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2k network FAQ

Additional information to accompany:

"Continental-scale temperature variability during the last two millennia"

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Contact information

Corresponding author
Darrell S. Kaufman
School of Earth Sciences and Environmental Sustainability
Northern Arizona University
USA
+1 928 523 7192
darrell.kaufman@nau.edu

PAGES Executive Director
Thorsten Kiefer
PAGES International Project Office
Zähringerstrasse 25
3012 Bern
Switzerland
+41 31 631 56 08
kiefer@pages.unibe.ch

German language contacts
Heinz Wanner
Oeschger Center for Climate Change Research
Zähringerstrasse 25
3012 Bern

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Switzerland
+41 31 631 88 59
heinz.wanner@oeschger.unibe.ch

Eduardo Zorita
Institute for Coastal Research
Helmholtz-Zentrum Geesthacht
Max-Planck-Str. 1
21502 Geesthacht
Germany
+49 41 5287 1856
eduardo.zorita@hzg.de

French language contacts

Hugues Goosse
Université catholique de Louvain
Centre de recherches sur la terre et le climat Georges Lemaître
Place Louis Pasteur, 3, boite L4.03.08
1348 Louvain-la-NeuveBelgique
+32 1047 3298
hugues.goosse@uclouvain.be

Valérie Masson-Delmotte
Laboratoire des Sciences du Climat et de l'Environnement
CEA Saclay
91 191 Gif-sur-Yvette cédex
France
+33 16 908 7715
valerie.masson@lsce.ipsl.fr

Spanish language contacts

J Fidel Gonzales-Rouco
Dpto. Astrofisica y CC. de la Atmosfera / Instituto de Geociencias (UCM-CSIC)
Universidad Complutense de Madrid
28040 Madrid
Spain
+34 91 394 4468
fidelgr@ucm.es

Ricardo Villalba
Instituto Argentino de Nivología, Glaciología y Ciencias Ambientales (IANIGLA)
CCT-CONICET-Mendoza
C.C. 330, (5500) Mendoza
Argentina

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+54 261 524 4237
ricardo@mendoza-conicet.gob.ar

Japanese language contact
Takeshi Nakatsuka
Graduate School of Environmental Studies
Nagoya University, Furo-cho
Chikusa-ku, Nagoya 464-8601
Japan
+81-52-789-3467
nakatsuka.takeshi@f.mbox.nagoya-u.ac.jp

Chinese language contact
Quansheng Ge
Institute of Geographical Sciences and Natural Resources Research
Chinese Academy of Sciences
11A Da Tun Road
An Wai, Beijing, 100101
China
+86-10-64889499
geqs@igsnrr.ac.cn

Russian language contact
Olga Solomina
Institute of Geography RAS
Staromonetny-29
Moscow 119017
Russia
+7-495-959-00-34
olgasolomina@yandex.ru

Hindi language contact
Thamban Meloth
National Centre for Antarctic & Ocean Research
Headland Sada, Vasco-da-Gama
Goa 403 804
India
+91-832-2525622
meloth@ncaor.org

