Correction to: A 2000-YEAR GLOBAL TEMPERATURE RECONSTRUCTION BASED ON NON-TREE RING PROXIES

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CORRECTION TO: A 2000-YEAR GLOBAL TEMPERATURE RECONSTRUCTION BASED ON NON-TREE RING PROXIES

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ABSTRACT

A climatic reconstruction published in E&E (Loehle, 2007) is here corrected for various errors and data issues, with little change in the results. Standard errors and 95% confidence intervals are added. The Medieval Warming Period (MWP) was significantly warmer than the bimillennial average during most of the period 820 – 1040 AD. The Little Ice Age was significantly cooler than the average during most of 1440 – 1740 AD. The warmest tridecade of the MWP was warmer than the most recent tridecade, but not significantly so.

Keywords: anthropogenic climate impacts, historical climate trends, Medieval Warming Period, Little Ice Age, hockey stick model, time series

INTRODUCTION

Historical data provide a baseline for judging how anomalous recent climate changes are and for assessing the degree to which organisms are likely to be adversely affected by current or future warming. A recent reconstruction (Loehle, 2007) used data that largely excluded tree ring records to investigate the possible effect of proxy type on reconstruction outcome. Several errors in data handling in that report have come to light, leading to the need for this report, which corrects these errors. In addition, confidence intervals are now computed for more robust evaluation of the results.

METHODS

Loehle (2007) obtained data for long series that had been previously calibrated and converted to temperature by their respective authors. Essentially no tree ring data were used. After an extensive search, all data were used that had at least 20 dates over the 2000-year period. The series used were: GRIP borehole temperature (Dahl-Jensen et al., 1998); Conroy Lake pollen (Gajewski, 1988); Chesapeake Bay Mg/Ca (Cronin et al., 2003); Sargasso Sea ^{18}O (Keigwin, 1996); Caribbean Sea ^{18}O (Nyberg et al., 2002); Lake Tsuolbmajavri diatoms (Korhola et al., 2000); Shihua Cave layer thickness (Tan et al., 2003); China composite (Yang et al., 2002) which does use tree ring width for two out of the eight series that are averaged to get the composite, or 1.4% of the total data input to the mean computed below; speleothem data from a South African cave (Holmgren et al., 1999); SST variations (warm season) off West Africa (deMenocal et al., 2000); SST from the southeast Atlantic (Farmer et al., 2005); SST reconstruction in the Norwegian Sea (Calvo et al., 2002); SST from two cores in the western tropical Pacific (Stott et al., 2004); mean temperature for North America based on pollen profiles (Viau et al., 2006); a phenology-based reconstruction from China (Ge et al., 2003); annual mean SST for northern Pacific site SSDP-102 (Latitude 34.9530, Longitude 128.8810) from Kim et al. (2004); and Spannagel Cave (Central Alps) stalagmite oxygen isotope data (Mangini et al., 2005). This gave a total of eighteen series (Fig. 1) with quite wide geographic coverage (including tropical) and based on multiple proxies. Many other series could not be used because they had too few dates within the 2000-year span or were not calibrated to temperature. In a few cases, data that were appropriate could not be obtained from authors. Whatever temperature calibration issues exist with these proxies are not common across the different proxies. The locations of the 18 series used are shown in Figure 1.

