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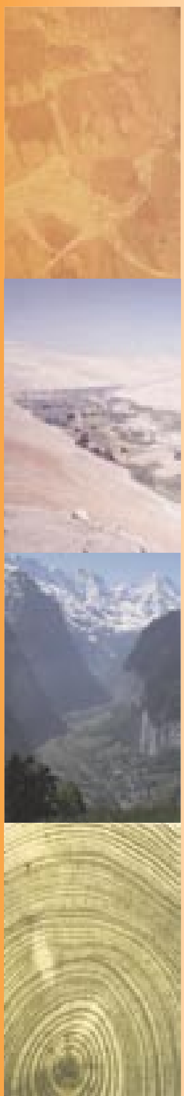
PAGES News
PAST GLOBAL CHANGES

Christoph Kull, Leah Christen and Keith Alverson, Editors

Vol.12, N°1 – April 2004

Paleoclimate Research



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A Peruvian-French-Austrian team carrying out accumulation measurements at 5350 m asl. on Glaciar Artesonraju, Cordillera Blanca, Peru (Photo: G. Kaser, see Science Highlight, page 15).

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Editorial: The Future of PAGES - Setting New Directions

PAGES is a service-oriented program that facilitates interdisciplinary science across international boundaries. Its goal is to support research aimed at understanding the Earth's past environments in order to make predictions for the future. This research support is not the traditional kind i.e., in the way of research funds; rather, we support the paleoscience community by developing the ways and means for collaboration and communication. PAGES supports scientists via sponsorship of workshops, symposia, and conferences that bring scientists from different countries together to share, compare and synthesize data from different high resolution archives recording climate change; it is especially about building up a science community that interacts on an international level. Many scientists already collaborate internationally without PAGES as a venue and this we recognize and applaud. However, the larger role for PAGES is in facilitating dialog among all scientists, including those who might not otherwise focus on common interdisciplinary themes and initiatives between countries.

PAGES, founded in 1991, has had a successful history due to the scientific vision of earlier members of the SSC and the IPO. But what will happen in the future? How can we improve on our success? How can PAGES best serve the needs of the widest possible international and interdisciplinary paleoscience community? What do YOU think about PAGES? What do YOU expect from PAGES in the future? Perhaps you have thought about a new crosscutting theme that could be developed into a new initiative within PAGES.

You may have received our E-news request for feedback (vol. 2004, No.1), or seen the EOS article (March 16, page 107), but to date, we have had only 40 responses from over 3500 subscribers. Your input is <u>needed and essential to crafting the future of PAGES</u> and would be greatly appreciated before 1 MAY 2004! Please go to our feedback site on the web: http://www.pages.unibe.ch/about/feedback.html or email your comments to Leah Christen (christen@pages.unibe.ch). Feedback can also be sent by fax (+41 31 312 31 68), or regular mail (Sulgeneckstrasse 38, 3007 Bern, Switzerland). Please take the time to send us your comments (good and bad) so that we can help shape PAGES' future together.

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THE CLIMATE OF THE NEXT MILLENNIA IN THE PERSPECTIVE OF ABRUPT CLIMATE CHANGE DURING THE LATE PLEISTOCENE

PAGES/DEKLIM Conference: 7-10 March 2005, Mainz, Germany

Convenors: Frank Sirocko, Jerry McManus, Martin Claussen, Keith Alverson

Call for Papers

"The climate of the past is the key to understanding the climate of the future". Is this often used statement truly correct for the next two millennia? The conference will examine past records of abrupt climate change and discuss if the processes that caused past abrupt change are indeed relevant for the Holocene and predicted climate evolution. Keynote lectures on the mechanisms that dominated past climate evolution will be followed by sessions (talks and posters) on long (0-3 ma), medium (0-150 ka) and very short (Holocene and last millennium) time scales. Discussions are intended to separate processes unique to the past from those that indeed have the potential to effect global climate during the next millennia. The conference is sponsored by the German DEKLIM program (www.deklim.de) and represents a German contribution to PAGES. We hope to welcome you in Mainz (50 minutes from Frankfurt International Airport) and would appreciate your early registration.

Registration

To receive a registration form for the conference, please send an email with your full address to the DEKLIM-EEM secretary, Saskia Rudert (email: rudert @uni-mainz.de). The registration form can also be downloaded at http://www.uni-mainz.de/FB/Geo/Geologie/sedi/en/index.html.

Conference fees are 75 Euro. The excursion costs 30 Euro, plus accommodation. There is a limited amount of support available to finance the participation of students. If you would like to apply for support, please put in a formal request. Abstracts should be no more than 1 page of text and 1 page of figures.

Deadlines: for registration - 31 October 2004; for abstract submission - 30 November 2004

Further Information: http://www.pages.unibe.ch/calendar/2005/deklim.html

Inside PAGES

PAGES welcomes five new members to its Scientific Steering Committee this year. **Jerome Chappellaz** is Deputy Director of the National Laboratory for Glaciology and Geophysics of the Environment in Grenoble, France. Jerome has scientific interests in geochemistry, isotope geochemistry, atmospheric dynamics and chemistry and biogeochemical cycles. **Eystein Jansen** is Research Director of the Bjerkness Center for Climate Research, and Professor of Geology at the University of Bergen. Major research accomplishments include documentation of changes in thermohaline overturning associated with the last deglaciation as well as using very high sedimentation rate sites to reconstruct oceanographic condition over the past millennium. **Peter Kershaw** is Professor of Geography and Environmental Science and Director of the Centre for Palynology and Palaeoecology at Monash University in Melbourne, Australia. Peter has worked on reconstructing the vegetation histories of the tropics and Australia and the impacts of Aboriginal peoples. His recent interest in marine palynology provides a valuable link between land and ocean paleoenvironments. **José Ignacio Martínez** is a researcher and lecturer in paleoceanography and micropaleontology at the Universidad EAFIT in Medellin, Columbia. He has expertise in the late Quaternary climates of South America and the tropical Pacific including ENSO. **Ricardo Villalba** is a senior researcher at the Argentinian Institute for Snow, Ice and Environmental Research in Mendoza. Ricardo brings expertise in Southern Hemisphere climate variability over the past millennium, Southern Hemisphere dendrochronology, and statistical analysis.

Tales from the Field

A Novel Use for the Classical Hiller Borer

This happened some 15 years ago in the remote tropical jungles of the Orinoco basin, in northern South America. We were conducting a survey on the summits of the tepuis, the spectacular sandstone table mountains that led Arthur Conan Doyle to write his popular 'Lost World' in 1912. We used to reach the target sites by helicopter, due to the inaccessibility of most of the tepui tops. The place with which the present story is concerned is called Cerro Ichún, and appeared on the topographical maps as a typical tepui that, at that time, was unexplored. We were very excited with the possibility of being pioneers, but not exactly in the way we became. Let me get to the point. The expedition departed by plane from Caracas in the direction of Canaima, a wonderful tourist spot in the core of the jungle, where the helicopter was waiting for us. To reach the Ichún, we split into two flights. The first group, with the expedition head, Otto, the phytogeographer, and all the field equipment, was charged with choosing the site and establishing camp. In the second group, were a geologist, a zoologist, and myself, a paleoecologist looking for peat bogs. After a recon flight, Otto did not observe any tepui in the area, and decided to land on a sandy riverbank with all the material, and wait for us to arrive to make a decision. When we reached the site, Otto was in shock, "A tiger!" he said, "A tiger!" and nothing else for quite a while. Once recovered, he told us that while he had been organizing the field gear a tiger (really a jaguar, called 'butterfly tiger' by the natives but no less frightening) had come from the other side of the river to inspect its territory and had begun to circle around him defiantly. At first Otto was paralyzed but after a while he reacted, got onto the boxes and looked for something with which to try to keep the beast away. The first idea that came to mind was...yes, my Hiller borer! Face to face with that fierce creature, he actually managed to assemble the borer extensions and put together a sort of taming tool, which he successfully used to protect himself until the "tiger" ran away when our helicopter approached the site. After hearing his story, we decided to relocate to a tepui we had visited previously. However, the helicopter was called away to put out a fire and had to leave us in a neighboring forest clearance. The clearance was no more than 50 meters in diameter and we didn't know when the helicopter would be available to come again. There we were, lost in the middle of an impenetrable jungle, with nothing to do, far from any tepui, and hundreds of kilometers away from the nearest city. We waited for days to be rescued. On that occasion, I didn't find any peat to bore with my Hiller device but it probably saved Otto's life.

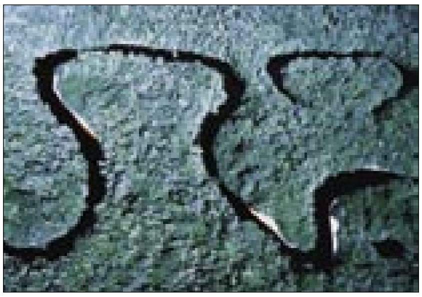

Fig. 1: Aerial view of a meandering blackwater river from the southern Orinoco basin, with several sandy riverbanks like that in the present story.

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

Lithuania

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MAJOR FUNDING AGENCIES:
Lithuanian State Science and Studies Foundation
http://www.vmsfondas.lt
Government of Republic of Lithuania

Territory:	**65 303 km2**
Population:	**3.48 million.**
Capital:	**Vilnius**
Latitudes:	56 27'N, 53 54'N
Longitudes:	- 20 56'E, 26 51'E

A NATIONAL SCIENCE HIGHLIGHT: Late Glacial and Holocene environment: natural effects and human impacts

Reconstruction of the Post Glacial environmental history of the second half of the Holocene, with emphasis on human interaction, is the main aim of investigations being carried out in Lithuania. A survey of Late Glacial deposits (Fig. 1) has provided new data that enables us to determine peculiarities of the vegetation cover, variations in the lake level table and the intensity of geological processes in this part of Europe. Ongoing investigations of the Holocene period are aimed at reconstructing the environmental history, including chronologization and a description of particular events, with special emphasis on anthropogenically induced changes (Fig. 2). Numerous interdisciplinary investigations are studying the negligible impact of the Mesolithic tribes, the rising activity of the Neolithic communities with the onset of subsistence economies, and the increase in human pressure throughout later periods. The Baltic Sea is of particular interest for the Lithuanian scientific community. A detailed survey of coastal formations and deep sea sections have provided information about sea level fluctuations, paleoecological regime, sedimentation and erosion processes.

Fig. 1. Coring in Varene Lake.

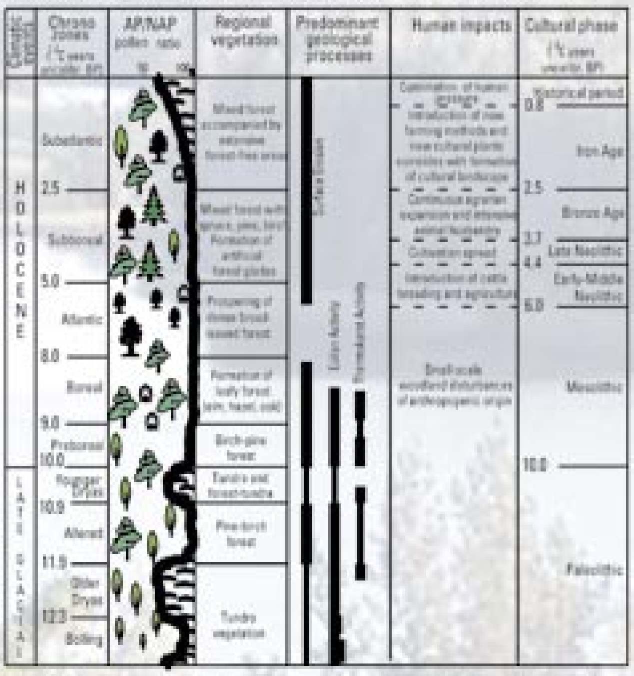

Fig. 2: Environmental changes and human activities during the Late Glacial and Holocene in Lithuanian territory.

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Kabailiene M. 1998. Vegetation history and climate changes in Lithuania during the Late Glacial and Holocene, according pollen and diatom data. PACT, 54: 13-30.

PALEOENVIRONMENTAL RESEARCH CENTRES:

Institute of Geology and Geography (http://www.geo.lt)
Department of Quaternary Research—Reconstruction of Interglacial and Post Glacial paleoenvironments. Elucidation of human impact during the Holocene.
Environmental Isotope Research and Dating Centre—Applications in isotope hydrology, Quaternary research, archeology and environmental studies. Evaluation of recent and past climatic and anthropogenic changes recorded from aquatic systems.

Vilnius University (http://193.219.43.40)
Department of Geology and Mineralogy—Paleoecological investigations of the Late Glacial and Holocene with special emphasis on the development of the Baltic Sea.

Geological Survey of Lithuania (http://www.lgt.lt)
Division of Quaternary Geology and IUGS Geoindicators Initiative (GEOIN)—Environmental studies of Pleistocene interglacials and interstadials.

Number of Lithuanian subscribers in the PAGES database (http://www.pages.unibe.ch/ppeople/ppeople.html) as of March 2004: 4

Rainfall Variation of Peninsular India Reconstructed From a 331-Year-Old Speleothem

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The southwest monsoon is of prime importance for the Indian sub-continent as it contributes the majority of annual rainfall. Any major departure from normal monsoon behavior seriously affects agricultural yield and the economy. To enable successful monsoon forecasting in order to plan agricultural activities, a systematic study of variations in monsoonal rainfall is required. This calls for long-term records of past rainfall. In tropical India, the major growth of speleothems occurs during the southwest monsoon (June to September) when water is most abundant. Therefore, speleothems would seem to show good potential as a rainfall proxy.

While $\delta^{18}O$ of tropical precipitation shows an inverse correlation with the amount of rainfall, it does not show a correlation with surface air temperature (Dansgaard, 1964). Speleothem $\delta^{18}O$, on the other hand, is related to both the $\delta^{18}O$ of meteoric water and the temperature of the cave during carbonate precipitation. Therefore, it should in principle function as a proxy for past variations in the $\delta^{18}O$ of meteoric water and the mean annual surface air temperature. Such an argument can be tested using a young speleothem.

An active stalagmite (Fig. 1), with distinct annual layers covering the past 331 years (the tip is AD 1996), was found in the Akalagavi cave in the mountainous terrain of the Western Ghats, in the state of Karnataka, peninsular India (Yadava et al., submitted). $\delta^{18}O$ measured along the growth axis varies between -2.7 and +1.6‰ (Fig. 2). During the past 300 years, mean annual temperature fluctuations of more than 1°C (corresponding to only a ~0.22‰ change in the speleothem $\delta^{18}O$) seem unlikely. Hence, past $\delta^{18}O$ variations in precipitation may have been largely responsible for the variations observed in speleothem $\delta^{18}O$.

