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Layout: Christoph Kull
Circulation: 3400

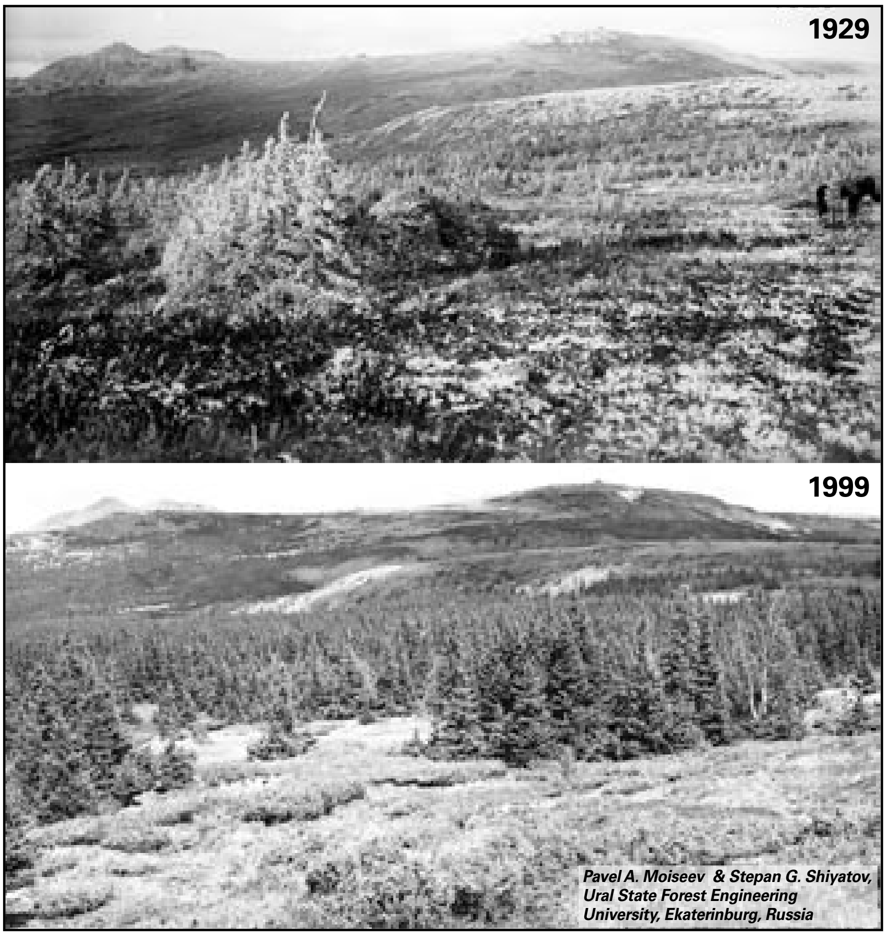
www.pages-igbp.org

PAGES PAST GLOBAL CHANGES News

André Paul, Guest Editor
Christoph Kull and Keith Alverson, Editors

Vol.11, N°1 – April 2003

Rates of Change



A pair of photos from the "Bol'shoi Irmel" mountain in the Southern Urals (Russia). The increasing density and height of the stands as well as the upward movement of the treeline during the 20th century is obvious (see Shiatov, this issue). PAGES is looking for similar pairs of illustrations about global change for its image database. Please contact: kull@pages.unibe.ch

Contents

ISSN 1563–0803

The PAGES International Project Office and its publications are supported by the Swiss and US National Science Foundations and NOAA.

Editorial

Much of paleoclimatologic research has focussed on (quasi-) equilibrium climate states of the past, such as the Eemian (roughly between 140,000 and 117,000 years before present) or the Last Glacial Maximum (21,000 years before present). Here the terms "climate state" and "climate system" include the whole Earth system as dealt with by climatologists, geologists and ecologists, among others. By making comparisons with the present-day climate state, we have been able to infer the magnitude of climate-sensitivity parameters, for example, the sensitivity to changes in radiative forcing. However, only non-equilibrium or transient climate states, such as the last deglaciation, allow us to assess the magnitude of the inertia of the climate system, for example, the effective heat capacity of the oceans. This inertia constitutes the resistance to changes in climate forcing and the memory of the climate system. It is of ultimate importance when considering the ongoing climate change in response to greenhouse gas and aerosol concentrations in our atmosphere.

Table 1: Rates of Change - Summary of the results derived from the studies presented in this issue.

Climate Variable (Proxy)	Modern Rate of Change	Past Rate of Change	Region/Period in the Past
CO_2 Change *(Stocker and Monnin)*	Mauna Loa, 1.3 ppmv/year (1958 - 1999) (200 ppmv/century)	1.5 to 2.5 ppmv/century	Antarctica Deglaciation intervals
Mid - Depth Ocean Temperature *(Rühlemann et al.,)*	0.5 °C/century	0.7 - 0.8 °C/century	Beginning of YD
Sea Level Rise *(Harvey)*	1 - 2 mm/year	9 - 24 mm/year	Deglaciation
Mass Balance, Aletschglacier *(Häberli & Holzhauser)*	-0.39 m/year (20th cent.) -1 m/year (1980 -2000)	-0.51 m/year	Onset "Medevial Warm Period"
Ural-Timberline Changes *(Shiatov)*	2 - 4 m /decade	1 - 4 m/decade	Last Millenium
Advance of European Oak Forest *(Cheddadi)*	Adaptation requires: > 100 km /century	100 km/century	Deglaciation

How fast did the climate system respond in the past? Estimates of past rates of change provide us with a long-term perspective on recent changes and help us to appreciate their magnitude. Furthermore, they give us a taste of how rapid climate change may operate in the future. State-of-the-art earth system models require a variety of estimates for the inertia of the climate system in order to make reliable predictions for the future. These inertia coefficients go beyond the effective heat capacity of the oceans that characterized the simple energy balance models of the early days of climate modeling in the late sixties of last century.

In the accompanying table, we collected estimates of rates of change that relate to atmospheric CO_2 as the primary climate forcing, as well as to such diverse components of the climate- and earth system as eurasian forests, alpine glaciers, the hydrological cycle of the Mediterranean area, the intermediate-depth Atlantic Ocean and the global sea level. A large number of important parameters are still missing from our table (e.g. regional air temperature and precipitation, frequency of extreme events such as storms and floods, biodiversity, land-cover etc.) and we would like to challenge our colleagues to fill in the respective values.

Taking into account that climate dynamics are crucial in assessing ongoing climate change, we recommend that the paleoclimatology community shifts gears and moves towards dynamic paleo-reconstructions. These must include the human dimension, which may have played the role of driver in the recent past as well as in the present. The PAGES office could help in this process by editing a special issue of a journal, dedicated to reconstruction and modeling past rates of change, and relating them to the present.

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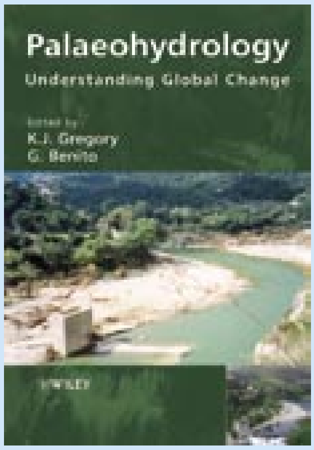
New on the PAGES bookshelf:

Palaeohydrology: Understanding Global Change



K. J. Gregory, Gerardo Benito (Editors)
ISBN: 0-470-84739-5, Hardcover, 392 p, April 2003, £95.00
www.wileyeurope.com/cda/product/0,,0470847395|desc|2877,00.html

With considerable interest in global change, this topical book provides a general overview of global paleohydrology. The first section provides a global review of the field by exploring real world hydrological scenarios during past environmental changes over extensive areas of Europe, America, Africa, Asia and Australasia. This is followed by an up-to-date review of the key methodologies of fluvial palaeohydrology and the hydrological methods for palaeohydrological construction

Tales from the Field

Forcing Mechanisms of Fieldwork in Yemen

Since 1995 our research group in Bern has been using stalagmites from Oman, Yemen and Saudi Arabia as paleoclimate archives. In 1999, we visited a cave in Hadramaut in Southern Yemen to drill a core out of a 3 meter long stalagmite (see photo). For tidy-minded scientists from Switzerland, Yemen is a strange and also fascinating country for many reasons. One peculiarity is the bureaucracy, which at times behaves much like the climate system. For Yemen this means that the paleoclimatologist must distinguish between an external (governmental) and an internal (tribal) forcing, where internal tribal forcing (ITF) shows a highly non-linear response to external governmental forcing (EGF). EGF and ITF were not in phase in the past (pers. communications) and fully coupled GBM's (General Bureaucracy Models) reveal that this relation will also not change in the near future. However, these facts were almost unknown to us when we arrived at the cave site. We felt safe for two reasons: (1) we were equipped with numerous official permissions from the ministry of interior and Sana'a University and (2) two soldiers, armed with the famous AK-47 (better known as Kalaschnikow) were guarding us. Because of these two facts we believed that EGF and ITF are indeed in phase. However, after three days of successful drilling we heard a loud discussion at the cave entrance and suddenly 10-15 angry persons, some armed with the AK-47s, entered the cave. They were accompanied by our two Yemeni colleagues (see photo), who told us what had happened at the surface 30 minutes before. They were sleeping outside, guarded by the two Yemeni soldiers (EGF), when they suddenly woke up and found themselves looking into several AK 47 barrels (ITF). Our two colleagues realised immediately that EGF was much weaker than we had assumed: the two Yemeni soldiers had disappeared. After 30 minutes of negotiation we convinced the people that we were neither digging for gold nor for diamonds but only for stalagmites. However, we were forced to immediately leave the cave and also our beautiful stalagmite. To be able to continue our work, we visited the local sheik (very strong ITF) the next day and tried to convince him of the necessity of our studies. At this point in time ETF was not strong enough to dampen the effects of ITF. However, after 2 hours of negotiation and hundreds of dollars (also known as bakschisch forcing BF) we finally received permission to continue our work. Over the next few days we drilled the stalagmite twice because the local people insisted on getting some of these obviously important and valuable samples. To summarize, ETF and ITF are dominated by BF. Additional studies from low and high-latitude countries are needed to better reveal the interaction between ETF, ITF and BF on a global scale.

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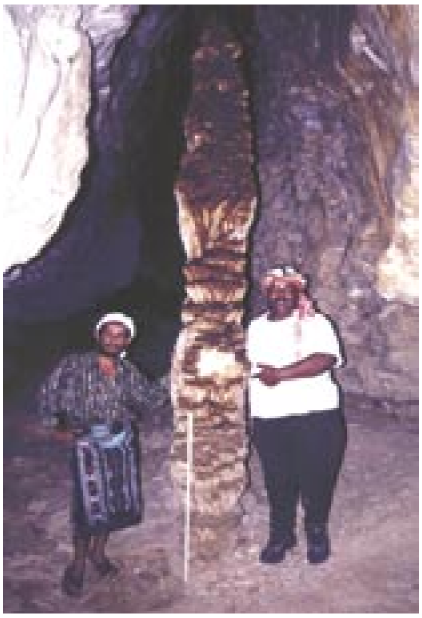

Fig. 1: Two Yemni helpers in front of the cored stalagmite. (Photo: D. Fleitmann)

Do you have an interesting and humorous story from your paleoenvironmental fieldwork? If you write it down in 500 words or less and send it to us, we will put it in PAGES news!

Inside PAGES

After several months maternity leave, **Selma Ghoneim**, the PAGES Office Administrator is back in the office. Congratulations on your son, Selma. **Antti Ojala**, a paleolimnologist and Quaternary geologist from the Geological Survey of Finland, was a visiting scientist at the PAGES office for a week in March. Antti was working on guest editing of the next issue of PAGES News, a special issue co-produced with the ESF HOLIVAR program. Starting in April **Olga Solomina** a dendrochronogist and glaciologist from the Russian Academy of Sciences Institute of Geography, and member of the PAGES Scientific Steering Committee, began a three month stint as guest scientist at the PAGES office. Her primary task will be editing a PAGES special issue of the Elsevier Journal Paleo –geography –climatology -ecology entitled "High Latitude Eurasian Paleoenvironments" – one outcome of a PAGES meeting held in Moscow last year.

Call for Contributions:

For the next issue of PAGES News science highlights relevant to the Holocene as well as the usual workshop reports and program news are welcome. If you are interested in contributing, contact **Christoph Kull** (kull@pages.unibe.ch). All submissions should follow the instructions for authors on our web-site (www.pages.unibe.ch/products/newsletters.html) and be submitted by May, 20th 2003.

The German Climate Research Programme DEKLIM

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The German Federal Ministry of Education and Research (BMBF) has launched a new climate research programme. DEKLIM, the German climate research programme pursues the following objectives.

- To improve understanding of the climate system and possible human influences on it.
- To reduce uncertainties in analysis and forecasting.
- To derive strategies for dealing with climate change (adaptation and mitigation).

DEKLIM's major aims are to increase integration of German research in the international assessment of climate development and to provide basic know-how and guidance in the field of practical climate protection measures. DEKLIM research activities started in 2001 with a runtime of up to 5 years. More than 100 individual projects co-operate in 37 joint projects, forming 4 major areas of research. DEKLIM also offers young scientists an opportunity to gain experience in heading research groups or in interdisciplinary co-operation. The financial volume of all DEKLIM projects amounts to 37 million $.

DEKLIM primarily supports larger integrated interdisciplinary networks. Research topics range from the examination of tree rings to satellite-based observation of land use changes, from climate simulation using numerical models to the development of strategies for sustainability of a rainforest margin area.

Selected spokespersons guarantee intensive communication, co-ordination and co-operation amongst the following 4 areas of research (Fig. 1):

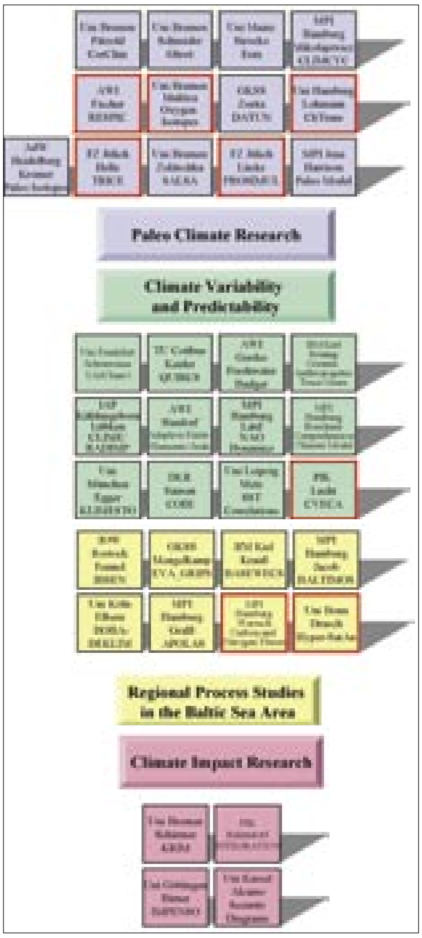


Fig. 1: The DEKLIM research structure.

