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PAGES news
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Japanese Paleoscience

Editors:
Takeshi Nakatsuka, Ryuji Tada, Kenji Kawamura and Lucien von Gunten

During the "Edo" era in Japan from the 17th to 19th century, corresponding to the Little Ice Age period, cold and rainy summers often caused serious famines in Japan, such as the "Tenpo famine" in the 1830s when this picture was painted.

Inside PAGES

PAGES publications

Publications resulting from PAGES activities over the last months are too numerous to be mentioned individually here, but you can browse them in our products database on the PAGES website. Nevertheless, three PAGES working groups (WGs) produced oeuvres in the form of special issues that deserve highlighting: The PALSEA WG published a special issue in Earth and Planetary Science Letters, the Global Monsoon WG in Climate Dynamics, and the LOTRED South America WG in Climate of the Past. All are listed and linked in the PAGES product database.

The Goa meetings

Anticipation is mounting about the rapidly approaching 4th PAGES Open Science Meeting (OSM) and 2nd Young Scientists Meeting (YSM), which will be held in February 2013 in Goa, India. The OSM will not only be a forum for the exchange of latest research results, but also one for open discussions on the best way forward for our research field, particularly in the context of changing scientific boundary conditions as envisioned by the Future Earth process (see page 89). The scientific OSM program will have plenary, parallel, and poster sessions and a public lecture. The 588 accepted OSM abstracts are an indication that we can look forward to a most lively event. Although abstract submission is closed, registration will remain open until the event itself for the more spontaneous attendees. The two days prior to the OSM will be all about the next generation of paleoscientists. During the YSM, 80+ competitively selected participants will talk science, train their professional skills, and forge connections across disciplinary and regional boundaries.

Staff updates

Saadia Iqbal has joined the PAGES International Project Office (IPO), replacing Anand Chandrasekhar as the new PAGES Project and Communications Officer. Saadia, a US citizen, has a background as a writer and editor. Before joining PAGES she worked, among other places, at the World Bank and *National Geographic* Magazine. We welcome Saadia to PAGES and are looking forward to working with her!

Guest scientists

Two early-career researchers, Emma Stone and Emilie Capron, spent two months this fall at the PAGES IPO to guest-edit the upcoming PAGES newsletter issue. The issue was initiated by the European project Past4Future and will focus on interglacial climate, specifically the last interglacial and the Holocene. Emma, a postdoc at the School of Geographical Sciences at the University of Bristol, UK, studies the climate of past warm periods using climate models of varying complexity. Emilie, a postdoc at the British Antarctic Survey, UK, is an ice core scientist studying the past evolution of firns and the temporal evolution of the last interglacial climate in polar and sub-polar regions. The guest-editing by the two young researchers was intended to add to their professional skill set. They indeed learned fast and well and the product is something to look forward to. Their newsletter issue will come out in early 2013.

If you are also interested in spending time as a guest scientist at the PAGES office to work in a focused way on PAGES-related work for a period of a few days to several months, get in touch and send us your application. Find detailed information on the website under My PAGES > Get involved.

SSC nominations

Earlier in the year than usual, PAGES is inviting nominations of scientists to serve on its Scientific Steering Committee (SSC). The SSC is the body responsible for overseeing PAGES activities. Scientists who serve on the SSC normally do so initially for a period of three years, with potential for renewal for an additional term. Up to three new members who can contribute to a committee that is balanced in terms of expertise, geography, and gender are sought to join in 2014. The deadline for sending in nominations is 10 January 2013, so as to be in time for discussion at the SSC meeting directly following the Open Science Meeting. Please refer to the PAGES website for nomination guidelines (My PAGES > Get Involved).

Meeting support

The next deadline for applying for PAGES meeting support is 10 January 2013, for evaluation by the PAGES SSC in mid-February. Support can be sought for workshop-style meetings relevant to PAGES Foci and Cross Cutting Themes. The three meeting categories eligible include PAGES Working Group workshops, an open call for other PAGES-relevant workshops, and one for educational meetings. Application guidelines and online forms can be found on the PAGES website (My PAGES > Meeting Support).

Next newsletter issues

The next two issues of PAGES*news* will showcase special sections on the last two interglacials and on ENSO, respectively. While the interglacial issue is closed, suitable articles on ENSO may still be included. Contact Pascal Braconnot (pascale.braconnot@lsce.ipsl.fr) before 31 December 2012. As always, you are invited to submit Science Highlights, Program News, and Workshop Reports for the Open Section of PAGES*news*. Find author guidelines on the PAGES website (My PAGES > Newsletter).

PAGES Calendar 2012-2013

50 Pressing Questions in Paleoecology
13 - 14 Dec 2012 - Oxford, UK

PAGES YSM&OSM 2013
11 - 16 Feb 2013 - Goa, India

3rd PAGES 2k Network Meeting
12 Feb 2013 - Goa, India

5th PIGS Workshop
04 - 06 Mar 2013 - Louvin, Belgium

Euro-Med2k Workshop
25 - 26 Mar 2013 - Reading, UK

South American Paleoecology Workshop
01 - 12 Apr 2013 - Santiago, Chile

Chironomid Workshop
10 - 12 Jun 2013 - Southampton, UK

12th NCCR Climate Summer School
01 - 06 Sep 2013 - Grindelwald, Switzerland

www.pages-igbp.org/calendar/upcoming

Editorial: How does research in Japan contribute to the global body of paleoscientific knowledge?

Takeshi Nakatsuka[1], Ryuji Tada[2] and Kenji Kawamura[3]

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Despite its long tradition, Japanese paleoscience was not well represented in the scientific world until recently. This may be partly due to Japan's geographical location at the eastern rim of the Eurasian continent, far away from the scientific hotspots of Europe and North America. In addition, numerous publications were written in Japanese and have not yet been translated.

To strengthen the contact with the Japanese paleoscience community and to highlight the diversity of Japanese paleoresearch, a PAGES Regional Workshop was held in Nagoya, Japan in 2010, alongside the PAGES Scientific Steering Committee meeting. That workshop resulted in the idea of a dedicated special section of the PAGES newsletter. The following thirteen science highlights showcase to the global community a cross-section of Japanese contributions to paleoscience.

The North Pacific Ocean around Japan was for a long time one of the most under-researched areas in paleoceanography due to the very deep waters and the resulting scarcity of calcareous microfossils in the sediments. However, by taking advantage of recent progress in sediment coring technology (e.g. through the IMAGES program), Japanese scientists now have access to many new sediment cores. For example, *Okazaki et al.* used cores from sea mounts and continental slopes to demonstrate that deep-water ventilation occurred in the North Pacific during the deglacial as it does today in the North Atlantic. Recent studies in the western North Pacific Region (*Harada et al., Nagashima and Tada, and Yamamoto*) also show that the western North Pacific and its marginal seas are well suited to reconstruct millennial-scale climate variability.

Climate in East Asia, including Japan, is characterized by the strong Asian summer and winter monsoon, resulting in a meridional "green" belt extending from the equator to the subarctic uninterrupted by any major mid-latitude desert. The monsoon signal is well preserved in the sediments of Lake Biwa, one of the most studied lakes in Japan (*Takemura*). At the northwestern coast of Japan, the strong seasonality intrinsic to the monsoon has led to the formation of distinct varve layers in the brackish lake sediments of Lake Suigetsu. Detailed counting of varve layers up to 150 ka by *Nakagawa et al.* revealed details of climate variations over the entire last glacial-interglacial cycle. Moreover, with several hundreds of ^{14}C data of plant fragments in the dated varve layers, Lake Suigetsu is now becoming a new international standard for ^{14}C calibration.

Asian summer monsoon often favors dense forests where it is difficult to extract significant paleoclimate signals from tree-ring width. Alternatives are presented by *Sano et al.* and *Watanabe et al.* They indicate that oxygen isotope ratios of tree-ring cellulose and oxygen and carbon isotope ratios in stalagmites are good proxies for past hydroclimate in the humid tropical-subtropical regions of Asia. Finally, data from glacial ice cores in high mountains (*Fujita and Sakai*) and from coral cores in subtropical islands (*Suzuki*) help elucidate past changes in Asian monsoon dynamics.

Japan has a very long history and a unique cultural heritage. Japanese paleoscientists have been utilizing many precious cultural artifacts, such as documentary information, to reconstruct past variations in climate and environment. One of the significant features in Japanese culture is that, until the 19th century, most buildings in Japan were made of wood. The construction timber can be recovered from old buildings or excavated at archeological sites, and utilized for high-resolution climate reconstructions. When coupled with $\Delta^{14}C$ and $\delta^{18}O$ analyses, these studies can even help in elucidating impacts of changes in solar activity on Earth's past climate (*Miyahara et al.*).

In Japan, the quantity of historical private and governmental documents and their conservation is remarkable, reflecting the high literacy rates in premodern Japan. By assembling numerous weather descriptions in national diary archives, daily meteorological conditions in Japan, including weather charts, have been quantitatively reconstructed for the last 400 years (*Zaiki*). Historical documents not only describe daily weather but often also local environmental conditions such as deforestation and animal extinction, together with the population's (political) reactions to those environmental changes. *Yumoto* has led a unique research project involving historians and archeologists, and reports how the Japanese environment has been managed in the past and what lessons can be learned for the sustainable management of ecosystems.

Compared to Europe and North America, past climatic and environmental changes in the western North Pacific and East Asian regions, and their role in the global system, are still poorly understood. Many interesting challenges remain for Japanese and Asian paleoscientists, together with colleagues from elsewhere, to elucidate the unique climate and environment in this region.

Ocean circulation in the North Pacific during the last glacial termination

Yusuke Okazaki[1,2], A. Timmermann[3], L. Menviel[4], M.O. Chikamoto[3], N. Harada[2] and A. Abe-Ouchi[2,5]

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Sedimentary and modeling evidence presume a major deglacial switch between the sites of deepwater formation in the North Atlantic and North Pacific. These results suggest that the North Pacific may have played a more prominent role in organizing the global ocean circulation and shifting climate regimes than previously thought.

The North Pacific is considered a terminal region of the "Ocean's Conveyer belt circulation". Abyssal waters from the south flow into the North Pacific, upwell to mid-depth, mix with surrounding waters, and return south (Schmitz 1996). In this configuration and as a result of mixing, the present North Pacific is characterized by high concentrations of surface nutrients, thus promoting high biological productivity. Today, no deep water forms in the North Pacific in response to surface buoyancy fluxes because the surface water of the North Pacific is not saline and dense enough to trigger deep convection and downwelling (Warren 1983). However, in certain areas, such as the Okhotsk Sea, surface conditions are still favorable to form North Pacific Intermediate Water (NPIW) to depths of about 300 to 800 m (Talley 1993).

Last Glacial Maximum

The glacial Pacific Ocean had two water masses: well-ventilated and nutrient-depleted glacial NPIW above ~2000 m and less-ventilated and nutrient-enriched deep water below ~2000 m (Keigwin 1998; Matsumoto et al. 2002). Compared to today, the NPIW volume under glacial conditions was significantly higher extending down to about 2000 m. Microfossil (Ohkushi et al. 2003) and neodymium isotope data (Horikawa et al. 2010) suggest that the glacial NPIW possibly originated from the Bering Sea. This "stratified" water mass structure of the glacial North Pacific prevented upwelling of nutrient-rich deep waters. Thus, biological productivity in the glacial North Pacific was relatively low (Narita et al. 2002; Jaccard et al. 2005; Galbraith et al. 2007; Brunelle et al. 2010).

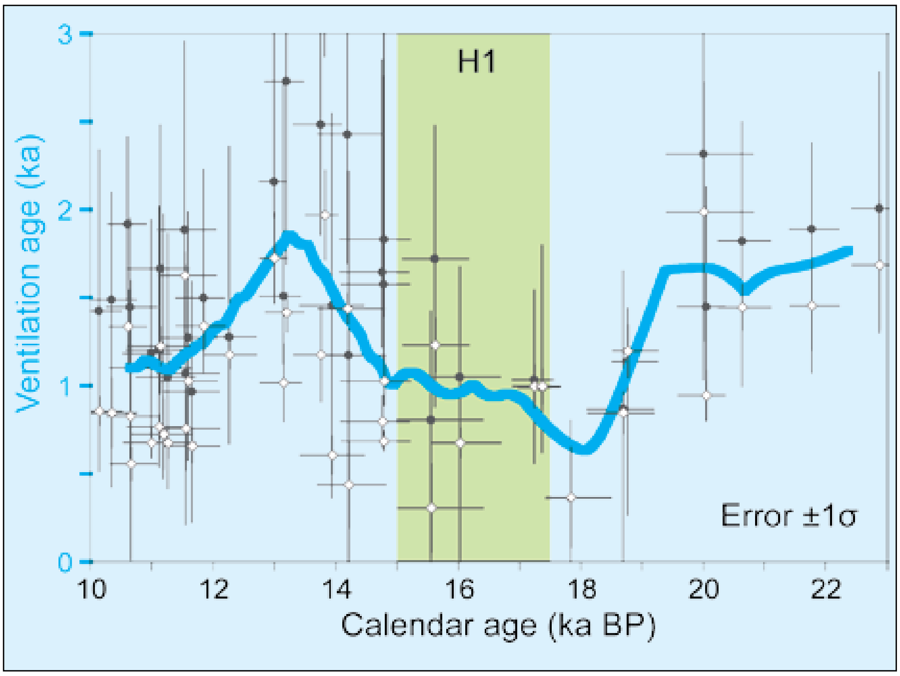

Figure 1: Ventilation age changes based on published radiocarbon data in the western North Pacific between 900 and 2800 m water depths (Okazaki et al. 2010). Reconstructed ventilation change based on the ^{14}C age offset between co-existing benthic (BF) and planktic foraminifers (PF; open diamonds), projection ages (considering atmospheric ^{14}C change; gray circles), and smoothed spline interpolation of averaged BF-PF age offsets and projection ages (blue line). H1: Heinrich event 1.

Last Glacial Termination

Major reorganization of water-mass structure in the North Pacific occurred during the last glacial termination, when a stratified glacial mode transformed to an upwelling interglacial mode. During the early period of the termination between 17.5 and 15 ka BP, the Meridional Overturning Circulation (MOC) in the Atlantic substantially weakened (McManus et al. 2004) due to freshwater forcing by melting icebergs in the North Atlantic (Heinrich event 1; H1). A compilation of sedimentary radiocarbon ventilation records in the North Pacific and freshwater perturbation experiment mimicking a Heinrich event performed with the earth system model of intermediate complexity, LOVECLIM, suggest that deep water formation in the North Pacific extended to a depth of ~2500 to 3000 m during H1 (Fig. 1 and 2; Okazaki et al. 2010; Menviel et al. 2011). The establishment of the Pacific MOC during times of Atlantic MOC weakening could have played an important global role in regulating poleward oceanic heat transport during H1.

During the Bølling-Allerød period (15-13.0 ka BP) and after the Younger Dryas (13-11.5 ka BP), the ocean circulation in the North Pacific resumed to an interglacial mode without deep-water formation, similar to the modern condition. At the beginning of the Bølling-Allerød, productivity in the subarctic Pacific rose rapidly (Crusius et al. 2004; Galbraith et al. 2007; Brunelle et al. 2010) in association with enhanced upwelling and breakdown of the glacial stratification.

The Atlantic MOC was weakened during the Younger Dryas event, but not as much as during H1 (McManus et al. 2004). Oceanic ventilation in the North Pacific during the Younger Dryas appeared to be stronger than that of the Bølling-Allerød possibly responding to the MOC weakening in the Atlantic. However, it is unclear whether an MOC was established or not in the Pacific during the Younger Dryas.

Role of the Bering Strait

Modeling studies demonstrate that a closed Bering Strait (sill depth 50 m) is required for the build-up and maintenance of higher surface salinity in the North Pacific during Heinrich events (Saenko et al. 2004; Hu et al. 2007; Okazaki et al. 2010), which is a precondition for establishing MOC in the Pacific. The role of the final opening of the Bering Strait between 11 and 12 ka BP (Keigwin et al. 2006) in the transition from the glacial to the modern NPIW regime is still not well understood.

Perspectives

Different thrusts have to be pursued to further elucidate the effects of North Pacific Ocean circulation changes on global climate change.

1. Model intercomparison

The establishment and extent of a Pacific MOC following an Atlantic MOC weakening are model-dependent (Chikamoto et al. 2012; Hu et al. 2012). Further model intercomparison studies should be performed to test the robustness of the proposed mechanism for the Pacific MOC set up as well as its extent in the North Pacific.

2. Error reduction for reconstructed ventilation records

As shown in Fig. 1, reconstructed ventilation data still have substantial errors. This is mainly caused by large uncertainties of the marine reservoir effect in the conversion from radiocarbon age to calendar age. In order to constrain the regional marine reservoir effect, precise age dating for the targeted sample is fundamental. High-resolution magnetostratigraphy and tephra chronology are potential tools for evaluating past regional marine reservoir ages.

3. Reconstruction of the Bering Strait gateway history

The Bering Strait opened and closed numerous times during the last glacial cycle (e.g. Brigham-Grette 2001). However, the detailed history is not reconstructed yet, but would provide new insights on the impact of this gateway on past global ocean circulation and climate change.

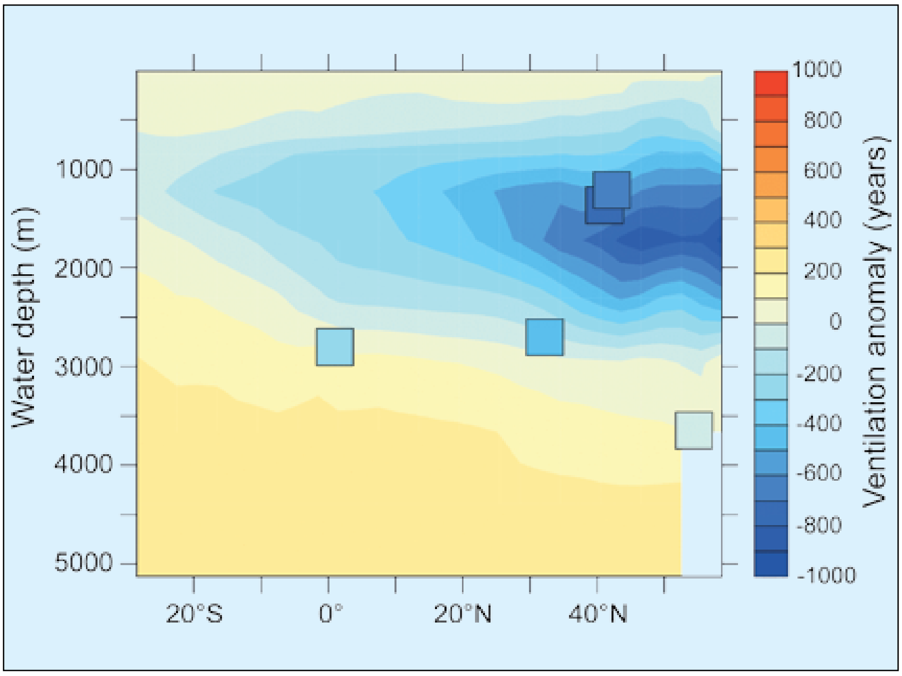

Figure 2: Zonally averaged simulated radiocarbon age anomalies in the North Pacific between a collapsed Atlantic MOC state and the preindustrial control simulation. Squares indicate projection age anomalies for the deglacial H1 period reconstructed from western North Pacific sediment cores (Okazaki et al. 2010).

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North Pacific - North Atlantic linkages during the Last Glacial Termination

NAOMI HARADA[1], A. TIMMERMANN[2], M. SATO[1], O. SEKI[3], Y. NAKAMURA[1], K. KIMOTO[1], Y. OKAZAKI[4], K. NAGASHIMA[1], S.A. GORBARENKO[5], L. MENVIEL[6], M.O. CHIKAMOTO[2] AND A. ABE-OUCHI[1,7]

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Statistical multivariate analysis of a new compilation of alkenone-derived sea surface temperatures from the western North Pacific indicates a coherent mode of millennial-scale variability that is closely linked to the deglacial changes of the Atlantic Meridional Overturning Circulation.

The mid- to high-latitude region of the western-central North Pacific including its marginal seas is an essential area for understanding paleoclimate change across Asia. Surface seawater conditions such as temperature (SST) and salinity (SSS) in this region play a key role in controlling the sinking branch of the Pacific Meridional Overturning Circulation. For instance, the formation of Dense Shelf Water (Martin et al. 1998) on the continental shelf of the northwestern Okhotsk Sea is affected by autumn SST (Ogi et al. 2001), SSS, and the sea-ice extent (Sakamoto et al. 2005). Sea-ice extent has a direct effect on the volume and characteristics of Okhotsk Sea Intermediate Water, a key component of the North Pacific Intermediate Water (Tally and Nagata 1995). Moreover, large-scale changes of temperature and salinity can weaken the stratification in the Bering Sea and lead to the formation of Pacific deep water, as described in Okazaki et al. (2010).

Understanding the drivers of North Pacific surface density changes during the large-scale climate transition of the last deglaciation may provide important insights into an often-overlooked branch of the global ocean conveyor belt circulation and its effect on climate and the global carbon cycle.

Here, we focus on the SST contribution to the surface density changes in the North Pacific. Despite previous efforts to synthesize compilations of deglacial SST (Kiefer and Kienast 2005), gaps still remain in our understanding of SST variations in sinking and subduction regions in the mid- to high-latitude western-central North Pacific. We present a new compilation of SST reconstructions for the last deglaciation derived from the $U^{K'}_{37}$ -index of alkenones (Brassell et al. 1986; Prahl and Wakeham 1987) from the western-central North Pacific. We discuss how these SST responded to millennial-scale variability in the North Atlantic during the last deglaciation, including Heinrich Event 1 (H1, 17.5-14.6 ka), the Bølling-Allerød period (B-A, 14.6-12.8 ka), and the Younger Dryas (YD, 12.8-11.5 ka) through associated changes in the atmospheric circulation.

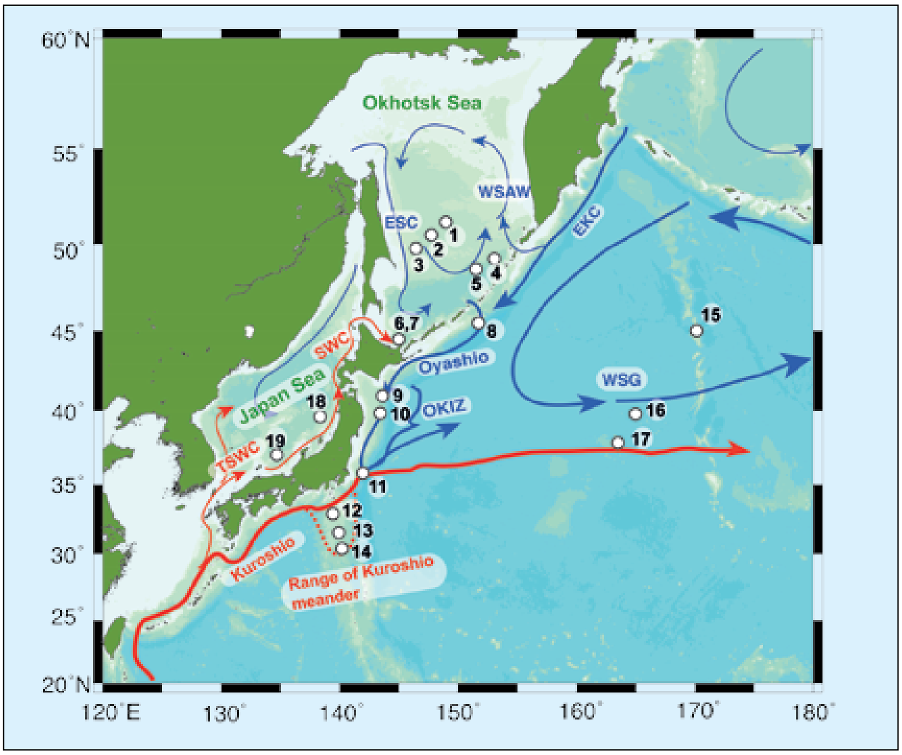

Figure 1: Sediment core locations in the western–central North Pacific and the Okhotsk and Japan Seas. Numbers indicate the coring sites as in Harada et al. (2012). Arrows show the average direction of flow of surface waters, with red and blue arrows indicating warm and cold currents, respectively. EKC, East Kamchatka Current; WSAW, Western Subarctic Water; ESC, East Sakhalin Current; SWC, Soya Warm Current; TSWC, Tsushima Warm Current; OKIZ, Oyashio–Kuroshio interfrontal zone; WSG, Western subarctic gyre.

Interpretation of alkenone SST

Alkenone-SSTs were reconstructed from 19 sites in the North Pacific (Fig. 1). Alkenone-SSTs are likely to exhibit seasonal biases towards early summer to autumn in the Okhotsk Sea (Seki et al. 2007) and western-central North Pacific (Harada et al. 2004; Minoshima et al. 2007) but represent more evenly weighted near-annual mean SST in the Sea of Japan (Ishiwatari et al. 2001). In a sediment-trap study in the western North Pacific (40-50°N), Harada et al. (2006) found that the season of the maximum alkenone export flux varied from the beginning of summer to late autumn, and the export period corresponded to the period when stratification had developed in the surface-subsurface layer. The light-limitation depth is also critical for alkenone producers (Harada et al. 2006). Thus calm conditions and high surface–subsurface light intensity are important for alkenone producers, and their main growing season might shift depending on when adequate conditions for their active growth occur. The high adaptability of alkenone producers might have often caused seasonal biases for alkenone-SST depending on the conditions at the coring locations.

Pacific-Atlantic SST linkages

An empirical orthogonal function (EOF) analysis was conducted for alkenone-SSTs of the interval 22-8 ka BP at 14 sites (Figs.

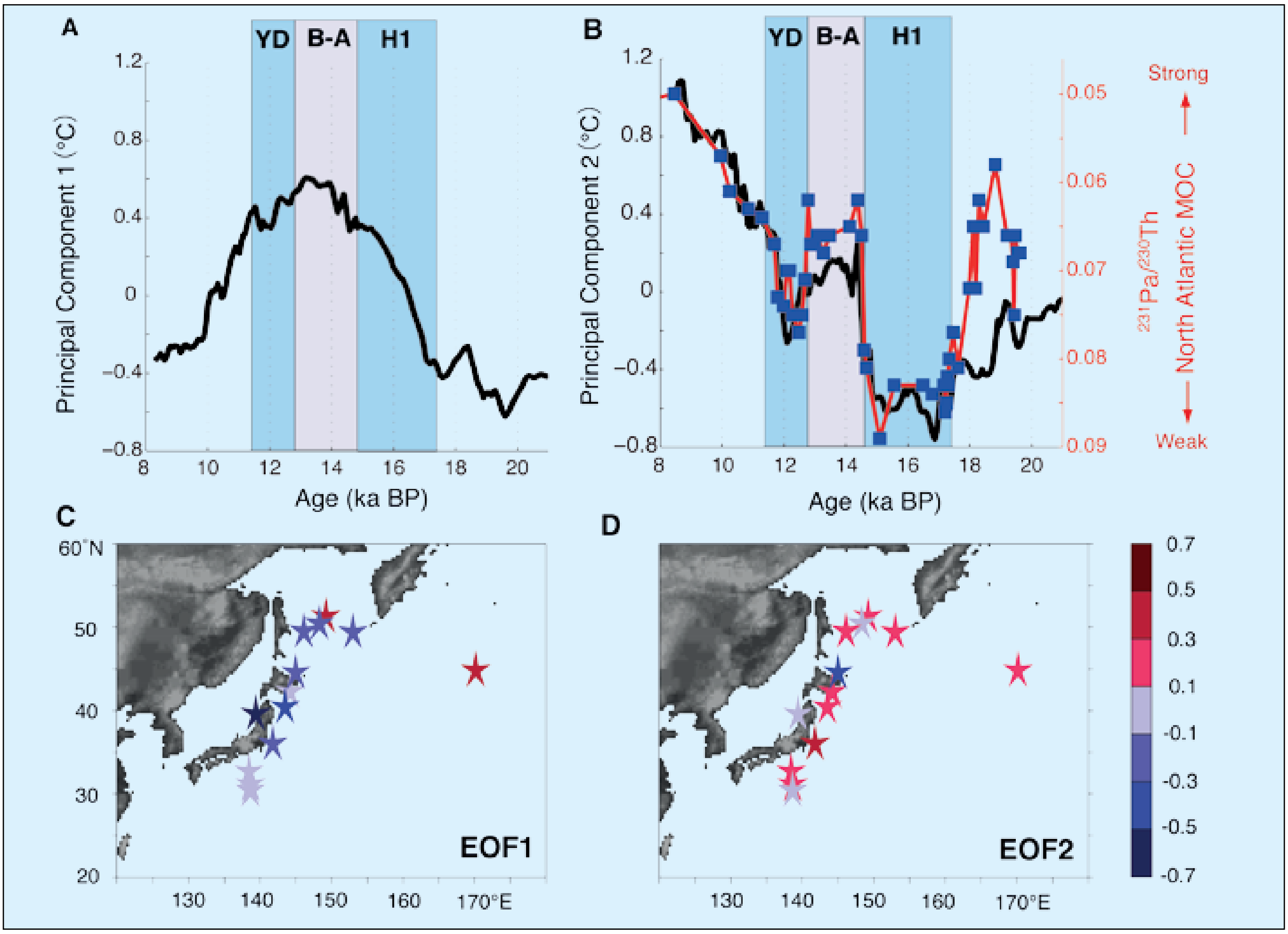

Figure 2: Empirical orthogonal function (EOF) analysis of alkenone-derived temperatures throughout 22-8 ka BP. ***A)*** *First principal component [°C] corresponding to EOF1 pattern.* ***B)*** *Second principal component [°C] corresponding to the EOF2 pattern, along with estimates of North Atlantic meridional overturning circulation (McManus et al. 2004).* ***C)*** *EOF1 and* ***(D)*** *EOF2 spatial patterns [unitless]. The color scale indicates the loading of the EOF pattern.*

2A-2D; Harada et al. 2012) to extract the common dominant features of spatio-temporal variability from all the records.

The dominant EOF mode (EOF1) is characterized at most core sites in the northwestern Pacific by a cooling trend from 20 to 14 ka BP and a subsequent warming trend from 14 to 8 ka BP (Fig. 2A). Note that the EOF contribution to the SST evolution at any core site is obtained by multiplying the principal components with the EOF pattern loading (Fig. 2C) at this site. A possible scenario is based on an independent EOF analysis from longer, but spatially more constrained alkenone-SST datasets (Harada et al. 2012), suggesting that the first EOF follows the precessional cycle of autumn insolation at 45°N, with increased insolation during the LGM and minimum insolation around 13 ka BP. These results suggest that the alkenone data track autumn temperature variations throughout the entire analysis period, and that warming during the fall season can be explained by strengthened surface stratification.

The second EOF mode (EOF2) clearly captures the main deglacial warming signal at most of the core sites as well as the millennial-scale variability associated with temperature and ocean circulation changes in the North Atlantic. It shows a distinct minimum during H1, a rapid increase, concomitant with the B–A transition, as well as the YD. The correspondence to a North Atlantic ventilation proxy, based on $^{231}Pa/^{230}Th$ isotope ratios (Fig. 2B) demonstrates a clear linkage between changes in the North Atlantic overturning circulation and Pacific climate variations. The spatial EOF2 pattern is dominated by two cores (from sites 6 and 11, purple and deep red colors, respectively in Fig. 2D) having an opposite pattern. During H1 and according to the EOF 2 reconstruction the waters near the location of site 11 would have cooled and those near the site 6 would have warmed. This opposite temperature pattern between southern and northern sites may relate to a south-north migration of the Kuroshio/Oyashio front. This pattern may be evidence of the heat convergence toward the north by the intensified Pacific Meridional Overturning Circulation (Okazaki et al. 2010). Wind-induced transport near the western boundary affected by an intensification or shift of the Aleutian Low might be another possible factor. An intensified Aleutian Low causes also a northward migration and a strengthening of the subtropical gyre, thereby warming the waters overlying site 6 and turning heat away from the area of the site 11.

Our analysis revealed a distinct pattern of millennial-scale variability in the western North Pacific that correlates well with millennial-scale climate variations in the North Atlantic. Overall, our study suggests that multivariate data analysis of core compilations can help to identify the dominant patterns of variability and provide important insight into the driving mechanisms of variability on a range of timescales.

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Teleconnection mechanism between millennial-scale Asian Monsoon dynamics and North Atlantic climate

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We present evidence for millennial-scale changes of the westerly jet path over East Asia during the last glacial period and suggest that the westerly jet plays a critical role in a millennial-scale climate teleconnection between Asia and the North Atlantic.

The $\delta^{18}O$ records of stalagmites from the Hulu Cave in southeastern China (Wang et al. 2001) and the grayscale profile of hemipelagic sediments from the Japan Sea (Tada 2004; Tada et al. 1999; core MD01-2407) show millennial-scale variations in East Asian Summer Monsoon (EASM) rainfall along the Yangtze River (Fig. 1) in association with Dansgaard-Oeschger (D-O) events (Fig. 2). Moreover, annual-resolution studies of a Greenland ice core suggest that decreases in the eolian dust flux from mid-latitude Asian deserts approximately coincided with or even led the temperature rises at the onsets of the Bølling-Allerød, the Pre-Boreal, and a prominent D-O interstadial (Steffensen et al. 2008; Thomas et al. 2009). These findings suggest a direct linkage of millennial-scale climate changes between Asia and the North Atlantic. However, the dynamics of such a teleconnection remains unresolved.

Here we focus on the westerly jet because of its high potential to link climate changes between East Asia and the North Atlantic. At present, the westerly jet axis over East Asia passes south of the Himalayas during winter and early spring, and then jumps to north of the Tibetan Plateau in late spring to early summer in association with intensified Hadley Cell circulation (Schiemann et al. 2009). Wang et al. (2011) proposed that for a summer monsoon rainband to develop along the Yangtze River, the westerly jet needs to be at or slightly north of the river's latitude during summer. This mechanism is well explained by Sampe and Xie (2010). They demonstrated that eastward advection of warm air from the eastern flank of the Tibetan Plateau along the westerly jet axis triggers the convection that forms the rainband. They further showed that the westerly jet anchors the rainband by steering transient weather disturbances, which promote convection by intensifying moisture advection with upward motion. Over the North Atlantic, the westerly jet also steers transient eddies that bring precipitation, and its path is largely controlled by the sea-ice extent and meridional gradient of sea surface temperature (Laîné et al. 2009). By analogy with the present close linkage of the westerly jet path with the positions of both the EASM rainband and weather fronts in the North Atlantic, we infer that dynamic changes in the westerly jet path may have played a critical role in linking millennial-scale changes in EASM precipitation and North Atlantic climate during the last glacial (Fang et al. 1999; Tada 2004). Supporting this inference, productivity changes of the western Mediterranean Sea estimated from geochemical proxies of marine sediments (Moreno et al. 2004, 2005) suggest westerly jet path changes over the North Atlantic in association with D-O events. However, millennial-scale changes of the westerly jet path over East Asia have not yet been demonstrated. Here we introduce the result of our recent study that reconstructed variations in the westerly jet path over East Asia during the last glacial by examining the provenance and grain size of Asian dust in a sediment core from the Japan Sea (Nagashima et al. 2011).

