Web 2.0 Collaborations Address Uncertainty in Climate Reconstructions of the Past Millennium

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Abstract

Reducing uncertainty in global temperature reconstructions of the past millennium remains the key issue in applying this record to society's pressing climate change problem. Reconstructions are collaborative, built on the research of hundreds of scientists who apply their diverse scientific expertise and field and laboratory skill to create the individual proxy reconstructions that underlie the multi-proxy, global average temperature time series. Web 2.0 features have enabled collaborative efforts that improve the characterization of uncertainty. Raw data shared via a repository (the World Data Center for Paleoclimatology) enable new reconstructions from the collection of user-generated data. Standards propagated by expert communities facilitate quality control and interoperability. Open access to data and computer code promote transparency and make the science accessible to a broader audience. Blogs, wikis, and listservs share background information and highlight contentious as well as unique aspects of paleo science. A novel approach now underway, titled the Paleoclimate Reconstruction Challenge, and based on the sharing of simulated data (pseudo-proxies) and reconstruction results, seeks to facilitate method development, further reducing uncertainty. Broadly-useful aspects of the Challenge may find application in other fields.

Introduction

The instrumental (thermometer-based) record of Earth temperature extends back to approximately 1880 (Smith et al. 2008). Prior to this time, the temperature must be reconstructed from proxy evidence including tree rings, ice cores, ocean and lake sediments, corals, cave deposits, and other natural archives. The key issue in utilizing

proxy information is to understand the uncertainty of the proxy evidence. The aim is to characterize uncertainty sufficiently that natural variations and long-term trends can be identified in the period prior to human influence. Characterizing uncertainty transcends basic science, for societies require credible information about past variability and trends in order to make decisions regarding anthropogenic climate change. Principle ways to understand and characterize the uncertainty are to 1) obtain evidence from different sources (termed multi-proxy reconstructions), 2) average multiple observations from the same source, and 3) to employ different statistical methods and calibration techniques. All strategies are facilitated by Web 2.0 technologies that enable data sharing and scientific collaboration.

Web 2.0 solutions (DiNucci 1999) provide the collaborative platform that enabled the initial multi-site, multi-proxy climate reconstructions, and more recently enable debate and the characterization of uncertainty. The initial multi-site reconstructions (Mann et al. 1998) were based on time series accumulated in a publically accessible long-term archive, the World Data Center for Paleoclimatology (Anderson et al. 2011). In the decade following the initial multi-proxy reconstruction, additional time series were contributed and subsequent reconstructions have been produced based on the accumulated archive. The reconstructions have been shared, fostering comparison, debate, and analysis of uncertainty. As this two-way sharing of data expanded, listservs and blogs became active venues for debates on data quality, methods, and uncertainty; and also became valuable sources of information. Social bookmarking augmented the older FTP-style data sharing, and on the World Data Center for Paleoclimatology web site a share button now lets one tweet or email data set URLs. In the following sections

we describe the data sharing that enabled the initial reconstructions, describe how Web 2.0 technologies have been used to address uncertainty, articulate the value of listservs and blogs and wikis, and conclude by describing a bold international collaboration aimed at improving methods and reducing uncertainty.

Sharing Data Enables Climate Reconstruction

Several aspects contributed towards creating a publically-accessible archive of proxy information that could be used for global reconstructions and synthesis. Adoption of a format standard for tree rings, the 'decadal format' (Grissino-Mayer 2001), enabled a large number of time series to be analyzed. Computer code to process the raw data into time series (Arstan) was shared, along with code to quality-control the data (Cofecha) (Holmes 1983; Grissino-Mayer 2001). Essentially the community collaborated to share data and code, producing a high-quality dataset amenable to synthesis. Experts in other domains (e.g., corals, ice cores), while not following the common-format/common-software protocol established by dendrochronologists, contributed their own time series to the archive. These experts loosely embraced the convention to archive both raw data and reconstructions of climate variables derived from the raw data, expanded the archive across multiple proxies, and created a framework where calibrations and quality could be assessed. By 1993 the archive contained hundreds of reconstructions, based on a dozen different proxies (Webb et al. 1993). Several multi-proxy reconstructions were published, and in 1998 a watershed paper using 112 time series was published, describing global-scale temperature patterns over the past six centuries (Mann et al. 1998). Since that time, hundreds of additional time series have been contributed to the archive, and