1. Climate Variability and Predictability

This area provides greater insight into the variability of today's climate. DEKLIM is closely linked to the World Climate Research Programme (WCRP) CLIVAR and especially the German contribution marin/CLIVAR, which comprises 11 projects funded by BMBF.

DEKLIM comprises integrated research projects which study the relevant climate subsystems or the climate system as a whole.

2. Regional Process Studies in the Baltic Sea Area

DEKLIM includes 8 research groups working in the catchment area of the Baltic Sea. Multidisciplinary research networks investigate how changes in the atmosphere, sea and land surface affect the climate in this region. Climate predictions in the Baltic are of practical significance for the Baltic states, particulary with regard to annual ice cover variability. DEKLIM projects are also providing an important contribution towards the final evaluation phase of the Baltic Sea Experiment (BALTEX), a sub-programme of the WCRP.

3. Paleoclimate Research

The principal objectives of DEKLIM paleoclimate research are:

- understanding how and why climate and ecosystems have varied in the past;
- assessing how climate change and variability have affected natural ecosystems and human society in the past;
- providing a basis both for developing and testing climate models that are needed to forecast climate change in the future.

For these reasons it is understandable that the DEKLIM projects in this area are closely linked to the IGBP program PAGES. For example the project EEM (climate change at the very end of a warm stage) is using high resolution geo-archives allowing annual time resolution. Eolian dust, pollen or stable isotope data serve as indicators of past atmospheric temperature and precipitation. Time series from the geo-archives are compared with modeled insolation forced climate time series. The synthesis of all nine research groups results will provide perspective on likely climate variability during the end of the ongoing warm-stage. Finally, both the paleoclimate and the modelling groups should be able to predict when our ongoing Holocene interglacial is likely to come to its natural end. The strong interconnection between model studies and data analyses is one of DEKLIM's principal aims.

4. Climate Impact Research

This area comprises the interaction between climate change, natural systems, and socio-economic systems. The aim is to provide a scientific basis for concrete measures to adapt to climate change and - in the long term - to control human influence on the climate system.

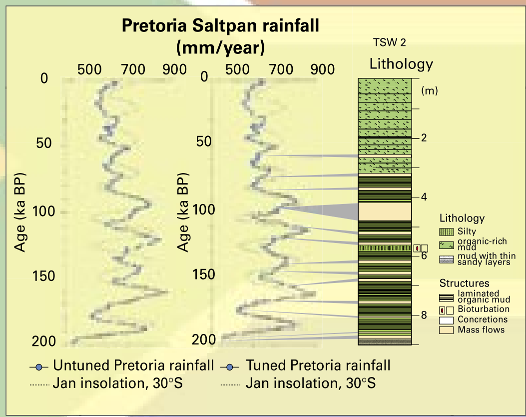
Further information about DEKLIM may be found at: www.deklim.de

Southern Africa's mid-latitude oceanic position with a rich floral, faunal, palaeontological and archaeological heritage provides diverse but challenging opportunities for establishing records of past environmental change. Unique features are including the "Fynbos" vegetation and the "Benguela upwelling system". Although South Africa has a relatively small field of palaeoenvironmental researchers, continued progress is maintained through local funding and international collaboration. Several institutions have participated in the PEP III transect of PANASH and other PAGES initiatives. A general review is presented in *The Cenozoic of Southern Africa*, Oxford University Press, 2000.

A National Science Highlight:

University of the Witwatersrand

On-going collaborative research by members of the Climatology Research Group (http://crg.bpb.wits.ac.za) include the investigation of Antarctic influences upon southern African climate and examination of a 200,000-year core recovered from the Tswaing impact crater (pictured). In Archaeology, large-scale excavations in the eastern Free State and KwaZulu-Natal have helped to establish the environmental context for cultural changes in the Late Pleistocene and Holocene.



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Tswaing impact crater record

The results of a proxy rainfall reconstruction based on sedimentological parameters (Partridge et al., 1997 - far left)shows clear precessional periodicity which allowed the rainfall record to be tuned to fluctuations in January insolation for the period beyond ^{14}C dating range (center). The recovery of two new cores has been funded by the Geo-Forschungs Zentrum, Potsdam. The base of the sequence has a fission track age of ~ 200 ka. These are being analyzed in detail in a joint programme of the University of the Witwatersrand, Johannesburg, GFZ and University College, London.

Some other National Institutions:

Quaternary Dating Research Unit

QUADRU (http://www.quadru.co.za) is the only facility within Africa to offer stable isotope analysis, radiocarbon and luminescence dating. Pioneering research was directed towards using stable isotopes to solve ecological, hydrological and palaeoclimatic problems (pictured). The dating service has become an essential component of most archaeological work within southern Africa. Members of the Stable Light Isotope Laboratory have been instrumental in developing new isotope-based approaches to palaeoecology and palaeoclimates, including high resolution records from stalagmites.

University of the Free State

The Palynology Research Group (http://www.uovs.ac.za/faculties/agrinat/plantsci/bot/botany.htm) has studied pollen spectra from across the subcontinent. The determination of carbon isotope ratios on hyrax dung (pictured) has enabled vegetation shifts over the last 20,000-years to be inferred. Phytolith analysis offers potential in detecting changes in grassland composition that relate to seasonal moisture and temperature variability.

National Research Foundation

The NRF (http://www.nrf.ac.za) provides research facilities and funds research capacity development in South Africa. The careful and systematic study of paleoresources etc. is seen by the NRF as a national responsibility.

Council for Geoscience

Research activities in the sphere of Quaternary research are linked to regional mapping programmes (http://www.geoscience.org.za/pmb/region al.htm).

University of Cape Town

In Archaeology (http://web.uct.ac.za/depts/age/), materials from hunter-gatherer sites on the West and Southern Cape coasts are used to build comparative records for marine and terrestrial environments.

SASQUA

The Southern African Society for Quaternary Research has about 140 members. Biennial meetings are held. Contact is via the current Secretary, John Rogers, (jrogers@ science.uct.ac.za).

Quaternary Research Centre

This interdisciplinary grouping of institutions in the Western Cape facilitates local and international collaboration among Quaternary scientists in academia and industry (http://web.uct.ac.za/depts/quarc/). The Centre is responsible for the only dedicated postgraduate courses in Quaternary Sciences in the region.

Article compiled by Iain Robertson (irobertson@webmail.co.za) and Julia Lee-Thorp.
Number of South Africa PAGES members registered on our database (http://www.pages.unibe.ch/ppeople/ppeople.html) on February 27, 2003: 17

Past Rates of Carbon Dioxide Changes and their Relevance for Future Climate

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Paleoclimatic data from the ice core from Vostok Station (Antarctica) provide the basis for one of the most fundamental statements of Global Change research: *"The present CO_2 concentration has not been exceeded during the past 420,000 years .... The current rate of increase is unprecedented during at least the past 20,000 years.»* (IPCC, 2001). These important findings are based on precise measurements of the CO_2 concentration in air bubbles enclosed in Antarctic ice (Petit et al., 1999) and testifies to the fact that one of the primary forcing factors determining global climate has moved significantly above the bounds defined by natural climate change. How fast atmospheric concentrations of CO_2 change, however, has attracted less attention essentially because only in the last few years, the resolution of the CO_2 reconstruction has increased sufficiently to permit calculations of rates of change.

Since 1999 we have worked on high-resolution records of CO_2 within two major projects. The first was a collaboration with Martin Wahlen from the Scripps Institute of Oceanography, in which high-resolution records of the Holocene and the Last Glacial (60-20 kyr BP) were measured. The samples were obtained from the ice core from Taylor Dome (Antarctica) drilled by a US team. The second ice core comes from Dome Concordia (Antarctica) which was drilled as part of EPICA (European Project of Ice Coring in Antarctica), funded by the European Commission and the participating ten European nations. Thanks to the excellent core quality of these polar ice cores, CO_2 measurements on samples of less than 10 grammes of ice reach an average reproducibility of 1.5 ppmv using Laser Absorption Spectroscopy.

In determining rates of change based on gas records from ice cores, one must address the problem of the enclosure process of gases in the ice. Before air bubbles are enclosed, gases are residing in the porous firn column with a depth of 80-120 meters, which overlies the ice. This leads to two important effects: (i) the gas-age/ice-age difference, and (ii), the age distribution of gas between different air bubbles within one sample. The first effect is relevant in the construction of the age scale and hence influences the calculation of rates of concentration changes. This effect is taken into account. The second is important only if abrupt and large changes of concentrations of trace gases occur in the atmosphere. Such rapid changes would be damped due to the primarily diffusive exchange of gases within the firn column and the somewhat erratic character of the close-off process. If one is to determine rates over very short time scales (centuries or less), this damping effect must be taken into account. Here, however, we first focus on mean rates over time intervals of several centuries to millennia, in which case the latter effect is not relevant.

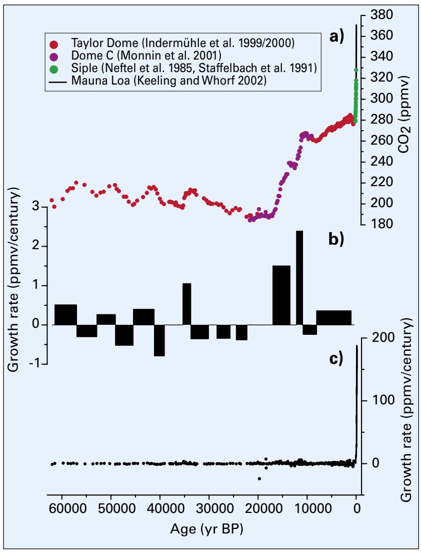

*Fig. 1: Composite high-resolution CO_2 records based on measurements of air enclosed in bubbles in two Antarctic ice cores from Taylor Dome and Dome Concordia. (**a**) CO_2 concentrations (red: Taylor Dome (Indermühle et al., 1999; Indermühle et al., 2000); purple: Dome Concordia (Monnin et al., 2001); green: Siple Station (Neftel et al., 1985; Staffelbach et al., 1991)), including the direct measurements from Mauna Loa (black line, (Keeling and Whorf, 2002)). (**b**) Estimated mean rates of CO_2 changes evolving over several millennia, calculated as the ratio between neighbouring relative maxima and minima divided by the time difference. Positive and negative rates are distinguished; the former fall into two classes. (**c**) rates between neighbouring measurements including the last 250 years during which the rates are about 100 times larger than anytime during the last 60,000 years. Through the values from Siple Station and Mauna Loa a spline function with a cut-off period of 10 years was fitted in order to remove the annual variability.*

Figure 1a shows a composite record of high-resolution CO_2 reconstructions for the last 60,000 years and the average rates of change for millennial intervals. In the Glacial and the Holocene, the data are from Taylor Dome (Indermühle et al., 1999; Indermühle et al., 2000), and the deglaciation is measured on ice from Dome Concordia (Monnin et al., 2001). As observed by Indermühle et al. (2000), the relative CO_2 maxima between 60 and 20 kyr BP are strongly correlated with the four Antarctic warming events during this interval (Blunier et al., 1998). The CO_2 changes therefore occur on a millennial time scale rather than the faster time scale characteristic of the sequence of abrupt warmings in the northern hemisphere known as Dansgaard/Oeschger events. This is an important biogeochemical constraint for models simulating abrupt climate change during the glacial and one of the strong indicators that the Southern Ocean must have played a key role in the CO_2 changes. Rates of change were calculated by identifying neighbouring relative maxima and minima, whose difference exceeds 6 ppmv, and then interpolating linearly the values between neighbouring minima and maxima. Before the anthropogenic increase of CO_2 starting in the 18th century, the positive rates (CO_2 increase) fall into two distinct classes (Fig. 1b). Changes during the glacial and the Holocene exhibit mainly rates of about 0.5 ppmv/century, whereas the rate of increase is 3-5 times higher during deglaciation, reaching about 1.5 to 2.5 ppmv/century. In constrast, negative rates appear rather uniform with about 0.3 to 0.8 ppmv/century. There are also extended intervals during which the CO_2 concentrations change by less than 6 ppm for several 1000 years. In terms of natural CO_2 changes, deglaciation appears as the time interval during which the fastest changes occurred. One should note that our determination of rates explicitly excludes step-like features such as those found by Monnin et al. (2001); the associated CO_2 increase is typically 10 ppmv or less. Larger decadal deviations in CO_2 (e.g., «CO_2 pulses») are very unlikely because large concentration changes would be detected at the current sample resolution. The CH_4 increase of 140% in two centuries at the Younger Dryas termination provides a good argument that large increases of atmospheric greenhouse gas concentrations can be recorded in the Dome Concordia ice core.

The positive CO_2 growth rates during the series of Antarctic warmings were smaller than those during deglaciation. As shown in model simulations, this variability can, at least in part, be explained by complete shutdowns of the Atlantic thermohaline circulation (Marchal et al., 1998). The model, however, severely underestimated the CO_2 amplitude by about a factor of 2, indicating that other effects, such as changes in the ocean chemistry of the Southern Ocean, or changes in sea ice cover might have contributed to the CO_2 amplitude (Keeling and Visbeck, 2001). CO_2-increases are significantly faster during deglaciation. This might indicate that the pace of forcing dictated the CO_2 rate during that period. Based on the available coarse record of isotopic data, we favoured a mechanism which postulated a strong release of terrestrial biomass during the Holocene (Indermühle et al., 1999).