Dust provenance reflects seasonal shifts of the westerly jet

Nagashima et al. (2011) demonstrated that the relative abundance of Asian dust emitted from two major Asian deserts, the Taklimakan Desert and the Gobi Desert in southern Mongolia (hereafter, Mongolian Gobi) reflects changes in the seasonal northward movement of the westerly jet axis. At present, dust emission events in both these deserts are most frequent in spring because the large temperature gradient between high and middle latitudes and the resulting synoptic-scale disturbance in the atmospheric circulation generates strong cold fronts that give rise to storms (Roe 2009). In spring, severe dust storms are approximately twice as frequent in the Mongolian Gobi as in the Taklimakan (Kurosaki and Mikami 2005; Sun et al. 2001) because the Mongolian Gobi lies along the main pathway of cold air masses from Siberia. In this season, the emitted dust is transported eastward

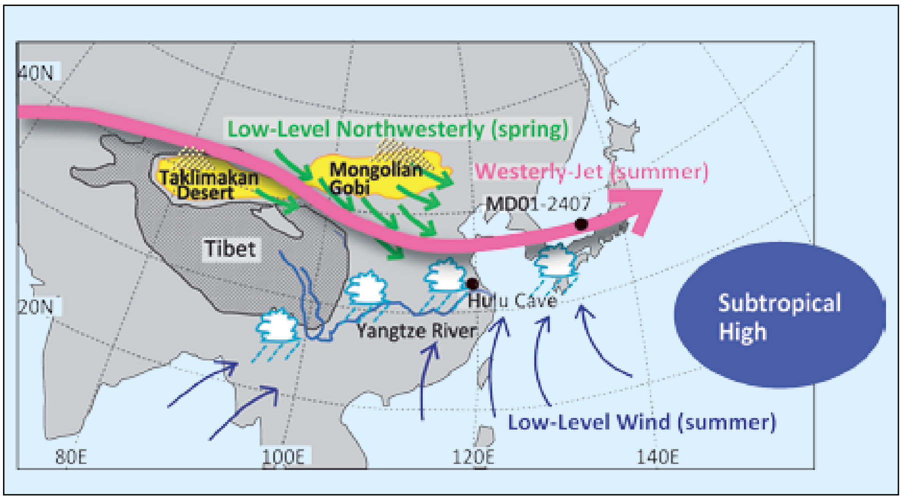

Figure 1: Spring and summer atmospheric circulation patterns and the East Asian Summer Monsoon rainband over East Asia (shown by clouds). The locations of the marine sediment core MD01-2407, the Hulu Cave speleothem, and important geographical features are also shown.

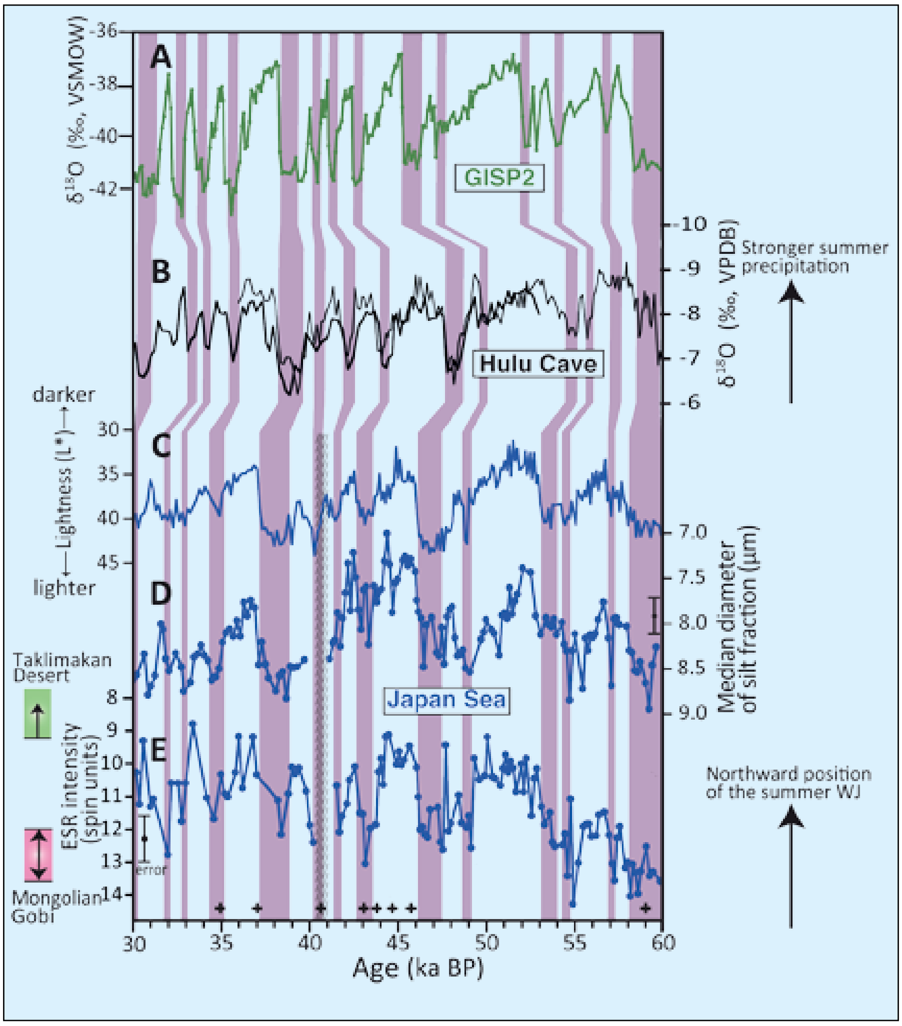

Figure 2: Dust provenance records from the Japan Sea compared with paleoclimate records from Greenland and southeastern China. ***A)*** *GISP2 δ18O record (Grootes and Stuiver 1997);* ***(B)*** *Hulu Cave stalagmite δ18O record (Wang et al. 2001);* ***(C)*** *lightness (L*; Watanabe et al. 2007),* ***(D)*** *median grain size of the silt fraction, and* ***(E)*** *ESR intensity of silt-sized quartz (Nagashima et al. 2011) in core MD01-2407 from the Japan Sea. Plus signs (+) mark age-control points in core MD01-2407 (Yokoyama et al. 2007). Vertical purple bars indicate stadials in GISP2, heavier oxygen isotope (weak Asian monsoon) events in Hulu Cave, and light-colored layers in core MD01-2407. The vertical hatched bar indicates an interval in the core containing volcanic ash.*

mostly by near-surface northwesterly winds. During summer, however, the latitudinal temperature gradient is smaller, suppressing storm event frequency in the Gobi (Roe 2009), whereas dust emission event frequency remains high in the Taklimakan (Kurosaki and Mikami 2005) because of the local circulation system between the desert and high surrounding mountains (Abe et al. 2005). When winds blowing against the northern margin of the Tibetan Plateau lift the dust above 5000 m, the emitted dust can be entrained into the westerly jet, which is north of the plateau during summer, and transported long distances. Thus, the relative abundance of dust from the Taklimakan versus the Mongolian Gobi mainly reflects the relative frequency of summer versus spring-type dust events. Since spring-type dust events cease once the westerly jet jumps to the north of the Tibetan Plateau (Nagashima et al. 2011), changes in the relative abundance of dust derived from these two deserts record the timing of this northward jump. This idea led us to reconstruct the changes in the provenance of dust from the Asian continent in sediment core MD01-2407 (37°04'00''N, 134°42'11''E) from the south-central Japan Sea (Fig. 1) by using the electron spin resonance (ESR) signal intensity of quartz (for details, see Nagashima et al. 2007; Sun et al. 2007).

Millennial-scale teleconnection via the westerly jet

Hemipelagic sediments in the Japan Sea are characterized by alternating dark and light layers; light layers were deposited during D-O stadials and dark layers during D-O interstadials (Tada 2004; Tada et al. 1999; Fig. 2C). The ESR signal intensities of silt-sized (eolian) quartz (Nagashima et al. 2007) in samples from core MD01-2407 ranged between values of 6.6-9.2 for Taklimakan and 12.0-13.6 for Mongolian Gobi (Nagashima et al. 2011). Lower ESR signal intensities (larger contribution from the Taklimakan Desert) clearly correspond to dark layers (D-O interstadials) and higher intensities (larger contribution from the Mongolian Gobi) to light layers (D-O stadials) (Fig. 2C, E). These inferred differences in dust provenance between dark and light layers are supported by the smaller median diameter of the silt fraction within the dark layers (Fig. 2D). Eolian grain size decreases with increasing distance from the source, and the Taklimakan Desert is more distant from the Japan Sea than the Mongolian Gobi; thus, the median grain size of eolian dust from the Taklimakan is smaller than that from the Mongolian Gobi. The dominance of dust from the Taklimakan in D-O interstadials suggests that the westerly jet jumped to the north of the Tibetan Plateau earlier during interstadials, favoring the development of a rainband along the Yangtze River during summer (Sampe and Xie 2010). Therefore, a northerly migration of the westerly jet path over East Asia can explain the increased precipitation over the Yangtze River during D-O interstadials (Fig. 2B), and also links millennial-scale changes in the EASM with those in the North Atlantic climate.

Oxygen isotope records of speleothems from the southwestern United States also suggest a northward shift of the polar jet during D-O interstadials (Asmerom et al. 2010). Furthermore, speleothem growth patterns in northeastern Brazil (Wang et al. 2004) and the chemical composition of Lake Malawi (East Africa) sediments (Brown et al. 2007) reveal a northward shift of the Intertropical Convergence Zone (ITCZ) during D-O interstadials over these respective regions. Taken together, these results suggest that a dynamic N-S displacement of the atmospheric circulation pattern (the westerly jet at mid-latitudes and the ITCZ at low latitudes) may almost simultaneously propagate D-O events on hemispheric and inter-hemispheric scales.

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Latent 1500-year climate oscillation in the Holocene

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A Holocene temperature record from the Japan margin shows a significant 1500-year period, suggesting the existence of a persistent cycle since the last glacial period.

Suborbital climate variability during the last glacial period has been suggested to be paced with a 1500-year period, but the expression and spatial distribution of this oscillation during interglacials remain unclear. Millennial-scale variations during the Holocene were first reported by Bond et al. (1997) based on ice-rafted hematite-stained grains (HSG) in North Atlantic sediments. Although spectral analyses did not yield a significant 1500-year period, the abundance of these grains peaked on average every 1.5 millennia (Bond et al. 2001). However, few other climate records have shown a clear 1500-year periodicity in the Holocene.

Here, I discuss 1500-year variability found in a multi-decadally resolved Holocene record of alkenone sea-surface temperatures (SST) from the northwestern Pacific off central Japan (Isono et al. 2009). In that region warm waters of the Kuroshio Current mix with cold waters of the Oyashio Current (Fig. 1).

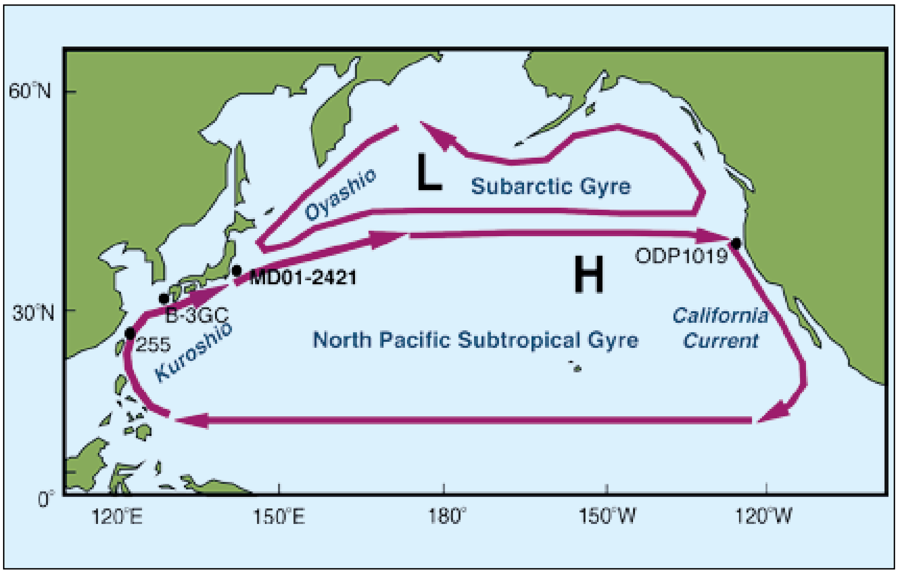

Figure 1: Locations of the study site MD01-2421, and other mentioned reference sites in the North Pacific. The subarctic and subtropical gyre circulations are driven by westerly and trade winds that are regulated by the summer North Pacific High (H) and the winter Aleutian Low (L). Figure modified from Isono et al. (2009).

A Holocene 1500-year cycle off Japan

Detrended SST variations at Site MD01-2421 show a series of SST minima (Fig. 2A; Isono et al. 2009). The youngest of them, centered at ~0.3 ka and ~1.5 ka, occur around the time of the Little Ice Age and the Dark Ages Cold Period in Europe, respectively. Spectral analysis of SST over the last 10.8 ka revealed a statistically significant periodicity of 1470 years. One cooling period at 8.5 ka is not consistent with the ~1500-year cycle, but might correspond with the 8.2-ka cooling event (Alley et al. 1997).

With the exception of the cooling event at 8.5 ka, the SST minima re-occur at intervals of 1.1-1.7 ka. In the 400-year running average of the detrended SST (Fig. 2B) the standard deviations for warming (i.e. mid-point between maximum and minimum SST), warmest, cooling, and coldest events of the last seven cycles from the 1470-year templates are 112, 237, 245, and 160 years, respectively. This implies that the periodicity is most stable for warming events, suggesting that the oscillation is paced at warming events. The standard deviation of the last seven warming events is nearly equal to the 130 years identified for glacial Dansgaard-Oeschger (DO) events (Schulz 2002; Rahmstorf 2003). The deviation of the last seven warming events in the Pacific from a regular 1470-year recurrence is about as small as for the deviation of DO events (Rahmstorf 2003; Fig. 2H). This correspondence suggests the existence of a persistent 1470-year cycle during both the Holocene and the last glacial period.

The occurrence of a persistent regular 1500-year cycle in glacial and interglacial modes suggests that it is a response to a periodic external forcing rather than an internal oscillation in the climate system (Rahmstorf 2003). Solar output variations estimated from variations in tree ring $\Delta^{14}C$ variations (Solanki et al. 2004) do not match the Japan-margin SST variation (Figs. 2A and 2G), except for the Little Ice Age when low temperatures at the Japan margin correspond to low solar output. Spectral analysis of solar radiation variation does not show a ~1500-year periodicity (Stuiver and Braziunas 1993). Braun et al. (2005) suggested that a non-linear response of freshwater input into the North Atlantic Ocean to the solar de Vries/Suess and Gleissberg cycles (210- and 87-year periodicities, respectively) is a candidate mechanism for the 1500-year cycle. Their modeling study suggested that some non-linear process might be producing a 1500-year cycle. Debret et al. (2007) distinguished solar forcing of 1000- and 2500-year oscillations from a 1500-year cycle in Holocene records from North Atlantic sediments by wavelets analysis. They attributed the 1500-year cycle to oceanic forcing.

The 1500-year oscillation was subdued in the Holocene, whereas it was amplified and dominant as DO events in the last glacial. This suggests that positive feedbacks operated to amplify the 1500-year oscillation under glacial boundary conditions.

Spatial distribution of the 1500-year cycle

Modern oceanographic modes indicate that the SST off Japan reflect variations in the North Pacific gyre system, i.e. the Pacific Decadal Oscillation (Mantua et al. 1997) and the North Pacific Gyre

Oscillation (Di Lorenzo et al. 2008). If such modes operated over millennia, then the 1500-year temperature variation at the Japan margin implies that the North Pacific gyre circulation is affected by 1500-year cycles. At the northern California margin site ODP 1019, analysis of an alkenone-derived SST record (Fig. 2F; Barron et al. 2003) revealed a broad peak of spectral density with a periodicity range of ~1470 to 1820 years. The 1470-year variation was coherent with the SST oscillations we found off Japan. Jian et al. (2000) generated foraminifera-based SST records for the northern and southern Okinawa Trough (sites B-3GC and 255) and claimed that the SST difference between the two sites varied with a 1500-year periodicity. However, only the SST minima 1, 2, and 4 at our site MD01-2421 correlate with ΔSST maxima at the Okinawa Trough (Fig. 2E). The SST minima at the Japan margin also correlate with Bond events 2, 5, and 7 and partly with events 0, 1, and 3 (Fig. 2C). The Japan margin record shows similarities to the degree of stratification in the subpolar North Atlantic (Fig. 2D; Thornalley et al. 2009). Although none of these correspondences are perfect, they suggest that the southward shift of the Kuroshio Extension jet in the northwestern Pacific was often synchronous with ocean circulation in the North Atlantic.

All of the sites discussed for displaying 1500-year oscillations are sensitive to the northern mid-latitude westerlies, which suggests that the westerlies and subtropical and subarctic gyre dynamics have been involved in propagating or generating 1500-year oscillations in the climate system. However, the forcing of the 1500-year variability and its effect on the climate system in both glacials and interglacials still remain puzzling. Future investigations are necessary to clarify these issues.

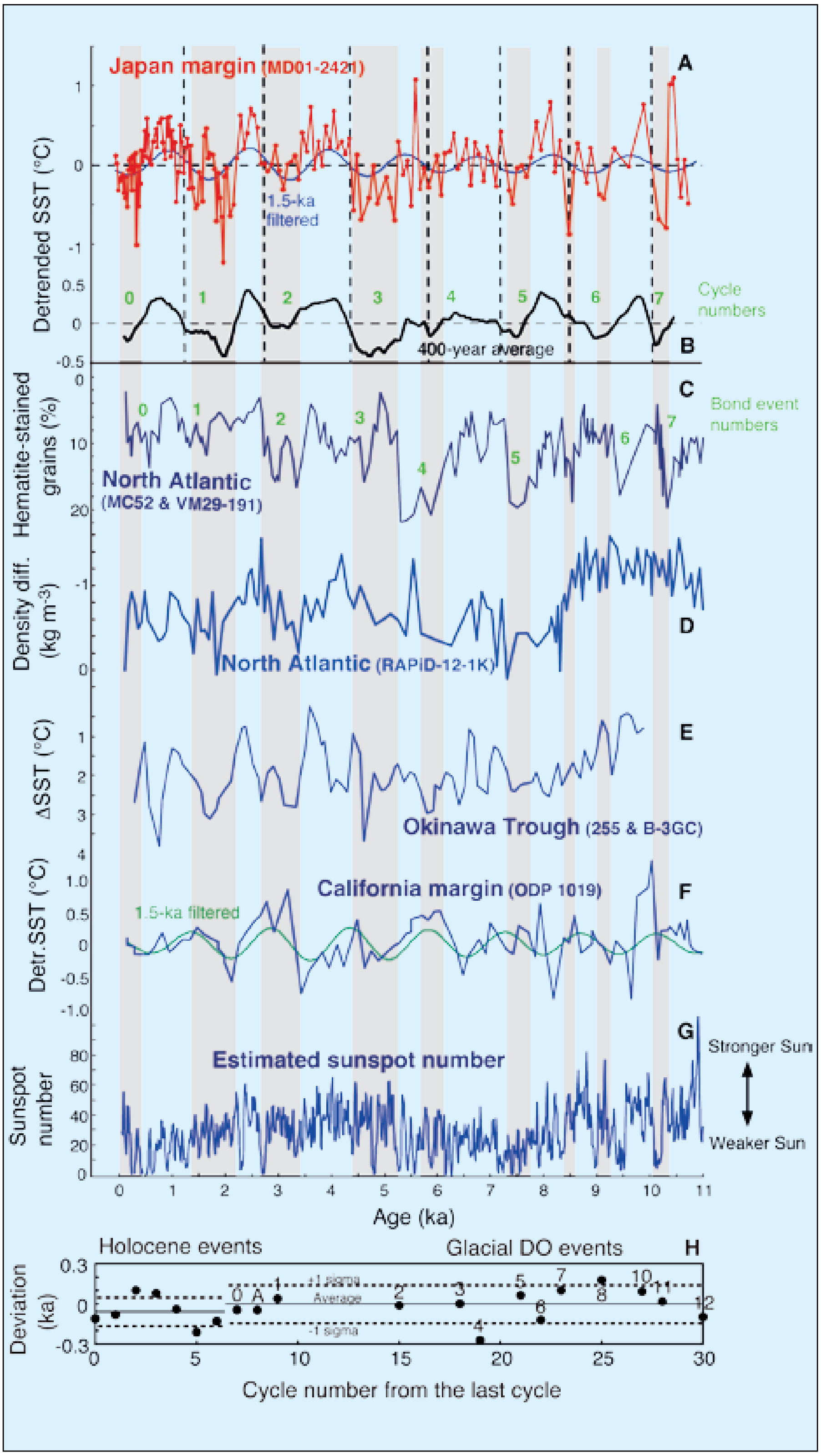

*Figure 2: Holocene variations in **(A)** detrended $U^{K'}_{37}$-derived SST at the study site (Isono et al. 2009), **(B)** its 400-year running mean omitting the cooling event at 8.5 ka, **(C)** hematite-stained grain content in a North Atlantic core (Bond et al. 1997), **(D)** mixed layer density in the North Atlantic (Thornalley et al. 2009), **(E)** lateral SST differences in the Okinawa Trough (Jian et al. 2000), **(F)** detrended $U^{K'}_{37}$-derived SST at ODP Site 1019 at the California margin (Barron et al. 2003), and **(G)** tree-ring $\Delta^{14}C$-based sunspot numbers (Solanki et al. 2004). Gray shading indicates cold periods at the Japan margin. **(H)** Time deviations from a regular 1470-year template for the mid-point of warmings at site MD01-2421 during the Holocene and at Greenland site GISP2 during the last glacial period (Rahmstorf 2003). Numbers in panel H indicate Dansgaard-Oeschger interstadials; "A" = Allerød. Figure modified from Isono et al. (2009).*

Notes

Data are available from the NOAA Paleoclimatology website www.ncdc.noaa.gov/paleo/paleo.html

Acknowledgements

I thank Dai Isono, Tomohisa Irino, Tadamichi Oba, Masafumi Murayama, Toshio Nakamura, and Hodaka Kawahata for discussions.

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The history of Lake Biwa drilling

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Sediments from Lake Biwa in central Japan preserve the paleoclimatic and tectonic history of the past 1 Ma of East Asia. In particular the uppermost massive clays are well suited to study high-resolution environmental change of the last 430 ka.

Lake sediments are important archives for understanding the environmental and tectonic history at regional to global scales. Located on the convergent margin of the Eurasian plate, the Japanese archipelago features many tectonic, volcanic, and coastal lakes well suited for paleolimnological studies. One of the most famous and most studied lakes in Japan is Lake Biwa. The first sediment core was retrieved in 1965 by Professor Shoji Horie and his team to study global climatic change and tectonic history of this convergent region. Since then, many more studies have been conducted on Lake Biwa. Here, I summarize the drilling history of Lake Biwa and put it in a broader perspective.

Southwestern Japan has been impacted by tectonic deformation throughout the Quaternary. The ca. 1.5 Ma old tectonic lake Lake Biwa (82 m a.s.l.) on south-central Honshu Island is the largest freshwater lake in Japan, measuring 22.6 km wide by 68 km long (Fig. 1). Lake Biwa is divided into two basins. The Northern Lake is a deep basin with a maximal depth of 104 m and average depth of 40 m. The much smaller Southern Lake is very shallow with an average depth of about 3 m.

Several attempts to recover core sediments from Lake Biwa have been made, mainly in the 65-70 m deep depression situated in the southern part of the northern Basin (Fig. 1). Horie et al. first recovered a six-meter long sediment core in 1965 and then an 11.5 m long piston core in 1967 (Horie et al. 1971). In 1971, with considerable effort, they managed to drill the sediments in the same depression (Fig. 1) and successfully obtained core samples totaling about 200 m (Horie 1984). Finally, in 1982 and 1983, they succeeded in recovering a 1400 m long core covering the entire sediment sequence. This record confirmed that the basin is filled with lacustrine and fluvial sediments about 800 m thick (Takemura and Yokoyama 1989; Horie 1991). Below 800 m the core is mainly composed of a ca. 100 m thick pebbles and cobbles layer, and Mesozoic-Paleozoic basement rocks. The uppermost unit consists of lacustrine clay and silt about 250 m thick, estimated to have deposited continuously during the last 430 ka (Takemura 1990; Meyers et al. 1993). In 1986, further samples of 141 m thick sediment were recovered

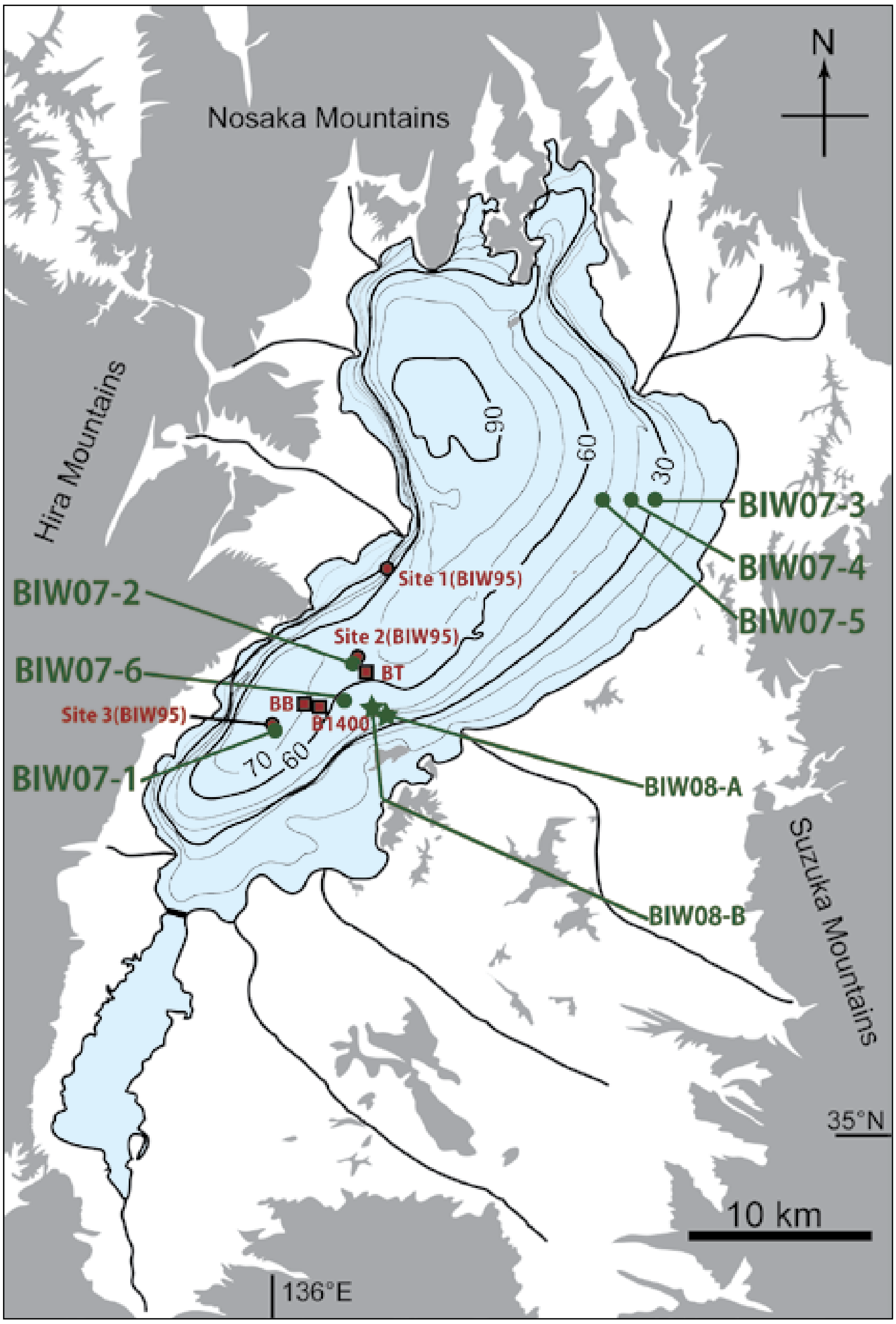

Figure 1: Map showing locations of principal coring sites in Lake Biwa (from Takemura et al. 2010). BB (200 m drilling in 1971; Horie 1984), B1400 (1400 m drilling in 1982-1983; Takemura 1990; Horie 1991), BT (141 m drilling in 1986; Yoshikawa and Inouchi 1991), Site 1, 2, 3 (BIW95; Piston cores in 1995; Takemura et al. 2000), BIW07-1 to BIW07-6 (Piston cores in 2007; Takemura et al. 2010), BIW08-A and BIW08-B (Drilled cores in 2008; Takemura et al. 2010).

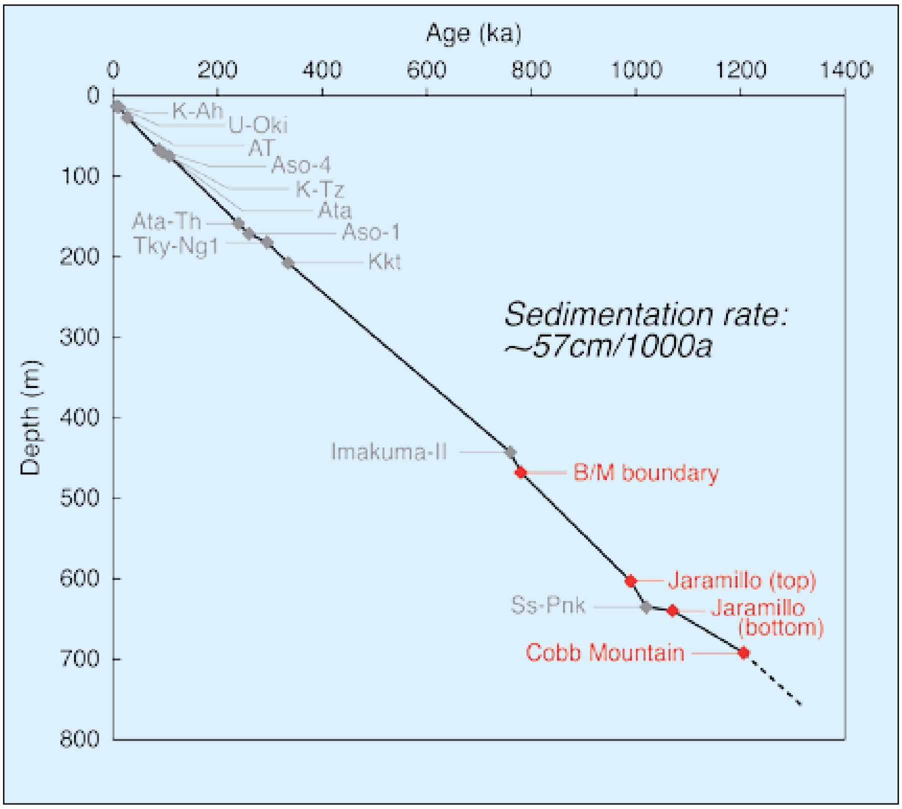

Figure 2: Summary of chronology of core B1400 based on the re-investigation of fission track ages, tephra identification and magnetostratigraphy (Danhara et al. 2010). Tephra horizons (gray): K-Ah, U-Oki, AT, Aso-4, K-Tz, Ata, At-Th, Aso-1, Tky-Ng1, Kkt, Imakuma II, Ss-Pink; Paleomagnetic information (red): B/M (Brunhes/Matuyama) boundary, top of Jaramillo event, bottom of Jaramillo event, Cobb mountain event.

about 5 km northeast of the older drilling sites (Fig. 1; Yoshikawa and Inouchi 1991).

Whereas the neighboring (ca. 20 km) basin of Lake Suigetsu has varved sediments of the past 150 ka, Lake Biwa has continuous sediments of a million years age. Therefore, together the two lake basin records will permit understanding the Quaternary climate and tectonics at annual to millennial time scales.

Initially, the scientific value of Lake Biwa sediments was not properly acknowledged because the first attempt of fission track dating gave a wrong Pliocene age to the basal part. This resulted in a significantly crooked sediment accumulation rate (SAR) curve, casting doubt on the continuity of the Lake Biwa sediment record. In 1993, based on a stratigraphic correlation of the Biwa core with marine data, Meyers et al. suggested that the fission track dates were erroneous. Then in 2005, improvements on the fission track timescale successfully identified the paleomagnetic reversal near the base as Jaramillo rather than Olduvai, estimating the time coverage of the Lake Biwa core as ca. 1.5 Ma (Danhara et al. 2010; Fig. 2). A highly linear SAR resulted for the 800 m deep Lake Biwa sediment record. This was evidence for the stable sedimentary environment of the basin, and the suitability of Lake Biwa as a paleoclimate archive. Moreover, progress in Japanese tephrochronology in recent decades enabled the identification of several marker tephras (Machida and Arai 2003) in and around the basin. Lake Biwa is, therefore, an ideal terrestrial site to explore paleoclimate and tectonic history during the past 1 Ma of East Asia.

Although the sediments of Lake Biwa have been analyzed by various methods, high-resolution studies have not yet been carried out. In most studies a single core was obtained at a single site. It was therefore difficult to evaluate the completeness of core recovery and disturbance of core samples. For example, we now know that in the deep drilling of 1982 and 1983, rotary coring caused disturbance of the upper sediment samples. For a detailed study of the sedimentary record, in 1995, we recovered seven piston cores (10-15 m long) at three localities (site 1, 2, 3) in the northern part of Lake Biwa (Fig. 1). We designed the coring plan (1) to take at least two cores from each site; (2) to take cores at three locations with different sedimentation rates; and (3) to recover the longest possible undisturbed sediment sequence. Analyses of the core samples include paleomagnetism, environmental magnetism, physical properties, organic and inorganic chemistry, pollen analysis and ^{14}C dating. We also demonstrated that magnetic susceptibility data are very useful to find microscopic tephra horizons, and establish correlation and age assignment of the core sediments from the different locations.

From the viewpoint of paleoclimatic change, Nakagawa et al. (2008) produced quantitative climatic reconstructions for the past 450 ka based on a long pollen record from Lake Biwa. Hayashi et al. (2010) reported a high-resolution pollen record covering the last 40 ka (BIW95-4) and found that they correlate with Dansgaard–Oeschger (D–O) cycles recognized from the anhysteretic remanent magnetization (ARM) record (Hayashida et al. 2007).

