regional scale using multi-proxy data systems for sharing and manipulating data, and forward modelling has major future potential as it allows the exploration of the processes that lie behind the climate-proxy relationship.

Data–model comparisons for the entire Holocene will not be possible for some years as an extended period of time is needed for data compilation and synthesis to take place. However, progress can be made by focussing jointly on time periods within the Holocene of known rapid change and for which data are available, such as the 8.2 ky BP cooling event, the period of aridification in low latitudes in the mid Holocene, the Sub-boreal/Sub-atlantic transition (about 2750 BP), and the last millennium.

Climate-human society interactions in the Holocene

Studies of past climate-human society interaction can contribute strongly to debates on the collapse of past civilisations and, although the nature of human society is today very different, they can provide useful insights into how humans might respond to climate change in the future (Figure 8). There are many examples throughout the world of rapid population expansion and decline during the latter part of the Holocene, and in most cases the role of climate, directly or indirectly, has been a central topic of debate. Explanations for civilisation collapse often range from the purely deterministic with climate as the main driver to those that favour human-induced over-exploitation of resources, environmental degradation or the development of dysfunctional societies, irrespective of climatic influences. Of key importance in these debates is the availability and quality of the palaeo-environmental data needed to assess the relationships between environmental and societal change.

Consequently HOLIVAR seeks to encourage the palaeoclimate research community to improve further our understanding of climate variability and its impacts across archaeologically important regions, and to engage in these debates with historians and archaeologists.

Figure 8: Multi-phase rock art from the Ennedi, NE Chad. Rock paintings of domesticated cattle in a currently arid region illustrating humid conditions during the early and middle Holocene. Late Holocene drier conditions are indicated by superposed camel drawings less than 200 years old. (S Kroepelin, Heinrich-Barth-Institute, Cologne)

Activities

Open Science Meetings

The HOLIVAR programme began in 2001 with an international conference co-sponsored by IGBP-PAGES in Aix-en-Provence on *Past Climate Variability through Europe and Africa*. The proceedings of this meeting will be published in 2003 by Kluwer. The programme will end in 2005 with a second international meeting on *Holocene climate variability: data, models and impacts*. scheduled for September 2005 in London.

Workshops

HOLIVAR has scheduled a series of annual workshops as follows:

- *Combining proxies*, April 2002 in Lammi (Finland); organised by Matti Saarnisto and Antti Ojala
- *Data-model comparisons*, June 2002 in Louvain-la-Neuve (Belgium); organised by Hans Renssen and Tim Osborn
- *Holocene dating, chronologies, and age modelling*, April 2003 in Utrecht (The Netherlands); organised by André Lotter
- *Database meeting*, scheduled for 2003/4
- *Holocene climate forcing*, scheduled for 2004
- *Climate-human society interactions during the Holocene*, scheduled for 2005

Training courses

Training courses that include all the HOLIVAR themes and that stress and exemplify the need to integrate climate change science are planned. The course title is *Quantitative Holocene climate reconstruction and data-model comparisons.* They will be offered both in 2003 and 2004 and are designed to bring together students with both modelling and data interests. The first course will take place in London, 23rd June – 4th July 2003.

External links

HOLIVAR is concerned with scientific issues identified as being of international importance for climate change studies by the PEPIII research community in IGBP-PAGES. It is also a contribution to The PAGES/CLIVAR Intersection which is a shared research agenda between WCRP and IGBP.

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For the latest information on this programme consult the *HOLIVAR* home page: www.esf.org/holivar

Figure 1 (cover):
Naturally occurring archives of palaeoclimatic proxy record (clockwise from top left): Raised bog profile, Bargerveen, the Netherlands (B van Geel); Lochnagar, Scotland (M Hughes); Quelccaya ice cap, Peru (L Thompson); Crag Cave, Ireland (A Baker); *Pinus sylvestris* (K Briffa); Ocean Drilling Program's drillship *JOIDES Resolution*, (ODP)

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