2. ARCHIVES AND PROXIES ALONG THE PEP III TRANSECT

FRANK OLDFIELD (f.oldfield@btinternet.com)
Department of Geography
University of Liverpool
Liverpool, L69 72T
UK

ROY THOMPSON (roy@ed.ac.uk)
School of Geosciences
The University of Edinburgh
Edinburgh, EH9 3JW
Scotland

Keywords: Palaeoclimate, Palaeoecology, Palaeoenvironment, Palaeo-archives, Palaeo-proxies, Pole-Equator-Pole, Transect, Calibration

Introduction

The PEP III Transect (Gasse and Battarbee, this volume) spans an immense range of environmental and cultural diversity. It includes regions that have been the cradle of Old World civilisations dating back many millennia, it is home to some of the most advanced and favoured societies on the planet, some of the least hospitable environments and some of the most vulnerable and economically impoverished peoples on earth. Documenting and understanding the ways in which climate has varied across the whole length of the Transect and teasing out the past interactions between climate and human welfare pose immense challenges to the scientific community. Moreover, the challenges encompass themes that are of outstanding practical importance for our future as well as part of our compulsive fascination with the past.

The challenges require us to make full use of the instrumental record of recent climate variability and this is the concern of the first part of this chapter. But that alone does not suffice. Valuable though it is, the brief instrumental record fails to encompass the full range of natural climate variability in both time and space that has characterised the last few thousand years. In order to provide a record of that variability, it is necessary to turn to a whole range of 'archives', both documentary and environmental, and to analyse them using methods that can capture datable and decipherable signals of past variability. For this, we rely largely on what are usually termed 'proxies'. After outlining the scope for instrumentally based climate reconstructions across the whole length of the Transect, the present chapter seeks to give a brief introduction to the archives and proxies that provide

R. W. Battarbee et al. (eds) 2004. *Past Climate Variability through Europe and Africa*

a basis for reconstructing past environmental and climatic variability within the F domain.

The main archives

Instrumental climate records

Instrumental records are a vital part of any research strategy for palaeoenvironmental structions, especially where our interest focuses on time intervals during which the bo conditions do not differ too greatly from those over which the records are availal strumental data (e.g., Vose et al. (1992)) provide a backbone for palaeoclimatology enable us to quantify objectively how the climate has varied and offer the most stati robust data from which to establish the spatial coherence of the currently dominant of climate variability. Furthermore they provide the basis on which diverse proxies calibrated to measured climatic properties, as well as forming a bridge that links the proxy records to the period of present day monitoring. Instrumental records cover a range of climatic parameters.

For much of the 20th century climate, was viewed as being effectively station only varying slowly over geological time. This static view dominated human de making. Recently however, the increasing body of evidence from instrumental rec warming temperatures and of changing patterns of precipitation has led to a new dyr view of climate change. Instrumental observations of the weather have been aggreg build up detailed records of climate change as far back as the seventeenth century. Ir years many previously forgotten old ledgers have been unearthed and their valuable c incorporated into climatic databases. Also during the past decade much progress h made in improving the fidelity of instrumental climate records by removing sys biases and by gathering together and analysing daily data rather than relying on n averages.

Today the vast observational network (surface and upper-air information from ra des), largely established for weather forecasting, coupled with satellite soundir imagery has led to millions of weather observations being made each day. Data are ty recorded at thousands of synoptic and climatological stations on land; hundreds of a ships and moored buoys; hundreds of radiosondes and from many satellites. Rea studies, in which daily observations since 1948 have been assimilated into a compre global representation of the daily state of the atmosphere, provide a synthesis of th wealth of instrumental weather data. These retrospective analyses of weather obser have great potential for providing very valuable data sets to researchers in the community. A particularly appealing aspect of reanalysis is that its four-dimensiona ilation and modelling system can transport information from data-rich to data-poor providing internally consistent climatic time-series in observationally sparse local

The PEP III pole-to-pole transect is rich in instrumental meteorological reco proxy data. It passes through Europe, the region of the world's longest instrumental (e.g., Camuffo and Jones (2002)), as well as Sub-Saharan Africa a locality wh experienced some of the most pronounced recent climate change of anywhere aro globe (Nicholson and Grist 2001). The instrumental data available for each of the

III geographical regions of the TS1 (time stream one) science plan (Gasse and Battarbee this volume) are briefly described.

High latitude, high altitude Europe

Climate reconstructions can be generated for the last three hundred years, even for localitie beyond the timberline in sub-arctic Lapland, by using regression analysis to extrapolat the instrumental records from the more populated regions of North and Central Europe The excellent skill exhibited by the multiple regression methodology relates to the higl quality of the European data and to the SW-NE anisotropy of air-temperatures across Europ (Sorvari et al. 2002). High altitude climates, from above the timberline, can similarly b reconstructed from lowland weather series (Agustí-Panareda and Thompson 2002). Th high Alps in particular are found to have warmed steadily in recent decades (Schönwies and Rapp 1997; Böhm et al. 2001). At many localities, permafrost, normally protecte from annual and inter-annual temperature fluctuations by its low thermal diffusivity, is nov experiencing conditions outside the range of natural climatic variability and is thawing fo the first time in millennia (Hoelzle and Haeberli 1995).

Mid latitude Europe

Europe is particularly well endowed with instrumental series (Thompson 1995; 1999). Th climatic parameter that provides the longest record is mean air temperature. The renowne Manley (1974) series for Central England starts in 1659. Precipitation series are availabl from 1697 (Kew), while the longest continuous surface-pressure sequence commences i 1722 at Uppsala in Sweden. The wide geographical coverage of European instrumenta records since 1781, means that fluctuations to the regional atmospheric circulation pattern can be established (Luterbacher et al. 1999) and hence climate change hindcast even i the less populated hinterlands of mid latitude Europe. For example, in the Annecy regio of the pre-Alps, daily discharge can be reconstructed for rivers back to the 1800s (Foste et al. 2003) and growing season degree-days estimated for marginal agricultural land on a annual basis back to the 1600s (Crook et al. 2002).

The Mediterranean Basin

The Mediterranean climate is characterised by dry summers and wet winters. Mediterranea precipitation records reach back to 1749. Good spatial coverage is provided by over 10 precipitation series spanning the last 150 years. Winter months (NDJF) exhibit a telecon nection seesaw pattern as demonstrated by the correlation coefficients in Table 1. Winter with higher than usual precipitation in the west (Portugal/W. Spain) tend to be dry winter in the east (Israel/N. Egypt), and vice versa. Exactly the same teleconnection pattern i found in the long term precipitation trends (Plate 1) which reveal a 150 year drying tren in the S. and E. Mediterranean (-0.1 mm/month yr^{-1}) which contrasts with an increasin trend in winter precipitation in the N. and W. Mediterranean ($+0.1$ mm/month yr^{-1}). Th S. European trend has recently reversed and S. Europe is currently drying in agreement wit predictions based on 2xCO_2 modelling (Ulbrich and Christoph 1999). The consistency o the teleconnection across frequency bands (from annual to centennial) suggests it is no unreasonable to search for the same teleconnection pattern in millennial long proxy records

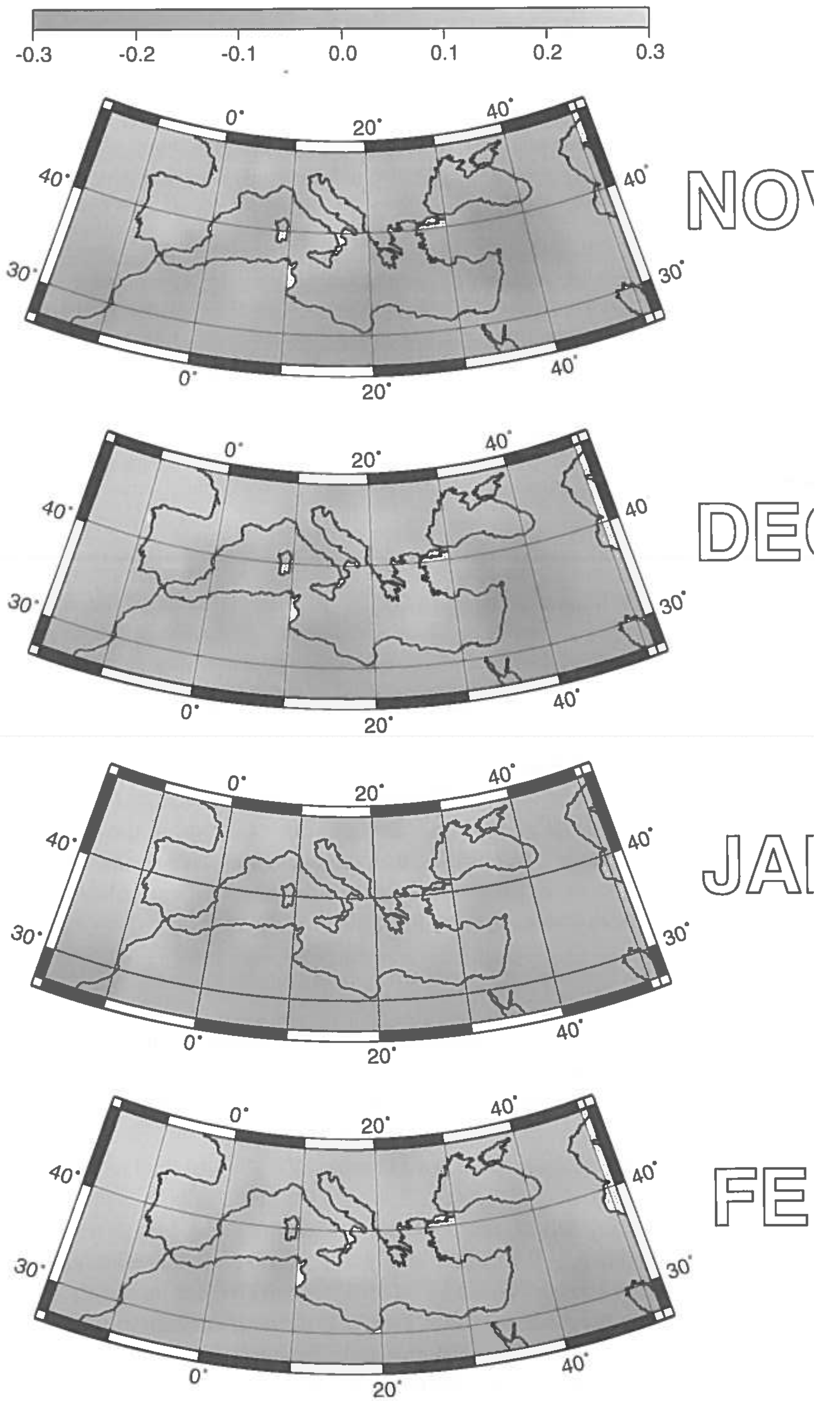
-0.3
-0.2
-0.1
0.0
0.1
0.2
0.3
NO
DE
JA
FE