Drilling challenges are continuing for high-resolution studies on paleoenvironments and island arc tectonics. In 2007 and 2008, we obtained six new piston cores covering at least 50 ka, two longer cores covering 300 ka (Takemura et al. 2010), and 300 km long shallow seismic surveys. Various interdisciplinary analyses are expected to generate high-resolution records of the environmental change of the Asian monsoon and of the dynamics of the tectonic convergence.

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Lake Suigetsu 2006 Varved Sediment Core Project

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Two decades of effort by three generations of researchers has contributed to the realization of the value of Lake Suigetsu's varved sediments to Quaternary science.

Lake Suigetsu has a long history in Quaternary research. In 1991, a group of Japanese researchers, led by Prof. Yoshinori Yasuda of the International Research Center for Japanese Studies (IRCJS, Japan), recovered a couple of >10 m long piston cores from the lake and found that the lower parts of those cores were annually laminated (varved; Fig. 1). This marked the initiation of varve studies in Japan.

Two years later (1993), the same group conducted deep drilling of Lake Suigetsu and recovered a >73 m long sediment core that reached bedrock. The top ca. 40 m of the core was quasi-continuously varved. The earliest important scientific outcomes from this long core (SG93) were delivered by Hiroyuki Kitagawa of IRCJS and Hans van der Plicht of Groningen University (the Netherlands). They extended terrestrial radiocarbon calibration close to the limit of the method (ca. 50 ka) by combining varve counting and >300 radiocarbon measurements obtained on terrestrial leaf fossils extracted from the core (Kitagawa and van der Plicht 1998a, 1998b, 2000). Since then the lake has acquired international recognition as an environmental archive of high value (it is sometimes even referred to as “The Japanese Lake”) - especially by the radiocarbon community.

The internationally ratified IntCal radiocarbon calibration model for deriving calendar ages from radiocarbon data was first proposed in 1998 (Stuiver et al. 1998) and subsequently updated in 2004 and 2009 (Reimer et al. 2004, 2009). Ideally, radiocarbon calibration should be based on independently-dated terrestrial materials such as tree rings and terrestrial plant remains in lacustrine sediments (speleothem records, although terrestrial, require correction for unknown dead carbon fractions). However, the present IntCal model relies on marine archives, such as corals and Cariaco Basin sediments for the period beyond the continuous tree-ring record. Even in the latest version, the tree-ring record reaches only back to 12,550 cal. BP. This still leaves three quarters of the radiocarbon calibration based on marine data, including the assumption of a constant offset from the atmospheric radiocarbon concentration, known as the marine reservoir age. As a terrestrial archive, the Lake Suigetsu radiocarbon data are free from the marine reservoir age problem. However, the dataset has never become an integral part of IntCal, mainly because of a significant deviation of the Suigetsu ^{14}C data from the marine-based records, which cast doubt on the SG93 varve chronology.

Early outputs from the SG93 core also included reconstruction and dating of paleoclimatic events. Based on the varve chronology and pollen analysis of >400 samples from the late glacial part of the core (ca. 16-10 ka), Nakagawa et al. (2003, 2005) argued that the late glacial climate in Japan exhibited similar millennial-scale oscillations to the North Atlantic but with centennial-scale offsets in timing. However, this was not widely accepted by the community, partly because of the issues with the SG93 varve chronology, and also because it was not in good agreement with East Asian speleothem records that were precisely U-Th dated (Wang et al. 2001; Shen et al. 2010).

More recently, Staff et al. (2010) re-analyzed the SG93 radiocarbon dataset by Bayesian statistical modeling techniques (Bronk Ramsey 2008, 2009) using IntCal09 as the matching target. This revealed that the gaps between core segments of SG93 were larger than initially supposed, and that the

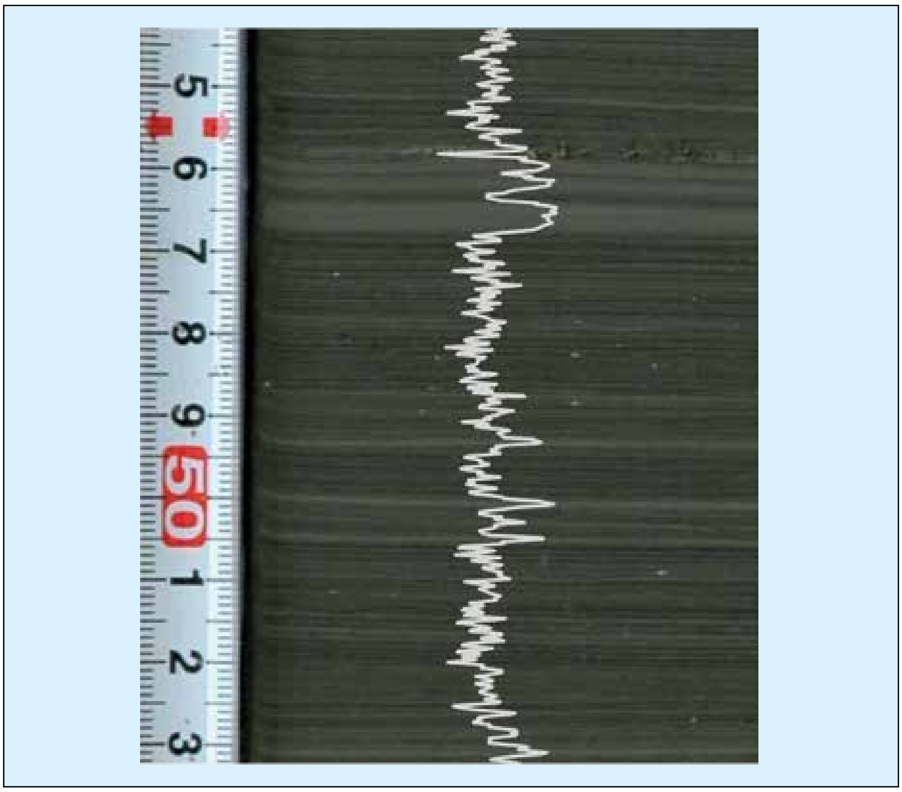

Figure 1: Varved sediments of Lake Suigetsu, Honshu Island, Japan. The curve shows relative gray scale values as measured on the displayed image.

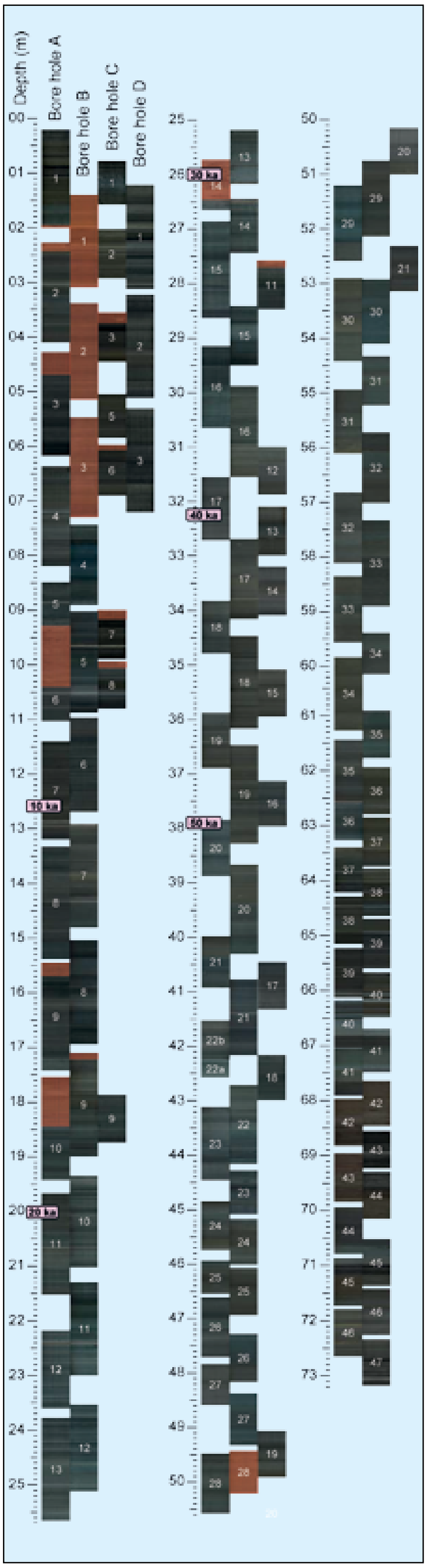

Figure 2: Photographic litho-stratigraphy of the SG06 core (modified after Nakagawa et al. 2012). Red shades show disturbed sediment sections. The coring team consisted of people from Newcastle University (UK), University of Tokyo, Osaka City University, Chiba University of Commerce, Naruto University of Education, Kyoto University (Japan), GeoForschungsZentrum Potsdam (Germany), and Royal Holloway University of London (UK).

estimated gaps were roughly sufficient to account for the departure of the SG93 radiocarbon data from marine curves. In other words, it convincingly demonstrated that (i) the SG93 varve chronology was generally too young, and (ii) the main source of error was the discontinuity of the core rather than varve counting inaccuracy. This meant that the potential scientific value of the Lake Suigetsu varved sediment remained very high, if sampled in the form of continuous sediment cores.

Suigetsu returns!

Phase Two of the Lake Suigetsu study began in 2006, when funding was secured from the Natural Environment Research Council (NERC), UK to recore the lake. An international team, consisting of researchers from the UK, Japan, and Germany, recovered a new master core (SG06) in summer 2006 from four parallel bore holes with sufficient overlap to provide a 100% continuous, 73.2 m long sediment profile covering the past ca. 150 ka (Nakagawa et al. 2012; Fig. 2). Building on the success of the SG06 coring, a further extended research group obtained additional funding from NERC and the German Research Foundation, along with other internal support from UK and Japanese institutions to analyze the core in detail.

Varve counting is the crucial part of the whole project. We therefore employed both conventional counting by thin-section microscopy, and ultra-high resolution scanning (60 µm stepping) using an Itrax™ X-radiograph and XRF scanner (Marshall et al. 2012; Francus et al. 2009). The two parallel counting results were merged into a single age-depth model using newly developed statistical methods (Schlolaut et al. 2012; Marshall et al. 2012). The merged varve chronology of the SG06 core has already been established down to ca. 30 ka. Soon, it will be extended beyond the radiocarbon limit (>50 ka).

More than 600 radiocarbon measurements were made on terrestrial tree leaf fossils, manually extracted from SG06. The distribution of the radiocarbon dates shows good agreement with the terrestrial part of the IntCal09 model (0-12,550 cal. BP) supporting the continuity of the sediment and the accuracy of the merged varve chronology (Staff et al. 2011; Marshall et al. in press).

A notable tephra horizon (the 'SG06-1288', or 'U-Oki' tephra) provides an important marker layer in the early Holocene part of the SG06 core, which has been precisely dated by numerous radiocarbon dates and Bayesian wiggle matching to the terrestrial part of the IntCal09 calibration model (Staff et al. 2011; Bronk Ramsey 2009). Recently we conducted Ar/Ar dating of 34 sanidine crystals extracted from the proximal deposits of this tephra, and attained excellent Ar/Ar age determination with errors < 3%, in spite of operating close to the younger limit of the Ar/Ar technique (Smith et al. 2011). This suggests that we will be able to apply the same method for the deeper part of the core, reduce the cumulative counting error of the SG06 varve chronology, and significantly improve the accuracy of the terrestrial radiocarbon calibration dataset beyond the tree ring limit.

The Lake Suigetsu 2006 project has also yielded a range of paleoclimatological data that are almost ready to be published. Most of them are still waiting for the independent chronology to be finalized. However, Kossler et al. (2011) have already reported decadal to sub-decadal scale sequential changes in diatom flora, sedimentary structure and local vegetation during the Lateglacial transitions. Papers on event timings based on high-resolution pollen, biomarker, and XRF results will follow shortly.

Summary

Our new Lake Suigetsu project aims to (i) provide a key dataset for more reliable terrestrial radiocarbon calibration over the whole range of the method, and (ii) provide a reference record for the East Asian Monsoon region. After two decades of effort by three generations of researchers to pave the runway, research on the Lake Suigetsu varved sediment record is now finally taking off.

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Monsoon reconstruction in subtropical Asia from oxygen isotope ratios of tree-ring cellulose

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Tree-ring records reveal that climatic sensitivity of cellulose δ^{18}O can be higher than that of ring width, that summer monsoon in the Himalayas has weakened over the last two centuries, and that El Niño-Southern Oscillation significantly affects the hydroclimate of Southeast Asia.

The impact of hydrologic regime shifts in the Asian Monsoon under changing global climate is significant, since the intensity of monsoon directly affects the agricultural production of the most densely populated regions in the world. Proxy climate records dating back to the pre-instrumental era are therefore essential for evaluating the roles of natural variability and anthropogenic impact on the Asian Monsoon system. Tree rings have often been used to reconstruct past climate variations with annual resolution, and extensive networks of tree-ring chronologies have been developed in North America and Europe. Unlike in higher latitudes, relatively few tree-ring chronologies were produced for tropical and subtropical Asia, since the lack of climatic seasonality hinders annual ring formation of most tree species in these regions. However, over the last couple of decades dendrochronologists have found increasing success in the low latitudes of Asia by selecting regions with more pronounced temperature or precipitation seasonality.

Tree-ring δ^{18}O as a hydrologic proxy

A major recent advance has been the hydroclimatic reconstructions from rare and long-lived Fujian Cypress (*Fokienia hodginsii*) growing in Vietnam (Buckley et al. 2010; Sano et al. 2009). These records based on ring width measurement revealed that the region experienced decadal-scale droughts in the past, which have no analog in the instrumental period. Interestingly, these exceptional droughts coincided with periods of social unrest (Buckley et al. 2010). In addition to this progress, other recent studies indicated that oxygen isotope ratios of tree-ring cellulose might help improve our understanding of monsoon activity (Sano et al. 2012a,b ; Xu et al. 2011). In this brief note, we show some advantages of using tree-ring δ^{18}O rather than ring width and wood density traditionally utilized in dendroclimatolgy.

It is well known that tree-ring width and wood density are controlled not only by climate but also by endogenous disturbance pulses, such as competition with neighboring trees. To reduce such disturbances, climatically sensitive trees are sampled predominantly at the species ecological boundaries, such as near arid or cold forest limits. This spatial limitation can be overcome by using oxygen isotope ratios, since the isotopic ratio in the wood is not significantly affected by ecophysiological processes. Tree-ring δ^{18}O is theoretically controlled by two climatic factors, δ^{18}O of the source water and relative humidity (e.g. Robertson et al. 2001; Saurer et al. 1997), both of which are closely related to monsoon activity in South and Southeast Asia. Our preliminary analyses using samples from the Himalayas (Sano et al. 2010) and Laos (Xu et al. 2011) clearly show that tree-ring δ^{18}O is more strongly correlated with precipitation, relative humidity, temperature and Palmer Drought Severity Index (PDSI) than is ring width or wood density. PDSI is a drought metric based upon a water balance model. Positive and negative values of the PDSI correspond respectively to wet and dry conditions (Palmer 1965; Dai et al. 2004).

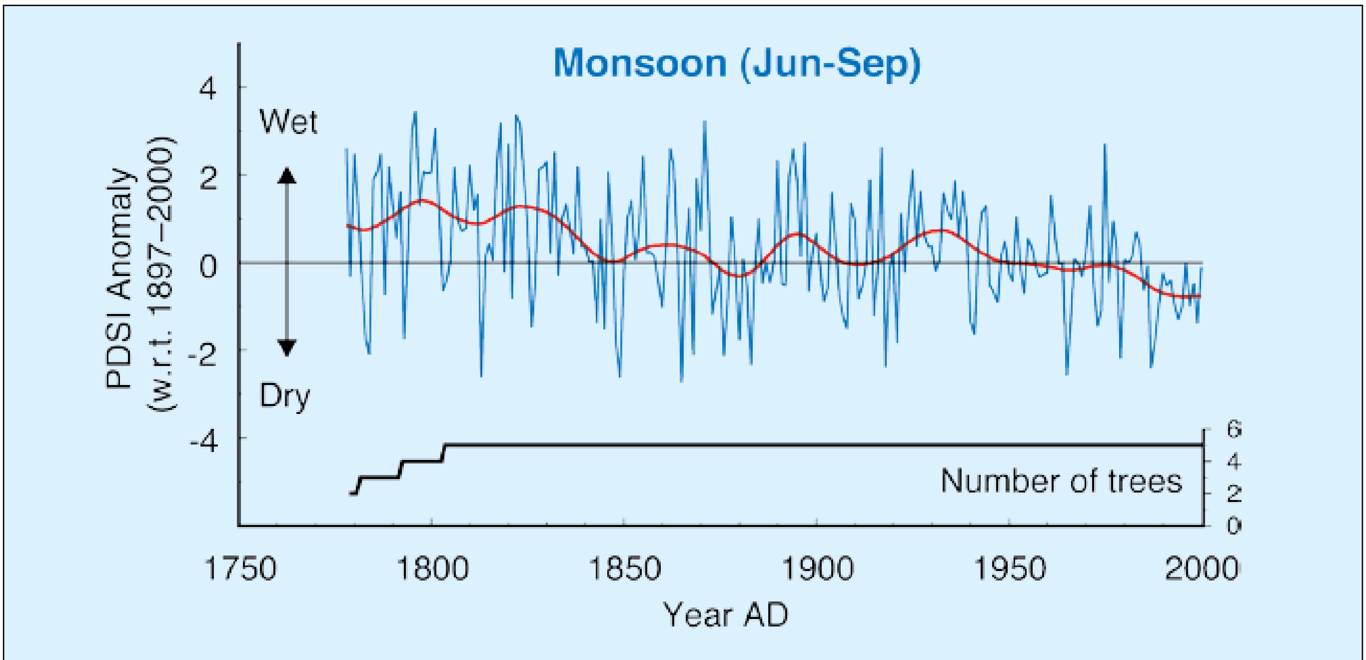

Figure 1: Reconstructed June-September PDSI from tree-ring δ^{18}O in the Nepal Himalayas. The thick curve represents a 30-year cubic spline. Figure modified from Sano et al. (2012a).

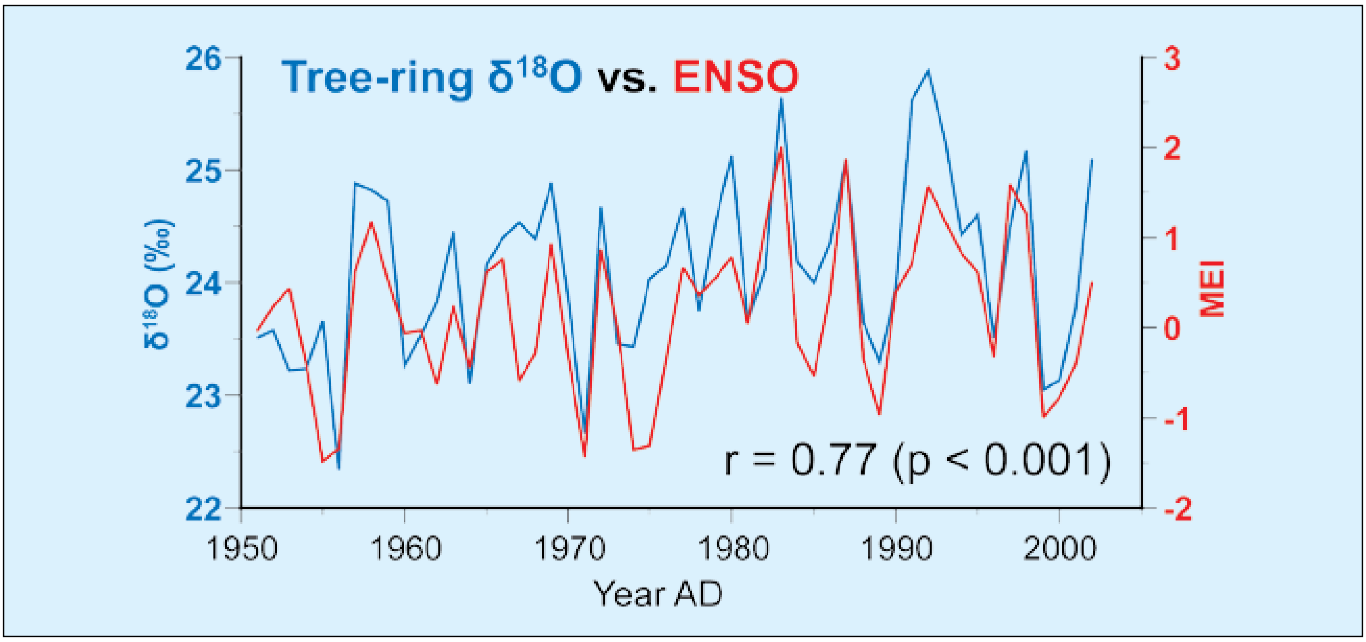

Figure 2: Comparison of inter-annual variations in tree-ring $\delta^{18}O$ from Laos and the Multivariate ENSO index (MEI) for the period of 1951-2002. Figure modified from Xu et al. (2011).

Evidence of weakening monsoon over the Himalayas and Tibet for the last two centuries

Tree-ring $\delta^{18}O$ from the Nepal Himalayas accounts for 34% of the inter-annual variability of the PDSI in the monsoon season (July–September), and clearly shows a decreasing trend of precipitation/moisture over the last two centuries (Fig. 1). Evidence for a decrease in summer monsoon rainfall was also found in $\delta^{18}O$ of tree rings from Tibet (Grießinger et al. 2011), δD of an ice core from Mt. Everest (Kaspari et al. 2007), snow accumulation of an ice core from Dasuopu, Tibet (Zhao and Moore 2006), and varve thickness of lake sediments in Tibet (Chu et al. 2011). The overall trends toward arid conditions indicate that summer monsoon has weakened across wide areas of the Himalayas and Tibet for at least the last couple of centuries.

Our reconstructed PDSI shows significant correlations with sea surface temperatures in the tropical Pacific and Indian Ocean, suggesting that the tropical oceans play a role in modulating hydroclimate in the Nepal Himalayas. A simulation model forced by observed sea surface temperature (SST) data reveals that a weakening trend of monsoon precipitation found in northern India and the eastern Tibetan Plateau over the latter half of the 20th century is deducible from the atmosphere's response to an increase in SSTs over the tropical Pacific and Indian Ocean (Zhou et al. 2008). Therefore, the consistent warming found in reconstruction of tropical SSTs over the last two centuries (Wilson et al. 2006) might be responsible for the weakening monsoon in the Himalayas. In contrast, other proxy records from lower altitudes indicate a strengthening of the monsoon winds (Anderson et al. 2002) and precipitation (Wang et al. 2005). The increased north–south difference of monsoon activity is likely induced by a southward shift in the overall position of the monsoon trough.

Links between ENSO and tree-ring $\delta^{18}O$ records from Southeast Asia

In contrast to ring-width-based reconstructions from the Himalayas and Tibet, those from Southeast Asia are rare, since most trees grow in relatively warm and wet environments. To overcome this limitation, isotopic analyses have been conducted on samples from four cypress trees from Laos for the past 52 years (1951-2002). It turned out that contrary to the tree-ring widths data (Xu et al. 2011), the $\delta^{18}O$ time series of the trees are significantly correlated with each other. Also, the $\delta^{18}O$ chronology built from the four trees shows significant correlation with temperature ($r = 0.64$, $p < 0.001$), precipitation ($r = -0.34$, $p < 0.05$) and PDSI ($r = -0.66$, $p < 0.001$) in the monsoon season. In contrast, no significant correlation was found between any climatic variables and a ring-width chronology based on 15 trees, which includes the four trees utilized for the isotope measurement. Finally, the $\delta^{18}O$ chronology is strongly correlated with ENSO-related indices, particularly with the Multivariate ENSO Index (MEI; Wolter and Timlin 2011) for the last 52 years (Fig. 2). To further explore the potential of isotope dendroclimatology, six more cypress trees from Vietnam have been subjected to $\delta^{18}O$ analyses. Surprisingly, the $\delta^{18}O$ chronology from Vietnam is closely correlated to that from Laos (Sano et al. 2012b), even though these sampling sites are around 150 km away from each other. Moreover, the teleconnected relationships between the $\delta^{18}O$ chronology and ENSO-related indices are stable over the 135-year period of available instrumental data.

Over the last decade, considerable effort has been devoted to reconstruct ENSO variability using tree rings and other proxy records that originate mainly from North America and the topical Pacific (e.g. D'Arrigo et al. 2005; Mann et al. 2000; Wilson et al. 2010). Although these records agree well during the twentieth century, there is relatively little agreement before this time. Wilson et al. (2010) point out that the teleconnected relationship between the tropical central/eastern Pacific and regions where proxy records are located does not seem to be stable. Since none of the previously published reconstructions of ENSO variability include data from mainland Southeast Asia, tree-ring $\delta^{18}O$ is of great use to independently reconstruct ENSO, and to explore the spatial influence of ENSO before the instrumental period.

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Hydroclimate reconstruction in Indonesia over the last centuries by stalagmite isotopic analyses

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Oxygen and carbon isotopic data from an Indonesian stalagmite help improve our understanding of past rainfall variation in the tropics.

Stalagmites as paleoclimate archives

Stable isotopic records of stalagmites are a powerful tool to reconstruct past climate change because stalagmites yield continuous terrestrial paleoclimate records and can be dated accurately by the U-Th dating method (e.g. McDermott et al. 2004; Fairchild et al. 2006). Figure 1 shows the formation process of stalagmites. In the soil and upper epikarst, water is enriched with pCO_2 derived from plant respiration and organic matter decay (Fairchild et al. 2006). During its percolation in the carbonate bedrock, water dissolves carbonate components and eventually reaches supersaturation. When the water emerges into a cave as dripwater, carbon dioxide is degassed into cave air and calcium carbonate precipitates, forming a speleothem. Under the formation process described above, stalagmites record fluctuations of rainfall and/or temperature on the land surface as variation in their $\delta^{18}O$ and $\delta^{13}C$ composition.

Previous studies on stalagmites in Asia

There are numerous studies based on $\delta^{18}O$ and $\delta^{13}C$ analyses of stalagmite investigating terrestrial climate changes on Milankovitch and millennial timescales (e.g. McDermott et al. 2001; Wang et al. 2001, 2008). In recent years, some stalagmite studies also focused on shorter timescales. Figure 2 shows stalagmite study sites in Asia targeting reconstructions of rainfall variation during the last 2000 years. Stalagmites collected in China, India and Thailand yield oxygen isotopic variations on subdecadal to subannual timescales (Zhang et al. 2008; Tan et al. 2009; Sinha et al. 2007, 2011; Cai et al. 2010). In these studies, oxygen isotopic variations in the stalagmites were generally interpreted as representing variability in monsoonal rainfall intensity, although the exact interpretation on the climatic causes for isotopic variations in precipitation were different at each study site (e.g. amount effect vs. source effect). While these studies provided important insight in the precipitation regime of southern and

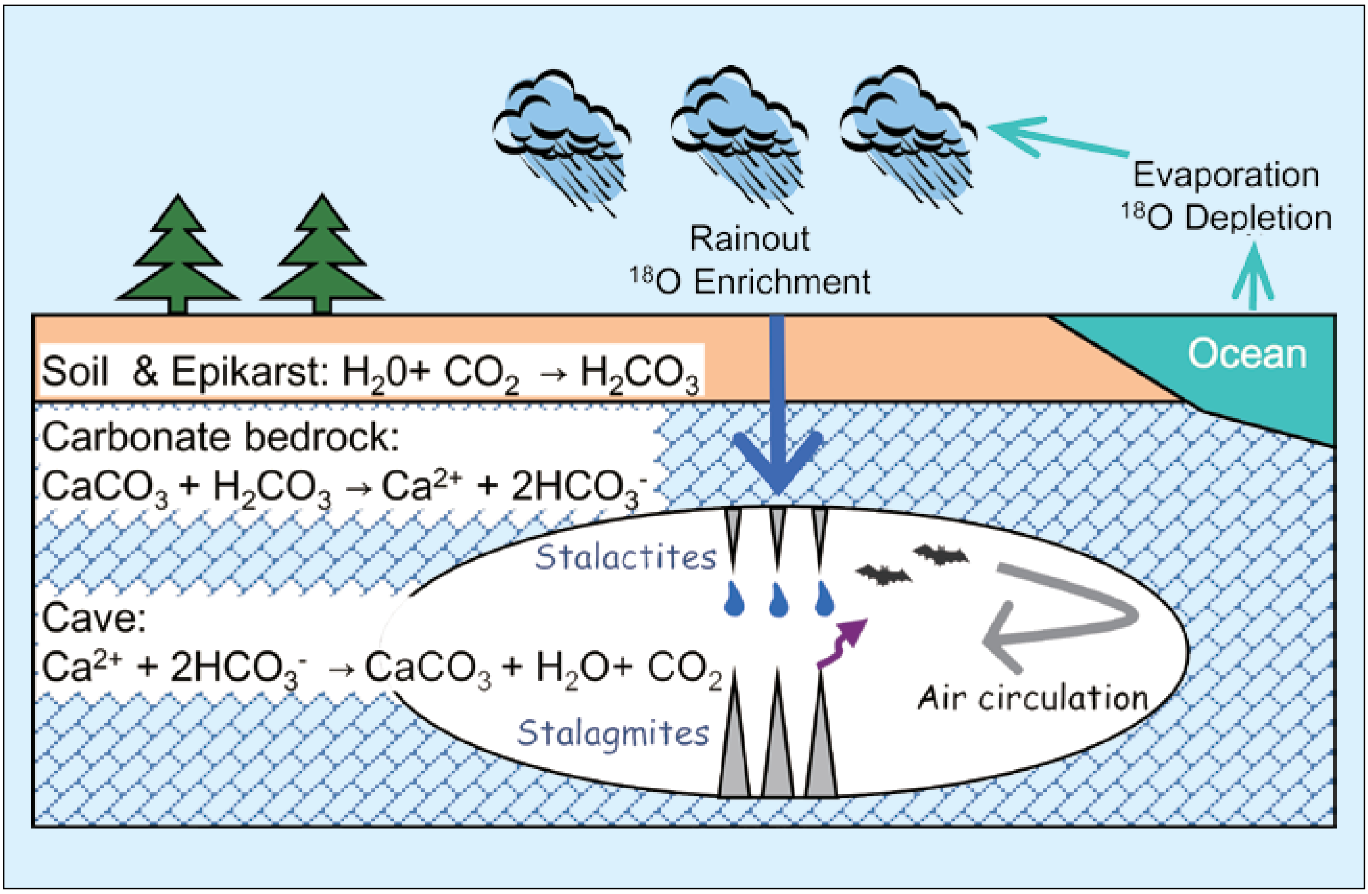


Figure 1:The formation process of stalagmites.

eastern Asia, little attention has been paid to the southeastern Asian tropical regions.

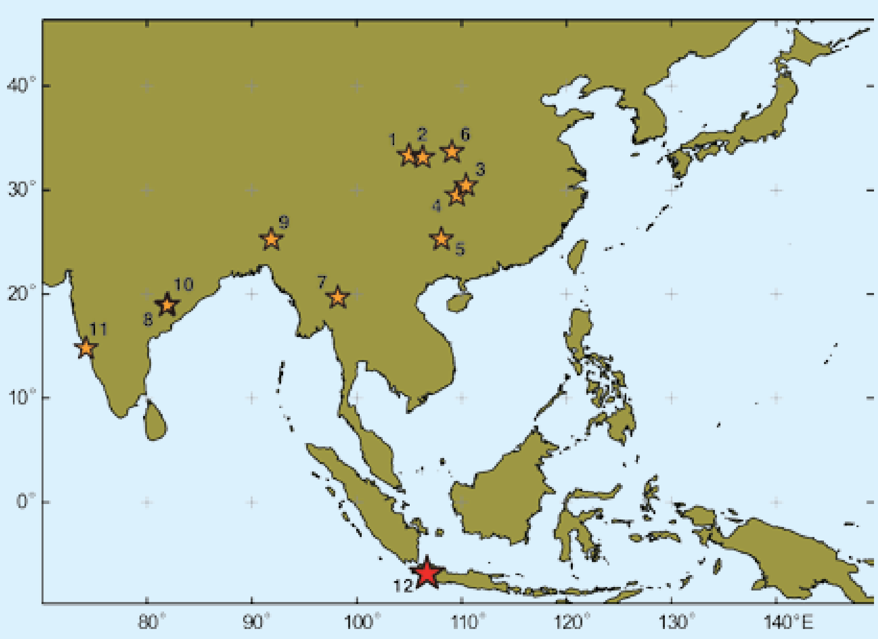
Our stalagmite study in Indonesia

The high insolation in the tropics is the driving force of poleward heat transport, and tropical climate anomalies, such as El Niño and La Niña events, also affect the rest of the world through teleconnection. Thus the tropics are a critical region to study the global climate system. However, instrumental meteorological data are very limited compared to Europe and eastern North America (Parker et al. 2000) and need to be supplemented by proxy records. In our study, we performed a systematic comparison between variations in precipitation amount and $\delta^{18}O$ and $\delta^{13}C$ measurements of an Indonesian stalagmite to reconstruct rainfall variability over the last 500 years.

First, we analyzed a stalagmite collected in the Ciawitali Cave in western Java and compared its $\delta^{18}O$ and $\delta^{13}C$ records with available instrumental rainfall records back to the 1950s. Negative correlations were statistically significant (r^2=0.50 for $\delta^{18}O$; r^2=0.85 for $\delta^{13}C$; Watanabe et al. 2010) and suggest that isotopic ratios of stalagmites are useful proxies for reconstructing rainfall amounts in the region. To account for the time lag of the water percolation from the land surface into the cave, we measured the percolation time of dripwater in the Ciawitali Cave by the ^3H-^3He dating method (Yamada et al. 2008). We obtained a percolation time of ca. 13 years. Taking this into account, the negative correlation disappears between the isotopic data and the instrumental rainfall record. This suggests that the $\delta^{18}O$ and $\delta^{13}C$ values of the stalagmite are immediately influenced by the climatic conditions outside the cave, probably via the piston-flow mechanism of groundwater and in-situ CO_2 degassing described by Watanabe et al. (2010).

In addition, we measured $\delta^{18}O$ and $\delta^{13}C$ values over the last 500 years (1440-2006 AD) and found that $\delta^{18}O$ and $\delta^{13}C$ varied from -7.7 to -5.4‰ and from -14.1 to -11‰, respectively. The $\delta^{18}O$ and $\delta^{13}C$ variations show synchronous changes throughout the entire period. Enriched ^{18}O signatures around 1600, 1800 and 1990 AD suggest episodes with drier conditions. These episodes coincide with evidence of droughts documented in lake sediments of East Java (Rodysill et al. 2011), and hence are likely associated with regional hydrologic anomalies caused by ENSO dynamics.