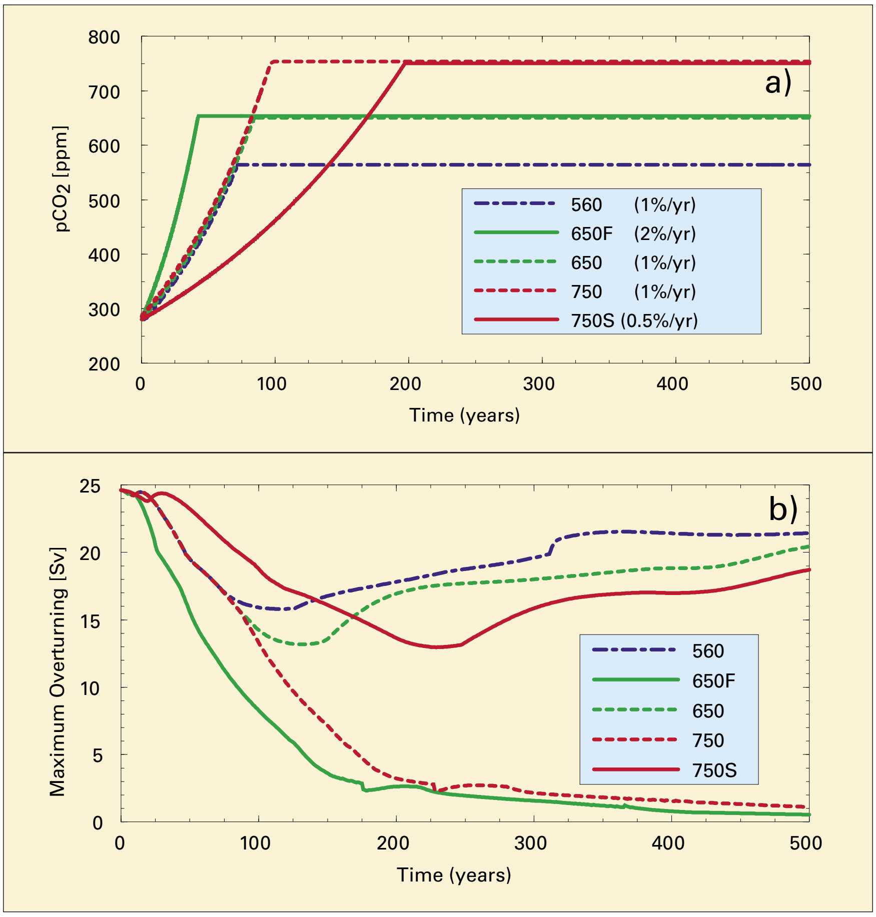

*Fig. 2: (**a**) Simulations using a reduced complexity climate model exhibit a bifurcation of the Atlantic meridional overturning circulation in global warming experiments. CO_2 is increased at a constant rate (compounded) up to a fixed level. (**b**) Maximum Atlantic meridional overturning circulation. Warming generally leads to a reduction of the circulation. If the warming or the rate stay below certain thresholds, the response of the circulation is linear. Otherwise, an irreversible transition to a second equilibrium solution results. Crossing of the threshold depends on the rate of CO_2 increase. (Figure from Stocker and Schmittner, 1997)*

However, shell weight changes and foraminiferal size indices suggest that the Holocene CO_2 increase might have been due to a combination of a net growth of the terrestrial biosphere at the end of the Last Glacial and the subsequent calcium carbonate compensation of the ocean (Broecker and Clark, 2003). Until we produce a reliable ^{13}C record with a resolution comparable to that of the CO_2 record, this important problem cannot be resolved.

The increase of the concentration of CO_2 and other greenhouse gases in the atmosphere is responsible for a large part of the observed warming since the beginning of the 20th century (IPCC, 2001). Apart from the continued global warming and sea level rise that is predicted by all climate models under all emissions scenarios, the majority of coupled models also simulates a decrease of the meridional overturning circulation in the Atlantic Ocean during the next 100 years. Due to nonlinearities associated with this circulation, thresholds are believed to exist beyond which this circulation may completely cease (Stocker and Wright, 1991). Such a transition might well be irreversible, i.e. even if CO_2 concentrations in the atmosphere returned back to preindustrial levels many centuries hence, the overturning circulation would not reestablish itself. This reorganisation in the ocean circulation would have wide ranging consequences for the climate in regions influenced by the Atlantic Ocean.

In a series of simulations it was demonstrated that the proximity of the threshold, beyond which the circulation collapses, depends on the rate of warming, and therefore on the rate of CO_2 increase (Stocker and Schmittner, 1997). This is illustrated in Figure 2. A transition to a state with no overturning circulation in the Atlantic Ocean occurs if the maximum warming exceeds a certain threshold. In addition to the level of achieved warming, also the rate of the warming is crucial. Faster warmings lead to lower thresholds, while slower warming makes the system more permissible and a larger warming can be achieved without a cessation of the overturning circulation. This was the first indication of a physical process which caused fundamentally different climate responses might result from slightly different emissions scenarios. These findings make a strong case for «early action» on CO_2 emissions reductions in order to keep away from potentially dangerous thresholds.

The increasing quality of paleoclimatic records, and the establishment of reliable time scales now allow the investigation of the rate of change of certain quantities. Such information provides important constraints for models simulating past climate changes. The quantification of CO_2 rates is potentially important in helping to disentangle the different mechanisms that are responsible for the observed changes. CO_2 rate will also play a crucial role in future climate change since they influence the proximity of certain thresholds in the climate system. Such thresholds could hold unwanted surprises of change. By paying special attention to CO_2 growth rates, and their possible limitation by carefully selecting emission paths in the future, such surprises may be successfully avoided (Alley et al., 2003).

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For full references please consult:
www.pages-igbp.org/products/newsletters/ref2003_1.html

Rates of Change in the Upper Treeline Ecotone in the Polar Ural Mountains

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Significant spatio-temporal changes took place in the upper treeline ecotone in the Polar Ural Mountains (66-67° N, 65-66° E) during the last millennium (Shiyatov, 1993, 1995). Within the treeline ecotone, which is located from 100 to 350 m a.s.l., Siberian larch (*Larix sibirica*) open forests dominate. Patches of larch-spruce (*Picea obovata*) closed forests grow at lower altitudinal levels in the ecotone. Up to this day, these forests have been mainly developing under the influence of natural factors. There are a great number of wood remnants on the ground up to 60-80 m above the present treeline and within the ecotone that have been preserved for a long time (up to 1300 years) because of the low rate of wood decomposition in severe climatic conditions. These provide us with the possibility of extending ring-width chronology back to 645 AD and of dating the lifetime of a large quantity of dead trees. In order to estimate displacement of the upper treeline (the highest altitudinal position of open forests) over the last millennium, a transect 430 m long and 20 m wide was set up on the south-eastern slope of Rai-Iz Massif, from the highest location of larch wood remnants (340 m a.s.l.) to the present upper treeline (280 m). The transect was divided into 10 x 10 m quadrates. All of the wood remnants were mapped and cuts from the base of trunk and roots were collected from each individual tree. Calendar years of establishment and dying off were determined by dendrochronological techniques. Altogether, a time span of 270 dead trees was defined. In addition, 16 young living trees and seedlings were also mapped and their age determined.

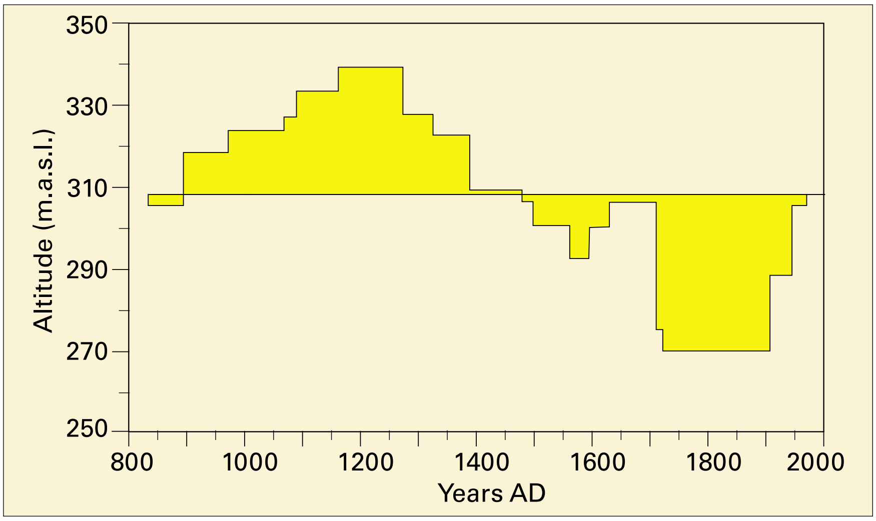

Fig. 1. Altitudinal displacement of the upper treeline in the Polar Ural Mountains during the last 1150 years.

Table 1: Area changes of different types of forest-tundra ecosystems from 1910 to 2000

Time	Forest Tundra Ecosystem Types			
	Tundra with Individual Trees	Sparse Growth of Trees	Open Forest	Closed Forest
1910	2403 ha	349 ha	328 ha	5 ha
Rate of Change	*-76 ha/decade*	*+37 ha/decade*	*+24 ha/decade*	*+15 ha/decade*
1960	2021 ha	535 ha	450 ha	79 ha
Rate of Change	*-26 ha/decade*	*-52 ha/decade*	*+36 ha/decade*	*+42 ha/decade*
2000	1917 ha	327 ha	593 ha	258 ha

Using this data, upper treeline displacement over the last 1150 years was reconstructed (Fig. 1). This time interval was divided into 5 periods, distinguished by differing directions of treeline shifting (rising or retreating) and differing rates of displacement. During the earliest period (430 years, 850-1280 AD), the upper treeline rose from 305 to 340 m a.s.l., i.e. 1-2 m/dec on average. The highest altitudinal position reached by the treeline and the densest and most productive larch stands observed in the last millennium were in the 13th century. The second period (300 years, 1280-1580 AD) was characterized by a severe retreat of the upper treeline (from 340 to 295 m) at a mean rate of 2-3 m/dec. During the third period (210 years, 1580-1790 AD), the treeline retreat stopped. The observed rise (from 295 to 305 m, 0.5-1.0 m/dec) was not significant. The most extreme retreat was seen in the fourth period (120 years, 1790-1910 AD), during which the upper treeline receded from 305 to 270 m, i.e. 2-4 m/dec. During this period, the upper treeline was at its lowest altitudinal position for the millennium. In the last period, from 1910 to the present day, intensive afforestation took place on sites that were forested during the Middle Ages. The rate of change was the highest for the millennium (from 270 to 308 m, 4-6 m/dec).

We are currently carrying out intensive studies of the last period of expansion of forest vegetation using both direct and indirect evidence (old terrestrial, aerial and satellite photographs, repeated stand descriptions of permanent plots and transects, morphological and age structure of stands, large-scale mapping within the ecotone, meteorological and dendroclimatic data).

Table 1 shows changes in area under different types of forest-tundra ecosystems within the ecotone during the 20th century. These data were obtained at the time of large-scale (1:10000) mapping of the key area (3085 ha) located at the bottom of the Tchernaya Mountain. Altogether, we obtained three maps, which show a spatial distribution of these types of forest-tundra ecosystems for the beginning, middle and end of the century. We made a quantitative estimation of the change in their area during two periods; 50 years from 1910 to 1960, and 40 years from 1960 to 2000.

Over these 90 years, the area under tundra with individual trees decreased significantly from 2403 to 1917 ha, or from 78 to 62% of the key area. The greatest rate of change (-76 ha/dec) was observed during the first 50 years, when isolated seedling establishment above the treeline was the most intensive. Data obtained on the area change

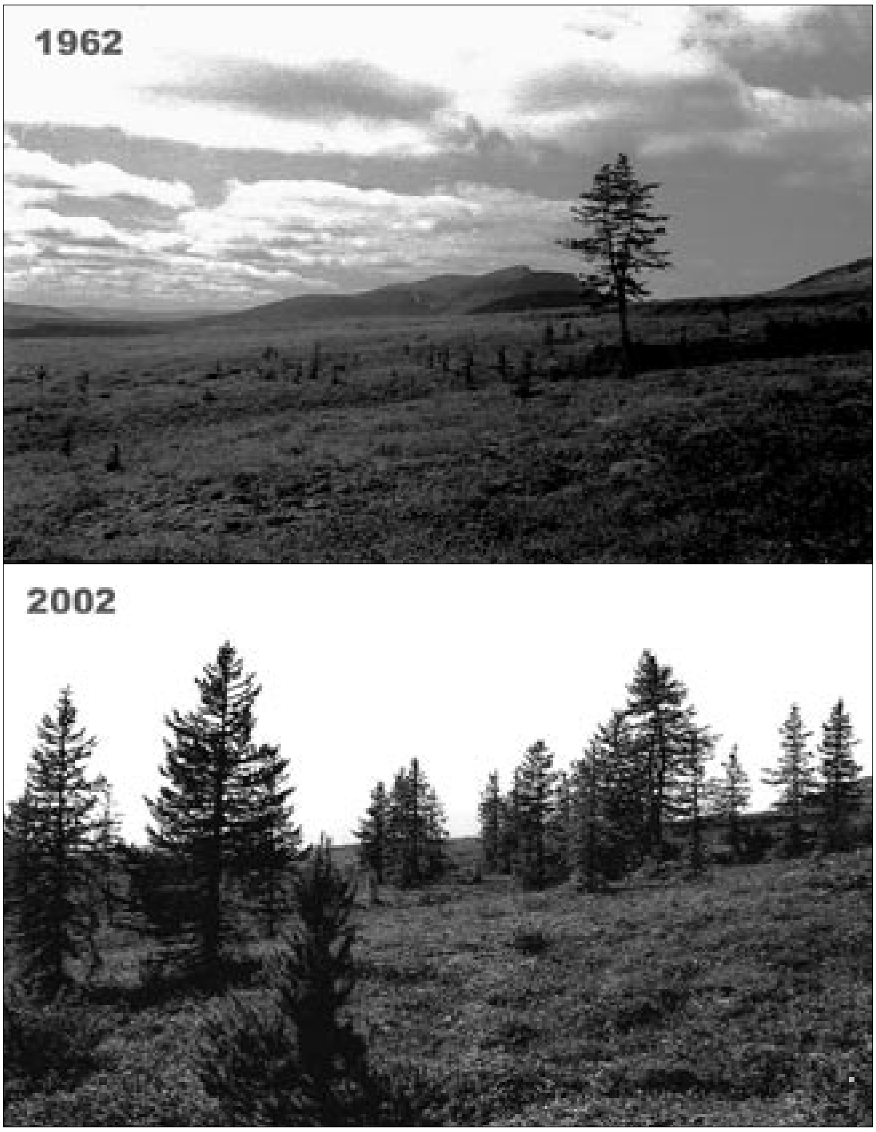

Fig. 2: Photographs taken from the same point, which show the formation of open larch forest on tundra with individual trees during the last 40 years.

of the sparse growth of trees is very interesting since during the first period the rate of change was positive (+37 ha/dec) but during the second period it was negative (-52 ha/dec). The decrease was caused when young established trees began producing seeds and as a result the density of stands increased (many of them turned into open forest). It is for this reason that the increase in area under open forest was so great during the period from 1960 to 2000 (from 450 to 593 ha, +36 ha/dec). However, the most impressive changes were seen with closed forests. The area increased from 5 to 258 ha over the 90 years with the transformation of open forests into closed forests.