Plate 1. Long-term linear trend in Mediterranean precipitation (mm/month/yr) during the 136 year period (185 to 1990). Note the drying trend (purple) for all four-winter months in the Near East compared to the increas (blue) for Western Iberia. The null change line runs approximately through Gibraltar-Sicily-Greece-Black Se: Note how the same east-west teleconnection seesaw is found for precipitation as in the interannual variation c Table 1. (Albers equal area projection). Colour version of this Plate can be found in Appendix, p.627

Table 1. Correlation coefficients (r) between the inter-annual precipitation for seven stations in Portugal/ Wester Spain and nine Eastern Mediterranean stations for the four winter months (NDJF), during the 136-year perio (1855 to 1990). Note the block of negative East-West teleconnections in the lower left quadrant, which contras with the blocks of positive teleconnections in the upper left and lower right quadrants.

	Lis	Coi	Evo	Bad	Por	Val	Bur	Lim	Nic	Bey	Jer	Ism	Sai	Cai	HQ	Alx
Lisbon	1	.70	.88	.82	.69	.70	.66	−.14	−.13	−.02	−.11	−.04	−.04	−.10	−.08	−.16
Coimbra	.70	1	.80	.62	.77	.79	.74	−.20	−.11	−.15	−.18	−.05	−.12	−.12	−.12	−.16
Evora	.88	.80	1	.86	.73	.75	.67	−.13	−.11	−.16	−.23	−.20	.00	−.28	−.25	−.17
Badajoz	.89	.62	.86	1	.56	.70	.66	−.20	−.17	−.19	−.18	−.12	−.16	−.17	−.17	−.17
Porto	.69	.77	.73	.56	1	.69	.63	−.15	−.11	.03	−.12	.03	−.04	−.06	−.14	−.15
Valladolid	.70	.79	.75	.70	.69	1	.81	−.16	−.15	−.03	−.19	−.03	−.11	−.15	−.12	−.15
Burgos	.66	.74	.67	.66	.63	.80	1	−.26	−.20	−.17	−.23	−.12	−.13	−.21	−.26	−.17
Limassol	−.14	−.19	−.13	−.20	−.15	−.16	−.26	1	.48	.15	.35	.11	.06	.17	.63	.19
Nicosia	−.13	−.11	−.11	−.17	−.19	−.15	−.20	.49	1	.15	.37	.10	.14	.08	.39	.49
Beyrouth	−.02	−.15	−.16	−.19	.03	−.03	−.17	.15	.15	1	.31	.59	.41	.58	.22	.24
Jerusalem	−.11	−.18	−.22	−.18	−.12	−.19	−.23	.34	.37	.31	1	.23	.32	.27	.30	.41
Ismailia	−.04	−.05	−.20	−.12	.03	−.03	−.12	.10	.10	.59	.23	1	.42	.85	.17	.19
Port Said	−.04	−.12	.00	−.16	−.04	−.11	−.13	.06	.14	.41	.32	.42	1	.34	.17	.43
Cairo	−.10	−.12	−.28	−.17	−.06	−.15	−.21	.17	.08	.58	.27	.85	.34	1	.15	.19
Cairo HQ	−.08	−.12	−.25	−.17	−.14	−.12	−.26	.63	.40	.22	.30	.17	.17	.15	1	.30
Alexand	−.16	−.16	−.17	−.17	−.14	−.15	−.17	.18	.49	.24	.41	.19	.43	.19	.30	1

Arid and sub-arid belt

Along the African and Arabian segments of the PEP III Transect, instrumental record are much shorter than those from Europe (Nicholson 2001) and tend to be restricted t the coast. Nevertheless in some places records of air temperature and precipitation ar available for over 150 years. There have been dramatic climatic changes even over thes times, especially in the W. Sahel, with the most pronounced drying of anywhere in th world (Senegal, 1884–1990, JJA, -1.3 mm/month yr^{-1}). At a similar latitude, but furthe east, through Mali, Niger and Ethiopia the same drying trend is found and averaged arounc -0.2 to -0.5 mm/month yr^{-1}.

Inter-tropical Africa

20th century instrumental data allow spatial climatic patterns and teleconnections to b well mapped through the tropics. Good coherence is found between various climatic pa rameters in the tropics. For example, rainy season daytime (maximum) air-temperatur and precipitation anomalies in Zimbabwe are closely anti-correlated, due to the effects o clouds (Unganai 1997). Long-term precipitation trends tend to have been low, with th exception of the Angolan coast (Luanda, 1879–1985, MAM, $+0.3$ mm/month yr^{-1}) an

Zimbabwe (1890–1989, DJF, -0.3 mm/month yr^{-1}). Various regions such as Sc
Uganda and Central Zimbabwe show statistically significant ENSO signals (Philli
McIntyre 2000; Unganai 1997). These ENSO signals are however both climatica
geographically limited compared to those from the other PEP transects (Markgraf an
2001).

Southern Africa

Southern Africa encompasses a particularly wide range of climatic zones, ranging fro desert through Mediterranean and humid sub-tropical to tropical, and a strongly cont range of seasonalities all within a small geographic region (500 × 1000 km). Thi precipitation series span the last 100 years. However, they reveal no century lo cipitation trends (Richard et al. 2000; 2001). Interannual variability of summer is linked to sea-surface temperatures in the Indian Ocean (Rocha and Simmonds Air-temperature data are available from 1857.

Documentary records

Europe especially abounds in documentary records of weather and climate spannin centuries (e.g., Frenzel et al. (1992), Glaser and Hagedorn (1991)). The special v documentary evidence lies partly in its spatial and temporal specificity and the inc skill with which the massive quantities of diverse evidence can be objectively transla more or less quantifiable descriptors (e.g., Pfister (1992)). These in turn permit a with seasonal, even daily resolution as well as interpretation in terms of synoptic p although one must beware of the limitations in comparison to direct instrument surements of the weather. For example, a comparison of the spatial coherence of s temperatures, at the inter-annual time scale, between Germany and Switzerland re marked drop in correlation coefficient as the data used changes from instrumental to documentary evidence. Counter-balancing such limitations are the insights c interpreted documentary records can provide into extreme events and their imp hydrology, ecosystems and human populations. In most cases, it is extreme events t human populations are vulnerable, rather than changes in mean annual climate.

Evidence linking changing climatic conditions to contemporary indicators of h human welfare, demographic changes and socio-cultural responses increases the documentary evidence, for it can deepen our understanding of the nature of the inte between environment and society during periods of stress (Brázdil et al. 1999). The r of the documentary record in providing indicators of human response as well as change gives it the added benefit of precluding and indeed transcending interpreta simple deterministic terms. The full range of applications for documentary reconst of past climate has yet to be realised. One novel application is illustrated by the work of Bugmann and Pfister (2000) in which Bugmann's forest succession mo been 'driven' by Pfister's reconstructed climate variability over the last five cent order to explore the reliability of the model as a predictor of tree line behaviour in th Alps (Fig. 1).

