Whether the medieval time was indeed a "warm period", merely a "climate anomaly", or something different altogether may be a matter of location, scale, resolution, and method. This newsletter provides perspectives from different angles on this fascinating climatic period. In 1965, Hubert Lamb had published a pioneering temperature reconstruction for Europe from historical documents. His curve is underlying this cover picture. It would suggest that the medieval scene painted by Jörg Breu the Elder with green pasture land and people enjoying good weather, was common in the Middle Ages. The research done since then, however, has provided us with a more detailed and nuanced picture.
New PAGES website
PAGES has launched a new version of the website in keeping with the latest trends in website design. During this transition period some web pages and databases may be temporarily unavailable or outdated. We apologize for any inconvenience caused. The new website provides a “My PAGES” section, which is designed to serve as a “one-stop shop” to access PAGES offerings and get involved in PAGES activities.

Staff update
The PAGES Office has seen a lot of staff movement lately due to back-to-back good news; Louise gave birth to a son and Michelle is expecting a child in the coming days! Lucien von Gunten replaces Louise Newman as PAGES Science Officer for the duration of her maternity leave until May 2011. Lucien, a paleoclimatologist working on South American lake sediments, is taking care of the 2k Working Groups and newsletter editing. Christoph Kull, a glaciologist and former PAGES Science Officer, has been roped in to bolster production of newsletters. For the time of her maternity leave, Michelle Kaufmann, the PAGES Finance and Officer Manager, has been replaced by Therese Jost. We congratulate Louise on the birth of her son and welcome Lucien, Christoph and Therese to the PAGES office. We also look forward to welcoming another PAGES baby soon!

PAGES OSM/YSM 2013: an update
In 2010, PAGES invited applications from groups interested in hosting the 4th PAGES Open Science Meeting (OSM) and 2 Young Scientists Meeting (YSM) in 2013. We received 10 exciting bids from 5 different continents and are delighted with this exuberant interest in hosting the events. Bids from Australia, India and Germany have been shortlisted and await a final decision after additional scrutiny.

New PAGES committee members
Heinz Wanner, former Scientific Steering Committee (SSC) co-chair, rotated off the committee after six years of dedicated service but shall continue his association with PAGES as coordinator of the Regional 2k Network.

Two new members have joined the PAGES SSC in 2011:

Hubertus Fischer, Professor of Experimental Climate Physics at the University of Bern, Switzerland is the new SSC Swiss co-chair alongside the US co-chair Bette Otto-Bleesner. Hubertus is an ice core scientist with broad interests in Quaternary changes in climate and biogeochemical cycles. He is active in the PAGES Working Groups Antarctica2k and ADOM.

Claudio Latorre is an Associate Professor in the Department of Ecology at the Pontifical Catholic University of Chile in Santiago. His research interests include paleoecology and palaeoclimatology of arid regions. For over a decade, he has been using rodent middens from the Atacama Desert to learn about the desert’s hydrological cycle over the last 40-50 ka. Claudio Latorre also specializes in plant macrofossil analyses and the applications of stable isotopes in these environments. His appointment to the SSC will strengthen and stimulate PAGES Focus 4.

Nominations for the PAGES SSC
PAGES invites nominations for new SSC members for 2012. Bette Otto-Bleesner (USA), Cathy Whitlock (USA) and Mohammed Umer (Ethiopia) will be rotating off the SSC at the end of 2011. The SSC provides overall guidance for PAGES and oversees major scientific activities. Members are chosen on the basis of their scientific excellence and their potential to promote PAGES science and activities. PAGES particularly encourages the nomination of women and scientists from underrepresented regions. The nomination deadline is 30 June 2011. A list of current SSC members and nomination details can be found on the PAGES website (My PAGES>Get involved).

PAGES support for meetings
PAGES Executive Committee (EXCOM) discussed the workshop proposals submitted to the second call in 2010. A total of 13 meetings were awarded financial support. PAGES Working Groups that were allocated workshop support include PALSEA (Sea-Level), LUCIFS (Fluvial Systems), NiCOPP (Marine Nitrogen Cycle), Varves, PAGES-CLIVAR Intersection, and the Australasian, Antarctic and North American groups of the Regional 2k Network, as well as a workshop for the entire 2k Network.

In addition, three proposals for general workshops relevant to PAGES science were approved. These include an interdisciplinary workshop on constraining estimates of future climate variability from geological records, a workshop on Greenland Ice Sheet reconstruction, and a regional paleoscience workshop focused on the Balkan and Carpathian region and community. An educational workshop on marine diatoms was also supported.

More information on funded workshops is available on the PAGES website (Meetings> Temperate Groups supported). The next deadline for proposals is 15 June 2011 for evaluation by EXCOM in late July (online proposal submission under My PAGES).

Planet Under Pressure Conference 2012
An open international Planet Under Pressure conference will be held on 26-29 March 2012 in London. It will be led by the PAGES parent organization, the International Geosphere-Biosphere Programme (IGBP), and involve its sister programs of the Earth System Science Partnership (ESSP). The conference is a unique opportunity to bring together global-change scientists with decision-makers in policy, development, resource management, industry and other non-government organizations. It aims to provide scientific leadership towards the 2012 UN Conference on Sustainable Development - Rio+20. (www.planetunderpressure2012.net)

New PAGES publications
A special issue on the timing and geographic extent of extreme arid and humid events during the Holocene, captured in lake sediment records from hydrologically sensitive regions was published recently (Quaternary International, 229: 1-148). The special issue is comprised of 18 selected papers from the 3rd PAGES LiMPACS (Human Impacts on Lake Ecosystems) Conference held in Chandigarh, India in March 2009.

Additionally, the PAGES special issue “Retrospective views on our planet’s
The Diatoms: Applications for the Environmental and Earth Sciences, 2nd Edition

Editors: John P. Smol and Eugene F. Stoermer

686 pages, 175 illustrations, 16 tables

Summary of contents:
Part I: Introduction
Part II: Diatoms as indicators of environmental change in flowing waters and lakes
Part III: Diatoms as indicators in Arctic, Antarctic and alpine lacustrine environments
Part IV: Diatoms as indicators in marine and estuarine environments
Part V: Other applications
Part VI: Conclusions

Ordering information: http://post.queensu.ca/~pearl/textbook2.htm
Research on the climate of the Middle Ages began in the 1960s. Motivated by historical accounts Hubert H. Lamb documented the increase in relative frequency of warm episodes, primarily around the North Atlantic and increased cool season precipitation across Britain during medieval times (Lamb, 1965). Lamb wrote first of a “Medieval Warm Epoch” and later of a “Medieval Warm Period” ending at approximately AD 1300. Lamb recognized that the available evidence implied that due to a “… shift in the upper westerlies, the depression tracks should have had an average position north of the modern normal (AD 1900–1939) position — a displacement that probably implies less sea ice …” (Lamb, 1965; 1969). He thus emphasized the relationship between changes in circulation and surface climate, and the idea of modest but persistent shifts in winter circulation over the North Atlantic and Europe during medieval times (see also Graham et al., 2010). Later, LaMarche (1974) used multi-elevation tree-ring and other data to infer late Holocene climate changes in the White Mountains of California. His analyses indicated that conditions were predominantly warmer and drier from AD 1000–1300, and cooler and wetter from AD 1400–1800. He showed that such changes could be explained by a northward-to-southward shift of the storm track over the region. LaMarche pointed out that the transition from the Medieval Warm Period to the subsequent Little Ice Age (LIA) over the western US was synchronous with the one inferred by Lamb (1965) for the North Atlantic and Western Europe, possibly indicating a shift in global circulation patterns, as already surmised by Lamb (1969; see also Graham et al., 2010).

Interestingly, within this period various important cultural events took place. From AD 800-1000 Iron Age Scandinavians colonized the North Atlantic islands and eastern North America. Iceland was settled around AD 874, Greenland ca. AD 985, and the short lived Vinland colony survived a few years around AD 1000 in Newfoundland (Arneborg, 2000; Wallace, 2000). By their arrival to Iceland, Scandinavian settlers encountered a mid-Atlantic island with favorable climatic and environmental conditions similar to those prevailing in Scandinavia (McGovern et al., 2007). In North America, the Vinland colony of the Vikings was abandoned by the mid–eleventh century. At that time drift ice had already started its appearance along the vital trade routes to Greenland (Lamb, 1995), increasing the threat of ice for seafarers. Climate change and human environmental effects on the island ecosystems played an important role in the unhappy ending to the “Norse Atlantic Saga” (Amorosi et al., 1997; Dugmore et al., 2004; Ogilvie and McGovern, 2000) combined with changes in politics and market forces in Europe (Ladurie, 1983; Jones, 1986).

A large number of studies on the temporal and regional expression of the Medieval Warm Period for different parts of the world have followed since the pioneering works of Lamb and LaMarche. A comprehensive review of those studies can be found in Hughes and Diaz (1994), Graham et al. (2010) and Diaz et al. (2011). The time frame is nowadays more commonly referred to as the Medieval Climate Anomaly (MCA). This term was coined originally by Stine (1994), who sought an explanation for the results of a wide-ranging geomorphic investigation of century-long low stands of lakes in the sub-tropical latitudes of western North and South America. The subsequent adoption of this term reflects the availability of much more information on the climate during medieval times since Lamb’s pioneering studies. Since then, new proxy paleoclimate records, temporally and spatially highly resolved reconstructions, and detailed modeling studies allow for a more accurate and detailed study of the climate since the MCA (Mann et al., 2009; Cook et al., 2010; Graham et al., 2010; Diaz et al., 2011 and references therein).

Bradley et al. (2003) questioned the statement “Climate in Medieval time is often said to have been as warm as, or warmer than, it is today. Still, many aspects of the climate during the MCA require careful examination and further investigations. Among areas of ongoing research are the onset and termination as well as the positioning of the MCA in the Holocene climatic context, the climate characteristics of the period, the nature of the transition to the subsequent LIA, the spatial extent and local expression as well as the impacts on societies, associated forcing factors, and most prominently its magnitude compared to the instrumental temperature records and the magnitude and pace of the twentieth century warming. These aspects are the focus of this PAGES Newsletter. The special section compiles latest information on climate and impacts during the MCA on global and regional scales. Historical documents, proxy records and climate models provide new insights into the temporal and spatial climatic pattern and related dynamics and forcings during medieval times.

References

The Sun is a variable star and the most important source of energy for the Earth. This raises the question whether the Sun affects the Earth’s climate. Several solar activity records show that the Sun has short- and long-term variability. An example is the well-known sunspot record (inset curve in Figure 1a), which reaches back to the year 1610 AD, when people started to use the telescope for astrophysical purposes such as observing the Sun. From the sunspot record it is known that solar activity was lower during the 17th and 18th century than today. In particular, the period from 1645 to 1715 AD named the Maunder Minimum (Eddy, 1976) is characterized by a nearly complete absence of sunspots. The sunspot record “only” goes back to 1610 AD and before this time other proxies of solar activity must be used. Presently the only proxies capable of extending the record of solar activity beyond 1610 AD are cosmogenic radionuclides, such as $^{14}$C and $^{10}$Be. The term “cosmogenic” points to the origin of the radionuclides — cosmogenic radionuclides are produced by nuclear reactions between cosmic ray particles and the gases of the Earth’s atmosphere. Thus, cosmogenic radionuclides record the intensity of the cosmic ray intensity at Earth.

**Link to the Sun**

Why do cosmogenic radionuclides record the solar activity? The link between $^{10}$Be and solar activity is illustrated in Figure 2. Cosmic ray particles are accelerated to high energies in the vicinity of supernova explosions in our galaxy. To reach the Earth they have to propagate through the heliosphere, which is formed by the solar wind carrying the solar magnetic field. Cosmic ray particles are charged and therefore get deflected by the solar magnetic field. The larger the strength of the solar magnetic field, the stronger is the deflection of cosmic ray particles and the lower the cosmic ray intensity at Earth. The solar magnetic field is directly related to solar activity, i.e., when solar activity is weak the strength of the solar magnetic field is weak. To summarize, the radionuclide production rate is high during a grand solar minimum like the Maunder Minimum and low during periods of high solar activity. Thus the radionuclide signal principally allows reconstructing solar activity.

In addition to the solar magnetic field, the geomagnetic field also modulates the cosmic ray intensity. From archaeointensity data it is known that the geomagnetic field has varied in time (e.g., Knudsen et al., 2008) and therefore a part of the variation found in cosmogenic radionuclides is of geomagnetic origin. Hence, variations of the geomagnetic field must first be removed from the radionuclide record before solar activity can be calculated. The physics-based dependencies between radionuclide production, solar activity and geomagnetic field strength have been determined using the Monte Carlo technique (Marsik and Beer, 2009). These calculations provide the dependence of the radionuclide production on solar activity and geomagnetic field strength. Based on this dependence and the known paleo-geomagnetic field, the solar activity can be derived from the radionuclide signal. After their production in the Earth’s atmosphere, the radionuclides are transported and distributed within the environment and partly stored in natural archives. The best-suited archives are tree rings ($^{14}$C) and polar ice ($^{10}$Be) and both have recorded the solar activity signal with high temporal resolution over many millennia. Tree rings and polar ice can both be dated very accurately, which is a prerequisite for high temporal resolution reconstructions. Some existing records have annual resolution for the past ca. 600 years (Berggren et al., 2009), and resolutions of a few years to decades for the Holocene (e.g., Muscheler et al., 2007; Usoskin et al., 2007; Steinhilber et al., 2008). Note that cosmogenic radionuclides are also found in other archives (e.g., alpine glaciers, lake sediments, ocean sediments) but generally the chronologies are less accurate.
The radionuclide signal not only reflects the cosmic ray variation due to solar and geomagnetic activity, it is also influenced by “system effects”. System effects are variations induced by the transport from the atmosphere where the radionuclides are produced to the ground where they are archived. In addition to the system effects, the cosmic ray signal has uncertainty due to uncertainty in the timescale and in the radionuclide measurements.

**Solar activity during the past 1200 years**

Recently, total solar irradiance (TSI) has been reconstructed from a composite of several $^{10}$Be records measured in polar ice for the past 9300 years (Steinhilber et al., 2008, 2009). The composite is mainly based on the $^{10}$Be record from the GRIP ice core, Greenland. As system effects mostly influence the signal on short time-scales, 40-year averages have been built from the $^{10}$Be records.

A part of the Holocene TSI reconstruction is shown for the past 1200 years in Figure 1a. Five distinct grand solar minima can be identified known as the Oort (1040-1080 AD), Wolf (1280-1350 AD), Spörer (1460-1550 AD), Maunder (1645-1715 AD), and Dalton (1790-1820 AD) Minima. The last four grand solar minima: Wolf, Spörer, Maunder and Dalton, occurred in a cluster. This cluster coincides with the Little Ice Age (LIA), a period of cold climate conditions from about 1350 to 1850 AD. Between the Oort and the Wolf Minimum a period of high solar activity of approximately 200 years is evident. This period coincides with the Medieval Climate Anomaly (MCA), which is generally characterized by warmer and drier climate conditions. The simultaneous occurrences of the LIA with a cluster of grand solar minima and of the MCA with a long-lasting period of high solar activity, points to an influence of the Sun on the Earth’s climate during these periods. In addition to solar activity, volcanic eruptions played an important role (Fig. 1b; Gao et al., 2008). During the LIA, several strong volcanic eruptions occurred at the time of grand solar minima, which had a further cooling effect. An inverse pattern is found for the MCA when only weak volcanic eruptions are identified and solar activity was high. With the beginning of industrialization in the 18th century, the importance of solar and volcanic forcing decreased while the influence of the anthropogenic greenhouse effect due to fossil fuel burning began to increase and is currently playing the dominant role (Hegerl et al., 2007).