If speleothem $\delta^{18}O$ is primarily governed by variation in rainfall, then a comparison of the $\delta^{18}O$ time series of the most recent part of the speleothem with the instrumental rainfall record of the region should result in a high correlation coefficient. Indeed, a comparison of the decadal running mean yields a significant value ($r = -0.62$, $n = 80$). This suggests that $\delta^{18}O$ in cave deposits is a reasonable proxy for decadal variations in local rainfall. A strong positive correlation ($r = 0.62$, $n = 301$) between $\delta^{18}O$ and $\delta^{13}C$ along the growth axis indicates that on an annual scale, $\delta^{13}C$ is also correlated with rainfall.

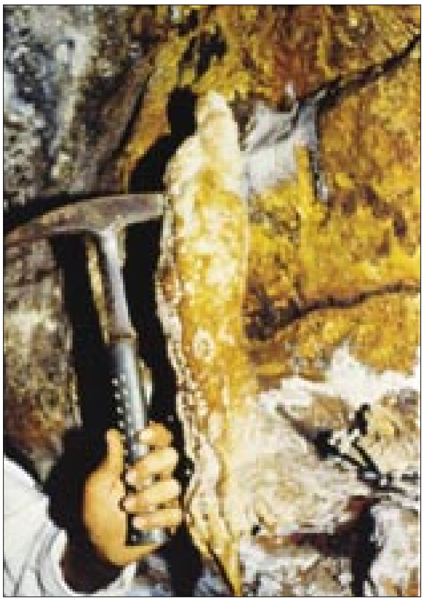

Fig.1: Akalagavi stalagmite before collection

Reconstruction of Rainfall at the Cave Site

IAEA island stations monitoring $\delta^{18}O$ in precipitation located in the equatorial belt, where annual temperature fluctuations remain within a narrow range, record a negative correlation between mean monthly $\delta^{18}O$ of precipitation and mean monthly rainfall (Yurtsever and Gat, 1981). The average rate of depletion is found to be -1.5 ‰ per 100 mm increase in monthly rainfall. This depletion rate should also be applicable to the coastal site where Akalagavi cave is located, since annual temperature fluctuations remain within a narrow range. At one of the sites influenced by the southwest monsoon, direct sampling of precipitation samples shows a similar depletion rate (-2.2 ± 0.8 ‰ per 100mm). Fig. 2 shows the $\delta^{18}O$ of the Akalagavi stalagmite converted into rainfall. Assumptions made include that changes in the speleothem $\delta^{18}O$ were solely due to variations in the amount-dependent $\delta^{18}O$ of the annual rain and that the depletion rate observed at the island stations is also applicable to the vapor sources at the cave site.

Period Covered by Instrumental Data (after AD 1813)

Years in which rainfall at a site is greater than the long-term average rainfall by more than 10% are defined as "excess" rainfall years (ER). Years in which it is lower by 10% or more are defined as "deficient" rainfall years (DR). Some of the severely deficient rainfall years (1982, 1979, 1941, 1925, 1918, 1915, 1905, 1899, 1877, 1854, 1815) as well as most of the excess rainfall years (e.g. 1988, 1975, 1961, 1956, 1953, 1917, 1910, 1894, 1893, 1884, 1878) observed in the AISRTS (All India Summer Rainfall Time Series) are also recorded in our speleothem-based rainfall reconstruction. Differences in timing, ranging from 0-6 years, are most likely due to errors in lamination chronology or to genuine differences in local rainfall as compared with the AISRTS.

The instrumental data in the rainfall reconstruction show an increasing trend over coastal and north-interior Karnataka from 1901-75. A dry period between 1901-30 in the AISRTS is clearly recorded as shortened width of layers and enriched level of $\delta^{18}O$ in the speleothem. Similarly, wet conditions from 1931-60 are also reflected in the speleothem. The dry conditions from 1961-90 are marked in our reconstruction by persistent deficient rainfall conditions. However, only some of the individual deficient rain-

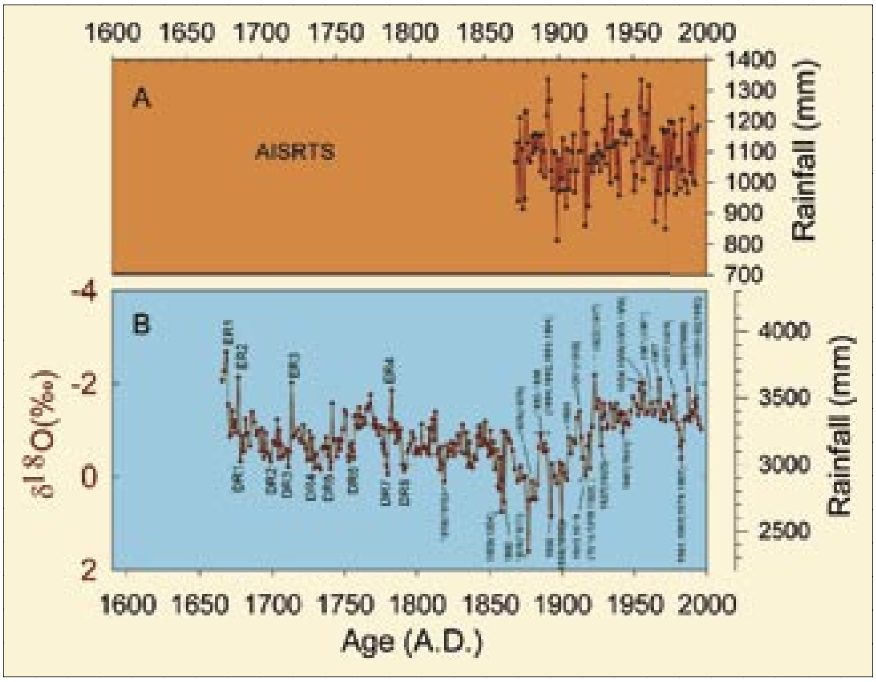

*Fig.2: (**a**) The all India summer rainfall time series (AISRTS) for the period 1871-1994 based on data from 306 stations. (**b**) $\delta^{18}O$ versus age obtained from lamination counting. The annual nature of the laminations is supported by the presence of bomb ^{14}C at the tip and agreement between the base ^{14}C age (210 ± 100 Yr BP) and the total number of laminations (331). Scale for the rainfall reconstruction is shown on the right. Depleted and enriched $\delta^{18}O$ signals coincide with excess and deficient rainfall years observed in the AISRTS. The year of their occurrence in the stalagmite is shown by the numbers outside brackets, in the AISRTS by numbers inside brackets. Numbers ER-1 to 4 and DR-1 to 8 are excess and deficient rain years observed before the period covered by instrumental data.*

fall years (~40%) observed in AISRTS are registered in the stalagmite, while most of the excess rainfall years (~86%) are recorded. A possible reason could be the proximity of the cave site to the coast, which would ensure that there were frequent rains due to orographic uplifting of clouds. Hence, a deficiency of rain may not have been experienced at the cave site despite a deficiency at inland sites. It also suggests that the cave site experienced only those deficient years during which the southwest monsoon system was severely weakened. Hence, regional variations in past rainfall may be responsible for the absence of some of the extreme rainfall events in the stalagmite.

Rainfall Before Instrumental Record (before AD 1813)

Low rainfall events DR7 and DR8 may coincide with the devastating droughts recorded during 1777 and 1796. Other events such as DR1 to DR6 should indicate extremely dry years. Growth in the stalagmite most probably took place when rainfall was high (near ER-1; ~1666). A peculiar feature of the rainfall reconstruction is that none of the deficient rainfall conditions observed before 1800 are comparable in magnitude to the deficient years that occurred around 1900. However, the average rainfall before ~1930 did remain lower than that during 1930-1996. In the reconstruction, all the deficient years (except 1892) and all the excess years (except 1967 and 1905) correlate with similar events in AISRTS. This suggests that there is a high possibility that the extreme events shown by ER1 to ER4 and DR1 to DR8 occurred countrywide.

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The Potential of Oxygen Isotopes in Diatoms as a Paleoclimate Indicator in Lake Sediments

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Oxygen isotope ratios ($\delta^{18}O$) measured in authigenic minerals are a valuable means of assessing paleoclimate, recording the ambient water temperature and $\delta^{18}O$ composition of the lake water at the time of formation (see Leng and Marshall, 2004). $\delta^{18}O$ measured from lake carbonates (authigenic carbonate, ostracods, etc.) has become a well-established paleoclimate technique, but in dilute and non-alkaline lakes where carbonates are rare, there are only a few suitable alternatives. The measurement of $\delta^{18}O$ in biogenic silica (mainly diatoms) is being increasingly utilised in low carbonate lakes (e.g. Barker et al., 2001; Shemesh et al., 2001). Diatoms are photosynthetic algae that secrete an internal shell composed of opaline silica (SiO_2 - H_2O) and are present in most lake sediments apart from some very alkaline lakes (typically pH > 9), or lakes where silica is limited (Barker et al., 1994). Here we discuss the types of lakes that are most suitable for this technique, the information that can be generated, and the potential problems.

The Effect of Lake Location on $\delta^{18}O_{diatom}$ Interpretation

The majority of lakes, for which oxygen isotope ratios from diatom silica have been successfully employed are in high latitude or altitude locations. The reasons for this lie in the nature of these lakes; diatoms are generally found in relatively high concentrations in low residence, well mixed, open lakes where diatom productivity is higher than other organisms. The water in these lakes reflects changes in the hydrological conditions of the lake basins (e.g. Leng et al., 2001, Barker et al., 2001) or the isotopic composition of precipitation (e.g. Shemesh et al., 2001; Jones et al., 2004, Rosqvist et al., 2004). Commonly, such lakes have low $\delta^{18}O$ variability, reflecting changes in temperature or the source of precipitation, rather than evaporation, except perhaps in low latitude lakes. However, diatoms may only record conditions during a specific season, for example the vernal mixing period in temperate lakes, or in high altitude/latitude lakes, during the ice-free summer months when temperatures are highest, runoff is heaviest, and nutrients are washed in from the catchment (Jones et al., 2004). By contrast, in low-altitude, mid-latitude and tropical lakes, higher temperatures may allow some diatom growth throughout the year, but this does depend on other mechanisms such as the seasonality of lake-water mixing and nutrient availability. Theoretically, diatom oxygen isotopes should record a seasonally averaged evaporation to precipitation balance of such lakes (e.g. Lamb et al., 2003), but few studies have been undertaken, in part because of the difficulty of separating the diatoms from the rest of the sediment.

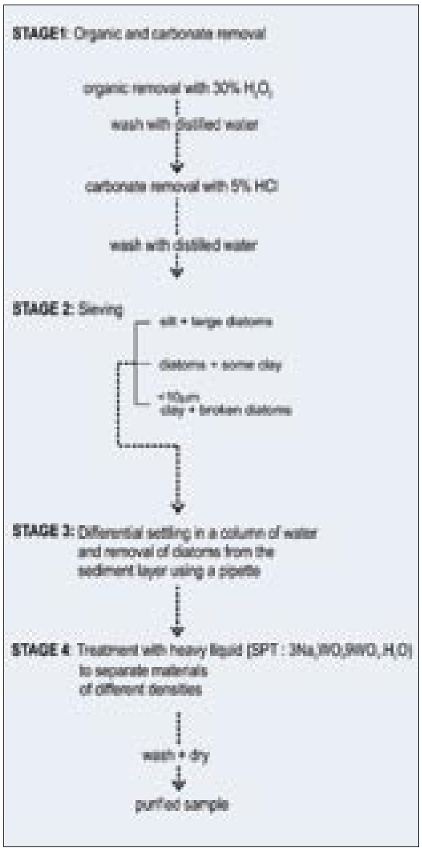

Fig. 1: Flow diagram showing the four-stage cleaning method for concentrating diatoms for $\delta^{18}O_{diatom}$ analysis from lake sediments. Adapted from Morley ***et al****. (2004).*

Fig. 2: Light microscope image of a sediment sample from Lake Tilo, Ethiopia. The sample is shown before sieving but after removal of carbonates and organics. Various diatom species are evident (predominantly Aulacoseira granulata*), along with a significant volcanic glass shard component. Photo courtesy of Philip Barker.*

Sample Cleaning

Analysis of the oxygen isotope composition of diatom silica requires samples that are almost pure diatomite, since the method most widely used (fluorination techniques) will also liberate oxygen from other components in the sediment, for example, silt, clay, volcanic glass (tephra), carbonates and organic matter. This is in contrast to the analysis of oxygen isotope ratios in carbonates, which only requires the removal of organic material and verification that the carbonate is authigenic. The precision of the $\delta^{18}O_{diatom}$ technique is several times lower (~0.2-0.5‰ as opposed to <0.1‰) than for $\delta^{18}O$ in authigenic carbonate, mainly due to the relative difficulty in breaking the Si-O bond, but also because of the higher risk of contamination in the diatom samples. Clay, silt and tephra can be difficult to remove from sediments and can have a large influence on $\delta^{18}O_{diatom}$ values. However, removal of these contaminants can be achieved via a series of cleaning stages, including organic and carbonate material removal, sieving, differential settling and heavy liquid separation (Morley et al., 2004; Fig. 1). In particular, sieving at various sizes is an important step in removing clay and silt; however, silt and tephra are often within the size range of the diatom frustules and thus cannot be easily removed (Fig. 2). Even small amounts of silt and tephra can have a significant effect on $\delta^{18}O_{diatom}$ because these materials often have $\delta^{18}O$ values that are significantly lower than the $\delta^{18}O_{diatom}$ values (Lamb et al., 2003, Morley et al., 2004). This emphasizes the need for microscopic examination of every sample and a cleaning method that is individually tailored to the core being analysed. An alternative approach to heavy liquid separation, currently being used at Lancaster University, is gravitational split-flow thin fractionation (SPLITT) developed by J.C. Giddings at the University of Utah and first applied to the separation of diatoms at the University of Jülich (Schleser et al., 2001). The advantages of SPLITT fractionation are high throughput by continuous flow, small losses, and sometimes the ability to isolate specific taxa (where they have different size, density and/or shape). It also avoids the need to introduce other products to the sample. Some