In the prevailing intellectual climate, those environmental historians whose wo what is essentially a humanistic methodology to areas of application in the nat ences risk being undervalued by both communities. One of the roles of the leader

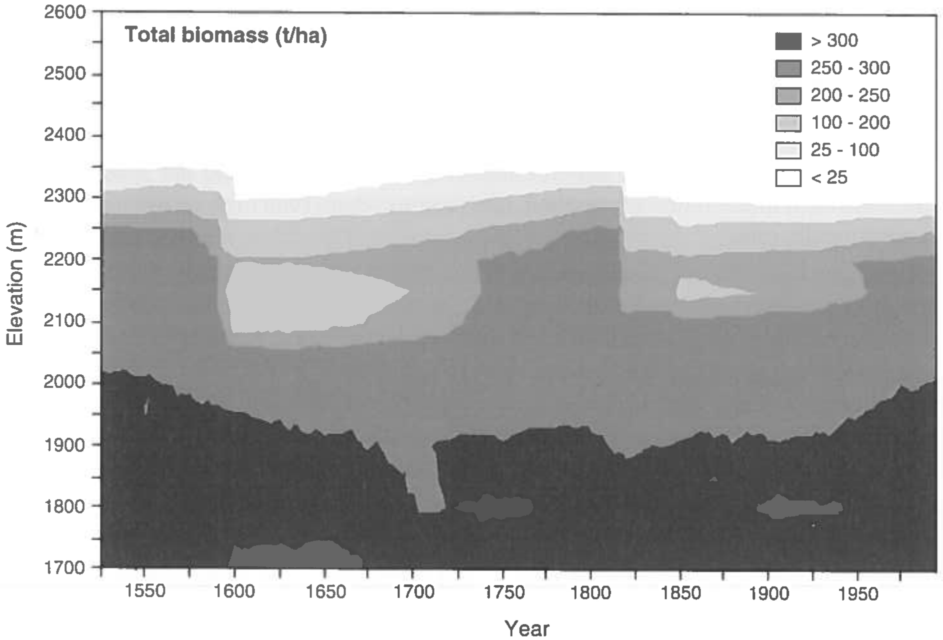

Figure 1. Total biomass (t/ha) on a south-facing slope in the European Alps simulated by a model of fores dynamics as 'forced' by a 470-year compilation of historical climate change from 1525 to 1995. Note the tw dramatic drops in the upper-tree line caused by major dieback events following two series of extremely col summers (1593-97 and 1812-18). (From Bugmann and Pfister (2000)).

palaeoclimate community might be to enhance recognition of the value of document-base reconstructions as well as to encourage those bold and scrupulous enough to bridge the tw cultures with skill and success.

Tree rings

One of the most powerful palaeoclimatic tools to emerge over the last few decades has bee dendroclimatology, which, by definition, achieves annual resolution and can often be linke to specific characteristics of the growing season (e.g., Lindholm and Eronen (2000)). B now, networks of researchers have developed circum-boreal records distinguished by bot rigorous calibration to instrumental records and compelling regional coherence. Spatia cover is also matched by long time series that have served to calibrate radiocarbon dates provide powerful chronologies in their own right and document high frequency climate variability, including the transient responses to volcanic events (Briffa et al. 1998), throughou the late Holocene. PEP III benefits from the fact that some of the leaders in this researc field have spent many years refining and extended the record in Europe and adjacent area of the former Soviet Union (Briffa 2000; Briffa et al. 2001; Briffa and Matthews 2002). Th research field has thus benefited from the creation of major databases that contain evidenc which combines precise chronologies with the results obtained by applying a commo methodology to comparable archives over a wide area (e.g., Schweingruber et al. (1996))

In this regard, the community of dendroclimatologists has set an excellent example rest of the research community.

Research along the PEP III Transect also includes tree ring, or at least, growth inc studies, from the east Mediterranean (D'Arrigo et al. 2001), the mountains of the S region (Pelfini et al. 2001) and the sub-Saharan Miombo woodland (Trouet et al. These extend the application of dendroclimatological method beyond the spatial where it has been most commonly applied, into regions where such high-resolution are exceptionally rare.

Speleothems

An increasing number of studies exploits the paleoenvironmental signals containec calcite precipitated by cave water. Speleothem based studies along the PEP III t span an amazing range of latitudes and environments from Northern Norway (La 1996; 2003) to South Africa (Holmgren et al. 1999; Lee-Thorp et al. 2001), Mediterranean region (Aylon et al. 2001; Bar-Matthews et al. 2001; Causse et al. 20(Oman (Fleitmann et al. 2001; 2002). The time-span covered is remarkably varied, ref differences in growth rate and also the way in which conditions for stalagmite grow sometimes occupied quite narrow and diverse time intervals, depending on the loca and water supply to, the site. Thus, even the discontinuities in speleothem develc may themselves reflect significant changes in regional climate.

The growing number and wide geographical spread of speleothem records has the establishment of a thematic group (SPEP) concerned with this type of archi led by Stein-Eric Lauritizen (Lauritzen 2001). Palaeoclimatic signatures reside in speleothem properties ranging from luminescence to geochemical and stable isotop (Lauritzen and Lundberg 1999). One of their major advantages is the scope they o dating using the U/Th method (Rosendal et al. 2001). In all cases though, there is to understand and, in so far as possible, make quantitative adjustment for all the pr that intervene to modify a climate signature as water passes from the lower atmo through soil and bedrock to the point of calcite precipitation. These processes region-, even site- or speleothem-specific. They therefore call for careful study the sequence of changes that is derived from speleothem analysis can be trans into climate parameters. The scope speleothems offer, for resolving both high a frequency variability, gives them special value particularly when viewed alongsid high resolution, precisely datable archives such as tree rings or varved lake sedime

Corals

Coral records, mainly spanning the last one to two centuries at most, have been stu favourable localities from the Red Sea (e.g., Klein et al. (1990), Felis et al. (2001)) wards to the coast of Madagascar (Zinke et al. 2001). The reliability with which seas is reflected in the fluorescent banding of corals coupled with their location in marine environments, makes them uniquely valuable palaeo-archives. The calibra stable isotope signatures and chemical ratios in corals usually involves comparin with short instrumental time-series. The correlations that often emerge have encc the use of coral records as indispensable indicators of Sea Surface Temperature (SST) an salinity changes on a seasonal and inter-annual basis. This in turn makes them extremel attractive for documenting the effects of ENSO variability not only in the Pacific region bu also along the east coast of tropical Africa. Coral research has important implications fo exploring changes to the periodicity of ENSO on decadal to century time-scales, as wel as the strength of the Indian Ocean-western Pacific teleconnection and its changes throug time.

In addition, increases in the barium/calcium quotient in corals have been shown t reflect increases in fluvial input and associated terrigenous sediment supply to the ree environment as a result of land clearance and soil erosion in recent times (Cole 2001). Th sum total of evidence from the coral record therefore provides an elegant illustration of th way in which human-induced changes on land can interact with an overall warming trend to exacerbate the damaging effects of coral bleaching and associated degradation of ree environments.

Lake sediments

Lake sediment records of almost infinite variety have clearly been among the most popula archives along the whole length of the transect. They defy generalisation. In terms of tim spans covered, they range from sites in Northern Fennoscandia where the development o a truly limnic environment postdates the time of isolation from the Baltic as a result o Holocene isostatic rebound (e.g., Hedenstrom and Risberg (1999)), to volcanic or impac crater lakes in central (Creer et al. 1990; Zolitschka 1998) and southern (Allen et al. 1999 2000; Ramrath et al. 2000; Roberts et al. 2001) Europe, or South Africa (Partridge et al 1997) respectively, where the sediment record may span several glacial-interglacial cycles Spatial extent and morphometry are equally varied and we may contrast the small glacia lakes of much of highland Europe (e.g., Birks (2000), Ammann (2000)) with both the majo lakes of the African rift system (Johnson 1996) and the once extensive but now dry lake that formerly covered vast areas of the Southern Sahara region during the early Holocen (Gasse et al. 1987; Kroepelin et al. 2001).

Lake sediments in much of Europe especially, have begun to provide quantitativ palaeoclimate proxies through the development of transfer functions linking aspects o lake biology, recoverable from fossil remains, to variations in water and air temperatur (e.g., Lotter et al. (1997), Lotter (2003 and Fig. 2)). Other lakes have yielded palaeoclimat records from variations in the stable isotope ratios in ostracods (von Grafenstein et a 1999), authigenic carbonates (Jones et al. 2002), organic extracts and diatom silica.

Of especial value are lake sediments in which the annual rhythm of sedimentatio gives rise to varves, which in turn can be used to provide potentially annual resolution i the palaeo-record as well as to establish a precise and accurate chronology of sedimen accumulation (e.g., Zolitschka (1998)). Indeed, variations in the character and thickness o the varves themselves may constitute a quantifiable climate proxy in favourable circum stances and, like other annually resolvable archives, they can give vital information o the incidence and the hydrological and sedimentological impacts of extreme events (e.g Thorndycraft et al. (1998)). Varves vary greatly in type and origin, but where they can b shown consistently to reflect an annual cycle over a long period of time, their presenc