dozens of reconstructions have been produced, most based on partly overlapping sets of the raw data, and employing different methods and assumptions (Wahl et al. 2010). In early 2011 the World Data Center for Paleoclimatology contained 8059 data sets (not all relevant to the last millennium), and additional Paleoclimate data are available from other repositories (PANGAEA 2011; Grimm 2011). Millennium temperature reconstructions appeared in the IPCC reports in 2001 and 2007 (IPCC 2001, 2007).

Paleoclimate reconstructions require the integration of different types of information from a globally-distributed array of sites, and this too is facilitated by data sharing. No single researcher has the experience or the geographic access needed to collect all of these records. Experts in high-altitude/ high-latitude ice coring, SCUBA-assisted drilling of corals, spelunking, and forestry collected records in extreme environments spanning the globe (PAGES 2011b). The archive development at the World Data Center tapped diverse scientific talent and expertise, pooling knowledge ranging from forestry to glaciology in interpreting raw data to produce meaningful climate-relevant time series (Anderson et al. 2011). International data compilation activities have been organized and sanctioned by the Past Global Changes Program, and many of these programs have their own collaborative web sites and procedures to share data. For example, pollen collections are developed by the Global Pollen Database (Gajewski 2010), the European Pollen Database (Bradshaw and Andrieu-Ponel 2011), and the North American Pollen Database (Grimm 2000). Regional reconstructions of the last two millennia are organized by PAGES (PAGES 2011a).

Examining the limitations of this collaboration two issues stand out. One is the immature development of many proxies when compared to the tree ring proxy (NRC

2006). Relative ease in producing individual ring-width series led to massive replication (chronologies are typically based on a dozen or more series) and cross-dating (comparison of events among individual series, which reduces the age uncertainty) (Grissino-Mayer 2001). The standard format and shared software yielded a high-quality data set. In contrast, almost all other proxy records are more difficult to obtain and are rarely replicated (Bradley 1999). Often because of time constraints or the limitations of the sample material, many proxies are sampled less frequently than one sample per year potentially aliasing the time series and contributing to age uncertainty.

Another issue is the perception that data and code are not freely available, an issue amenable to Web 2.0 solutions. In 2007 the Government Accountability Office issued a report describing the data sharing policies for federally-funded climate change research and noted that 'more could be done to enhance the availability of data' (Government Accountability Office 2007). McIntyre and McItrick (McIntyre and McKitrick 2003) criticized the archived data related to the Mann, Bradley, and Hughes (19898) paper, and Mann et al. subsequently updated the publically available data, describing the changes in a Corrigendum (Mann et al. 2004). These criticisms, and subsequent changes were facilitated by the Internet availability of data and the update capability of long-term archives. The availability of computer code has also been criticized (McIntyre and McKitrick 2005). The distribution of open-source packages for the R programming language is one way that code is being more freely shared (The R Project for Statistical Computing 2011), and R code for reconstructions sometimes appear on web sites (Wahl 2010; Ammann 2006). By facilitating the sharing of data and code, Web 2.0 solutions are addressing a perceived problem in climate change research.