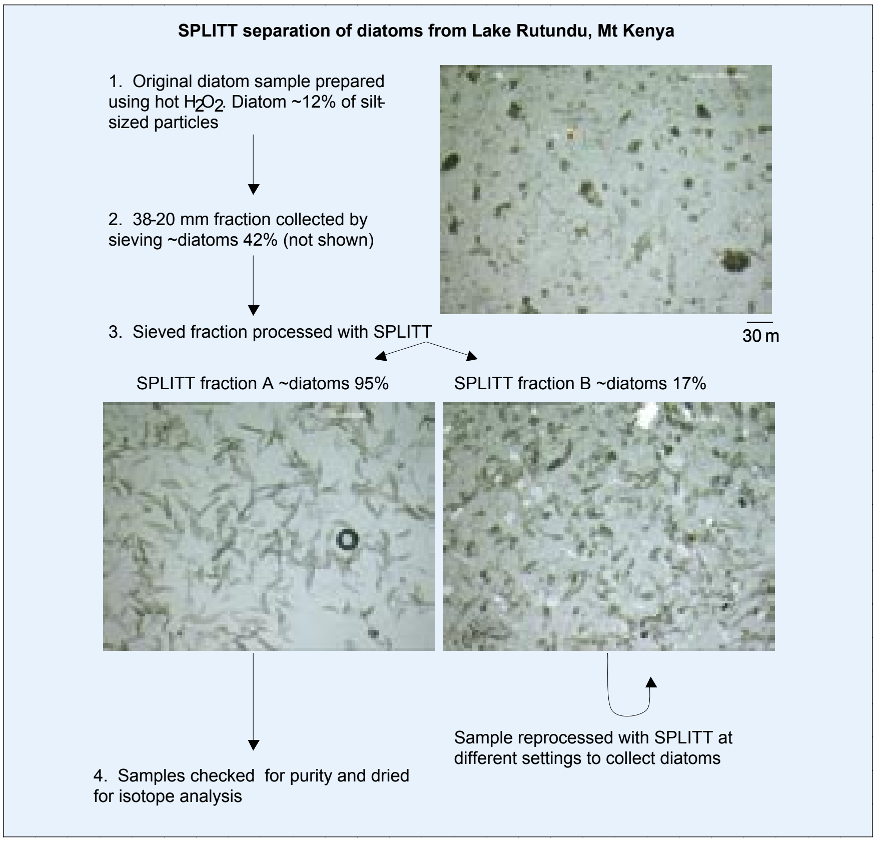

Fig. 3: Procedure used in the extraction of diatoms from Lake Rutundu, Mt Kenya. Diatom concentration is estimated optically and expressed per number of silt-sized particles. In this case, sieving of the chemically cleaned material was not sufficient to obtain pure samples. SPLITT separation produced one fraction with about 95% diatoms and another with a mixture of diatoms and silt. Fraction (B) could be recycled under different experimental conditions to try and extract the remaining diatoms. Additional processing of sample A could improve the concentration of diatoms further.

results of SPLITT separation are shown in Figure 3.

Comparing $\delta^{18}O_{carbonate}$ and $\delta^{18}O_{diatom}$

It is rare that both carbonate and diatom silica exist simultaneously in lakes in significant concentrations, due to the influence of pH. Lake pH is a central controlling factor in diatom dissolution rates as it controls the dissociation of silicic acid (e.g. Barker et al., 1994). Lakes in carbonate catchments, where silica is not limited and that have a pH of 7 or 8, can sometimes support both carbonates and diatoms in high concentrations, but this is quite unusual. As a result, only two recent studies have measured $\delta^{18}O$ in both diatom silica and authigenic carbonate (Leng et al., 2001; Lamb et al., 2003). A small Ethiopian Rift Valley lake core record shows similar $\delta^{18}O_{diatom}$ and $\delta^{18}O_{calcite}$ values through the early Holocene, suggesting that both diatom silica and calcite precipitated from the lake water at the same time during the year and were subject to the same climate controls (Lamb et al., 2003). In contrast, $\delta^{18}O_{diatom}$ and $\delta^{18}O_{calcite}$ values from a temperate setting in southern Turkey show entirely different curves and therefore suggest that diatom silica is not always a direct substitute for carbonate-based isotope analysis. The reasoning for this is thought to be that the diatoms grow predominantly in spring on the Anatolian plateau, thus reflecting the spring thaw lake-water composition, while the calcite precipitates during the summer months (Leng et al., 2001). Clearly different climatic settings, and thus seasonal differences in diatom production, will lead to different aspects of climate being recorded by $\delta^{18}O_{diatom}$, but equally, carbonate-based records may be only indicative of conditions during a short summer season.

Future Potential

Many $\delta^{18}O_{diatom}$ studies where contamination problems have been overcome are successfully producing sensitive paleoclimate records, mostly reflecting changes in the source, temperature and amount of past precipitation, and local lake hydrology. Diatomaceous sediments from important lakes such as Baikal and Malawi are now being studied to produce multi-millennial isotope records. The current push to improve cleaning methods (Barker et al., 2003; Lamb et al., 2003, Morley et al., 2004) should soon start yielding significant improvements in accuracy, and open up the methodology to a broader range of lakes.

Acknowledgements

Many people have helped in the production of this article and in the technical aspects of analysis. Peter Greenwood and Hilary Sloane are thanked for their contribution to the setting up of the technique at the NERC Isotope Geosciences Laboratory. Sophie Theophile and Patrick Rioual did some of the early cleaning experiments at University College London. Diatom separation using SPLITT is funded by NERC grant NER/B/S/2002/00512 to Philip Barker and Melanie Leng. Sarah Watkins, the technician on the project, produced the diatom separations and the images in Figure 3. Alayne Street-Perrott made material from Lake Rutundu available. The samples cleaned with SPLITT are to be analyzed at NIGL under the NERC award IP/800/1103.

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Reconstructing Past Mass Balance and Climate Conditions from a Cerro Tapado Ice Core (Central Andes, Chile)

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Cerro Tapado (5550m asl, 30°S/ 69°W, Fig. 1) is located in the south central Andes of northern Chile. In 1999, an ice core was drilled and field experiments were carried out in order to understand the recorded ice core history. In this dry area, mass balance is driven by accumulation and sublimation (Fig. 2a). Precipitation on the western side of the Andes at 4000m increases from 100mm a^{-1} at 26°S to 400mm a^{-1} at 30°S, and winter precipitation with Pacific moisture is dominant. The summer months are dry. This southward increase in precipitation is also manifested in the presence of isolated glaciers south of 27°S, where Equilibrium Line Altitudes (ELAs) decrease from 5900m at 27°S to 5300m at 30°S (Hastenrath, 1971, Kull et al., 2002, Fig. 2a). Cerro Tapado is glaciated as low as 4600m due to this precipitation increase. However, higher peaks adjacent to Cerro Tapado, (e.g. Cerro Olivares, 30°17'S, 69°54'W, 6252m, Fig. 1b), are currently free of glaciers, suggesting that local climatic conditions (e.g., excess precipitation) play an important role (Kull et al., 2002).

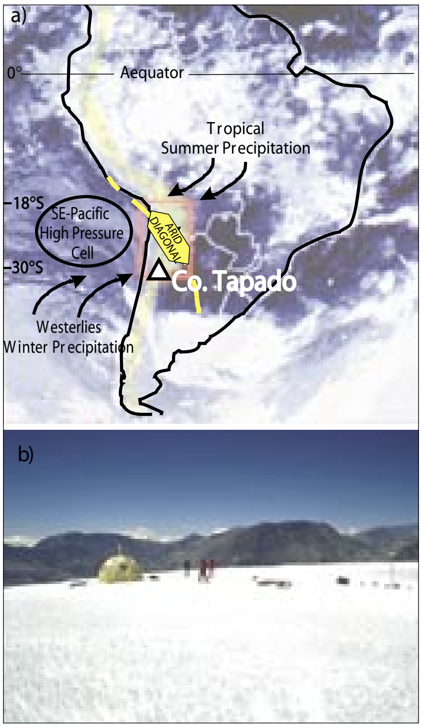

*Fig. 1: (**a**)Location of Cerro Tapado (5550m asl./30°S) in the North Chilean Andes where the ice core was drilled to bedrock in 1999. (**b**)View from the ice core drilling and experimental site on Cerro Tapado at 5550m to the neighboring higher and ice-free peak of Cerro Olivares (6252m)*

Motivation

Chemical species captured in the ice (e.g., Cl^-, SO_4^{2-}, Ca^{2+}, Na^+) are accumulated by dry and humid deposition and their concentrations are influenced by both changes in their respective sources and climatic conditions. In drier areas, interpretation of chemical concentration records is often difficult due to the strong influence of sublimation. $\delta^{18}O$, often used for temperature reconstruction, depends also on a range of site-specific climatic conditions, on changes in moisture source properties and on moisture transport history. Thus, ice core records arise as a result of a complicated accumulation history, modified by a myriad of different processes. In the past, climate may have been markedly different, including periods of sufficiently low accumulation to be associated with negative mass balance, and therefore a hiatus in the core. Similar gaps in a supposedly "continuous" core can also arise in shear zones. Failure to diagnose such a hiatus in the record leads to an erroneous chronology, an underestimation of past accumulation and an overestimation of the deposition of chemical species—in other words, a completely flawed climatic interpretation. Such effects are often difficult to detect but may play an important role when interpreting "continuous" ice core records back to the Last Glacial Maximum.

Methodology

A modeling approach was used to obtain a more rigorous ice core based climatic reconstruction of the site- and archive-specific accumulation history. Field experiments were carried out (Fig. 2, Kull et al., 2002, Ginot et al., 2001, Stichler et al., 2001, Ginot et al., submitted, Schotterer et al., 2003) in order to quantitatively estimate the climatic controls on local mass balance (sublimation, melt, accumulation) and to assess the post-depositional effects on environmental tracers stored in the firn (Fig. 2b). These experiments confirmed that post-depositional processes, mainly sublimation, have a substantial influence on the ice and snow surface. The loss of water by sublimation (around 2 mm per day) during fair weather results in an enrichment of conservative chemical species and a reduction in accumulation. This process may even lead to a negative mass balance in particularly dry years. In a second step, the mass balance (sublimation, accumulation, melt) at the coring site and the related changes in the concentration of conservative chemical species was modeled (Ginot et al., 2001, Kull et al. 2002). These models were based on local climatic data and field measurements of sublimation and

Table 1: Climate reconstruction from the accumulation history in the core using the mass balance model from Kull and Grosjean (2000) and Kull et al. (2002). The paleo reconstruction suggests more humid and colder conditions with a very pronounced precipitation seasonality, in marked contrast to 20th century conditions (Schotterer et al., 2003; Ginot et al., submitted).

Parameter	1998 / 1999 measured /modeled	1920 / 1999 modern average	23-28 m weq. paleo-conditions	Difference paleo-modern
Mean annual Temp. (°C)	-11.5	-12.4 ± 0.2	- 15 ± 1.5	- 3 (± 1.5)
Total accumulation (mm/y)	750	540 ± 45	830 ± 50	+ 290 ± 150
Winter accumulation (mm)	500	310 ± 45	780 ± 50	+ 470 ± 100
Summer accumulation (mm)	250	230 ± 45	50 ± 50	- 180 ± 100
Sublimation (mm/y)	490	240	620	+380
Net accumulation (mm/y)	260	300	210	-80

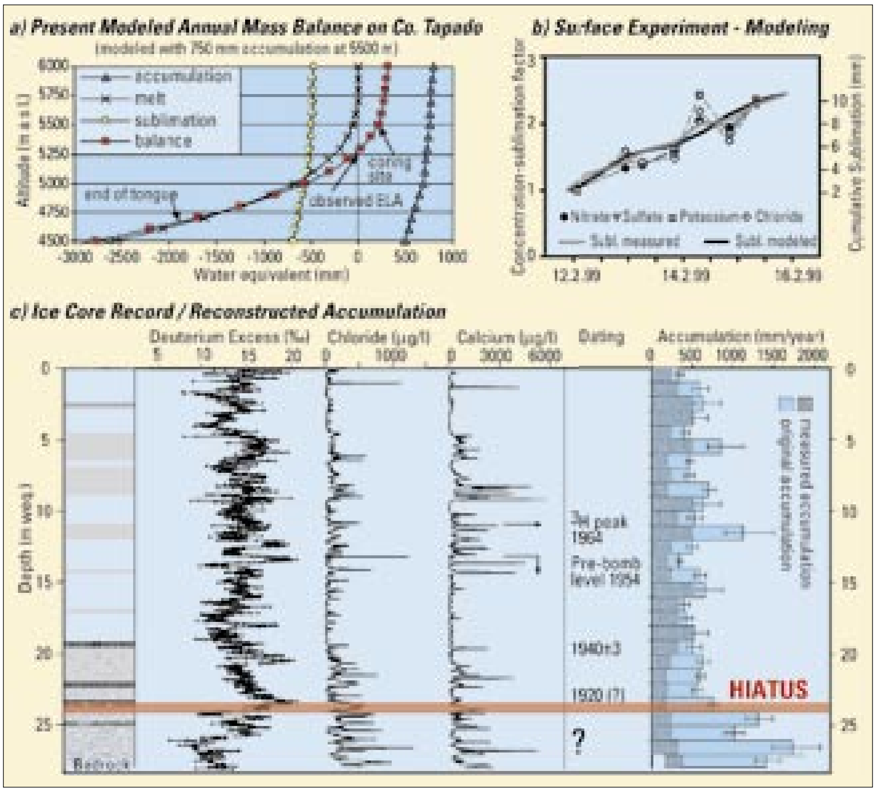

*Fig. 2: (**a**)Balance-elevation distribution of Cerro Tapado modeled with local climatic data. A local surplus of 250mm is necessary to explain the recent isolated glaciation in the region. This value is supported by the ice core data. Ablation is mainly driven by sublimation. (**b**)Results of the surface experiment showing the measured and modeled daily sublimation amounts, as well as the related concentrations of chemical species. There is a clear linear relationship between the measured concentrations of chemical species and measured sublimation. This relationship can then be applied to model past sublimation from measured chemical species concentrations in ice cores. A mass balance model (Kull and Grosjean, 2000; Kull et al., 2002) and a model for the concentration of chemical species (Ginot et al., 2001) can be used to calculate specific mass balance and climate conditions from the ice core record (Table 1). (**c**)Ice core record from Cerro Tapado: The ice core stratigraphy and ^2H excess both show clear differences between the core sections below and above 23m weq. The variation in the concentration of the chemical species, which is directly linked to sublimation changes, results from climate variability (Schotterer et al., 2003; Ginot et al., submitted). Reconstruction of the original ice accumulation as corrected for sublimation losses.*

enrichment of some chemical species (Fig. 2b).