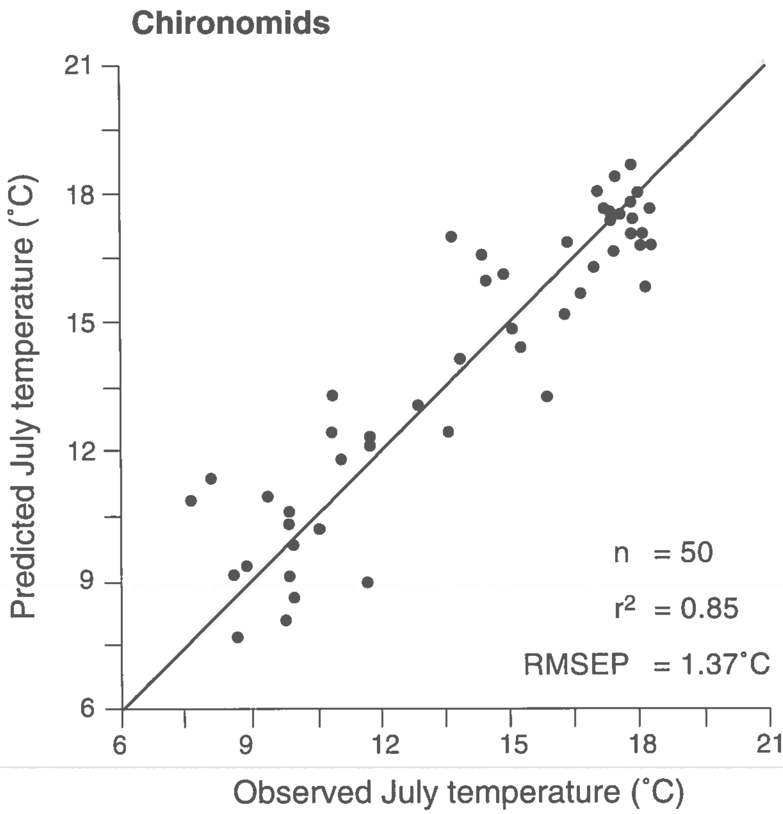

Figure 2. Chironomid data from the Alps illustrates the skill that can now be achieved in climate recons
Here a spatial calibration of July temperatures, based on a training set of lakes along an elevation gradi
a cross validation r^2 of 0.85 and a prediction error of 1.37 °C. (From Lotter et al. (1997)).

endows any sediment sequence with added significance, for without them, estat a reliable chronology of sedimentation can often provide a major and at times, present state of knowledge, insurmountable obstacle to making the fullest possibl palaeolimnological evidence.

Lake basins and their sediments often provide crucial evidence about past lak and hence about changes in the balance between precipitation and evaporation. especially significant in regions where major fluctuations in available moisture crucial significance for human welfare and even survival. In much of Africa, sides of the Equator, the evidence for major changes in lake level during the H provides one of the most powerful counters to the polar-centric view of the H as a period of relatively stable climate (Gasse and Van Campo 1994; Verschure 2000; Bergner et al. 2001). These changes can be identified using both geomorp sedimentary evidence; they occur on time-scales ranging from sub-decadal to millen their dramatic implications for human societies in the past are becoming increasin documented. While climate/vegetation models for N. Africa in the mid-Holocene, w strengthened summer monsoon, predict pronounced shifts in the climate and in ve patterns, the direct effects of orbital changes alone are found to be insufficient to generate th major changes indicated in the palaeoenvironmental reconstructions. Vegetation feedback can produce further intensification in monsoonal precipitation during the mid-Holocen especially in W Africa (Ganopolski et al. 1998; Doherty et al. 2000). However, the dramati and widespread shifts of lake levels in N. Africa are still not fully explained. Soil and ocea feedbacks in fully coupled vegetation-atmosphere-ocean models may provide a means o resolving some of the remaining discrepancies between the modeled and proxy lake-leve data.

Peat

Here we consider only those instances where peat stratigraphy and the contained fossi record have been used to provide direct proxies for climate change. This excludes the mor numerous instances where peat profiles have provided the context for pollen analytica studies. Ombrotrophic (precipitation-dependent) peatlands are widespread in the cool tem perate and boreal parts of the Transect and their direct link with the atmosphere make them attractive archives for recording past changes in the balance between precipitatio and evaporation. It is over a hundred years since peat stratigraphy was first interpreted a a record of climate change in Northern Europe during the Holocene and the terminolog to which these early studies gave rise still has wide currency. Plant macrofossils, includin *Sphagnum* species with well established habitat requirements relative to the water table, tes tate amoebae and peat humification measurements have all been shown to reflect variation in surface moisture status at the point of sampling (Charman and Hendon 2001; Barber an Langdon 2001; Barber and Charman 2003). Current work includes several studies designe to quantify this relationship and to test the extent to which the temporal sequences of surfac wetness reconstructed from individual cores can be replicated within and between site (Barber et al. 2000; 2003). This work requires detailed and precise chronological control Fortunately, ombrotrophic peat can provide the raw material for this, especially if care i taken to eliminate time-transgressive components in the dated material and if the densit of radiometric determinations undertaken is close enough to open up the opportunity t establish precise dates by matching onto dendrocalibration 'wiggles' (Van Geel and Mool 1989; Mauquoy et al. 2002).

Groundwater

Groundwater is both an archive and a vital human resource (Edmunds 1999). Its availabilit as a recorder of past climate in areas where many of the other commonly used archives ar absent adds to its attraction. Within the saturated zone of major aquifers in arid and semi-ari regions, and despite the rather low temporal resolution of the record, the combined result from stable isotope and noble gas (Stute and Talma 1998) measurements have provide evidence of outstanding importance for developing quantitative estimates of difference in mean annual temperature between the present day and the last glacial maximum. It i also important in currently arid and semi-arid regions, to combine evidence from groun water with that derived from changing lake levels, for the lakes are often simply the surfac expression of water bodies that lie mainly below ground level (Fontes et al. 1993; Edmund et al. 1999). Interpreting past hydrological changes from the lakes alone thus provid part of the story.

Much of the evidence already obtained from groundwater studies highlights t that in many areas, currently exploited groundwater is 'fossil' and dates from peri greater moisture availability thousands of years ago. In too many cases, from count diverse as Spain, Libya and Northern Nigeria, it is being mined at a rate vastly exceed rates of recharge possible under current climatic conditions. So societies find them in a dangerous dilemma. While populations and demands on water are growing, in priate management is leading to rapidly declining water resources. Human societi fail to heed the incontrovertible evidence of the extremely slow recharge rates o groundwaters do so at their peril.

Records of climate changes in the more recent past can be obtained from profiles o chemistry within the unsaturated zone (Goni and Edmunds 2001). Conservative el such as chlorine can be used as tracers that record changes in the degree of evap concentration in past groundwater. In this way, the groundwater profiles can pre clear record of such events as the Sahel drought of the 1970's and 80's.

Other types of continental archive

A wide range of other archives such as alluvial or colluvial sequences, loess p and geomorphic or stratigraphic indicators of past glacier behaviour have all cont vital information along the Transect. Although, in many cases, they lack the co of some of the other archives they can nevertheless often provide essential con on inferences derived from other lines of evidence. Many also provide contexts in palaeo-environmental and archaeological evidence can be directly linked. Special inherent to archives in which a direct association can be established between evide environmental variability and the archaeological record of societal response.

Special mention should be made of the Kilimanjaro ice core record (Thompson 2 forms the only African example of a whole series of ice core records from tropical g ranging from the Andean peaks of South America to the mountains of Central Asia thus form one of the most significant of several emerging links between the PEP Tr The importance of the record from Kilimanjaro, as from other low latitude ice-c enhanced by the rate at which such archives are disappearing.

Marine sediments

Over the last few decades, the temporal resolution achievable in favourably located sediment sequences has made them of increasing interest as a complement to the terr derived evidence that has been the main concern of the PEP Transects. High-res records from giant piston cores obtained during IMAGES cruises have proved es valuable (Cortijo et al. 2000). Much of the marine evidence available over the Transect takes the form of stable isotope analyses particularly on planktonic foram From these, along with additional sedimentological, biological and geochemical a reconstructions of past changes in SST, salinity, ventilation, sediment provenan deposition and sea ice extent have been made. These marine proxies provide par the terrestrial record (e.g., Cullen et al. (2000)) as well as evidence for the role that changin ocean circulation has played in modifying and, at times, dramatically amplifying the impac of changes due to external forcing. In the context of the PEP III domain, special interes attaches to past changes in North Atlantic deep-water formation and its impact on ocea circulation (Bond et al. 2001). One of the most important messages inherent in the longe term records from PEP III is the close link on all timescales from decadal to millennia between largely salinity-driven changes in thermohaline circulation in the North Atlanti and dramatic changes in climate regime over a wide area including, but extending we beyond the Atlantic margins of the PEP III Transect (Peterson et al. 2000).

The position of the Mediterranean Sea within the Transect endows its sedimentar record with special significance. One of the most striking features is the presence of saprope layers (Rossignol-Strick 1985), which are now believed to be linked to periods of increase freshwater discharge into the basin. The coherence of the link between marine evidenc for sapropel formation and the terrestrial evidence for moister conditions over much of th Mediterranean region during parts of the early to mid-Holocene is a striking example of th way in which marine and terrestrial archives can be mutually reinforcing. There is scope fc exploiting this linkage much more, especially in marine cores with high temporal resolutio where continental 'signatures' such as pollen, or markers of changing terrigenous sedime flux, can be set alongside evidence for changes in the marine realm (e.g., Oldfield et a (2003a)). In this regard, contexts with rapid sediment accumulation like the western flank of the Adriatic or the Nile delta may prove especially attractive.