**Future solar activity**

An interesting question is what role the Sun is going to play in the near future. The 9300-year long composite of solar activity (Steinhilber et al., 2008) shows that during the past six decades the Sun has been in a state of high solar activity compared to the entire period of 9300 years. The statistics of the occurrence of periods of high activity suggests that the current period of high activity will come to an end in the next decades (Abreu et al., 2008). Furthermore, the distribution of grand solar minima in the past 9300 years shows that it is likely that a Maunder Minimum-like period would occur around 2100 AD (Abreu et al., 2010). Such a period of low solar activity would probably lead to a temporary reduction in Earth’s temperature rise due to the anthropogenic greenhouse effect. However, the 9300-year long record shows that in the past a grand maximum has always been followed by a period of high activity, with the very likely assumption that the Sun’s future behavior will be similar to that of the past, it is clear that the Sun will not permanently compensate for human-made global warming.

**References**


Inter-model differences and model/reconstruction comparisons suggest that simulations of the Medieval Climate Anomaly either fail to reproduce the mechanisms of climate response to changes in external forcing, or that anomalies during this period are largely influenced by internal variability.

Comparing model simulations with proxy-based climate reconstructions offers the possibility to explain mechanisms of climate variability during key periods, such as the Medieval Climate Anomaly (MCA) and the Little Ice Age (LIA). Discrepancies between both sources of information may also help to identify possible deficiencies in our understanding of past climate, its modeling or its representation by proxy records.

Information derived from proxy records suggests the following picture of the MCA in comparison to the subsequent colder period, the LIA, that involves quasi-coordinated climate shifts across different regions of the globe (e.g., Seager et al., 2007; Mann et al., 2009; Graham et al., 2010): evidences of an increased zonal gradient in the tropical Pacific produced by La Niña-like conditions in the eastern Pacific and anomalous warmth in the western Pacific and Indian Ocean, and a broad expansion of the Hadley Cell with associated northward shift of the zonal circulation that might have led to a more positive North Atlantic Oscillation (NAO) type of signature in the North Atlantic. Graham et al. (2010) recently showed that a pattern of change consistent with such anomalies is obtained for the MCA with an Atmosphere Ocean General Circulation Model (AOGCM) if anomalously warm sea surface temperatures are induced on the Indian Ocean and western tropical Pacific.

Current AOGCM millennial forced simulations do represent an overall warmer MCA and a cooler LIA at global and hemispherical scales (e.g., González-Rouco et al., 2006; Ammann et al., 2007) as a response to long-term changes in volcanic activity and solar irradiance. The amplitude of this response is dependent on the model sensitivity and on the specific set of forcing reconstructions used to drive the simulations. Mann et al. (2009) show that in spite of agreement in simulating global and hemispheric warming, the reconstructed pattern of MCA-LIA temperature change, and specifically the La Niña-like conditions in the eastern Pacific, were not reproduced by forced simulations with the GISS-ER and the NCAR CSM1.4 climate models. In this contribution, we will examine the MCA-LIA transition in all available high complexity AOGCM transient simulations of the last millennium.

**Simulation of MCA-LIA temperature difference by AOGCMs**

Simulations from six different AOGCMs are considered (see original references for details): the National Center for Atmospheric Research Climate System Model 1.4 (Ammann et al., 2007; CSM1.4 hereafter); a new version of the same model, the Community Climate System Model 3 (Hofer et al., 2011; CCSM3 hereafter); the Max Planck Institute for Meteorology ECHO-G (González-Rouco et al., 2006); the Institute Pierre Simon Laplace IPSL-CM4, v2 (Servonat et al., 2010; IPSL hereafter); the Centre National de Recherches Météorologiques CNRM-CM3.3 (Swingedouw et al., 2010; CNRM hereafter); and the Max Plank Institute for Meteorology Earth System Model (Jungclaus et al., 2010; MPI-ESM hereafter). This suite of simulations has been performed by different groups and institutions and represents forcing uncertainty through somewhat different choices of external forcing. Only some comments about the forcing that are relevant for the MCA-LIA period are provided herein.

All simulations incorporate solar variability, volcanic activity (except for IPSL) and greenhouse gas concentration changes. Variations in solar irradiance for the last millennium are smaller than previously thought (see discussion in Jungclaus et al., 2010 and Schmidt et al., 2011). The majority of simulations were performed with a comparatively high solar variability scenario, except for the specific case of MPI-ESM for which two different ensembles were made including smaller (E1) and larger (E2) irradiance changes. The total solar irradiance (TSI) change in the high solar variability scenarios ranges from 0.24% (CSM1.4, CCSM3) to 0.29% (ECHOG) from the Late Maunder Minimum (LMM) to present and from 0.17% (CCSM3) to 0.27% (MPI-ESM-E2) from the MCA to the LMM; in MPI-ESM-E1 the values of TSI change are of 0.09% (0.04%) for the transition LMM-present (MCA-LMM). Volcanic forcing was implemented differently in the suite of models, although comparable global and annual averages were retained. With regard to greenhouse gases, all models incorporate prescribed values of CO₂ concentration except for MPI-ESM, which interactively calculates them within the carbon cycle submodel. Similarly, land use changes before 1700 AD are incorporated only in the MPI-ESM simulations as variations in vegetation types due to agricultural activities.

Figure 1 shows the MCA–LIA annual temperature differences (hatched areas indicate non significance for a p<0.05 level) in a forced simulation from each of the six models and also in the proxy-based reconstruction from Mann et al. (2009). For the specific case of the MPI-ESM model, results are shown for four simulations, two arbitrarily selected from each ensemble to illustrate the existing differences between the members. All simulations tend to produce an almost globally warmer MCA, except for the one of CNRM, which shows a large cooling in the Southern Hemisphere. Warming tends to be higher over the continents than oceans, particularly over the sea-ice boundary at the high latitudes of both hemispheres. Regional scale cooling (not significant everywhere) is simulated around Antarctica, mid-latitudes of the Southern Hemisphere (all models), in the North Pacific (ECHOG), in the North Atlantic (CCSM3) or in northern Asia (CNRM).

However, many of these regional scale features may well be simulation-dependent and related to initial conditions and
internal variability as evidenced by the differences within the members of each MPI-ESM ensemble. Differences arise in the magnitude of warming and cooling over the North Pacific, South America or Africa in E2 or in the spread of cooling regions in the E1 members. Among the two ensembles, E1 simulates more regional/large-scale widespread cooling, a sign of the lower weight of TSI changes that allows for internal variability to become more prominent. Therefore, even if widespread warming is simulated in the MCA, the spatial pattern of temperature change is very heterogeneous and can vary considerably from model to model and even within simulations of the same model. None of the model simulations reproduce the reconstructed pattern in Mann et al. (2009) depicting a La Niña-like state in the Pacific. Other features in the reconstructed evidence discussed by Graham et al. (2010) are also not evident in the simulated MCA–LIA temperature differences. This includes the anomalous warm pool over the western Pacific-Indian Ocean and enhanced tropical zonal temperature gradient, as well as an NAOLike temperature signature, suggestive of a northward shift of the zonal circulation. Therefore apart from the generally higher changes in continental and polar areas, the MCA–LIA change across the available model simulations is inconsistent, and shows a different response to proxy evidences.

Conclusions
The results presented here highlight major discrepancies between millennium simulations and reconstructions. If proxy-based reconstructions were considered reliable and changes in radiative forcing factors were responsible for the MCA–LIA reconstructed temperature signal, these results would have implications on our understanding of the MCA–LIA transition. These discrepancies suggest that either the MCA–LIA changes arose from internal variability only, or transient simulations with state-of-the-art AOGCMs fail to correctly reproduce some mechanisms of response to external forcing; for instance, changes in the tropics like the enhancement of the zonal gradient in the tropical Pacific is not well simulated, with implications for related teleconnections elsewhere.

Most models have used relatively high TSI variations from the MCA to the LIA and their pattern of response is typically a uniform warming in the earlier period. In spite of this, there are considerable differences among the simulations that highlight a feasible influence of initial conditions and internal variability. Furthermore, if reduced levels of past TSI are given more credit, as in the MPI-ESM-E1 ensemble, the temperature response for the MCA–LIA is less uniform in sign and visibly more influenced by internal variability. Therefore, under both high and low TSI change scenarios, it is possible that the MCA–LIA reconstructed anomalies would have been largely influenced by internal variability.

References


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Evidence for global climate reorganization during medieval times

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A synthesis of global climate model results and inferences from proxy records suggests an increased sea surface temperature gradient between the tropical Indian and Pacific Oceans during medieval times.

A range of in-situ proxy records indicate that tropical eastern and central Pacific sea surface temperatures (SSTs) were relatively cool during the Medieval Climate Anomaly (MCA, ca. 900-1350 AD; e.g., Cobb et al., 2003; Rein et al., 2004; Crowley et al., 2008). This idea is supported by hydroclimate changes indicated by proxy records from extra-tropical western North and South America (e.g., Swetnam et al., 1993; Stine et al., 1994; Jenny et al., 2002; Cook et al., 2004; see Fig. 1).

At the same time, indications of a distinct MCA appear in proxy records distributed around the planet, many far removed from the Pacific sector (also Fig. 1). Many of the climate shifts inferred from these latter records are inconsistent in strength or character of the changes expected on the basis of a cooler tropical Pacific alone (at least as judged from observations and model results) suggesting an important role for SST changes in other tropical oceans (Seager et al., 2007; Graham et al., 2007; Graham et al., 2010). Among such “inconsistent” shifts are indications of a more “positive NAO”-like circulation pattern during boreal winter; with impacts on European climate (e.g., Lamb, 1965; Mangini et al., 2005; Trouet et al., 2009), North Atlantic SST and sea ice (e.g., Keigwin, 1996; Jensen et al., 2004; Sicre et al., 2008; Wanamaker et al., 2008; Massé et al., 2009), aridity in equatorial Africa (Verschuren et al., 2004; Russell et al., 2007; Shanahan et al., 2009) and in parts of southwest Asia (Hassan, 1981; von Rad et al., 1999; Fleitmann et al., 2003), and increased monsoon rainfall in parts of south-central and eastern Asia (Sinha et al., 2007; Tan et al., 2008; Zhang et al., 2008; Buckley et al., 2010).

Model simulations of the climate and circulation changes ensuing from the late 20th century warming of the Indian Ocean (e.g., Bader and Latif, 2003; Hurrell et al., 2004; Hoerling et al., 2004; Bader and Latif, 2005) show some of the “inconsistent” features noted above. To explore the possibility that similar warming may have occurred during the MCA, simulations were performed with a full-physics global coupled model (NCAR CCSM) in which tropical Indian, or tropical Indian and western Pacific, SSTs were increased over the range ~0.2-0.8°C. The simulated global climate and circulation shifts for boreal winter (Figs. 1 and 2; see Graham et al. (2010) for the corresponding results for boreal summer) show many of the climate changes inferred from global proxy records for the MCA, including many of those not well explained by a cooler tropical Pacific alone. These include a systematically stronger NAO during boreal winter, with associated changes in North Atlantic SSTs and sea ice, and European/North African precipitation. The simulated changes also include cooling and reduced rainfall in the equatorial eastern Pacific (boreal winter), seasonal aridity in equatorial and northeast Africa and into southwest Asia, transitioning towards relatively more moist conditions proceeding east across the Indian subcontinent, southeast Asia and into parts of China.

Overall, the findings support the general pattern of tropical SST changes seen in a recent statistical reconstruction (Mann et al., 2009), with a stronger zonal SST gradient between the Indo-Pacific Warm Pool and the eastern/central tropical Pacific during medieval times, relative to subsequent centuries.

Figure 1: Schematic diagram of MCA vs LIA climate shifts as seen in a range of globally distributed proxy records.
Medieval hydroclimate revisited

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Can the global pattern of Medieval hydroclimate be explained by a persistent La Niña-like state and a persistent positive North Atlantic Oscillation (NAO) and, if so, why did this happen?

North American megadroughts

The hydroclimate of the Medieval period (here loosely defined as the period from about the 9th Century to the end of the 15th Century) features some dramatic anomalies with respect to the modern climate. Perhaps the most remarkable are the series of multidecadal “megadroughts” that struck vast areas of Southwest North America which combined to create a generally more arid climate in the region that lasted centuries. These are well documented from tree-ring records (Herweijer et al., 2007; Cook et al., 2007, 2010). In addition, there is evidence for a strong Asian monsoon during the Medieval period, wet conditions over much of tropical South America, dry conditions in equatorial East Africa, wet in South Africa, a dry western Mediterranean region and wet northwest Europe (see compilation of proxy data in Seager et al., 2007, Burgman et al., 2010 and Figure 1). What could have caused such a global reorganization of hydroclimate for such a long period of time? The North American megadroughts immediately suggest a link to tropical ocean sea surface temperatures (SSTs). Climate modeling has clarified that the historical droughts of the 19th and 20th centuries were forced by small variations in tropical SSTs. All were forced, wholly or in part, by a cold, La Niña-like tropical Pacific Ocean. In addition, a warm subtropical North Atlantic Ocean played a role in forcing the 1930s and 1950s droughts. The tree-ring data clarified that the spa
tial patterns of the modern and Medieval droughts were essentially the same extending from Mexico up to Oregon and from the Pacific coast into the Great Plains and sometimes as far as the Atlantic coast of the eastern USA. Persistent, multi-year La Niña force modern droughts. Likewise, past shifts of the tropical Pacific to a more La Niña-like state for multiple decades at a time could, conceivably, have forced changes in atmospheric circulation that created the megadroughts.

**Modeling of tropical Pacific Ocean forcing of North American megadroughts**

Marine proxy data are quite sparse for the Medieval period. However Cobb et al. (2003, and updates at the Lisbon symposium, September 2010; http://mw-plisbon2010.fc.ul.pt/) used coral oxygen isotope data from Palmyra in the central equatorial Pacific Ocean and showed that SSTs were quite likely reduced throughout most of the Medieval period they were able to sample. However more work is needed to be certain since the coral oxygen isotope composition could also be influenced by changes in salinity. Graham et al. (2007) examined other marine proxies from the Pacific and showed that they were consistent with a Medieval La Niña-like state. The Cobb et al. (2003) record has been used to create tropical Pacific SST fields for 1320-1462 AD that were imposed as forcing for an ensemble of 16 atmosphere GCM simulations (Seager et al., 2008a). The coral-reconstructed tropical Pacific SSTs were sufficiently cool and persistent to create multidecadal megadroughts over North America that had comparable spatial pattern and amplitude to the tree-ring reconstructed megadroughts during this 1320-1462 AD period. However, the model did not track the year-to-year evolution of the reconstructed North American hydroclimate very well.

**Possible tropical Atlantic Ocean role on North American Medieval hydroclimate**

In the last few years, climate modeling has shown that North American drought is also influenced by tropical North Atlantic SST variations, either via an indirect influence that involves the Pacific in winter or directly by forced stationary Rossby waves in summer (Kushnir et al., 2010; Seager et al., 2008b). Hence part of the model vs. tree-ring reconstruction discrepancy for 1320-1462 AD could be attributed to the neglect of the influence of Atlantic SST variations. Indeed Feng et al. (2008) have argued that the North Atlantic was warm during the Medieval period (in a pattern resembling the Atlantic Multidecadal Oscillation) and that this, in combination with the cold tropical Pacific, forced the North American megadroughts (see Oglesby et al., this issue). It is highly likely that the decade-to-decade and century-to-century evolution of North American hydroclimate during the Medieval period (including the succession of megadroughts interrupted briefly by wetter periods more akin to the current climate) was forced by the evolution of tropical Pacific and Atlantic SSTs acting in concert at some time and in opposition at other times. The extent to which the Pacific and the Atlantic Oceans themselves interacted is not known but it has been speculated that the two oceans can vary in a coordinated manner with possibilities for each to force and respond to the other.