Results

Mass loss and modification of chemical constituents have significant consequences for the interpretation of the paleo-record from the Cerro Tapado ice core. Bedrock was reached at 36m (28m water equivalent (weq) (Fig. 2c). Dating was performed by a combination of annual layer counting (assuming that regular wet and dry periods lead to low and high concentrations of chemical constituents), ^{210}Pb, tritium fallout from nuclear weapons tests, and a firn densification model. Dating showed that the upper half of the accumulated ice is younger than 50 years, as indicated by the pre-bomb tritium level of 1952, and that more than 80% of the ice has accumulated during the 20th century (Schotterer et al., 2003, Figure 2c). However, the lowermost ice must have been formed under very different climatic conditions in the more distant past. Below 23m weq, a distinct change is apparent in both the ice core stratigraphy and the concentration profiles of isotopes and chemical constituents compared to the upper part of the ice core (Fig. 2c). The reconstructed history in this part of the core shows that accumulation must have been driven by massive sublimation losses during the buildup of the glacier (Fig. 2c). The climatic interpretation, consistent with both the ice core data and the climate-mass-balance model (Kull and Grosjean, 2000, Kull et al., 2002), points to lower temperatures (-3° ± 1.5°C), higher annual precipitation (290 ± 150mm) and increased seasonality in the moisture supply (Table 1). High precipitation in the humid winter season is responsible for the necessary accumulation, while the extended dry season relates to the pronounced sublimation. Today the timing of this climatic regime remains unclear. However, the presence of a time and accumulation hiatus of unknown age and duration is clearly indicated and raises concerns and speculations.

Paleoclimatic Implications - Outlook

When did the buildup of the glacier start? In 1890, Brackebusch reported that the Agua Negra glacier, located a few kilometers east in Argentina (30°15´S, 69°50´W), showed a markedly greater extension than today. It is therefore probable that the nearby Cerro Tapado glacier also existed during this time. On the other hand, given the dry climate of the mid-Holocene (Maldonado and Villagran, 2002) one would not expect any glacier growth in the region.

Since the formation of the basal ice body, climate conditions have not caused a complete ablation. A significantly high concentration peak of the conservative chemical species and accumulation of mineral particles would be expected to identify a hiatus by partial ablation of the glacier due to sublimation, as recorded from the Agua Negra glacier (Milana and Maturano, 1999). This is not observed and implies that the hiatus must be explained by ice flow over the basal frozen ice body.

Today, a negative annual mass balance results if the annual net-accumulation does not exceed 500mm (Fig. 2a, Table 1). Assuming extremely dry climatic conditions, as observed in the ice-free "South American Arid Diagonal" (annual precipitation around 280mm, Fig. 1), a negative annual mass balance of -500mm is calculated after Kull and Grosjean (2000), requiring ~50 extremely dry years for a complete ablation of the actual ice mass. Therefore, extremely dry periods could not have persisted over longer periods since the glacier buildup. A late-Holocene (< 2600 BP) glacier advance is recorded in the area around 30°S. (Grosjean et al., 1998). These morrains also exist in the surroundings of Cerro Tapado. Ongoing research aims to test whether the glacier model can produce the observed late Holocene glacier extent using the ice core derived climate conditions, and therefore link ice core and modeling results with geomorphological evidence of past glacier advances.

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The Southern Ocean as the Flywheel of the Oceanic Conveyor Belt Circulation

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The last ice age came to an end between 20 and 10 ka BP. This time span was punctuated by a series of abrupt climate sequences (Fig.1a). In particular, the rapid transition in the North Atlantic from the cold Heinrich 1 to the Bølling/Allerød (B/A) warm-phase and its cold reversal counterpart in Antarctica (ACR) have attracted much attention. During deglaciation, the North Atlantic was exposed to a large meltwater discharge from the melting Laurentide and Fennoscandian ice sheets. This continuous meltwater release on the order of about 0.1 Sv (Marshall and Clarke, 1999) posed a constant threat to the "Achilles Heel" of the oceanic conveyer belt circulation (Broecker, 1991), located in the North Atlantic (schematic picture in Fig. 2a, b). Paleodata (Duplessy et al., 1988; Sarnthein et al., 1994) and modeling work (e.g., Ganopolski and Rahmstorf, 2001; Prange et al., 2002) indicate a weaker glacial thermohaline circulation (THC) compared with the interglacial circulation. Based on evidence of a weak glacial conveyor belt, it is natural to ask about the "flywheel" of the ocean circulation, which might have initiated the transition to a strong interglacial ocean circulation. This "flywheel" is not necessarily confined to the North Atlantic realm, where the "Achilles Heel" is located. Our recent modeling results (Knorr and Lohmann, 2003) using an Oceanic General Circulation Model (OGCM) (Maier-Reimer et al., 1993; Lohmann et al., 2003) suggest that Southern Ocean warming and the accompanying sea ice retreat induced a non-linear transition to a strong Atlantic overturning circulation (Fig. 1b). This is consistent with ice core and ocean-sediment records, showing that a progressive warming in the Southern Hemisphere preceded Greenland warming by more than 1000 years (Sowers and Bender, 1995), a time lag that was even lon-

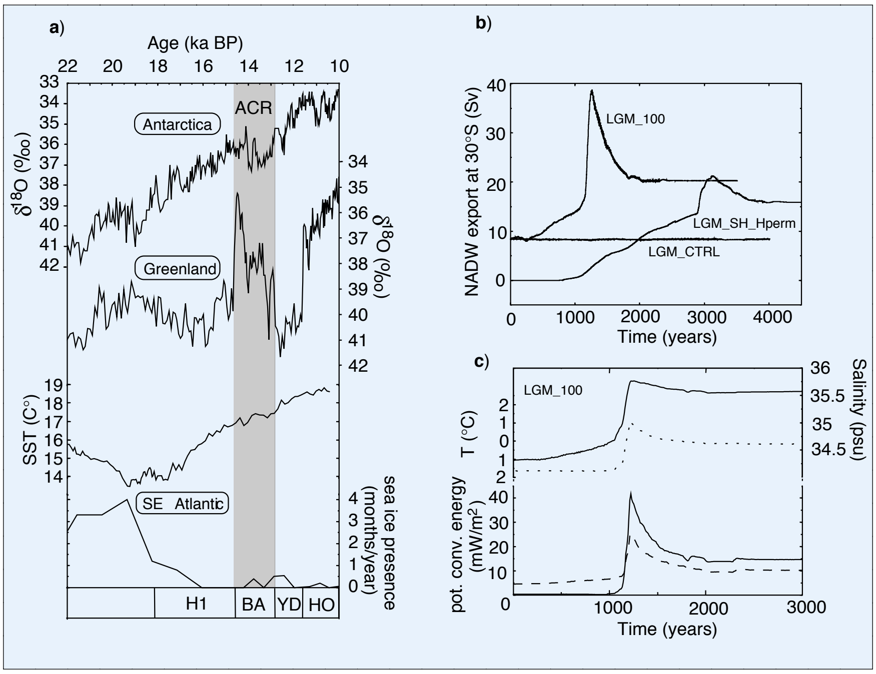

*Fig. 1: Deglacial climate records and modeling results for the Bølling/Allerød transition induced by Southern Hemisphere warming. (**a**) High-resolution climate records from 22 to 10 ka BP based on polar ice cores from Antarctica (BYRD) and Greenland (GISP2) during the last deglaciation (Blunier and Brook, 2001), including a sequence of abrupt climate changes (boundaries of climate intervals, defined as per the GISP2 record: H1, Heinrich 1; BA, Bølling-Allerød; YD, Younger Dryas; HO, Holocene). The temperature evolution of alkenone-based sea-surface temperatures (SST) in the south east Atlantic (Sachs et al., 2001), showing that deglacial warming at 41°S, 7.5°E commenced between 17.5 to 19 ka BP, similar to the Antarctic warming trend. At the same time, sea ice in the Southern Ocean retreated to present day limits (Shemesh et al., 2002). (**b**) Temporal changes in NADW export at 30°S. In LGM_100 and LGM_SH_Hperm, glacial conditions in the Southern Ocean (south of 30°S) are gradually replaced by interglacial conditions over 1500 years. LGM_SH_Hperm is started from the THC "off-mode" and superposed by a permanent freshwater flux of 0.15 Sv (1 Sv = 10^6 m^3 s^{-1}) to the North Atlantic. LGM_CTRL represents the glacial control run. (**c**) LGM_100 time series of sea surface temperature (°C, dotted curve), salinity (psu, solid curve) and potential energy loss by convection (mW/m^2) in the North Atlantic averaged between 55°N and 65°N (solid curve) and between 40°N and 55°N (dashed curve).*

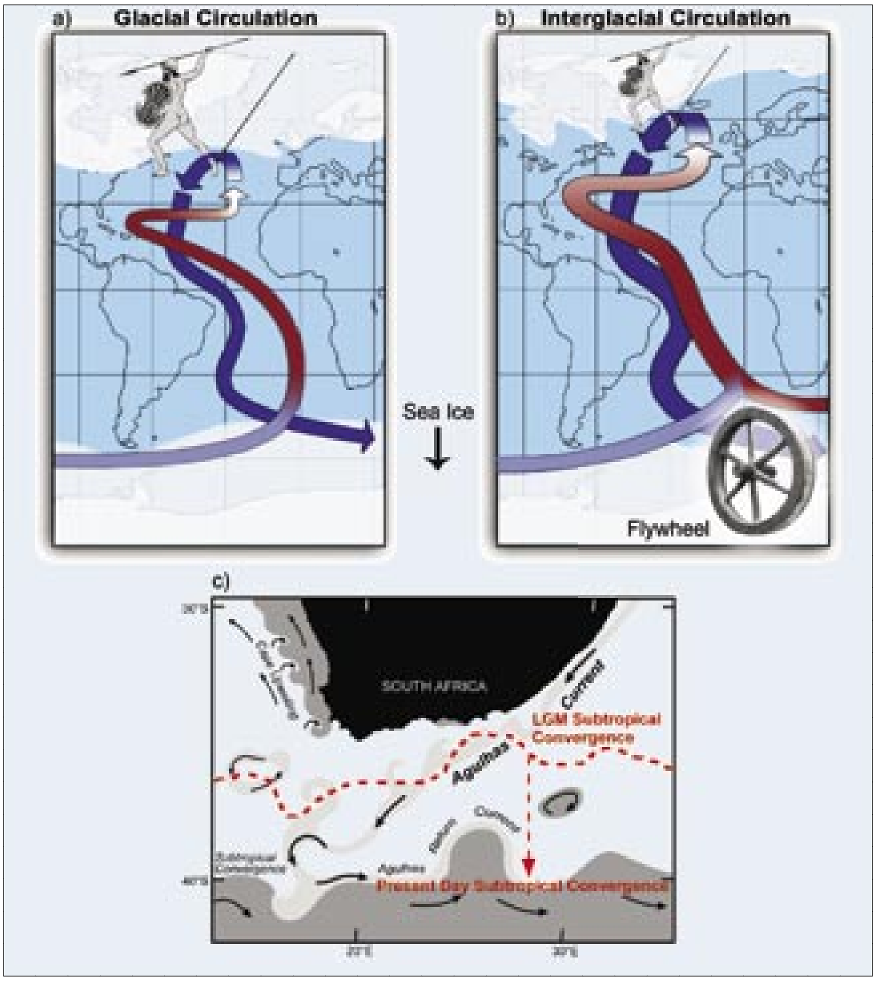

*Fig. 2: Schematic representation of the differences between the glacial and the restarted interglacial ocean circulation, and a conceptual diagram of the Agulhas Current system. (**a**) Glacial circulation is characterized by a weaker mode without a warm water route that is activated by Southern Hemisphere warming, operating as a pathway for relatively warm and saline water from the Indian Ocean in the interglacial mode (**b**). Moreover, the Antarctic circumpolar current accelerates and increases volume transport from the Pacific Ocean via the cold-water route into the South Atlantic. (**c**) Conceptual diagram of the southern Agulhas Current system (adapted from Lutjeharms, 1981) summarizing the main circulation features and a potential northward displacement (red line) of about 2 - 4° of latitude of the glacial subtropical convergence zone (Brathauer and Abelmann, 1999; Gersonde et al., 2003) that might cause a reduction or "switch-off" of the warm water route.*

ger for the penultimate deglaciation (Petit et al., 1999).

The flywheel of the ocean conveyor belt, located in the Southern Ocean, worked as follows: the warming and sea ice retreat in the Southern Ocean induced a southward migration of the Antarctic Circumpolar Current (ACC) and associated ocean-fronts, which increased mass transport into the Atlantic Ocean via the warm and cold water routes of the oceanic conveyor belt circulation (Broecker, 1991; Gordon et al., 1992). The thermal anomaly was attenuated along the northward conveyor route but the salinity characteristics of the warm water route persisted (Weijer et al., 2002). The salinity increase in the upper layer of the North Atlantic preconditioned North Atlantic deep water (NADW) formation comparable to a mechanism proposed by Gordon et al. (1992) that gradually intensified convection during the first 1000 years (Fig. 1c). Along with increased Atlantic overturning, the meridional heat transport warmed the surface water of the North Atlantic, triggering a sea ice retreat after 1000 years. In addition to the advective feedback, a convective feedback contributed to the resumption of the THC. Once convection was initiated in parts of the formerly ice-covered North Atlantic, the relatively warm and saline water masses from deeper layers coming up to the surface lost their heat readily, but kept their salt, and thus reinforced the starting process of convection (Fig. 1b, c). This catalyst of NADW formation lead to an abrupt decrease of sub-surface temperatures. Experiment LGM_SH_Hperm has shown that this mechanism prevailed over the destabilizing effect of meltwater on THC, characterizing the deglacial Heinrich sequence (Fig 1b).

As a result of the restarted conveyor circulation (Fig. 1b), the maximum heat transport and temperature in the North Atlantic increased dramatically, consistent with the temperature rise of the B/A onset (Bard et al., 2000). This demonstrates that slow changes in the South can have abrupt and far-reaching consequences on the THC or ice-sheet discharges (Stocker, 2003). The ACR represents the Southern Hemisphere counterpart (Fig. 1a), in accordance with the oceanic interhemispheric teleconnection that increased THC cools the Southern Hemisphere (Crowley, 1992; Stocker, 1998).