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Pages consortium authors

Moinuddin Ahmed, Kevin J. Anchukaitis, Asfawossen Asrat, Hemant P. Borgaonkar, Martina Braida, Brendan M. Buckley, Ulf Büntgen, Brian M. Chase, Duncan A. Christie, Edward R. Cook, Mark A. J. Curran, Henry F. Diaz, Jan Esper, Ze-Xin Fan, Narayan P. Gaire, Quansheng Ge, Joëlle Gergis, J. Fidel González-Rouco, Hugues Goosse, Stefan W. Grab, Rochelle Graham, Nicholas Graham, Martin Grosjean, Sami T. Hanhijärvi, Darrell S. Kaufman, Thorsten Kiefer, Katsuhiko Kimura, Atte A. Korhola, Paul J. Krusic, Antonio Lara, Anne-Marie Lézine, Fredrik C. Ljungqvist, Andrew M. Lorrey, Jürg Luterbacher, Valérie Masson-Delmotte, Danny McCarroll, Joseph R. McConnell, Nicholas P. McKay, Mariano S. Morales, Andrew D. Moy, Robert Mulvaney, Ignacio A. Mundo, Takeshi Nakatsuka, David J. Nash, Raphael Neukom, Sharon E. Nicholson, Hans Oerter, Jonathan G. Palmer, Steven J. Phipps, Maria R. Prieto, Andres Rivera, Masaki Sano, Mirko Severi, Timothy M. Shanahan, Xuemei Shao, Feng Shi, Michael Sigl, Jason E. Smerdon, Olga N. Solomina, Eric J. Steig, Barbara Stenni, Meloth Thamban, Valerie Trouet, Chris S.M. Turney, Mohammed Umer, Tas van Ommen, Dirk Verschuren, Andre E. Viau, Ricardo Villalba, Bo M. Vinther, Lucien von Gunten, Sebastian Wagner, Eugene R. Wahl, Heinz Wanner, Johannes P. Werner, James W.C. White, Koh Yasue, Eduardo Zorita

Link to study data

All of the data used for the continental-scale temperature reconstructions are available for download through the NOAA Paleoclimatology website: www.ncdc.noaa.gov/paleo/paleo.html

Press releases

> 2k consortium press release (English, 16 April 2013)

> University of Bern (Switzerland) press release (German, 16 April 2013)

> 2k consortium press release (French, 16 April 2013)

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Images

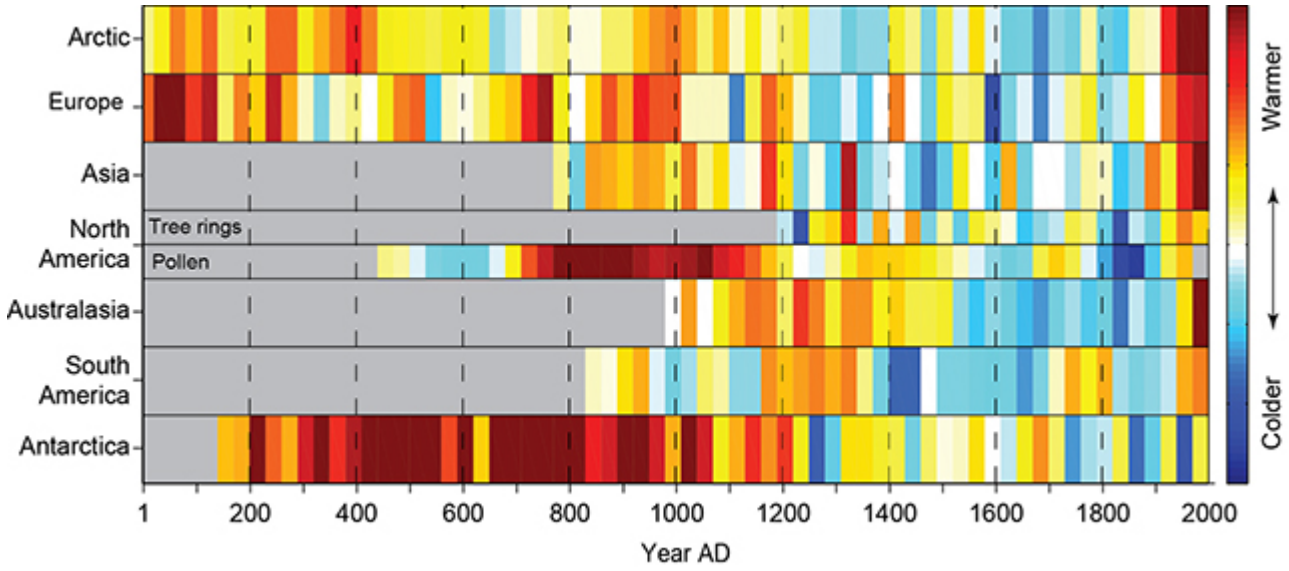

Figure description: Thirty-year mean temperatures for the seven PAGES 2k continental-scale regions arranged vertically from north to south. Colors indicate the relative temperature. The most prominent feature of nearly all of the regional temperature reconstructions is the long-term cooling, which ended late in the19th century. North America includes a shorter tree-ring-based and a longer pollen-based reconstruction. Modified from: PAGES 2k Consortium, 2013, Continental-scale temperature variability during the past two millennia, *Nature Geoscience*,