**Explaining the global pattern of Medieval hydroclimate: La Niña and a positive NAO**

Turning to Medieval hydroclimate beyond North America, Herweijer et al. (2007), Seager et al. (2007) and Burgman et al. (2010) found around 30 proxy records from various types of archive (tree rings, speleothems, sediment cores, etc.) that showed evidence of a well defined Medieval hydroclimate anomaly (extending into the 14th and 15th centuries) relative to the subsequent Little Ice Age and modern periods. These were simply characterized as wet or dry following the interpretation of the original authors. These were then plotted together with the 1320-1462 AD time-averaged soil moisture anomalies from the ensemble mean of the model simulations forced with the tropical Pacific coral-reconstructed SST. Figure 1 presents an update of that figure.

There is general agreement on the dry conditions in the extratropical Americas and wet in the tropical Americas, typical
of a La Niña-state. The model also agrees with proxy evidence for dry conditions in equatorial East Africa and wet conditions in southern Africa. There is some indication of a stronger monsoon. The model also produces a dry Mediterranean region in agreement with some proxies. However, the model does not capture the wet conditions that proxy data indicate for north-west Europe. Data presented at the Lisbon millennium for several reasons. First, as for in southern Africa. There is some indication of a stronger monsoon. The model also produces a dry Mediterranean region in agreement with some proxies. However, the model does not capture the wet conditions that proxy data indicate for north-west Europe. Data presented at the Lisbon millennium for several reasons. First, as for

What caused Medieval La Niña and positive NAO states? Why might a persistent Medieval La Niña and positive NAO have occurred? One argument is that relatively high solar irradiance and weak volcanism could have forced the tropical Pacific into a more La Niña-like state (Emile-Geay et al., 2007) with a positive NAO then being forced as a teleconnected response. Other arguments have been made that high irradiance could directly force a positive NAO (e.g., Rind et al., 2008). Recently Marchitto et al. (2010) have presented sedimentary evidence from the Soledad Basin off Baja California that La Niña-like states have coincided with increased solar irradiance throughout the Holocene, with the Medieval period being the most recent of these events. Should Medieval hydroclimate be externally forced, it would raise two important issues. The presumed amplitude of the external forcing is very small and the Medieval response would indicate a surprisingly high regional climate sensitivity. That regional climate sensitivity comes from a strong projection of forcing onto the patterns of the ENSO and NAO modes of climate variability. On the other hand, it is possible that these atmosphere-ocean states could arise from internal variability of the climate system on timescales longer than generally considered possible and potentially including as yet unknown interbasin couplings that act to persist certain preferred states. Either way, global Medieval hydroclimate is a fascinating and important challenge to our understanding of climate variability and change.

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The Medieval Climate Anomaly in Europe in simulations with data assimilation

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Data assimilation improves our understanding of the origins of climate changes during the past millennium in Europe.

Model data-comparison in the presence of large internal variability

The analyses of past climate changes are based on two main sources of information. First, proxy records provide qualitative and quantitative estimates of the changes. Second, the knowledge of the physical processes governing climate allows us to propose interpretations of the observed signals and possible explanations of their origin. This understanding of the system is generally formalized in models, ranging from conceptual models to sophisticated general circulation models. A successful study needs to stand on those two pillars and thus requires an efficient way to compare model results with proxy records.

However, such a comparison is not straightforward, in particular for the past millennium for several reasons. First, as for any paleoclimate study whatever the time-scale is, proxy records covering the last millennium and model outputs do not represent the same quantity. Proxies include non-climatic signals and are generally influenced by local climate, while models simulate physical, and sometimes biogeochemical quantities averaged over thousands of square kilometers. Forward proxy models (where the variable recorded in the archive is directly estimated from the model output instead of using a calibration of the proxy in terms of simple physical variables like annual mean temperature) and regionalization techniques will certainly contribute to reduce the uncertainties associated with those issues in the near future (Hughes et al., 2010).

A second problem for the last millennium is the large role of the internal variability of the system during this period, in particular at continental and regional scales (Goosse et al., 2005). If a signal recorded in proxies is related to a known forcing such as a change in the insolation in summer or a decrease in greenhouse gas concentration, then a model that includes the adequate physics and is driven by this forcing should ideally reproduce the observed signal at the right time. However, even a perfect model cannot simulate at the right moment an event that has its origin internally in the non-linear dynamics of the climate system. Instead, a similar event may occur in the simulations earlier or later in time but never with identical temporal and spatial structure. Therefore, any difference between model results and observations can be due to model deficiencies but also simply due to a different realization of internal variability. This strongly reduces the constraints that model-data comparison could put on the realism of models. Furthermore, using a model to interpret an observed signal is nearly impossible if the model does not sim-
Combining model results and proxy data through data assimilation

Data assimilation provides a way to partly bypass this latter problem. The goal of this technique is to optimally combine data with model results in order to obtain a state of the system that is compatible with both, taking into account the uncertainties on all the elements (for a recent review of applications of data assimilation devoted to the last millennium, see Widmann et al., 2010). As the obtained model state reproduces the observed signal, it is then possible to describe the origin of this signal by analyzing all the model variables.

However, data assimilation should be used in conjunction with simulations without data assimilation. In simulations with data assimilation, it is not possible to determine if a simulated event is related to a particular forcing or just to the internal variability of the system. By contrast, the average of an ensemble of simulations without data assimilation can be used to estimate the response of the system to the forcing. It is then tempting to consider that the differences between the simulations with and without data assimilation are related to the internal variability of the system. Nevertheless, this step should be made with caution since it assumes that the contributions of forced and internal variability linearly add to each other without any interactions between them and that the forced response estimated from models is perfect. This is of course only a first order approximation and data assimilation also compensates for uncertainties in the estimates of forcing reconstructions, as well as for errors in the model response to this forcing to an extent that is usually difficult to estimate.

The data assimilation technique that has been selected in our studies is a particle filter (Sequential Monte Carlo method, e.g., van Leeuwen, 2009) because it is relatively intuitive to use and because it is well adapted to strongly non-linear systems. Starting from an ensemble of initial conditions (96 in our case) obtained for instance from simulations without data assimilation, simulations are performed for one year using the climate model LOVECLIM (Goosse et al., 2010). The likelihood of each model state is then estimated from a comparison with proxy-based reconstructions. The simulations that show the largest disagreement with the proxies are stopped while the ones that are in better agreement are maintained. In order to keep the same number of particles (i.e., of members in the ensemble of simulations), the simulations that display the highest likelihood are duplicated, the number of copies being proportional to the likelihood, and then a small perturbation to the model state is added. The procedure is then prolonged for an additional year until the end of the period of interest. This technique guides the model results to follow the signal recorded in proxies. One of the limitations of the particle filter is that it requires a large number of members to reproduce the development of the system. Consequently, it is generally necessary to focus on a particular region or, when interested in a larger scale, to apply a spatial filter to remove high frequency spatial variations and to reduce the number of degrees of freedom of the system.

Application to the study of the MCA in Europe

Using this technique, it is possible to directly constrain the model to follow the relatively large number of proxy records available for the past millennium (e.g., Jones et al., 2009), eventually using forward proxy models and regionalization techniques. However, as a first step, we found it easier to use spatial reconstructions either of annual mean temperature over a large part of the world (Mann et al., 2009) or of summer temperature over Europe (Guoiet et al., 2010) since they provide fields that are easy to compare with model results (Fig. 1).

In summer and winter, both reconstructions and simulations with data assimilation show a clear warm period in Europe between 900 and 1050 AD during the Medieval Climate Anomaly (MCA). This contrasts with the ensemble mean of the simulations without data assimilation (i.e., the forced response of the model), which shows only a small decrease between the early part of the millennium and the 16th-18th century (often referred to as the Little Ice Age). This weak forced response has also been found in other models driven by similar forcing as the one used here (Jungclaus et al., 2010). The analyses of the origin of the larger warming in the simulation with data assimilation shows that, in the simulation constrained by the Mann et al. (2009) reconstruction, the atmospheric circulation displays stronger westerly winds bringing warm air to northern Europe during the MCA, mainly in winter. In the simulation driven by the Guoiet et al. (2010) reconstruction, westerlies are weaker in summer and a northward flow transports air from Africa to the central Mediterranean Sea and southern Europe during the MCA, contributing to the simulated warming.

References


European tree-ring data and the Medieval Climate Anomaly

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European tree-ring chronologies reveal that temperatures during the Medieval Climate Anomaly (MCA) were likely as warm as during the 20th century, that earlier hydroclimatic changes have at times exceeded recent variations, and that evidence for a clear spatiotemporal pattern of the MCA remains puzzling.

Europe possesses a dense network of long instrumental station measurements, and with Scandinavia and the Alps, harbors at least two of the world’s hotspots of dendroclimatic research that provide an exceptional pool of archeological wood material. Annually resolved millennium-long tree-ring chronologies that enhance our understanding of the Medieval Climate Anomaly (MCA, ca. 900-1400 AD), exist for different parts of Europe and northern Africa. Individual records that combine an adequate number of recent and historical samples can reflect high-to-low-frequency variations in either warm season temperature or precipitation.

Reconstructions
Millennium-long tree-ring based-temperature reconstructions exist in northern Scandinavia (e.g., Briffa et al., 1992; Grudel et al., 2002; Grudel, 2008; Gouirand et al., 2008; Helama et al., 2009b) and the Alpine arc (e.g., Büntgen et al., 2005, 2006, 2009; Corona et al., 2010; Nicolussi et al., 2009). The Scandinavian composite records are based on living conifers, which grew during the past few centuries, and utilize dry-dead and sub-fossil material further back in time (see Linderholm et al., 2010 for a review). The Alpine temperature reconstructions are mainly based on high-elevation living conifers and historical construction timber. Slightly shorter temperature reconstructions that reach back into the 12th and 13th centuries are available from the Romanian Carpathians (Popa and Kern, 2009) and the Spanish Pyrenees (Büntgen et al., 2008). Both records show distinct summer temperature variations that are comparable to those obtained from the Alps. Dendrochronological studies in southern France (Serre, 1978), Albania (Seim et al., 2010) and Bulgaria (Panayotov et al., 2010) also revealed millennium-long ring width chronologies, but they only contain a mixed and overall lower climate signal (e.g., Büntgen et al., 2010a).

Northern and central European sites may reflect different patterns of temperature change (Büntgen et al., 2010b).

Scandinavian summer temperatures were roughly below the 1860-2004 AD average from ca. 800-900, 1100-1400, 1570-1750, and from 1780-1920 AD (Fig. 1a). Summer warmth centered on the 760s, between ca. 980 and 1100 AD, and again in the 1410-1420s was comparable to, or even higher than, conditions during the 1930s and after ca. 1980. The timing of Scandinavian medieval warmth may have coincided with the establishment of Norse colonies in the cold and harsh environments of Iceland and Greenland (Patterson et al., 2010). In contrast, Alpine summer temperature depressions were estimated during the Little Ice Age (LIA) from the mid 15th century to ca. 1820 AD and coinciding with the Oort Solar Minima ca. 1050-1120 AD. Alpine summer temperatures during the late 20th century were unprecedented over the past 1500 years (Fig. 1b). Earlier warm periods occurred in the 990s and between ca. 1150-1250 AD and may have coincided with a rapid demographic and economic, as well as cultural and political rise of medieval Europe (McCor- mick, 2001).

While a few evenly distributed and highly replicated composite tree-ring chronologies (of distinct temperature sensitivity) are sufficient to capture the spatial character of European summer temperature variability (Büntgen et al., 2010b), many more records are necessary to provide a comparable meaningful picture of the continent’s hydroclimatic variability. It should also be noted that most of the local-to-regional-scale hydroclimatic records best reflect drought conditions, such as soil moisture availability (Büntgen et al., 2010b), whose sensitivity is generally restricted to the early vegetation period of intense cell formation. Millennium-long ring width-based reconstructions from southern Finland (Helama et al., 2009a), south-central England (Wilson et al., unpublished data), central Europe (Büntgen et al., 2011), and the southern Mediterranean Maghreb (Esper et al., 2007; Touchan et al., 2010) preserve high-to-low-frequency precipitation/drought variability (Fig. 2). Data also contain a pronounced level of synoptic-scale coherency amongst the same latitudinal belts. The two northern-most records agree well and show a drier
MCA, a wetter LIA and average 20th century conditions compared to the individual record length (Fig. 2a). The central European records illustrate a similar picture with slightly higher amplitude between a drier MCA and a wetter LIA (Fig. 2b). The two records from the southern Mediterranean show decadal-scale hydroclimatic variations (Fig. 2c), but convincing indication for a longer-term contrast between an overall dry MCA, a wet LIA and an abrupt recent drought is largely derived from the study by Esper et al. (2007). It must be noted that the reconstructed northwest African drought fluctuations are based on a compilation of 39 site chronologies (Touchan et al., 2010), which are somewhat restricted in potentially preserving lower frequency information, and therefore partly deviate from the low-frequency signal displayed by Esper et al. (2007).

Evidence for a generally drier climate from ca. 1000-1200 AD is expressed in all regions (Fig. 2c), but convincing indication for a longer-term context and increasing the number of high-resolution proxy records will thus gain in importance. In this regard, it appears interesting that several multi-millennial-long chronologies of annually resolved ring width measurements have been developed for different parts of Europe. These compilations represent a unique dating tool, not only for archaeological artefacts and historical construction wood, but also for antique artwork, instruments and furniture (see Haneca et al., 2009 for a review). Continuous chronologies of the past millennium are available for most countries of central and northern Europe. Oak composites of 2000 years exist for different sub-regions in England, Ireland, Denmark, Germany, Poland and France. Additional deciduous species including beech, ash and alder, as well as conifers (i.e., fir, spruce and pine) yield millennium-long chronologies for Germany, Austria, Switzerland, France and the Czech Republic. Their sample size comprises hundreds and thousands of series in Roman, Medieval, and Modern times, but dramatically drops during the so-called transition periods of increasing and continuing political turmoil. The paleoclimatic value of such compilations was recently demonstrated by introducing a random sampling strategy to update archeological chronologies into the 21st century while avoiding statistical over-fitting during the calibration (Tegel et al., 2010).

The annual-precise felling dates of historical wood can provide additional insight into socio-economic dynamics of past civilizations when carefully analyzing the dendrochronological records and utilizing dates of timber harvest as a surrogate for construction activity.

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For full references please consult:

Was there a common hydrological pattern in the Iberian Peninsula region during the Medieval Climate Anomaly?

In order to understand the causes and spatial extent of the Medieval Climate Anomaly (MCA; ca. 900-1350 AD) and the Little Ice Age (LIA; ca. 1350-1850 AD), a better characterization of temperature and precipitation changes in a larger number of sites around the globe is required. Understanding the dynamics of MCA in the climatically-vulnerable Mediterranean region is particularly interesting since it encompasses a comparison between the hydrological response to a generally accepted warm period (the MCA) and to the present global warming. To tackle the question of how the MCA and the present global warming compare, the most pertinent approach is to study highly resolved records that are mostly driven by moisture changes. Sediments from small lakes that experience considerable fluctuations in terms of lake level and chemistry and biological proxies record such information on effective moisture variability. Coastal and marine sediments also provide evidence of changes in sea surface temperature (SST), river sediment delivery, and wind patterns related to climate.

The Iberian MCA signal: Marine and terrestrial records

Their relative small size, direct connection to surface aquifers, and rapid response to precipitation make Iberian karstic lakes particularly sensitive to moisture changes. Detailed sedimentological and geochemical analyses, complemented with the study of biological proxies (chironomids, diatoms and pollen), have been performed on long sedimentary records retrieved in 2004 from several Spanish lakes. In Figure 1 we show the location of the lakes where the MCA signal is recorded, together with some marine cores discussed below.