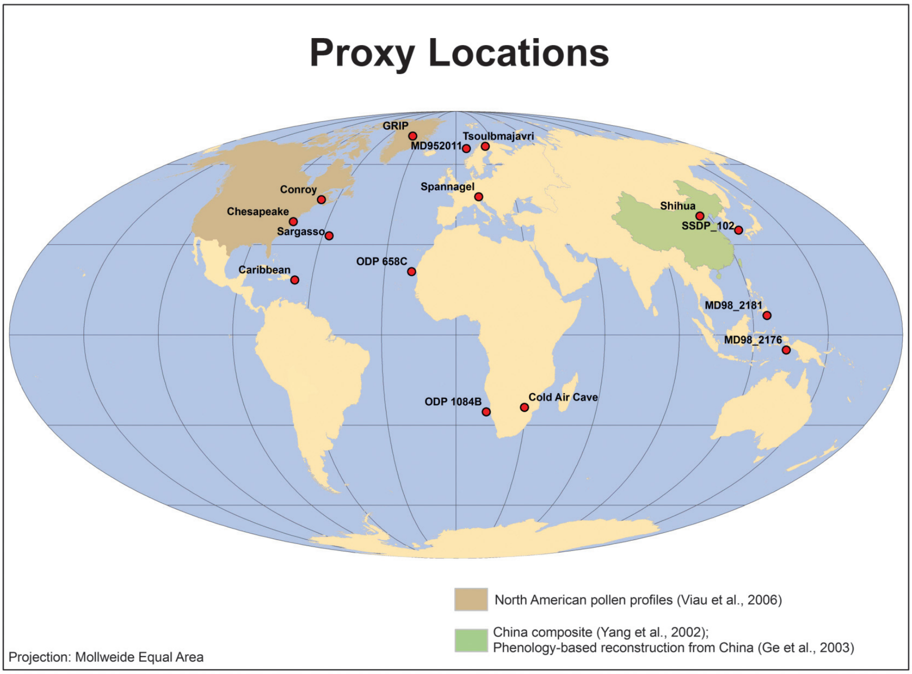

Figure 1. Map of study sites. Thanks to Mike Martin.

Four of the series (Calvo et al. 2002, deMenocal et al. 2000, Farmer et al. 2005, and Kim et al. 2004) were assumed by Loehle (2007) to be reported in ages relative to 2000, but in fact were implicitly relative to 1950. The previous study also used the proxy data column in Farmer et al. (2005) rather than the temperature column. Both these errors are corrected in the present note.

In addition, the present note treats the 18 series on a more uniform basis than in the original study. Data in each series have different degrees of temporal coverage. For example, the pollen-based reconstruction of Viau et al. (2006) has data at 100-year intervals, which is now assumed to represent 100 year intervals (rather than points, as in Loehle, 2007). Other sites had data at irregular intervals. This data is now interpolated to put all data on the same annual basis. In Loehle (2007), interpolation was not done, but some of the data had already been interpolated before they were obtained, making the data coverage inconsistent. In order to use data with non-annual coverage, some type of interpolation is necessary, especially when the different series do not line up in dating. This interpolation introduces some unknown error into the reconstruction but is incapable of falsely generating the major patterns seen in the results below. An updated version of the Holmgren data was obtained. Data on duplicate dates were averaged in a few of the series.

Data in each series (except Viau, because it already represents a known time interval) were smoothed with a 29-year running centered mean (previously called a 30 year running mean). This smoothing serves to emphasize long term climate patterns instead of short term variability. All data were then converted to anomalies by subtracting the mean of each series from that series. This was done instead of using a standardization date such as 1970 because series date intervals did not all line up or all extend to the same ending date. With only a single date over many decades and dating error, a short interval for determining a zero date for anomaly calculations is not valid. The mean of the eighteen anomaly series was then computed for the period 16 AD to 1980 AD. When missing values were encountered, means were computed for the sites having data. Note that the values do not represent annual values but rather are based on running means.

COMPUTATION OF CONFIDENCE INTERVALS

Standard errors and confidence intervals are somewhat complicated by the presence of cross-sectional heteroskedasticity (unequal variances) in the data. The variance about the global mean temperature of Calvo et al. (2002), for example, is almost 7 times as great as that of Viau et al. (2006). Because of this heteroskedasticity, conventional pointwise variance estimates will not have their customary χ^2 distribution, and hence the Student t distribution (see e.g. Casella and Berger 2002) will not provide accurate critical values to form confidence intervals.

It is assumed here that

$$X_{jt} = \mu_t + \varepsilon_{jt},$$

where X_{jt} is the temperature reconstruction from proxy j at time t and μ_t is global mean temperature at time t. The errors ε_{jt} are assumed to be normally distributed with mean 0 and proxy-specific variance V_j and to be independent across proxies at each point in time. As in Loehle (2007), μ_t is estimated by the simple mean

$$m_t = \frac{1}{n_t}\sum_j X_{jt},$$

where the sum is taken over the n_t proxies that are active at time t ($n_t = 18$ for most dates). The variance of m_t is therefore

$$Var(m_t) = \frac{1}{n_t^2}\sum_j V_j,$$

where again the sum is taken over the n_t proxies that are active at time t.