We speculate that, in conjunction with other effects, (Toggweiler, 1999; Stephens and Keeling, 2000, Weaver et al., 2003), the increase in maximum northward oceanic heat transport from 0.8 PW to 1.6 PW contributed to the reduction of the great Northern Hemisphere ice sheets. If this additional heat was exclusively dissipated as latent heat, the modelled onset of the THC would account for a melting of 12 x 10^{15} m^3 ice within two centuries, which is an upper estimate for the oceanic contribution for deglaciation. This reduction of global ice volume captures the order of magnitude representative for the B/A warm period. Such a meltwater input would weaken but not stop NADW formation, due to the stabilising effect of the different sources of deep water formation (Lohmann and Schulz, 2000). Southern Ocean warming and the associated sea ice retreat during deglaciation as observed in paleoclimatic data (Shemesh et al., 2002) might be the result of tropical sea surface temperature anomalies that were transmitted from the tropical Pacific to the Antarctic region (Lea et al., 2000; Koutavas et al., 2002), or a response to local Milankovitch forcing on the precessional period (Kim et al., 1998). Another possibility is that a 19-kyr meltwater pulse originating in the Northern Hemisphere contributed to early deglacial warming in the Southern Hemisphere, while maintaining a cold Northern Hemisphere through its effect on the Atlantic THC and ocean heat transport (Clark et al., 2004).

A similar temporal shape to the B/A onset (Fig. 1a) is detected at other abrupt stadial (cold) to interstadial (warm) transitions, named Dansgaard-Oeschger (DO) events, during the last glacial period (Dansgaard et al., 1984). These millennial-time scale variations have been linked to various mechanisms such as a salt oscillator (Broecker et al., 1990), deep-decoupling oscillations (Winton, 1993; Schulz et al., 2002), latitudinal shifts in convection sites associated with THC changes induced by freshwater flux perturbations in the North Atlantic (Ganopolski and Rahmstorf, 2001), and a stochastic resonance phenomenon (Ganopolski and Rahmstorf, 2002; Rahmstorf and Alley, 2002). The trigger of these millennial-time scale variations is unknown and there is debate as to whether these fluctuations are regular or stochastic (Wunsch, 2000; Schulz, 2002; Rahmstorf, 2003). Here we argue that our mechanism for the B/A transition might be similar to other DO events during the glacial phase. However, the warm and cold water routes of the oceanic conveyor belt only temporarily gained in strength, and returned to the glacial mode with reduced strength of the ACC and a relatively northward circum-Antarctic frontal system compared to its present day position. In contrast, the southward migration of these fronts prior to the B/A transition is accompanied by deglacial warming, which activates the "flywheel" of the oceanic conveyor belt (Fig. 1, 2). Like the "conveyor belt" metaphor (Broecker, 1991; Brüning and Lohmann, 1999) the flywheel metaphor illuminates a basic idea. In our case the Southern Ocean can be understood as the engine for the oceanic transport system on glacial-interglacial time scales.

Our study suggests that the Achilles Heel (Broecker, 1991) and the flywheel of the Atlantic overturning circulation on paleoclimate timescales are located in the North Atlantic and the Southern Ocean, respectively (Fig. 2). A zone of special interest is the area around the Cape of Good Hope because it represents an import route of relatively warm and saline water from the Indian Ocean (Fig. 2c) that is thought to precondition NADW formation (Gordon et al., 1992). Berger and Wefer (1996) surmise that this narrow portal is directly related to the position of the sup-tropical convergence zone. Therefore, a northward displacement of this front could reduce (Gersonde et al., 2003; Paul and Schäfer-Neth, 2003) or even pinch off access, leading to speculation that the reopening of the Agulhas gap at the end of the last ice age may have played a role in restarting the Atlantic THC (Berger and Wefer, 1996). Since the South Atlantic is characterized by a number of unique dynamical features, such as the large Agulhas Rings (Schouten et al., 2002) that form a key link in the THC, it is of interest to investigate the flywheel and its respective energy source, using high-resolution models of the South Atlantic, to obtain a more detailed view of this region.

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Sharp Cooling of the Northern Hemisphere in the Early Subatlantic Age (650 - 280 BC)

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About 2,500 years ago, a strong cooling happened on the Earth. The evidence for this is found not only in numerous climatic indicators (glacier and tree-line position in the mountains, tree ring thickness, fossil pollen spectra, isotopic composition of ice, lacustrine and marine deposits) but in social history as well. Papers by many ancient authors (Herodotus, Livy Andronicus, Eratosthenes), as well as Chinese and Babylonian chronicles, describe a climatic pattern that differs greatly from the present, not only in temperature but also in humidity. They come from that period when the Scandinavian legend of Ragnarök originated (the doom of the gods and the entire world). Presumably, it implies that there was a critical change in the common natural environment. It is not surprising that it was this cooling that was chosen in paleoclimatology as a universal chronological boundary separating the penultimate (Subboreal) from the present (Subatlantic) epoch. However, there are still no satisfactory answers to the following fundamental questions:

- Was the Subatlantic cooling-global?
- When and at what level was the maximum cooling attained?
- What was the distribution pattern of temperature and precipitation during this period?

A few highlights of my study, which addresses these questions, are presented here. Detailed information is given elsewhere (Klimenko, 2004).

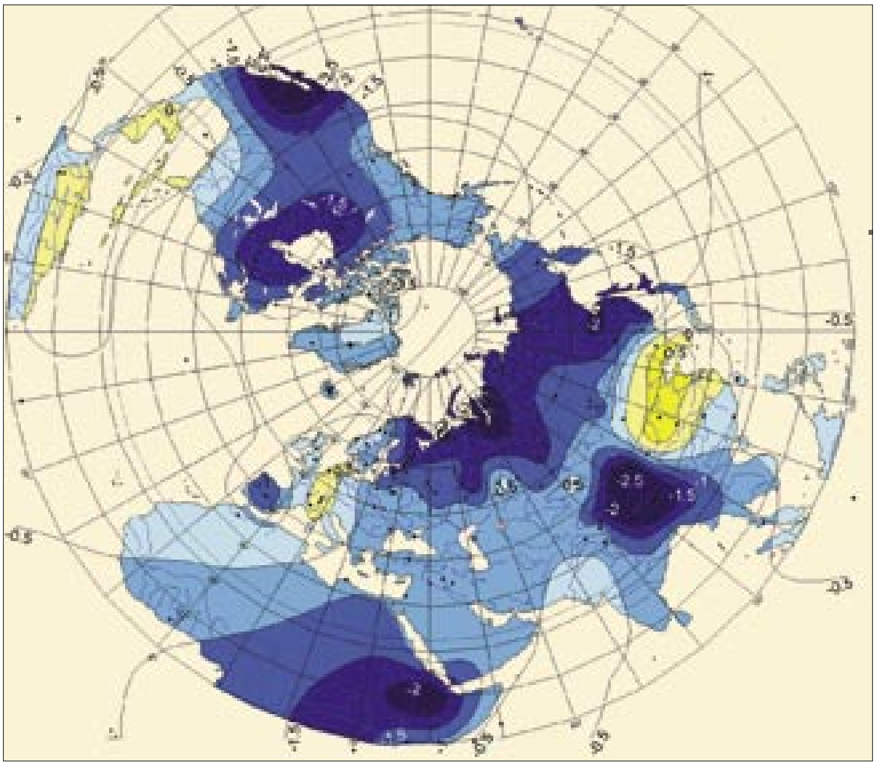

Fig. 1: Mean annual temperatures (°C) during the maximum cooling of the Early Subatlantic Epoch compared to present values. Dots represent the locations of paleoreconstruction sites (Klimenko, 2004).

There are grounds to believe that the cooling of the Early Subatlantic Age (ESA), along with the Little Ice Age (LIA), was one of the strongest throughout the Late Holocene and, hence, marks the lower boundary of the natural climatic change at a millennial timescale. Not only climatology is actively interested in studying the ESA cooling, since its chronological boundaries roughly correspond to what Karl Jaspers referred to as the 'axial age' of history, i.e. the epoch of a remarkable, unique outburst of human intellectual and spiritual life that left clear historical evidence in different parts of the world. That such a coincidence is not accidental is confirmed by historical/climatological comparative studies (Klimenko 1998).

Even though the fact that a sharp cooling occurred during the ESA does not itself seem to be questioned, there are appreciable discrepancies concerning the chronological boundaries of this event. The majority of the data fall within the range of 2500-2200 radiocarbon yr BP, or 650-280 B.C. according to modern calibration (Stuiver et al., 1998). A thorough study of the most precisely dated experimental material enables the ESA event to be characterised as an asymmetrical double cold episode, in which two cooler stages were separated by a short-term warming between ca. 450 and 380 B.C. The second cool stage was more prominent, culminating at 280±50 B.C.

In order to compile maps of the main climatic parameter anomalies, I used the whole set of available paleoclimatic data, which involved reconstructions based on palynological data, glacier oscillations, and lake level fluctuations, as well as isotopic, dendrochronological, and historical data. In addition to our own data, I used literature data from 330 independent sources comprising information about the ESA climate in 579 sites of the Northern Hemisphere, 192 sites having quantitative reconstructions. The deviation of the annual mean temperature from present-day values (1901-1960 average) shows considerable spatial irregularity (Fig 1), the maximum negative anomalies being observed not only in high latitudes (on the continental periphery of the Barents and Kara Seas) but also on the Tibetan and Ethiopian Highlands. Nevertheless, against this background of dominant negative anomalies, there are areas where the annual mean temperature was higher than at present (e.g. Central America or China).

For the Northern Hemisphere, I assess the annual temperature anomaly during the ESA maximum cooling to be between -0.5

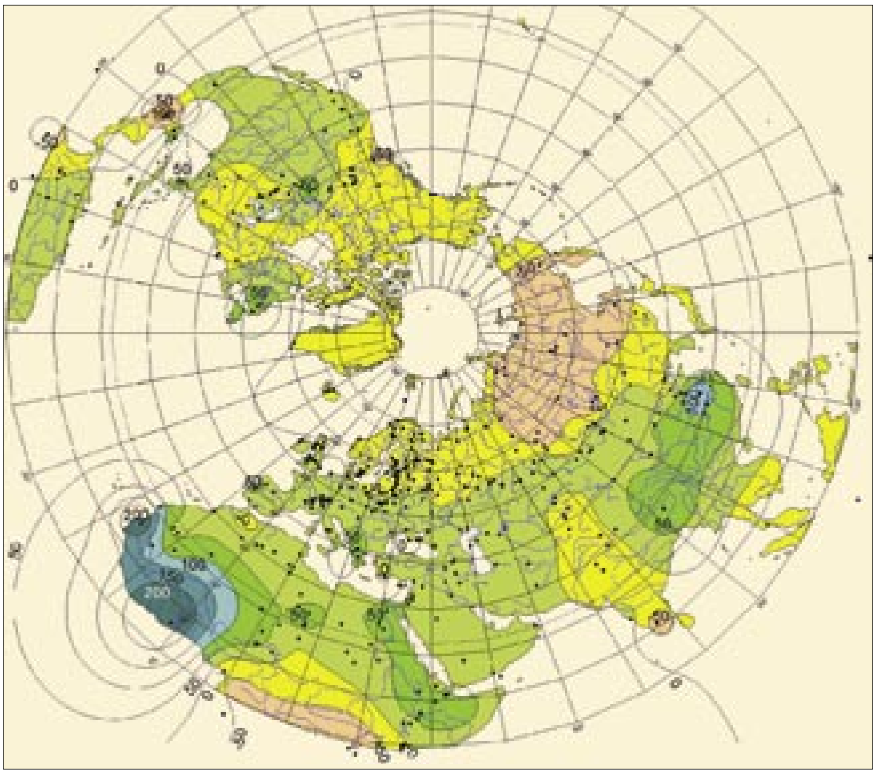

Fig. 2: Mean annual precipitation rate (mm/year) during the maximum cooling of the Early Subatlantic Epoch compared to present values (Klimenko, 2004).

and -0.6°C, when compared to the 1901-1960 reference period. This is substantially lower than the anomaly of -0.23°C for the coldest decade of 1901-1910 in the period of modern instrumental observations and, I think, matches the values of the coldest Little Ice Age decades (e.g. 1450's or 1690's).

In paleoclimatology, the ESA period is generally considered to have been cold and humid. Indeed, positive anomalies of annual mean precipitation prevailed in most of the Northern Hemisphere and occasionally reached substantial values, in excess of 150–200 mm/yr, in western Africa and eastern China (Fig. 2). The whole Sahara was considerably more humid than now and there is historical evidence that men could easily cross what is now the world's greatest desert (Hennig, 1944). At the same time, only negative precipitation anomalies were observed in high latitudes on all the continents. Another vast drier zone spanned tropical areas of Asia, Africa, and Central and South America.

According to my estimates, the precipitation anomaly, averaged over the Northern Hemisphere, was 14 mm/yr or ca. 1.5% higher than the present-day value. Hence, the ESA cold epoch was actually humid. This indicates that the relationship between zonal and hemispheric temperature and humidity is not merely nonlinear, which is well known, but nonmonotonous, i.e. humidity might increase with slight cooling. This is probably related to the fact that some decrease in the moisture content of the atmosphere is completely compensated by stronger westerlies in temperate and subtropical latitudes.

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The Behavior of Modern Low-Latitude Glaciers

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Around 1990, glaciers on low-latitude high mountains—in the South American Andes between Venezuela and Northern Chile, on the East African mountains Kenya, Rwenzori and Kilimanjaro, and on Irian Jaya (New Guinea)—covered an area somewhat less than 2,500 km^2. More than 99% of this area was in the Andes (Kaser, 1999; Kaser and Osmaston, 2002). These glaciers have all, following the global trend, retreated from their Little Ice Age extent after 1850 (Table 1) (Hastenrath, 2001). Secondary to the general retreat, and embedded in the global trend again, advances were observed around 1900, in the 1920's and in the 1970's (Kaser, 1999; Hastenrath, 2001). In the Cordillera Blanca, as most probably throughout the Peruvian Cordilleras (Albert, 2004), a more or less continuous snow cover on most of the glacier surfaces from October 1998 until May 2002 led to an interruption in the general retreat and even to tongue advances of some glaciers. Still, detailed information is scarce and the overall picture is all but complete. Nevertheless, the general retreat was strong and in some areas glaciers have vanished or are close to disappearing (Ramírez et al., 2001; Thompson et al., 2002). Glacier remnants on Irian Jaya (New Guinea) are about to disappear, as revealed by recent IKONOS satellite images from June 2002, showing that there are only two small glaciers left (Klein, pers. comm.).

Table 1: Modern retreat of low-latitude glaciers (after Kaser, 1999); (1) Thompson et al., 2002, (2) Georges, 2004.