Most of the studied lakes (e.g., Estanya, Taravilla, Zohar, Arreo and Montcortés) record relatively shallower lake levels and more arid conditions during the MCA. This is indicated by higher chemical concentrations in the water, and the predominance of sclerophyllous Mediterranean vegetation, heliophytes and more evergreen trees in the catchment. In Figure 2, the most representative Iberian records are compared with global reconstructions, such as the number of sunspots (Vaquero et al., 2002). The fact that each lake is unique and responds differently to climate variability according to its geological, hydrological, and limnological characteristics makes it necessary to use case-specific proxies and apply local individualized interpretations. The reconstruction of lake level in Lake Estanya in the Pre-Pyrenees, mostly based on sedimentary facies and elemental and isotopic geochemistry (Morellón et al., in press), clearly shows a lake level increase from the end of the MCA to the LIA (Fig. 2). Similarly, the presence of gypsum-rich laminated facies in Arreo Lake (northern Ebro Basin, Fig. 1) suggests generally lower lake levels during the MCA (Corella et al., unpublished), while a thermophilous plant association recorded in the Montcortés Lake sedimentary sequence (Rull et al., in press) points towards warmer climate in the central Pre-Pyrenees. A comparable paleohydrological signal is recorded in Lake Taravilla, located in the Iberian Range. In this lake, coarser grain-size layers with higher siliciclastic content reflect paleoflood events during periods of increased run-off triggered by intense rainfall (Moreno et al., 2008). These layers are more frequent during the LIA and almost absent during the MCA (Fig. 2). Rb/Al ratios and Si concentration, used as proxies for run-off in Lakes Zohar and Basa de la Mora, further indicate that a drier climate extended across the Iberian Peninsula during the MCA, compared to the following centuries (Martin-Puertas et al., 2010; Pérez et al., unpublished data). Despite local differences and some dating uncertainties, the MCA stands out as a relatively dry period, which was characterized by decreased lake water balance in the eastern and, likely, the southern part of the Iberian Peninsula. The western Iberian Peninsula lacks high-resolution lake records of the MCA, but marine sediment cores provide some paleohydrological information. Several studies conducted offshore of Lisbon indicate that the MCA was a dry interval as inferred from reduced run-off (Abrantes et al., 2005; Lebreiro et al., 2006). On the Mediterranean side, the percentage of coarse particles in
a sediment core from north of Minorca, located in a contourite drift, highlights an episode of weaker deep-water formation after 1300 AD, corresponding to the LIA (Fig. 2). At that location, particle grain-size is directly related to the intensity of deep-water currents that are formed in the nearby Gulf of Lions (Frigola et al., 2007). This result points to weaker westerlies during the MCA, which is consistent with a positive North Atlantic Oscillation (NAO) index at this latitude.

**Climatic versus anthropogenic forcings**

The areas surrounding some of the studied Iberian lakes were well populated during medieval times. This raises the need to discriminate climatically forced signals from anthropogenic effects on the lake dynamics (Rull et al., in press). For instance, in both Montcortés and Arreo lakes, sedimentation rates increased during the MCA (Fig. 2). However, discerning whether the higher sediment delivery was the result of climatic factors (increase in high-intensity storm events, relatively lower lake levels due to higher temperatures, more intense evaporation and decreased precipitation or more development of littoral environments) or produced by changes in land use practices (deforestation, farming and intensification of cultivation) is not an easy task. Most likely, human impact and climate variability had a joint effect on Iberian lakes during historical times. Fortunately, an integrated multiproxy approach provides some clues to detangle both factors. In Taravilla Lake, peak contents of Cerealia and other “anthropogenic” taxa associated with crops and ruderal plants occur at the base of the sequence when terrigenous paleoflood layers are scarce (Fig. 2). Thus, significant removal of vegetation by human attributed fires or deforestation practices cannot be considered the main forcing for the increase in terrigenous layers (Moreno et al., 2008). In the same period, pollen reconstructions from Estanya (Morellón et al., in press) and Montcortés (Rull et al., in press) reflect warmer and drier conditions in a landscape dominated by junipers, Mediterranean elements (evergreen Quercus, Olea, Phillyrea, Buxus, Thymelaea and Rosmarinus), a relatively low presence of mesophytic woody taxa, heliophytes, some cultivated plants and a poorly developed aquatic component.

**A global context for the Iberian aridity during the MCA**

The Iberian records clearly documenting warmer conditions during the MCA are consistent with global paleoclimate reconstructions (e.g., Mann et al., 2009). Climate variability during the last millennium has been related to solar irradiance fluctuations and tropical volcanic eruptions (e.g., Shindell et al., 2001; Wanner et al., 2008). Recently, a persistent positive mode of the NAO during the MCA has been suggested (Trouet et al., 2009). This would lead to warmer and more arid climate in the western Mediterranean region. The Iberian Peninsula serves as a laboratory to explore the long-term pattern of the NAO index because of its location at the southern edge of the storm tracks associated with mid-latitude westerlies. Thus, a dry climate during the MCA is coherent with a dominant positive phase of the NAO, characterized by lower river discharge offshore Lisbon (Lebreiro et al., 2006; Alt-Epping et al., 2009), lower lake levels in northeast (Morellón et al., in press) and southwest Iberia (Martín-Puertas et al., 2010), fewer flood events in the Tagus River Basin (Benito et al., 2004; Moreno et al., 2008), and less intense westernly winds offshore Minorca Island (Frigola et al., unpublished data). Recent model simulations for temperature and precipitation in the Iberian Peninsula during the last millennium support the role of the NAO in creating a dry anomaly during medieval times (Gómez-Navarro et al., 2010). More analyses in progress and improved chronologies will facilitate a more detailed comparison of records to clarify the internal structure and spatial coherence of the main phases of environmental change during the MCA in the Iberian Peninsula.
Medieval drought in North America: The role of the Atlantic Multidecadal Oscillation

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The sea surface temperature anomalies associated with the Atlantic Multidecadal Oscillation may have been a major factor contributing to widespread drought in North America during Medieval times.

The role of the Atlantic Multidecadal Oscillation

Medieval times (900-1330 AD; hereafter referred to as MT) in central and western North America were, according to proxy data reconstructions, generally warm, and especially dry (Fig. 1), with numerous decadal or longer “megadroughts” that were the worst of the past 2000 years (Woodhouse and Overpeck, 2000). Considerable attention has been paid to the role of sea surface temperature (SST) anomalies in forcing these prolonged periods of drought, especially that of the La Niña-like condition in the eastern tropical Pacific (e.g., Graham et al., 2007; Seager et al., 2007). Compelling recent evidence suggests that North Atlantic SST, through the Atlantic Multidecadal Oscillation (AMO), may also have a strong effect on persistent summertime drought in North America (Fig. 1b). At present, the AMO expresses a 60-80 year cycle between relatively warm (warm phase) and cool (cold phase) SST (Kerr, 2000; Enfield et al., 2001).

We investigated the role of the AMO in MT drought in North America using modern (present-day) observations, proxy paleo-data, and simulations from multiple climate models (Feng et al., 2010). Considering present-day relationships, for which instrumental observations can be used, the results show that persistent summertime droughts in the U.S. Great Plains and southwestern North America are closely related to multidecadal variations of North Atlantic SST (AMO). During the AMO warm (cold) phases, most of North America is dry (wet). Next, the influence of North Atlantic SST on modern North American drought was examined using simulations made by five global climate models (Feng et al., 2010).

When forced by warm North Atlantic SST anomalies, all models captured significant drying over North America despite some regional differences. Specifically, all the models simulate dry summers in the Great Plains and southwestern North America. The response of precipitation to a cold North Atlantic is much weaker, with greater disagreement among the models. Overall, the ensemble of the five models reproduced the statistical relationships between dry/wet fluctuations in North America.

Figure 1: A) Spatial distribution of the proxy data of temperature changes during MT. Blue squares, gray dots and red squares indicate cooling, no changes and warming during Medieval Times, respectively. The contour lines are the observed temperature anomalies associated with AMO warm phases for the period 1901-2006 AD. The contour interval is 0.1°C. Details of the proxy data can be found in Feng et al. (2009). B) Difference in tree ring reconstructed Palmer Drought Severity Index (PDSI) for 900-1200 minus 1901-2000 AD. Shadings indicate the differences are significant at 95% confidence level by two-tailed student-test. The figure is adapted from Feng et al. (2010).
The AMO during Medieval times

Investigations of proxy SST records in both the tropical Pacific and North Atlantic (Feng et al., 2008, 2009) found a consistent basin-wide warming in the North Atlantic Ocean during MT (Fig. 1), supporting previous studies that there were generally warm periods in the North Atlantic realm (Lamb, 1977). The proxy records from the Pacific Ocean, however, yielded opposite results about SST changes in the eastern tropical Pacific during MT, with some suggesting La Niña-like conditions, while others suggest neutral or even El Niño-like conditions (Feng et al., 2008).

Using one particular model, the NCAR Community Atmosphere Model (CAM3), we further demonstrated that warm North Atlantic SST anomalies might have played a major role in the MT drought over much of North America (Feng et al., 2008). The MT drought could be simulated either by perpetual La Niña-like conditions in the eastern Pacific or by the warm phase of the AMO in the North Atlantic. La Niña conditions alone resulted in the best simulation of the intensity of MT drought (Fig. 2a), while simulation with a warm phase AMO alone reproduced well its areal extent (Fig. 2b). The two together can explain both the severity and longevity of the droughts (Feng et al., 2008) as shown in Figure 2c.

The AMO throughout the Holocene

To provide a longer-term perspective, we analyzed SST variations in the North Atlantic Ocean for the last 10 ka using empirical orthogonal functions (EOF). The first spatial mode (EOF1) accounts for 52.5% of the variance of the Holocene SST and demonstrates a basin-wide structure in the North Atlantic that clearly resembles the AMO pattern recorded during the recent instrumental period (Feng et al., 2009). The first principal component (PC1) associated with EOF1 is thus a good index that represents the temporal variations of the AMO-like SST pattern during the Holocene. The proxy record indicates that the MT drought is just one of many previous droughts on centennial timescales that impacted North America. We further demonstrated that these centennial droughts appear closely related to the AMO-like SST variations in the North Atlantic (Feng et al., 2010).

How does the AMO affect North American drought?

Clearly, the AMO or AMO-like SST had the capacity to strongly modulate precipitation and drought over North America throughout the Holocene. But the evidence presented above is all essentially statistical in nature, i.e., over a variety of timescales the AMO appears highly correlated with precipitation (and drought) over North America. The question arises: through what physical processes and mechanisms do the SST patterns reflected by AMO affect North American precipitation? Preliminary analyses from a suite of long model simulations made with the CAM3 suggest some intriguing and even surprising results (Hu et al., unpublished).

A primary connection is through the influence of the AMO on the subtropical high-pressure zone in the North Atlantic (Wang et al., 2007). In summer, the poleward flow on the western side of this high-pressure system funnels moisture into the central and western US, providing a source for most of the summertime precipitation in those regions. During the warm phase of AMO, the subtropical high is displaced north and east of its mean location, reducing moisture transport into the US except along the mid-Atlantic coast. During the cool phase, the subtropical high strengthens and pushes westward, allowing for more moisture transport into the central and western US. Similar mechanisms appear to be at play during MT (Feng et al., 2008).

Future directions

The above results are intriguing, but still very preliminary. Proxy reconstructions and modern observations suggest that the AMO is associated with drought in North America. Understanding the physical mechanisms by which the AMO affects this drought remains, however, less clear. Furthermore, the AMO acts along with other phenomena, especially El Niño Southern Oscillation and the Pacific Decadal Oscillation. A much deeper understanding is
Reconstructed and simulated Medieval Climate Anomaly in southern South America

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An austral summer temperature reconstruction for southern South America for the last millennium is compared to paleoclimate simulations provided by two Atmosphere–Ocean General Circulation Models with special emphasis on the Medieval Climate Anomaly.

The understanding of the current and future processes, and dynamics of the climate system can greatly benefit from the knowledge of past spatial patterns, trends, amplitudes, and frequencies of climatic variations (Jones et al., 2009, and references therein). Until recently, the rather low number and uneven spatial distribution of temporally highly resolved proxies from the Southern Hemisphere did not allow reliable continental scale reconstructions at interannual-to-interdecadal timescales (Neukom et al., 2010). Given the importance of the potential seesaw mechanism between the Northern and Southern Hemispheres (NH and SH) and the driving role of the SH oceans in regulating global climate variability, South America is a key region for the study of climate processes and dynamics. Climate in South America is influenced by a variety of oceanic and atmospheric patterns, such as the El Niño Southern Oscillation (ENSO) and the Southern Annular Mode (SAM; Garreaud et al., 2009). Thus, SH climate reconstructions covering the past centuries to millennia can provide insights into the underlying mechanisms of climate variability and forcing imprints. Such reconstructions are essential for data/climate model comparisons. Here, we present results from a new multiproxy-based austral summer (DJF) temperature reconstruction that covers the last 1000 years in southern South America (SSA) (Neukom et al., 2010). Special emphasis is given to the temperature difference between the periods 1001-1350 (“Medieval Climate Anomaly”, MCA) and 1400-1700 (“Little Ice Age”, LIA). Furthermore, austral summer temperature reconstructions are also compared with two coupled atmosphere-ocean general circulation models (AOGCMs): The two ECHO-G simulations Erik1 and Erik2 using identical external forcings, but different initial conditions (i.e., the initial conditions used in year 1000 AD in Erik2 where cooler than in Erik1; González-Rouco et al., 2006), and one simulation with CCSM3 (Hofer et al., 2010). The models use slightly different anthropogenic and natural forcings, including different levels of atmospheric concentrations of carbon dioxide, methane, and nitrous oxide, of solar activity, and of volcanic aerosols. We also provide austral summer temperature difference patterns (MCA minus LIA; 1001-1350 minus 1400-1700 AD) for both the multiproxy reconstruction with their associated uncertainties and the corresponding simulations from the three model simulations.

Austral summer temperature reconstructions back to the MCA and comparison with two AOGCMs

Figure 1 shows the austral summer (DJF) land-surface air temperature anomalies (with respect to the 1001-1700 AD reference period) for SSA (south of 20°S) both for the principal component-multiple regression based reconstructions (Neukom et al., 2010) and the three model simulations spanning the period 1001-1990 AD. The reconstruction generally points to warmer conditions during the MCA. A strong decrease in temperature is visible in the second half of the 14th century. The climate reconstruction for this period mainly relies on tree-ring information from the Andes, lake sediments from Central Chile and an ice core from the tropical Andes (Neukom et al., 2010; see Fig. 1 bottom left). Cooler conditions prevail throughout the late 17th century (LIA). The difference in mean austral summer temperature between the two periods (1001-1350 minus 1400-1700 AD) is approximately 0.39°C in the reconstruction, 0.14°C and 0.49°C in CCSM3 and Erik1, respectively. A possible explanation for the rather small difference in the CCSM3 simulation compared to the Erik1 simulation is the lower equilibrium climate sensitivity of CCSM3. The associated ±2 Standard Error (SE) uncertainties of this difference (based on the uncalibrated variance in the 20th century calibration period; see Neukom et al., 2010, for more details) for the MCA and the LIA are of the order of ±0.3°C (shaded parts in Fig. 1 top panel). The interpretation for the sudden drop in the mean temperature during the “MCA-LIA” transition is not known yet.

The reconstructions (Neukom et al., 2010) point to positive temperature anomalies in the 18th century, followed by a cooling phase that starts in the early 19th century. Since approximately the 1850s, SSA has experienced a long-term warming trend with superimposed shorter cooling periods. The multiproxy-based reconstruction and the AOGCMs generally agree on the centennial-scale warm and cold phases and their amplitude. However, there are differences between the reconstruction and the models in the timing of the MCA-LIA transition, which appears around 60 years later in the models. Additionally, the simulated transition is a two step process: a first step is initiated with

References

the strongest volcanic eruption of the last millennium around 1258 AD and a second step coincides with the Spörer solar Minimum (ca. 1460-1550 AD). Thus the model simulations seem to be more sensitive to external forcings than the multiproxy reconstruction would suggest. This leads to larger model temperature amplitudes on decadal timescales, in particular for the ECHO-G simulations. The models overestimate the warming in industrial time with respect to the proxies, most likely because of aerosol forcing and land use changes which are not considered in the simulations.