Further $\delta^{18}O$ and $\delta^{13}C$ measurements are in progress to reconstruct rainfall anomalies in the Asian tropics during the past millennium, especially during the Medieval Climate Anomaly and Little Ice Age.



No.	Country	Location	Elevation	Cave name	Duration	Time-resolution	Reference
1	China	33°19′ N 105°00′ E	1200 m	Wanxiang	192-2003 A.D.	2.5 yr	Zhang et al. (2008)
2	China	33°08′ N 106°18′ E	870 m	Dayu	1249-1983 A.D.	0.5 / 2-4 yr	Tan et al. (2009)
3	China	30°27′ N 110°25′ E	294 m	Heshang	9450 yr BP-2001 A.D.	2 / 16 yr	Hu et al. (2008)
4	China	29°29′ N 109°32′45″ E	455 m	Lianhua	6590 yr BP-present	1-2 / 8 yr	Cosford et al. (2008)
5	China	25°17′ N 108°5′ E	680 m	Dongge	9000 yr BP - 2002 A.D.	4.5 yr	Wang et al. (2005)
6	China	33°40′ N 109°05′ E	500 m	Buddha	1270 yr BP-present	1-3 yr	Paulsen et al. (2003)
7	Thailand	19°40′30″ N 98°12′12″ E	923 m	Namjang	1900-2005 A.D.	0.2–1 yr	Cai et al. (2010)
8	India	18° 52′ N 81° 52′ E	600 m	Jhumar	1075-2008 A.D.	1.45 yr	Sinha et al. (2011)
9	India	25° 15′ N 91° 52′ E	1290 m	Wah Shikar	1399-2007 A.D.	0.97 yr	Sinha et al. (2011)
10	India	19°00′ N 82°00′ E	400 m	Dandak	600-1500 A.D.	0.4 / 2.7 yr	Sinha et al. (2007)
11	India	14°16′ N 75°08′ E	600 m	Akalagavi	1666-1996 A.D.	1.1 yr	Yadava et al. (2004)
12	Indonesia	7°02′ S 106°55′ E	750 m	Ciawitali	1963-2006 A.D.	1.1 yr	Watanabe et al. (2010)

Figure 2: Study sites of Asian stalagmites used to reconstruct rainfall variations over the last 2000 years. The red star shows the location of the Ciawitali Cave on West Java, Indonesia.

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River runoff over 2000 years in the arid Heihe River Basin, northwestern China

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We reconstructed long-term river runoff from a glaciated catchment to better understand the role of glaciers as a water resource and the impact of climate change on human activities at an oasis on the Silk Road.

The glacier as a water resource

As glaciers continue to retreat due to the ongoing effects of global climate change, the availability of water during summer within river systems is expected to decline (e.g. IPCC 2007). Consequently, there has been considerable interest in gaining a better understanding of the contribution of glacial meltwater to river runoff in a number of catchments (e.g. Immerzeel et al. 2010; Kaser et al. 2010; Huss 2011). A mutual conclusion in these studies is that fluctuation of glacier meltwater significantly affects the river runoff if the river flows into arid terrain because water supply from precipitation will for a large part not attain the lower reaches. These studies tend to focus on evaluating the present-day contribution of meltwater to river runoff, and projections of likely future levels. In contrast, there has been less interest in the reconstruction of long-term historical runoff patterns at high temporal resolutions (e.g. annual) in glaciated catchments. One explanation for this may be that while paleoclimatic studies use several established proxies to reconstruct climate indices such as temperature, precipitation, or flood and drought events, finding an appropriate proxy for river runoff remains challenging. In this paper, we use models and climate reconstruction data to estimate the long-term (past 2000 years) runoff of the Heihe River in an arid basin in northwestern China (Fig. 1), where precipitation in the surrounding mountain ranges plays a significant role in providing water for the desert and oasis cities.

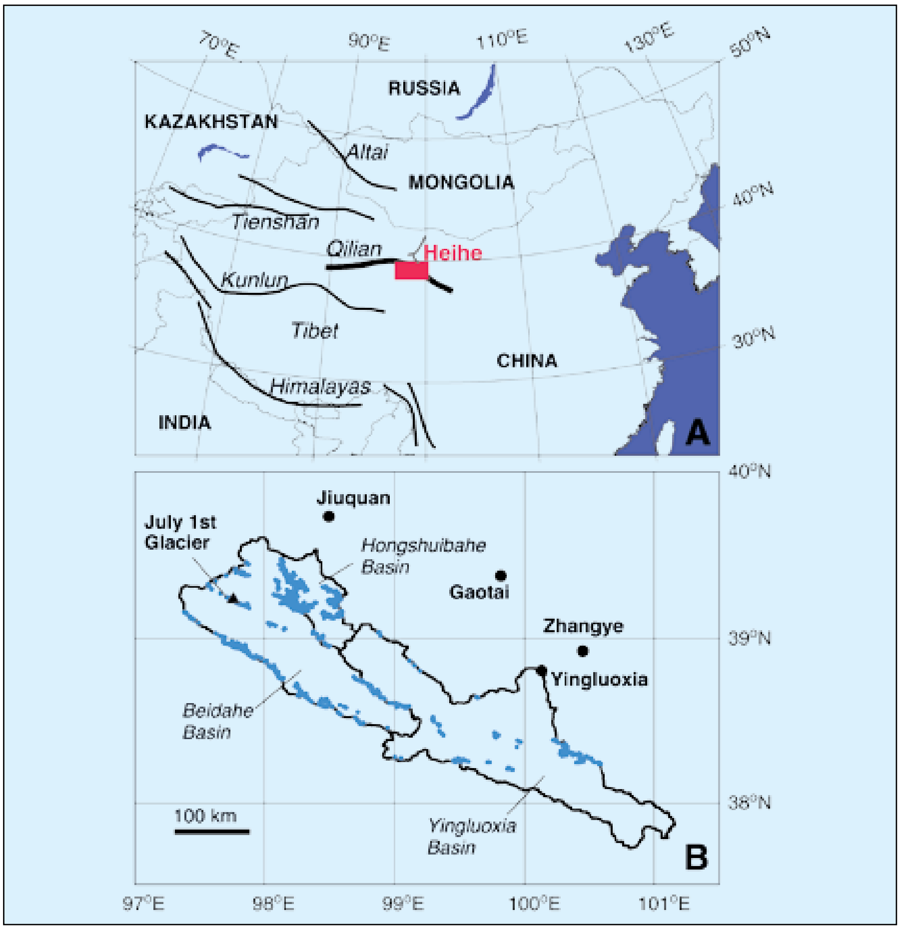

*Figure 1: **A)** Location of the Heihe River, northwest China. Red rectangle indicates the area shown in panel B. **B)** The catchments of upper stream basins. Stations where several decades worth of hydrological and meteorological data are available are indicated (black circles), as is the July 1st Glacier, where glaciological observations were conducted for the period 2002-2005. Blue dots denote glaciers in the basin delineated from satellite images. Each grid square is equivalent to the grid of the used APHRODITE precipitation dataset (0.5°; Yatagai et al. 2009).*

Reconstructing glacial runoff

We calculated river runoff components using an energy-mass balance model for glacier runoff (Fujita and Ageta 2000; Fujita et al. 2007) and a simple hydrological model for runoff from glacier-free terrain (Sakai et al. 2010). As meteorological variable input for the models, we used temperature and precipitation, and estimated relative humidity and solar radiation from precipitation (Matsuda et al. 2006; Sakai et al. 2010). Temperature and precipitation input data for the past 2000 years were obtained from tree-ring and ice-core studies (Yang et al. 2002; Zhang et al. 2003; Fig. 2A). Statistical downscaling was performed using meteorological data from neighboring stations (Fig. 1B). The spatial distribution and lapse rate were established by reference to gridded datasets (Kalnay et al. 1996; Yatagai et al. 2009) and are assumed to have remained constant through time. Accuracies of the models were tested against observed hydrological and glaciological data in the same region (Sakai et al. 2009, 2010). Changes in the size of the glacier are significant over the long term, as water runoff is significantly affected by changes in the extent of the ice cover. A simple but plausible glacier fluctuation model was established using an area-volume relationship for the glacier (Chen and Ohmura 1990; Liu et al. 2003). Glaciers in the catchment were delineated from a Landsat ETM+ image (Fig. 1B), and were classified into five classes based on the area they cover, as changes in glacier size vary according to their geometry (van de Wal and Wild 2001; Raper and Braithwaite 2006).

Controls on glacial runoff

We validated our calculated results against the known extent of glaciation in the Little Ice Age (LIA), which was determined from the positions of moraines on the satellite image and the present extent (Fig. 2B). River runoff levels reconstructed throughout the last 2000 years correlate closely with precipitation ($r = 0.997$, $p<0.001$; Fig. 2A and 2C), due to the small proportion of the catchment that was glaciated (1.3±0.2%). The average contribution from glacier runoff (1.8%) is slightly larger than might be expected based on the proportion of the glaciated catchment (1.3%), due to the effect of altitude on precipitation (it increases with altitude), which allows the glaciers to provide relatively more water than their extent would indicate.

We defined the trend of glacier extent (GT, $km^2\ yr^{-1}$) by the following equation,

$$GT_{(t)}=(GA_{(t+1)}-GA_{(t-1)})/2,$$

where GA and t denote glacier extent and time, respectively. Glacier runoff, and its contribution to the total river runoff, both showed a strong negative correlation with the trend of glacier extent ($r=-0.741$ and $r=-0.925$ respectively, both $p<0.001$, Fig. 2C). This implies that the glaciers have supplied excess meltwater to the river by reducing their ice storage during periods of glacier shrinkage. In contrast, when the glaciers were expanding during colder or more humid periods, storage of ice mass in the body of the glacier increased, and glacier runoff and its relative contribution to total runoff decreased accordingly. These results suggest that variations in glacier runoff and its contribution to river runoff do not always relate directly to glacier extent, but are also influenced by the nature of glacier response to changing environmental conditions.

Impact of human activities

Many historical documents covering the last 800 years are available for the Heihe River catchment, and allow us to compare our reconstructed river runoff levels with contemporary accounts (Fig. 2D). We use a record of drought events and highlight five of the most significant drought periods, which continued intermittently for periods of several years (labeled a-e), and a record of relative agricultural activity in the middle reach of the river (Inoue et al. 2007; Nakawo 2011). River runoff levels during drought events a, c, and e were relatively small; consequently, we suggest that these droughts were climate driven. In contrast, reconstructed river runoff during drought events b and d were relatively large. Therefore, these drought events may be attributable to human activity rather than climatic factors, and might have been caused for example, by excessive extraction of river water for irrigation. Indeed, in this region, the pioneering phase of agricultural land-use had already begun in the 13th century. In figure 2D, three relatively long drought-free periods are marked with thick lines. During the first period (AD 1355-1425), agricultural land-use had declined; therefore, human-induced droughts were unlikely, as there was a plentiful supply of natural water available (high runoff) to meet demand. The latter two periods (AD 1825-1855 and AD 1885-1925) coincide with the Dongan Revolt, during which agricultural land was left uncultivated.

Our results suggest that longer drought-free periods in the Heihe River catchment only occurred during phases with relatively low human impact and high river runoff (Sakai et al. 2012).

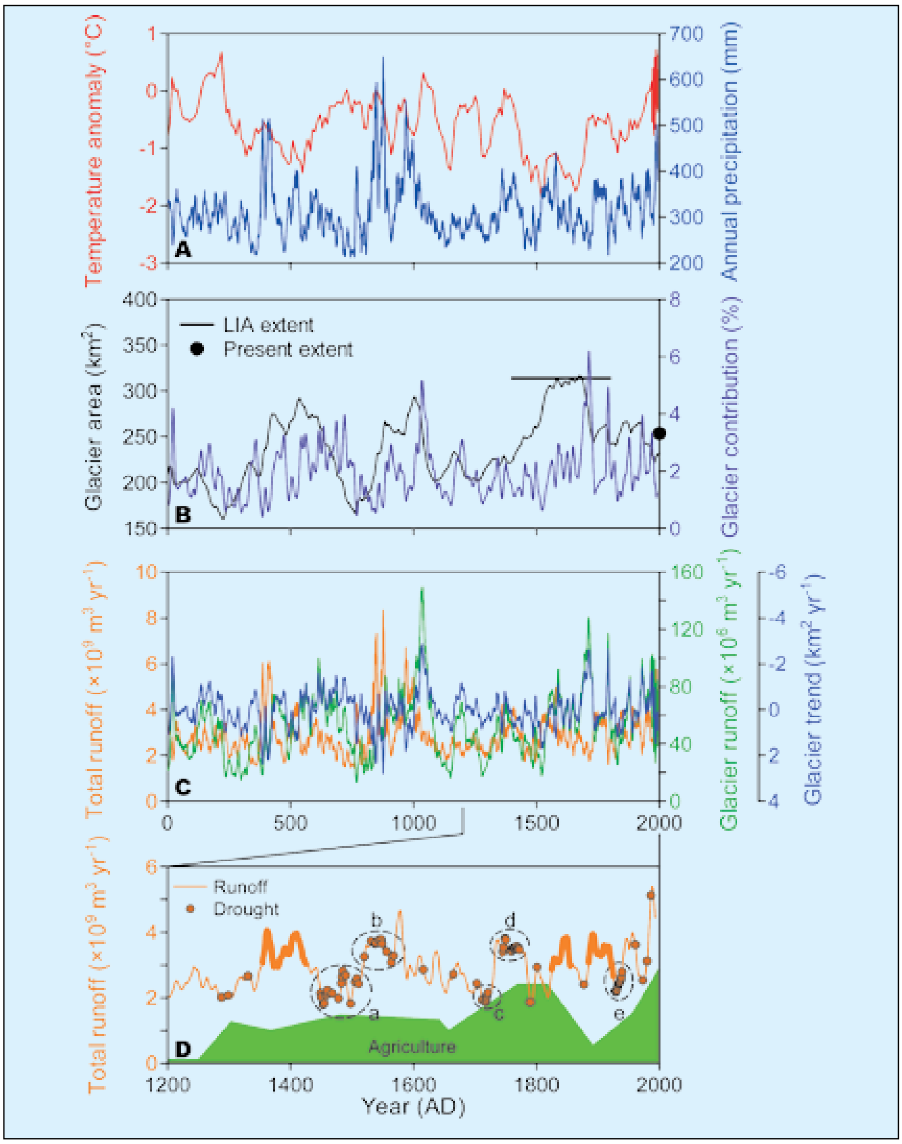

Figure 2: Climate and runoff records for the Heihe Basin covering the past two millennia. ***A)*** *Annual mean temperature anomaly rel. to AD 1966-1995 (Yang et al. 2002), and annual precipitation (Zhang et al. 2003).* ***B)*** *Glacier area and contribution of glacier runoff to total runoff (Sakai et al. 2012). The present and LIA extents are shown by the black dot and line, respectively.* ***C)*** *Total annual catchment runoff, annual glacier runoff (Sakai et al. 2012), and trend of glacier extent (see equation in the main text).* ***D)*** *Five-year moving average of river runoff and drought events recorded in historical documents. Five prolonged drought periods (a-e) are highlighted (Sakai et al. 2012). Thick lines denote drought-free periods, which are discussed in the main text. Green shading denotes trends of agricultural activity in the region as retrieved from historical documents (Inoue et al. 2007; Nakawo 2011).*

Past or future?

In the studied catchment, glacier extent is too small for glacier runoff to significantly affect the total runoff of Heihe River. Fluctuations in river runoff are primarily controlled by precipitation. Consequently, patterns of past precipitation levels reconstructed from ice cores and tree rings can be used to reconstruct changes of water availability in this region. However, in a more glaciated catchment, river runoff can fluctuate in a more complicated way and the influence of the glaciers is more important. It is generally believed that glacier shrinkage will lead to a shortage of water resources under a warming climate; however, our study suggests that the trend of glacier extent, advancing or retreating, is, on a shorter term, a more significant control on glacier runoff and its contribution to the river system.

Forecasting changes to the extent of glaciers, and the impact on river runoff is a societal need under the present warming climate. Current river-runoff level projections contain numerous uncertainties caused by changing environmental conditions and the application of differing general circulation and regional models. We have shown that our river runoff reconstruction based on paleoclimatological data combined with historical documents from the region, can be used to discriminate the runoff types and attribute the nature of drought events in the arid Heihe River Basin.

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Two centuries of climate events detected in coral records from Ishigaki and Ogasawara Islands, Japan

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Coral records from the subtropical northwestern Pacific reveal abrupt cooling and a shift toward fresher surface ocean conditions between 1900 and 1910 AD.

Only about 100 years or less of observational data for the ocean environment in the subtropical northwestern Pacific exist. Geochemical tracers, such as stable oxygen isotopes ($\delta^{18}O$), strontium/calcium (Sr/Ca) and uranium/calcium (U/Ca) ratios in skeletons of massive corals are excellent paleoclimatic and paleoceanographic proxies to extend our knowledge of the ocean environment beyond the instrumental record. Recently, a coral record going back to 1873 AD from Chichijima in the Ogasawara Islands (Felis et al. 2009) and a 165-year long record from Ishigaki Island, southern Ryukyus (Mishima et al. 2010) have become available (Fig. 1). These coral records reveal several coupled ocean-atmosphere phenomena during the early 20th century in the northwestern subtropical Pacific.

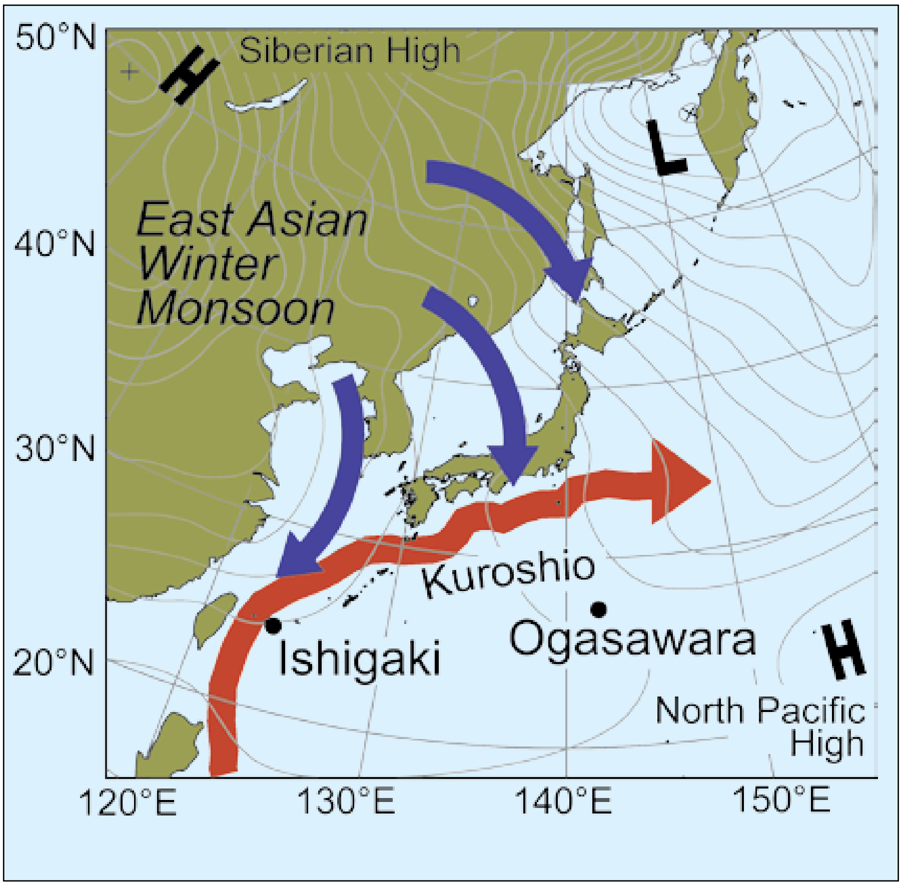

Figure 1: Map of the northwestern Pacific showing the locations of the Ishigaki and Ogasawara Islands. The typical winter East Asian sea-level atmospheric pressure distribution (isolines) and the path of the Kuroshio current (red arrow) are also shown. Northerly winds (East Asian winter monsoon) blowing from the Siberian High influence the climate around Japan in winter (blue arrows). Modified from Mishima et al. (2010).

Abrupt freshening event recorded in the Ogasawara coral

The Ogasawara Islands (27°N, 142°E), approximately 1000 km south of Tokyo, Japan, are exposed to the open ocean environment. Felis et al. (2010) reported that the winter Sr/Ca and U/Ca paleotemperature records from an annually banded coral were significantly correlated with the instrumental winter Pacific Decadal Oscillation (PDO) index over the last century. The PDO is an indicator of North Pacific sea surface temperature (SST) anomalies poleward of 20°N.

Felis et al. (2009) also reconstructed annually resolved sea surface salinity (SSS) variations since 1873 from the $\delta^{18}O$ record and identified an abrupt shift toward fresher surface ocean conditions between 1905 and 1910 (Fig. 2C). They concluded that the Ogasawara freshening could not be explained by precipitation changes but resulted from a combination of atmospheric and oceanic convection processes.

The Ishigaki coral record and the East Asian winter monsoon

Ishigaki Island (24°N, 124°E) is in the marginal East China Sea (Fig. 1), where the ocean environment reflects complex influences from the Kuroshio Current and the East Asian monsoon. Although $\delta^{18}O$ can record changes in both SST and SSS, at Ishigaki, seasonal SSS changes are very small, whereas seasonal SST are well reflected by the $\delta^{18}O$ values. Winter $\delta^{18}O$ and observed SST, measured at Ishigaki Port, showed a significant linear correlation (Fig. 2A, B), which suggests that the winter $\delta^{18}O$ data from this coral sample is a good proxy for reconstructing past climate change. SST reconstructions can be used to investigate the relationship between the East Asian winter monsoon (EAWM) and the El Niño–Southern Oscillation (ENSO). Before 1988/1989, the coral-based and instrumental winter SSTs were related to the EAWM, whereas after that winter they were more highly correlated to ENSO, reflecting a regional change in the climate regime (Tsunoda et al. 2008).

The Ishigaki $\delta^{18}O$ coral record revealed abrupt cooling during 1900-1905 (Fig. 2A). This cold event was also seen in the coral Sr/Ca data, and its timing is consistent with Japanese observations of exceptionally low temperatures in the winter of 1902. The presence of a strong Siberian High coupled with a strong EAWM and weak

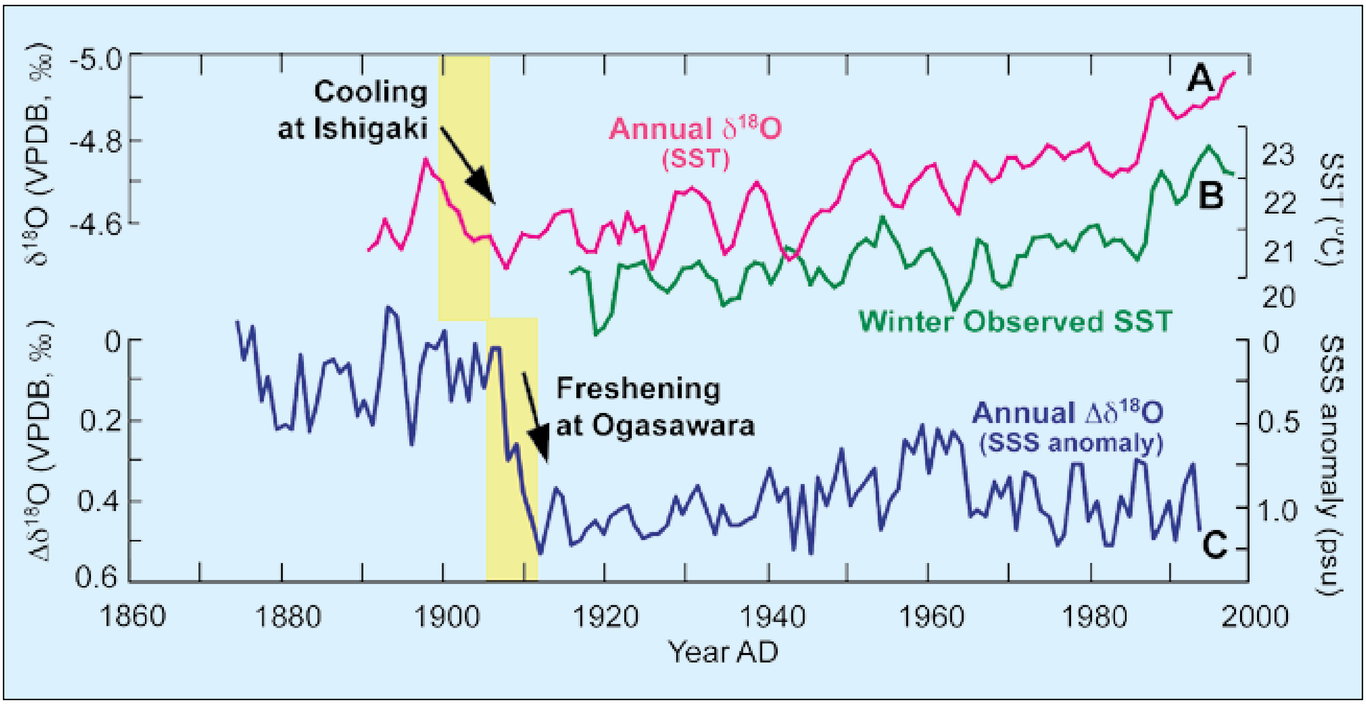

*Figure 2: Time series of **(A)** annual coral δ18O (SST) data, **(B)** observed winter (December–February average) SST at Ishigaki Island, and **(C)** residual coral δ18O records (Δδ18O) in the Ogasawara Islands, based on both δ18O and Sr/Ca. VPDB refers to the Vienna PeeDee Belemnite standard. The coral-based sea surface salinity (SSS) anomaly was calculated from the regional δ18O seawater–salinity relationship (0.42‰ per 1 psu; Felis et al. 2009). The yellow bars correspond to the abrupt cooling (1900-1905) inferred at Ishigaki Island and the abrupt freshening (1905-1910) in the Ogasawara Islands.*

westerly winds, possibly accompanied by active heat convection in the tropics, might account for the cold winter at this time (Mishima et al. 2010).

Unique observations of coupled early 20th century climate events in the northwestern Pacific

Interestingly, the abrupt cooling at Ishigaki Island occurred several years before the abrupt freshening in the Ogasawara Islands inferred from the coral isotope and trace element variations (Felis et al. 2009). The North Pacific High, which dominates the North Pacific Ocean, affects SSS; a strong North Pacific High is associated with high salinity. Strong westerly winds tend to enhance the North Pacific High because of its great height, approaching the height of the jet stream. Conversely, the freshening at Ogasawara suggests weak westerly winds, possibly associated with a weakened Kuroshio recirculation gyre, which flows from south of Honshu, Japan's main island, toward the Ogasawara Islands. In contrast, the Kuroshio's path from Taiwan to Ishigaki Island is relatively stable. Thus Ishigaki tends to be always under the influence of the saline Kuroshio and is thus unlikely to experience freshening such as that inferred at Ogasawara.

The decrease in SST indicated in the Ishigaki coral δ18O record was not observed in the Ogasawara coral record. A strong EAWM, which brings cold winds to the Japanese archipelago, is not likely to affect more pelagic environments such as the Ogasawara Islands. The approximately five-year time lag between the cold SSTs at Ishigaki and the freshening in the Ogasawara Islands is consistent with the findings of Deser et al. (1999), who reported that changes in the Kuroshio and associated North Pacific Ocean circulation lagged westerly wind changes by four to five years. By this mechanism, the early 20th century cooling recorded by the Ishigaki coral may be related to the surface ocean freshening record in the Ogasawara coral. Thus, these records are unique evidences of coupled ocean-atmosphere phenomena during the first decade of the 20th century in the subtropical northwestern Pacific.

Future research

The reliability of paleoclimate reconstructions could be improved by applying the dual proxy approach, utilizing element ratios such as Sr/Ca along with oxygen isotope data, to the Ishigaki coral record. This approach would allow independent reconstruction of SST and SSS variation and make it possible to determine whether cold events around Ishigaki Island are associated with successive regional climate regime shifts. Coral-based reconstructions are now being extended to different time windows, including the Little Ice Age, the mid-Holocene warm period (Yokoyama et al. 2011), the last glacial maximum (Mishima et al. 2009), and the mid-Pliocene Warming Period (Watanabe et al. 2011). Also, the investigation of *Porites* coral tsunami boulders is a promising approach for long-term paleoclimate reconstruction (Suzuki et al. 2008; Araoka et al. 2010). The robustness of *Porites* coral records has been tested in a series of laboratory culture experiments to provide practical guidelines for the interpretation of coral climate proxies (Suzuki et al. 2005; Omata et al. 2008, Hayashi et al. in press).

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Tracing the response of climate to galactic cosmic rays

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Anomalous changes in the heliospheric environment and incident cosmic rays during the Maunder Minimum in the 17th century may enable us to understand the impact of galactic cosmic rays on Earth's climate system.

Solar activity and climate change

The history of solar activity can be reconstructed by measuring cosmogenic nuclides such as ^{14}C in tree rings and ^{10}Be in ice cores. Comparisons between reconstructed solar activity and climate during the past 10,000 years have revealed that their variations are synchronized at a wide range of time scales, from decades to millennia. Given that the variability in solar irradiance is assumed to be small (~0.1%), it is necessary to consider other solar-related forcings to explain observed climatological phenomena such as the expansion of glaciers and changes in monsoonal activity. One possible medium of solar forcing is galactic cosmic rays modulated by the solar magnetic field in the heliosphere. The decadal and longer cycles of solar activity lead to temporal variations in the attenuation level of cosmic rays. Cosmic rays influence atmospheric ionization and the production of cloud condensation nuclei (Kirkby et al. 2011), although the detailed mechanism of their influence on the amount of clouds in the troposphere is not fully understood. Solar UV and solar wind also influence the climate by promoting chemical reactions in the stratosphere and mesosphere. The intensity of solar-related parameters follows the 11-year cycle of solar activity and is more or less synchronized among the various parameters. This makes it difficult to distinguish the climatic influence of cosmic rays versus other solar-related effects. Here we discuss the cosmic ray events around the 17th century that might help shed some light on the influence of cosmic rays on regional and global climate.

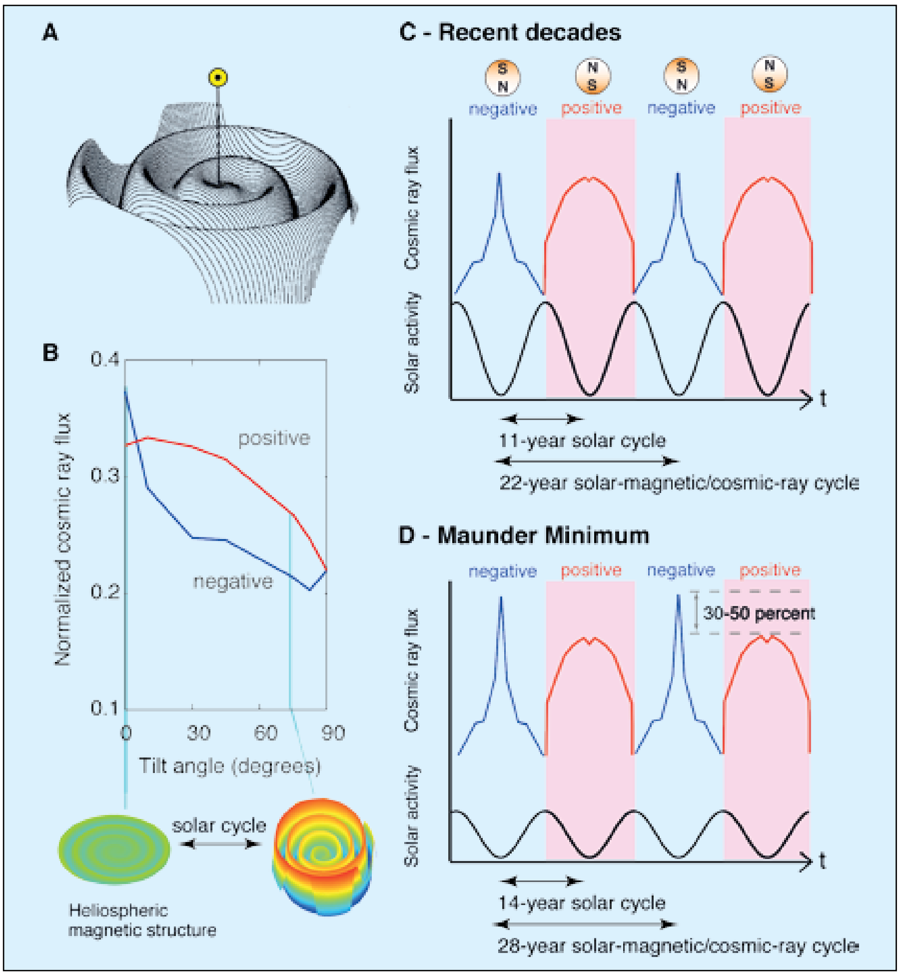

*Figure 1: **A)** Schematic of the heliospheric magnetic field with the Sun located at the center (modified after Jokipii and Thomas 1981). **B)** Relation between the numerically calculated intensity of galactic cosmic rays at the Earth and the waviness of the heliospheric magnetic field (as illustrated by the schematics below the graph), for both positive and negative polarities of the solar dipole magnetic field (based on Kota and Jokipii 2001). **C)** Cosmic-ray time profile at the Earth in the case of a tilt angle of 5° at solar cycle minima and 75° at maxima, as is observed during the recent decades. **D)** As for **(C)**, but for tilt angles of 0° at cycle minima, which reproduces the cosmic ray variation at the Maunder Minimum. Note that the polarity reverses at every maximum of the solar cycle, and that the length of the solar cycle tends to be longer (e.g. 14 years during the Maunder Minimum) when solar activity is suppressed.*

Heliospheric environment and cosmic rays

Galactic cosmic rays are attenuated in the heliosphere, which is an expansion of the wavy solar magnetic field (Fig. 1A). The complex magnetic structure of the solar surface is swirled by the 27-day rotation of the Sun and dragged outward by the solar wind to form a spirally wound heliospheric magnetic field. The attenuation level of cosmic rays is influenced by changes in the intensity of the solar magnetic field, magnetic polarity, and the large-scale structure of the wavy heliospheric magnetic field. The waviness of the field tends to be greater when solar activity is high; consequently, it changes over the 11-year cycle of solar activity as well as at centennial to millennial time scales. The reversal in solar magnetic polarity that occurs at each decadal maximum in the solar cycle is also influencing the attenuation level of cosmic rays. The changes in the polarity of the solar magnetic dipole and in the direction of the solar magnetic field line alter the trajectory of positively charged galactic cosmic rays in the heliosphere. A numerical simulation of the intensity of cosmic rays incident to the Earth can reproduce variations in the intensity of cosmic rays due to changes in solar magnetic polarities (Fig. 1B; Kota and Jokipii 2001). In recent decades, the waviness of the heliospheric magnetic field has been suppressed to about 5° at cycle minima, and has increased to about 75° at cycle maxima. The observed cosmic ray variations are well reproduced by the simulated time profile in Figure 1C; however, changes in the range of tilt angles can cause anomalous variations in the time profile of cosmic rays incident to the Earth. For example, if we assume that the heliospheric magnetic field is completely flattened at every cycle minimum, the graph in Fig. 1B suggests that the time profile of cosmic rays would become that shown in Fig. 1D. Indeed, the record of beryllium-10 from an ice core in Greenland (Fig. 2C; Berggren et al. 2009) reveals that cosmic ray variations at the Maunder Minimum, a period of very low sunspot activity in the 17th century, may have had the profile shown in Fig. 1D (Yamaguchi et al. 2010). The ^{10}Be record around the Maunder Minimum (AD 1645-1715) shows four anomalous spikes near minima of the solar cycle at negative polarity. The intensities of the cosmic-ray spikes are 30%-50% greater than those of peaks during times of positive polarity. We propose that the disappearance of sunspots at the Maunder Minimum (Fig. 2D) resulted in a completely flattened heliospheric magnetic field at solar minima, and caused anomalous enhancements in incident cosmic rays. It is also possible that maxima in long-term solar activity, such as the Medieval Solar Maximum, are characterized by anomalous temporal variations in cosmic rays.