Two terrestrial photographs taken from the same point in 1962 and 2002 (Fig. 2) show an example of forest expansion during the last century. Only one middle-aged larch tree and several seedlings up to 1 m in height were established between 1910 and 1960. Now, however, a typical open forest has developed on the site and new seedling establishment is taking place (Fig. 2). To date, we have taken more than 550 repeated terrestrial photographs, which can be used to reconstruct stand parameters for the middle of the 20th century.

Warming during the 20th century was the major cause of spatio-temporal expansion of trees in the treeline ecotone. The mean temperature for June at Salekhard weather station (50 km to the east of the study area) increased from 7.2°C (1883-1919) to 8.5°C (1920-1998). The mean for July increased from 13.8°C to 14.3°C. Mean temperatures in the winter months (November-March) increased from -20.8°C to -19.6°C. Critical for tree growth, the average June-July temperature increased from 10.5°C to 11.4°C, or by 0.9°C. This means that the June-July isotherm rose 120-130 m in altitude (in this area the gradient is 0.7°C/100 m). However, the upper treeline did not rise to this altitude. In fact, the mean rise was only 20-40 m. The main reason for this was a deficiency of viable seeds on sites remote from fertile trees and stands.

Table 2: Rates of Change within the treeline ecotone on the eastern slope of the Polar Ural Mountains (Sob River basin, 66-67° N, 65-66° E) during the last 1150 years

Climate Variable / Proxy	Modern Rate of Change	Past Rate of Change
Treeline Displacement	Rise: 4-6 m/decade (1910 - 2000 AD)	Rise: 1-2 m/decade (850-1280 AD, 430 years)
		Retreat: 2-3 m/decade (1280-1580 AD, 300 years)
		Rise: 0.5-1.0 m/decade (1580-1790 AD, 210 years)
		Retreat: 2-4 m/decade (1790-1910 AD, 120 years)
Degree of Afforestation (within the treeline ecotone)	+2 %/decade (1910 - 2000 AD)	

We revealed earlier (Shiyatov, 1966), that the opening of larch cones and subsequent seed dissemination occur only on days of elevated temperatures (such as occur from the end of June to the end of July). Wind is the primary method of seed dissemination, with the influence of other methods, such as animals and birds, being insignificant. Since seed dissemination takes place in summer when snow cover is absent, it is difficult for seeds to be transported upwards over long distances. Heavy larch seeds are carried no more then 40-60 m from a tree and most of these seeds become stuck in the lichen-moss and shrub layers. That is why abundant seedling establishment took place only close to individual trees (Fig. 2) and within stands.

Impressive changes have occurred in the structure of existing stands during the 90 years. Most of them have become much denser and more productive (up to 4-5 times) and many tundra sites located within the treeline ecotone have been afforested. The degree of afforestation increased from 22 to 38% (calculation based on data from Table 1). Thus, many parameters affecting forest-tundra ecosystems react well to summer temperature changes. For the purpose of climatic reconstruction, the best are those obtained from existing stands (tree rings, biomass, density of stand and canopy, degree of afforestation). Although the displacement rate of the upper treeline is a good reflection of long-term climatic fluctuations (Table 2), reconstruction of actual temperature changes is complicated because of the response lag caused by the slow growth of seedlings and the lack of seeds on remote sites. For example, the recent warming observed in summer months is of the same degree seen in the Middle Ages (about 1°C) but the upper treeline has not reached the altitudinal position on which forests grew in the 13th century. To overcome such discrepancies, it is necessary to use corrective factors. These will be different for each period and study area. For example, in the Polar Ural Mountains over the 90 years, the upper treeline rose 20-40 m in altitude but the June-July temperature isotherm rose 120-130 m. Therefore, reconstructed temperatures based on this parameter should be increased by a factor of 4.

Acknowledgements
This study was financially supported by the Russian Foundation of Basic Research, grants 99-04-48984 and 02-04-48180.

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Rates of Change in Oak Forest Distribution During the Last Deglaciation

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The distribution of plant species over continents changes drastically during climatic cycles. The range of temperate species in Europe has expanded and retreated several times during the last few climatic cycles. Mapping these ranges over a period of time (such as the last 15,000 years) helps visualize the distribution changes (oak map by Brewer et al., 2002, Fig. 1). However, time series are a more appropriate tool for estimation of the rapidity of these changes.

During the last glacial maximum, most temperate tree species survived the extremly cold and dry climate within a few limited areas known as refugia. In Europe, such refugial areas have been identified in Spain, Italy, Greece and the Balkans. They are localized in mountainous regions, usually with southern exposure, where sufficient moisture and warmth existed for plants to survive glacial periods. At the end of each glacial period, temperate trees migrate, with different rates, from their refugia to occupy more extensive areas. The same species do not necessarily survive in the same refugia from one glacial to another. A given species may propagate from it's refugium during an interglacial and not be able to return to it during the following glacial. Thus, it is difficult to compare the rates of distribution change over several climatic cycles for the same species.

Here we focus on the last deglaciation during which oak forests underwent dramatic changes in both population density and distributional range. Roughly, the deciduous oak started to migrate from its glacial refugia between 15 and 14,000 years BP and reached its northern climatic limit during the Holocene around 6000 years BP. During deglaciation, Oak forest «boundaries» moved at a maximum rate of approximately 100 km/century. Fossil pollen records provide quantitative information about the rates of change in oak forest distribution throughout this period of time. Jacobson et al. (1987) showed that the difference of the square root of pollen percentages over prescribed even time intervals provides a good measure of the rate of change in species prevalance in the landscape. Application of this method requires that paleo proxy-data be interpolated onto an evenly time spaced scale whereas pollen records are often unevenly sampled and their chronological frame is based on a few ^{14}C dates. Lotter et al. (1992) pointed out that «rates of change [derived] from proxy-data are critically dependent on a reliable chronology». Such caution should be applied to reconstruction of any abrupt event, irrespective of proxy type, when the chronology is based on the ^{14}C time scale.

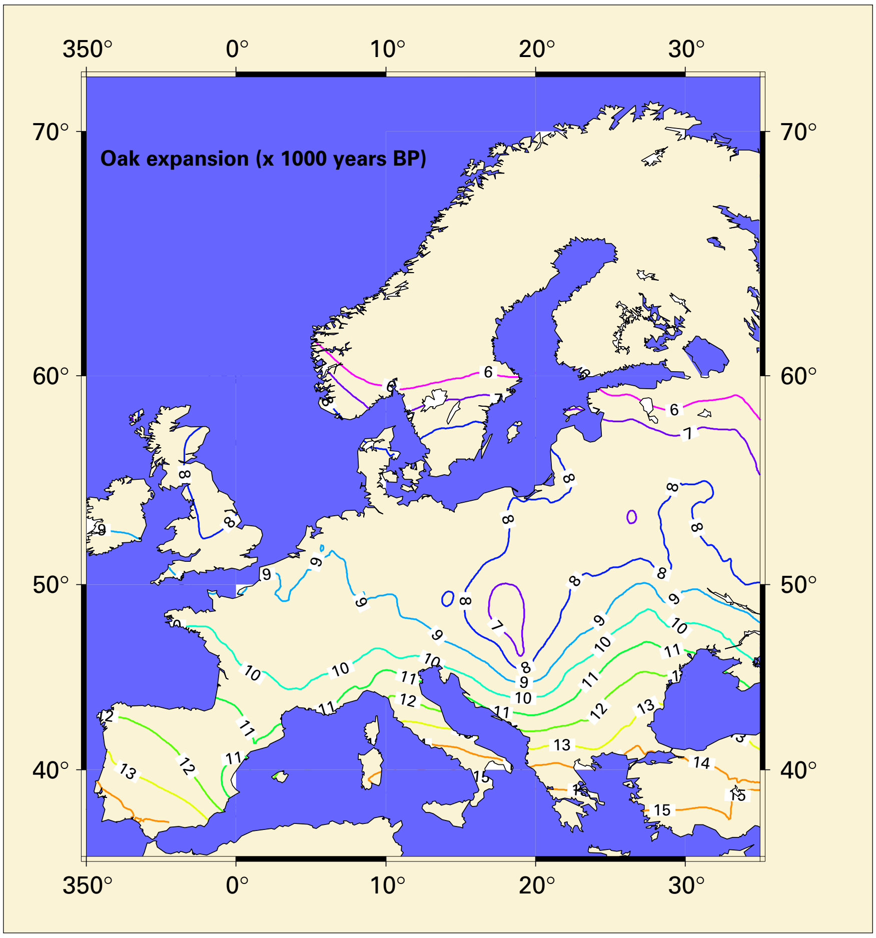

Fig. 1: Expansion of oak during the period between 15,000 and 6,000 years BP (Brewer et al., 2002)

The comparison of the rates of change estimates from two sites with very different geographical locations relative to glacial refugia from which oak originated may be interesting. The Padul pollen record (southern Granada, Spain) is located in an area where a glacial refugium for deciduous oak has been identified. Lac Noir (Massif Central, France) on the other hand was surrounded by open vegetation where oak did not survive during the last glacial maximum. Genetic studies have shown that the deciduous oak now growing in France originated from the Iberian and the Italian peninsulas (Petit et al., 2002). The chronological time frame (Figs. 2 and 3) for the two pollen records indicate that there was 3000 year time lag required for the expansion of oak between the two sites.

The oak pollen percentages obtained from Lac Noir (Guenet and Reille,1988) and from Padul (Pons and Reille, 1988) illustrate the timing of both the distributional spread and the local expansion of the population (Figs. 2a, 3a). The overall rates of change at both sites (Figs. 2b, 3b) indicate a great variability but show two distinctly different patterns in both timing and amplitude. The southern Padul record shows an early and abrupt change corresponding to the Bolling warming. Other peak rates of change are detected between 13 and 10,000 years BP in Padul. Although independent proxy data indicate that a succession of warm and cold climates were also recorded in France at this time, no change is observed at Lac Noir as oak had simply not yet reached the area. Only after 10,000 years BP did oak arrive in the Massif Central. It then expanded between 10 and 6,000 years BP and a decline is recorded afterward. The rate of change associated with the first expansion of oak (around 9,700 years BP) is the highest of the whole record. This first high rate of change at Lac Noir is lower than the first one at Padul. These differences might be explained by the fact that a change in the vegetation is more rapid and amplified when the landscape offers less competition with other species. On the other hand, the oak pollen percentages suggest a progressive pattern of colonization and the rates of change show a distinct succession of peaks which are less obvious in the Padul record. Such discrepancies may confirm more competition with other temperate species around Lac Noir than in Padul. The next highest peak of rate of change is recorded (more or less synchronously) at both Padul and Lac Noir at the beginning of an irreversible decline in oak populations between 6500 and 6000 years BP when the oak pollen percentages decrease steadily at both sites. This second high peak may indicate the response of oak to similar climatic change at both sites. These two pollen records had 7 to 8 times of rapid change during the warming which occured during postglacial period and therefore illustrate well how fast a temperate species such as the deciduous oak, may respond to environmental changes. However, will temperate species overcome the greenhouse effect and the expected induced global warming during the next decades? Will all temperate species present in an ecosystem follow such abrupt changes? Although, the Oak case shows that a temperate tree species may adapt to rapid climate changes, the expected abruptness of the climate change may require more than the 7 or 8 time rapid change recorded during the deglaciation.

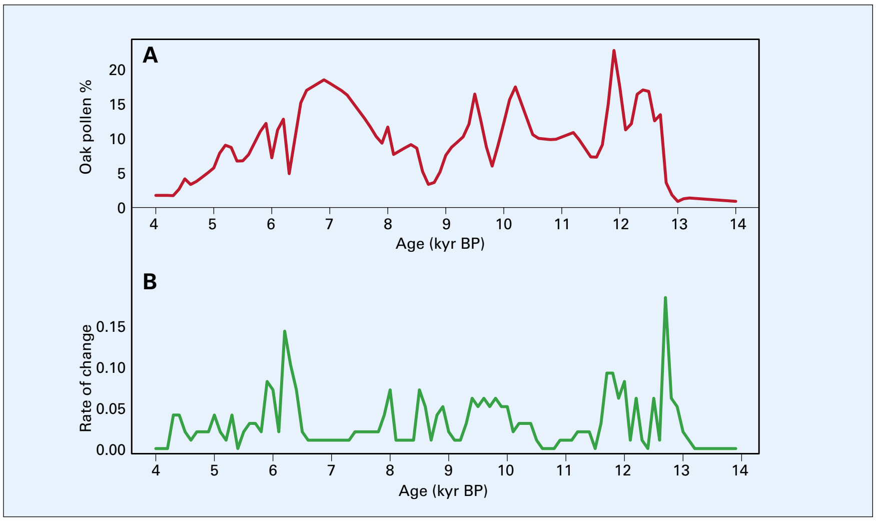

Fig. 3: (**a**). Deciduous oak pollen percentages from Padul, South Granada (Spain) obtained from the European Pollen Database www.ngdc.noaa.gov/paleo/epd/epd_main.html, contributed by M. Reille. (**b**). Rates of changes of deciduous oak at Padul.