Figure 1 (bottom panels) shows the austral summer surface air temperature difference patterns (MCA minus LIA; 1001-1350 minus 1400-1700 AD) for the multiproxy reconstruction (left; interpolated to the 3.75°x3.75° grid of the AOGCMs) and the AOGCMs simulations. The inset in the left panel represents the available proxy time series in the pre-1700 period (green: tree ring series; purple: lake sediment record; blue: ice core) and the 2 SE derived from the 20th century calibration period, averaged over the period 1001-1700 AD (Neukom et al., 2010).

Conclusions

The paucity of high-resolution proxy data covering the early part of the last millennium results in uncertain multiproxy reconstructions for the medieval period. Though not homogeneous in time, this early period until approximately the mid 14th century is, on average, warmer than the subsequent period until around 1700 AD. There is a rather good agreement between the reconstruction and the two AOGCMs both in terms of mean conditions as well as the general spatial anomaly pattern. Future work based on more high-resolution proxy records, including detection and attribution studies, will help to refine these patterns, as well as the timing and causes of the MCA-LIA transition.

References


For full references please consult:
A recent focus on the land-sparse and data-sparse Southern Hemisphere (SH) has begun to fill critical gaps in our observational record of past climates identified by the paleoclimate research community (Jansen et al., 2007). This thrust is providing balance to Northern Hemisphere (NH) reconstructions, and is facilitating linkages between archives from the tropics through to Antarctica. Underscoring the usefulness of Australasian mid-latitude climate reconstructions are newly emerging perspectives about past extremes and mean climate state changes for the region. These new views are supplementing the general understanding of natural climate variability ranges prior to land-based instrumental records (typically less than 150 years coverage), and are expanding knowledge about tropically-based climate phenomena (El Niño-Southern Oscillation (ENSO), Interdecadal Pacific Oscillation (IPO), Indian Ocean Dipole, the Madden-Julian Oscillation, Australasian monsoon and the South Pacific Convergence Zone (SPCZ)) and other key extra-tropical components of the global climate system (e.g., the Antarctic Circumpolar Current (AAC), the Southern Annular Mode (SAM), and the mid-latitude westerlies).

Regional paleoclimate reconstructions in Australasia are being undertaken to increase natural climate variability understanding, leading to more robust validation of global climate models and improved model selection for future scenario-building. This approach is feeding into improved formulation of scenarios that are guiding mitigation and climate change adaptation strategies for Australia, New Zealand, and the small island nations of the Southwest Pacific. Observed patterns in multi-proxy paleoclimate syntheses are currently being compared to broad-scale circulation outputs from paleoclimate models (i.e., Paleoclimate Modelling Intercomparison Project (PMIP)), which will verify how well some climate models perform for the Australasian region. A key time span includes the last 2000 years, which contains the Medieval Climate Anomaly (MCA). The MCA expression in Australasia is particularly relevant to study because this period is considered as a key analogue to a future warmer-than-present world.

**Approaches to integrating proxies**

For New Zealand, a paleoclimate proxy integration approach called Regional Climate Regime Classification (RCRC) is being used to link paleoclimate time slices to modern circulation analogues (Lorrey et al., 2007, 2008). Uniquely, inferences about past atmospheric pressure patterns made from RCRC time slices provide a qualitative “upsampling” that can complement limited downscaled paleoclimate model information. This approach has been a boon for directly comparing proxies that are sensitive to atmospheric circulation changes and paleoclimate model outputs that lack sufficient locally downscaled precipitation or temperature results (e.g., PMIP), opening a new avenue for climate model testing and validation.

An alternative approach is employing pressure gradient and threshold detection algorithms to identify hemispheric circulation patterns associated with regional paleoclimate anomalies (Goodwin et al., 2010). The approach links modern synoptic type sets to unique climate responses at each proxy site.

With the exception of annually-resolved proxies used in the aforementioned synoptic paleoclimatology approaches, there is some uncertainty in the alignment of the archive signals that cover the MCA because of chronological uncertainties and sampling resolutions. In addition, some proxies are more susceptible to distortion than others due to geophysical and anthropogenic activity (Lorrey et al., 2010). However, careful interpretations of the records within a regionally-comprehensive network have meant multi-centennial approximations of past circulation patterns are possible using the two aforementioned approaches.

**Regional synoptic circulation reconstructions for the MCA**

The example RCRC time slice shown for ca. 750 to 925 AD (Fig. 1a) covering New Zealand is analogous to what occurs in a typical La Niña year, when northern and eastern regions tend to receive normal or above normal rainfall, and southern and western regions are often drier than normal. Overall the pattern is analogous to a blocking regime (Kidson, 2000), typified by more frequent northerly and easterly circulation synoptic types that block the prevailing west-to-east progression of anticyclones and troughs that characterize New Zealand’s daily weather variability. Blocking patterns are generally more frequent during the warm season in La Niña years when the sub-tropical high pressure belt moves southward, conspiring with the SAM (often in a positive mode during Austral summer; L’Heureux and Thompson, 2006) to increase anticyclone presence over southern New Zealand. This pattern also has a spatially similar signature to the penultimate IPO-negative phase between 1944-1976 AD.

Time slices produced for New Zealand suggest an MCA that can be broken into at least three phases; an early (ca. 750-1075 AD), middle (ca. 1100-1300 AD), and late (ca. 1350-1550 AD) phase (Lorrey et al., 2010). Weaker precipitation anomalies in the northern and eastern regions of New Zealand in the late MCA phase indicate a slackening of the blocking strength. The middle phase is characterized by oscillations back and forth between more frequent northerly and easterly circulation (blocking) and periods of more frequent southerly flow (zonal regimes). The oscillatory nature of the mid-MCA phase is also suggested by at least three surface exposure age- and radiocarbon-dated glacier advances in the Southern Alps (Schaefer et al., 2009) and periods of cooler summer temperatures reconstructed from tree rings in western South Island (Cook et al., 2002).

**Variability and drivers during the Polynesian Warm Period**

The early 2nd millennium AD heralded the arrival and permanent occupation of New Zealand by Maori (Wilmshurst et al., 2008), and it has been suggested that this
interval could be termed “the Polynesian Warm Period” (PWP; Williams et al., 2009). The PWP corresponds to the mid- to late-MCA phases described above, which saw significant Polynesian voyaging episodes and cultural shifts in the southwest Pacific (Anderson et al., 2006; Allen, 2006). The “La Niña-like” blocking patterns that are strongly indicated for New Zealand prior to and during the PWP support evidence from other paleoclimate reconstructions that suggest the SH westerly wind belt and ACC shifted northward between ca. 650-1250 AD with Antarctic cooling that affected the mid-latitudes. It is proposed that high latitude changes in this interval helped set up a positive high-latitude/tropical feedback that initiated a more “La Niña-like” climate state in the equatorial Pacific (Mohtadi et al., 2007), consistent with reconstructions of a “cool” ENSO signature in the central-eastern Equatorial Pacific, expansion of the Hadley circulation, and ridging in the NH mid-latitudes (Graham et al., 2010). Under a blocking regime, there would have been enhanced anticyclonic activity in the SH mid-latitudes, including the Tasman sector. However, significant zonal regime episodes during the mid- to late-MCA/PWP suggest that blocking regimes were not exclusive at the time, but rather there were sustained, strong periods of bi-modal circulation operation. This raises the likelihood that the regional variability associated with both ENSO (and IPO) phases (including droughts, storms, SPCZ shifts, local changes in tropical cyclone incidence, prevailing wind change, and SST anomalies) were probably as significant during the MCA/PWP to Australasian and Pacific Island populations as they are at present.

The atmospheric circulation anomalies reconstructed for New Zealand during the early MCA are nested within a larger SH pattern that blankets the Australasian and southwest Pacific sectors (Fig. 1b), indicated by a multi-proxy-based pressure gradient reconstruction using Eastern Australian coastal behavior and wave climate, Southern Australian mega-lake hydrology, coral-based subtropical seasurface temperatures, East and West Antarctic ice core glaciochemistry, and Antarctic lake hydrological balance and katabatic wind records (Goodwin et al., 2010). Composites of the joint archive signals for the Southern Hemisphere during the early MCA alludes to the basic structure of the Tasman region circulation anomaly suggested by the New Zealand RCRC reconstruction. More important, the synoptic reconstructions produced from the New Zealand and wider spatial approaches have been done independently, but thus far have yielded some similar results for the characteristic patterns and also timing of circulation changes during the MCA. Both reconstructions suggest predominance of Tasman Sea region blocking during the early MCA, and easing of the anomaly pattern between ca. 1350-1550 AD (Goodwin et al., 2010; Lorry et al., 2010).

Future direction
Comparison of different paleo-integration approaches (qualitative and quantitative) based on multi-proxy data assemblages that are aligned to reconstructing atmospheric pressure patterns are adding confidence to past change interpretations for
Climate during the Medieval Climate Anomaly in China

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Various climate archives reveal a heterogeneous occurrence of the Medieval Climate Anomaly in China in terms of timing, amplitude and duration. Uncertainty analyses indicate that it is difficult to assess whether the medieval warmth exceeded that of the late 20th century.

During the past few decades, the Medieval Climate Anomaly (MCA), a supposed interval of elevated temperatures between approximately AD 900 and 1300, has generated considerable interest due to its potential value as a natural analogue of 20th century “greenhouse” warming. Recently published National Research Council (2006) and IPCC (2007) reports have placed a high priority on identifying the confidence level in regional to hemispherical temperature changes during the past 2000 years, including the putative MCA.

China is one of the few regions in the world with almost all types of climate archives that could provide high-resolution proxy data, including the world’s longest continuous written historical records. Temperature time series of the last 500 to 2000 years have been reconstructed based on historical documents and natural archives (e.g., tree rings, ice cores, stalagmites, lake sediments) from China. In this paper, the results of regional proxy-based reconstructions are reviewed and the associated reconstruction uncertainty is assessed.

Regional reconstructions

Five climate regions of China have been selected (Northeast, Northwest, Central East, Tibet, and Southeast) to conduct the uncertainty assessment of the regional reconstructions (Ge et al., 2010). However, the Southeast has been excluded from the regional reconstructions assessment because the time series from that region are too short to cover the MCA. Examples of regional reconstructions from the climatic zones are shown in Figure 1.

For the Northeast region temperature proxy data from lake sediments, peats and stalagmites cover the last 2000 years. The MCA is heterogeneously expressed in all three series in terms of timing, amplitude and variation patterns. The annually resolved 2650-year warm season (May, June, July and August: MJJA) temperature series reconstructed by a stalagmite layer thickness record from the Shihua Cave (115°56'E, 39°47'N), Beijing, indicates a pronounced warmth occurring from the 9th to 13th centuries (Fig. 1e) (Tan et al., 2003). The δ18O proxy record from peat cellulose with a 20-year resolution from the Jinchuan peat (126°22'E, 42°20'N), Jilin Province, reveals a pronounced warm period at around AD 1100-1200 (Hong et al., 2000). However, the MCA is not visible in the quantitative reconstituted mean July temperature from the Daihai Lake sediment (Xu et al., 2003).

The Tibet region has four reconstructed temperature series covering more than 950 years. One is a composite of the ice cores Dasuopu, Dunde, Guliya and Puruogangri (Fig. 1c), one is based on tree rings and two are individual lake sedimentary records. The MCA is discernable in form of a δ18O maximum in Dunde and Guliya ice records, invisible in Puruogangri ice record, and shows a negative trend in the Dasuopu record (Thompson et al., 2006a). When the four ice cores are composed as one series, the MCA is not discernable (Thompson et al., 2006b) (Fig. 1c). The temperature reconstruction based on tree-ring widths of Qilian juniper from Wulan (Fig. 1b), Qinghai Province, indicates a moderate warming around AD 1144-1264 (Zhu et al., 2008). A lower resolution Total Organic Carbon (TOC) record from Qinhai Lake sediment in the Qinghai Province reveals warm and dry conditions from AD 1160-1290 (Shen et al., 2001); while the sediment record of Sugan lake in the same province shows a pronounced warm period from AD 500-1200 (Qiang et al., 2005).

In Central East China, Ge et al. (2003) reconstructed winter (October to April) temperatures at a 10- to 30-year resolution from phenoological observations recorded in Chinese historical documents.

References


Acknowledgements

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For full references please consult:
for the past 2000 years (Fig. 1d). According to this reconstruction, the winter temperatures from AD 930-1310 in central eastern China were 0.2°C higher than those of the 1950s-1970s, with a maximum warming of 0.9°C occurring during the AD 1230-1250 period. This pronounced warm anomaly was once disregarded by Chu (1973), one of the most famous Chinese climatologists who initiated the study of climatic changes by historical documents. He found that the climate turned cold at the beginning of the 11th century. Although it warmed at the 13th century, the mean amplitude during this period was lower than the average conditions during the past 2000 years. So he suggested that as a whole the Song periods (AD 960-1279) were generally characterized by a cold period (Fig. 1f). However, later studies pointed out that Chu’s reconstruction were based on an incorrect calendar conversion applied to dates of spring snowfall in Hangzhou, the capital of the Southern Song Dynasty (AD 1127-1279) (Zhang, 1994). Subsequent studies suggested the existence of an MCA in Central East China by using multiple independent subjective phenological evidences, which include the distribution and the north cultivation boundaries of winter wheat, sugarcane, tea plant, citrus and ramie, the safety date for full heading time of rice in Kaifeng, the capital of the Northern Song Dynasty, and plant phenological evidence in Hangzhou (Zhang, 1994; Man, 1996).

In the Northwest, the only highly resolved temperature reconstruction is a tree-ring record form the middle Qilian Mountain covering the last millennium, which reveals that a discernable warm period occurred AD 1050-1150 (Liu et al., 2007) (Fig. 1a). Seen from a regional perspective, all four studied regions experienced warm periods within the 10th to 14th centuries. However, the timing, duration and magnitudes of these warm periods vary substantially in each region and between regions. The maximal temperature in
Central East China in the AD 1240s is ~0.8°C above the AD 1901-1950 average (due to the various regions from where reconstructions are available and the variable instrumental data availability, the period AD 1901-1950 has been selected as the common reference period for all areas). The maximal temperatures are 0.4°C warmer in the 1190s for the Northeast and 0.2°C in the 1000s for the Tibet region. In the Northwest, the highest temperatures were reached in the 1100s. In the Northeast, Central East and Southeast regions, the warm peaks during AD 900-1300 are higher than temperatures of the late 20th century (Ge et al., 2010). (Fig. 2).

Uncertainty analysis
The proxy-based reconstructions are subject to uncertainties mainly due to dating, proxy interpretation to climatic parameters, spatial representation, calibration of proxy data during the reconstruction procedure, and available sample sizes. Recently, Ge et al. (2010) conducted an assessment in the uncertainty of the regional reconstructions by adopting the envelope assessment method used in the fourth assessment report of IPCC.

The results (Fig. 2) indicate that the proxies have a high level of confidence in the Northeast, Central East and Southeast for the last 500 years, but large uncertainties exist prior to the 16th century. On multidecadal to centennial timescales, several reconstructions show warming peaks that occurred during the period AD 900-1300, whereas their low confidence levels do not allow to assess whether the MCA has been warmer than the late 20th century.