Regional and global responses to cosmic ray spikes

The anomalous variations in cosmic rays during the Maunder Minimum enable us to trace the response of regional–global climate to galactic cosmic rays, and to understand the response of the climate system overall. It can be assumed that decadal-scale variations in solar irradiance and UV were suppressed during this 70-year period, given the absence of sunspots. In contrast, variations in cosmic rays were amplified during this period due to changes in the heliospheric environment, and four anomalous spikes occurred during this time. A comparison of the reconstructed climate and cosmic-ray-induced nuclides during the Maunder Minimum reveals that annually resolved records of climate from Greenland and Japan have synchronized 1-year-scale anomalies around the time of these four spikes (Fig. 2; Yamaguchi et al. 2010). The ^{10}Be record from the Greenland ice core has a dating error of several years, giving rise to a discrepancy in timing between the ^{10}Be record and the two climate records; however, a comparison of the superimposed spikes in ^{14}C and climate data obtained from annually-dated tree rings suggests that the climate responded to the 1-year cosmic ray spikes without a time lag. A search for these 1-year spikes in climate records (e.g. precipitation and temperature) over the globe may help to understand how cosmic rays affect the climate system.

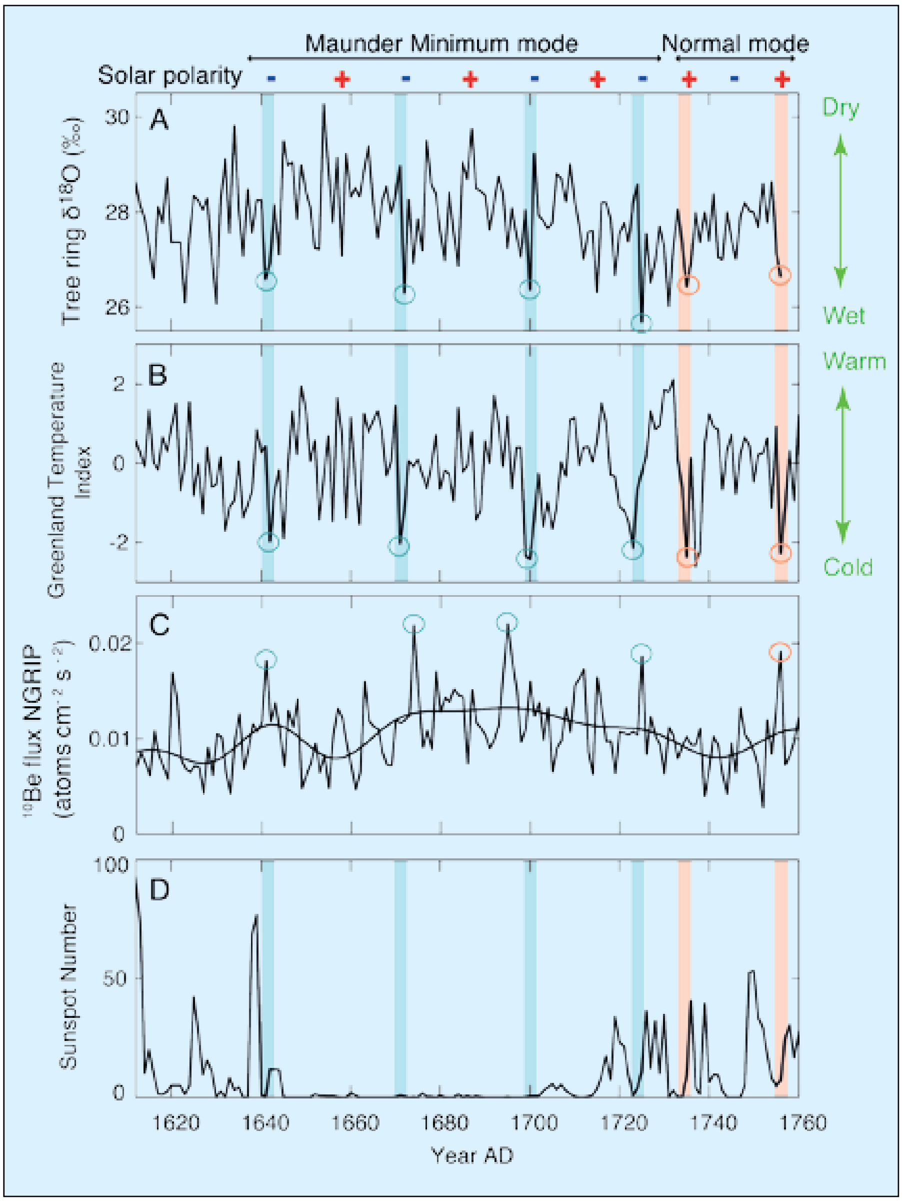

Figure 2: Temporal trends in ***(A)*** *relative humidity in Japan reconstructed based on ^{18}O in tree-ring cellulose (Yamaguchi et al. 2010),* ***(B)*** *reconstructed temperature in Greenland based on ^{18}O in ice cores (Vinther et al. 2003),* ***(C)*** *cosmic-ray-induced nuclides (Berggren et al. 2009), and* ***(D)*** *sunspot numbers (Hoyt and Schatten 1998). Open circles denote annual-scale 30%-50% enhancements in cosmic rays* ***(C)****, and the corresponding climate response* ***(A, B)****. Blue and red shadings periods of negative and positive solar polarity, respectively. Figure modified from Yamaguchi et al. 2010.*

Changes in the 11-year solar cycle

Frequency analyses of annually resolved ^{14}C records obtained from absolutely-dated tree rings enable a reconstruction of past changes in the solar decadal cycle. The long-term record of ^{14}C reveals that solar activity has quasi-periodic variations at centennial to multi-decadal time scales, and that a long-term absence of sunspots occurs every 100-300 years. The ^{14}C records also show that the solar cycle continues uninterrupted during periods without sunspots, such as the Maunder Minimum, although the length of the cycle increases from 11 to ~14 years (Fig. 1D). Inversely, the ^{14}C record indicates shorter periods in the solar cycle during maxima in long-term solar activity. During the Early Medieval Solar Maximum (9th-10th centuries), the length of the solar cycles decreased from 11 to ~9 years (Miyahara et al. 2008).

These results suggest that the incident cosmic rays have complex time profiles at decadal to multi-decadal scale, due to the changing solar cycle length and the heliospheric environment. This variation may help explain the complexity of multi-decadal climate variations.

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Document-based reconstruction of past climate in Japan

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Proxy and instrumental data from historical documents in Japan provide a picture of climate variability during the "Little Ice Age".

Paleoclimate reconstruction is essential for understanding past climate variability and its driving mechanisms within the global climate system. From the abundant historical documents preserved in Japan, unique climate reconstructions have been developed using qualitative meteorological information contained in them. Additionally, documents with instrumental meteorological data collected before 1872, when official meteorological observations began, were recently discovered and prepared for scientific analysis. Such approaches to reconstructing past climates are included in the field of historical climatology. In this article, the characteristics of these proxy and instrumental data from documentary sources are introduced and reconstructed climatic variations in and around Japan are described.

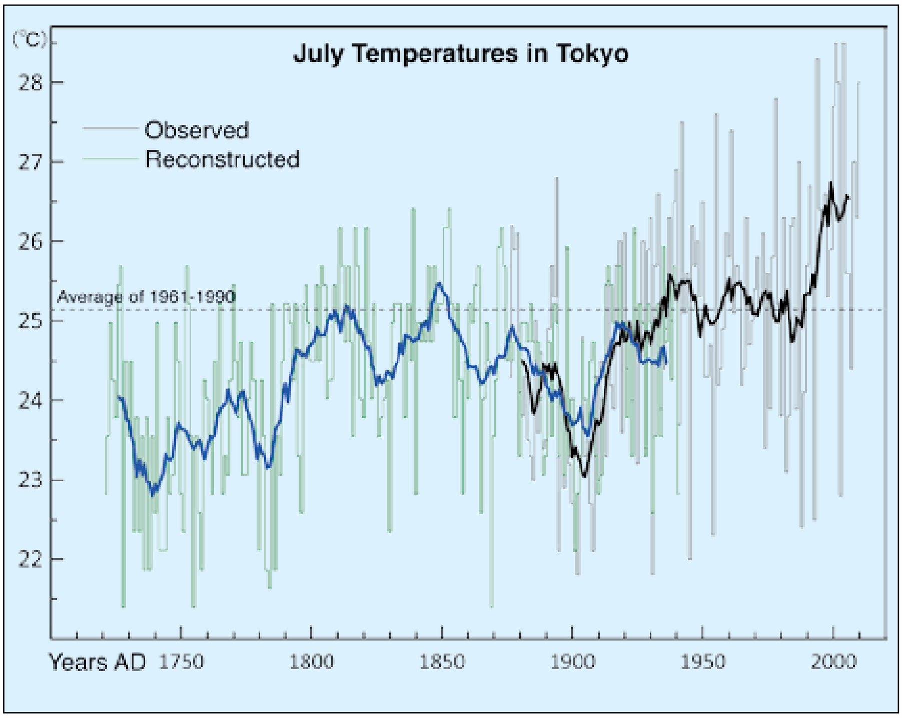

Figure 1: Time series of reconstructed (green lines) and observed (black/gray lines) July temperatures in Tokyo for 1721-2000. Thin lines indicate year-to-year variations and thick lines indicate 11-year running mean. Figure modified and updated from Mikami (1996).

Qualitative meteorological information from historical documents

In Japan, official meteorological data collected by the Japan Meteorological Agency (JMA) have been available only since 1872. There are however, several kinds of historical documentary sources, which enable reconstructions of climate variations before the 19th century in and around Japan. Historical documents including diaries of individuals, logs of clan offices, government documents, and reports from temples and shrines are preserved in local libraries and museums. These documents often contain daily weather descriptions such as "cold", "fine", "rainy" and "windy", and mention special climate-related natural phenomena such as "lake freezing" and "flower blooming".

Figure 1 is an example of a summer temperature reconstruction based on daily weather descriptions from the Ishikawa diaries; continuous family diaries kept in the western suburbs of Tokyo from 1721 to 1940 (Mikami 1996). Under present conditions, generally hot summers are experienced in Japan under the influence of strong subtropical highs, which bring dry and sunny weather conditions. Cool summers occur under the influence of stagnant polar fronts and passing extra-tropical cyclones, which bring cloudy and rainy weather conditions. As the number of rainy days highly correlates with the mean temperature in a summer month, especially in July (the correlation coefficient is -0.70 based on the JMA data for 1876-1940), it is possible to reconstruct July temperatures in Tokyo for the period 1721-1940 based on the weather records in the Ishikawa diaries. The reconstructed temperature series show several cooler and warmer periods. From 1721 to 1790, temperatures are estimated to have been about 1 to 1.5°C lower than at present. It should be noted that the temperatures in the 1780s were often very low with large inter-annual variations. In the summer of 1783, an extremely poor rice harvest occurred due to exceedingly cool and wet conditions, and this unusual weather led to a severe famine in Japan. In the 19th century, in contrast to the warmer periods of the 1810s and the early 1850s, the 1830s, late 1860s and late 1890s were relatively cool, and great famines occurred in the 1830s as they had in the 1780s. For the temperatures during the modern period, it is also notable that Tokyo has a very strong urban heat island effect and this is likely to have contributed to warming evident in the 20th century.

As with the reconstruction of summer temperatures, winter temperatures in Nagasaki, in southwestern Japan have been reconstructed based on a highly correlated relationship between snowfall ratio and monthly winter temperatures (Mikami 1992).

In addition to the temperature reconstructions, historical documents and other documentary sources have been used to reconstruct a chronology of typhoons affecting Japan in the 19th century based on diary weather descriptions of "strong wind" and "strong rain" which could be assumed to describe typhoon events. These weather descriptions were corroborated by reports in other historical documents (Grossman and Zaiki 2009).

Information about special climate-related natural phenomena such as "lake freezing" and "flower blooming" are also contained in historical documents. The dates of the complete freezing of Lake Suwa in central Japan have

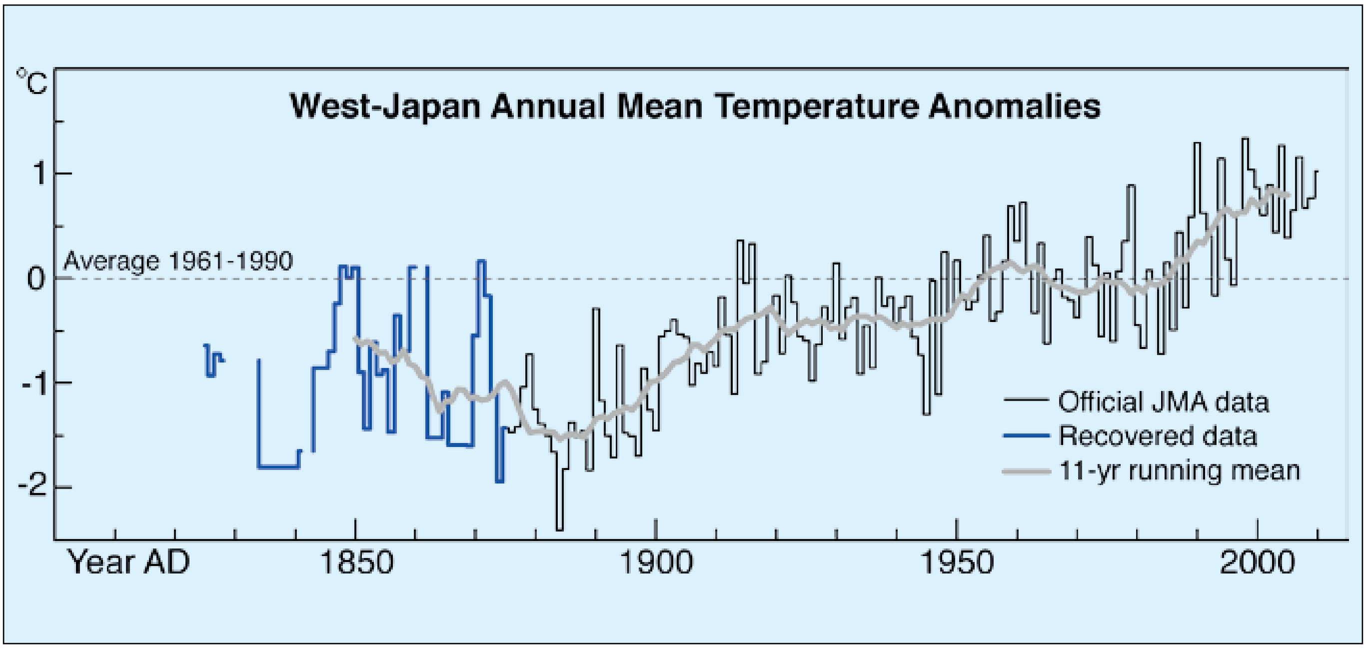

Figure 2: Time series of West-Japan Temperature (WJT) anomaly for the period 1820-2010. Blue line is derived from newly recovered meteorological data, black line is from official JMA data, and the gray thick line is a smoothed 11-year running mean. Figure modified and updated from Zaiki et al. (2006).

been recorded by the Suwa shrine since the 15th century and winter temperatures were reconstructed based on correlations between the freezing dates and December/January temperatures (Mikami and Ishiguro 1998). Additionally, March mean temperatures in Kyoto since the 9th century have been derived from the cherry blossom flowering date records (Aono and Kazui 2008; Aono and Saito 2010).

Instrumental records before the foundation of the Meteorological Agency

Prior to the founding of JMA, no instrumental meteorological records were believed to exist in Japan apart from qualitative weather descriptions in historical documents. However, documents containing instrumental meteorological data collected in several locations in the 19th century have been (re)discovered. Sub-daily meteorological records from the first half of the 19th century were collected routinely by Dutch scientists living in Japan and by the so-called "Dutch Study", Japanese scholars who learnt modern western science from the Dutch. Also, in the second half of the 19th century at the end of the period of international isolation of Japan, various Europeans (French, German, Russian) and Americans came to Japan and carried out meteorological observations.

The recovered instrumental observations cover the periods 1825-1828, 1839-1855, and 1872-1875 in Tokyo; 1860-1874 in Yokohama; 1828-1833 and 1869-1871 in Osaka; 1869-1871 and 1875-1888 in Kobe; and 1819-1878 in Dejima/Nagasaki (Können et al. 2003; Zaiki et al. 2006). Before the scientific analysis of the recovered data, the temperature and pressure data were converted to modern units and digitized into a computer readable format. The pressure data were corrected for temperature, elevation, and gravity where needed. The temperature data were homogenized to compensate for changes in recording location. Then, both data sets were homogenized to account for varying observation schedules. The corrected and homogenized data were shown to be reasonable after further testing for homogeneity and comparison with modern JMA data.

The availability of the recovered 19th century temperature observations taken at five locations made it possible to construct a West-Japan Temperature (WJT) series, a representative temperature series for the western Japan region (Fig. 2; Zaiki et al. 2006). The results indicate the existence of a relatively warm period from the late 1840s to the 1850s with a few interspersed cold years over western Japan followed by a downward temperature trend that lasted until the early 20th century as previously observed in the documentary data.

The significance of historical meteorological data recovery in Japan reaches beyond just being an extension of the Japanese instrumental record back in time. First, the recovered series occur in a region of the world that is poorly covered by instrumental data, and second, it overlaps with the series of qualitative weather descriptions in historical documents kept at many places in Japan.

Conclusions

A number of climate reconstructions based on qualitative weather descriptions have been carried out in Japan. Although the reconstructed data represent temperatures in particular months or seasons, they have sufficient time resolution to characterize inter-annual variations. Additionally, using this approach for reconstructing a chronology of typhoons further demonstrates the importance of historical climatology in Japan. The instrumental meteorological data collected before the founding of the JMA provide sub-daily meteorological data. In the future, more records will be needed to fill in gaps in this fragmented record.

Past climate variations reconstructed from Japanese historical documents partly enable us to discuss the "Little Ice Age" period especially with regard to regional differences and the magnitude of the cold. To achieve this, further exchange of and constructive corroboration with past climate information reconstructed from various proxy sources will be needed.

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Human-environment interaction and climate in the Japanese Archipelago

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To reconstruct the relationship between humans and their environment in the Japanese Archipelago, several chronological charts were compiled based on a collective work by interdisciplinary research groups.

Japan is one among 34 global biodiversity hotspots (Conservation International 2012). The Japanese Archipelago extends over 3000 km from north to south, and includes subarctic, cool temperate, warm temperate and subtropical climatic zones. There is evidence that these diverse climatic zones existed even during the global environmental changes that have taken place over the past 100 ka (Tsukada 1983). Under the influence of climatic change and human activities, the distribution of individual species of plants and animals in the Japanese Archipelago has constantly changed. Populations have repeatedly divided, expanded and diminished in response to changes in the availability of suitable habitat. Where suitable habitat was unavailable, the species became extinct.

The knowledge and skills that humans have developed seem to harbor the idea that biological resources should be used in a sustainable way, and the desire to harvest without fear of exhausting the limited resources. Throughout the period of human habitation, the Japanese Archipelago has been blessed with a warm climate and abundant rainfall, and consequently abundant bioresources. But were those resources overused and exhausted in the past? To answer these questions, we initiated a project to investigate: 1) How subsistence and economic systems were maintained in the past, and how and why they ended, and 2) the underlying social system (social structure, economic foundation, system of spatial organization, technical system, perception of nature) and how it evolved after the collapse of the subsistence and economic systems.

Research methods and structure

To elucidate the historical process of change in human-nature relationships in Japan, we used regional pollen records, archeological remains and historical documents. In addition, we examined the historical and economic

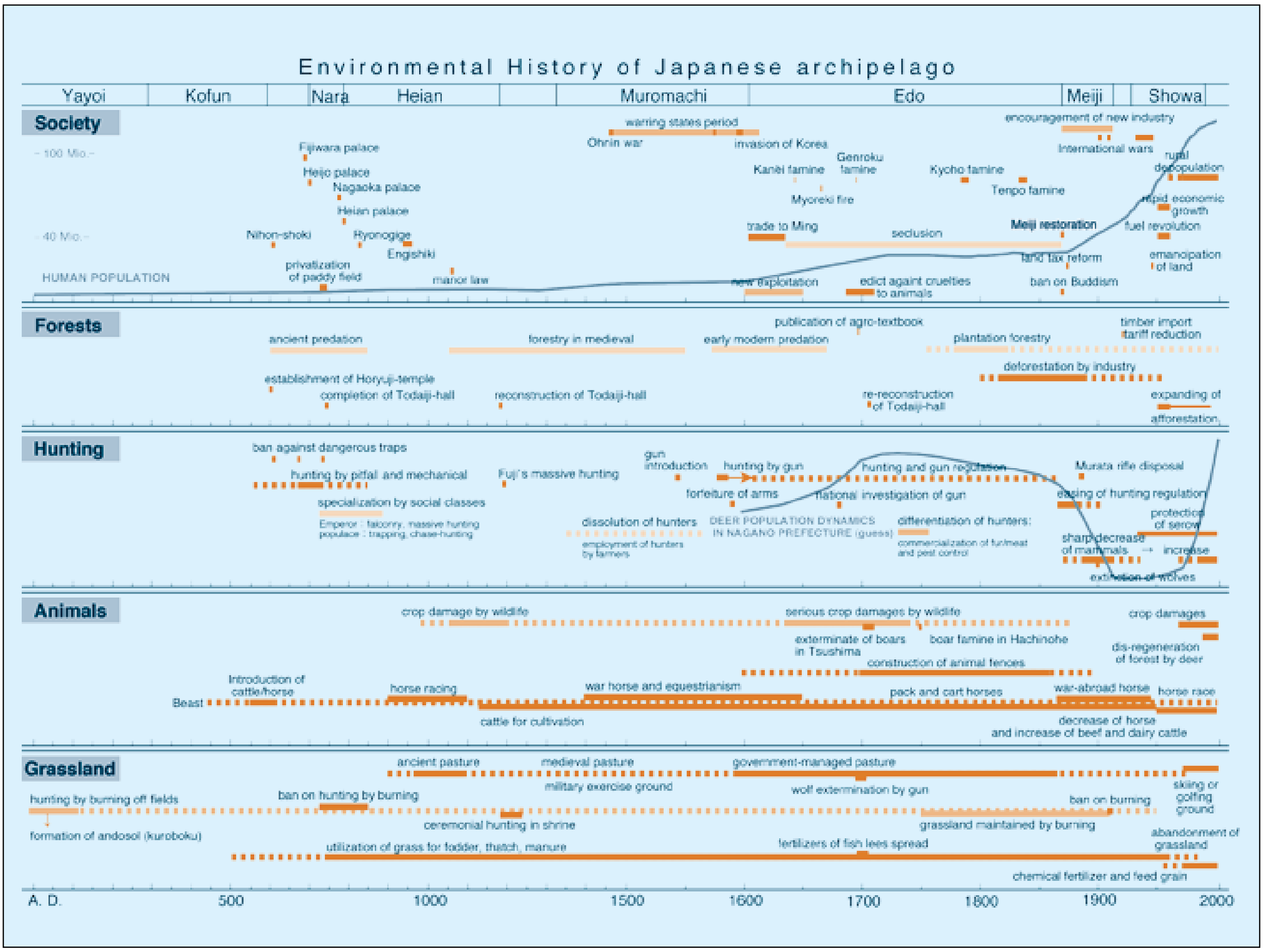

Figure 1: Chronological chart of the Japanese Archipelago during 0-2000 AD. The periods of governance and their names are given at the top of the figure.

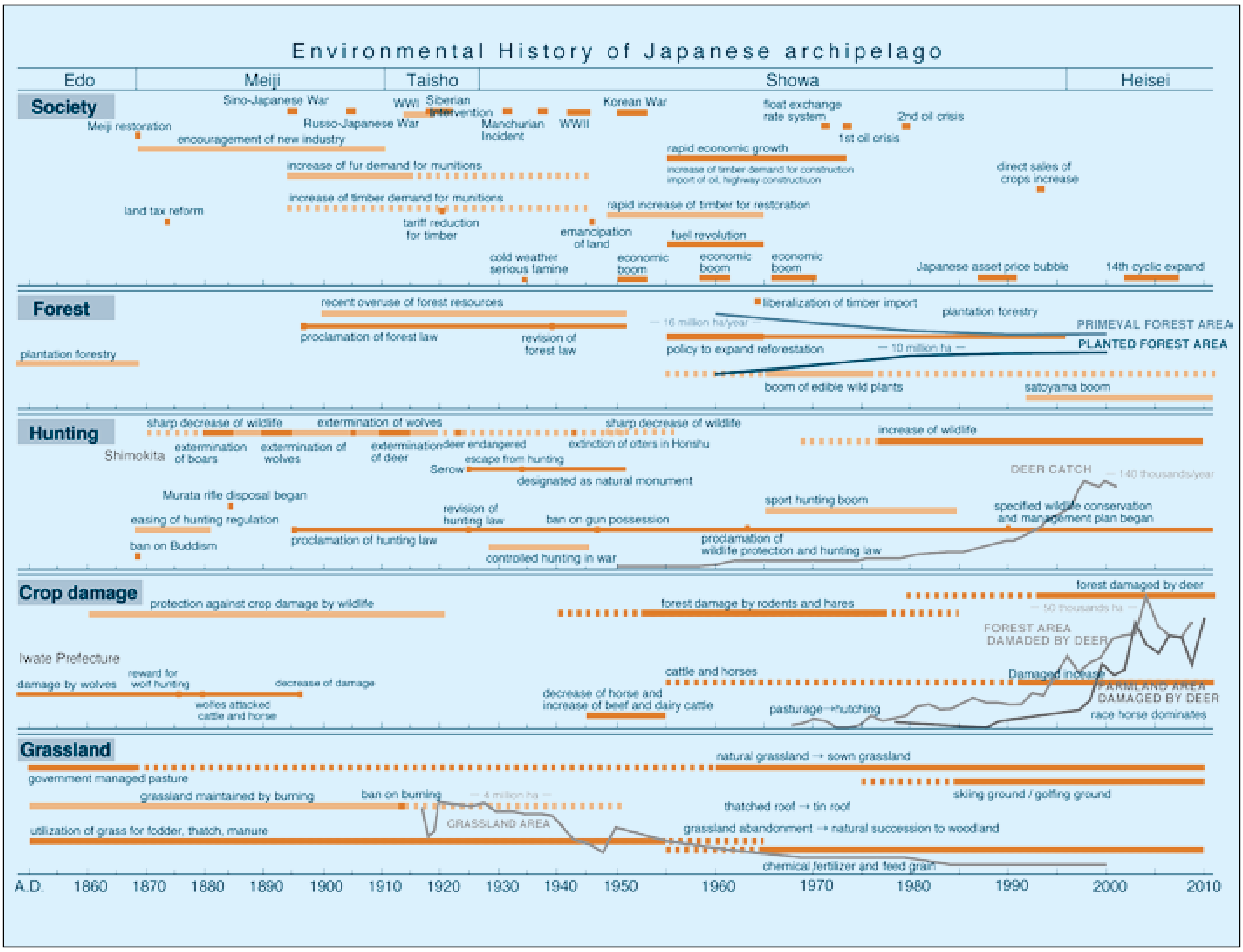

Figure 2: Chronological chart of the Japanese Archipelago during 1850-2010 AD. The periods of governance and their names are given at the top of the figure.

background, in particular knowledge and skills concerning the environment, to study their relation to the disappearance or thriving of plants and animals that were closely related to human subsistence. The project was subdivided into several working groups:

1) To reconstruct and analyze ancient vegetation and changes in the distribution of plant and animal species based on fossil records (Sasaki and Takahara 2011; Sasaki and Takahara 2012), DNA from living organisms, and historical documents (Kawase et al. 2010; Tsujino et al. 2010),

2) To reconstruct regional human diets by analyzing stable isotopes on human and faunal bones (Kusaka et al. 2010),

3) To reconstruct the past human-nature relations and analyze the regional social systems.

4) To synthesize the evidence and ideas from the project, and propose policy and guidelines for better human-environment interaction.

Compiled chronological charts

A series of chronological charts of environmental history for each region were compiled from epoch-making events on environmental issues and policy changes on resource managements (Fig. 1 and 2). The charts were completed by adding data of estimated vegetation changes (based on pollen analysis) and population change (based on historical demography). In total, more than 6000 chronological data were compiled in a time-sequence database. High-resolution climatic data are still missing in the compilation, but will be implemented at a later stage. The chronological charts revealed that the multi-layered governance (e.g. community, local government, national government, international organization) either sustainably managed their bio-resources or collapsed.

"Wise use" of what, by whom, for whom

The expression "wise use" was defined as the knowledge and skills needed to use the bio-resources and ecosystem services in sustainable ways. Examples of "wise use" and "unwise use" from each region were sorted out and categorized by identifying which multi-layered governance took an initiative role. Our results showed that governance at the community level always played a critical part in the sustainable use of the ecosystem services, whereas regional governance covering wider areas sometimes led to their collapse. This is an important lesson from the past, showing that the community level or local layer of governance driven by the people who suffer most from the degradation of the ecosystem service should be given priority over larger-scale governance. Also, in cases showing sustainability or recovery from a collapse, collaboration between the local communities and regional to national governances was critical.

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An 800-year decadal-scale reconstruction of annual mean temperature for temperate North America

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A tree-ring based reconstruction of decadal annual mean temperature over temperate North America for the period 1200–1980 is presented. Temperatures generally cool from the early 1300s to the early 1800s and are consistently above the long-term mean after the early 1900s, a unique feature in this record.

The PAGES 2k Network initiative aims to reconstruct basic climate variables for the last 2000 years. This article describes an effort to produce a long (1200-1980 AD) annual temperature reconstruction for temperate North America (30-55°N, 75-130°W) at decadal-average resolution based on tree-ring records primarily from western North America. We describe the methodology used in the reconstruction, briefly compare it with lower resolution regional temperature reconstructions based on fossil lake pollen records from upper midwestern and northeastern United States (Wahl et al. 2012; Viau et al. 2012), and offer a brief discussion of our results in the context of other climate reconstruction studies (e.g. Hughes et al. 2011).

Two semi-independent tree-ring data sets (approximately 30% overlap) are used in the reconstruction. One set extends from 1500-1980 AD covering an area in western mid-latitude North America bounded by 30°-55°N, 95°-130°W (with one additional chronology in west-central Mexico, Wahl and Smerdon 2012). The proxy data were calibrated and validated using the HadCRUT3v 5°x5° gridded surface temperature data for the selected region for the period 1875-1980. The resulting annual temperature reconstruction is hereafter referred to as the WS12 series. A second tree-ring data set covering a longer period (1200-1980 AD) and extending into eastern North America in the same latitude range and into Alaska and the Canadian Yukon was calibrated and validated against the western-region modern record in the same manner as WS12.

Similar to other reconstructions that use sequential calibrations going back in time, the longer time series (1200-on), while well validated, exhibits lower skill than the shorter WS12 reconstruction. WS12 exhibits validation grid-scale RE/spatial-mean RE/spatial-mean CE of 0.40/0.62/0.42, respectively, while the 1200-on reconstruction exhibits 0.13/0.53/0.31 for the same measures, respectively. We thus used WS12 as the reconstruction for 1500-1980 AD and joined the 1200-on reconstruction to it to cover the period 1200-1499 AD. To ensure comparability across the splice at 1500 AD, we regressed WS12 onto the 1200-on reconstruction over the 1500-1980 AD period, and then used this regression and the 1200-on reconstructed values to fit WS12-consistent values for the western region spatial mean during 1200-1499 AD. Decadal averages of this common 1200-1980 AD western temperate-reconstruction were then used as predictors in a calibration against instrumental decadal averages of annual temperatures over the larger mid-latitude

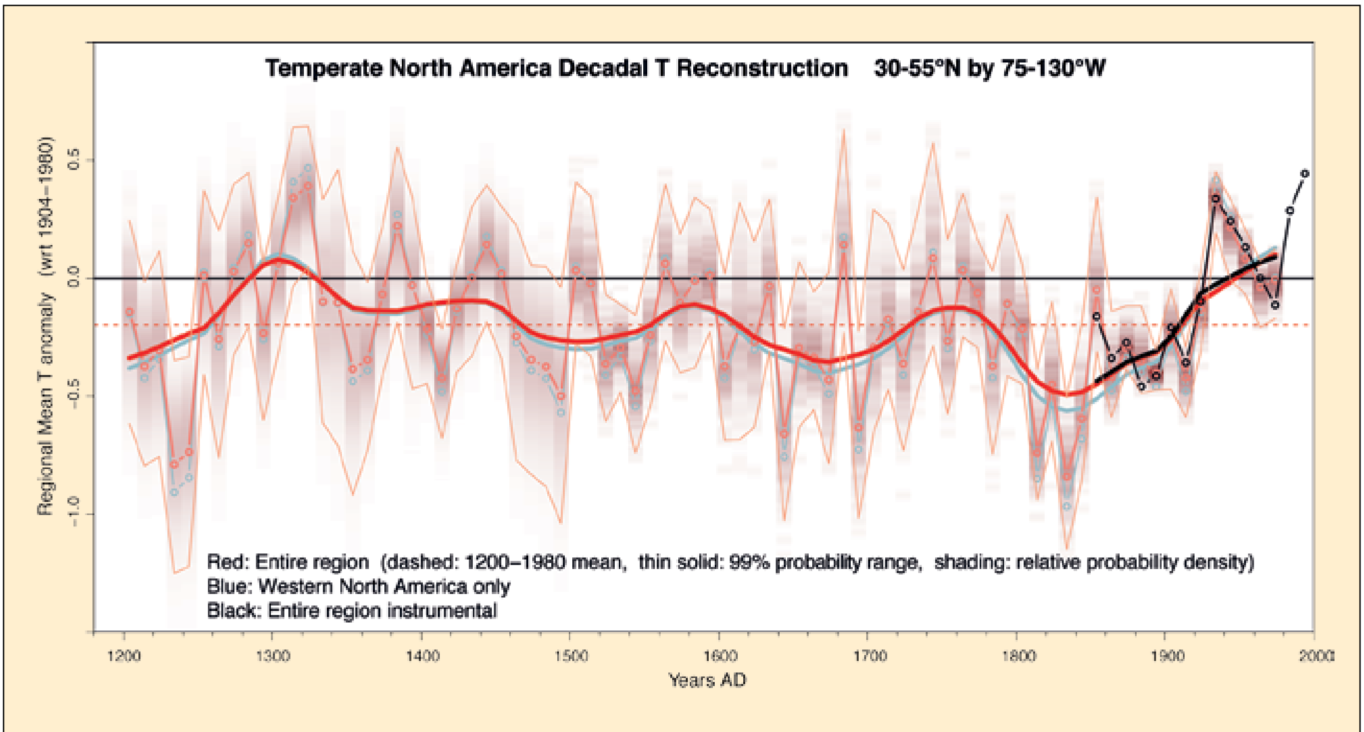

Figure 1: Reconstruction of annual mean temperature deviations from a 1904-1980 AD average (thin black line) for North America (30°-55°N, 75°-130°W). Values shown are decadal means and a lowess filter to highlight low frequency fluctuations. The average for the full period of record (1200-1980 AD) for the entire region is shown as a dotted red line, variable shading gives relative probability density for each decadal value, thin red envelope lines denote 99% probability range associated with each decadal mean value.

domain 30°-55°N, 75°-130°W, for a period covering 1850-1980 AD (n=13, using the infilled instrumental data set of Mann et al. 2009). Finally, this calibration fit was used to reconstruct decadal averages of annual temperature over the larger domain for the entire 1200-1980 AD period (n=78). In both regressions, the fitted values were scaled so that their variance matched that of the target data during the fitting period. The results are shown in Figure 1; the red (blue) curves give the full (western) North American expected value (EV) reconstructions, and the black curve shows the 1850-2000 AD full North American instrumental values.