Photographs are available on the online FAQ page only:
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Frequently Asked Questions (FAQ)

What are the primary conclusions of the study?

(1) The most coherent feature in nearly all of the regional temperature reconstructions is a long-term cooling trend, which ended late in the 19th century.

- The regional rate of cooling varied between about 0.1 and 0.3°C per 1000 years.

- A preliminary analysis using a climate model indicates that the overall cooling was caused by a combination of decreased solar irradiance and increased volcanic activity, as well as changes in land cover and slow changes in the Earth's orbit. The simulations show that the relative importance of each factor differs between regions.

(2) Temperatures did not fluctuate uniformly among all regions at multi-decadal to centennial scales. For example, there were no globally synchronous multi-decadal warm or cold intervals that define a worldwide Medieval Warm Period or Little Ice Age.

- The period from around 830 to 1100 CE generally encompassed a sustained warm interval in all four Northern Hemisphere regions. In contrast, in South America and Australasia, a sustained warm period occurred later, from around 1160 to 1370 CE.

- The transition to colder regional climates between 1200 and 1500 CE is evident earlier in the Arctic, Europe and Asia than in North America or the Southern Hemisphere.

- By around 1580 CE all regions except Antarctica entered a protracted, multi-centennial cold period, which prevailed until late in the 19th century.

- Cooler 30-year periods between the years 830 and 1910 CE were particularly pronounced during times of weak solar activity and strong tropical volcanic eruptions. Both phenomena often occurred simultaneously. This demonstrates how temperature changes over large regions are related to changes in climate-forcing mechanisms. Future climate can be expected to respond to such forcings in similar ways.

(3) The 20th century ranked as the warmest or nearly the warmest century in all regions except Antarctica. During the last 30-year period in the reconstructions (1971-2000 CE), the average reconstructed temperature among all of the regions was likely higher than anytime in nearly 1400 years. However, some regions experienced 30-year intervals that were warmer than 1971-2000. In Europe, for example, the average temperature between 21 and 80 CE was warmer than during 1971-2000.

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What is new about the study?

Our study is the most comprehensive evaluation to date of temperature change at the surface of Earth's continents over the past one to two thousand years.

Previous studies have focused on hemispheric or global-scale temperature reconstructions, which are useful for understanding overall average conditions, but overlook important differences at the continental scale.

Temperature reconstructions from Antarctica, Australasia and South America clarify the temperature history for Southern Hemisphere continents.

The consortium of authors comprises 78 regional experts from 24 countries. The authors are familiar with the proxy temperature records from individual sites and how they relate to the climate of that region.

All of the data for the 511 individual proxy temperature records that were used for the continental-scale reconstructions, including some that extend back 2000 years, have been assembled for public release in a uniform format for future analyses.

Why is it important to know about regional temperature changes during the past few thousand years?

Investigating the patterns of past climate variability over space and time helps to understand and quantify the processes that cause climate to change, which is important as we prepare for the full range of future climate changes due to both anthropogenic and natural factors.

Climate varies naturally on long time scales. Centennial and longer time scales are beyond the time frame covered by instrumental measurements. Natural archives offer indirect (proxy) records of past climate variability, which can be tapped to extract information about past climate changes.

The last two thousand years are a key period because, earlier than that, the amount of information about climate variability decreases and fundamental aspects of the climate system diverge from more recent conditions. The last two thousand years is relatively well represented by proxy data in many places.