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The Medieval Climate Anomaly in Greenland ice core data

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Temperature signals in ice core data

Greenland ice core data can be used to derive information on past climatic conditions in the Greenland area. Recently, Vinther et al. (2010) demonstrated a high correlation between δ18O data and Greenland coastal temperature observations, even on seasonal timescales, reaffirming the ability of ice core δ18O to capture local temperatures, first proposed by Dansgaard (1954).

The Vinther et al. (2010) analysis of the seasonal ice core δ18O data showed that the winter δ18O contains the strongest temperature signal, and that even annual average Greenland temperatures are more accurately captured in the winter δ18O rather than annual average δ18O data. This surprising fact is partly explained by the observation that Greenland winter temperatures are much more variable than summer temperatures and thus dominate the annual average variability (Vinther et al., 2010). Past Greenland climatic conditions can also be derived directly from Greenland ice core borehole temperature observations, by solving the equation of heat conduction in moving ice and firn (Dahl-Jensen et al., 1998). Using a Monte Carlo inversion technique, Dahl-Jensen et al. (1998) derived temperature histories from both southern and central Greenland from high precision borehole temperature measurements obtained at the DYE-3 and GRIP ice core drill sites. A third way of estimating past Greenland temperature conditions is to measure isotopes on nitrogen and argon trapped in air-bubbles within the ice (Severinghaus et al., 1998). These gases undergo a temperature dependent mass fractionation in the snow column before the air-bubbles are formed in the ice, thus retaining a retrievable temperature signal.

Greenland temperature conditions during the past two millennia

The Dahl-Jensen et al. (1998) inversions of two Greenland ice core borehole temperature profiles are shown in the top panel of Figure 1. Looking at the inversions it is important to remember that temperature signals in the ice sheet diffuse with time, meaning that the inversions will lose more and more high frequency information as we move back in time. Even so, it is clear from both the DYE-3 and the GRIP borehole temperature inversions that a warm Medieval Climate Anomaly (MCA) can be observed with peak temperatures from 800 to 1000 AD being some 1.3K warmer than the 1881-1980 AD reference period. From 1000-1400 AD a general cooling is observed at both drill sites, followed by two cold periods culminating around 1500 and 1860 AD, respectively. A recent warming culminating in the 1950s is also seen in both records. One noteworthy difference between the DYE-3 and GRIP temperature inversions is the amplitude of the most recent temperature oscillations. While some of the difference is probably climatic, it is also possible that the much higher accumulation rate at the DYE-3 drill site allowed for a better preservation of the recent temperature signals in the DYE-3 borehole, thus contributing to the higher amplitudes in the DYE-3 inversion. In the bottom panel of Figure 1, winter δ18O records from three Greenland ice cores all spanning the past 1450 years are presented (Vinther et al., 2010). To ease comparison with the borehole inversions, the records have all been smoothed with a Gaussian filter (tuned to have 50% damping of a signal with a 50-year cycle). The MCA warmth is also seen in the winter δ18O data and it seems to coincide with the warmth observed in the borehole inversions. The first cold spells around 1500 AD are only clearly identifiable in the DYE-3 winter δ18O data, while the 1860 AD cold period and the warming culminating in the 1950s are seen in all three winter δ18O records.

It is noteworthy that the winter δ18O records and the DYE-3 borehole temperature inversion all suggest that the warming culmination in the 1950s resulted in Greenland temperatures comparable to or only slightly cooler than peak MCA warmth. This observation is supported by a recent study spanning the last millennium by Kobashi et al. (2010). Using the gas fractionation technique on ice cores, they found that peak Greenland temperature conditions in the in the 12th century were just 0.3K warmer than those observed during the 1950s. The GRIP borehole inversion is therefore the only data set suggesting significantly higher temperatures during the MCA than during the 1950s, lending further support to the speculation that the quite low accumulation rate at the GRIP drill site did hamper the inversion of this recent short-lived climatic warming.

References


Assessing the Medieval Climate Anomaly in the Middle East: The potential of Arabic documentary sources

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New evidence from documentary sources provides detailed climatic information to fill the Middle East gap in Medieval Climate Anomaly reconstructions.

The Middle East region harbors a wealth of documentary and natural archives that contain detailed information on climate conditions and events. To date, however, only a few proxy-based climate reconstructions are available from the area for the assessment of thermal and hydroclimatic characteristics of the Medieval Climate Anomaly (MCA). Existing chronologies and reconstructions mostly provide information for specific seasons and hydroclimatic parameters (commonly precipitation and droughts). The reconstructions are based on natural proxies such as tree rings (e.g., Touchan et al, 2007), pollen records (Kaniewski et al, 2010), speleothems (e.g., Bar Matthews et al, 1997; Frumkin et al., 1991; Fleitmann et al., 2004), lake sedimentary records (e.g., Kuzucuoğlu et al, 2011), Dead Sea sedimentary records (e.g., Enzel et al, 2003; Migowski et al, 2006) or Red Sea corals (e.g., Felis and Nimbur, 2010). For compilations of available data from natural and documentary archives the reader is referred to Luterbacher et al. (2006, 2011) and references therein. Most of this data is hampered by a high degree of spatial and temporal variability and/or insufficient spatio-temporal resolution to assess in detail the MCA climate. Therefore its spatial and temporal extent in the Middle East requires further investigations.

Historical climatological studies have shown that documentary archives are a valuable source for climate reconstructions during the last centuries (Brázdil et al., 2005, 2010; Glaser and Riemann, 2009; Glaser, 2008; Pfister et al., 1998, 1999). The large body of written historical sources from Islamic Medieval times shows great potential and perspective for climate reconstructions in the Middle East during the MCA. Apart from a few preliminary studies, e.g., by Grotzfeld (1991, 1995) and Oliver (1991), these sources have not yet been adequately explored from a climatological perspective (Jones et al., 2009). The recently funded German Science Foundation project “Historical Climatology of the Middle East based on Arabic sources since AD 800” aims at using Arabic sources to reconstruct past climate, including hydrological variations and extremes in the Middle East and northeastern Africa back to 800 AD.

Arabic historical documents as sources for climate reconstruction
In contrast to Europe, archives with regular and continuous records from Arabic medieval administrations have almost all either been completely destroyed or are barely accessible. Consequently, the source types for climate information for the period from 800 to 1500 AD are mainly restricted to the akhbar genre (historiographical literature) including universal and town chronicles, accounts of journeys, and occasional diaries. A basic principle in the analysis of these sources is the focus on reported events by contemporary authors.

Here we present preliminary results based on a survey of around 50 medieval Arabic historiographical literature sources. We include well known, edited works that have in some cases also been translated into English, German and French, such as al-Tabari’s “History of Prophets and Kings” (al-Tabari, 1960-1969 AD, 1985-2002 AD) but also less known chronicles and diaries from manuscripts (for an example see Figure 1). From some diaries, weather tables can be derived, e.g., for the period from 1480-1500 AD from the diary of the Damascene notary Ibn Tawq. In total, more than 3000 excerpts amounting to 5000 references on climate related information, have been extracted from these sources.

The peak in the amount of available data for MCA occurred in the 13th century in the Arabic regions; this is much earlier than in Europe where such sources were mainly produced after ca. 1500 AD (Glaser and Riemann, 2009; Brázdil et al., 2010; Pfister et
al., 1998). The decrease in available records after the 13th century could be related to a shift in the writing style and focus of the Arabic chronicles from accounts of events to biographical data and anecdotes at the turn of the 16th century (Grotzfeld, 1995).

Figure 2 shows the spatial distribution of information held in our database to date for the time period from 800 to 1500 AD. The geographical coverage includes Iraq, Egypt, Syria and Palestine as well as the Hejaz and Yemen. In the course of time from the 9th to 16th centuries the spatial focus of the reports is moving from the Abbasid centers of power and science in Iraq to the Ayyubid centers in Syria and Palestine and finally to Fatimid and Mamluk Egypt reflecting the political and cultural changes in the area.

Winter rain and almond blossom instead of summer drought and tasty wine

In terms of climate-related information, the Arabic and European sources are in many respects similar. The authors usually report on events in their hometown and vicinity. Sometimes comparisons with remote or historical events are also made. The climatic information within a source is more or less sporadic, describing single events, especially natural hazards such as floods, droughts, and exceptionally cold or dry winters. In addition, the impacts of such events, their effects on harvest yields, food supply, economic and social crises are described. Reported events focus mainly on hydroclimatic and less on thermal conditions. The onset of the winter rainy season is one of the most frequently reported features due to its crucial role for agricultural production. Also, closely related to food supply are reports on droughts. For some cities like Baghdad, there exists the potential to establish continuous flood chronologies (Weintritt, 2009). An often-reported specific type of extreme event in the Middle East is sand storms, which are often connected to a specific circulation pattern (lower level Red-Sea Troughs, Saaroni et al., 1998). Cloud coverage is typically reported in connection with observations of the lunar crescent. Phenological information is linked to regional agricultural products such as dates or almonds. However, this kind of information is too sparse for the reconstruction of continuous time series.

Comprehensive data set to reconstruct climate for medieval times

Preliminary results show that the methodology of historical climatology, which has been mainly developed on the basis of European documentary sources, can be applied to this body of data as well. The hermeneutic approach, including critical source analysis and interpretation using information beyond the source texts, as well as classification and derivation of (semi-quantitative) indices can be adopted, but specific adaptations are required. These include methodological aspects of the analysis of Arabic sources, for instance the evaluation of isnad (chain of narrators) when assessing the reliability of relevant accounts in secondary sources. The dating is given in the Hijri calendar system based on lunar months. Its conversion into the Gregorian calendar is typically possible with a precision of one day. Arabic documentary data can be used to establish time series of hydroclimatic information with at least decadal resolution for most of the time span from 800 to 1500 AD. However, for some sub-periods much higher resolution can be achieved, e.g., daily resolution for periods in the 13th and 15th century where we can rely on information from diaries. The spatial distribution of the data for some periods further allows the reconstruction of large-scale temperature and precipitation fields (Fig. 3b, for details on methodology see Riemann, 2011). Future work also includes the reconstruction of more or less continuous temperature and precipitation series at a seasonal time scale. Figure 3a presents a preliminary time series of hydroclimatic winter conditions for Iraq. This time series is not fully homogenous yet, with major data gaps between 1200 and 1400 AD and therefore it does not allow an interpretation of the climate in the area for the whole period. However, in the currently available data, for instance for the periods 900-950 and 1020-1070 AD, a higher frequency of particularly wet winters can be observed.

The results will be further refined and compared with independent climate evidence from natural archives. Furthermore, links with North Atlantic/European and subtropical/tropical climate will be analyzed. Paleo-model output will be used to understand climate variations from the MCA over the Little Ice Age onwards to current conditions in the Middle East.

Acknowledgements

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References


Nile flood discharge during the Medieval Climate Anomaly

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Records of Nile flood discharge from AD 930 to 1450 reveal pronounced variability in the frequency of extreme floods due to differential influence of global climatic forcing mechanisms on the two main catchment areas of the Nile tributaries, namely Equatorial Africa and the Ethiopian Highlands.

A record of variations in Nile flood discharge dating back to the 7th century AD (Hassan, 1981) provides a basis for analyzing the relationship between Nile floods, climate change, and famines in Egypt during the Medieval Climate Anomaly (MCA). The volume of Nile flood discharge, as well as its seasonality, is primarily governed by the impact of climate on rainfall over the Nile catchment areas in Ethiopia and Equatorial Africa. Throughout Egyptian history, Nile floods influenced food production, which depended on Nile water for irrigation and the amount of silt annually deposited on the floodplain. Correction and calibration of the primary historical annual records of Nile minimal and maximal flood levels, followed by an analysis of the calibrated data reveal that Nile floods discharge during the MCA interval from AD 930 to 1350 were not constant. Instead, this period is characterized by multi-decadal long episodes of major low Nile flood levels from AD 930 to 1070, and from AD 1180 to 1350, as well as periods of major high Nile flood levels from AD 1070 to 1180 and from AD 1350 to 1470 (Fig. 1).

In addition, examination of the frequency of periods of anomalously extreme Nile floods (i.e., annual floods with unusually high or low levels) with known historical crises (Hassan, 2007) reveals that the onset of the MCA was marked by a dramatic increase of extreme low floods. The percentage climbs from 0-3% to 12% during the period from AD 930 to 1070 and to 14% from AD 1070 to 1180, in spite of an overall increase of the volume of flood discharge during that latter period. Subsequently, from AD 1180 to 1350, the number of extremely high floods increased at the expense of extremely low floods (Fig. 1). This period, characterized in general by a decrease in Nile flood discharge, coincides with the epic droughts that occurred from AD 1209 to 1350 in Californian mountain ranges as documented by tree stumps (Stine, 1994), suggesting a global climatic teleconnection. These droughts, according to Knox (1993), were apparently associated with changes in mean global annual temperature of 1-2°C. Nevertheless, apparently slight climatic changes in mean global temperature from the 9th to the 15th century were associated with pronounced hydrological responses. This is confirmed by the simulation of the hydrology of the Nile in response to different climate change scenarios (Conway and Hulme, 1996); precipitation anomalies were found to produce larger changes in runoff of about threefold magnitude. The high sensitivity of Nile flood discharge to changes in precipitation is further confirmed by recent historical changes with a 20th century (AD 1900-1984) average of 85 billion cubic metres compared to 110 billion cubic meters from AD 1870 to 1899 (Said, 1993).

The impact of fluctuations in Nile flood discharge during the MCA on the geomorphology of the flood plains is attested by the dramatic changes in the area of the capital city Cairo during this period (Hassan, 1997). Until AD 942, the eastern bank of the Nile floodplain was narrow and restricted to the area currently known as Old Cairo (Misr al-Qadima). Almost all of the area now occupied by the city was created in the ensuing period from AD 942 to 1403.

Comparison of the variations in Nile flood discharge with proxies of the North Atlantic Oscillation (NAO; Jansen and Koç, 2000; Baker et al., 2000) demonstrate a remarkable coherence between the fluctuations of Nile flood discharge and variations in North Atlantic sea surface temperature (SST). In general, variations in Norwegian Sea summer SST from AD 910 to 1070, from AD 1180 to 1340, and from AD 1400 to 1500 are inversely correlated with the fluctuations in Nile flood maxima (Jansen and Koç, 2000). By contrast, the Norwegian Sea summer SST variations are positively correlated with the fluctuations in Nile flood maxima from AD 800 to 910, from AD 1070 to 1180, and from AD 1700 to 1800. This “flip-flop” relationship is also manifested when variations in summer sea surface temperatures at Voring Plateau off central Norway (Jansen and Koç, 2000) are compared with the Nile flood discharge, albeit not synchronously (Hassan, 2007). However, from AD 930 to 1010 and again from AD 1200 to 1350, as well as from AD 1400-1500 and AD 1700-1900 the temperatures at Voring Plateau are inversely correlated with the height of Nile flood maxima. By contrast, from AD 800 to 850, from AD 1070 to 1180, and again from AD 1350-1400 the relationship is concordant (Hassan, 2007).

Nile flood discharge was also found to be in concordance with the Indian monsoons (Zickfeld et al., 2005), co-varying positively, except for the period from ca. AD 850 to 1080, when they are inversely correlated (Hassan, 2007). This may be in part related to the effect of ENSO and the extreme El Niño events between AD 967 and 1096, which often cause a reduction in Nile flood discharge (Quinn, 1992). Indeed, Nile discharge was low from AD 930 to 1070.