Uncertainty estimation was done using the uncertainty ensembles generated for both the WS12 and the 1200-on reconstructions (see Wahl and Smerdon 2012 for the statistical bootstrap method used) in a two-way Monte Carlo design. In this design, the process described above to estimate the EV reconstructions was repeated for each possible combination of 500 WS12 and 500 1200-on ensemble members. The 99% probability range estimated by this analysis (from the 0.005 and 0.995 quantiles of the MC output) is shown by the thin solid red line in Figure 1. Note that these 99% ranges are for the decadal means and thus are significantly narrower than the corresponding ranges for annual values would be expected to be, from theory of the standard error of the mean.

Several side-by-side comparisons of the tree-ring derived reconstruction with observations were done to investigate its ability to reproduce the large-scale patterns of change on decadal and multi-decadal time scales. The comparisons (not shown) indicate that the western North America-based reconstruction captures the primary features of temporal variability during the instrumental period, along with many sub-regional spatial features such as warming in the interior Southwest associated with the 1950s drought, and also likely captures decadal variability over the larger continental region east to 75°W. Additionally, the reconstruction was compared against lake-sediment pollen temperature reconstructions for the Upper Midwest and eastern portion of the mid-North American continent (Wahl et al. 2012; Viau et al. 2012; Trouet et al., this issue). We find general agreement between the results shown here and the bulk of the regional temperature reconstructions reported in these pollen-based studies.

There have been relatively few reconstruction studies of long-term North American temperature compared to precipitation or related drought indices (e.g. Cook et al. 1999, 2007). We single out two recent articles (Kaufman et al. 2009; Ljungqvist et al. 2012) that present millennial length reconstructions for portions of the Northern Hemisphere, since they include some information regarding North American temperature changes. A direct comparison between these reconstructions and that of Figure 1 is not possible however, because of differing reference periods and data sources on the one hand (Ljungqvist et al. 2012) and a pan-Arctic regional focus on the other (Kaufmann et al. 2009). Nevertheless, some similarities are evident, particularly the cold periods of the 17th and 19th centuries, and warmer temperatures prevailing prior to the 15th century.

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A pollen-based extension of the 800-year decadal-scale reconstruction of annual mean temperature for temperate North America dating back to 480 AD

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We present a tree-ring and pollen based mean annual temperature reconstruction for temperate North America (480-1980 AD) that shows two prominent low-frequency periods: the warmer Medieval Climate Anomaly (750-1100 AD) and the cooler Little Ice Age (1300-1850 AD).

The PAGES 2k Network initiative aims to reconstruct climate variables for the last 2000 years. In a parallel effort, the NAM2K group produced an 800-year (1200-1980 AD) decadal scale annual mean temperature reconstruction using a network of tree-ring records in western North America (Wahl et al. 2012a, this issue; Wahl and Smerdon 2012). That reconstruction is referred to henceforth as D1200 (for decadal 1200). Here we present a pollen-based 30-year resolution mean annual temperature reconstruction for the temperate region of North America (30°-55°N, 95°-130°W) extending D1200 back to 480 AD. In the following, we describe the methodology used for this reconstruction and briefly compare it with other regional temperature reconstructions.

We performed a principal component analysis (PCA) using four North American regional pollen-based temperature reconstructions (Viau et al. 2012); specifically those based on pollen sequences from deciduous, hardwood, boreal, and mountain ecoregions of North America. The prairie ecoregion reconstruction for the center of Northern America was not used as its vegetation is mainly controlled by precipitation (Viau et al. 2012). Mean annual temperature reconstructions were used instead of summer temperature anomalies as in Viau et al. (2012) for a more direct comparison of the pollen reconstructions to

D1200. The resulting 30-year PCA scores (360-1950 AD; n=54) were then included in a stepwise multiple linear regression against the D1200 curve. For this purpose, D1200 was smoothed using a ~110 year lowess filter and sampled every 30 years to conform with the time scale and sampling resolution of the pollen-based reconstructions. Three combined PC axes explaining 87% of the common variance in the pollen reconstructions were retained in the stepwise regression and explained 33.4% of the variance (corrected for autocorrelation) in D1200.

Uncertainty was estimated based on the 1 and 2 standard error (SE) limits for the pollen-based reconstructions and the SE of the regression model. The SEs for the pollen-based reconstructions were developed using a Monte Carlo resampling technique that generated random sequences by sampling values at each time step of the individual pollen series within each series' uncertainty limits. This process was repeated 10,000 times to generate the pollen-based reconstruction uncertainty bands. These were then inputted into the previously developed PCA and multiple linear regression equations to determine the component of the overall 1SE and 2SE uncertainty limits that is inherent in the pollen-based reconstruction method. The pollen-based reconstruction 1SE and 2SE limits estimated in this manner were augmented with the corresponding regression 1SE and 2SE values at each time step, by adding the squares of the errors and taking the square root of the sum. Because estimated uncertainties were unrealistically high prior to 480 AD, we truncated our temperature reconstruction at this date.

Comparison between D1200 and the pollen reconstruction is quite reasonable (Fig. 1). Except for a peak around 1300 AD, the smoothed D1200 falls nearly entirely within the 1SE uncertainty envelope. The overall amplitude of change for the entire period is ~±0.55°C and thus falls within the range of amplitudes found for hemispheric-scale temperature reconstructions over the last millennium (0.4-1°C, see Esper et al. 2012). The start date of our reconstruction is too recent to capture warmth during Roman times (0-400 AD) and this is likely one of the reasons why a millennium-scale cooling trend, caused by orbital forcing, is not as evident as in high-latitude temperature reconstructions for the same period (Kaufman et al. 2009; Esper et al. 2012).

There are three prominent low-frequency periods in the North American extended reconstruction, notably the cooler Dark Ages (ca. 500-700 AD), Little Ice Age (ca. 1300-1850 AD), and warmer Medieval Climate Anomaly (MCA; see also Wahl et al. 2012b). Our results show that the MCA, here between ca. 750 and 1100 AD, was slightly warmer than the baseline period (1904-1980 AD), but much cooler than the early 21st century (Fig. 1). The MCA shows peaks around 850 and 1050 AD. Following the MCA, mean annual temperatures decreased until the mid-19th century, after which temperature began to increase rapidly. Our reconstruction shows similarities with other long temperature reconstructions, not only at the centennial scale (e.g. cold Dark Ages in Büntgen et al. 2011), but also at the decadal scale. Warmth in the mid-11th century and cool 17th and 19th centuries, in particular, are well replicated in multiple hemispheric-scale temperature reconstructions (e.g. Frank et al. 2010; Mann et al. 2009; Moberg et al. 2005).

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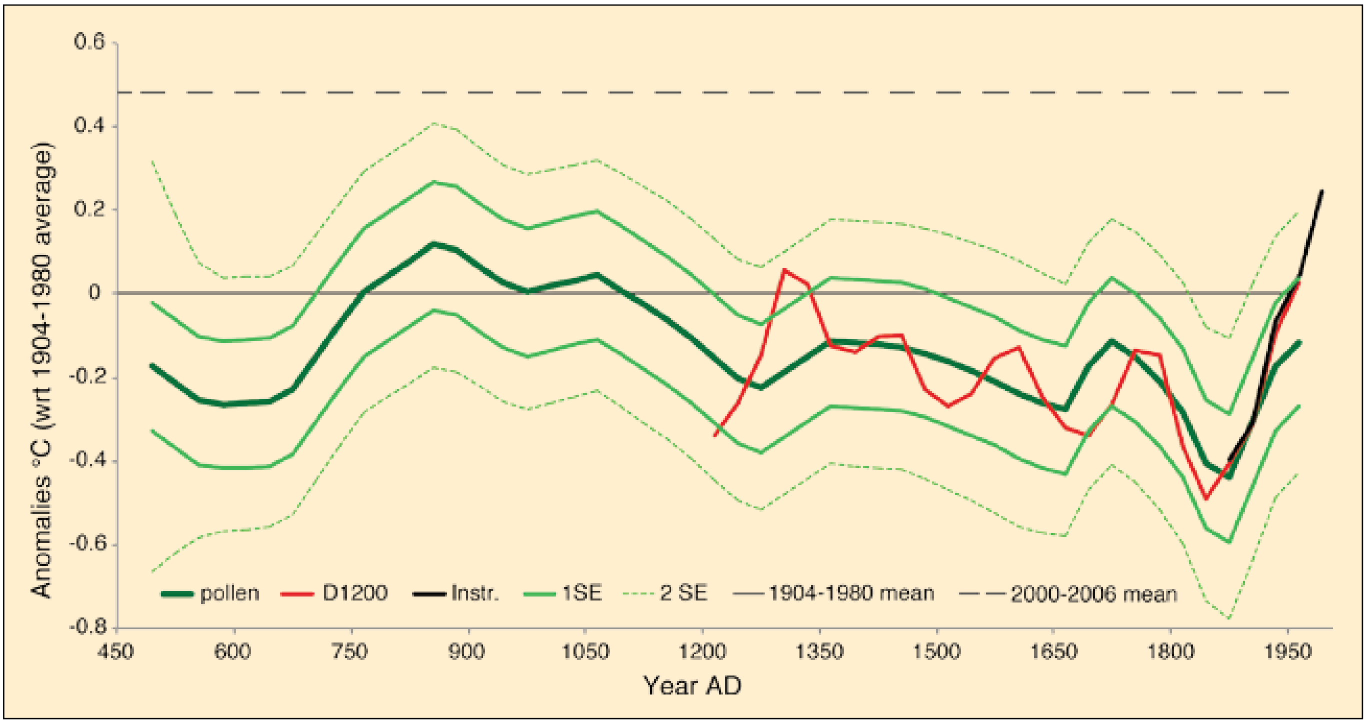

Figure 1: Reconstruction (dark green curve) of 30-year averages of annual mean temperature deviations from a 1904-1980 AD average for North America (30°-55°N, 75°-130°W). Values shown correspond to the combination of three pollen-reconstruction PCs resulting from a stepwise multiple linear regression with the 30-year-subsampled RC temperature series (red curve), and thus reflects low frequency variations. Dashed (full) light green lines give 2SE (1SE) uncertainty estimations associated with each 30-year value. Full black curve shows comparably smoothed instrumental temperature values. Dotted black line represents the average deviation for the period 2000-2006 AD, also from comparably smoothed instrumental data.

Future Earth – Research For Global Sustainability

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Change is on the way for Global Environmental Change.

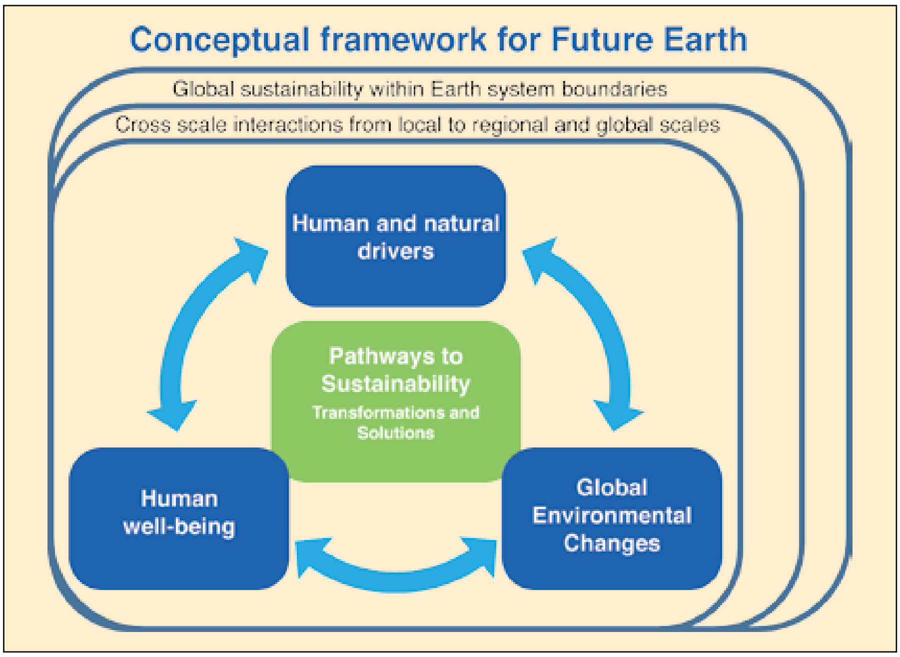
You may have heard some buzz around an initiative called Future Earth. The project, in the works since 2009, will affect all Global Change scientists, and is expected to become operational over the next 1-2 years.

Future Earth is expected to give Global Environmental Change (GEC) science a total makeover, by unifying existing programs and removing disciplinary boundaries, ultimately creating more streamlined communication and cooperation across the broad range of GEC disciplines.

An alliance of several organizations—jointly representing international cooperation, education, and GEC science funding—is behind Future Earth. The program will unify three of the four existing GEC programs, namely the International Human Dimensions Programme (IHDP), DIVERSITAS, and PAGES' parent organization, the International Geosphere-Biosphere Programme (IGBP). The fourth GEC program, the World Climate Research Programme (WCRP), will be associated with Future Earth while remaining a separate entity.

The program's full name, "Future Earth– research for global sustainability", indicates that it is more than a mere merger of program themes, however. Future Earth activities will be expected to contribute to finding solutions toward challenges that societies face as a direct or indirect consequence of environmental change. (See Figure 1 for a visual illustration of these goals.)

Achieving this will require lively communication between the producers and users of scientific knowledge, i.e. between scientists and stakeholders. Thus, Future Earth is set to involve not only a broad spectrum of scientists, but also of stakeholders, from policy-makers to those in industry. The idea is to invite stakeholders to co-design research agendas and to even co-produce knowledge. By bringing together natural and social sciences, humanities, economics, and technology development, Future Earth aims at a broadly interdisciplinary and inclusive effort, better suited for effectively tackling interconnected and multi-faceted problems.



Future Earth at Present

So far, a task force group (Transition Team) has been set up, which has drafted frameworks for the research and for the structural organization of Future Earth. While still subject to modifications, the current version of the research framework contains three broad themes:

(1) Dynamic Planet: Observing, explaining, understanding, projecting Earth, environmental and societal system trends, drivers and processes and their interactions; anticipating global thresholds and risks.

(2) Global Development: Providing the knowledge for sustainable, secure, and fair stewardship of food, water, biodiversity, health, energy, materials, and other ecosystem functions and services.

(3) Transformation toward Sustainability: Understanding transformation processes and options, assessing how these relate to human values, emerging technologies and economic development pathways, and evaluating strategies for governing and managing the global environment across sectors and scales.

Future Earth and PAGES

PAGES has provided occasional input to Future Earth's development in several ways. Given that Paleoscience can obviously contribute a lot to Theme 1, and to some aspects of Theme 2, PAGES has provided the Future Earth Transition Team with two "Past lessons" essays that explain how paleoscience can contribute generally to climatic and environmental themes. These essays can be downloaded from the PAGES website (Products > Other).

Additionally, the PAGES Scientific Steering Committee has put forward several requests to developers of Future Earth: To make sure that existing communities and expertise are maintained, to commit to basic science, to complement disciplinary science with a well-funded platform for interdisciplinary science, to provide professional science communication, and to adopt long-term and historical/geological observations as part of their observation strategy.

The shifting framework of GEC science is prompting associated communities and organizations to revisit their agendas and strategies. For PAGES, the upcoming Open Science Meeting titled "The Past: A Compass for Future Earth" will serve as a platform to discuss the opportunities and challenges Future Earth could bring to paleoscientific research, and how PAGES can help to make best use of the opportunities while mastering the challenges.

This Program News article provides only a brief introduction to Future Earth. For more detailed information, please visit the Future Earth website at: http://www.icsu.org/future-earth.

Sea Ice Proxy Working Group (SIP)

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Figure 1: The edge of the pack ice in the Weddell Sea. Photo by P. Bucktrout (British Antarctic Survey, UK).

The sea ice is a crucial component of the polar climate system, and has an impact on albedo, heat and gas exchange, primary productivity and carbon export, atmospheric and ocean circulation, freshwater budget, ocean stratification, and deep water mass formation. It is therefore critical that it is correctly specified as a forcing or predicted as a feedback in modeling studies.

However, full and reliable knowledge (through satellite observation) of the area and seasonal variability of sea ice extends only to 1978. Some earlier observational data are available, but their coverage is patchy and their reliability uncertain. Proxy data are therefore critical for extending the sea-ice record to the geological past, to improve understanding of the interplay between sea ice and the climate system over a broad range of conditions.

Apart from the more intermittent (such as occurrence of terrigenous components, driftwood or whalebone) or indirect (inference of climate and hence sea ice from terrestrial data) methods, the most important sea-ice proxies are derived from marine sediments and ice cores. In the marine records, proxies such as diatom or dinoflagellate cyst assemblages and organic biomarker occurrence have been used. In ice cores, sea salt and methanesulfonic acid have been proposed as chemical proxies. However, there are uncertainties on the reliability of each proxy, and insufficient knowledge of the modern processes that control them.

PAGES has therefore set up the Sea Ice Proxies (SIP) Working Group with the objective to critically assess and compare the different proxies for sea ice, in order to make recommendations on their reliability and applicability in the Arctic and Antarctic. An extended objective will be to facilitate the production of new synthesis estimates of past sea-ice extent based on the assessed proxies.

In the Southern Hemisphere most sea-ice extent estimates from marine sediments are based on diatom assemblages from marine sediments, but different methods and species are considered and a new biomarker-based proxy (similar to the isoprenoid biomarker IP25 used in the Arctic) is under development.

In the Arctic Ocean and subarctic seas, a wide range of proxies is used in marine cores, including the occurrence of particular diatoms, dinoflagellate cysts, foraminifera and ostracodes; more recently the concentration of IP25 has become a popular proxy. In ice cores, both methanesulfonic acid and sea salt sodium have been proposed as sea ice indicators.

Goals of this WG

(i) To assess each proxy individually: What is the physical, chemical and biological basis for its use? What is the sea-ice related parameter for which it may permit reconstruction? How has it been calibrated and how robust and stationary is that calibration? In what geographical and temporal range is the proxy reliable?

(ii) Where different proxies are available, to inter-compare their findings and develop a strategy for multi-proxy compilation and reconstructions.

(iii) To prepare recommendations on proxies suitable for making robust estimates of past sea ice conditions.

These methodological aspects will make up the majority of the work of the Working Group. However we will work with existing projects such as the EU Past4Future to deliver new synthesis estimates of past sea-ice extent for key time periods.

A first workshop was held at GEOTOP in Montreal, Canada in March 2012 and a separate report will be submitted summarizing that. It was aimed mainly at assessing the significance of each proxy and addressing the questions in paragraph (i) above.

A second workshop will be held in Cambridge (UK) in 2013.

Solar Forcing – a new PAGES Working Group

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The Sun is the main driver of the climate system. However, its contribution to climate change is still highly uncertain despite the considerable scientific advances made in recent years. A large number of new paleoclimate records with high temporal resolution have been produced. Simultaneously, high precision measurements of the solar total (TSI) and spectral (SSI) irradiance have been performed using satellite bound radiation monitors. Attempts have been made to use proxies of solar activity to extend the instrumental records of TSI and SSI back in time for the past 10 ka. In order to link the solar forcing with the observed climate response, climate models have been improved to simulate dynamical couplings between stratosphere and troposphere, the effect of UV changes on the ozone, and the influence of solar energetic particles and cosmic rays on the upper atmospheric chemistry (Gray et al. 2010; Wanner et al. 2008).

In spite of these significant efforts many open questions remain; some of which will be addressed by the new PAGES working group on solar forcing.

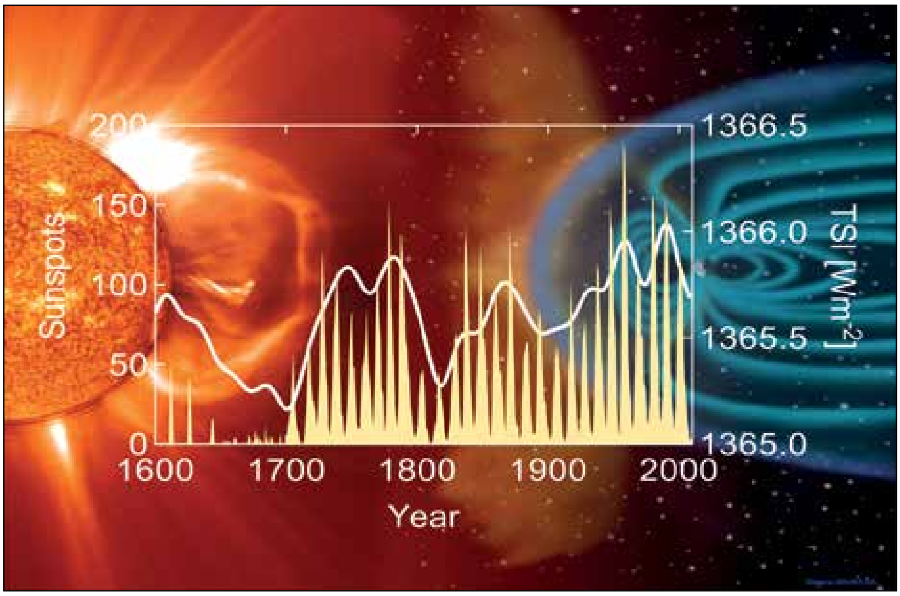

Figure 1: Background picture - The Sun emitting electromagnetic radiation and hot plasma (solar wind) carrying magnetic fields. While the radiation reaches the Earth directly solar particles are partly shielded by the geomagnetic field. Graph - Sunspot numbers reflect the solar magnetic activity which is dominated by the 11-year Schwabe cycle. The reconstructed smoothed total solar irradiance (TSI) follows the envelope of the sunspot record with minima at 1645-1715 AD (Maunder Minimum) and at 1790-1830 AD (Dalton Minimum) and a maximum in the second half of the 20th century.

Calibration of the instrumental TSI record

Since 1978 TSI is continuously measured most of the time simultaneously by several instruments on different satellites. Different research groups applying different corrections produced at least three different TSI composites with significant discrepancies. A new instrument points to a mean TSI that is about 5 Wm^{-2} lower than the often-assumed value of 1365 Wm^{-2}. Nevertheless, simple semi-empirical models of TSI are capable of reproducing the observed annual and shorter changes. However, the physical mechanisms that relate solar activity with TSI and SSI changes are still not well understood.

Past role of solar forcing

Even larger discrepancies exist between the long-term reconstructions that are based on proxy data such as cosmogenic radionuclides. These nuclides are produced by cosmic rays in the atmosphere and stored in polar ice (^{10}Be) and tree rings (^{14}C). Their production rate is to a large extent modulated by solar activity. However, the geomagnetic field intensity and the transport from the atmosphere into the archive also play a role. The main problem is that these proxies need to be calibrated by the instrumental TSI data, which besides their own uncertainties only cover 30 years of high and relatively constant solar activity (grand maximum). The instrumental record is therefore not representative of the mean global solar activity of the Holocene. This raises the fundamental question of how much lower TSI and SSI were during grand solar minima such as the Maunder Minimum. There is general agreement on the shape of the past solar forcing record, which is characterized by specific cycles of 11, 87, 208 and 500 years and prolonged periods of solar minima (e.g. Maunder) and maxima. However, there is still considerable uncertainty regarding the amplitudes of these changes.

The solar cycle minimum of 2008

The 2008 solar minimum was lower (fewer sunspots, lower TSI) and lasted longer than previous ones. Are the current TSI models capable of explaining it? Does it point to an imminent new grand minimum?

Future role of solar forcing

The fact that the past six decades or so were a period of very high solar activity suggests that solar activity will decrease in the near future. This expectation is corroborated by the last solar minimum of 2008. The possibility of an imminent new grand solar minimum has led to claims that the diminished solar activity will reduce global warming considerably. Although this is very unlikely, a solid quantitative estimate of such a scenario is very important.

To address all these questions an interdisciplinary working group has been set up (www.pages.unibe.ch/working-groups/solar-forcing). Solar physicists try to better understand the known physical processes and to identify potential new mechanisms responsible for solar forcing. Experts in atmospheric physics and climatology address the response of the Earth system to the solar forcing and in particular the effects of solar induced changes in the upper atmosphere on the climate. Paleoclimatologists provide observational data, which need to be explained by climate modelers complementing their models with additional processes and putting some important constraints on the role the Sun has played in the past and will possibly play in the future.

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Arctic2k: Spatiotemporal Temperature Reconstruction

Helsinki, Finland, 15-16 November 2011

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The Arctic2k Working Group aims at elucidating the variability of the arctic climate in the past to provide a reference context for the recent rapid warming in the region. Thirteen Working Group members attended the workshop, reviewed the collected proxy records and the preliminary temperature reconstructions made thereof, and prepared the groundwork for a publication on results and methods.

While the arctic region was found to feature many proxy records covering much of the area between 60° and 80° northern latitudes, records further north are virtually non-existent. When the collected records were subjected to the stringent selection criteria set in the previous Working Group workshop (Hanhijärvi 2011), the number of acceptable records was reduced by a large fraction. Furthermore, the temporal extent of the selected records is generally short, so that the coverage diminishes rapidly when going back in time. Figure 1 shows the spatial and temporal extent of proxy records used for the Arctic2k project. Both spatial and temporal sparsity had to be taken into account when carrying out the reconstructions.

The correlations between the gathered proxy record data were presented and analyzed, and the amount of shared signal between the records compared. The same procedure was repeated with the NASA GISS instrumental temperature station data (Hansen et al. 2006) and between the proxy records and instrumental data. The analyses displayed significant correlations between many of the records, indicating that the reconstructions will reflect a real climate behavior.

The proxy data are inherently heterogeneous and the records have different temporal resolutions. Interpolation was discussed and was shown to be a suboptimal solution for unifying the temporal resolution. Instead it was suggested that the proxy records are used in their original resolution while considering each sample (e.g. slice of a core) of a proxy record to represent a time frame, and to use reconstruction methods that can handle such data.

Two new methods, PaiCo (Pairwise Comparisons) and MuReMo (Multi-Resolution Monotonic), were presented, both of which can handle data of various resolutions in their original format. Furthermore, both methods use the assumption that the transfer functions from climate parameter to proxy are monotonic, instead of linear, unlike all other approaches. PaiCo is a new, yet unpublished method that can calculate the most likely common climate parameter time series from a collection of proxy records. MuReMo combines the idea of PaiCo with the Bayesian model of BARCAST (Tingley and Huybers 2010) to reconstruct spatiotemporal fields. The qualitative properties of these methods compare favorably with the existing methods, and will thus be used for calculating the climate reconstructions. Preliminary results were coherent with the existing knowledge about the arctic climate, and therefore considered promising.

The next research milestone of the working group is to finalize the reconstruction of the arctic temperatures during the past 2000 years. As Kaufmann et al. (2009) have already presented a similar reconstruction, it was decided that an important goal would also be the calculation of a spatial temperature field for the Arctic. This will build upon the previous knowledge and reveal spatial climate patterns.

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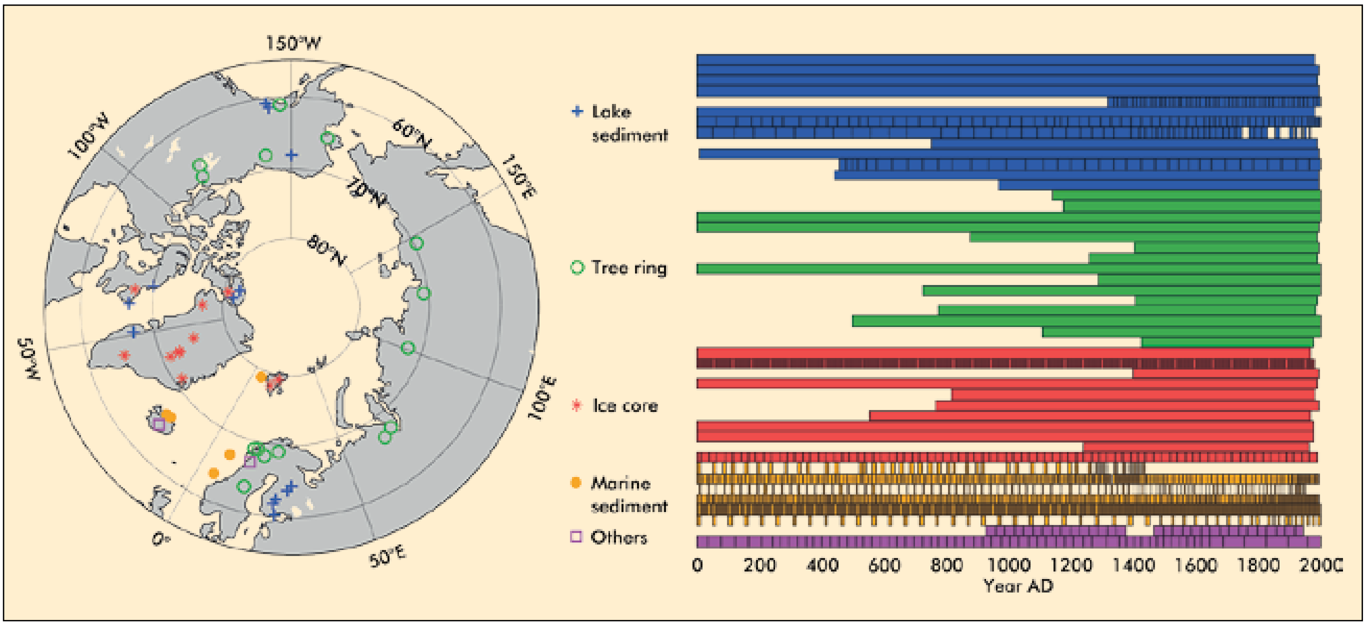

Figure 1: Spatial and temporal distribution of the Arctic2k proxy records. Single solid box in temporal extent signifies annual resolution. Otherwise, each box represents the time frame of a single value of a single proxy record. Records have been truncated prior to 1 BC. All proxy series in this figure are or will be archived on the NOAA paleoclimatology database.

2nd Workshop of the PAGES Asia2k Working Group

Chiang Mai, Thailand, 9-11 January 2012

Masaki Sano[1], Shi Feng[2], Takeshi Nakatsuka[1] and Asia2k members

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The 2nd Workshop of the PAGES Asia2k Working Group was attended by 21 paleoclimate researchers from Japan, China, USA, Russia, Switzerland, Sweden, Nepal, and Pakistan. The workshop aimed at (1) collecting proxy records that are not yet stored in any public repositories, (2) producing and discussing a preliminary reconstruction of annual temperature fields based on the available proxy records, and (3) conducting a methodological training course focused on statistical climate reconstruction techniques.

Asia2k committee member Edward Cook (Lamont-Doherty Earth Observatory, USA) gave an introduction to the temperature field reconstruction methods, followed by presentations from data holders who contributed their data to the workshop. While the Monsoon Asia Drought Atlas (MADA; Cook et al. 2010) derived from 327 tree-ring chronologies is currently the most extensive, high-temporal resolution reconstruction record available for Asia, a variety of new proxy records consisting of additional tree rings, ice cores, speleothems, lake sediments, and historical documents were contributed. The new records were incorporated into the Asia2k database along with the MADA series resulting in a total of 467 proxy records (Fig. 1).

A task group was assigned to produce a preliminary reconstruction of temperature fields. As shown in Figure 1, tree rings are the dominant proxy records in Asia. By incorporating the well-organized MADA procedures, a preliminary analysis using tree-ring records was created, including the newly contributed data. More specifically, a modified form of point-by-point regression (PPR), a well-tested and easily interpreted principal component regression method, was employed to produce past temperature fields.

The participants discussed all proxy records with an emphasis on climatic interpretation, seasonality, preservation of low- and high-frequency variability, and calibration/verification. The integration of time series of different resolution was also discussed, acknowledging that creating a multi-proxy reconstruction is undoubtedly a challenging task. In this regard, the Working Group agreed to produce a comprehensive reconstruction of temperature fields based on two different approaches. One approach is based solely on tree-ring data, to which a variety of methods is employed to reduce uncertainties and biases. The other approach also attempts to utilize several methods, but will also include non-annually resolved proxy records. Both analyses are conducted independently, making it possible to objectively compare and improve the final reconstruction products.