Climate proxies

The dominant concern of the PEP Transects has been with the reconstruction of past *climat* As a consequence, the interpretation of most of the palaeo-environmental records has bee in predominantly climatic terms, sometimes at a rather descriptive, qualitative level, bı increasingly in more quantitative ways. This calls for at least two types of interaction b tween instrumental and non-instrumental data. Wherever proxy climate signatures, wheth documentary or environmental, are interpreted in quantitative terms, this requires calibr tion against instrumental records. This can be achieved by using a spatially distribute training set of observations that span a wide climatic range at the present day (Fig. 2), or b comparing the proxy with an instrumental time series during the period of overlap (Fig. 3

An elegant example of the use of time series of instrumental data in deciphering t climatic signal preserved by clastic varves is provided by the validation study of Wohlfar et al. (1998). Multiple regression analysis of the 90-year sequence, from 1860 to 1950, fro the Ångermanälven Estuary in North Central Sweden revealed strong correlations betwee spring/summer precipitation and varve thickness. The clearest climatic relationships we found between the precipitation in the mountains (the source region for the river discharg and the estuarine varves. Turning to another striking example, dates of the beginning of t grape harvest from wine regions in Central Europe correlate ($r = +0.85$) extremely we with one another (Ladurie and Baulant 1981) and with spring and summer temperatur (Fig. 3). The validation of the grape harvest dates against the thermometer records not on provides reassurance as to the reliability of phenological sources but also a quantitati measure of the dominant climatic variables that control ripening date. Tree-ring widths a

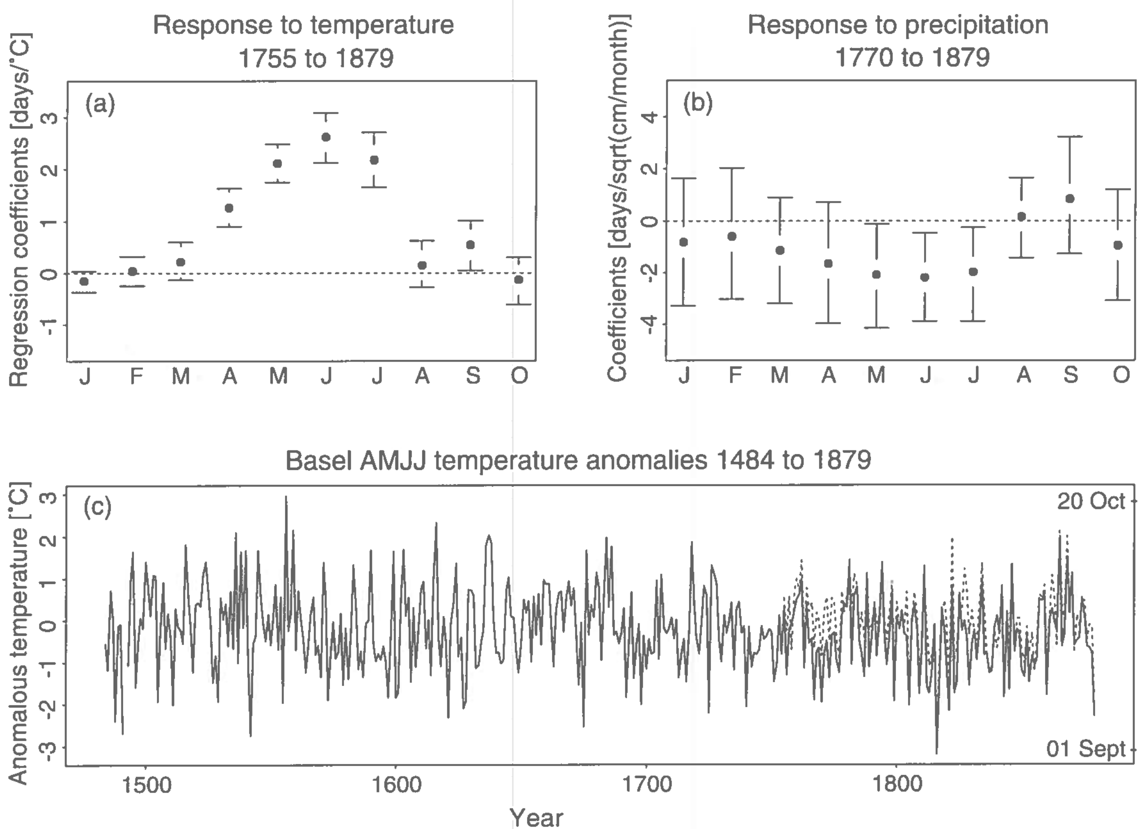

Figure 3. Reconstruction of Basle temperatures, from the fifteenth through nineteenth centuries, based on archival records of grape harvest dates. (a) Temperature anomalies of four months (April through July, AMJJ) are found to display significant relationships with grape harvest date. Warmer months lead to earlier grape harvests (positive correlations). (b) For three months (May through July, MJJ at Paris) wet years are found to result in later harvests (negative correlations). The 95% confidence interval limits

late-wood densities provide a third example of calibration of proxy records using the tim series approach. Tree-ring calibrations make a major contribution to most reconstructio of the climate of the past millennium (see e.g., Mann et al. (1999)). These reconstructio are currently of great concern as they demonstrate how the abrupt 20th-century warming h ended a 900-year natural cooling trend. They also strikingly highlight how the 1990s we the warmest decade of the millennium. Consequently they have been a major contribut to the influential 2001 IPCC report being able to reaffirm, in much stronger language th previously, that *'the present climate is changing in ways that cannot be accounted for l natural variability'* (Houghton et al. 2001).

In addition to the need for calibration, developing transcontinental or regional synthes of past climate change imposes the requirement to harmonise all the many data type both instrumental and non-instrumental, in terms of their climatic implications and spati representation. Only through the co-ordination, intercalibration and fusion of all availab sources of evidence will it be possible to express the nature of past climate change at range of spatial and temporal scales and thereby gain an improved understanding of t complex interactions between environmental change and human societies.

The need for quantitative calibration applies to proxy signatures as contrasted, wide used and 'archive-transgressive' as pollen and stable isotopes as well as to a range of mu less popular lines of evidence. Among the long list of proxy signatures used, two typ merit consideration that is more general.

In the first of these two types the varying frequency of biological remains such as poll (Guiot et al. 1989; Huntley 1993), diatoms (Bigler and Hall 2002) or chironomids (Broo et al. 1997), are used to derive statistical relationships between assemblage characteristi in contemporary training sets and climatic parameters. These kinds of statistically bas proxy signature have proved highly successful in generating palaeoclimate reconstru tions, provided that the range of variability in both the climate space and the biologic assemblages has remained reasonably comparable to that of the present day. Uncertain increases greatly once the record from the past indicates no-analogue situations or present unrepresented domains of variability (Huntley and Prentice 1993). By contrast, when usi the second type of approach to climate reconstruction, for example when using stab isotopes, the interpretation often rests more on an understanding of the processes a the physicochemical laws that control any link between atmospheric properties and t environmental archive.

Increasingly, multiproxy studies are the norm and the climatic inferences derived fro range of proxies can be compared (Birks 2000; Ammann 2000). The multiproxy approa can lend much greater confidence and statistical rigour to the palaeoclimatic inferenc derived from a single site or region. It can also open up a rich vein of future researc especially where the climate inferences derived from mutually independent proxies diff significantly. Such frustrating discrepancies are among the best points of departure f improving future understanding.

Chronologies and temporal resolution

Our best estimate suggests that less than 15% of the research presented at the PEP Aix-en-Provence Conference (August 2001) has the potential for annual resolution a the ascription of a calendar date with an error of less than three percent. An add few may be resolvable at a decadal level or thereabouts, with a similar accuracy ascription. It follows that the vast majority of the work has a time resolution at c level at best and, in many cases, a dating uncertainty equally is great. This unfo situation reflects the intractable nature of the problem of chronology for many of th popular archives, such as lake sediments, which, despite the chronological problen often pose, can provide proxy records of outstanding interest. Despite the existence o dating problems, it is abundantly clear that much of the evidence presented has enc significance for documenting climate variability on all timescales, for providing t material from which greater insight into the spatial coherence, persistence and re expression of major modes of variability can be derived, for developing regional syr of past climate change (notable examples of which are contained within this volum identifying the key mechanisms of external forcing and internal dynamics and for climate models against the ground truth of the past.

This said, future progress in all these respects will depend in part on better chrono A greater investment in dating is a prerequisite for improving insights into questi phasing and spatial coherence, for achieving better harmonisation of data sets b archives, proxies and regions and for the full realisation of many of the main initia of the PEP III Transect. The investment must include both a widening of access to facilities, especially for those working in less developed countries, and a continuing c with testing and refining the evidence upon which some standard procedures such as reservoir correction of ^{14}C dates are based.

Proxies, ecosystems and people

Using every available line of evidence to reconstruct past climate precludes ex the effects of climate change on ecosystems without resorting to unacceptably c argument. Nevertheless, a significant proportion of the work completed along the I Transect does deal explicitly with ecosystem responses, using lines of evidence as as pollen, phytoliths and ^{13}C ratios (Huang et al. 1999) indicative of shifts in the r importance of plants using different metabolic pathways.

At the stage where the most robust climate proxies have been tested and, in sc possible, validated, there is a case for using them as independent variables, thus al more of the biological records to be interpreted as indicators of ecosystem *res* to past climate change (Oldfield et al. 2000). It seems inevitable that incorporati type of approach in the future research agenda of the PEP III scientific communi become attractive, indeed essential, as policy makers become increasingly concerne understanding the likely response of ecosystems to future climate change. The re encompassed within the PEP III Transect can make a vital contribution to this impact studies without compromising its primary aim of palaeoclimate reconstruct

PEP III spans regions of the world more severely impacted by human activity than any others. Evidence for human activities and their effect on terrestrial ecosysten back thousands of years, especially in those areas close to the cradle of ancient civilis Alongside the reconstruction of climate change, there is the parallel need to do the history of human impacts. Several papers demonstrate how such impacts hav overprinted any decipherable signature of climate change (e.g., Oldfield et al. (20C

Others illustrate well the difficulty of either disentangling the two types of influence o shedding light on the many ways in which they have interacted in the past (see e.g., Oldfiel and Dearing (2003)). Our present biosphere is a no-analogue one created by the combine and interactive influences of human and natural processes. Any suggestion that we ma use the past to inform policy for the future has to recognise the crucial importance of bot natural and anthropogenic influences. Documenting the history of their interaction in al its richness and complexity is therefore an essential task. At the heart of PEP III has bee the need to isolate climate influences, by careful selection of sites and types of archive, a well as by the ingenious use and calibration of proxies. In the longer term, there will als be a parallel and interlocking need to address more explicitly the history of the relationshi between natural variability and human activities, not as a one-way street in which huma societies merely respond, but as an interactive process. The progress achieved so far withi the framework of PEP III encourages us to believe that this challenge too will be met. On of the next steps will be achieved through the European Science Foundation sponsore HOLIVAR initiative which seeks to coordinate and present the full range of evidence fo climate variability during the Holocene (www.esf.org/holivar).