Figure 1: Percentage of anomalously low floods (red) and of both extremely low and high floods (blue) superimposed on the major episodes of low and high Nile flood discharge.
The Nile, is influenced by ENSO, and the land surface moisture, lakes and swamps. East Africa, one of the main sources of SST of nearby Indian and Atlantic oceans. Atlantic multidecadal regimes, and that precipitation in the catchments is influenced by the proxies, their locations. In this respect, it is particularly important to realize that the main catchment areas of the Nile tributaries—the Ethiopian Highlands (10°N) and the Equatorial Highlands. Throughout the period from AD 950 to 1350, famines and plagues have sometimes at close intervals. The deleterious impact of the fluctuations in Nile flood discharge was relatively high. This was associated with an increase in water flow from Ethiopia relative to that from Equatorial Africa (Hassan, 1981). These results indicate that Nile flood discharge in the Main Nile is influenced by multiple variables associated with the differential effects of global climatic mechanisms, such as NAO and ENSO, on the catchment areas in Equatorial Africa and the Ethiopian Highlands. Throughout the period from AD 950 to 1350, famines and plagues have had an adverse effect on society. The famines were in numerous instances caused by clusters of deficient Nile flood discharge, sometimes at close intervals. The deleterious impact of the fluctuations in Nile flood discharge were compounded by the impact of extremely high and low Nile flood discharges on the geomorphology of the channel and floodplain, influencing land use. Shifts in the relative contribution from the Equatorial and Ethiopian tributaries characterized by different rainfall seasons would have also negatively influenced agricultural food production.

An understanding of the variations in Nile flood discharge must take into consideration the various global and local climatic variables influencing rainfall in the main sources of the Nile. Correlations with proxies of change elsewhere are also subject to the peculiarities of the proxies, the integrity of the evidence, and their locations. In this respect, it is particularly important to realize that the main catchment areas of the Nile tributaries—the Ethiopian Highlands (10°N) and the Equatorial Plateau (equator) are more than 1000 km apart and are influenced by different climatic regimes, and that precipitation in the catchments is influenced by the proximity to oceans, highland topography, land surface moisture, lakes and swamps. East Africa, one of the main sources of the Nile, is influenced by ENSO, and the SST of nearby Indian and Atlantic oceans. Farther North, the effect of NAO is more pronounced (Dore, 2005). Zhang and Delworth (2006) concluded that multidecadal variability in the Atlantic Ocean could cause observed multidecadal variations of Sahel and Indian summer rainfall. Street-Perrott and Perrott (1990) observed that several prolonged droughts in the Sahel during the past 14 ka were associated with large injections of freshwater into the northern Atlantic Ocean.

Using proxy data from Scotland and Morocco, Trouet et al. (2009) found persistent positive NAO during the MCA, resulting in stronger than average westerlies across the mid-latitudes and to a northward migration of the Intertropical Convergence Zone, affecting rainfall both in Equatorial East Africa and Ethiopia (the main water sources of the Nile; Fig. 2). This may explain the two wet episodes from AD 1070 to 1180 and again in the transition to the Little Ice Age from AD 1350 to 1470. However, this modality was interrupted by a low discharge episode from AD 1180 to 1350.

The Nile record clearly indicates that a distinct anomaly marked by extremely low floods and an overall diminution in Nile flood discharge lasted from AD 930 to 1070 (Fig. 1). Although the frequency of total extreme floods (blue line) persisted, there was a shift to a higher percentage (ca. +10% from AD 900 to 1350) of extremely high floods relative to extremely low floods (red line). Even though a period of relatively high flood discharge lasted from AD 1070 to 1180, a return to lower flood discharge occurred from AD 1180 to 1350.

By AD 1350 and until 1470, coinciding with a transition to the Little Ice Age, the Nile flood discharge was relatively high. This was associated with an increase in water flow from Ethiopia relative to that from Equatorial Africa (Hassan, 1981). These results indicate that Nile flood discharge in the Main Nile is influenced by multiple variables associated with the differential effects of global climatic mechanisms, such as NAO and ENSO, on the catchment areas in Equatorial Africa and the Ethiopian Highlands. Throughout the period from AD 950 to 1350, famines and plagues have had an adverse effect on society. The famines were in numerous instances caused by clusters of deficient Nile flood discharge, sometimes at close intervals. The deleterious impact of the fluctuations in Nile flood discharge were compounded by the impact of extremely high and low Nile flood discharges on the geomorphology of the channel and floodplain, influencing land use. Shifts in the relative contribution from the Equatorial and Ethiopian tributaries characterized by different rainfall seasons would have also negatively influenced agricultural food production.

**References**


The Medieval Warm Period redux: Where and when was it warm?

Lisbon, Portugal, 22-24 September 2010

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In recent years, an increasing number of studies have been published describing elements of the Medieval Climate Anomaly (MCA). The general time frame for this epoch is generally taken to span from ca. 950-1300 AD. In order to assess the most updated and comprehensive characterization of the MCA period at regional and global scales, a symposium was organized and held in Lisbon, in September 2010. The symposium topics, within the framework of the PAGES 2k Network, are at the interface of Regional Climate Dynamics and Global Earth-System Dynamics (PAGES Foci 2 and 3), and overlap with the goals of Cross-Cutting Theme 2 (Proxy development, calibration, validation) and Cross-Cutting Theme 3 (Modeling).

The main objective of the 3-day symposium was to revisit the MCA by incorporating widespread and continuous palaeoclimatic evidence in a homogeneous and consistent manner, and to scale it against the instrumental temperature record to allow a meaningful quantitative comparison in the magnitude of warming against the 20th-century pace. The déjà-vu title was chosen on purpose, as the organizers wanted to revisit the question posed already in 1994 by Hughes and Diaz in their Climatic Change review “Was there a Medieval Warm Period, and if so, where and when?”, taking into account that the latest IPCC report in 2007 (WG1) emphasizes the same ambivalence: “Regionally restricted evidence by itself, ... is of little practical relevance to the question of whether climate in medieval times was globally as warm or warmer than today”.

The symposium, attended by 35 participants from 10 different countries including a mix of senior scientists and early career researchers, was divided in two parts: 1) Establishing the MCA Epoch as a Distinct Period, and 2) Climate Reconstruction Tools and Numerical Modeling of the MCA Climate. The first part focused on already existing and new proxies capable of resolving temperature changes in the last two millennia and covering a wide spectrum of regions (R. Bradley), including Tropical Pacific (K. Cobb), the Mediterranean basin (E. Xoplaki), western Europe (J. Guiot; D. McCarroll; A. Moreno), North America (J. Overpeck; A. Vlau), the North Atlantic (G. Miller), Greenland (B. Vinther), the Arctic (D. Fisher; D. Kaufman) and South America (J. Luterbacher). Other authors provided a wider picture on the spatial and temporal extension of the MCA event (D. Fleitmann; M. Hughes; P. Jones; F. Luntqvist; M. Mann) or the underlying large-scale dynamics associated with the MCA and the LIA period (R. D’Arrigo; V. Trouet; E. Wahl; H. Wanner). The second part of the symposium was mostly devoted to the latest results obtained by the modeling community (D. Shindell; N. Graham; F. González-Rouco), emphasizing the need for better assimilation procedures (H. Goosse), capacity to reproduce major drought and wet periods (R. Seager) but also reproduction of large-scale patterns such as the AMO (R. Oglesby) and blocking (D. Barriopedro), as well as the need to improve the characterization of the solar activity variability (R. Trigo).

In summary, in answer to the question posed above regarding the spatial and temporal scales of the MCA, the general consensus of the participants is that in the past 15 years additional evidence has become available of a climatic anomaly occurring during the time interval ca. 900-1300 AD, albeit with important differences regarding the timing and spatial extent. The participants also stressed that a Northern Hemisphere or global mean value is of less relevance when looking at the regional spatial scales where the impacts of climatic anomalies are experienced.

A more detailed description including scientific conclusions of the symposium can be found in this issue of the PAGES Newsletter. A special issue in the journal Global and Planetary Change (Elsevier) has also been negotiated and the organizers are confident that a significant number of talks presented at the symposium will be published in this dedicated issue. Additionally, a review article with the current state-of-the-art consensus on the MCA epoch is currently submitted to Bulletin of American Meteorological Society.

Acknowledgments

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Reference

Active Tephra 2010: International field conference on tephrochronology

Kirishima City, Japan, 9-17 May 2010

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INTAV meets in Japan
INQUA’s international focus group on tephrochronology and volcanism (INTAV) met in Kirishima in southern Kyushu. A total of 76 participants (including 25 students) from 12 countries attended. Around 50 oral papers, including six invited keynote talks, were presented over three days alongside nearly 40 posters. Financial support from PAGES and the INQUA INTREPID project enabled 11 young scientists to attend the conference. Further support was provided by the Tokyo Geographical Society, Paleo, West Japan Engineering, Asahi, JAQUA, and the city of Kirishima.

Papers and Eyjafjöll session
The conference commenced with two public lectures by David Lowe (Waikato University) “Connecting with our past: using tephras and archaeology to date the Polynesian settlement of Aotearoa/New Zealand” and by Hiroshi Machida (Tokyo Metropolitan University) “Widespread tephras originating from Kagoshima occurring in northeast Asia and adjacent seas.”

A highlight was a special session on the 2010 eruptions from the Icelandic Eyjafjöll volcano, which attracted local TV and newspaper coverage. This Eyjafjöll session included talks by Chris Hayward and Thor Thordarson (both Edinburgh University) and by Siwan Davies (Swansea University). It became evident that this eruption would provide an excellent opportunity to enhance knowledge on cryptotephras from Icelandic volcanoes, which are being increasingly utilized for time control in the Northern Hemisphere ice-core, marine and terrestrial records (Davies et al., 2010). An INTAV-sponsored meeting on the eruption and its implications for tephra studies will be held in Edinburgh on May 5-6, 2011 and a tephrochronology session is scheduled at the INQUA Congress in Bern in July 2011.

Further keynote presentations were given by Nick Pearce (Abertystwyth University) on developments and applications in LA-ICP mass spectrometry, Duane Froese (Alberta University) on Yukon-Alaskan Quaternary permafrost studies linked by tephras, Siwan Davies (Swansea University) on tephras in Greenland ice cores, Mitsuhiro Nakagawa (Hokkaido University) on petrology and eruption processes of Shikotsu and Aira calderas, Simon Blockley (London University) on tephra age-modeling including Bayesian studies, and Takeshi Nakagawa (Newcastle University) on recent geochronological and analytical work of the exceptional varve sequence of Lake Suigetsu.

Field trips
An intra-conference fieldtrip included a visit to the Uenohara Jomon-no-mori archeological centre where a village from the Jomon period (ca. 9.5 ka ago) had been preserved under tephra deposits. The group was then treated to a stunning and apt backdrop for a tephra-based meeting: the Sakurajima volcano has been active since 1955, with more than 8670 eruptions since then. Around 500 eruptions had already taken place in 2010 prior to this visit. Two small volcanic eruptions took place in Showa crater, by a remarkable coincidence, whilst the group visited the eastern flank of the volcano at the closest point to the active crater (Fig. 1). Furthermore, participants were taken to outcrops of layers of tephras and buried soils dating back 30 ka, to the spectacular Jomon Tenjindan archeological site, and to a magnificent coastal exposure, ~20-30 m high, of the deposits of the voluminous Aita tephra formation dated at ca. 30 ka.

The conference was followed by a three day trip to the Unzen volcano where deposits from the 1990-1995 eruption series, including lava domes, block-and-ash flow deposits, and pyroclastic flow deposits, were seen. Visited sites also included the extremely impressive ~25-km-wide, Aso caldera and associated deposits, the volcanic vents in central Kyushu, and the volcanoes of Kuj and Yufu-Tsurumi in northeastern Kyushu.

Conclusion
The conference and field trips were remarkable. As one veteran participant remarked, “tephra studies have never been so healthy.” The rise of young tephrochronologists was especially prominent and augurs well for future research and leadership of the discipline. Papers from the meeting are to be published in a volume of Quaternary International that will also commemorate the career of Hiroshi Machida.

Reference
Paleochronology building workshop

San Miguel de Allende, Mexico, 17-21 August 2010

Maarten Blaauw1, J. André Christen2 and Workshop Participants

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Chronologies are vital for the study of past global change. The strength of conclusions based on paleoenvironmental reconstructions is often constrained by the precision and reliability of their chronologies. However, constructing paleochronologies can be a daunting task requiring a detailed knowledge of statistical techniques and/or dedicated software. For example, radiocarbon dates require calibration, ages might have to be estimated for non-dated core depths, and chronological uncertainties need to be quantified as reliably as possible.

This summer an educational workshop on paleochronology building was held in San Miguel de Allende, central Mexico. The workshop attracted 27 participants (Fig. 1) from a range of continents (North America, Europe, Asia, Australia, Africa), career stages (from early PhD students to senior faculty), and scientific backgrounds (e.g., 14C dating, modeling, statistics, palynology, oceanography and peat research).

Lectures were given on the theory of radiocarbon calibration, classic and Bayesian sediment age-depth modeling and multi-site interpretations. In addition to the theoretical sessions, much time was devoted to hands-on computer sessions where participants used some of the latest age-modeling software, in particular clam (Blaauw, 2010), OxCal (Bronk Ramsey, 2008), Bchron (Haslett and Parnell, 2008), and Bacon (a recent update to Bpeat; Blaauw and Christen, 2005).

A very interesting poster session was held, with an innovative promenade guided tour by each of the poster presenters. Local cuisine was sampled and excursions were organized to the town’s beautiful colonial center and to El Charco Del Ingenio, a huge botanical garden with an impressive range of cacti). Time was also set aside to discuss plans for future collaborations and papers. The workshop started by introducing the ideas and methods of calibrating radiocarbon dates, basic age-depth modeling (e.g., linear interpolation), and Bayesian statistics. This was followed by more advanced topics including models of sediment accumulation, detection and treatment of outlying dates, methods to decide which depths of a core to date next, and multiple-site synthetic methods such as tuning and Bayesian synchronicity tests. Eric Grimm (Illinois State Museum) gave an additional presentation on the Neotoma metadatabase initiative for paleo-data.

The following workshop days were mostly devoted to applying the discussed methods in practice. Next to producing age-models for individual sites, the chronological uncertainties of the proxies themselves were plotted as “ghost graphs” (Blaauw et al., 2007), and several methods were applied to integrate multiple proxy sites. For example, if multiple sites contain the same imprecisely dated tephra, an integrated age estimate of that tephra based on all sites will be more precise and reliable than if calculated from individual sites. Another approach was to test for the synchronicity of environmental proxy events between multiple sites, without resorting to tuning. Of course, participants were given ample time to the age-modelling techniques to their own sites.

Information about the workshop, including presentations and software, can be found on http://chrono.qub.ac.uk/blaauw/Workshop/ and http://www.cimat.mx/Eventos/PBW/.

Acknowledgments

The workshop organizers wish to thank PAGES and INQUA (under the tephra initiative INTREPID led by Prof. David Lowe, New Zealand) for their financial support of this meeting.

References

Paleo-ocean acidification and carbon cycle perturbation events

NSF-PAGES workshop, Santa Catalina Island, USA, 25-29 August 2010

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Ocean acidification is a current area of concern for the future functioning of marine ecosystems and ocean biogeochemical cycles. The term “ocean acidification” describes the effects of the oceanic uptake of anthropogenic CO₂ including a progressive decrease of seawater-pH. While seawater is not likely to ever become acidic, a reduction in pH and associated carbonate system changes may nevertheless affect ocean biogeochemical processes, particularly biological calcification. However, modern ocean observations and laboratory experiments consider time scales that are too short to reveal the long-term potential of marine organisms to acclimatize or adapt to changing environmental conditions. Furthermore, as experiments focus on a few species or isolated strains, they provide little information on the potential for whole ecosystem changes. The U.S. National Science Foundation (NSF) and PAGES jointly sponsored this workshop to bring together an international group of carbon cycle modelers, carbonate chemistry specialists, and biological, chemical and physical (paleo-) oceanographers to discuss past carbon cycle perturbations and the long-term response of marine organisms to changing conditions, and to provide a geological perspective on future concerns.