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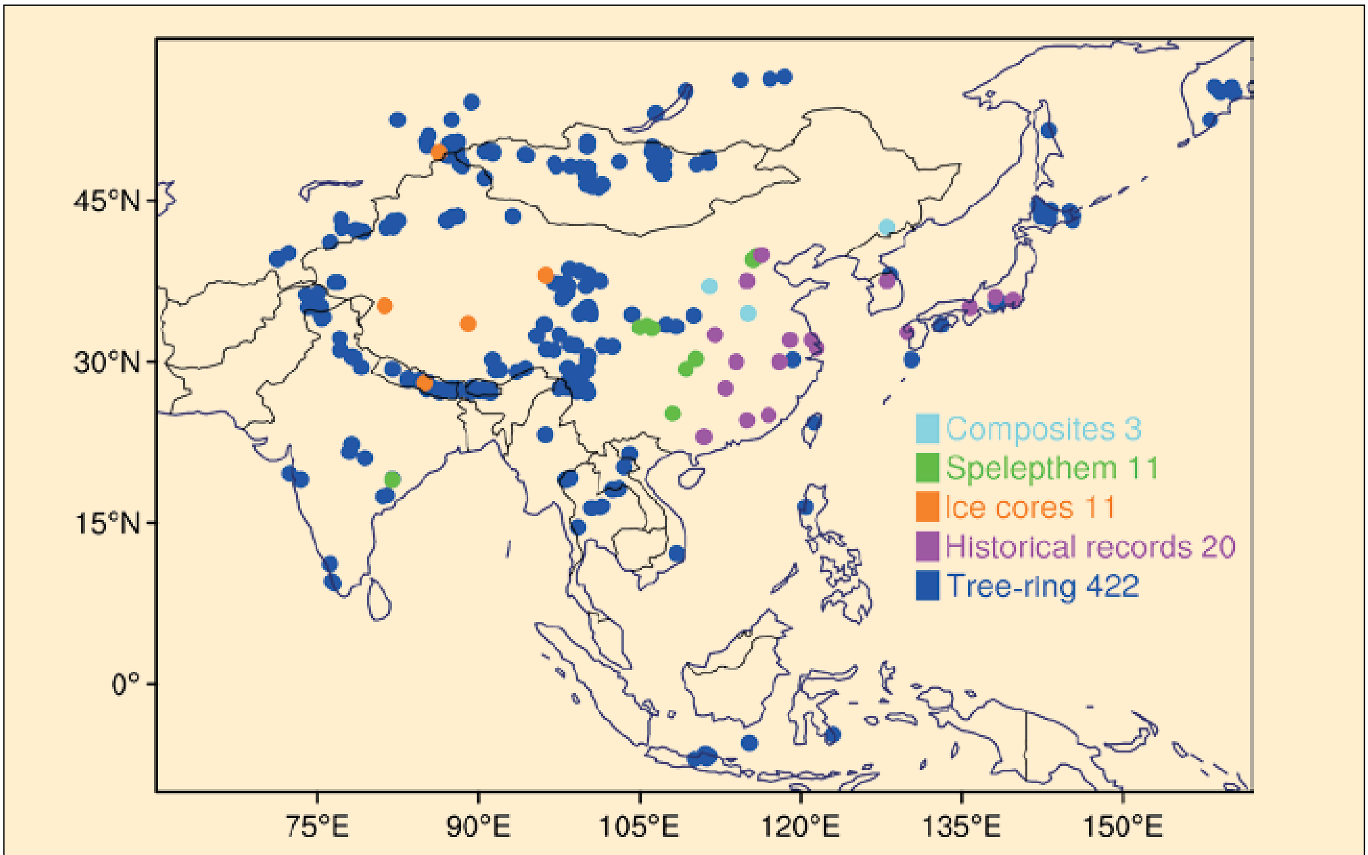

Figure 1: The locations, types and numbers of available proxy records considered by the Asia2k group.

Synthesizing paleoclimatic data to reconstruct 2000 years of European/Mediterranean temperature change

EURO-MED2k

2nd Meeting of the PAGES Euro-Med2k Working Group – Hamburg, Germany, 21-23 May 2012

Jürg Luterbacher[1], F.J. Gonzalez-Rouco[2], D. McCarroll[3], S. Wagner[4] and E. Zorita[4]

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The PAGES Euro-Med2k Working Group was initiated to reconstruct and analyze the climate of the European/Mediterranean region within the past 2000 years. To date, the Working Group's efforts have been focused on collecting proxies with high spatio-temporal resolution from natural and documentary archives. This meeting was attended by 20 participants and focused on discussing new proxy evidence for summer temperatures in the Euro-Med region, with annual resolution and continuous sampling over time. Eleven annually-resolved tree-ring chronologies that preserve low-frequency variability and documentary records from 10 European countries/regions were selected for the subsequent European scale reconstructions to be developed (Figure 1 shows the two longest series from the Alps and Northern Scandinavia; Büntgen et al. 2011; Esper et al. 2012).

During the second part of the meeting the strengths and weaknesses of different statistical methods to reconstruct temperature variations over the past 2000 years were discussed. Composite-Plus-Scaling (CPS) and Bayesian Hierarchical Modeling (BHM) were considered as options for the mean European estimates and BHM for the gridded reconstructions over the last 1200 years. BHM has recently been proposed as a method suitable to overcome the known loss-of-variance problems of conventional multivariate statistical reconstruction methods (Tingley and Huybers 2010; Werner et al. 2012). One of the advantages of BHM is the possibility to form models for the underlying processes and the system response (instrumental measurements and proxies) and to assess different contributions to uncertainties. Discussions also included questions concerning the representation of low and high frequency variability in the proxy-based reconstructions, calibration/verification issues, uncertainty estimation, spatial dependence and autocorrelation. The third and final part of the workshop was devoted to discussing the approaches for model-data comparisons at continental scale. Results from a large multi-model archive, including simulations prior to Fernández-Donado et al. (2012) and those belonging to the CMIP5/PMIP3 initiative were considered.

The Group submitted peer-reviewed papers on two new European summer temperature reconstructions: a 2100 year CPS and BHM-based mean European and a 1200 year BHM-based gridded reconstruction. The workshop outputs will be used to address the extreme character of the recent decades in the context of the last two millennia and the comparisons of reconstructions with the ensemble of simulations for key climate periods related to the medieval period and the "Little Ice Age". This will allow us to assess the degree of consistency between the mutually independent model and paleo proxy histories at regional scales, involving the ability of climate models to reproduce the continental summer temperature response to external forcings and to generate realistically the low-frequency internal variability at these spatial scales.

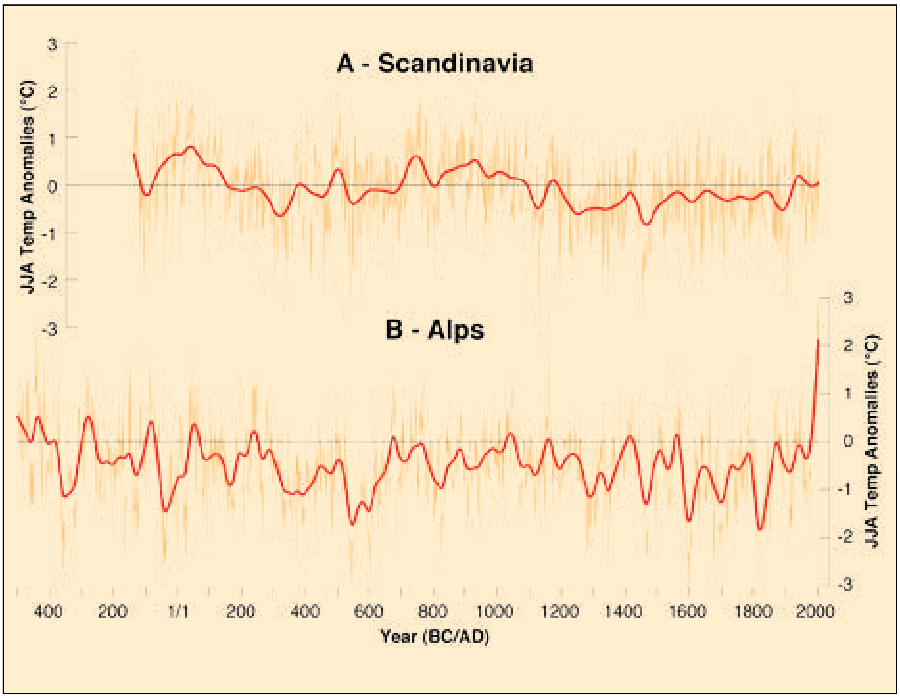

Figure 1: Reconstructed 2000 years of Northern Scandinavian (A) and Alpine (B) summer temperatures based on tree-ring data (Büntgen et al. 2011; Esper et al. 2012)

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Deciphering climatic and environmental signals from varved sediments by applying process-related studies

varves

3rd Workshop of the PAGES Varves Working Group, Manderscheid, Germany, March 20-25, 2012

Bernd Zolitschka[1], P. Francus[2], A.E.K. Ojala[3] and A. Schimmelmann[4]

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The workshop was hosted by the Maarmuseum in Manderscheid in the Eifel region, and was an opportunity for stimulating discussions amongst scientists active in analyzing annually laminated (varved) lacustrine and marine sediments for climatic and environmental reconstruction. Supporting funds were obtained from the German Science Foundation and PAGES. The Maarmuseum's director Martin Koziol provided invaluable logistical support.

A diverse range of high-resolution archives from five continents and the marine realm was discussed. Forty-one scientists from 16 countries, including 16 early career scientists, represented a wide range of research fields including climate modelers, geophysicists, and biologists. This cross-disciplinary communication between data and model specialists was essential to understand relationships between climatic and environmental changes.

The workshop focused on deciphering climatic and environmental signals contained in varved sediments by applying complementary process-related studies. We learned from other scientific disciplines about alternative techniques for proxy development, calibration and validation. Additional foci were advances in studying varved records, identification of challenging new coring sites, and managing data.

The first session was devoted to the reconstruction of hydro-climatic events. In his keynote lecture Scott Lamoureux (Canada) presented long-term process studies at varved Arctic lake sites to demonstrate complex links between climatic forcing and sedimentological responses.

The second session's focus was directed toward calibration of biological proxies. The keynote given by Andy Lotter (The Netherlands) highlighted the potential of biota-based transfer functions that provide enough temporal resolution to study the resilience and recovery time of ecosystems after external and internal disturbances.

Learning from other communities in terms of calibration and validation was the topic of the third session with three keynotes. Joel Guiot (France) presented the evolution of climate reconstruction methods from statistical techniques to complex model inversions and emphasized the need for high temporal resolution data as provided by varved records. The second keynote by Dominik Fleitmann (Switzerland) about speleothems directed the attention to annual growth bands of stalagmites and their paleoclimatic significance. Finally, keynote speaker Tom Swetnam (USA) linked dendrochronology with varved records pointing out the challenges obtained by combining both archives. Complemented by moderated poster and wrap-up sessions, the workshop was characterized by lively scientific discussions. Compiled abstracts of all talks and posters are available online (Zolitschka 2012).

The first product emerging from the VWG – a multi-authored article in *Quaternary Science Reviews* – relates to the worldwide distribution of varved records and the fidelity of their chronologies (Ojala et al. 2012). Discussions resulted in the plan to produce a second publication stressing the need for the development of best practice examples for varve counting applied to different varve types, including error estimations and corroboration by radiometric dating techniques and automated image analyzing methods for comparison. A different product of the VWG is the growing on-line varve image library (preliminary version at: www.geo-polar.uni-bremen.de/varves) to help researchers in the evaluation of laminated sediments. It shows annotated examples of the overall macroscopic appearance, internal structure and composition of varves.

Another highlight of the 3rd workshop of the VWG was the one-day field trip to the iconic maar lakes (Fig. 1) of the West Eifel Volcanic Field boasting Central Europe's longest varve chronology – 23,220 calendar years BP at Lake Holzmaar.

Figure 1: Lakes like Meerfelder Maar are important archives for climatic and environmental reconstructions since the Late-Glacial. The record of this site extends back into the Weichselian and provides a potential target for a future integrated lake deep drilling project. Most of the Holocene and Late Glacial sediments are annually laminated (varved). As an example the microphotography (inset) shows minerogenic varves of Younger Dryas age (courtesy A. Brauer).

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A strategic plan for scientific drilling in the East African rift lakes

Providence, USA, 14-16 November 2011

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The East African Rift Lakes offer unparalleled opportunities to investigate long-term environmental and climatic change in a low-latitude continental setting. Their sediments hold signals of the evolution of tropical temperature and rainfall at seasonal to geological timescales (Cohen et al. 2006; Tierney et al. 2008), record the environmental backdrop against which Africa's flora and fauna – including our own species – evolved (Martens 1997), and provide insight into tectonic processes that shape the world's largest active continental rift system (Ebinger 1989). The past decade has witnessed enormous advances in our efforts to obtain long records of East African climate, highlighted by the scientific drilling of Lake Malawi in 2005 (Scholz et al. 2007). Recent and ongoing geophysical surveys of a number of potential future drilling targets, including Lakes Turkana, Albert, and Tanganyika (Fig. 1), have set the stage for the next phase of continental scientific drilling in East Africa. To this end, PAGES and the US National Science Foundation supported a "Continental Drilling in the East African Rift Lakes" strategic planning workshop, attended by about 40 African, European, and US scientists.

We used plenary presentations on current initiatives to reconstruct and model East African paleoenvironments using marine and lacustrine sediments, the mechanisms behind the geologic and biological evolution of the East African rift, and the stratigraphic architecture and environmental history of Lakes Turkana, Albert, and Tanganyika to initiate a series of breakout discussions. These breakouts defined critical scientific hypotheses and questions for future drilling projects, including:

- What are the timing and dynamics of key transitions in the Plio-Pleistocene evolution of African climate as a consequence of global and tropical climate reorganizations, including the expansion of Northern Hemisphere ice sheets, the termination of a permanent Pliocene El Niño, and the closure of the Indonesian seaway?
- What is the sensitivity of East African temperature and rainfall to radiative forcing (insolation and greenhouse gases) and high-latitude processes?
- What are the rates and amplitudes of millennial to decadal East African climate change, and how do these vary with changes in the Earth's mean climate state?
- What are the rates, sensitivities, and thresholds for ecological and evolutionary responses of ecosystems and communities to climate and environmental change across different timescales?
- What are the regulating mechanisms and emergent properties of the dissociation and reassembly of aquatic ecosystems and communities through time?
- What are the rates of border fault slip in the rift basins, how are they controlled by geothermal gradients and volatile concentrations, and how do long-term fault slip rates relate to short-term seismic hazards such as earthquake frequency?

Addressing these questions will require analysis of long and continuous sediment cores that archive signals of climate variability at a hierarchy of timescales (seasonal, interannual, orbital); sites that preserve a variety of biological materials such as pollen, diatoms, ostracods, and fish remains; and integrated, 4-D studies of rift evolution.

While Albert, Turkana, and Tanganyika can all provide insight into the climatic, biological, and geological evolution of East Africa, the group nominated Lake Tanganyika as its highest priority target. Tanganyika uniquely holds long and continuous sedimentary records extending well into the Pliocene at modest (1-1.5 km) drilling depths (McGlue et al. 2008), an extraordinary variety of endemic lacustrine fauna and flora with proven fossil records, and a relatively simple rift architecture uncomplicated by extensive volcanism. Efforts are now underway to acquire new intermediate resolution seismic reflection data from Tanganyika to site drilling targets, reanalyze existing Tanganyika sediment cores to expand our arsenal of proxies, and to build our knowledge of the structural evolution and tephra stratigraphy of this basin. These activities will refine our understanding of the environmental evolution of tropical East Africa, and serve as milestones in the road to drilling Lake Tanganyika.

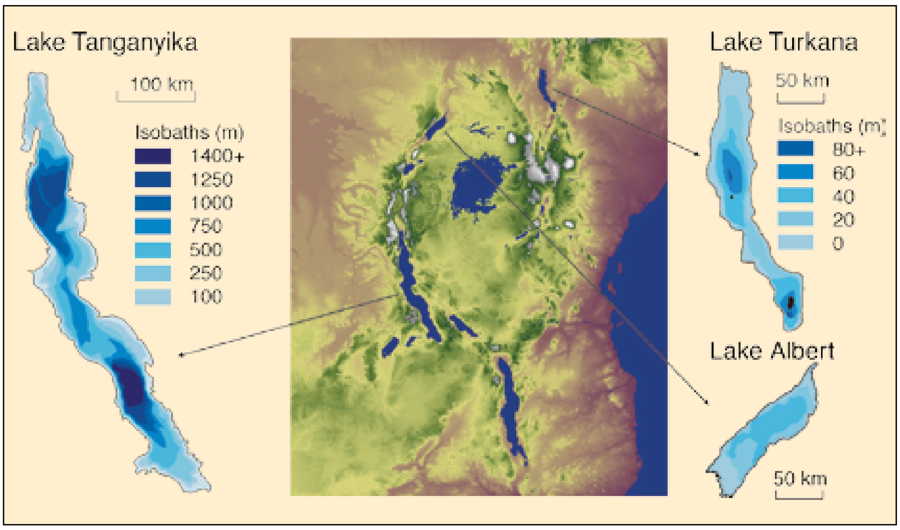

Figure 1: Map of East Africa with bathymetric maps of Lakes Tanganyika, Turkana, and Albert. Note the different scale for Tanganyika.

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Assessing the history of the Greenland Ice Sheet through ocean drilling

Corvallis, USA, 7-9 November 2011

Anders Carlson[1,2] and Joseph Stoner[2]

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The primary goal of this workshop was to assess whether ocean drilling of the geological record can provide information on the sensitivity of the Greenland Ice Sheet (GIS) to climate warming. Discussion focused on potential marine archives, proxies of GIS behavior and climate, and methods for dating such records. The participants represented a range of disciplines, including climate and ice-sheet modelers, glaciologists, organic and inorganic geochemists, geophysicists, paleomagnetists, paleoceanographers, glacial geologists and sedimentologists, and paleobiologists. The group concluded that process-oriented topics could be addressed through ocean drilling and that the following questions were of significant importance: What controls the rate of ice mass change on Greenland and the respective roles of atmospheric and oceanic forcings? Is subsurface oceanic temperature important in predicting the behavior of the GIS? What is the role of ice shelves and sea ice? How does Greenland freshwater influence global ocean circulation?

Following the theme of process-oriented questions, participants selected several key climate periods spanning the entire history of the GIS that would be important targets to focus on. First, the background climate state of an ice-free Greenland should be established to document when and to what extent Greenland valley glaciers expanded and became an ice sheet. Then, exploring GIS volatility during the Pliocene would provide information on long-term GIS sensitivity to greenhouse gas concentrations similar to current levels. Finally, the Quaternary offers several climate targets of interest, such as GIS behavior during the transition from 40 to 100 ka glacial-interglacial cycles. These document which glacial periods had a fully extended GIS on the continental shelf, and the amount of ice retreat inland of its current extent during interglacial Marine Isotope Stages 1, 5e, 7, 11, 19 and 31. The participants also noted that ice sheet-climate modelers should be involved at all steps of addressing these targeted time periods.

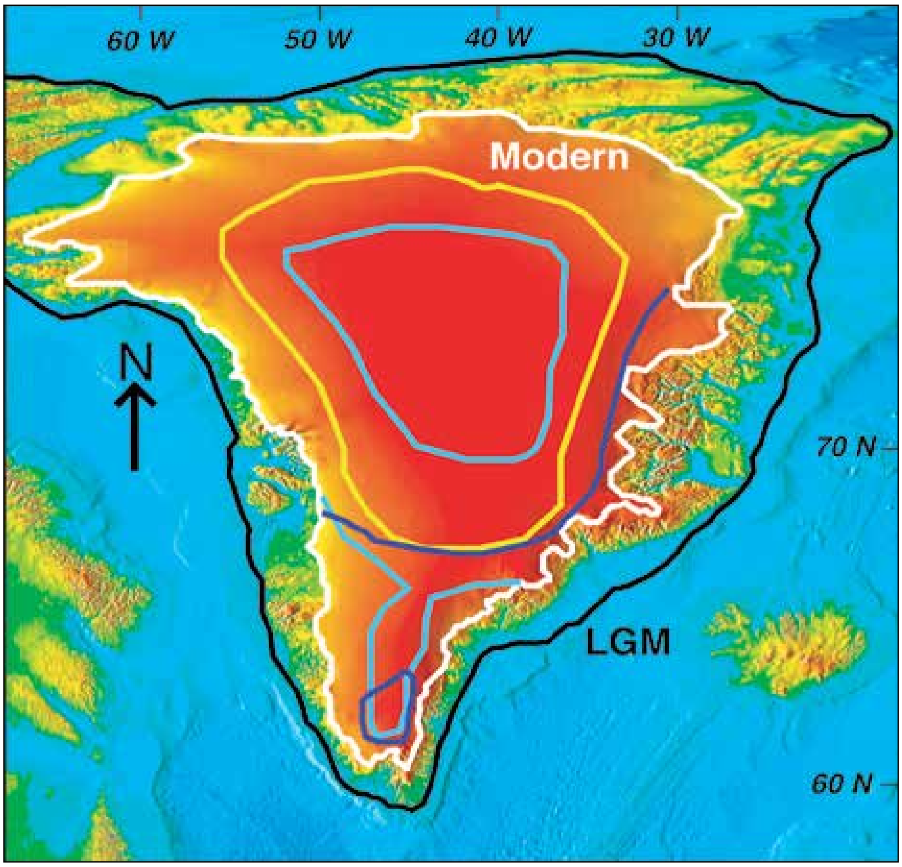

Figure 1: Last interglaciation (~125 ka) modeled GIS extents using the same ice-sheet model but different climate forcing schemes. Light blue lines are two extents of Cuffey and Marshall (2000) with only a remnant ice dome in central Greenland or significant ice persisting in south Greenland. The dark blue line shows the maximum retreat modeled by Otto-Bliesner et al. (2006) with only a small ice dome persisting in south Greenland; a second simulation of their model had an extent similar to the minimum retreat of Cuffey and Marshall (2000). The yellow line denotes the minimum retreat predicted by Lhomme et al. (2005), with south Greenland completely deglaciated. The black line shows the estimated extent of the GIS at the last glacial maximum (LGM) on the continental shelf by Funder et al. (2011). This wide range in modeled last interglaciation GIS extents predicts a sea-level rise contribution of 2 to 5.5 m, highlighting the need for geologic records of past GIS behavior.

Different strategies and drilling platforms will be needed for tackling these questions and retrieving sediment cores covering the key time periods. Continental slope drilling cores could be used to address large-scale GIS changes, which can better inform ice-sheet models, but may be difficult to date. Small-scale instability related processes might be better addressed through localized investigation at the individual fjord outlet glacier scale on the continental shelf. Sediment drifts on the continental rise integrate these signals in well-dated records that will facilitate interpretation of the more proximal records. Ocean temperature and sea-ice records should also be constructed to test GIS sensitivity to oceanic changes. A reoccurring issue at the workshop was the need for detailed site surveying prior to drilling to identify the best sites for studying the climate targets and addressing the process-oriented questions. Extensive seismic surveying and bathymetric mapping will allow the collection of the best cores, and for the linkage of discontinuous continental shelf, fan and slope records to the continuous records obtained on the continental rise.

To continue the development of a "Greenland" community, the workshop conveners, Anders Carlson and Joseph Stoner, have set up a website for further discussion of ideas and advancement of drilling plans and proposals (www.geoscience.wisc.edu/degree). The conveners and steering committee will develop a working group called DEGREE (DEglaciated GREEnland) that will facilitate future workshops to advance research, and foster discussions of new records and model results of past GIS behavior and its climate forcings. The DEGREE strategy is to develop a community that will foster International Ocean Discovery Program (IODP) expedition proposals focusing on specific aspects of Greenland paleo-history.

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Processes and Quaternary history of dust dynamics: low-latitude records and global implications

2nd meeting of the PAGES ADOM Working Group, Bremen, Germany, 31 October-3 November 2011

Jan-Berend Stuut[1,2], U. Merkel[2] and D.-D. Rousseau[3]

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Understanding the role of mineral dust in the climate system and its radiative impact is expected to reduce existing uncertainties about global climate change. In this context, the PAGES "Atmospheric Dust during the last glacial cycle: Observations and Modeling (ADOM)" working group intends to combine the evidence from aeolian records from continents, oceans, and ice sheets with model simulations of the past atmospheric circulation and modern process understanding.

Following up on the first ADOM workshop (Hyères-les-Palmiers, France, 2009; Rousseau et al. 2009), and the results of the DUSTSPEC meeting (Lamont, USA, 2010; Winckler et al. 2010), it was recognized that there is a specific need for an integration of datasets of dust deposition on land and in the ocean. Furthermore, it has been acknowledged that there are still large gaps in our knowledge on dust processes and dynamics. Open questions exist about emission-related processes at the various sources of dust, dispersion at different altitudes in the atmosphere, deposition on both terrestrial and marine environments and the effects of mineral dust after deposition.

To address these questions, the second ADOM workshop focused on strategies to derive quantitative and physically consistent synoptic reconstructions by integration of dust records, climate observations, and model simulations.

The workshop was organized according to the following themes: (1) Present-day dust, meteorology and remote sensing; (2) Ice, marine, and terrestrial dust archives; (3) Modern and (paleo-) dust modeling; (4) Open discussion on future activities and strategies.

The open discussion raised different questions of importance: Which are the relevant (paleo) sources of dust (a key point for climate model setups)? Are the differences between atmospheric measurements and observations of paleo-dust particle size distributions significant? Which size range should be used in climate models given the fact that present-day observations of particle-size variations cannot be explained in terms of basic physics? How reliable is the reconstruction of wind-strength variations from dust/loess grain-size data given that grain size is also determined and constrained by other factors such as transport-distance and altitude or mixing? Which parameters influence the atmospheric processing of dust, including dry and wet deposition?

Several recommendations resulted from the final discussion. These include a strategic remapping of global soil distributions and the collection of more meteorological and mineral-dust data closer to the dust sources. Methods on dating and the measurement of particle grain size and shape should be standardized, and the definitions of isotope ratios for the characterization of different source regions refined. ^{222}Rn should be monitored in polar regions to constrain atmospheric transport times. Furthermore, new marine sediment proxies should be developed to constrain the provenance of dust in Antarctica. Seasonal to millennial timescales should be taken into account when studying dust processes and mechanisms. In the context of abrupt climate change, selected Dansgaard/Oeschger events deserve more focus where detailed evidence from ice cores exists. Finally, there is a need for a coordinated exchange of data between the paleo and modeling communities, which should flank ongoing database initiatives such as DUSTSPEC, PASH2 or DIRTMAP.

Almost 50 participants from 10 countries made this workshop a very successful and fruitful one. It was organized by Jan-Berend Stuut, Ute Merkel, and Denis-Didier Rousseau, with sponsorship from MARUM, NIOZ and PAGES. A PAGES newsletter dedicated to the dust topic is planned.

Figure 1: Dust storm over China in April 2001. Dust from this event crossed the Pacific Ocean and was deposited as far as the Great Lakes region in the USA. Image credit: NASA.

More information:
www.marum.de/dust-workshop2011.html
and
www.pages-igbp.org/workinggroups/adom

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Human-climate-ecosystem interactions: learning from the past

New Forest, UK, 4-6 January 2012

John Dearing and Peter Langdon
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The annual discussion meeting of the Quaternary Research Association was held in the picturesque, winter landscape of the New Forest National Park in southern England. The overall theme of the meeting was "Quaternary Science and Society" and it proved to be popular, attracting over 100 attendees. The PAGES-Focus 4 sponsored open sessions "Human-climate-ecosystem interactions: learning from the past" took up four of the 10 sessions. PAGES helped to support eight early career researchers from Australia, Romania, the USA, and the UK to attend the Focus 4 sessions. The Focus 4 presentations were split into several groups. One group focused on the response of past human societies to climate change as reconstructed linking archeological and paleoecological data. Within that group Andy Dugmore (Edinburgh, UK) showed how resilience theory could be combined with detailed and interdisciplinary studies of past communities across the North Atlantic to explain the reasons for either social collapse or long-term sustainability. Michael Grant (Wessex, UK) described how the past trajectories of woodland species in the local New Forest were providing insight into modern day management of the woodlands. One of the PAGES-supported early-career researchers, Giri Kattel (Ballarat, Australia), used paleolimnological data to assess human-climate-ecosystem linkages illustrating how sediments in maar (crater) lakes could be used as recorders of climate regime shifts and to study adaptability of past ecosystems.

A second group of papers were methodology-centric with reports on the development of isotopic and bimolecular analyses, and on approaches to translate pollen records into land use cover. Virgil Dragusin (Bucharest, Romania) explored possible human-environment interactions during the Bronze and Iron Ages in SW Romania as recorded by carbon stable isotopes in speleothems. Joseph Williams (Kansas, USA) was drawn to the discussion of novel approaches in environmental and biodiversity change, such as the ongoing development of plant biomarkers and ancient DNA analysis. Hazel Reade (Cambridge, UK) assessed the paleoclimatic interpretation from the isotopic analysis of tooth enamel with regard to the archeological record of Northeastern Libya.

A third group linked paleoenvironmental studies to past and present

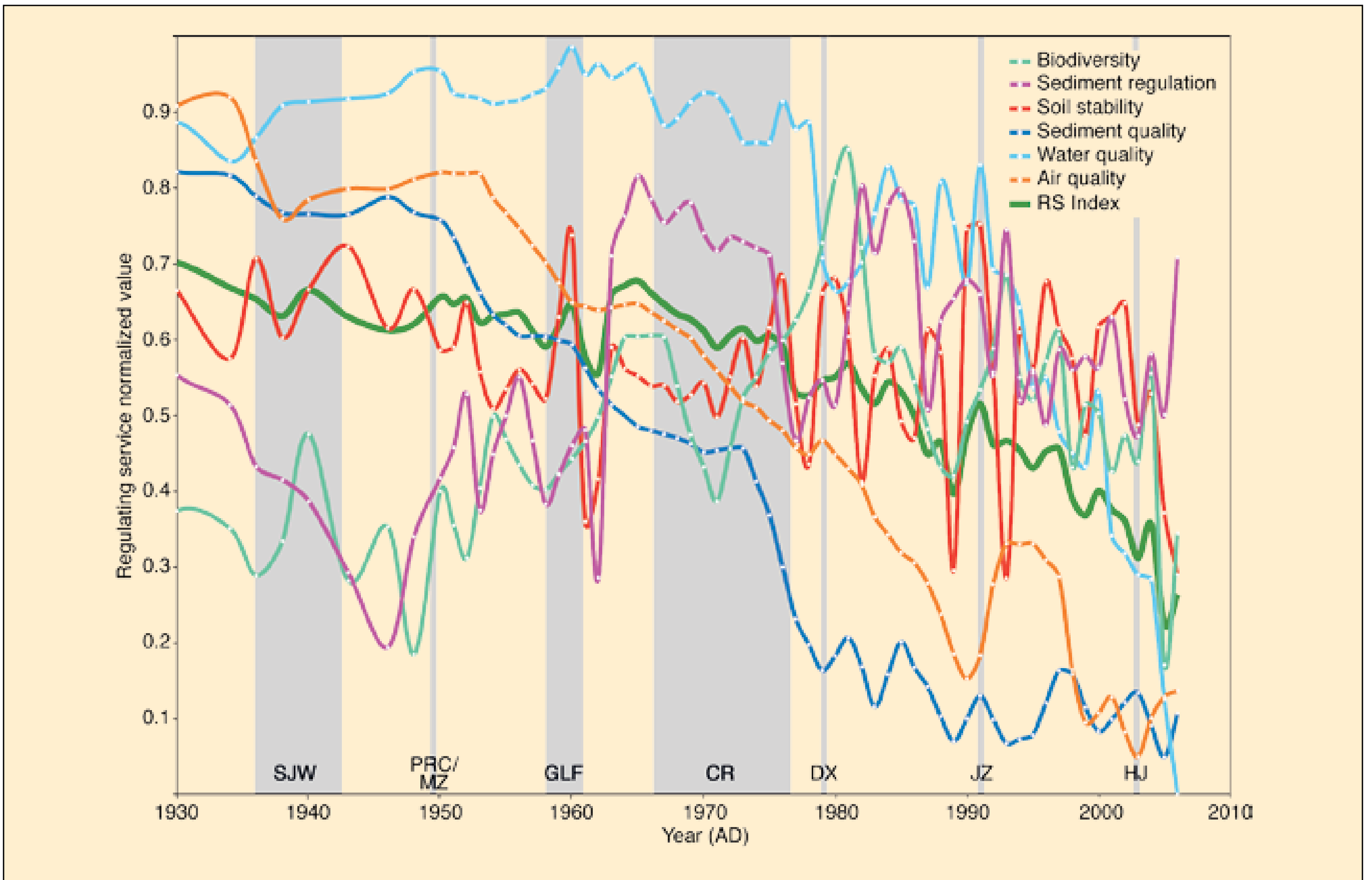

Figure 1: Lower Yangtze basin 1930-2006: normalized regulating service proxy records for biodiversity, sediment regulation, soil stability, sediment quality, water quality, air quality and regulating service (RS) Index based on lake sediment analyses, showing downward trends (losses of services) towards the present. Vertical bars show major 20th-21st century political events (from left to right): Sino-Japanese War 1937-1945 (SJW); People's Republic of China founded by Mao Zedong 1949 (PRC); Great Leap Forward 1958-1961 (GLF); Cultural Revolution 1966-1976 (CR); Deng Xiaoping's economic reforms from late 1970s-early 1980s (DX); leadership of Jiang Zemin from 1989 (JZ); leadership of Hu Jintao from 2003 (HJ). After Dearing et al. (2012).

socio-ecological resilience. Using multi-proxy records, this group of studies revealed long-term interactions between climate, human activities and ecosystem services, the presence of thresholds and early warning signals, and reference conditions for conservation. Zhang Ke from Southampton (UK) shed light on recent attempts to use paleoenvrionmental records as proxies for ecosystem services in the lower Yangtze basin (Fig. 1). The paper by Wang Rong (Southampton, UK) examined the evidence for early warning indicators of eutrophication in lake sediments from southwestern China. And Helen Shaw (Lancaster, UK) assessed paleoecological and historical contributions to understanding sustainability, resilience, and ecosystem services within traditional pastoral management. The wide range of questions that were addressed across many geographical zones, served to emphasize the growing use of paleoenvironmental archives to understand human-environment interactions. Reflections on the meeting by recipients of PAGES support gave a flavor of the intellectual atmosphere and rapport generated during the meeting. One recipient commented that the meeting was timely: taking place not only when ecosystems are increasingly threatened by rapid climate change and human activities but when scientific communities across the globe are trying to find the best possible approaches to mitigate these effects. This meeting was a significant step toward our efforts for a comprehensive understanding of the human-climate-ecosystem interactions during the 21st century that help promote societal and ecosystem resilience against future climate change. The use of a range of proxy indicators to understand ecosystem response to climate and human drivers can help us develop not only management tools but also our theoretical understanding of ecosystem responses to multiple and complex forcing.