	Year: glacier surface area (km^2)			
Irian Jaya	**1850**:	19.3	**1990**:	3.0
Mount Kenya	**1899**:	1.6	**1993**:	0.4
Kilimanjaro	**1850**:	20.0	**2000**:	2.6 *(1)*
Central Rwenzori	**1906**:	6.5	**1990**:	1.7
Cordillera Real	**1920**:	28.6	**1975**:	25
Cordillera Blanca	**1850**:	870	**2000**:	600 *(2)*

The impact of climate on low-latitude glaciers can be described with common glaciological laws but—because of the particular climate in the tropics and subtropics—various parameterizations have to be re-evaluated from several simplifications successfully applied to mid- and high-latitude glacier studies. If mechanical processes like avalanches and calving are excluded, the mass balance of a glacier is composed of accumulation of solid precipitation and ablation due to melting and sublimation. All these processes are related to solar radiation at the top of the atmosphere, air temperature, and atmospheric moisture content, only the first being entirely independent from the others. The atmospheric moisture content influences atmospheric emissivity and determines cloudiness, precipitation, and air humidity.

Relations between glacier mass balance and atmospheric moisture content are complex. The crucial role of sublimation from the glacier surface is noteworthy. Sublimation is driven by the vapor pressure gradient between the glacier surface and the overlying atmosphere. In contrast, melting has no driving force and happens passively only if there is a surplus of energy. Consequently, air humidity controlls the separation of available energy for sublimation and melting. In the mid and high latitudes, air temperature determines the climate's seasonality with positive temperatures representing the availability of energy for ablation (e.g. Ohmura, 2001) and negative temperatures the potential occurrence of solid precipitation. Sublimation, though varying with the degree of aridity, is rather constant as a mean over longer time periods. For these reasons, ablation correlates highly with the sum of so called "positive degree days" in the mid and high latitudes and, moreover, glacier fluctuations reflect fluctuations in air temperature very well (Ohmura, 2001).

This is different in the low latitudes, where seasonal temperature variations are small and the climate's seasonality is primary due to changes in air humidity, advection of moisture, and precipitation. Cloudiness, precipitation, albedo of the glacier surface, the resulting available and effective solar energy, and sublimation vary more or less markedly throughout the year. Thus, not only trends in air temperature but to a much higher degree variations in the seasonality of moisture govern the fluctuations of low-latitude glaciers (Wagnon et al., 1999; Kaser, 2001). The effect of air humidity on glacier ablation is impressively shown in a series of energy balance measurements taken by Wagnon et al. (1999) over the ice surface of Glaciar Zongo in Bolivia (Fig. 1). There, the year-round constant energy from solar radiation is primarily consumed by sublimation during the dry season. Sublimation dissipates 8.5 times the energy of melting when removing the same amount of ice mass. Thus, during the dry season, ablation (and melting) on Glaciar Zongo's surface are markedly reduced.

Beyond the importance of sublimation, another strong effect of a varying hygric seasonality, the short wave albedo of the glacier surface, has been described recently as a key factor on low-latitude glaciers

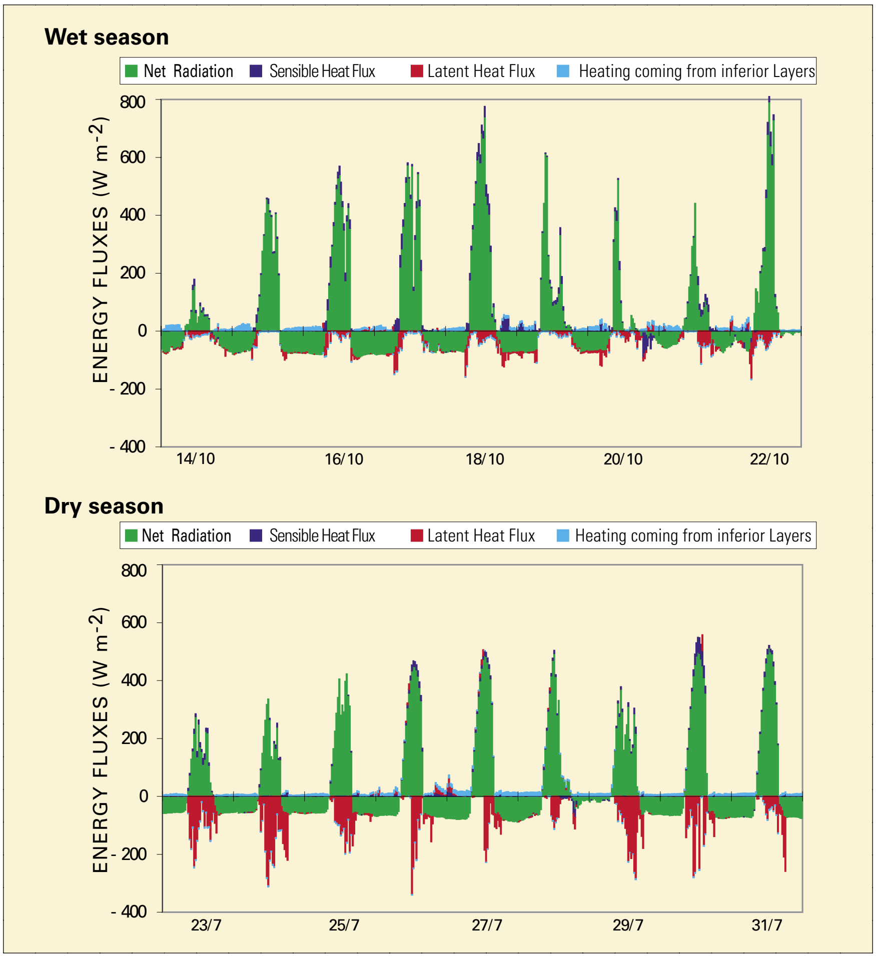

Fig. 1: Half-hourly values of the different energy balance terms measured close to the mean equilibrium line at Glaciar Zongo, Cordillera Real, Bolivia (5150 m asl) (after Wagnon et al., 1999) during a selected 9-day period of the dry (July 23–31, 1996) and wet seasons (14. – 22.10.1996). In both seasons, net radiation is the main energy source at the glacier surface but is almost totally consumed by the strong sublimation (i.e. the latent heat flux) during the dry season.

(Wagnon et al., 2001; Francou et al., 2003; Kaser et al., 2004). Related to hygric variations, a highly mass consuming scenario can be imagined as follows: If, after a dry season, the onset of the wet season occurs rather gradually, air humidity may rise, quickly turning sublimation into melt. Also, the atmospheric emissivity may increase and ablation will become considerably higher. At the same time, the reduction of solar radiation, due to increasing cloud cover, is comparatively small but the absorption of solar radiation by the glacier is strongly enhanced due to low-albedo bare ice at the glacier surface. The extreme ablation rates will, therefore, only be stopped by precipitation and consequent albedo increase. Hence, the immediate occurrence of snowfall at the beginning of the wet period can be crucial for the positive mass balance of a low-latitude glacier. In general, this means that any climate interpretation deduced from glacier fluctuations in the low latitudes as well as any prediction, e.g., in terms of water availability from glacier runoff, must consider changes in hygric seasonality, including the occurrence of solid precipitation (Kaser, 2001). Several detailed analyses of 20th century glacier retreat in the low latitudes indeed reveal that the multiple effects of a drier climate dominate over increased air temperature (Kruss and Hastenrath, 1987; Kaser and Georges, 1997; Mölg et al., 2003a).

Although these considerations are also valid when looking at the glaciers on Kilimanjaro's Kibo cone, which have recently attracted broad interest (Thompson et al., 2002), they are a special case. There, the existence of vertical ice cliffs at the margin of the glaciers on the summit plateau and other ice features, such as penitentes or sharp edges, rules out available energy from pos-

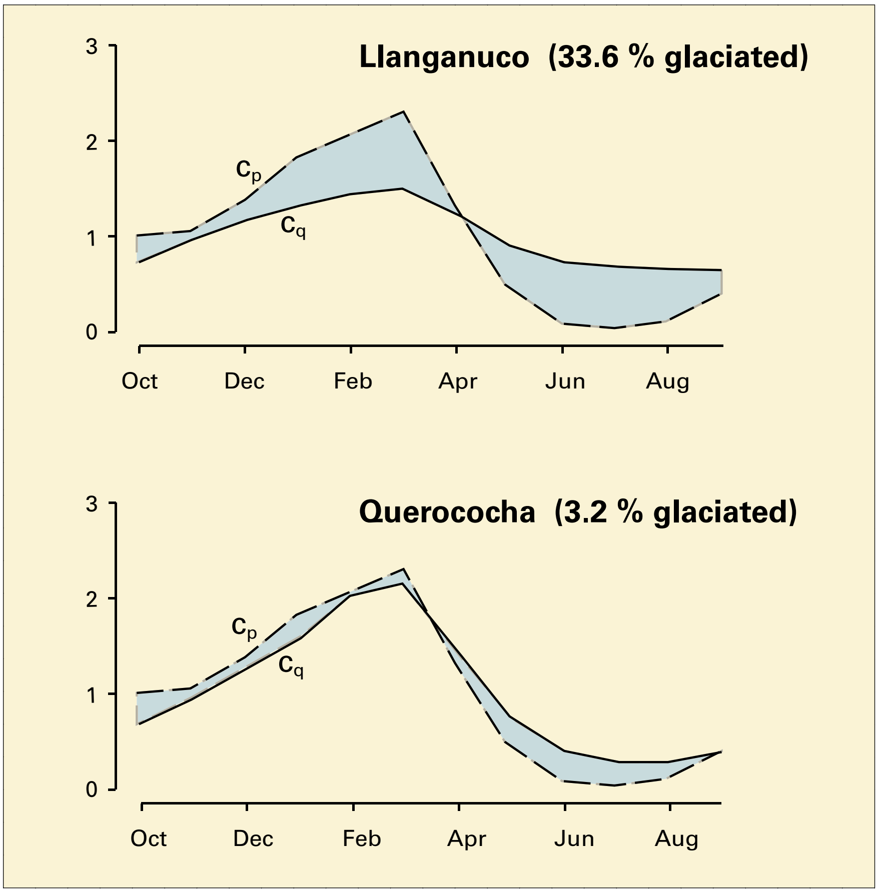

Fig. 2: Mean seasonal precipitation and runoff shown as dimensionless coefficients c_p (for precipitation) and c_q (for runoff) for two differently glacierized catchment areas in the tropical Cordillera Blanca, Peru (after Kaser et al., 2003). Coefficients indicate the ratio between the long-term mean for each month and the overall long-term monthly mean. Note that a coefficient value of zero is equivalent to zero as an absolute value. Glaciers determine the availability of water during the dry season.

itive air temperatures (Kraus, 1972). Rather, it is persistently dry and cold conditions that have formed these features. On the cliffs, only ablation driven by solar radiation can occur (Mölg et al., 2003b). Thus, summit glaciers on Kilimanjaro will disappear if mechanisms of extensive moisture transport to the summit plateau continue to be absent. The spatial distribution of today's largest ice remnants, the Northern and the Southern Icefields, clearly reflects the seasonal cycle of solar incidence, which is strongest during the solstitial periods and weakest when equinoctial cloud cover protects the mountain (Mölg et al., 2003b). The convex shape of the slope glaciers, which are dynamically independent from the plateau ice masses and currently descend to about 5,000 m on Kibo's flanks, illustrates that they are near to equilibrium with the present dry climate. Yet, permafrost found at 4,700 m indicates that these slope glaciers could extend to much lower elevations if only precipitation was more abundant (Kaser et al., 2004). Twentieth century glacier recession on Kilimanjaro is an adjustment to a climate that abruptly "switched" from more humid to persistently drier conditions around 1880 (Hastenrath, 2001; Nicholson and Yin, 2001).

Additionally, any impact of Kilimanjaro's glaciers on the hydrology of the surrounding foothills and lowlands has to be rejected because:

- sublimation plays a substantial role in glacier ablation,
- melt water evaporates directly to a large extent from the dark ashes, and
- any possible melt water runoff would be radially distributed from the mountain cone over concentrically, and therefore rapidly increasing, areas.

Runoff from Kilimanjaro glaciers has hardly ever played a role in the water supply to the lowlands (Lambrechts et al., 2002), which will also be unaffected when the plateau glaciers disappear. However, the water issue is completely different for glacierized mountain ranges in the Andes. There, in many cases, glaciers provide the primary source of runoff during the dry period and reduce the amount of runoff variability in proportion to the degree of glacial cover (Figure 2). Any major retreat or vanishing of glaciers will modify runoff until it exclusively depends on rainfall (Kaser et al., 2003). In such a scenario, some highly populated areas will face serious problems with their water supply.

Studying low-latitude glaciers is essential both in terms of regional water management and in providing a highly valuable tool for detecting climate change on a global scale beyond a temperature-orientated view. Understanding how snow ever accumulated on top of Kilimanjaro—to take a prominent example—and formed glaciers there requires looking at large-scale atmospheric dynamics, as well as the vertical structure of the tropical atmosphere.

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Early Anthropogenic Overprints on Holocene Climate

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PAGES research on Holocene climate rests in part on the implicit assumption that humans had negligible effects on large-scale climate until the industrial era, followed by large and accelerating impacts during the last 200 years. With this two-part division, scientists use pre-industrial climatic proxies to define the natural state of the climate system, and thereby to isolate and quantify the anthropogenic overprint during the last 200 years.

A paper recently published in the journal *Climatic Change* (Ruddiman, 2003) suggests that this basic premise is flawed. The interval between 8000 years ago and the industrial era was a time of significant and slowly increasing human impact on greenhouse-gas concentrations and global climate, and the cumulative impact of these changes by 200 years ago was equivalent to the subsequent impacts during the industrial era.

Long-term orbital-scale cycles predict ongoing decreases in CO_2 and methane through the entire Holocene, but ice-core trends show a ~100-ppb rise in atmospheric methane during the last 5000 years and a 20-25 ppm rise in CO_2 during the last 8000 years. Natural orbital-scale variations cannot account for these increases.

I attribute these anomalous increases to early anthropogenic activity. The CO_2 rise occurred during a time of large-scale deforestation in southern Eurasia, as agriculture advanced from the primitive practices of the late Stone Age to the much more sophisticated package of skills in the early Iron Age. The methane increase correlates with an interval in which wet-rice irrigation began in the lowlands of Southeast Asia and later spread to hillside rice paddies.