Richard Zeebe (University of Hawaii) and Andy Ridgwell (University of Bristol) presented the boundary conditions of past marine carbonate chemistry and stressed the importance of distinguishing between extended periods of high pCO₂ with relatively slowly evolving ocean carbonate chemistry, and geologically rapid changes which reflect chemical effects more comparable to the consequence of ongoing CO₂ emissions. Acknowledging that the rate of anthropogenic CO₂ emissions is probably unparalleled in recent Earth history, Zeebe defined an “ocean acidification event” as one having a duration shorter than about 10 ka. Pleistocene glacial to interglacial transitions and early Cenozoic hyperthermals fall under this definition, but the only event that may be comparable in magnitude of CO₂ release is the Paleocene-Eocene Thermal Maximum (PETM).

Daniela Schmidt (University of Bristol), Luc Beaufort (CEREGE) and Sam Gibbs (NOC Southampton) reiterated the importance of the rate of environmental change in assessing the potential for future changes in marine ecosystems. They also focused on the complications associated with attributing biological responses to paleo-ocean acidification. Identifying stressful conditions at the sea surface, which would affect organisms’ biology including calcification, is often indistinguishable from competing factors affecting preservation at the seafloor. Similarly, synergistic effects of temperature or nutrient changes cannot necessarily be separated from shifts in ocean carbonate chemistry. Independent proxy evidence is therefore of utmost importance to identify the physical and chemical boundary conditions that led to physiological and ecological shifts. In addition, the fossil record is biased towards those organisms that secrete skeletal hard parts, in particular marine calcifiers. Ecologically important phyto- and zooplankton are rarely preserved in the sediment and little is known about their fate under past ocean acidification conditions.

Proxies for ocean carbonate chemistry include the boron isotope proxy for seawater-pH, the carbon isotopic composition of alkenones for aqueous CO₃, foraminiferal B/Ca and U/Co ratios for bottom-water carbonate saturation and carbonate ion concentration, foraminiferal shell weights, and the depth of the carbonate compensation depth to constrain whole-ocean carbonate saturation. Gavin Foster (NOC Southampton) and Jimin Yu (LDEO) presented proxy comparisons and recent advances in paleo-pH reconstructions. They demonstrated that quantitative reconstructions beyond the Pleistocene glacial/interglacial cycles are limited by uncertainties on the elemental and isotopic composition of seawater, and the lack of estimates on a second parameter of the carbon system from the same surface or deep-ocean environment. In addition, most of the established proxies are based on marine carbonates. This is problematic for ocean acidification events in which widespread dissolution of carbonates occurs, such as during the peak of the PETM (when only clays and organic molecules were preserved in many Atlantic sediments) (e.g., Fig. 1). As a novel approach to address this issue, Appy Sluijs (University of Utrecht) presented promising findings on the carbon isotopic composition of organic dinoflagellate cysts as a candidate proxy for aqueous CO₂.

The workshop reiterated that no perfect analogue to anthropogenic ocean acidification has yet been found in Earth’s geological record, but that an improved knowledge of the physicochemical boundary conditions in the surface and deep ocean, their rates and magnitudes and biological responses will nevertheless place important constraints on the consequences of current and future ocean acidification. A more comprehensive report on the rates, magnitudes and evidence for paleo-ocean acidification will be published as a peer-reviewed paper.

References


Figure 1: Core section from Shatsky Rise ODP Site 1210A, showing reduced carbonate preservation at the Paleocene-Eocene Thermal Maximum. During the PETM 30-50% of deep-sea benthic foraminifer species suffered extinction (Thomas, 1998). The scale bar on the right indicates depth of the core section in cm, which reflects on the lower sedimentation rate after the onset of the event. Picture credit: Laura Foster, University of Bristol; dates after Westerhold et al. (2008).
The evolution of floodplain lakes systems was the theme for a workshop held in Fayetteville, in September 2010. This workshop attracted 30 participants from across the USA, but also from Australia, Russia, Canada, Brazil, and China, with case histories presented from the Murray-Darling, Yangtze, Mississippi and Missouri, Amazon, Rio Manu, Sacramento, White River, Peace-Athabasca and Cauca (Columbia) river systems.

The meeting arose from a gathering at the 3rd PAGES Open Science meeting in Corvallis, Oregon, in 2009 and was set within Focus 4 ("PHAROS") of PAGES, and particularly aligned with the Theme "Water" and the associated Working Groups Human Impacts on Lake Ecosystems (LIMPACS) and Land Use and Climate Impacts on Fluvial Systems (LUCIFS).

The presentations spanned three main themes: proxy and chronological development, regional integration and evidence of human impact. The 20 presentations and seven posters covered evidence of accelerated catchment sediment yields, lead and other metal pollutants, and the response of floodplain wetlands to connectivity to the river, regulation of flow, and alteration to water quality. Situated in the Mississippi Basin, the meeting explored in detail the evolution of meander belts in the Missouri River with climate-driven shifts between meandering and braided states, as evident from dated paleo-wetland sequences (Fig. 1).

Considerable discussion was directed towards the particular challenges that are posed by undertaking paleoenvironmental research in such dynamic systems and the need to develop links between researchers working on the history of these systems. Despite recognition of these challenges, study after study showed that sedimentary profiles provided decipherable and informative records of hydroecological changes, and participants identified that a focus on river-wetland interactions holds considerable promise for addressing scientific and management issues of high societal concern. In particular, capacity was seen to engage with those river authorities that were underpinning policies and management decisions only with short-term instrumental records. It was also noted that floodplain sites were of cultural significance as many communities live within floodplains and it is often via rivers that humanity experiences climate variability (droughts and floods).

In line with the goals of PHAROS the meeting initiated discussion on regional upscaling of data. This was exemplified by the presentation of a regional synthesis of wetland change from the Murray Darling Basin. This further stimulated the creation of a network of floodplain lake researchers across North America to roll-start the process of assembling a database of geomorphic and paleolimnological research with a view to providing evidence for regional patterns of change and for identifying regions in need of research.

The organizers received considerable interest in response to the call for papers for a special issue of the Journal of Paleolimnology. The participants also made plans for a biannual meeting at which point the community may be in a position to plan for a substantive review output such as an issue in the Developments in Paleoenvironmental Research (DPER) series. Further, the focus of several projects on RAMSAR (convention on wetlands of international importance) sites (in Australia, Columbia, USA and Brazil) stimulated a proposal for a future activity focussed on exchanging palaeoecological evidence of change with agencies vested with the responsibility of assessing the natural ecological character of listed wetlands and setting limits of acceptable change.

![Figure 1: The evolving styles of Missouri River channels. Channel fills older than 3.5 ka BP are highly sinuous with neck cutoffs generating long oxbow lakes. An abrupt climate driven shift in channel shape induced shorter oxbows from lower sinuosity channels, interspersed with sandy islands. From 3.0 ka BP the channels adopted a more braided pattern with few substantive oxbow lakes, with braiding the prevailing state by 1.5 ka BP. The evolving pattern reflects sustained and ongoing increases in the ratio of bedload to discharge.](image)

**Lakes, rivers and floodplains: Evolving relations**

**Floodplain Lakes Workshop, Fayetteville, USA, 16-19 September 2010**

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Southern Hemisphere (SH) high-latitudes are challenging places to document and understand the mechanisms of natural climate variability: (1) the regional climate response involves complex and poorly documented interactions involving all the components of the climate system; (2) temperature changes are amplified compared to low latitude environments; and (3) Antarctica and its surroundings are characterized by a strong regional variability. These regional differences are obvious during the recent instrumental period, which depicts a large warming over western Antarctica during the last 50 years while no clear trends were observed for other Antarctic regions. Regional differences have also been highlighted over the course of the Holocene from geological and glacial records, supported by model experiments.

In the framework of the European Science Foundation (ESF) PolarCLIMATE program (http://www.esf.org/research-areas/polar-sciences/polarclimate.html), HOLOCLIP aims to bring together the ice core, marine sediment core and modeling communities to study the processes linking the different components of the climate system and linking the climatic response to the external forcing over the Holocene. Key areas of the Antarctic Ice Sheet and their marine surroundings have been selected (Fig. 1).

The objectives of this Joint Research Project are multiple and can be grouped as follows:

1. To validate and calibrate our proxies through investigation of the modern systems, to improve understanding of the tools that we currently use for climatic reconstructions.
2. To document changes in the different components of the Holocene climate system in terms of amplitudes, frequencies and timing, using a multi-proxy approach.
3. To document the regional heterogeneity of the different climate components over the Holocene by investigating several marine cores from the Antarctic continental margin and ice cores from the ice sheet and integrating the results in climate models via assimilation techniques.
4. To evaluate relationships between the different components / parameters, through a detailed comparison of marine and ice-core records, to better document the interactions among atmosphere-cryosphere-ocean.
5. To quantify the main forcing factors and to detect the regional climate sensitivity to these forcings.
6. To document the feedbacks between different system components.

LOCEAN (Laboratoire d’Océanographie et du Climat: Expérimentation et Approches Numériques) at University Pierre and Marie Curie, hosted the HOLOCLIP kick-off meeting. Nineteen scientists from the ice, sediment and climate modeling communities gathered to discuss available data, plan activities and coordinate the scientific teams for the next year.

Each project partner presented their main contribution to HOLOCLIP to provide an overview of the available data and the plans for new data to be obtained (Fig. 1). Climate modelers presented the model (LOVECLIM) that will be used to perform transient and snapshot simulations.

The actions to be performed before the end of the first year of the project are:
- Laboratory measurements on ice and sediment cores to produce additional high-resolution data sets.
- The compilation of a database hosted on the project website (www.holoclip.org) to facilitate a number of synthesis products.
- Data synthesis of Antarctic temperatures, sea-surface temperatures and sea ice cover at five time slices (8, 6, 4, 2, 0 ka BP). Data synthesis will serve as a ground truth for climate model evaluation and data assimilation.
- Exchange of samples among partners (both modern and fossil) to achieve the best calibration and paleo-reconstructions possible.
- Exchange of young scientists among partners for training.

ESF-HOLOCLIP is funded by national contributions from Italy, France, Germany, Spain, The Netherlands, Belgium and the United Kingdom, with Stanford University as an associated partner.

Figure 1: The investigated areas (green boxes) are reported on a map showing the ice (red dots) and marine (blue dots) core locations. The gray shaded area is the position of the modern polar front zone.
Asia is an important region in the PAGES 2k Network for the reconstruction of climate of the last 2000 years. Around 60% of people in the world live in Asia and major climate phenomena, such as large-scale monsoon systems, affect their livelihood regionally and the climate system globally. However, paleoclimate data of last two millennia have not been integrated well in Asia until now.

For the reconstruction of paleoclimate with annual or sub-annual time resolution, tree rings are one of the most advantageous climate archives. Many long tree-ring chronologies have been established in cold and dry Asia such as the Tibetan plateau and Gobi desert. Unlike most higher latitude regions, tree-ring studies in tropical and subtropical Asia are constrained by the additional challenge of harboring only few tree species that form annual rings. However, dendrochronologists have recently managed to overcome this limitation by systematically searching for ring-forming and climate-sensitive tree species, and have successfully developed the first tree-ring based reconstructions of past precipitation and temperature in humid and temperate Asia, including Indochina, Taiwan, and Japan.

Furthermore, historical documents, especially from China, provide exceptionally long records of past climate with a seasonal resolution that can reach back to more than two millennia. Lake and marine sediment studies have also resulted in important data sets of high-resolution climate variations in Asia. A growing number of speleothems records from China and many other countries reflect past hydroclimates on various time scales. Ice cores from the mountains and corals from coastal regions provide further unique data sets on climate dynamics from land and ocean.

The first Asia 2k Regional Workshop was designed to review the state of paleoclimate science in Asia towards the synthesis of various kinds of proxy-based Asian climate reconstructions during last two millennia.

A total of 73 scientists and students, including the 15 invited international scientists, attended this workshop with 24 oral and 26 poster presentations. Oral sessions consisted of keynotes by members of the scientific committee (E. Cook, H. Borgaonkar, B. Buckley and O. Solomina), followed by presentations on state-of-the-art proxy-based reconstructions of Asian paleoclimate using tree rings, ice cores, stalagmites, lake sediments, marine archives and historical documents together with climate modeling. Proxy, region and time range covered by all oral presentations are illustrated in Fig.1. All abstracts and presentations can be viewed on the Asia 2k website (http://www.pages-igbp.org/index.php/workinggroups/asia2k/publications).

The tree-ring session started with the presentation of a gridded reconstruction of the Palmer Drought Severity Index (Monsoon Asia Drought Atlas) using a continental scale database of tree-ring width ((1) E. Cook, same hereafter). Tree-ring chronologies did not only reveal long climate histories in the cold and dry Asia ((2) Y. Liu, (4) R. Yadav, (5) J. Palmer, (11) O. Solomina) but they also demonstrated the value of tree rings for climate reconstructions in humid and temperate Asia ((3) H. Borgaonkar, (6) B. Buckley, (7) W. Wright, (8) K. Yasue, (9) Y. Hoshino, (10) T. Nakatsuka). After a comprehensive review of Asian mountainous ice core studies ((12) K. Fujita), new speleothem records were presented from South and Southeast Asia ((13) V. M. Padmakumari, (14) C. Muang song). Lake and marine sediment records presented ((15) Shankar, (16) Yamada, (17) M-T. Chen) covered more than 2000 years with decadal time resolutions. Finally, various climate records were presented from Chinese historical documents ((19) Q. Ge, (20) T. Nagano).

After the workshop, the Scientific Committee and other workshop participants discussed future directions of the Asia 2k Working Group in detail and tentatively concluded that the second Asia 2k workshop should be held in the fall of 2011 in order to conduct a training course for analyses and compilation of past climate data sets towards the 2k paleoclimate synthesis in Asia.
This educational course on quantitative paleoecology and South American climatology was organized as a pre-conference event prior to a major international PAGES symposium in Valdivia (see below). The objective of this course was to impart a high level of first-hand knowledge to early career researchers from Latin American countries working in paleoecology and paleoclimatology. The course topics had been selected on the basis of students’ enquiries that followed the “International Workshop on Methods in Quaternary Palaeoecology” held in La Serena in 2007 (Maldonado and Latorre, 2008).

A total of 27 participants from Argentina (11), Chile (8), Brazil (3), Colombia (2), Switzerland (2) and Bolivia (1) were chosen from over 70 applicants. All participants were graduate students or young post-doctoral scientists working with a variety of different paleo-proxies (pollen, diatoms, tree rings, plant macrofossils, etc.) on projects across South America (Fig. 1).

The lectures on the first three days of the course were given by Prof. John Birks (University of Bergen) on quantitative paleoecology and environmental reconstructions, including an overview of the major numerical methods such as ordination analysis, analysis of stratigraphical data, data calibration and transfer functions. The last two days, Prof. René Garreaud (University of Chile) gave a presentation on South American climatology including the basic climate dynamics, the fundamental statistical tools applied in climatology and the general concepts of South American climate. After the lectures, the participants had the opportunity to discuss their own data with the lecturers and immediately apply their newly acquired knowledge.

Given that the course topics were highly relevant to the general PAGES objectives, all participants also attended the II International Symposium “Reconstructing Climate Variations in South America and the Antarctic Peninsula over the last 2000 years” (LOTRED-SA) the following week. At the LOTRED-SA conference, they met experienced researchers working on different projects in South America and had the opportunity to exchange and discuss ideas with them.

Initiatives like this PAGES supported educational meeting, offer emerging South American researchers the chance to gain access to the finest knowledge and expertise.

The conveners wish to thank Prof. John Birks and Prof. René Garreaud for their willingness to deliver the course and PAGES, University of La Serena, Centre for Advanced Studies in Arid Zones (CEAZA), Southern University of Chile (UACH) and Center for Scientific Studies (CECS) for financial and logistical support.

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