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Report on the PAGES/CLIVAR Intersection Panel Meeting

WCRP, Denver, USA, 28 October 2011

Gavin A. Schmidt[1] and Valérie Masson-Delmotte[2], Co-Chairs

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[2]Institut Pierre Simon Laplace and Laboratoire des Sciences du Climat et de l'Environnement, Gif-sur-Yvette, France

Since 1999, the PAGES/CLIVAR (Climate Variability and Predictability) Intersection Panel (www.clivar.org/organization/pages) has focused on benefitting from the combined expertise and insights of scientists working on modern climate observations and processes and those collecting and interpreting paleoclimate records.

The World Climate Research Programme (WCRP) Open Science Meeting in Denver, USA, in October 2011, featured many examples of paleoclimate information being used to extend the instrumental record, evaluate climate models, and place modern changes in a longer-term context. It was therefore an excellent backdrop for the annual committee meeting of the Intersection Panel.

Our Panel meeting was dedicated to finding the best strategies for boosting collaborations across the WCRP "seamless" community (not just CLIVAR). Panel member rotation was addressed with an objective of ensuring a wide range of interests and geographical spread in new members. This selection is now underway, and any readers interested in joining the panel are encouraged to contact the chairs.

Links with other panels and working groups were also an important topic of discussion. Representatives from the Global Monsoon working group, CLIVAR Atlantic panel, and others expressed great interest in increasing the paleoclimate component in their discussions and projects. In particular, the PAGES Ocean2K synthesis project (www.pages-igbp.org/workinggroups/ocean2k) (motivated by our Panel thanks to CLIVAR Scientific Steering Committee inputs) that focuses on bringing together high-resolution ocean proxy data for the last two millennia was highlighted as an important bridge to the observational oceanographic community. The Panel has instituted a new mailing list (clivar-pages-open@clivar.org) that we hope will be a resource for notifications of cross-cutting projects and workshops, and a platform for ideas on how to engage wider community participation. To subscribe, please go to www.clivar.org/clivarpages-mailing-list.

The centerpiece of discussion at the meeting was the Coupled Model Intercomparison Project (CMIP5) and database. For the first time within the CMIP protocol, paleoclimate simulations for the Last Glacial Maximum (21 ka ago), mid-Holocene (6 ka ago) and last millennium (Paleoclimate Modelling Intercomparison Project, PMIP3) have been included alongside historical simulations for the 20th century and future projections. This allows for a much greater analysis of whether and how paleoclimate model/data comparisons are informative of future projections.

The Panel organized a workshop focused on this topic in March 2012 (Schmidt et al., this issue), and the outcomes were presented to the wider CMIP5 community. The Panel is working to produce a refereed "white paper" on the best practices for using the PMIP3 simulations to help constrain projections. The white paper will address issues of statistical robustness, dataset synthesis, comparison strategies and quantification of uncertainties due to the model structure, data set uncertainty and forward modeling approaches.

Overall, this is an exciting time to be bringing these communities together, and the resulting new initiatives have enormous potential.

Using paleo-climate model/data comparisons to constrain future projections

PAGES-CLIVAR Workshop, Honolulu, Hawaii, 1-3 March 2012

Gavin A. Schmidt[1], E. Guilyardi[2,3], M. Kageyama[4], M.E. Mann[5], V. Masson-Delmotte[4] and A. Timmermann[6]

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The Bishop Museum in Honolulu, Hawaii, provided a picturesque backdrop to the PAGES-CLIVAR Intersection Panel workshop. The main objective of the workshop was to bring together modelers, theoreticians and paleoclimatologists to commence analysis of results from Phase 5 of the Coupled Model Intercomparison Project (CMIP5) simulation database. The CMIP5 project is a community-wide effort to provide standard protocols for climate model simulations covering the historical instrumental period, future projections and a number of idealized simulations to aid the understanding, detection and attribution of climate change. Significantly, and for the first time, there is a concurrent paleoclimate component, in collaboration with the Paleoclimate Modelling Intercomparison Project Phase 3: PMIP3, that uses the same models for three specific experiments covering the Last Glacial Maximum (LGM, 20 ka ago), the Mid-Holocene (MH, 6 ka ago) and the Last Millennium (a transient simulation from 850 to 1850 AD; Taylor et al. 2012).

Comparisons of paleoclimate simulations and proxy observation have a long history via earlier incarnations of PMIP and many individual studies, which motivated comprehensive data syntheses. However, it has been a challenge to quantitatively link the future simulations with skill or sensitivity in the paleoclimate simulations. There are a number of reasons for this, not least because paleo-simulations were often not performed with the same models being used for future projections and through a lack of suitable paleoclimate metrics; predominantly large scale syntheses of the proxy data. The workshop focused specifically on this missing step – to make the quantitative connections, so that paleo-climate can become demonstrably useful for constraining future projections.

The workshop began with a comprehensive discussion on the nature of the multi-model ensemble of opportunity and the techniques available for assessing model skill. The evidence indicates that the current models don't differ in kind from previous efforts (and so previous work can be analyzed in the same framework) and that there is sufficient reason to expect that, particularly for the LGM, the model spread likely encompasses the observations. However, it was widely acknowledged that it is challenging to find diagnostics of the models which can be compared to paleoclimate observations and that also correlate to model projections of the future. The remainder of the workshop was focused on specific uncertainties highlighted in IPCC AR4 for which there are some clear indications that paleo-climate might help. These included patterns of regional rainfall, temperature seasonality, climate sensitivity, ocean-atmosphere modes in the tropical Pacific, the response of the North Atlantic Meridional Circulation, and spectra of climate variability.

Assessments of climate sensitivity using the LGM are very promising, with a large increase in available and relevant simulations over PMIP2. In the preliminary data there appears to be a correlation of verifiable temperature patterns at the LGM to future projections (Fig. 1). Large-scale changes in rainfall patterns are also very promising targets, with a clear coherence of tropical rainband shifts in latitude as a function of equatorial SST gradients across all the model simulations. Ocean circulation metrics – whether for the overturning circulation or the spectral character of tropical Pacific ocean-atmosphere dynamics including El Niño/Southern Oscillation – are not quite at the same stage due to a lack of sufficiently constraining proxies, and continuing uncertainty of the sampling biases arising from the short time over which modern observations have been collected.

Participants at the workshop are working on a full white paper describing the approaches that can be taken and highlighting the preliminary results, but one conclusion is already clear: paleoclimate simulations have come of age as part of the suite of evaluations any model must undergo.

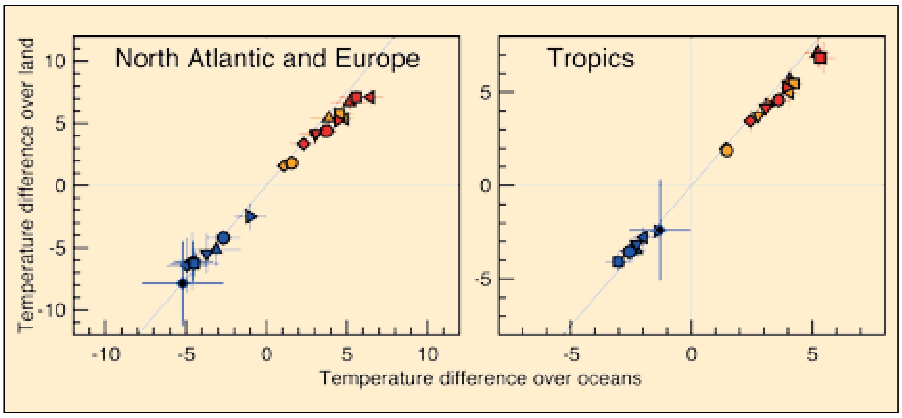

Figure 1: Preliminary results from the CMIP5 archive showing the multi-model ensemble for temperature differences at the LGM and in idealized increased CO_2 experiments. ***Left-hand panel*** *shows the robust relationship between the North Atlantic and European ocean and land temperatures in both cold and warm climates (using an average of the simulation data over points only where there are observations).* ***Right hand panel*** *shows equivalent results for the Tropics. The blue crosses indicate the results (with uncertainties) from the observational data syntheses from the LGM. Red and yellow symbols show the CMIP5 model results. Figure courtesy of Masa Kageyama.*

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The Paleo-ocean challenge: data meet models

PMIP-MARUM-PAGES Workshop on Comparing Ocean Models with Paleo-Archives 2012 (COMPARE 2012) – Bremen, Germany, 18-21 March 2012

Michal Kucera, A. Paul and S. Mulitza
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Comparisons of model simulations with data on the state of the ocean in the past are frequently used to study climate processes under different boundary conditions and to understand climate and ocean change in Earth history. Such approaches can be used to benchmark climate models and model ensembles (Hargreaves et al. 2011). They hold considerable promise in demonstrating the ability of climate models to simulate the response to changes in forcing factors (Braconnot et al. 2012) and to help constrain critical parameters, such as climate sensitivity (Schmittner et al. 2011).

The Phase 3 of the Paleoclimate Modelling Intercomparision Project (http://pmip3.lsce.ipsl.fr), which is the paleo-component of the fifth phase of the Coupled Model Intercomparison Project (http://cmip-pcmdi.llnl.gov/cmip5), is currently being completed with a number of new model run results. For the first time, the paleoclimate simulations use the same model setups as those used for projecting future climate. One of the goals of PMIP3 is to examine climate predictability and to determine why similarly forced climate models produce a range of climate responses. To this end, the PMIP3 model runs have to be confronted with paleodata for the time intervals that have been modeled. Among these are the last glacial maximum (LGM), but also the last interglacial, the early Holocene, and the last deglaciation. For this comparison, marine sedimentary data will play a crucial role, because of their precise and consistent dating, and the fact that they record regionally representative patterns in key modeled variables, which can be reconstructed quantitatively (e.g. Lynch-Stieglitz et al. 2007; MARGO 2009).

Considering the wealth of existing proxy data on the state of the past oceans and the imminent release of the new PMIP3 paleoclimate simulations, the scientific community became convinced that the upcoming data-model comparisons would benefit from the joint expertise of modelers and paleoceanographers. Joint initiatives potentially include working towards innovative statistical methods, quantifying uncertainty, and making the most of proxies for parameters besides sea surface temperature. With

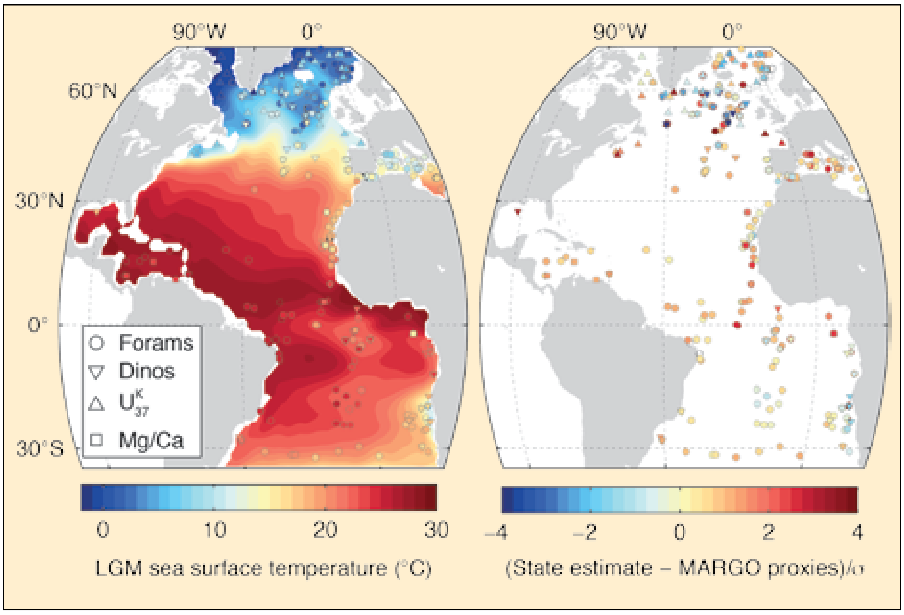

*Figure 1: An example of the application of an inverse approach to LGM ocean data (MARGO 2009). The **left panel** shows annual mean sea surface temperature (SST) in an LGM Atlantic ocean state estimate (contours) with MARGO LGM SST proxy records overlaid (symbols; Forams and Dinos refers to SST estimates from transfer functions based on assemblages of planktonic foraminifera and dinoflagellate cysts). The state estimate is created by application of the "adjoint method" to identify an ocean state that is consistent with both oceanic physics and with the proxy records, given their uncertainties. The **right panel** shows normalized misfits, computed as [(state estimate – MARGO proxies)/σ] where σ is the uncertainty in the data. Symbol colors show where the state estimate is consistent with the data, given their uncertainties. Values near zero indicate consistency. In this map, a satisfactory fit is obtained for most low latitude data. In the high latitudes, large values indicate that a satisfactory fit to all of the MARGO data simultaneously is not possible. Analysis and graphics: unpublished data courtesy of Holly Dail, Massachusetts Institute of Technology, USA.*

this in mind, the COMPARE 2012 meeting was conceived as a joint initiative of PMIP3, PAGES and MARUM. Over 40 scientists from nine countries assembled in Bremen to work towards establishing the union between paleo-ocean data and model simulations. The first half of the workshop was dedicated to presenting the latest model results of the status of paleo-ocean data and emerging new approaches for combining the two, including inverse methods (Fig. 1) and forward modeling of proxies.

The workshop culminated in splinter meetings of three task groups that brainstormed the main issues that arose from the initial discussions: how to best deal with data uncertainty, how to quantify model data misfit and model error, and what the potential benefits and challenges are to working with non-traditional variables, time slices and transients. A number of individual projects, including an ocean data synthesis for the 6 ka time slice, were set up. Besides this, the workshop delivered important take-home messages: A thorough consideration of uncertainty is essential for a meaningful data-model comparison; a dialogue between data and modeling communities is important in finding most useful ways of evaluating model results; multi-proxy information adds complexity to data but helps reveal uncertainties that would otherwise have gone unnoticed; and future data-model comparisons need to be quantitative and "intelligent" (diagnostic, process-oriented). The complexity of handling multiple sources of uncertainty in proxy data (proxy attribution, age model) calls for the development of a data portal or interface allowing an interactive access to large datasets, their on-line handling and visualization.

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Paleoclimate modeling: an integrated component of climate change science

2nd PMIP3 General Meeting, Crewe, UK, 6-11 May 2012

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Past climates provide an opportunity to examine the working of the Earth system under a much wider range of forcing than those experienced during the historical period. The Paleoclimate Modelling Intercomparison Project (PMIP) is an ongoing program tasked with the systematic comparison of models and observations of past climate. Over the last 20 years, through the definition of model experimental designs and the syntheses of paleoenvironmental data, PMIP has made significant progress in the understanding of a number of key periods of the past. Previous PMIP experiments have included the mid-Holocene (MH) and the Last Glacial Maximum (LGM). For the latest iteration, PMIP3, the last millennium (LM), the Eemian (last interglaciation) and the mid-Pliocene warm period (approximately three million years ago) have been added. Three of these PMIP3 experiments (MH, LGM, LM) have been included as high-priority simulations in the Coupled Model Intercomparison Project (CMIP5; Taylor et al. 2012), which provides the framework for coordinated climate change experiments used in the Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC AR5).

In May 2012 over 80 scientists from more than 30 institutions gathered at Crewe Hall, a former Jacobean mansion in the English county of Cheshire, for the second general meeting of PMIP3. For the first time, model results for the PMIP3 experiments were shown. Over the course of five days many different aspects of paleoclimatology were examined, from the causes of temperature changes over the last 1000 years to a data-model comparison for the Eocene (56-34 Ma); from changes in Arctic sea ice to tropical Pacific El Niño teleconnections; from multi-model temperature patterns to global climate reconstructions based on pollen data. PMIP has identified some key paleoclimate features, which are relevant to each of the time periods by varying degrees and are also relevant to future climate change. These include climate variability, climate/Earth system sensitivity, polar amplification, and data-model comparison. Significant time was devoted to discussing these topics in break out groups, and new working groups were established to examine these topics in detail through the lifetime of PMIP3.

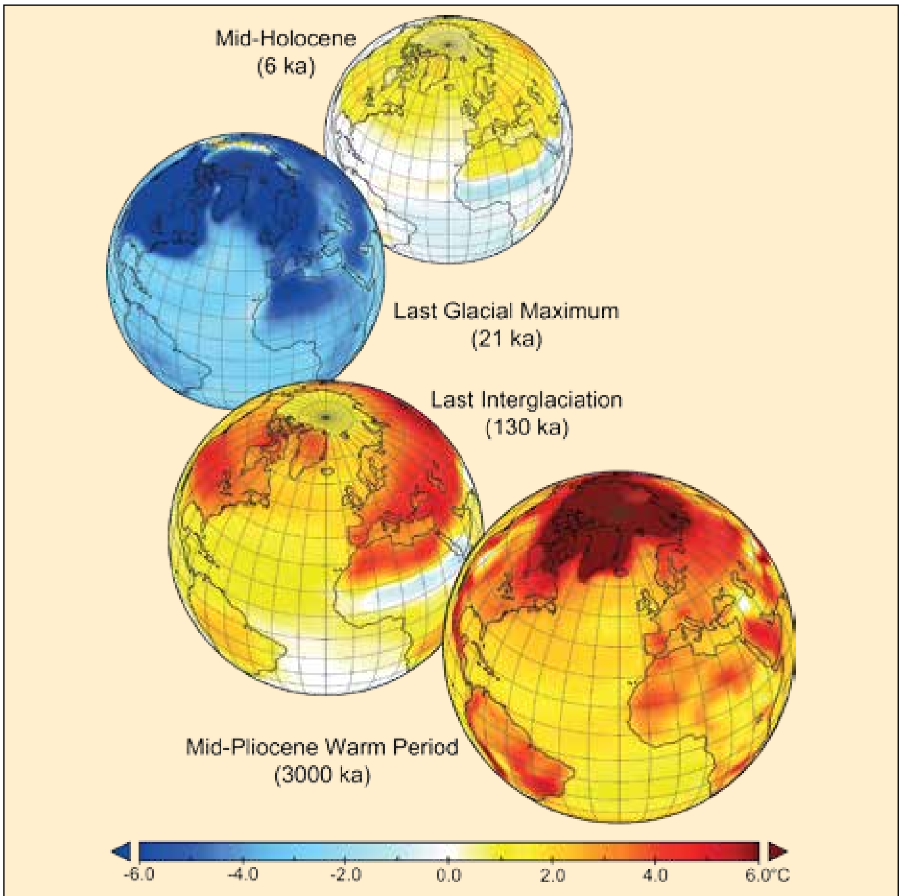

Figure 1: Multi-model mean summer (JJA) warming in the main Paleoclimate Model Intercomparison Project (PMIP3) equilibrium time periods, mid-Holocene, Last Glacial Maximum (Braconnot et al. 2012), Last Interglacial (Lunt et al. 2012) and the mid-Pliocene Warm period (Haywood et al. 2012).

Integrated quantitative analysis of paleoclimate model simulations and climate reconstructions show that global scale climate models are generally capable of reproducing past climate change. However, many questions remain about the abilities of these models on regional scales. Can they reliably reproduce the large Arctic changes seen in the past? Why does the Atlantic Meridional Overturning Circulation respond differently in different models given the same forcing? Why do the simulated climates of the continental interiors change so little? Discrepancies between model simulations and paleoclimate reconstructions based on observations can arise from a combination of uncertainties in the interpretation of paleoenvironmental observations, uncertainties in the model physics and problems with the experimental design. The PMIP philosophy is that a better understanding of past climates and the workings of the Earth System can only be achieved by addressing each of these sources of uncertainty in an integrated way.

A special issue highlighting many results of the PMIP3 meeting is being prepared for the journal Climate of the Past. The Crewe meeting was hosted by the Universities of Leeds and Bristol, and sponsored by PAGES, SCAR (Scientific Committee on Antarctic Research), NCAS (UK National Centre for Atmospheric Science), The Royal Meteorological Society, The Geological Society, and the UK Meteorological Office.

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Second International Cave Monitoring Workshop

Innsbruck, Austria, 18-21 April 2012

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A successful paleoclimate reconstruction based on proxy archives rests not only on understanding how regional climate and local weather patterns are related to variability of the climate proxy, but equally on the understanding of local processes that influence how the climate signal is captured in the archive. Speleothem deposits in caves yield a wealth of proxy data that can be related to changes in atmospheric circulation, precipitation and vegetation.

Monitoring cave environments is key to understanding relationships between weather and the processes that affect calcite precipitation inside caves. These include for example knowledge of the production rate of CO_2 in the soil zone and its movement in and out of caves, the relationship between rainfall and the composition and movement of groundwater, and the impact of seasonal changes on the precipitation of carbonate as speleothem. Setting up and maintaining reliable cave monitoring programs presents a challenge in wet caves, which are often remote and difficult to access even for experienced speleologists.

Back in 2009 we held a first workshop on cave monitoring techniques in Gibraltar to discuss the technology that was available and share experiences in best practices among the small group of researchers in this field. Three years later many more groups are involved in cave monitoring and have acquired considerable expertise. In April 2012 we held the 2nd International Cave Monitoring Workshop in Innsbruck bringing together scientists and PhD students from 14 countries to discuss new ideas in methodology and instrumentation.

The workshop provided an informal discussion forum for exchange of experiences covering all practical aspects of cave monitoring. Four main themes were discussed: strategies for monitoring the hydrology and meteorology of cave systems, instrumentation and data logging, sampling and analysis protocols, and in-situ studies of carbonate precipitation and other cave processes. It is clear that some challenges still remain, such as finding a reliable way to precisely measure the relative humidity, and avoiding unwanted interference by insects and other animals as well as humans. However, the three years since the first workshop saw significant advances in the ability to carry out automatic logging and sampling of key parameters using ingenious, custom-built instruments.

Cave monitoring is now being actively carried out in many cave systems over the world (e.g. Fig 1) and clearly shows that every cave has its own "personality" that takes several annual cycles to properly characterize and evaluate. Once this is done, features of the chemical proxy record preserved in speleothem can then be assigned to specific local processes, and thus improve the reliability of climate reconstructions from proxy records.

A day trip to Spannagel Cave, an 11 km-long high-alpine marble cave hosting Europe´s highest show cave, marked the end of the workshop. The workshop organizers are grateful for financial support from the Office of the Vice Rector for Research, the Faculty of Geo- and Atmospheric Sciences and the Research Centre Geodynamics and Geomaterials (all University of Innsbruck, Austria) and Gemini Data Loggers (UK).

Figure 1: Dripwater collection in Obir Cave, Austria. Photo credit: Robbie Shone (shonephotography.com).

Climate Refugia: Joint Inference from Fossils, Genetics and Models

Eugene, USA, 1-3 August 2012

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Climate refugia, i.e. areas where populations of a species avert extinction during periods of unfavorable regional climate, may play a central role in maintaining regional-to-global biodiversity. Paleoecologists and biogeographers have a long-standing interest in refugia as a means to explain latitudinal migration or stasis of the geographic distribution of a species through glacial periods and the resulting relictual distributions and endemism (Hampe and Jump 2011). More recently, the burgeoning field of phylogeography has demonstrated the value of genetic information to complement the fossil record in understanding past species distributions. This has lead to increased recognition that far more species than previously thought may have maintained small and scattered populations through the Last Glacial Maximum in refugia situated at relatively high latitude (Stewart et al. 2010). Indeed, a generally low rate of extinction attributable to the dramatic climate change of the Quaternary is not congruent with high rates of future extinction that are projected by many species distribution models (Botkin et al. 2007). The existence of climate refugia in heterogeneous landscapes may provide one solution to this conundrum and contribute to important assessments regarding the risks of future climate change to biodiversity. Specifically, a better knowledge of the functioning and dynamics of historical climate refugia can enhance our understanding of how current populations may react to future climate changes, help with identifying potential refugia for species of concern, and improve our understanding of biotic responses to continued climate warming (Keppel et al. 2012).

We convened a three-day workshop, with support from PAGES and the University of Oregon, to bring together experts from diverse disciplines that provide complementary insights into the identification, characterization, and importance of climate refugia. The workshop engaged 33 participants from 10 countries with backgrounds in paleoecology, climatology, phylogeography, biodiversity research, and species distribution modeling. Three days of meetings were used to discuss advances within each discipline and opportunities for transdisciplinary research approaches.

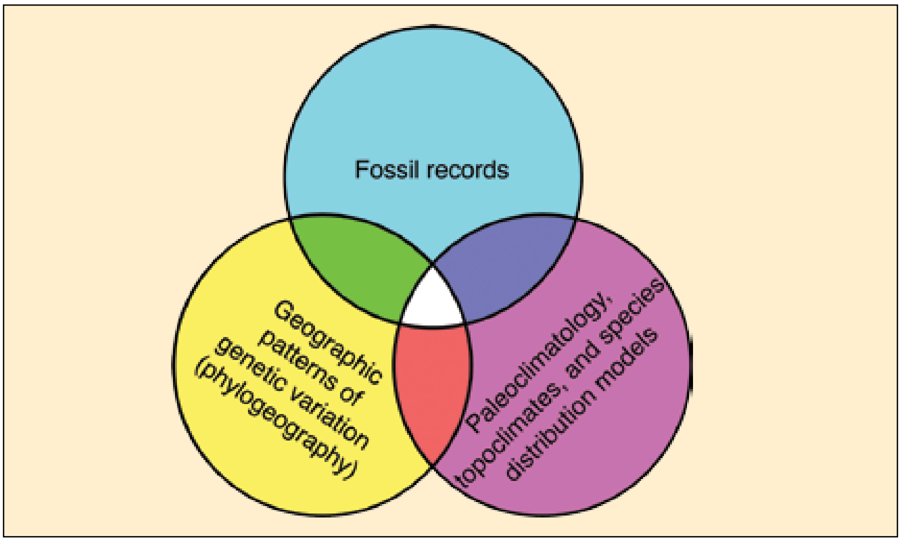

Figure 1: Three broad approaches to studying past species responses to climate change may be used jointly to exploit the complementary strengths of each approach to obtain the most complete reconstruction of historical refugia.

There remains much untapped potential to study climate refugia by using a joint inference across multiple disciplines (Fig. 1). Joint analysis of data across disciplines enables a clearer and more robust picture of species history, as the strengths of the different disciplines are combined. For instance, the fossil record can be used to evaluate the performance of paleoclimate simulations and species distribution models (Varela et al. 2011). Second, hindcasted species distributions have been used to generate hypotheses that can be tested by phylogeographic studies (Richards et al. 2007), or simply to reveal past range dynamics that can explain the current distribution of genetic lineages (e.g. Hugall et al. 2002). The successful application of species distribution modeling to the study of refugia requires not only reliable paleoclimate estimates from coarse-resolution models, but also realistic downscaling of relevant variables over complex terrain in the present and the past (Dobrowski 2011). Phylogeography can notably help to detect small populations (cryptic refugia) and reveal the direction of past population expansions that went undetected in the fossil record, whereas the fossil record can constrain the timing of such expansions and detect past range contractions (i.e. local extinctions; Hu et al. 2009). Where sufficient data exist, a network of fossil sites may be interpreted with respect to the refugia inferred from genetics to constrain the spatial and temporal patterns of postglacial expansion, as has been done for *Fagus sylvatica* in Europe (Magri et al. 2006). Few studies to date have attempted joint inferences across all three approaches, and a quantitative framework that considers the strengths and weaknesses of each approach is needed for rigorous assessment of past species refugia and migration patterns. Such studies are likely to provide the most informed view of how individual species persisted through the Quaternary and, potentially, into the future.

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Landscape Planning for the Future: Using fossil records to map potential threats, opportunities and likely future developments for biodiversity and ecosystem services

Oxford, UK, 9-11 January 2012

Kathy J. Willis[1], S. A. Bhagwat[2] and E. S. Jeffers[1]

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[2]School of Geography and the Environment, University of Oxford, UK

The first meeting of the PAGES Focus 4 Biodiversity Theme was co-sponsored by PAGES and the Oxford Martin School Biodiversity Institute. The overall aim of the meeting was to bring together paleoecologists, modelers and neo-ecologists whose research contributes to understanding the dynamics over time and space of biodiversity and ecosystem services. Forty people attended the meeting representing 14 different countries and five continents.

The three-day meeting was split into seven sessions. The first four focused on the presentation of paleodata relevant to the four key ecosystem services categories (Box 1). Two sessions focused on using the past to assess biodiversity risks in the future, and modeling of long-term data for managing ecosystem services. The final session examined the use of long-term data in ecosystem service valuation and management tools.

Figure 1: Ecosystems, such as the Tibetan Plateau depicted here, provide a wide variety of ecosystem services such as clean water, recreation space and fodder for grazing. Information on the response of these goods and services to environmental change is recorded in natural archives and is essential for the sustainable management of these resources. Photo: Shonil A. Bhagwat.

Box 1: Ecosystem services are benefits that people obtain from ecosystems and are divided into four categories:

- **Supporting services**
  e.g. dispersal of seeds and pollen, cycling of nutrients, primary production
- **Provisioning services**
  e.g. supply of food, water, pharmaceuticals, energy
- **Regulation services**
  e.g. crop pollination, carbon sequestration, waste decomposition and detoxification
- **Cultural Services**
  e.g. recreational and cultural experiences, scientific discoveries

In addition to the plenary presentations there were also two breakout sessions, which stimulated discussion on (i) the different types of paleoecological data that are relevant to assessing ecosystem services through time and (ii) the databases and sources already available to enable landscape-scale reconstructions, and the identification of data gaps. The overall conclusion from these breakout sessions was that there is already a vast wealth of excellent data and models available for assessing ecosystem function and service provision through time. The major challenge is to determine the appropriate means to disseminate this information to policy makers, habitat managers, and other academics. In particular, the participants discussed the need to devise new methods to present paleodata in a format that is more accessible, possibly through the development of new data management tools and better web-portals.

The main outputs of the meeting will be an edited volume in *The Holocene* entitled Dynamics of Ecosystem Services Through Time: Looking to the Past to Plan for the Future. A policy brief is also in progress to communicate the need for a long-term perspective in national and international ecosystem assessments. Future planned activities of the PAGES Biodiversity Theme include a workshop at the International Ecology Congress (INTECOL) 2013 and a second Working Group meeting in Oxford, UK. The recent establishment of the International Panel on Biodiversity and Ecosystem Services (IPBES) renders this PAGES Theme and its focus on biodiversity and ecosystem services extremely timely.

Geoarcheological Workshop – Actual stage of the environmental archeology investigations in southern Poland and northern Czech Republic

Poznań, Poland, 25 October 2011

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[2]Institute of Archaeology, University of Wrocław, Wrocław, Poland; [3]Institute Geoecology and Geoinformatics, Adam Mickiewicz University, Poznań, Poland

Geoarcheology brings together many disciplines such as geology, geomorphology, archeology, paleobotany or zoology. The traditional geoarcheological approach is based mainly on geological and soil science methods, but during the last 20 years detailed microstratigraphic studies and analyses of microfacies have become more and more important (Courty 2001). These approaches were recognized as essential to recover and understand the full cultural and environmental potential of archeological deposits (Goldberg and Macphail 2006).

The main aim of this workshop was to initiate scientific discussion on the new challenges for geoarcheology in Central Europe. Scientifically, the focus was on ongoing environmental archeology research in southern Poland and the northern Czech Republic, and their implications for paleoclimate research. The presentations mainly concentrated on the Late Pleistocene and Middle to Late Paleolithic (130-12 ka BP), for which archeological evidences are more frequent than for earlier periods.

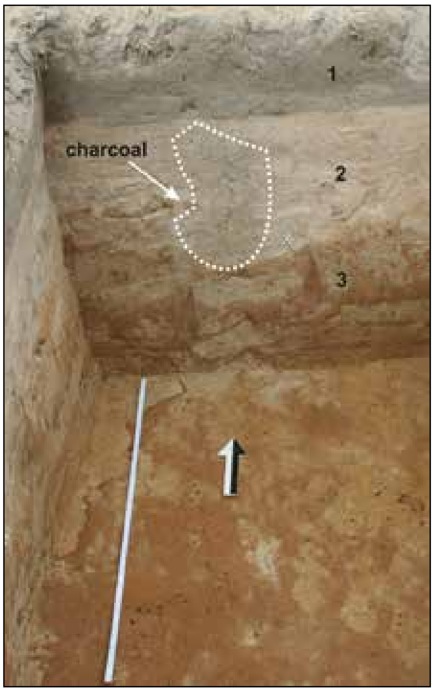

Figure 1: Excavation trench from the Late Pleistocene archeological site Sowin in the Silesian region of Southwestern Poland. The profile shows three main stratigraphic units (recent soil, eolian sands, and sand-clayish sediments) and anthropogenic charcoal deposition. Photo by A. Wisniewski.

The organizers had invited a range of specialists from the Czech Republic and Poland to discuss "key" questions of the Late Pleistocene stratigraphy and Paleolithic evidences from southern Poland. Topics addressed ranged from subsistence strategies of Late Paleolithic hunter groups to the MIS3-MIS1 stratigraphical records in the region (Połtowicz-Bobak 2009; Wiśniewski et al. in press; Bobak and Poltowicz-Bobak, in press). In addition, applications of relatively new methodological approaches for the field were presented, such as microstratigraphy, isotopic studies or GIS analyses (see Skrzypek et al. 2011). In total, nine presentations raised questions about chronological accuracy in the context of terrestrial and marine data as well as chronostratigraphy from the view-point of archeology (e.g. Fig 1; Wiśniewski, University of Wrocław; Bobak, University of Rzeszów) and sedimentology (Lisa, Institute of Geology, Academy of Sciences of the Czech Republic; Kalicky, University of Kielce), subsistence strategies in the context of environmental changes (Łanczont, University of Lublin; Madeyska, Polish Academy of Science; Warszawa, Połtowicz-Bobak, University of Rzeszów; e.g. Boguckyj et al. 2009, Sytnyk et al. 2012) and on the paleozoological records of environmental change (Nadachowski, Polish Academy of Sciences; Kraków, University of Wrocław; Nadachowski 2011). Finally, Iwona Hildebrant-Radke (Mickiewicz University Poznań) presented new methodological aspects for the use of GIS in geoarcheological investigations (Jasiewicz and Hildebrand-Radke 2009). The presentations were followed by plenary discussions.

The major outcomes from the meeting in Poznań are plans for a new co-operation, especially within the scope of the study of the Late Paleolithic in the historical region of Silesia. One example is the transfer of methodological knowledge between institutes from the Czech Republic and Poland. The participants agreed to build a network for sharing such information. Until now, the exchange of knowledge between the Polish and Czech groups was rather scant and it was decided that an important step to improve it would be to designate a contact person in each country who will share the information about forthcoming meetings. The contact persons for the Polish part are Katarzyna Issmer and Andrzej Wiśniewski. The contact person on the Czech side is Lenka Lisa. Another approach to facilitate communication in the scientific community is the creation of two virtual groups on the social network Facebook with the title "Quaternary Group" (www.facebook.com/#!/groups/253485648040066/) and "Zooarchaeology and Paleonthology" (www.facebook.com/#!/groups/paleontologie/). Also, a scientific platform for Central Europe was set up (http://geoinfo.amu.edu.pl/sas/en/egp/index.php).

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