Summary

The PEP III Transect is concerned with climate change through Western and Easter Europe, the Middle-East and Africa. The PEP programme aims to: understand how an why climate has varied in the past; assess how climate change and variability has affecte natural ecosystems and human society in the past; and provide a basis both for developin and testing climate models that are needed to forecast climate change in the future. Thi chapter outlines and illustrates the range of archives and proxies used in the PEP III Transec In view of the special importance of instrumental records, both for documenting rece climate variability and for calibrating proxies, these are dealt with at some length. Man of the special characteristics of the main archives and proxies are discussed, along wit the kinds of information they provide. The major themes of palaeoclimate reconstructio chronologies and temporal resolution, and past human impact and ecosystem change ar considered towards the end of the chapter.

Acknowledgments

We are especially grateful to Sandra Mather for her expert help in producing the Figures

References

Agustí-Panareda A. and Thompson R. 2002. Reconstructing air temperature at eleven remote alpin and arctic lakes in Europe from 1781 to 1997 AD. J. Paleolim. 28: 7–23.

Allen J.R.M., Watts W.A. and Huntley B. 2000. Weichselian palynostratigraphy, palaeovegetation an palaeoenvironment: the record from Lago Grande di Monticchio, Southern Italy. Qua. Intern 73/74: 91–110.

Allen J.R.M., Brandt U., Brauer A., Hubberten H.-W., Huntley B., Keller J., Kraml M., Mackense A., Mingram J., Negendank J.F.W., Nowaczyk N.R., Oberhänsli H., Watts W.A., Wulf S. an

Zolitschka B. 1999. Rapid environmental changes in Southern Europe during the last period. Nature 400: 740–743.

Ammann B. 2000. Biotic responses to rapid climatic changes around the Younger Dryas an oscillations on an altitudinal transect in the Swiss Alps. Palaeogeogr. Palaeoclim. Pal: 159: 191–201.

Aylon A., Vaks A., Gilmour M., Fremkin A., Kaufman A., Matthews A. and Bar-Matthews M Pleistocene paleoclimate evidences from speleothem record of a karstic cave located at th boundary — Maale-Efraim, Eastern Shomron, Israel. In: Past Climate Variability through and Africa: Abstracts. 56–57. PAGES-PEP III/ESF HOLIVAR International Conference, Provence, August 2001.

Barber K.E., Maddy D., Rose N., Stevenson A.C., Stoneman R. and Thompson R. 2000. Re proxy-climate signals over the last 2000 yr from two distant UK peat bogs: new evid regional palaeoclimate teleconnections. Quat. Sci. Rev. 19: 481–487.

Barber K.E., Chambers F. and Maddy D. 2003. Holocene palaeoclimates from peat strati macrofossil proxy climate records from three oceanic raised bogs in England and Irelan Sci. Rev. 22: 521–539.

Barber K.E. and Langdon P. 2001. Testing the palaeoclimatic signal from peat bogs — tempe precipitation forcing? In: Past Climate Variability through Europe and Africa: Abstracts PAGES-PEP III/ESF HOLIVAR International Conference, Aix-en-Provence, August 20

Barber K.E. and Charman D. 2003. Holocene palaeoclimate records from peatlands. In: Ma Battarbee R.W., Birks H.J.B. and Oldfield F. (eds), Global Change in the Holocene. Arn 210–226.

Bar-Matthews M., Almogi-Labin A. and Aylon A. 2001. The east Mediterranean speleothen vs. the Atlantic and the Indian ocean Monsoonal system. In: Past Climate Variability Europe and Africa: Abstracts. 58. PAGES-PEP III/ESF HOLIVAR International Con Aix-en-Provence, August 2001.

Bergner A.G.N., Trauth M.H. and Bookhagen B. 2001. The magnitude of precipitation/ eva changes in the Naivasha basin (Kenya) during the last 150 kyr. In: Past Climate Va through Europe and Africa: Abstracts. 163–164. PAGES-PEP III/ESF HOLIVAR Inter Conference, Aix-en-Provence, August 2001.

Bigler C. and Hall R.I. 2002. Diatoms as indicators of climatic and limnological change in Lapland: a 100-lake calibration set and its validation for palaeoecological reconstruc Paleolim. 27: 97–115.

Birks H.H. (ed.) 2000. Palaeoecosystem reconstructions at Kråkenes lake. J. Paleolim. Spec 23:1–114.

Böhm R., Auer I., Brunetti M., Maugeri M., Nanni T. and Schöner W. 2001. Regional tem variability in the European Alps: 1760–1998 from homogenized instrumental time serie Climat. 21: 1779–1801.

Bond G.C., Kromer B., Beer J., Muscheler R., Evans M., Showers W., Hoffmann S., Lotti-B Hajdas I. and Bonani G. 2001. Persistent solar influence on North Atlantic climate du Holocene. Science 294: 2130–2136.

Brázdil R., Kotyza O. and Dobrovoln P. 1999. History of Weather and Climate in the Czecl V. Period 1: 500–1599, Masaryk University, Brno.

Briffa K.R. 2000. Annual climate variability in the Holocene: interpreting the message from trees. Quat. Sci. Rev. 19: 87–105.

Briffa K.R., Jones P.D., Schweingruber F.H. and Osborne T.J. 1998. Influence of volcanic e on Northern Hemisphere summer temperature over the last 600 years. Nature 393: 450-

Briffa K.R. and Matthews J.A. (eds) 2002. Analysis of dendroclimatological variability and as natural climates in Eurasia (ADVANCE-10K). Special Issue of The Holocene 12: 639–

Briffa K.R., Osborn T.J., Schweingruber F.H., Harris I.C., Jones P.D., Shiyatov S.G. and Vaganov E.A. 2001. Low-frequency temperature variations from a northern tree ring density network. J. Geophys. Res. 106D: 2929.

Brooks S.J., Mayle F.E. and Lowe J.J. 1997. Chironomid-based Late-glacial climate reconstruction for Southeast Scotland. J. Quat. Sci. 12: 161–167.

Bugmann H. and Pfister C. 2000. Impacts of interannual climate variability on past and future forest composition. Reg. Env. Change 1: 112–125.

Camuffo D. and Jones P.D. (eds) 2002. Improved Understanding of Past Climatic Variability from Early Daily European Instrumental Sources. Kluwer Academic Publishers, Dordrecht, 400 pp.

Causse C., Bakalowitz M., Chkir N., Genty D., Karray R., Mellieres M.A., Plagnes V. and Zouari K. 2001. First data on Tunisian speleothems. In: Past Climate Variability through Europe and Africa: Abstracts. 68. PAGES-PEP III/ESF HOLIVAR International Conference, Aix-en-Provence, August, 2001.

Charman D. and Hendon D. 2001. Calibrating peat-based palaeoclimate reconstructions with instrumental climate data. In: Past Climate Variability through Europe and Africa: Abstracts. 69–70. PAGES-PEP III/ESF HOLIVAR International Conference, Aix-en-Provence, August 2001.

Cole J. 2001. Environmental variability in East African coral records: links to human activity and the global tropics. In: Past Climate Variability through Europe and Africa: Abstracts. 26. PAGES-PEP III/ESF HOLIVAR International Conference, Aix-en-Provence, August 2001.

Cortijo E., Labeyrie L., Elliot M., Balbon E. and Tisnerat N. 2000. Rapid climatic variability of the North Atlantic Ocean and global climate: a focus of the IMAGES program. Quat. Sci. Rev. 19: 227–241.

Creer K.M., Thouveny N. and Blunk I. 1990. Climatic and geomagnetic influences on the Lac du Bouchet palaeomagnetic SV record through the last 110 000 years. Phys. Earth Planet. Int. 64: 314–341.

Crook D.S., Siddle D. J., Jones R.T., Dearing J.A., Foster G.C. and Thompson R. 2002. Forestry and flooding in the Annecy Petit Lac Basin, 1730–2000. Environment and History 8: 403–428.

Cullen H.M., deMenocal P.B., Hemming S., Hemming G., Brown F.H., Guilderson T. and Sirocko F. 2000. Climate change and the collapse of the Akkadian Empire: Evidence from the deep-sea. Geology 28: 379–382.

D'Arrigo R., Nuzhet Dalfes H., Cullen H., Jacoby G. and Onol B. 2001. Tree-ring records from Eastern Turkey. In: Past Climate Variability through Europe and Africa: Abstracts. 73. PAGES-PEP III/ESF HOLIVAR International Conference, Aix-en-Provence, August 2001.