Uncertainty Characterized Using Web 2.0 Technologies

The uncertainty of millennium temperature reconstructions has become better characterized through Web 2.0 collaborations. These improvements, while not necessarily yielding a decrease in uncertainty measured in degrees Celsius, have provided increasingly quantitative, meaningful improvements in how uncertainty is characterized. Uncertainty was unconstrained in the early reconstructions (Lamb 1988) described in the First Assessment Report (IPCC 1990). Ten years later, the development of reconstructions based on multiple sites (obtained from data archives) allowed uncertainty to be displayed as the two-standard deviation error (Fig. 1) (Mann et al. 1998). In the following decade, as more reconstructions were published, sharing of the time series led to the 'spaghetti graphs' visually showing the agreements and disagreements among different reconstructions (Fig. 2) (Jansen et al. 2007). Quantifying the agreement among reconstructions, the 2007 report showed for the first time the percent overlap among different reconstructions (Fig. 2). While there is substantial variation among the time series from one decade to the next, and differences in the decadal variability, the overall agreement shown in Figure 2 has been interpreted to indicate confidence in the unprecedented warming of the 20th century, the presence of a cool period (the Little Ice Age) between 1450 and 1900 AD, and the presence of warmer temperatures prior to the Little Ice Age, particularly around the turn of the first millennium (950-1100AD) (IPCC 2007). The question of whether the Medieval Warm Period had temperatures warmer than present remains debated, partly because there are fewer time series during this older interval and partly because the percentage of agreement is not as great (NRC 2006).

Current efforts to reduce uncertainty seek to identify the variability within ensembles of multiple reconstructions. Well-specified mathematical models of the processes involved lead to explicit probabilistic ensembles of reconstructions from which true probability percent-intervals can be derived for both the mean estimate and for estimates of variability. Such a true probabilistic outcome stands in contrast to confidence intervals that only apply to where the mean estimate might lie. This approach can also benefit from Web collaborations because the ensembles can be readily shared and incorporated into more complex reconstruction models that combine the ensembles using statistical post-processing techniques (Ohlwein and Wahl in press). Finally, web collaborations can also lead to continuously improved modeling of the fundamental processes and probabilistic nature of reconstructions, and thus additionally improved ensemble generation.

Listerservs, blogs, wikis Support Debate, Information Sharing

Listservs and blogs have become increasingly active, both as sources of information and debate for contentious issues. Without attempting to be comprehensive, a few examples are described here to show the breadth of activity and the types of issues being debated.

Paleoclimate data are used for more than just temperature reconstructions, and a listserv provides a means for scientists to cross boundaries and tap foreign expertise. One interesting application of dendrochronology involves dating. Ring-width series can be developed from building timbers, and dates established when unique features of the series can be associated with a master chronology. Of course, this approach to dating requires

access to a master chronology, the subject of this February 7, 20011 post to the ITRDB Dendrochronology Forum: *Hello Dendro-Forum, I'm working on the Basilica of the Nativity in Bethlehem, with my colleagues of the CNR-IVALSA. Currently we are trying to date the roof dendrochronologically. We found many different species: cedar, oak, pine, cypress and we already have interesting results that I hope to publish somewhere, in the near future. But the real problem now is dating the oak (section Quercus petraea). The church is probably one of the oldest in the entire Holy Land. During the time of the Crusades, it escaped destruction by the Muslims because Jesus' birthplace was considered sacred also in the Islamic religion. Hence, over many centuries, there have been interventions of restoration in the Basilica by many people of different origins: the King of England, the Duke of Burgundy, Venetians, Mamluks, Greeks, Turks, Armenians. I built a 315-year oak chronology for the church that is well-replicated, and whose samples demonstrate high values of statistical correlation with each other. But the question now is: is there some laboratory out there that would be interested in checking my Basilica oak chronology against its own (or other available) oak master chronologies that should be valid for Europe or the Near-East, covering a period of at least the last 2000 years? Obviously, any useful master will be cited in our final report. Furthermore, even if you don't have any long oak master, any suggestions about the origin of oak wood in that area would be very much appreciated.* Collaborative forums such as the ITRDB allow the application of the data to communities far beyond the climate reconstruction community.