More advanced answers

Analyzing the response of climate to factors that caused it to change ("climate forcings") provides essential information about feedback processes that amplify or dampen the changes in climate at regional

scales. These feedbacks will likely play a role in future changes due to natural variability and anthropogenic impacts.

Whereas the average temperature of the Earth's surface indicates changes in the global energy budget (radiative perturbations and ocean heat uptake/release), regional temperatures provide information about heat redistribution by ocean and atmosphere dynamics.

During the past 2000 years, natural external perturbations acted on the Earth's climate: slow changes in the Earth's orbit redistributed the incoming solar radiation; fluctuations in solar activity affected incoming radiation; major volcanic eruptions injected aerosols, which also influenced the radiation budget. More recently, new perturbations have emerged from human activities, with changes in the atmospheric load of aerosols and greenhouse gases. The dynamics of the atmosphere, ocean, cryosphere, and biosphere also generate variability, called "internal variability", which, combined with the climate response to external perturbations, causes climate variability on timescales ranging from days (weather events) to seasons, years, decades, centuries and longer.

How does this study contribute to understanding the future earth?

Climate change at the regional to local scale is more relevant to people and ecosystems than are globally averaged conditions. Reconstructing past regional climate variability can inform us about the regional expressions of climate change and the impacts of climate change on ecosystems and societies.

Future climate projections focus on the influence of human factors, especially the build-up of greenhouse gasses. However, future climate will also be influenced by natural factors, and it will be complicated by internal variability within the climate system. Climate model projections can be improved by accounting for both anthropogenic and natural factors.

What type of evidence was used to infer past temperatures?

The PAGES 2k dataset includes 511 individual time series from natural archives that reflect temperature changes through various biological and physical processes. Most of the information comes from tree-ring measurements, but additional evidence comes from glacier ice, speleothems, sediments from lake and ocean bottoms, and historical documents in Europe. The individual records used in the temperature reconstructions in this synthesis were available through the scientific literature or online databanks.

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How were the temperature reconstructions created?

Each regional group identified the currently available proxy climate records that they found best suited for reconstructing temperature variability within their region. Most of the regional groups used either a scaling approach to adjust the mean and variance of a composite of the proxy records to an instrumental target (based on data from thermometers during the 20th century), or a regression-based technique to extract a common signal from the proxy data. The mathematical procedures that were used are presented in the 54-page Supplementary Information that was published along with the article.

What are the "alternative reconstructions" and "site-level analyses" and why were these included?

In addition to the reconstructions generated by each of the regional PAGES 2k groups, we applied uniform mathematical procedures to the same proxy data to generate three additional reconstructions from each region. The reconstructions using different approaches are similar and they generally support the primary conclusions of the study. As described in the Supplementary Information, these include a (1) new pairwise comparison, (2) Bayesian hierarchical model, and (3) basic non-calibrated composite.

In addition, each of the records used in the continental temperature reconstructions were analyzed separately at the site level, and without assumptions about the relation with regional temperatures, to determine the extent to which some of the primary conclusions are robust. The results show that the long-term cooling trend and recent warming are predominant features of the site-level records; however, a sizable fraction of the records do not conform to the overall average, highlighting the importance of spatial variability at the continental scale.

How were uncertainties accounted for in the temperature reconstructions?

Measuring proxy values, placing them on a timescale, integrating records from unevenly distributed sites, and converting them to temperature all involve uncertainties. Each of the PAGES 2k Network groups used somewhat different approaches to estimate the uncertainty in the reconstructed temperature (as described in the Supplementary Information). The synthesis does not formally address these uncertainties, focusing instead primarily on the best (expected-value) estimates of temperature. In addition, some of the analyses circumvent most sources of uncertainty. For example, the site-level analysis of individual records assumes only that the proxies are sensitive to temperature.

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Is there independent evidence that the temperature reconstructions are accurate?