The observed increases are only part of the story, because the full anthropogenic signal must also include the natural decreases that should have happened but did not. I estimate the total anthropogenic anomalies by the start of the industrial era at 40 ppm for CO_2 and 250 ppb for methane (Fig. 1). For the 2.5°C IPCC (2001) estimate of global climate sensitivity to CO_2 doubling, the pre-industrial global-mean warming effect from anthropogenic sources would have been ~0.8°C, about the same size as estimates of the greenhouse-gas contribution to the measured industrial-era warming. The pre-industrial warming at high latitudes would have been larger (~2°C) because of amplification by snow and sea ice feedback. This large signal has escaped notice until now because of an even larger natural cooling caused by decreasing insolation. In summary, humans were altering global climate well before we built cities, discovered writing, or founded religions.

In addition, I investigated relatively rapid CO_2 oscillations of 5-10 ppm found in high-resolution ice-core records of the last 2000 years from Antarctica. Natural variations (solar-volcanic forcing) do not appear to be capable of explaining such large CO_2 changes. Simulations with the Bern carbon-cycle model (Gerber et al., 2003) indicate that each 1-ppm change in CO_2 in response to solar-volcanic forcing

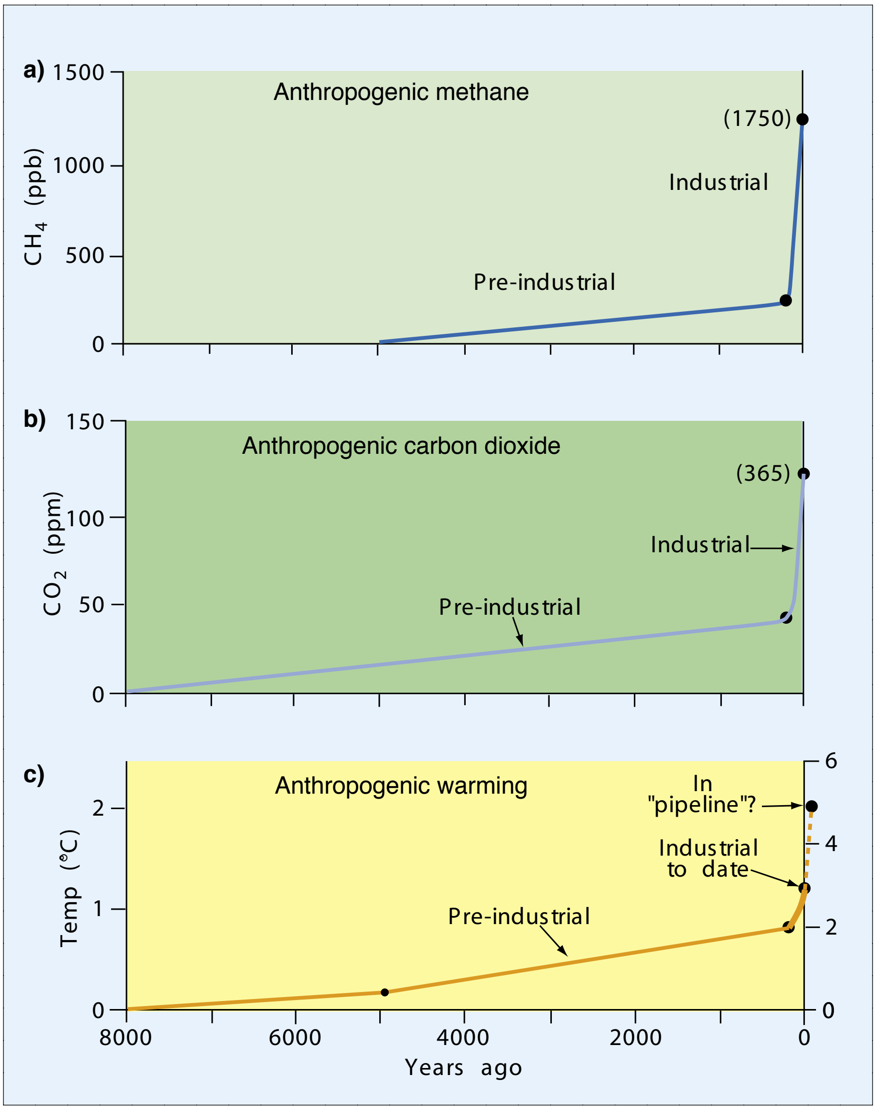

*Fig. 1: Anthropogenic changes in (**a**) CH_4, (**b**) CO_2, and (**c**) global and high-latitude temperature, based on the IPCC (2001) estimate of the sensitivity of the climate system. Pre-industrial anthropogenic changes rival those of the industrial era.*

should be accompanied by a 0.08°C change in global temperature. If so, a 10-ppm CO_2 drop requires a global cooling of 0.8°C. Yet, reconstructed temperature changes for the northern hemisphere (for example, Mann et al., 1999) only permit a cooling of ~0.2°C over intervals of many decades to centuries, enough to explain only 2-3 ppm of the 10-ppm CO_2 decreases.

Because these CO_2 drops are superimposed on a slow background increase attributed to deforestation, I propose that they result from intervals of reforestation tied to human history. Within the large uncertainties of the ice-core dating, the three CO_2 drops correlate with bubonic plague pandemics that caused enormous levels of human mortality in western Eurasia from 200-600, 1300-1400, and 1500-1720 AD. In addition, major depopulation of native communities across the Americas occurred in the 1500's and 1600's as a result of diseases contracted from initial contact with Europeans. In both cases, historical documents reveal massive abandonment of rural farms and villages after these pandemics.

Trees and shrubs will re-occupy untended farms and sequester atmospheric carbon in amounts equivalent to full reforestation levels within just 50 years, and this mechanism can explain the 10-ppm size of the CO_2 drops. CO_2 decreases caused in this way would then produce a global-mean cooling of 0.15-0.2°C (again using the 2.5°C IPCC sensitivity estimate), a value that does not violate the hemisphere-wide reconstructions of temperature change. Once the series of plagues abated, the farms were re-occupied, the newly grown forests were cut, and CO_2 returned to its long-term rising trend.

The major implications for PAGES are these:

- The underlying long-term climatic trend for the last 8000 years of the Holocene is not natural. Rather than a climate held nearly stable by natural processes, Holocene temperature stability reflects an accidental balance between a large natural cooling and an almost equally large anthropogenic warming.
- During the last 2000 years, shorter-term (decadal- and century-scale) climatic oscillations were not entirely natural. Deforestation episodes, linked to anomalously high human mortality caused by disease, played a significant role in reducing CO_2 and cooling climate.
- Distinguishing natural from anthropogenic forcing of Holocene climate will be more difficult than PAGES had thought.

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GLOBEC Investigation of Interdecadal to Multi-Centennial Variability in Marine Fish Populations

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The overarching goal of the Global Ocean Ecosystem Dynamics Project (GLOBEC) of IGBP is to advance our understanding of the structure and functioning of the global ocean ecosystem and its response to physical forcing, and to work towards developing a predictive capability to forecast the regional responses of marine ecosystems to global change. In the past several decades, we have witnessed fundamental changes in the organization and dynamics of large marine ecosystems, which have been manifested in the abundance, diversity and productivity of animal populations, with changes in dominant species. The interaction of climate variability and fishing has also lead to dramatic changes in the abundance and distributions of marine fish populations.

Investigating the nature and cause of these remarkable changes is a formidable challenge because of the need for sampling the ocean over scales of 1000's of square kilometers and for periods of at least several decades. GLOBEC has, therefore, actively encouraged the development of information on ecosystem history contained in the natural, high-resolution archives of marine sediments found in rare locations associated with mid-water oxygen minima in the eastern boundary current regions of the North and South Pacific, and in the South Atlantic, as well as from the glacial fjords located on the poleward edges of these systems in the Pacific. This information allows us to examine the nature of large-scale variability over a hierarchy of time scales from interannual through interdecadal and centennial. Retrospective research directed toward both paleo- and modern sources, integrated with comparative studies of large ecosystems, provides the historical perspective and framework to describe the underlying natural modes of variability affecting their structure and dynamics. These studies are particularly important for distinguishing the direct effects of human intervention resulting from harvesting or habitat modification, from the natural variability in these systems.

One of the sources of information of particular interest to GLO-

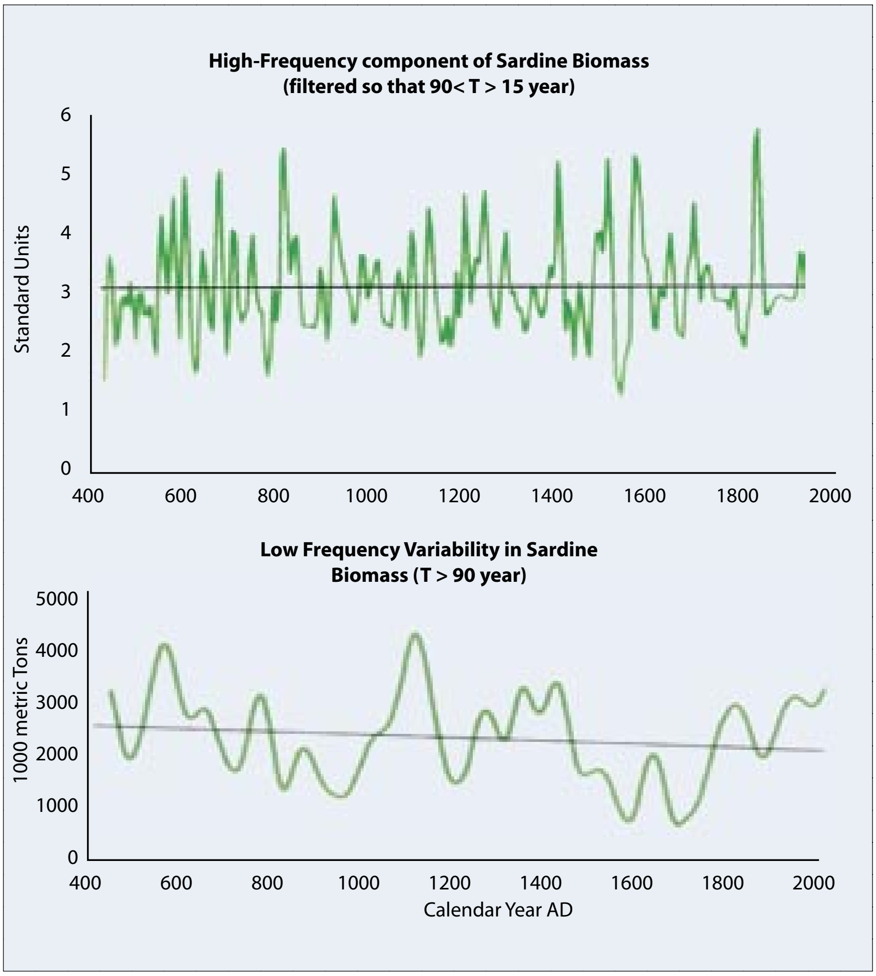

Fig. 1: Biomass of the Pacific sardine population off California reconstructed from 5-year intervals of fish scale deposition in varved sediments of the Santa Barbara Basin: AD 400-1975. The biomass series is partitioned into its high-frequency and low-frequency components.

BEC that has also contributed to the PAGES-PANASH efforts (Markgraf et al., 2000) is the rate of deposition in coastal marine sediments of the scales of small, schooling planktivorous species like sardines and anchovies that form important trophic links in these ecosystems. We believe that these small pelagic fish may be used as bellwether species to infer major changes in the structure of the community. The records of scale-deposition rates allow us to document the modes of variability in abundance (and, where possible, the variability in age structure - from scale sizes) of these populations in the California, the Humboldt and Benguela Current systems, over interdecadal and multi-centennial time scales. We also are striving to develop background environmental information that reflects the regional ocean climate associated with these changes. Depositional sites that provide such detailed histories of ocean populations are rare because of the suite of conditions that must exist—the principal condition being the depletion of oxygen in the overlying bottom water, to enhance the preservation of fish scales and other biological remains and to minimize bioturbation. Under the best circumstances, this combination provides natural calendars of deposition with annual (or near-annual) resolution for the past several thousand years.

Baumgartner et al. (1992) and Holmgren and Baumgartner (1993) demonstrated the value of fish scale records for reconstructing the natural variability of the populations of coastal pelagic fish over time scales of several decades to many centuries. Variability in the abundance of fish scales preserved in coastal marine sediments reflects the rate of scale shedding by live fish, a phenomenon common to the small pelagics that produce rates of scale deposition proportional to local densities of the population. This can be used to hindcast abundance where local density is correlated to overall population size.

The best-developed record of these populations so far is the 1600-year history of the sardine demonstrated from sediment cores from the Santa Barbara Basin off California. This record is shown partitioned into its high-frequency and low-frequency components in Fig. 1. Variability in these records is a response to basin-scale changes in ocean climate over the Pacific which

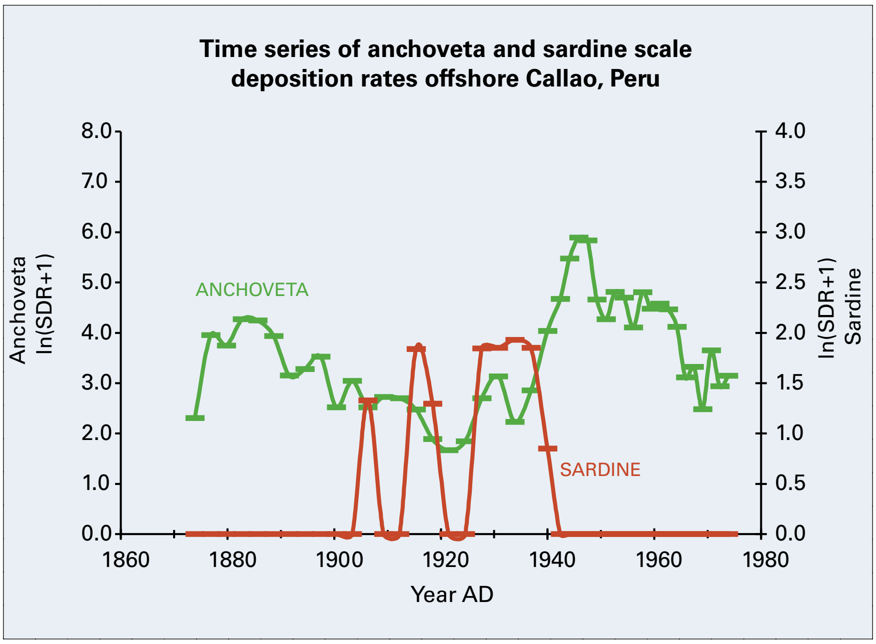

Fig. 2: Time series of anchovy and sardine scale deposition rates (SDR) off Callao, Peru.