Doherty R., Kutzbach J., Foley J. and Pollard D. 2000. Fully coupled climate/dynamical vegetation model simulations over Northern Africa during the mid-Holocene. Clim. Dynam. 16: 561–573.

Edmunds W.M. 1999. Groundwater: a renewable resource? Focus in Sahara and Sahel. Brochure for the GASPAL (Groundwater as Palaeoindicator) project (EC ENRICH, ENV4-CT97-0591).

Edmunds W.M., Fellamn E. and Baba Goni I. 1999. Environmental change, lakes and groundwater in the Sahel of Northen Nigeria. J. Geol. Soc. Lond. 156: 345–355.

Felis T., Patzold J., Al-Moghrabi S.M., Loya Y. and Wefer G. 2001. Northern Red sea corals: Seasonal archive of Middle east climate variability during the Holocene and the last Interglacial. In: Past Climate Variability through Europe and Africa: Abstracts. 80. PAGES-PEP III/ESF HOLIVAR International Conference, Aix-en-Provence, August 2001.

Fleitmann D., Burns S.J., Mudelsee M., Neff U. and Mangini A. 2001. Early- to Late-Holocene Indian Ocean Monsoon variability recorded in stalagmites from Southern Oman. In: Past Climate Variability through Europe and Africa: Abstracts. 82. PAGES-PEP III/ESF HOLIVAR International Conference, Aix-en-Provence, August 2001.

Fleitmann D., Burns S.J., Mudelsee M., Neff U., Kramers J., Mangini A. and Matter A. 2002. Holocene variability in the Indian Ocean Monsoon: A Stalagmite-based high-resolution oxygen isotope record from Southern Oman. PAGES Newsletter 10: 7–8.

Fontes J.C., Gasse F. and Andrews J.N. 1993. Climatic conditions of Holocene groundwater r in the Sahel zone of Africa. In: Isotope Techniques in the Study of Past and Current Enviro Changes in the Hydrosphere and the Atmosphere. International Atomic Agency, Vienna.

Foster G.C., Dearing J.A., Jones R.T., Crook D.S., Siddle D.S., Appleby P.G., Thompson R., Ni J. and Loizeaux J.-L. 2003. Meteorological and land use controls on geomorphic anc processes in the pre-Alpine environment: an integrated lake-catchment study at the P d'Annecy. Hydrological Processes (In press).

Frenzel B., Pfister C. and Gläser B. (Hrsg.) 1992. European climate reconstructed from docu data: methods and results. 2nd EPC/ESF Workshop, Mainz, 01.-03.03.1990. Stuttgart: Fischer.

Ganopolski A., Kubatzki C., Claussen M., Brovkin V. and Pethoukhov V. 1998. The i of vegetation-atmosphere-ocean interaction on climate during the mid-Holocene. Scier 1916–1919.

Gasse F. and Battarbee R.W., this volume. Introduction. In: Battarbee R.W., Gasse F., and C.E. (eds), Past Climate Variability through Europe and Africa. Kluwer Academic Pul Dordrecht, the Netherlands, pp. 1–6.

Gasse F., Fontes J.C., Plaziat J.C., Carbonel P., Kaczmarska I., De Deckker P., Soulie-Ma Callot Y. and Dupeuple P.A. 1987. Biological remains, geochemistry and stable isotope reconstruction of environmental and hydrological changes in the Holocene lakes fror Sahara. Palaeogeogr. Paleoclim. Paleoecol. 60: 1–46.

Gasse F. and Van Campo E. 1994. Abrupt post-glacial climate events in the West Asia an African monsoon domains. Earth Planet. Sci. Lett. 126: 435–456.

Glaser R. and Hagedorn H. 1991. The climate of lower Franconia since 1500. Theor. Appl. C 43: 101–104.

Goni I.B. and Edmunds W.M. 2001. Evidence of climate change in the S W Chad basin f geochemistry of unsaturated zone moisture and groundwater. In: Past Climate Variability Europe and Africa: Abstracts. 89. PAGES-PEP III/ESF HOLIVAR International Con Aix-en-Provence, August 2001.

Guiot L., Pons A., de Beaulieu J.-L. and Reille M. 1989. A 140,000 years continental reconstruction from two European pollen records. Nature 338: 309–313.

Hedenstrom A. and Risberg J. 1999. Early Holocene shore displacement in Southern Central as recorded in elevated isolated basins. Boreas 28: 490–504.

Hoelzle M. and Haeberli W. 1995. Simulating the effects of mean annual air temperature on permafrost distribution and glacier size. An example from the Upper Engadin, Swi Annals of Glaciology 21: 399–405.

Holmgren K., Karlén W., Lauritzen S.E., Lee-Thorp J.A., Partridge T.C., Piketh S., Rep Stevenson C., Svanered O. and Tyson P.D. 1999. A 3000-year high resolution stalagmi record of paleoclimate for Northeastern South Africa. The Holocene 9: 295–309.

Houghton J.T., Ding Y., Griggs D.J., Noguer M., van der Linden P.J. and Xiaosu D. (ed Climate Change: The Scientific Basis. Contribution of Working Group I to the Third Ass Report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge Universi UK.

Huang Y., Freeman K.H., Eglinton T.I. and Street-Perrott F.A. 1999. δ^{13}C analysis of individu phenols in Quaternary lake sediments: a novel proxy for deciphering past terrestrial ve changes. Geology 27: 471–474.

Huntley B. 1993. The use of climate response surfaces to reconstruct palaeoclimate from Qu pollen and plant macrofossil data. Phil. Trans. Roy. Soc. B. 341: 215–223.

Huntley B. and Prentice I.C. 1993. Holocene vegetation and climates of Europe. In: Wright Kutzbach J.E., Webb J. T. III, Ruddiman W.R., Street-Perrott F.A. and Bartlein P.J. (eds) Climate since the Last Glacial Maximum. University of Minnesota Press, Minneapolis, Johnson T.C. 1996. Sedimentary processes and signals of climate change in the large lakes of the East African Rift Valley. In: Johnson T.C. and Odada E.O. (eds), The Limnology, Climatology and Paleoclimatology of the East African Lakes. Gordon and Breach, Amsterdam, pp. 367–412

Jones R.T., Marshall J.D., Crowley S.F., Bedford A., Richardson N., Bloemendal J. and Oldfield F. 2002. A high resolution multi-proxy Late-glacial record of climate change and intrasystem responses in NW England. J. Quat. Sci. 17: 329–340.

Klein R., Loya Y., Svistzman G., Isdale P.J. and Susic M. 1990. Seasonal rainfall in the Sinai Desert during the late Quaternary inferred from fluorescent bands in fossil corals. Nature 345: 145–147

Kroepelin S., Hoelzmann P. and Keding B. 2001. Lake evolution and human occupation in the Eastern Sahara during the Holocene. In: Past Climate Variability through Europe and Africa: Abstracts 106. PAGES-PEP III/ESF HOLIVAR International Conference, Aix-en-Provence, August 2001

Ladurie E. Le Roy and Baulant M. 1981. Grape harvest from the fifteenth through the nineteenth century. In: Rotberg R.I. and Rabb T.K. (eds), Climate and History: Studies in Interdisciplinary History. Princeton University Press, New Jersey, pp. 259–269.

Lauritzen S.-E. 1996. Calibration of speleothem stable isotopes against historical records: a Holocene temperature curve for North Norway? In: Climatic Change: the Karst Record. Karst Water Institute Special Publication 2, Charles Town, West Virginia, pp. 78–80.

Lauritzen S.-E. 2001. SPEP: a speleothem transect: contribution from the North Atlantic. In: Past Climate Variability through Europe and Africa: Abstracts. 45. PAGES-PEP III/ESF HOLIVAR International Conference, Aix-en-Provence, August 2001.

Lauritzen S.-E. 2003. Reconstructing Holocene climate records from spelothems. In: Mackay A. Battarbee R.W., Birks H.J.B. and Oldfield F. (eds), Global Change in the Holocene, Arnolds, pp 227–241.

Lauritzen S.-E. and Lundberg J. (eds) 1999. Speleothems as high-resolution palaeo-climatic archives Special Issue of The Holocene 9: 643–722.

Lee-Thorp J.A., Holmgren K., Lauritzen S.-E., Linge H., Moberg A., Partridge T.C., Stevenson C and Tyson P.D. 2001. Rapid climate shifts in the southern African interior throughout the mid t late Holocene. Geophys. Res. Lett. 28: 4507–4510.

Lindholm M. and Eronen M. 2000. A reconstruction of mid-summer temperatures from ring-width of Scots pine since AD 50 in Northern Fennoscandia. Geograf. Annal. 82: 527–535.

Lotter A.F., Birks H.J.B., Hofman W. and Marchetto A. 1997. Modern diatom, cladocera, chirono mid, and chrysophyte cyst assemblages as quantitative indicators for the reconstruction of pas environmental conditions in the Alps. I. Climate. J. Paleolim. 18: 395–420.

Lotter A.F. 2003. Multi-proxy climatic reconstructions. In: Mackay A., Battarbee R.W., Birks H.J.B and Oldfield F. (eds), Global Change in the Holocene. Arnolds, pp. 373–383.

Luterbacher J., Schmutz C., Gyalistras D., Xoplaki E. and Wanner H. 1999. Reconstruction of monthl NAO and EU indices back to AD 1675. Geophys. Res. Lett. 26: 2745–2748.