One of the primary features of nearly all of the continental-scale temperature reconstructions is the long-term cooling trend prior to the 20th century. An overall cooling trend has also been detected in other global-scale proxy temperature reconstructions, including two that are primarily based on evidence from marine sediment (Marcott et al., 2013, Science v339: 1198; PAGES/Ocean2k Working Group, 2012, Abstract PP11F-07, American Geophysical Union).

Another primary feature of the temperature reconstructions is the recent warming in all regions except Antarctica. Other evidence also shows broad-scale warming during the 20th century, including the widespread retreat of glaciers and shifts in the temperature profiles measured in boreholes.

At the multi-decadal scale, average temperatures across the regions generally cooled in concert with increased volcanic eruptions and decreased solar activity, as determined by independent evidence.

A recent study has confirmed that proxy records are able to reproduce observed changes in the global climate over the past 130 years (Anderson et al., 2013, Geophysical Research Letters v40: 189). The proxy time series is strongly correlated with globally averaged temperature as measured by thermometers.

What are the main limitations of the study?

The temperature reconstructions are based on inferences made from natural archives that store information about past climate (such as tree rings), but are not thermometers per se. Translating proxy evidence to past temperatures involves making important assumptions. For instance, we assume that the relation between temperature and the proxy record that existed during the instrumental period is the same as that which existed during pre-historic time.

Large uncertainties about past temperature variability remain, especially during the first millennium when only some regions are represented. In Africa, there are currently too few records to make a reliable continental-scale temperature reconstruction.

Some of the reconstructions focus on summer conditions and others on annual averages. The two can be somewhat different, although they are correlated in meteorological records from our regions.

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Have all of the reconstructions in the article been published previously?

No. The synthesis represents a snapshot of constantly progressing efforts, some more recent than others. The data selection and reconstruction methods used for all of the regional reconstructions are discussed in the 54-page Supplementary Information. This was peer-reviewed along with the primary manuscript, and reviewers were given access to the entire dataset. In addition to the reconstructions generated by each regional group, the study includes three additional reconstructions for each region, and an analysis of all individual records at the site level. These are new to this synthesis (see above).

Why was the study published as a "progress article"?

Nature Geoscience considers a "progress article" a type of review paper. Our synthesis builds on a large body of available data and involves a large group of regional experts. The new PAGES 2k database will no doubt be analyzed using alternative approaches that will reveal additional patterns and address further research questions. For example all reconstructions, except for North America, are resolved at annual scale, but our study of the most prominent trends only considers averages over 30-year periods.

What are the next steps for the project?

PAGES 2k regional groups are continuing to assemble proxy climate data as new records are constantly published. They are exploring proxy records that attest to changes in precipitation and other aspects of climate.

The reconstructions presented in this study are dominated by evidence from tree rings. The PAGES 2k Network aims to expand the reconstructions in space and time by further including other types of proxy records, such as those from lake sediments and speleothems.

Our synthesis only considered the major features of the new temperature reconstructions by averaging them over 30-year intervals. Annual-scale patterns have not yet been explored in the temperature reconstructions.

Our reconstructions and proxy-data compilation will be useful in future studies, including as a benchmark for comparisons with climate-model simulations.

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How does this study compare with the similar study by Marcott et al. that was recently published by *Science*?

The most recent study to use proxy evidence to reconstruct long-term temperature was that of Marcott and co-authors (Science v339: 1198). They reconstructed the average global temperature back over 11,000 years by focusing mostly on proxy records from marine sediments, which are generally resolved at centennial scale, and which can be problematic near the sediment-water interface. In contrast, our study reconstructed temperature using non-marine records (mostly) at the continental scale. It focuses on the last one or two thousand years at higher temporal resolution (annual for most reconstructions and 30-year-average intervals in the synthesis study).

When averaged among the continental-scale regions, the long-term cooling trend prior to the 20th century detected in our study agrees with the global cooling trend reconstructed by Marcott and co-authors

Marcott and co-authors included a comparison between their long-term temperature reconstruction and the instrumental data, including those of the last decade (2000-2010), as well as future climate projections, whereas we focus on proxy-based reconstructions.