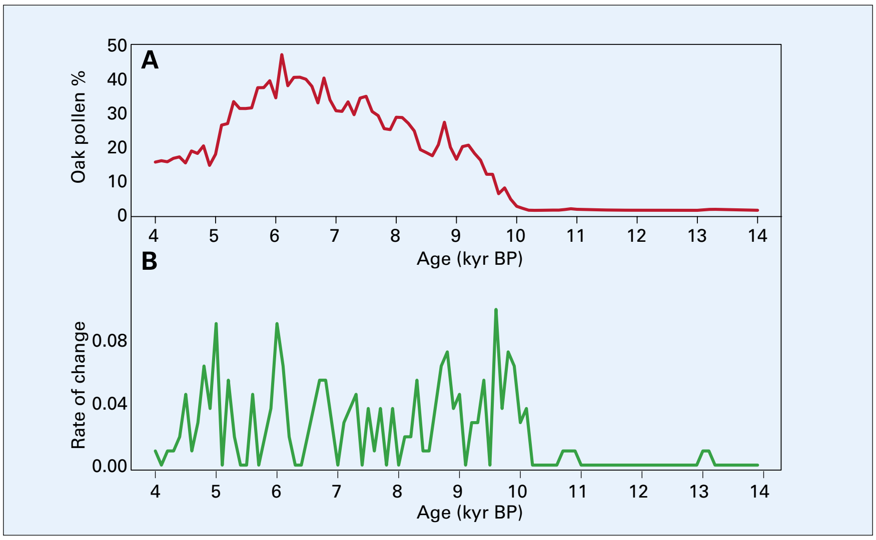

Fig. 2: (**a**). Deciduous oak Pollen percentages from Lac Noir, Massif Central (France) obtained from the European Pollen Database www.ngdc.noaa.gov/paleo/epd/epd_main.html, contributed by P. Guenet. (**b**). Rates of changes of deciduous oak at Lac Noir.

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Alpine Glacier Mass Changes During the Past Two Millennia

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The advance and retreat of mountain glaciers during historical and Holocene time periods reflect pre-industrial changes in ice mass and corresponding energy fluxes. Quantitative data analysis can be based on a simple approach comparing assumed steady state situations separated by time intervals of decades to a century. Detailed information spaning the past two millennia is available for the Great Aletsch Glacier, the largest glacier in the European Alps, including an extraordinary number of absolute age and geometry determinations from historical documents, radiocarbon dating of fossil trees and tree-ring analyses. Rates of mass change and associated energy fluxes, during the 20th century as a whole, lie between the average and the extreme of historical values, but appear to have recently increased beyond these limits.

Fig. 1: The Great Aletsch Glacier seen from Belalp around 1856 and in 2001 (Photographs taken by Fréderic Martens, Alpine Club London, and Hanspeter Holzhauser).

Glacier Fluctuations and Climate Change Detection

Volume and mass changes of mountain glaciers represent key variables within global climate monitoring programmes, especially with respect to strategies for early detection of an enhanced greenhouse effect (Haeberli et al., 2000). Such strategies require quantitative information on both current and past rates of change. Overall energy fluxes associated with annual changes in ice thickness can be estimated based on a latent heat content of 3.338×10^5 J/kg. Thus, an annual change in ice thickness of 0.1 meters roughly corresponds to an additional energy flux of 1 W/m^2 irrespective of the details of the complex energy exchange processes involved. Direct determination of glacier mass changes began with the advent of modern cartography and repeated mapping of a few glaciers in the Alps at the end of the past century. In most regions of the world quantitative information became available only much later. Information on pre-industrial mass changes of mountain glaciers must therefore be deduced from records of cumulative changes in glacier length (advance and retreat) which reach further back in time.

Curves of cumulative glacier advance and retreat can be converted into time series of temporally averaged mass balance by applying a continuity model and considering stepwise changes associated with full dynamic response and establishment of new equilibrium conditions. According to this method, a mass balance disturbance (∂b) leading to a corresponding glacier length change (∂L) depends on the original length (Lo) and the annual mass balance (ablation bt) at the glacier terminus: $\partial b = bt \times \partial L/Lo$. The dynamic response time is h/bt, where h is a characteristic ice thickness, usually taken at the equilibrium line where ice depths are near maximum. Assuming a linear adjustment of the mass balance b to zero during the dynamic response, the average mass balance <b> is taken as $\partial b/2$. This value <b> is given in annual ice thickness change (meters of water equivalent per year) averaged over the entire glacier surface, and can be directly compared with values measured in the field (cf. Hoelzle et al., 2003 for details, calibration and application to worldwide observations during the 20th century). The main limitation is time resolution. For example the Great Aletsch Glacier has a characteristic ablation at the terminus (bt) of 12 meters per year and a maximum thickness (h) of about 900 meters (at Konkordiaplatz close to the equilibrium line), thus the response time is somewhere between 50 and 100 years.

Historical Fluctuations of the Great Aletsch Glacier

Past glacier length changes can best be documented in cases of glaciers advancing into forested or cultivated areas (Fig. 1). Direct radiocarbon dating and dendrochronological analysis of formerly overridden and now reappearing tree trunks greatly help with the reconstruction of former ice geometries based on historical sources and moraine investigations. An especially detailed record is available for the Great Aletsch Glacier (Holzhauser, 1997). The Great Aletsch Glacier with a length of around 23,2 km and a surface area of approximately 86 km^2, is the largest glacier in the European Alps. In the past, its tongue repeatedly reached

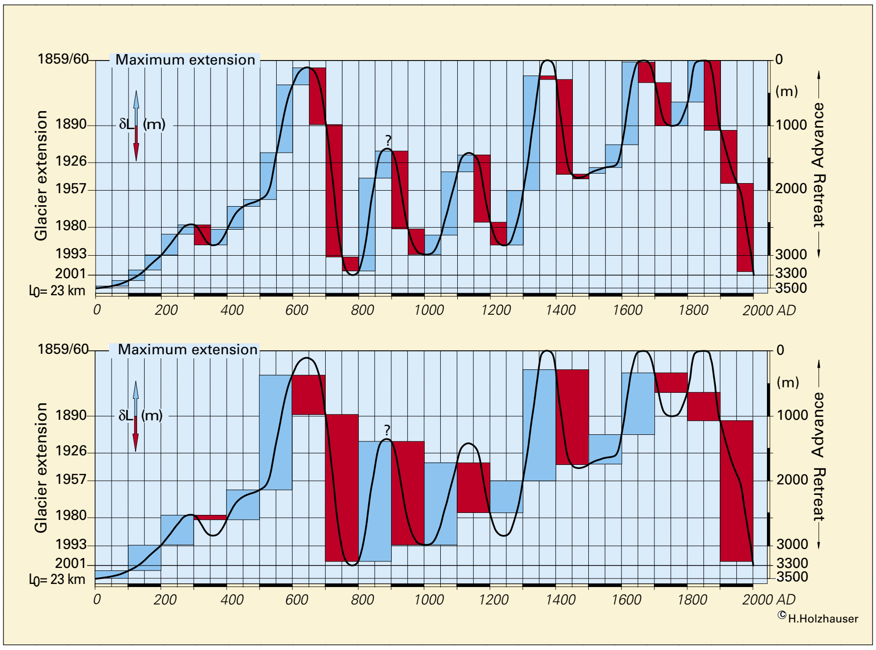

Fig. 2: Fluctuations of the Great Aletsch Glacier during the last 2000 years reconstructed with historical documents and dendrochronologically/absolutely dated fossil wood. Average mass balance calculated for time intervals of 50 years (on top) and of 100 years (below).

deeply into stands of coniferous forest, sometimes coming very close to inhabited areas and destroying mountain huts, affecting a regionally important irrigation channel or covering forests and arable land. Such conditions enable glaciological methods (geodetic surveying, detailed topographic mapping), historical and archaeological sources (written and pictorial historical records), geomorphological evidence (dated organic material from overriden soils and crushed trees within, and at the edge of, areas becoming ice-free) to be combined to reconstruct a detailed time series of cumulative changes in the length of the Great Aletsch Glacier over the past two millennia (Fig. 2). Only roots, stumps and trunks of trees found in their original place of growth (in situ) are suitable for the exact reconstruction of past glacier fluctuations, because complex transportation paths from the place of growth to the place of reappearance are of no concern. The accuracy of such reconstructions generally decreases further back in time.

From 1892 to the present, the continuously decreasing tongue length has been precisely measured every year, providing an exceptional record for the last century. The so defined retreat covers a substantial period of previous variability, thereby enabling evidence from earlier times to be related to stages measured in modern times. Historical pictures and texts document fluctuations during the 18th and 19th centuries, especially the final advance to the last „Little Ice Age" maximum extent around 1856. Dendrochronological analysis allows an exact reconstruction of the marked advance leading to a maximum glacier extent from 1670 to 1680 AD (Holzhauser and Zumbühl, 1999). A very small advance around 1500 AD is dated by both, dendrochronology and archaeology (destruction of an irrigation channel). Sparse evidence from the 15th century consists of written documents indicating that the glacier size was similar to that of the 1940's. The time period between the year 0 to the end of the 14th century is exclusively reconstructed by dendrochronologically absolutely dated fossil wood. The „Medieval Warm Period" from around 800 AD to the onset of the „Little Ice Age" around 1300 AD was interrupted by two weak advances.

Past Variabilities and Beyond

The reconstructed cumulative length changes of Great Aletsch Glacier show relatively regular ocillations of advance and retreat with characteristic amplitudes of one to two km and periods of around two centuries. Interannual and decadal climate variability are not registered due to the slow dynamic response of the relatively long glacier tongue. The glacier tongue is now approaching the previous minimum length of record as documented around the calendar year 0. As a consequence, the overall mass change during the entire time of the considered two millennia is close to zero. Average rates of mass change modelled for 50- and 100-year time intervals (Fig. 2) provide a variability (standard deviation of the mean, Table 1) of a few decimeters of gain/loss per year (corresponding to a few W/m^2 towards/away from the surface) with extremes near half a meter per year. Mass losses during the 20th century appear to be at the limits of the characteristic variability during the past two millennia if not close to extremes probably reached around 700 to 800 AD. Accelerated atmospheric warming could soon lead to rates of mass change beyond such historical extremes. In fact, directly measured mass losses of Alpine glaciers since 1980 have been comparable with a

Table 1: Reconstructed average mass balance b (m/y) of the Great Aletsch Glacier during the last 2000 years. The values for 1980 - 2000 are doubled values for the 20th century, ±∂ is the standard deviation of the mean.

Considered Time Step	**Mean Mass Balance Change (m weq/year) - during the past 2000 years**				
	±∂	**Maximum**	**Minimum**	**20th Century**	**1980 - 2000**
50 years	± 0.31	+ 0.43	- 0.48	- 0.26	- 0.52
100 years	*± 0.25*	*+ 0.48*	*- 0.53*	*- 0.51*	- 1.02
Mean	***± 0.28***	***+ 0.46***	***- 0.51***	***- 0.39***	***- 0.77***

doubling of mean 20th-century loss rates (Haeberli et al. 1999, Fig. 3).

Critical points associated with this analysis include: (1) the choice of the starting/end point for the calculation/comparison (the model with the 50-year time interval obviously fits the curve better) and (2) the delay in the onset of terminus reaction to mass balance forcing (a few decades in the case of the Great Aletsch Glacier). The first effect means that an optimal fit has still to be found and the latter phenomenon indicates that today's terminus position of the large glacier reflects climatic conditions around the 1970s or so. In view of the rapid warming during the past two decades, it is highly probable that the glacier tongue would have to be hundreds of meters shorter than now in order to adjust to conditions around the year 2000. The previous minimum extent of Roman times may, therefore, soon be markedly exceeded.

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Cyclical Climatic-Environmental Changes in the Mediterranean Area (2500 BP-Present Day)

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The Mediterranean area acts as a boundary zone between humid and desert zones and is highly sensitive to variations in climate and environment. Indeed, shifts in the climate bands towards north or south by only a few degrees of latitude may result in dramatic changes in soil surface conditions. This may cause, for example, desertification in areas that previously had a humid climate or vice versa.

Multidisciplinary geoenvironmental research was carried out to shed light on the climatic significance of different sediment types that have accumulated over the last 2500 years (Fig. 1), located at various latitudes and in geographical areas with different morphoclimatic conditions (Ortolani et al., 1991; Ortolani and Pagliuca, 1993, 1994, 2001). The sediments, which cover many archaeological sites, were not affected by human impact between the Archaic Period and the Middle Ages.

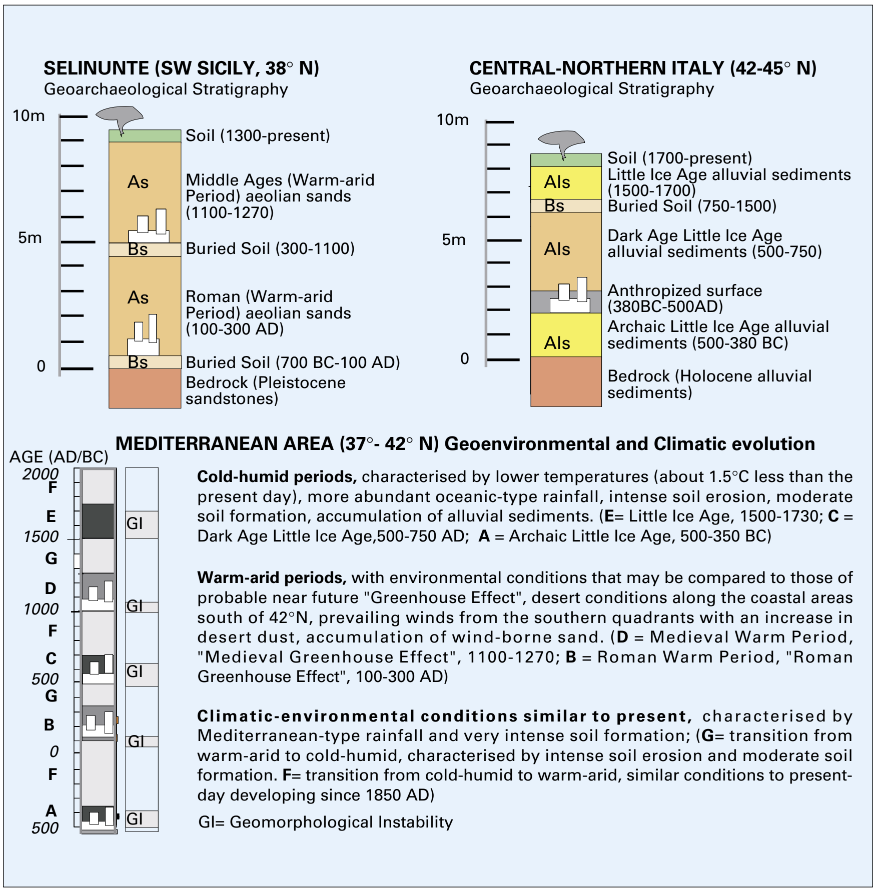

Fig. 1: Mediterranean Area Geoarchaeological Stratigraphy and Geonvironmental-Climatic Evolution (2500 BP-Present Day).