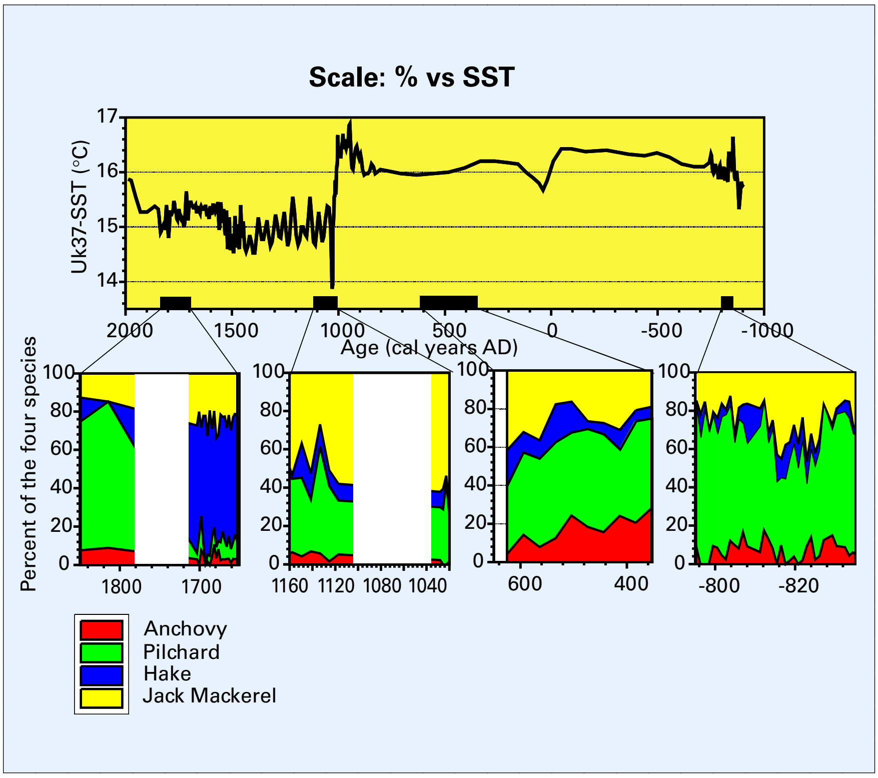

Fig 3: Sea surface temperature (SST) as estimated from the alkenone undersaturation and relative abundance of fish scales from sardine, anchovy, hake and horse mackerel from a sediment core taken in the upwelling area of the Benguela Current off Walvis Bay, Namibia.

results in the latitudinal expansion and contraction of habitat, with associated increases/decreases in abundance of the sardine population. The variance spectra of the high frequency component in Fig. 1 indicate that the expansion and contraction of the sardine habitat of the California Current occurs over a period of around 50 to 60 years. The low-frequency component of sardine biomass in Fig. 1 shows considerable multi-centennial variability, indicating successive warming, cooling and warming of the coastal ocean along North America over the past 1000 years. These changes are correlated with the Medieval Warm Period (950-1350 AD) and the Little Ice Age (1400-1800 AD) and agree with the detailed record of stable isotopes under development from the Santa Barbara Basin (Field and Baumgartner, 2000). Through the use of the geographically separated sites, it may also be possible to reconstruct not only temporal records of change, but also records of space-time variability in the populations and the coastal pelagic environment within each current system, using latitudinal comparison of sites through time. Work is now underway to develop north-south comparisons between the Santa Barbara records and a glacial fjord on the west coast of Vancouver Island, British Columbia (500 years of record so far) and with the region off southern Baja California, Mexico (150 years of record so far, Baumgartner et al., 1996).

In the Humboldt Current, our knowledge of very high-resolution records of fish scale-deposition is limited to a couple of sites off Peru that were collected in the 1970s by A. Soutar (Fig. 2). However, this area promises to provide excellent histories of the last several hundred to 1000 years, and renewed efforts at exploration of coring sites are now underway. The relationship between the anchoveta and sardine off Peru shown by Fig. 2 is consistent with the assumption that sardine abundance was relatively high in the Humboldt Current during the 1930's and 1940's although no catch records are available for that period.

In addition to providing high-resolution data on fish population dynamics, analysis of varved sediments can provide information on past ocean temperatures and be used to infer changes in ocean circulation and marine species distributions. Sediments also preserve remains of micro-organisms such as diatoms, foraminifera and radiolarians, which are used to reconstruct ancient food webs and productivity changes. Studies on fish scale deposition rates and other proxies in varved sediments off Walvis Bay, Namibia, initiated in the late 1990's, show that sea surface temperature (SST), as estimated from the alkenone undersaturation, varied considerably over the last 1000 years after a relatively steady phase during the preceding 2000 years (Fig. 3). Relative abundances of the major fish populations, determined from fish scale sedimentation records, changed drastically in response to temperature. As in the California Current, fish populations in the Benguela Current exhibited drastic fluctuations long before fisheries existed.

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Climate Change: Impacts on Terrestrial Ecosystems

2ND INTERNATIONAL NCCR CLIMATE SUMMER SCHOOL GRINDELWALD, SWITZERLAND, 30 AUGUST – 6 SEPTEMBER 2003

The 2nd NCCR Climate Summer School commenced on 30 August 2003, following the PAGES meeting in Bern on 29 August 2003.

A total of 70 enthusiastic participants from 20 different countries attended this year, bringing along their own individual research interests. PAGES supported the attendance of four students from developing countries. The NCCR Climate Summer School proved to be an excellent platform for dynamic and stimulating conversation among students dedicated to research on the impacts of climate change in terrestrial ecosystems. The lectures, presentations and keynote speeches were conducted by an equally dynamic group of leading senior scientists from various scientific disciplines. Lectures covered terrestrial biosphere, hydrological, and atmospheric research. Topics of interest included mitigation and adaptation of plants and animals to climate change, global perspectives that integrated the socio-economic aspect of climate change issues, and finally an overview of the role of science in the UNFCCC/Kyoto process.

Fig. 2: Martin Grosjean explaining the Grindelwald geology to participants under advice of a local expert (Photo: C. Cunningham).

Fig. 1: The Wetterhorn (3701 m asl.) as seen from Grindelwald (Photo: C. Cunningham).

We are grateful to the conference planning committee for thoughtfully orchestrating this diverse team of senior scientists and encouraging them to share not only the latest advancements in their selected field, but also important background knowledge on their topic. This style of presentation effectively allowed all the students from varying disciplines to engage in the discussions that followed. The conference truly succeeded in encouraging a multi-disciplinary knowledge exchange, both in the academic and the social arena. Climate and global change effects on terrestrial ecosystems is such an enormously complicated topic that it necessitates interaction among specialists. Thus, it was encouraging to learn that our generation of field ecologists and ecosystem modeling experts are really delighted at the prospect of working together in research teams to solve the critical problems of climate change affecting our natural environment today.

But wait! The Summer School was not all lectures and discussions and 'brain-drain'. After all, scientists are also fun-loving and sociable people. Evenings were dedicated to relaxation, conversation about other common interests, sharing stories from one another's homeland, and, hanging out in the now-famous Eiger Bar. The highlight of the week was a half-day hiking excursion (Figs. 1, 2) up to the Grindelwald Glacier, where we were graced by witnessing an icefall. All conference attendants stood in awe at this marvel of nature. An indication of warmer temperatures in this alpine environment?

The 2nd International NCCR Climate Summer School came to an end on Friday, 6 September with closing speeches given by Prof. Heinz Wanner, the Director of NCCR, Prof. Jürg Fuhrer, the visionary behind this Summer School, and Prof. Martin Grosjean, the guiding hand behind the organization of all the pieces for this dynamic and successful event.

Thanks again to NCCR, the Organizing Committee, and PAGES!

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Topics in Biogeochemistry, Paleoceanography and Paleoclimate

Austral Summer Institute, Dichato, Chile, 5 - 30 January 2004

Fig. 1: Participants of the ASI - Workshop in Dichato, Chile.

Dichato, a small fishing cove and summer resort in central Chile, was invaded by local and international oceanographers from 5-30 January 2004. A total of 24 participants and seven instructors passed through the seaside village in connection with the fourth annual Austral Summer Institute (ASI), hosted by the Universidad de Concepción at its Marine Biology Station.

The ASI series began in 2001 as part of a cooperative agreement between the Universidad de Concepción, Woods Hole Oceanographic Institution, and the Fundación Andes. Additional funding from PAGES and POGO helped defray costs for ASI-4 participants traveling from Brazil and Colombia.

After a rather hectic opening day, instructors and participants settled quickly into the communal bilingual life structured for ASI-4 by coordinators Carina Lange and Silvio Pantoja, Universidad de Concepción. For four weeks, a core group of 10 participants lived in several cabins, hosting new participants and bidding farewell to others on a weekly basis.

In accordance with the ASI philosophy that learning takes place outside as well as inside the formal classroom—a philosophy deeply appreciated by both participants and instructors—ASI-4 instructors also stayed on site. The interaction between the students, mostly Latin American, and the teachers, some of the most prominent figures in paleoclimate and biogeochemistry, was one of the best results of this summer school. Participants and instructors shared class time as well as many incidents of daily life; opportunities to interact abounded.

ASI-4's first cycle featured Anthony Rathburn (Indiana State University) on "Marine productivity and seasonality: Responses of microbenthos in oxygen-poor environments, past and present" and Lloyd Keigwin (Woods Hole Oceanographic Institution; WHOI) on "Topics in Quaternary ocean and climate change". Cycle two brought a highly coordinated unit, with John M. Hayes (WHOI) teaching "Isotope Biogeochemistry" and Jürgen Rullkötter (University of Oldenburg) presenting "Molecular organic geochemistry".

During the third cycle, Jennifer Pike (Cardiff University) worked with "Quaternary ocean and climate history from laminated marine sediments", and Daniel Repeta (WHOI) with "Organic compounds as tracers for paleoclimate". ASI-4 participants were also treated to a special talk by Jeremy Jackson (Scripps Institution of Oceanography) on "Caribbean marine extinctions on different timescales: the changing roles of geology, climate and people".

The final cycle was led by Robert Dunbar (Stanford University), who took an in-depth look at "Air-sea interactions and the global carbon cycle: A paleoclimate perspective from the tropics to the poles". The unfortunate postponement of the afternoon session (Christopher Charles, Scripps Institution of Oceanography, "Ocean chemistry and climate change on timescales of decades to millennia") in the end afforded participants much more time for hands-on practice with Ocean Data Viewer technology, a novel experience for many.

Each cycle had its own dynamic and class structures were varied. There was a wide variety of presentations, practical activities, and evaluations offered by the different teachers. Papers were discussed, lab practicals performed, microfossils and thin sections analyzed, ideas and information exchanged, exercises worked out, skills tested, and evaluations given during ASI-4.

At the end of January, the group left Dichato with a comprehensive wealth of new knowledge. The chance to learn from and work side-by-side with top-level investigators resulted in unique learning opportunities for the participants, whose backgrounds ranged from engineering to marine biology. Since the topics presented were highly relevant to a such a widely diverse group, new research horizons were opened up and ideas for future collaborations were explored.

After the success of ASI-4, it seems Dichato can expect another invasion next January. Details of ASI-5 will be available at www.udec.cl/udecwhoi in July 2004. The ASI-4 picture gallery will be available in April 2004 on the same web page.

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CALENDAR 2004

May 23 - 28, 2004, Blois, France
16th Rencontres de Blois Meeting: Challenges in the Climate Sciences

Further information:
http://opserv.obspm.fr/confs/climates.html

June 3 - 12, 2004, Amsterdam, The Netherlands
PROPER - Proxies in Paleoclimatology: Education and Research - Course 1

Further information:
http://sheba.geo.vu.nl/users/pal/proper/

July 5 - 9, 2004, Suntec City, Singapore
PEP2 Session: Low-Latitude and High-Latitude Climate and Linkages in the Asia-Oceania Sector in the Late Quarternary

Further Information:
http://www.asiaoceania.org

July 19 - 20, 2004, Nairobi, Kenya
Africa START-PAGES Workshop on African Paleo-perspectives: Linking the Past to the Present and the Future

Further information:
http://www.pages.unibe.ch/calendar/2004/africa.html

August 30 - September 2, 2004, Belgrade, Serbia
Paleoclimate and the Earth Climate System: Milankovitch Anniversary Symposium

Further information:
http://www.pages.unibe.ch/calendar/calendar04.html

September 1 - 3, 2004, Bergen, Norway
Bjerknes Centenary 2004: Climate Change in High-Latitudes

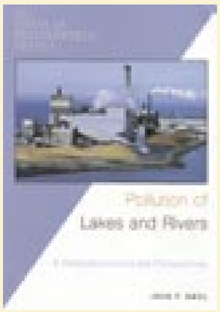
Further Information:
http://www.bjerknes.uib.no/conference2004/

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

New on the PAGES Bookshelf:

Pollution of Lakes and Rivers: A Paleoenvironmental Perspective

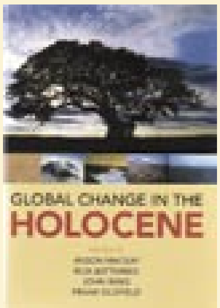
John P. Smol, Department of Biology, Queen's University, Kingston, Canada
ISBN: 0340741465; Arnold Publishers, London; Co-published by Oxford University Press, New York. 280 pp. Glossary, Index.Publication date: 28 June 2002, Price: £20.99 (Paperback)
http://www.hodderheadline.co.uk



This major new text provides an authoritative overview of the use of sedimentary records to study the environmental degradation and recovery of lakes and rivers. The book includes the results of the most recent research and up-to-date data, much of which is found in a wide range of technical sources and normally inaccessible to students. A distinctive feature of the book is its temporal focus, allowing for discussion of the lessons to be learned from the past in understanding and solving current and future problems of lake and river pollution.

Global Change in the Holocene

Rick Battarbee, Anson MacKay, John Birks and Frank Oldfield,
480 pages; 50 halftones, 50 line illus., & 20 color photos; ISBN: 0340762233 Publisher: Hodder & Stoughton Educational 29/8/2003
£95.00 RRP Hardback
http://www.hodderheadline.co.uk/



Global Change in the Holocene demonstrates how reconstructing the record of past environmental change can provide us with essential knowledge about how our environment works and presents the reader with an informed viewpoint from which to project realistic future scenarios. The book brings together key techniques that are widely used in Holocene research, such as radiocarbon dating, dendrochronology and sediment analysis and offers a comprehensive analysis of various archives of environmental change including instrumental and documentary records, corals, lake sediments, glaciers and ice cores.