Markgraf V. and Diaz H.F. 2001. The past ENSO record: A synthesis. In: Diaz H.F. and Markgraf V (eds), El Niño and the Southern Oscillation: Multiscale Variability and Global Impacts. Cambridg University Press, Cambridge, pp. 465–488.

Manley G. 1974. Central England temperatures: monthly means 1659 to 1973. Quart. J. R. Met. So 100: 389–405.

Mann M.E., Bradley R.S. and Hughes M.K. 1999. Northern Hemisphere temperatures during th past millennium: Inferences, uncertainties, and limitations. Geophys. Res. Lett. 26: 759–762.

Mauquoy D., van Geel B., Blaauw M. and van der Plicht 2002. Evidence from northwest Europea bogs show 'Little Ice Age' climatic changes driven by variations in solar activity. The Holocen 12: 1–6.

Nicholson S.E. 2001. Climatic and environmental change in Africa during the last two centurie Climate Research 17: 123–144.

Nicholson S.E. and Grist J.P. 2001. A Conceptual model for understanding rainfall variabilit West African Sahel on interannual and interdecadal timescales. Int. J. Climat. 21: 1733–

Oldfield F., Asioli A., Accorsi C.A., Juggins S., Langone L., Rolph T., Trincardi F., Wolff G Z., Vigliotti L., Frignani M. and Branch N. 2003a. A high resolution Late-Holocene environmental record from the Central Adriatic Sea. Quat. Sci. Rev. 22: 319–342.

Oldfield F. and Dearing J.A. 2003. The role of human activities. In: Alverson K., Bradl and Pedersen T.F. (eds), Palaeoclimate, Global Change and the Future. Springer Verlag, pp. 143–162.

Oldfield F., Dearing J.A., Gaillard M.-J. and Bugmann H. 2000. Ecosystem processes and dimensions — The scope and future of HITE (Human Impacts on Terrestrial Ecosystems). Newsletter 8: 21–23.

Oldfield F., Wake R., Boyle J.F., Jones R., Nolan S., Gibbs Z., Appleby P.G., Fisher E. an G. 2003b. The Late-Holocene history of Gormire Lake (N.E. England) and its catch multi-proxy reconstruction of past human impact. The Holocene, in press.

Partridge T.C., de Menocal P.B., Lorentz S.A., Paikar M.J. and Vogel J.C. 1997. Orbital foı climate over South Africa: a 200 000-year rainfall record from the Pretoria saltpan. Qı Rev. 16: 1–9.

Pelfini M., Cremaschi M., Arzuffi L., Di Mauro V., Santilli M. and Zerboni A. 2001. Tree- *Cupressus dupretiana* from the Wadi Tanezzuft area (NW Fezzan, Libyan Sahara). A sc palaeoclimatic information for the middle and late Holocene of the Central Sahara. In: F mate Variability through Europe and Africa: Abstracts. 127–128. PAGES-PEP III/ESF HO International Conference, Aix-en-Provence, August 2001.

Peterson L.C., Haug G.H., Hughen K.A. and Röhl U. 2000. Rapid changes in the hydrolog of the tropical Atlantic during the last Glacial. Science 290: 1947–1951.

Pfister C. 1992. Monthly temperature and precipitation in Central Europe 1525–1979: quaı documentary evidence on weather and its effects. In: Bradley R.S. and Jones P.D. (eds), since AD 1500. Routledge, London, pp. 118–142.

Phillips J.G. and McIntyre B. 2000. ENSO and interannual rainfall variability in Uganda: Impl for agricultural management. Int. J. Climat. 20: 171–182.

Ramrath A., Sadori L. and Negendank J.F.W. 2000. Sediments from Lago di Mezzano, Centr a record of Late glacial/Holocene climatic variations and anthropogenic impact. The H 10: 87–95.

Richard Y., Fauchereau N., Poccard I., Rouault M. and Trzaska S. 2001. 20th century droı Southern Africa: Spatial and temporal variability, teleconnections with oceanic and atmo conditions. Int. J. Climat. 21: 873–885.

Richard Y., Trzaska S., Roucou P. and Rouault M. 2000. Modification of the Southern African variability /El Niño Southern Oscillation relationship. Clim. Dyn. 16: 886–895.

Roberts N., Reid J., Leng M.J., Kouzugouglu C., Fontugne M., Bertaux J., Woldring H., E S., Black S., Hunt E. and Karabiyikolu M. 2001. The tempo of Holocene climatic chang eastern Mediterranean region: new high resolution crater lake sediment data from Central The Holocene 11: 721–736.

Rocha A. and Simmonds I. 1997. Interannual variability of south-eastern African summer rainf I: Relationships with air-sea interaction processes. Part II: Modelling the impact of sea- temperatures on rainfall and circulation. Int. J. Climat. 17: 235–290.

Rosendahl W., Weigand B. and Kempe S. 2001. Speleothems and Pleistocene climate — nev results from caves in Germany and their correlation with GRIP ice core record. In: Past Variability through Europe and Africa: Abstracts. 133–134. PAGES-PEP III/ESF HO International Conference, Aix-en-Provence, August 2001.

Rossignol-Strick M. 1985. Mediterranean Quaternary sapropels, an immediate response of the Monsoon to variation of insolation. Palaeogeogr. Palaeoclim. Palaeoecol. 49: 237–263.

Schweingruber F.H. and Briffa K.R. 1996. Tree-ring density networks for climate reconstruction. In Jones P.D., Bradley R.S. and Jouzel J. (eds), Climate Variations and Forcing Mechanisms of th last 2000 Years. Springer, Berlin, pp. 43–66.

Schönwiese C.-D. and Rapp J. (eds) 1997. Climate Trend Atlas of Europe: Based on Observation 1891–1990. Kluwer, Academic, 224 pp.

Sorvari S., Korhola A. and Thompson R. 2002. Lake diatom response to recent Arctic warming i Finnish Lapland. Global Change Biology 8: 153–163.

Stute M. and Talma S. 1998. Glacial temperatures and moisture transport regimes reconstructed fron noble gas and δ^{14}O, Stampriert aquifer, Namibia. In: Isotope Techniques in the Study of Pas and Current Environmental Changes in the Hydrosphere and the Atmosphere. Proceedings of th Vienna Symposium 1997. IAEA, Vienna, SM-349-53, pp. 307–328.

Thompson L.G. 2001. Tropical ice core records from the ice fields of Kilimanjaro, ice retreat an asynchronous glaciation. In: Past Climate Variability through Europe and Africa: Abstracts. 24 PAGES-PEP III/ESF HOLIVAR International Conference, Aix-en-Provence, August 2001.

Thompson R. 1995. Complex demodulation and the estimation of the changing continentality o Europe's climate. Int. J. Climatol. 15–2: 175–185.

Thompson R. 1999. A time-series analysis of the changing seasonality of precipitation in the Britis Isles and neighbouring areas. J. Hydrology 224: 169–183.

Thorndycraft V., Hu Y., Oldfield F., Crooks P.R.J. and Appleby P.G. 1998. Individual flood event detected in the recent sediments of the Petit Lac d'Annecy, Eastern France. The Holocene 8 741–746.

Trouet V., Haneca K., Coppin P. and Beeckman H. 2001. The value of growth ring series from trees c the miombo woodland in Southern and Eastern Africa as proxy data for climate reconstructio In: Past Climate Variability through Europe and Africa: Abstracts. 154. PAGES-PEP III/ES HOLIVAR International Conference, Aix-en-Provence, August 2001.

Ulbrich U. and Christoph M. 1999. A shift of the NAO and increasing storm track activity over Europ due to anthropogenic greenhouse gas forcing. Clim. Dyn. 15: 551–559.

Unganai L.S. 1997. Surface temperature variation over Zimbabwe between 1897 and 1993. Theo and Appl. Climatol. 56: 89–101.

van Geel B. and Mook W.G. 1989. High resolution ^{14}C dating of organic deposits using natural ^{14} variations. Radiocarbon 31: 151–155.

Verschuren D., Laird K. and Cumming B.F. 2000. Drought in East Africa during the past 1,100 year Nature 403: 410–413.

von Grafenstein U., Erlenkeuser H., Brauer A., Jouzel J. and Johnsen S.J. 1999. A Mid-Europea decadal isotope-climate record from 15,500 to 5000 years BP. Science 284: 1654–1657.

Vose R.S., Schmoyer R.L., Steurer R.L., Peterson T.C., Heim R., Karl T.R. and Eischeid J.K. 199 The Global Historical Climatology Network: Long-term monthly temperature, precipitation, se level pressure, and station pressure data. NDP-041. Carbon Dioxide Information Analysis Cente Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Wohlfarth B., Holmquist B., Cata I. and Linderson H. 1998. The climatic significance of clastic varv in the Ångermanälven Estuary, Northern Sweden, AD 1860 to 1950. The Holocene 8: 521–53

Zinke J., Pfeiffer M., Heiss G., Dullo W.-Chr., Joachimski M. and Eisenhauer A. 2001. A 338 ye coral oxygen isotope record off Madagascar: Interannual and interdecadal sea-surface temperatu variability. In: Past Climate Variability through Europe and Africa: Abstracts. 163–164. PAGE PEP III/ESF HOLIVAR International Conference, Aix-en-Provence, August 2001.

Zolitschka B. 1998. A 14000 year sediment yield record from Western Germany based on annual laminated sediments. Geomorphology 22: 1–17.