Why don't the temperature reconstructions extend up to the present?

Many of the proxy records used in the reconstructions were generated some years ago and end before the year 2000. The reconstruction for North America, Asia and South America do not extend to the 21st century. The instrumental record shows that the last several decades have generally been warmer than previous decades. Therefore, the most recent 30-year period in our analysis (1971-2000) underestimates the actual temperature of the last 30 years.

Are the new temperature reconstructions independent of those developed by Michael Mann and co-authors?

We are still analyzing the extent to which the PAGES 2k database overlaps with previously published global data collections. On the basis of our current assessment, about 360 of our 511 records were not used in the reconstruction of Mann et al. (2008, 2009), and about 35 are updated versions of the records included in their dataset.

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Do the reconstructions attest to the unusualness of late 20th-century temperatures?

The temperature averaged across the seven continental-scale regions indicates that 1971-2000 was warmer than anytime in nearly 1400 years, keeping in mind that this analysis focuses on the best average estimated temperatures and does not consider the uncertainty associated with the temperature estimates, and also that the reconstructions are different lengths.

The increase in average temperature between the 19th and 20th centuries exceeded the temperature difference between all other consecutive centuries in each region, except Antarctica and South America.

The results show that some regions were likely warmer during some decades of the medieval period and Roman times than they were in 1971-2000. Does this suggest that recent warming is part of a natural cycle?

Determining the extent to which recent temperature changes are unusual is different than ascribing them to natural or anthropogenic causes. Because temperatures have been higher during past periods of Earth's history does not imply that humans activities are not presently influencing climate.

The global warming that occurred in the 20th century reversed a long-term global cooling trend. This pre-industrial cooling trend was likely caused by natural factors that continued to operate through the 20th century, making the 20th century warming more difficult to explain without the likely impact of increased greenhouse gasses.

Does the study indicate that humans are the cause of recent warming?

The study was not designed to assess the extent to which temperature change can be attributed to different natural and human-caused factors. That is the domain of "attribution studies", which use specific methods to identify the climate response to each type of climate forcing.

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What is the origin of this large group project?

This project was initiated and coordinated by PAGES, which was established in 1991 through the International Geosphere Biosphere Programme (IGBP) to facilitate international research into understanding climatic and environmental dynamics by studying the past.

The PAGES 2k Network was initiated in 2006 with the goal of compiling and analyzing a global array of regional climate reconstructions for the last 2000 years. The Network includes nine working groups, which represent eight continental-scale regions and the oceans. Group membership and meetings are open to all interested participants. The authors of the article volunteered their time and effort. Further information about the PAGES 2k Network can be found at: http://www.pages-igbp.org/workinggroups/2k-network

What is the relation between this study and the report of the Intergovernmental Panel on Climate Change (IPCC)?

The IPCC periodically reports on the current knowledge of the scientific community. Their assessment is based on the full breadth of the published literature. We hope that our study will be among those to be considered by the IPCC in its Fifth Assessment Report (AR5), which is due for publication in late 2013 and 2014.

Authors for IPCC reports are active researchers in their field. Accordingly, some of the PAGES 2k Consortium authors are also contributing to the AR5. The fourth IPCC Assessment Report published in 2007 revealed a lack of regional-scale climate information beyond the instrumental period. The PAGES 2k Consortium therefore aimed to make its first synthesis of continental temperature reconstructions available to the IPCC by meeting the publication deadlines for AR5. Nevertheless, the IPCC independently assesses all published information and decides how to prioritize whatever material it finds most relevant. IPCC reports are controlled by an extensive peer-review process.

Where are the data?

All of the data used for the continental-scale reconstructions are tabulated in a user-friendly format and available for download through the NOAA Paleoclimatology website: www.ncdc.noaa.gov/paleo/paleo.html. Any future corrections will be updated on the version at NOAA Paleoclimatology.