In the Mediterranean area, the presence of wind-borne sand in coastal dunes (Als, Fig 1) is the most significant geoenvironmental indicator linked to warm-arid climatic conditions. Under conditions of heightened aridity (rainfall lower than 200 mm, typical of desert areas), wind-borne coastal sand may even invade areas a considerable distance from the sea, forming wind-borne accumulations that cause the vegetation cover to disappear. This has been widely shown in the literature and verified by direct research (Ortolani and Pagliuca, 2001).

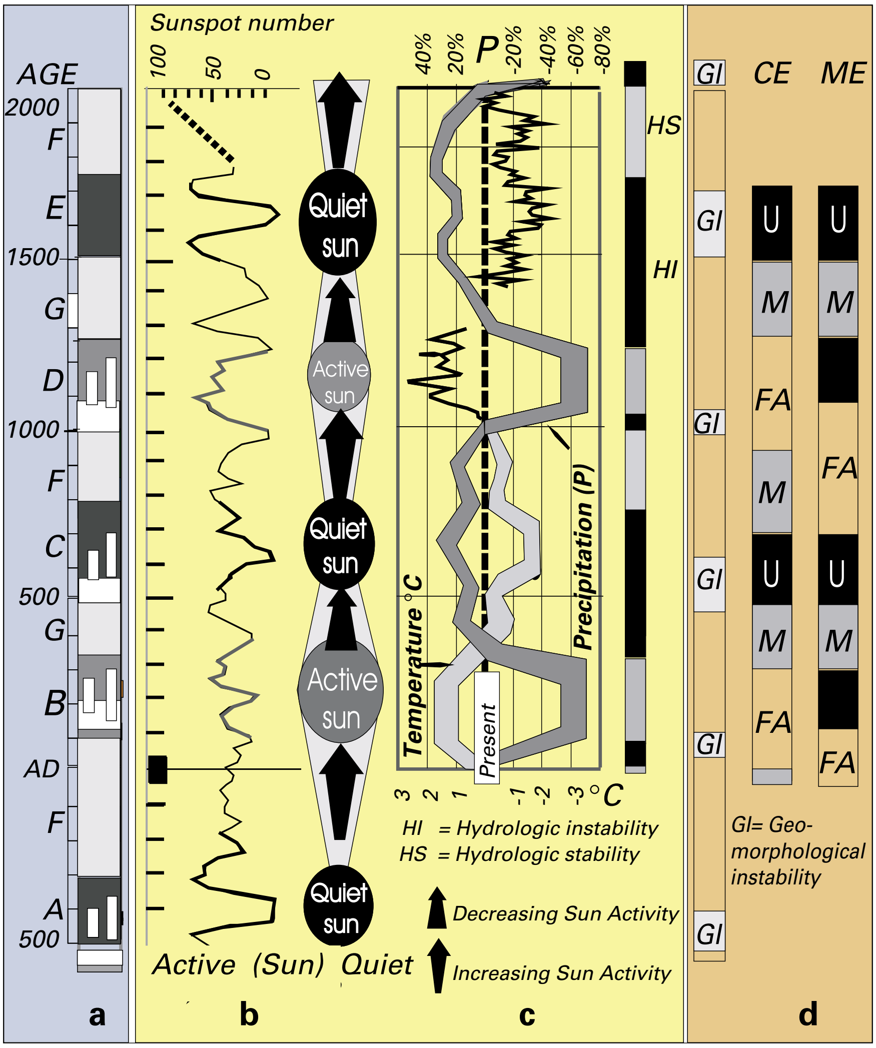

*Fig. 2: (**a**) Correlation between Mediterranean Area Geonvironmental-Climatic Evolution, (**b**) Solar Activity, (**c**) Temperature-Precipitation and (**d**) Socio-Economic Conditions. CE = Central Europe; ME = Mediterranean Area South 42° N; FA = Favourable; U = Unfavourable; M = Moderately Favourable).*

The most typical sediment characterising wetlands consists of soil that allows the development of vegetation and which differs according to latitude, local climatic and morphological conditions, and substrate lithology (Ortolani and Pagliuca, 2001). The vegetation occurs both on the surface of coastal sand dunes, which are thus stabilised, and on the alluvial sediments of the plains and altered substrate of the rocks of hill and mountain slopes.

The most significant sediments found in Mediterranean coastal dune zones in which severe climatic and environmental changes have occurred in the past consist of buried soils within layers of wind-borne sand (As, Fig 1). The presence of buried soils indicates that precipitation increased appreciably for a sufficiently long period of time to allow soil formation. Hence, there was a change in climatic conditions from desert to humid. Sediments indicating considerable climatic changes in currently humid areas include wind-borne sand (As, Fig. 1) and alluvial deposits of considerable thickness that cover areas where human impact has occurred (Als, Fig. 1). The presence of wind-borne sand indicates that rainfall decreased sharply until desertification (rainfall below 200 mm) resulted (Ortolani and Pagliuca, 2001).

During the peak of warm-arid climatic changes, "greenhouse effect" environmental conditions similar to those expected in the near future were established (Figs. 1 and 2). During the transition periods from humid to warm-arid and at the beginning of cold-humid climatic variations, other significant geoenvironmental variations (hydrologic (HI) and geomorphological (GI) instability) occurred concurrently with the marked increase in rainfall that took place after warm periods (figures 1 and 2).

During periods in which the temperature increased by 1-2 °C, coastal zones were affected by desertification up to about latitude 42° N (Fig. 1). During temperature decreases, the areas of alluvial plains subject to human impact and settlements were affected by an accumulation of huge volumes of sediments. This resulted in aggradation and progradation of the coastlines in the northern part of the Mediterranean, while soil formation occurred on the surface of the coastal dunes in the southern and northern parts (Fig. 1).

The main result achieved through geoarchaeological research is the identification of cyclicity (period of about 1000 years) of the major climate and environmental changes that have resulted in 100- to 200-year environmental crises (Fig. 1). Paleoenvironmental, paleoclimatic and geoarchaeological data show that the Mediterranean area was chiefly affected by environmental conditions similar to those of the present day (Figs. 1 and 2) (Ortolani and Pagliuca, 2001).

There is clearly a close correlation between climatic and environmental changes and solar activity. Prolonged solar activity maxima coincide with warm "greenhouse effect" periods and repeated solar activity minima coincide with cold periods, such as the Little Ice Ages (Figs. 1 and 2a, b). The history of mankind and the environment in the last few millennia highlights progressive, cyclical climatic and environmental changes that consistently occur in multicentennial periods (Figs. 1 and 2a).

Using instrumental data and those obtained from natural archives, we propose a climatic reconstruction of the past 2500 years (Fig. 2c). Variations in rainfall are expressed as percentages of current values.

A valid frame of reference for assessing and quantifying the changes that will occur at different latitudes during the Greenhouse Effect of the Third Millennium is provided by: (1) climatic and environmental data relating to the Warm Medieval Period in the Mediterranean area; (2) results achieved from research into geoenvironmental changes linked to historical climatic variations, especially those of the last few centuries, and; (3) various multidisciplinary data obtained from research conducted in various parts of the world (Fig. 2).

Instrumental data chiefly concerning the last 150 years in the Mediterranean show a consistently close correlation between environmental variations (increase in solar activity and temperature and changes in the quality and quantity of rainfall) and the period of transition from the cold-humid climatic conditions of the Little Ice Age to those that may probably characterise the Warm Period of the Third Millennium (Greenhouse Effect of the Third Millennium).

If cyclical climatic variation as occurred in the past will continue, it might result in new environmental conditions along the belts bordering the current climatic zones. In particular, a large part of the areas that are currently subtropical deserts might be transformed into humid areas. These conditions may be at times better and at times worse than those of the Little Ice Age.

This speculated shift in Mediterranean climatic conditions a few degrees to the north would cause an appreciable change in rainfall in central-northern Europe. Since the 18th century, this area has been characterised by an almost homogeneous distribution of rainfall over the year and consequently, a constant river water regime. Mediterranean-type rainfall could probably increasingly affect this area in the near future. This seasonalisation of rainfall would result in an increased frequency of bankful flow conditions. Ongoing millennial climatic cyclicity (Fig. 2) forecasts that river valleys will be affected by repeated catastrophic flooding. Given that these valleys were urbanised on the basis of a constant river water regime, serious damage to the consolidated socio-economic organisation of central-northern Europe would therefore result.

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Abrupt Warming of the Intermediate-Depth Atlantic Ocean in Response to Thermohaline Circulation Slowdown During the Last Deglaciation

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Climate modeling studies predict that anthropogenic increases in greenhouse-gas concentrations will possibly cause a weakening or even a shut-down of the meridional overturning circulation in the Atlantic (thermohaline circulation, THC), through global warming and an intensification of the hydrological cycle (Cubasch et al., 2001). Therefore it is essential to monitor the Atlantic THC, preferably on a permanent basis. Present field observations of the THC, however, are insufficient to detect whether its strength is changing. Climate models exhibit pronounced and rapid warming of the tropical intermediate-depth Atlantic Ocean in consequence of a THC slowdown, suggesting that mid-depth Atlantic temperatures may serve as an indicator of THC change. Applying different forcings to an ocean general circulation model, representing present-day and glacial climates, we show that this mid-depth water response is a robust feature in both climatic situations (Fig. 1). Given that dramatic changes of the THC occurred during the last deglaciation, the reconstruction of Atlantic intermediate-depth temperatures from sediment cores provides an opportunity to evaluate the reliability of the model simulations and the suitability of tropical mid-depth Atlantic temperature change as a tracer of THC strength. For this purpose we studied two sediment cores recovered from high accumulation areas, southeast of the island of Grenada (M35003-4; 12°05′ N, 61°15′ W; 1299 m water depth) and off the coast of Angola (ODP 1078C; 11°55′ S, 13°24′ E; 426 m water depth). Site M35003 is located in the transition zone between Antarctic Intermediate Water and Upper North Atlantic Deep Water while ODP Site 1078C is situated within the South Atlantic Central Water. In order to reconstruct intermediate-depth temperatures for the last deglaciation we measured the oxygen isotope composition of the endobenthic foraminifer *Bolivina dilatata* along ODP core 1078C with an average temporal resolution of 65 years for the time interval 24,000 to 8,000 calendar years before present (24 - 8 cal. kyr BP). The $\delta^{18}O$ record of the benthic foraminifera *Cibicidoides wuellerstorfi* for the Caribbean core M35003-4 (Hüls, 2000) has an average resolution of 330 years.

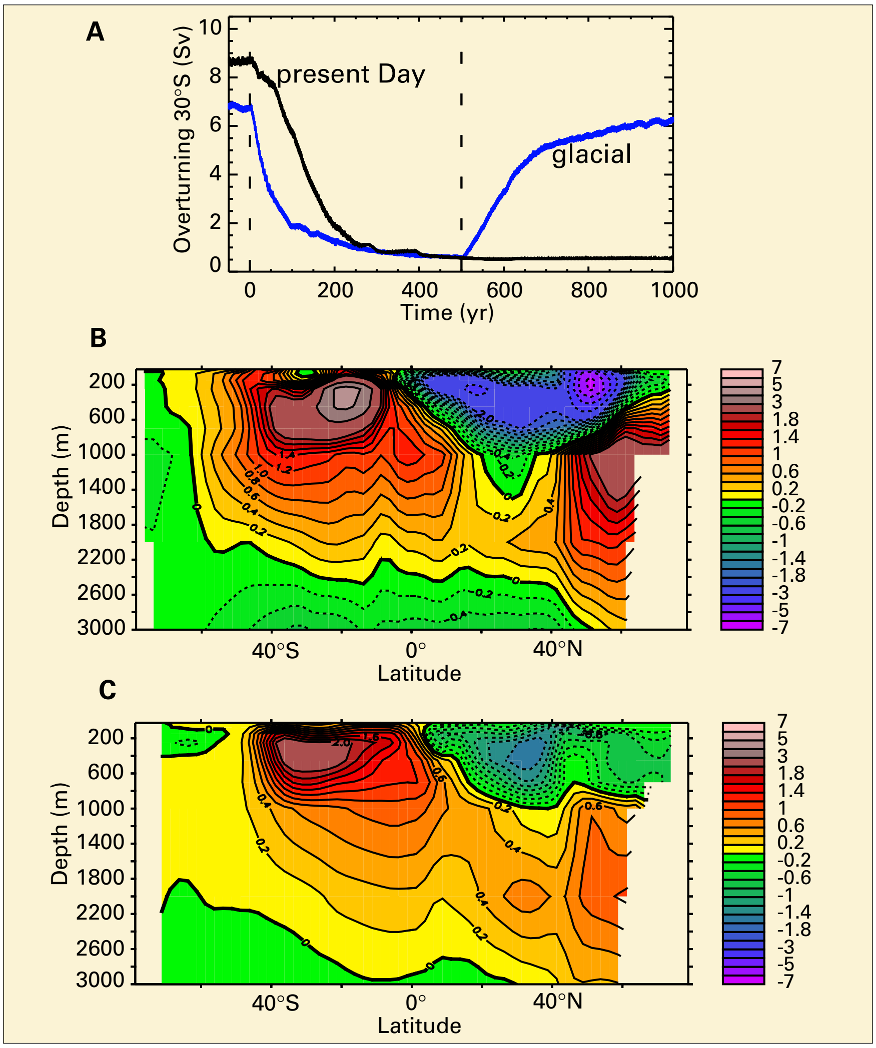

*Fig. 1: Change of overturning strength and temperature in meltwater perturbation experiments using a hybrid-coupled model for present-day and glacial climate conditions. The model is designed as follows: The atmosphere model ECHAM3/T42 is forced by present-day observed or reconstructed (CLIMAP with 3°C additional cooling in the tropics) sea surface temperatures. Computed fields of surface air temperature, freshwater flux and wind stress are then used to drive an improved version of the ocean general circulation model LSG. The applied heat flux formulation allows for scale-selective damping of temperature anomalies. (**a**) Temporal evolutions of the Atlantic meridional overturning circulation. A meltwater input of 0.15 Sv is applied to the North Atlantic between 40°N and 55°N from year 0 to year 500. After termination of the anomalous freshwater forcing, the present-day circulation remains in the "off" mode, whereas the glacial circulation recovers. This mono-stable behavior of the glacial THC has been discussed by Prange et al. (2002). (**b**) Zonally averaged temperature change (in °C) at year 500 (end of the meltwater perturbation) relative to the unperturbed state for the present-day Atlantic Ocean. Between –2°C and +2°C the contour interval is 0.2°C, for larger anomalies the interval is 1°C. (**c**) Same as in (**b**) but for the glacial Atlantic.*

We corrected the benthic isotope records by subtracting the global $\delta^{18}O$ ice effect caused by the melting of continental ice and freshwater runoff during the last deglaciation. The residual $\delta^{18}O$ curve ($\delta^{18}O$) shows rapid and pronounced decreases of 0.5 to 0.9‰ at the beginning of Heinrich event H1 (17 cal. kyr BP) and at the Younger Dryas (13 cal. kyr BP) (Figs. 2c and 2d); climatic periods when deep water formation was greatly reduced (Clark et al., 2002) (Fig. 2b). These $\delta^{18}O$ shifts could either reflect increase in temperature, local changes in the oxygen isotope composition of seawater ($\delta^{18}Ow$), or a combination of $\delta^{18}Ow$ and temperature. A change of $\delta^{18}Ow$ in the range of 0.5 to 0.9‰ seems unlikely since both core sites are remote from direct influence of isotopically light meltwater. In the freshwater perturbation experiment of the glacial ocean we found a salinity decrease of ~0.25 psu at the location of core M35003-4 and hence estimate that the reduction of $\delta^{18}Ow$ did not exceed 0.2‰. The modeled salinity decrease at the position of ODP core 1078C is even smaller (< 0.1 psu). Consequently, the major proportion of the benthic $\delta^{18}O$ shifts at Heinrich event H1 and the Younger Dryas must be explained by warming of 1-3°C when a decrease in $\delta^{18}O$ of 0.22‰ per 1°C temperature increase is applied. The rate of intermediate depth warming at the onset of Heinrich event H1 and the Younger Dryas (averaged between 12.9 and 12.2 cal. kyr BP) is 0.8 and 0.7°C century^{-1}, respectively.