Another example of the listserv as a forum for collaboration involves sharing information about meetings, for example this call for abstracts for a meeting session on

millennium reconstructions that appeared on August 26, 2010, on Paleoclimate-list: *The Fall AGU meeting is approaching (December 13-17), and with it the impending deadline of abstract submission (September 2nd). We would like to draw your attention to session PP04: 'The Climate of the Common Era', to which we invite papers on all aspects and approaches to the study of the climate of the last two thousand years.*

Blogs are being used to broadcast opinion and discovery, and also to criticize data quality and methods. Arguably the most controversial aspect of the climate change debate regards the accuracy of the 'hockey stick' reconstruction (NRC 2006). Posts to climateaudit.org, and to realclimate.org explain aspects of the debate.

This post, from climateaudit.org (FAQ 2005), identifies problems with the Mann, et al. study: *The present articles build on the first article. In that article, we pointed out that there were serious problems with the data set in MBH98 and, in particular, with the tree ring principal component series. We also showed that quite different results could be obtained for the 15th century under reasonable assumptions using the MBH98 method. Since then, and largely because of the effect of the original article, a great deal of new information about MBH98 has been made available. In July 2004, at the direction of Nature, Mann et al. published a Corrigendum, which included a voluminous archive on data and methods used in MBH98.*

A post to realclimate.org (July 22, 2010) defends aspects of the reconstruction: *As a great deal of other research has shown, you can even reconstruct past temperature without bristlecone pine tree rings, or without any tree ring data at all, resulting in: a hockey stick. It also shows, consistently, that nobody is trying to "get rid of the medieval warm period" or "flatten out the little ice age" since those are features of all*

reconstructions of the last 1000 to 2000 years. What paleoclimate researchers are trying to do is make objective estimates of how warm and how cold those past centuries were. The consistent answer is, not as warm as the last century and not nearly as warm as right now.

Blogs also extend the discussion to non-research scientists, as this post to climateaudit.org (March 3, 2010) relates: *I am not a researcher. I am an ordinary citizen who wants to learn the facts for himself. I teach high school chemistry in the United States. Can you please explain to me why the Bristle cone pine is a bad proxy for temperature?*

Wiki technology provides a way to share knowledge outside the realm of peer-reviewed publications. The Wikipedia entry for Paleoclimatology (Wikipedia Contributors 2011b) is noteworthy because it integrates information across many of the traditional sub-discpline boundaries within the field of paleoclimatology. The page integrates information from 'deep time' (millions of years before present) with shorter time periods (thousands of years before present), and integrates information from different proxies. In contrast, the Wikipedia entry for dendroclimatology (Wikipedia Contributors 2011a) is narrowly focused in geologic time and breadth of the topics described.

Paleoclimate Reconstruction Challenge

The last two millennia Paleoclimate Reconstruction Challenge ("PR Challenge") is designed to engage the scientific paleoclimate community in examining its methods in a common framework for the purpose of evaluating their relative strengths and weaknesses

(Ammann 2008). A key portion of the PR Challenge design is to allow true "apples to apples" comparison of methods across identical experimental platforms, with the ultimate goal to identify ways to improve last two millennia PR methods more generally, including improved characterization of reconstruction uncertainties.

The PR Challenge is organized around four primary themes: 1) reconstruction of Northern Hemisphere (NH) annual mean temperatures using a very limited set of "proxy" climate information (e.g., annual tree growth or the oxygen isotope composition of ice); 2) reconstruction of both the NH mean and spatial climate patterns from a more extensive proxy data set concentrated north of 40 degrees latitude; 3) reconstruction of both the NH mean and spatial climate patterns from a global proxy data set; and 4) reconstruction of regional drought patterns from corresponding regional proxy data. For each theme, a set of long global climate model (GCM) runs is used to develop simulated proxy and instrumental target data for the reconstruction exercises. Working in such a simulation environment allows the target information to be known for over 1,000 years, increasing the time span over which reconstruction fidelity can be examined by up to ten times in comparison to real-world reconstructions. A number of GCM runs are used in each case, to present a range of simulated climate evolutions that present different reconstruction challenges. Collaborators include climate modelers who produce simulated series, proxy experts who produce reconstructions, and statisticians who compare methodologies and develop new methods that can be used in the Challenge framework.