The relationship between the strength of the THC and tropical Atlantic intermediate-depth temperatures during the last deglaciation may be highly relevant for tracing present-day and future changes of the THC. Freshening of the North Atlantic (Dickson et al., 2002) and a concomitant reduction in the Iceland-Scotland overflow (Hansen et al., 2001) over the past four to five decades suggests that a weakening of the THC might already be under way. Akin to the oceanographic processes during the last deglaciation we expect that a slowing of the THC is accompanied by a warming of tropical Atlantic intermediate-depth waters. Indeed, section data from the 1920s through the 1990s in the Atlantic Ocean reveal a considerable warming trend of 0.5°C century^{-1} between 1000 and 2000 m water depth for latitudes between 32°S and 36°N (Arbic and Owens, 2001). Arbic and Owens (2001) show that this warming in the tropical North Atlantic over the past decades is associated with a downward displacement of isopycnals which they ascribe to a volumetric increase of Labrador Sea Water (LSW) at the expense of deep water from the overflow across the Greenland-Scotland Ridge. In fact, such a change in volumes can explain a downward shift of isopycnals only below the depth of LSW. The isopycnal displacement at 1000 m, however, must be caused by other mechanisms. We argue that a slowdown of the thermohaline overturning is the most likely explanation for the tropical intermediate-depth warming in the Atlantic Ocean. Disturbing our model of the

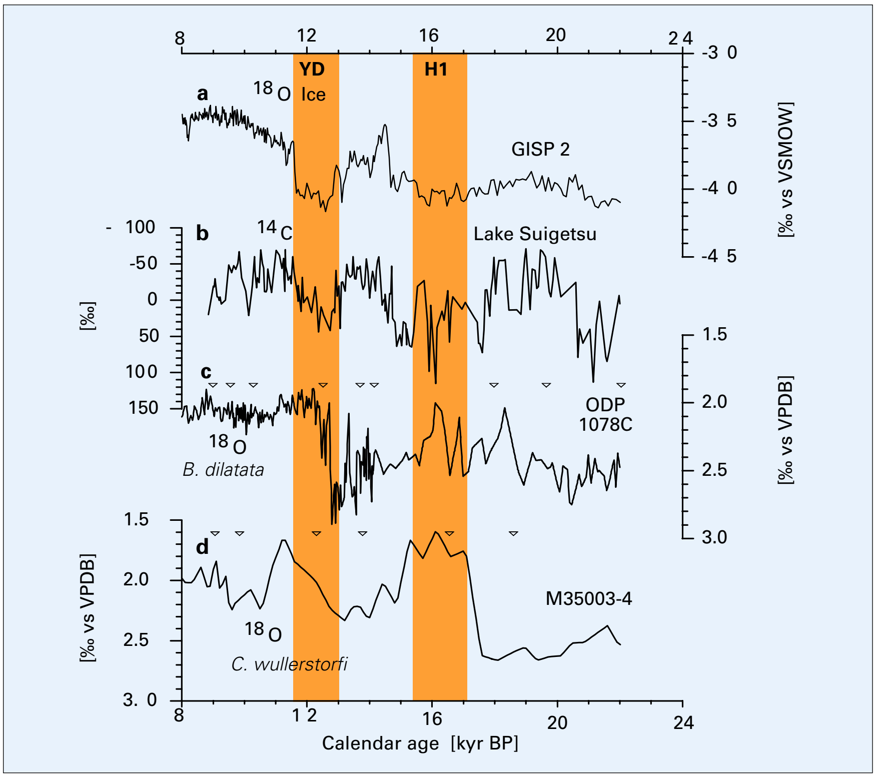

*Fig. 2: Comparison of oxygen isotope ratios of the benthic foraminifera B. dilatata (**c**) and C. wuellerstorfi (**d**) (Hüls, 2000) from sediment cores ODP 1078C (11°55' S, 13°24' E; 426 m water depth) and M35003-4 (12°05' N, 61°15' W; 1299 m water depth), respectively, indicating tropical Atlantic intermediate-depth temperatures, with (**a**) oxygen isotopes from the GISP2 ice core displaying air temperatures over Greenland, and (**b**) atmospheric radiocarbon from sediments of Lake Suigetsu, Japan (Kitagawa et al. 2000; adapted from Clark et al., 2002). ^{14}C AMS control points for ODP 1078C and M35003-4 are denoted by triangles above the respective record. H1 and YD denote Heinrich event H1and the Younger Dryas period, respectively. The record of $\Delta^{14}C_{atm}$ (**b**) is a function of the production rate of ^{14}C in the upper atmosphere and the sizes of and exchange rates between the major carbon reservoirs. North Atlantic Deep Water (NADW) is presently the major source of ^{14}C to the deep sea, and changes in the strength of this water mass probably dominate the variations in $\Delta^{14}C_{atm}$. Positive anomalies in the $\Delta^{14}C_{atm}$ record hence largely reflect reduction of NADW production and thermohaline overturning (Clark et al., 2002).*

present-day circulation with a weak North Atlantic freshwater flux of 0.03 Sv (1 Sv = 10^6 m³ s^{-1}), we find that the observed mid-depth warming rate in the low-latitude Atlantic (Arbic and Owens, 2001) is consistent with a weakening of the THC by only 5-15% (not shown here).

In view of uncertain Atlantic overturning reduction, it is inevitable to design a proper strategy for the early detection of THC change. Intermediate-depth waters provide a potentially sensitive indicator of anthropogenic climate change related to the THC, which has shown to be one of the most uncertain processes of possible future climate shifts. A primary objective of several climate research programs is to design practical strategies for monitoring climate variability and THC changes. Using a novel combination of paleoceanographic records, climate modeling results and recent oceanographic evidence we highlight the importance to include long-term temperature measurements of the low latitude mid-depth Atlantic as an integrative indicator of THC change in such a monitoring system. We argue that the rates of temperature change of intermediate-depth waters at Heinrich event H1 and the Younger Dryas provide a benchmark against which to assess warming rates in the 20th century as well as in the future.

Acknowledgments

This research was funded by the Bundesministerium für Bildung und Forschung. More information about the projects DEKLIM and RASTA can be found under www.deklim.de and www.geomar.de/projekte/rasta/.

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Past Rates of Sea Level Change

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Rates of sea level change identified from the geological record can be separated into longer-term (<1,000 ka), the post-glacial marine transgression (20 ka to 7 ka) and the subsequent adjustment to modern levels (>7 ka). In addition, there are historic rates from instrument measurements.

<1,000 ka

Long term geological rates of sea-level change provide a perspective on the cyclical nature of sea level and the extent to which current and predicted sea-level changes are perturbations from natural cycles. Oxygen isotope ($^{18}O/^{16}O$) ratios of planktonic foraminifera from deep-sea sediments provide evidence of sea level fluctuations over numerous glacial/interglacial cycles with the Vostok ice core providing additional detailed records for the last four cycles. An approximate 100 ka periodicity for these cycles has been identified in the geological record and correlated with the oxygen isotope record in southeast Australia where, a series of stranded dune barriers dating back to 800 ka is associated with at least 10 interglacial high stands of sea level. Geological evidence of the rate of sea-level change across an entire glacial-interglacial cycle is provided by the coral record from Barbados and the detailed record of coral terraces preserved on the rapidly uplifting coast of the Huon Peninsula in New Guinea.

20 ka to 7 ka

Some of the fastest rates of sea-level rise from the glacial/interglacial cycles are associated with the post-glacial periods of deglaciation and global warming, most recently following the last glacial maximum of 20 ka.

Detailed geological investigations reveal rapid rates, such as in the South Australian gulfs where a sea-level rise of 9 mm/yr has been estimated between 10-8 ka and a more rapid rate of 24 mm/yr (Fig. 1) between 8-6.7 ka (Belperio, 1995).

7 ka to Modern

Coastal adjustment to the post-glacial redistribution of water and ice and differential loading of the lithosphere has produced varying rates of sea-level change around the globe. Post glacial sea-level changes are still impacting on the coast in many parts of the world as demonstrated by local or regional glacio-isostatic movements in the northern hemisphere and the global pattern of hydro-isostatic coastal adjustment (Houghton et al, 2001; Peltier, 2001). This has produced a sea level fall over the last 6-7 ka for some locations such as for Port Pirie in South Australia where Harvey et al. (1999) use paleo sea level indicators to demonstrate a rate of fall of 0.33 mm/yr. Higher rates of sea-level fall occur away from the continental margin at Port Augusta and lower rates at Ceduna closer to the margin (see Fig. 1).

Elsewhere, the use of fixed biological indicators such as coral microatolls (Fig.2) and encrusting

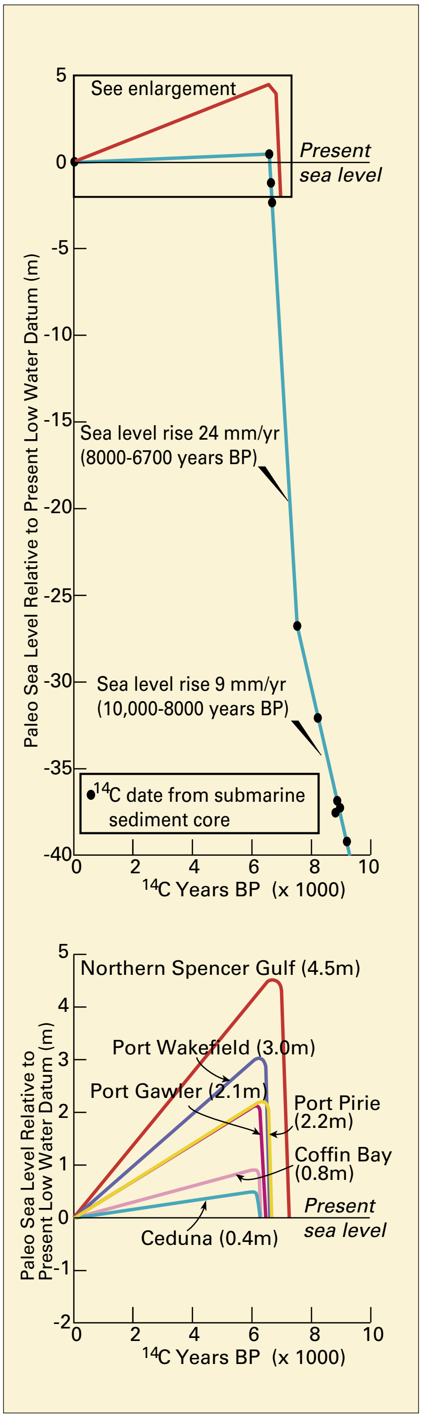

Fig. 1: Sea-level rates from South Australia following the postglacial maximum period and for the subsequent period of hydroisostatic shelf deformation (source: Harvey et al, 2002 after Belperio, 1995).

tubeworms provide high-resolution paleo sea-level datums from which palaeo sea level curves and rates can be derived and correlated with the geophysical models. However, there is debate over the method of deriving these rates and the use of smooth or oscillating sea-level curves (see Baker and Howarth, 2000).

Historic Records

Rates of change measured by tide gauges require geological correction but are becoming more refined with the use of satellite altimetry and geodetic measurements. The IPCC third assessment report (TAR) draws a number of conclusions from its analysis of global average sea level rise derived from tide gauge records (Houghton et al., 2001).

- First, very long tide gauge records suggest that the average rate of sea level rise was less in the 19th century than the 20th century.
- Second, tide gauge records for the 20th century give a mean sea-level rise in the range 1-2 mm/yr with a central value of 1.5 mm/yr.
- Third, although there is a decadal variability in extremes there is no widespread increase in extremes apart from that associated with a change in the mean (Houghton et al., 2001).

Methodical Remarks and Modern Rates

Tide gauge records measure only relative sea level so that it is important to have long-term reliable records, which are free of vertical crustal movements due to plate tectonics. These records need to be correctable for glacial rebound and should be either insensitive to small changes or be capable of editing based on oceanographic considerations (Douglas, 2001). Douglas selects 27 sites (with records exceeding 70 yrs) from around the globe to establish a 20th century global rate of sea level rise (Douglas, 2001). However, sites from the relatively stable Australian continent are excluded and Houghton et al. (2001) comment on the omission, given that the two longest records from Australia are both in excess of 80 years.