The PR Challenge themes represent four key scientific challenges in last two millennia climatology. The PR Challenge is the first time that exactly common data sets are widely available to the scientific community across these areas to enable systematic

comparison of the variety of methods that have been developed to address them. Descriptions of the methodologies employed, along with computer code used to implement them, will also be made available with the reconstructions, with the goal to increase the speed of method development as has been noticed in other fields of science in which code sharing has become commonplace. Workflow for the project embodies the Web 2.0 experience: a small expert team will publish data on the Challenge website (Graham et al. 2011), and the data will be downloaded by many teams. Teams will create reconstructions and place them back on the Challenge website for comparison and analysis by others. Verification and skill metrics will also be posted, providing the primary forum to judge reconstruction success. Data Stewardship including the development of metadata and long-term preservation ensures that the process will be documented, transparent, available to a broad audience, and provide a basis for future efforts.

Figures

Figure 1. Reconstruction of the global temperature anomaly for the last 600 years from multiple proxies (Mann et al. 1998). The reconstruction was based on 112 individual proxy time series. Many of the tree ring time series were contributed to the International Tree Ring Data Bank (Bauer 2011). Uncertainty indicated by two standard deviations (dashed lines).

Figure 2. 'Spaghetti diagram' showing different reconstructions, and the percent of overlap among the reconstructions. This figure appeared in the Intergovernmental Panel

on Climate Change Working Group 1 Report, 2007 as Figure 6.10 with the following caption: Records of NH temperature variation during the last 1.3 kyr. (a) Annual mean instrumental temperature records, identified in Table 6.1. (b) Reconstructions using multiple climate proxy records, identified in Table 6.1, including three records (JBB..1998, MBH..1999 and BOS..2001) shown in the TAR, and the HadCRUT2v instrumental temperature record in black. (c) Overlap of the published multi-decadal time scale uncertainty ranges of all temperature reconstructions identified in Table 6.1 (except for RMO..2005 and PS2004), with temperatures within ±1 standard error (SE) of a reconstruction 'scoring' 10%, and regions within the 5 to 95% range 'scoring' 5% (the maximum 100% is obtained only for temperatures that fall within ±1 SE of all 10 reconstructions). The HadCRUT2v instrumental temperature record is shown in black. All series have been smoothed with a Gaussian-weighted filter to remove fluctuations on time scales less than 30 years; smoothed values are obtained up to both ends of each record by extending the records with the mean of the adjacent existing values. All temperatures represent anomalies (°C) from the 1961 to 1990 mean. The time series from Table 6.1 appearing in the figure legend are JBB..1998 (Jones et al. 1998), MBH1999 (Mann et al. 1999), BOS..2001 (Briffa et al. 2001), ECS2002 (Esper et al. 2002), B2000 (Briffa 2000), MJ2003 (Mann and Jones 2003), RMO..2005 (Rutherford and et al 2005), MSH2005 (Moberg et al. 2005), DWJ2006 (D'Arrigo et al. 2006), HCA..2006 (Hegerl et al. 2006), PS2004 (Pollack and Smerdon 2004), and O2005 (Oerlemans 2005).

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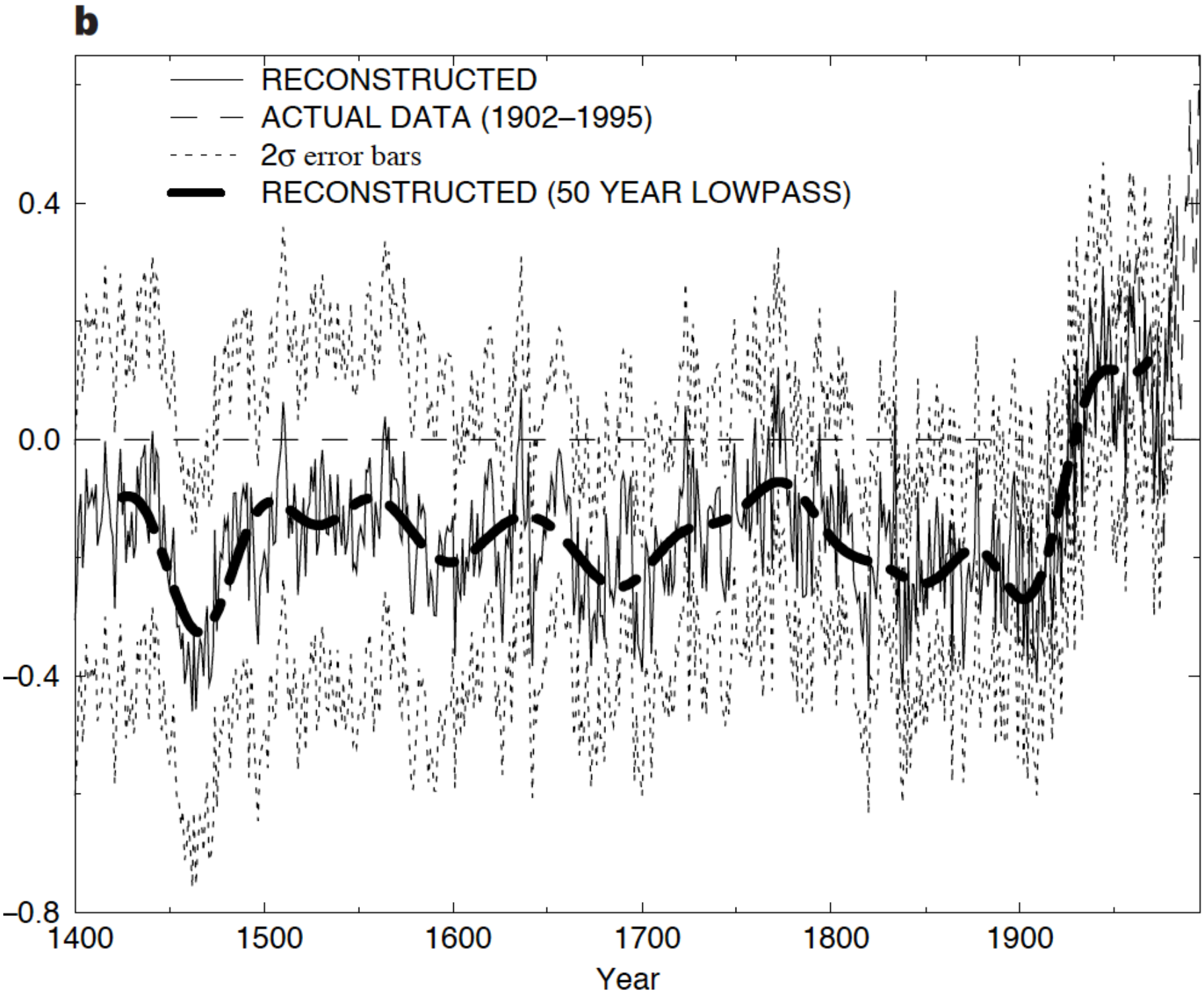
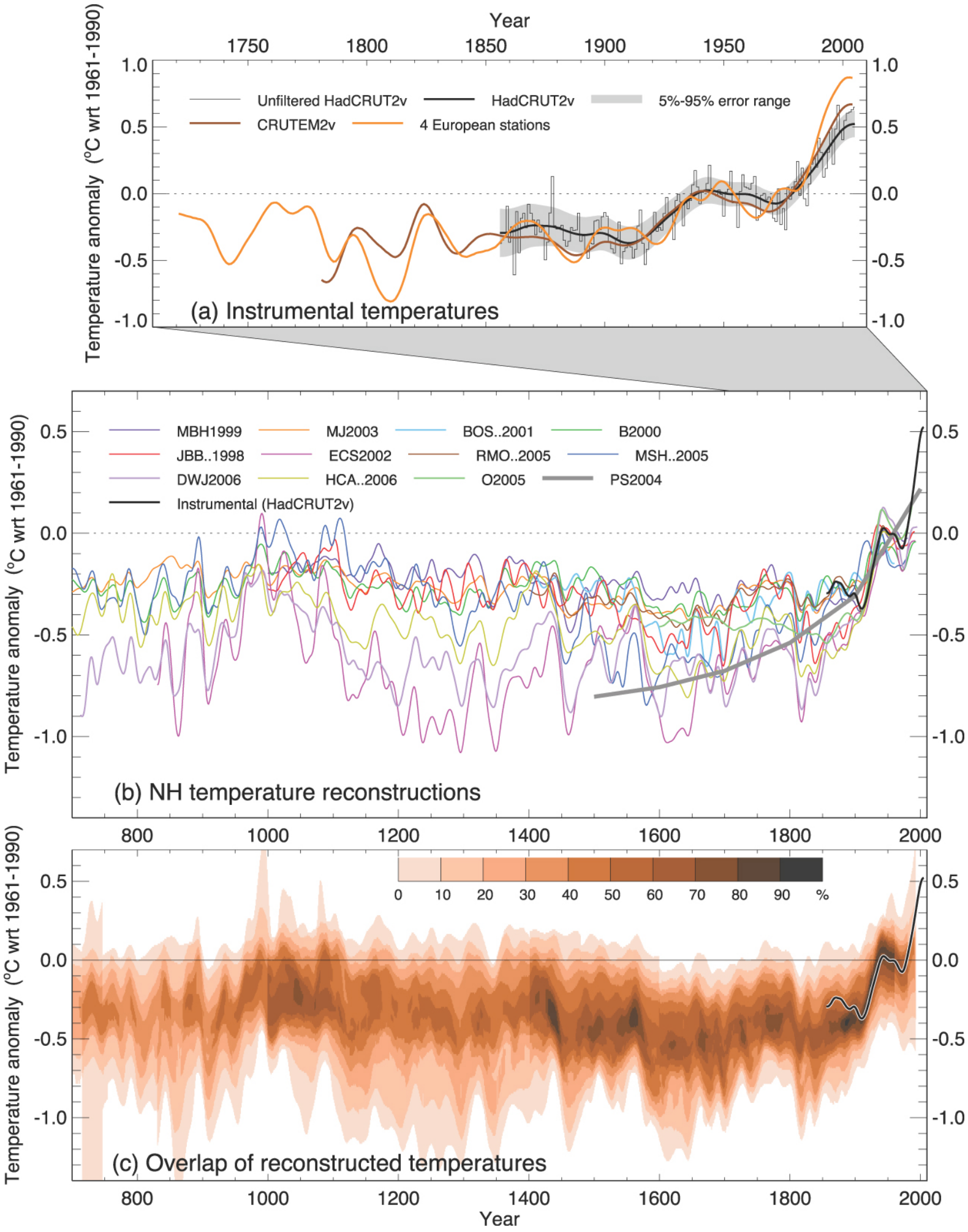

b
RECONSTRUCTED
ACTUAL DATA (1902–1995)
2σ error bars
RECONSTRUCTED (50 YEAR LOWPASS)
0.4
0.0
–0.4
–0.8
1400
1500
1600
1700
1800
1900
Year


Year
1750
1800
1850
1900
1950
2000
Temperature anomaly (°C wrt 1961-1990)
1.0
0.5
0.0
-0.5
-1.0
Unfiltered HadCRUT2v
HadCRUT2v
5%-95% error range
CRUTEM2v
4 European stations
(a) Instrumental temperatures
MBH1999
MJ2003
BOS..2001
B2000
JBB..1998
ECS2002
RMO..2005
MSH..2005
DWJ2006
HCA..2006
O2005
PS2004
Instrumental (HadCRUT2v)
(b) NH temperature reconstructions
800
1000
1200
1400
1600
1800
2000
0
10
20
30
40
50
60
70
80
90
%
(c) Overlap of reconstructed temperatures
Year