In order to obtain a clearer picture of mean sea-level trends it is important to correct the records for local and regional influences. For example, Harvey et al. (2002) demonstrate geologic, isostatic and anthropogenic influences on southern Australian tide-gauge records occurring at time scales of 106 yrs, 104 yrs, and 102 yrs, and rates of 0.07 mm/yr, 0.4 mm/yr and 2.0 mm/yr, respectively. Elsewhere, long-term tide gauge records have been adjusted for vertical land movements using either geological methods or post-glacial rebound models. The estimates provided by various authors were discussed in the TAR which noted that the wide range of rates reflects, in part, the different assumptions and methods used for estimating vertical land movement and also the different selection criteria for the tidal data used (Houghton et al., 2001).

Houghton et al. (2001) comment on different sea-level rise rates for the North American east coast where Peltier's rates (1.9 mm/yr) are significantly higher than those of both Gornitz (1.5 mm/yr) and Mitrovica and Davis (1.4 mm/yr) for the same region. Houghton et al also comment on the difference between lower European rates (1-1.1 mm/yr) relative to the higher North American rates (1.4-2.0 mm/yr). They suggest that this may reveal a real regional difference in sea level because of higher rates of sea level rise for the sub-tropical gyres of the North Atlantic in recent decades (Houghton et al., 2001, p. 661).

Australian data from two long-term sites, Sydney (82 yr record) and Fremantle (91 yr record) have been calculated by Houghton et al. (2001) using GIA corrections from the Australian-based rebound model of Lambeck and Nakada (1990), giving rates of 1.07 mm/yr and 1.55 mm/yr respectively. Sea-level rise rates from Southern Australia (Harvey et al., 2002) are significantly lower. These rates corrected using geological methods have been obtained for a number of sites with record lengths of up to 60 years, giving individual tide-gauge site rates of between 0.14 to 0.87 mm/yr. Thus, the far field data from the relatively stable Australian continent suggest sea-level rise rates lower than the central value of 1.5 mm/yr for global average sea-level rise adopted by Houghton et al. (2001) in the TAR.

Fig. 2: A microatoll from the south coast of Fiji showing both living coral and an elevated section related to a higher sea level. Such palaeo sea-level indicators are used to determine Holocene sea-level curves.

The most recent IPCC scientific assessment (Houghton et al., 2001) draws a number of conclusions on the factors affecting current rates of sea level change. Over the last century, ocean thermal expansion is estimated to have contributed between 0.3 to 0.7 mm/yr based on Atmosphere-Ocean General Circulation Models. The contribution from the melting of glaciers and ice caps is estimated to range from 0.2 to 0.4 mm/yr based on observational and modeling studies. Modeling studies also estimate the contribution from the Greenland ice sheet of 0.0 to 0.1 mm/yr and from the Antarctic ice sheet as -0.2 to 0.0 mm/yr. These figures result in a total estimate of eustatic sea level rise for the last century between -0.8 to 2.2 mm/yr producing a central value lower than expected from the observational records (Houghton et al., 2001).

Comparison of Past and Present Rates

It is clear that most recent post-glacial sea level transgression has produced rates of sea-level rise (>24 mm/yr) from prehistoric time well in excess of current rates (1-2 mm/yr). Although the rates for the 20th century appear faster than the rates for the 19th century it has been estimated that in order to reach the IPCC projected sea level (central value) by 2100, it would require a rate of sea level rise between 2.2 and 4.4 times the rate for the last century (Houghton et al., 2001).

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LIMPACS Workshop: Long-Term Response to Reduced Nutrient Loading

Silkeborg, Denmark, January 18-22, 2003

Although climate change holds the attention of both the general public and the science community, other environmental problems are equally important for freshwater ecosystems. The effect of nutrient inputs to aquatic systems was the focus of considerable research in the 1970s and it is now returning to the environmental agenda. The possible negative interplay between climate-driven changes in lakes and nutrients may undo the positive effects of nutrient reduction strategies over the last 15-20 years at many lakes in Europe and North America (Fig. 1). Reduced nutrient loading (or oligotrophication) brings about substantial changes to lakes but long-term monitoring indicates that these are rarely the simple reverse of those changes that resulted from increased nutrient loading and are often delayed. New quantitative paleolimnological techniques have helped to describe the effects of changing nutrient loadings over much longer time frames than contemporary data have permitted. In an attempt to synthesize the available data, we held a LIMPACS-sponsored workshop on the biological effects of reduced nutrient loadings to lakes.

Oligotrophication illustrates the mutual interdependence of sediment-based environmental reconstruction and contemporary limnology. For many lakes, there is no information about their background ecological status so it is difficult to determine whether remedial action is working or not. For those lakes with long-term datasets, continuous monitoring started at the peak of eutrophication problems, as its effects became visible (e.g. algal scums). As a result, long-term records are now often >20 years and provide the possibility of validating palaeolimnological reconstructions for both nutrient concentrations and eventually perhaps, whole-system dynamics.

The workshop was attended by 35 people from 15 countries (including China, Estonia, Russia and Hungary as well as the USA, Canada and many EU countries). The range of lake types reflected this diverse geographical context, including coastal Mediterranean lagoons, shallow, sub-tropical Lake Apoka (Florida), small lakes in Northern Europe and large, deep pre-Alpine lakes. The workshop was based around two questionnaires (one for the palaeo-group and one for the contemporary limnology-group) that participants had to complete prior to arrival at the meeting. As well as presentations of individual case studies for those sites where there was long-term data (e.g. Lough Neagh, Lake Constance, Lago Magiorre and Lake Washington), there was considerable discussion on the comparative response of different lake types to nutrient reduction. To what extent is it possible to generalise about the observed responses to nutrient reduction across such a wide range of lake types? Nutrient reduction primarily targets phosphorus. Is the role of nitrogen in lake functioning altered and will it continue to change? Does the sediment record reflect the changes observed in the water column? The answer to these questions will appear in the meeting proceedings that are to be published in a special issue of Freshwater Biology.

Fig. 1: Many Danish lakes have experienced major reductions in nutrient loadings over the last 20 years - a good reason for holding a LIMAPCS workshop on oligotrophication in Denmark.

LIMPACS is an attempt to create a holistic approach to understanding past and present lake variability and to reduce the largely artificial boundaries between palaeolimnology and contemporary limnology. The Silkeborg workshop was an important step towards this union, as it included limnologists who had not considered the possible benefits of sediment-based approaches, those who have a foot in both camps and palaeolimnologists who need to understand the complexity of contemporary lake dynamics, and hence avoid limnologically-naive interpretations. The discussion at the meeting was lively and reflected this range of interests.

Oligotrophication has provoked fundamental questions about our understanding of the predictability of lake ecosystems. It provides an opportunity for limnologists to test theories about ecological interactions between different trophic levels and for palaeolimnologists to consider the integrity of the sediment record. There is also considerable relevance for the future, however, as we try to understand the synergism between varying nutrient loads and climate. Oligotrophication is mainly the result of point-source reductions, but modern farming practice and the growth of the agricultural phosphorus surplus means that diffuse phosphorus losses to freshwater will become increasingly important. There is plenty of material for future LIMPACS activities.

The meeting was sponsored by the National Environmental Research Institute (NERI) in Silkeborg, Denmark. PAGES provided funding for the participation of scientists from less developed countries.

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Late Quaternary Environmental Change – "Emerging Issues"

Pondicherry, India, February 10-15, 2003.

The French Institute of Pondicherry organized an International PAGES Workshop and a Training programme on "Late Quaternary Environmental Change – Emerging Issues". About 70 participants from 7 countries (India, Bangladesh, Sri Lanka and Thailand, Germany, France and the USA) participated. An optimal mix of both young and established Global Change Scientists with diverse specializations but all with an interest in the South Asian region made this meeting a scientifically useful event.

The programme comprised sessions in the format of plenary lectures, oral and poster presentations and a special symposium followed by training including field and laboratory protocols in quantitative palynology, GIS, data management and relevant software for construction of pollen diagrams and statistical analysis of pollen, vegetation and climatic data.

A one-day symposium on the theme "Model specific data sets and data specific models – The South Asian context" was also organized.

Other sessions reviewed the paleoclimatic archives including terrestrial archives, ocean cores from the Arabian sea and quantitative multiproxy approaches. Applications of emerging new techniques and methodological approaches such as luminescence dating, magnetostratigraphy, environmental magnetism, Electron Spin Resonance, clay mineralogy, dendrochronology archaeoclimatology, remote sensing and GIS to palaeoenvironmental studies in South Asia were also discussed.

A highlight of the meeting were the first results from a new multidisciplinary research programme (INDian SUbcontinent BIOmes, INDSUBIO) involving field studies in targeted regions, laboratory analysis and remote sensing input. New initiatives from the remote sensing community were also presented and results from a powerful and cover change detection computer algorithm that permits identification of undisturbed sites using a grid hierarchal scheme was presented. Other multidisciplinary projects (HITE–TERRAPIN, Tracking the Environmental Records in Reservoirs and Agro-ecosystems of Peninsular India) transgressing barriers between natural and human sciences, with combined inputs from archaeologists, historians and geographers in reconstructing past environmental changes, were additional highlights. In this context for example, luminescence dating and micro morphology of pedogenic carbonate cutans (secondary carbonate coatings) emerged as additional tools for reconstructing landscape history in arid peninsular Indian archaeological sites. Further, the widespread occurrences of artificial and interlinked rain harvesting systems (irrigation tanks/ lakes) in Peninsular India, providing a high-resolution sedimentary record of erosion and environmental change for the past few centuries, were discussed. Initial results are highly promising.

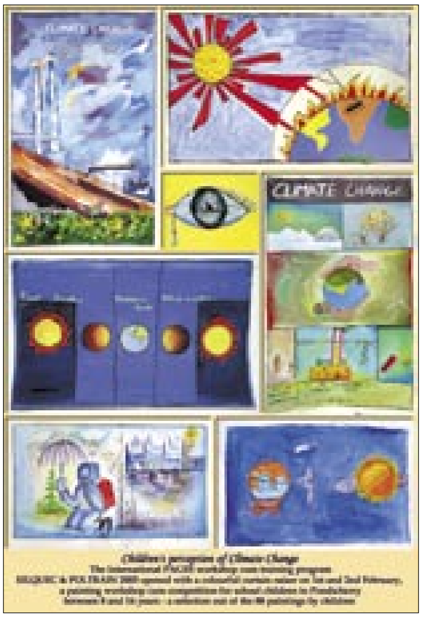

Fig. 1: Public Events - Painting competition on Climate Change for school children.

A three-day training programme comprised a field excursion into a dry deciduous forest of the Eastern Ghats (a disjoint chain of hills in south-eastern peninsular India) to introduce field-sampling protocols for quantitative pollen and vegetation studies.

This meeting was planned in tandem with another important national meeting at Anna University Chennai - that organized a workshop on understanding dry land soils and early Quaternary paleoclimate under the aegis of UNESCO sponsored international geological correlation programme (IGCP-413 on drylands) along with a training course on Quaternary soils as palaeoclimate indicators and a common seminar with the french institute on "Radiometric dating methods and Palaeoenvironments during the Quaternary". This synergy aimed at optimising resources and increasing the outreach of the PAGES science to a wide cross section of Earth system scientists researchers, particularly young scientists who could avail the benefits of both training programmes.

The response and feedback from the participants during and after the programme has motivated the organizers to plan regular summer or winter training schools. Although specialized, the meeting did capture the attention of the local media based on a curtain raiser including several public events, such as a painting competition on the theme for school children, a photographic and poster exhibition and popular multimedia presentations to introduce the overall science, economics and politics of climate change, formed a part of this programme. The response was tremendous.

The Meeting was funded by PAGES, the French and German embassies in India, DST (Department of Science and Technology, India) and ISRO-GBP (Indian Space Research Organization's Geosphere Biosphere programme).

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CALENDAR 2003

May 19 - June 7, 2003, Tucson, Arizona, USA
Tucson Tree-Ring Summer School, 2003

Further information:
http://www.ltrr.arizona.edu/
Malcom Hughes: mhughes@ltrr.arizona.edu

June 30 - July 11, 2003, Sapporo, Japan
IUGG 2003: Holocene Climate session MC12

Further information:
http://www.jamstec.go.jp/jamstec-e/iugg/
Michael Mann: mann@virginia.edu

July 23 - 31, 2003, Reno, Nevada, USA
XVI th INQUA Congress; Special PAGES Session: Human-Environment Interactions: Past and Present

Further information:
http://www.inqua2003.dri.edu/inqua_home.htm

Aug. 30 - Sept. 6, 2003, Grindelwald, Switzerland
2nd International Swiss NCCR Climate Summer School

Further information:
http://www.nccr-climate.unibe.ch/events/SummerScool/03/information.html

Oct. 11 - Oct. 16, 2003, San Feliu de Guixols, Spain
Euresco Conference: Achieving Climate Predictability Using Paleoclimate Data. A PAGES/CLIVAR Intersection Meeting

Further information:
http://www.pages.unibe.ch/calendar/2003/euresco.html

November 16 - 19, 2003, Trieste, Italy
First International Young Scientists Global Change Conference

Further Information:
http://www.ictp.trieste.it/%7etwas/YS_START_2003_announce.html

http://www.pages-igbp.org/calendar/calendar.html

PAGES Synthesis:

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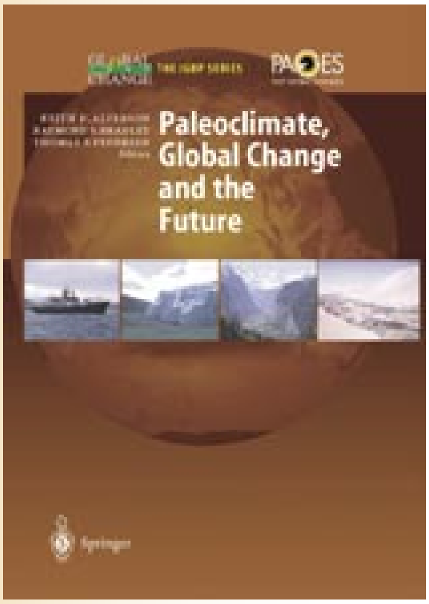
Alverson, K. D., Pedersen, T. F. and Bradley, R. S. (Editors)
2003 XIII, 221 p. 88 illus., 51 in color. Hardcover
3-540-42402-4; Springer
Recommended Retail Price: EUR 79,95 *



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