The proxy-specific variances V_j may be estimated over the time-series dimension, with a conservative adjustment for degrees of freedom, by

$$\hat{V}_j = \frac{1}{N_j}\sum_t \frac{n_t(X_{tj} - m_j)^2}{n_t - 1},$$

where the sum is now over the N_j dates for which proxy j is active. The heteroskedasticity-adjusted standard error of m_t is then

$$s_t = \frac{1}{n_t}\left(\sum_j \hat{V}_j\right)^{1/2},$$

again taking the sum only over the n_t proxies that are active at time t.

During 148 – 1425 AD all 18 proxies are active and s_t is constant at 0.136 °C. The standard errors increase gradually as proxies drop out, rising to 0.178 °C in 1935 when only 11 proxies are still active. Although the V_j are estimated with almost 2000 points in time, the 29-year running mean implies that effectively at most only about 60 of these are independent. Assuming approximately 60 degrees of freedom, the 95% confidence intervals in Figure 2 extend $2.00s_t$ above and below m_t.

The maintained assumption of cross-sectional independence of the errors is not unreasonable with the present data set, given the good geographical distribution of the proxies used. In studies with a substantially denser network of proxies, however, cross-sectional correlation would eventually become an important consideration.

RESULTS

The corrected point estimates of global temperature anomalies produced by taking the mean of the smoothed deviations are shown in Figure 2, together with 95% confidence

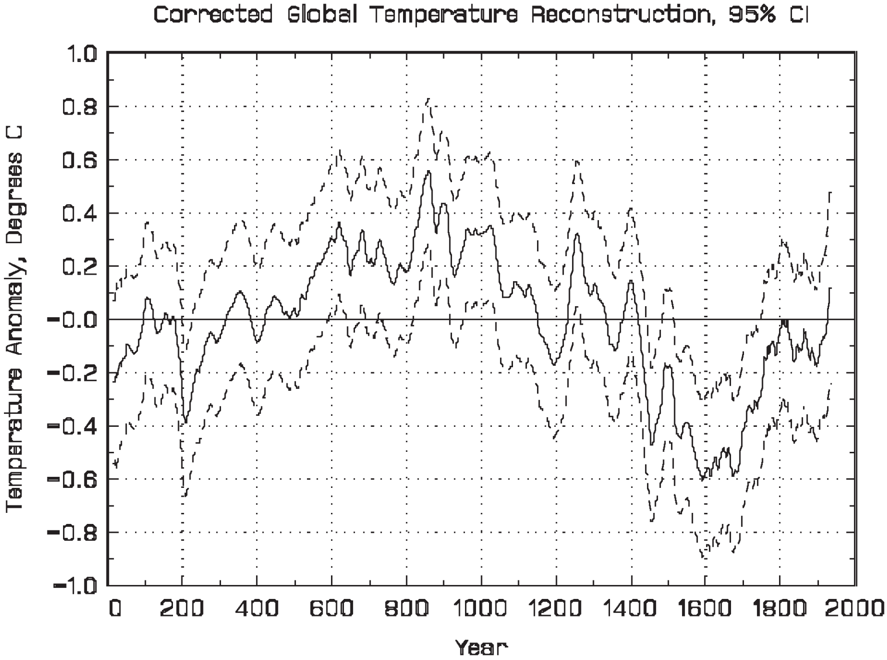

Figure 2. Corrected reconstruction with 95% confidence intervals.

Data for this graph is online at <http://www.econ.ohio-state.edu/jhm/AGW/Loehle/>

intervals. With the corrected dating, the number of series for which data is available drops from 11 to 8 in 1935, so that subsequent values of the reconstruction would be based on less than half the total number of series, and hence would have greatly decreased accuracy. Accordingly, the corrected estimates only run from 16 AD to 1935 AD, rather than to 1980 as in Loehle (2007).

The corrected estimates are very similar to the original results, showing quite coherent peaks. Note that the use of smoothed data (29-year running mean) and the existence of dating error in the series means that peaks and troughs are damped compared to annual data and are likely even damped compared to the true history (Loehle, 2005). Some of the input data were also integrated values or sampled at wide intervals. Thus it is not possible to compare recent annual data to this figure to ask about anomalous years or decades.

The corrected data continue to show the Medieval Warm Period (MWP) and Little Ice Age (LIA) quite clearly. The confidence intervals in Figure 2 indicate that the MWP was significantly warmer than the bimillennial average during most of approximately 820 – 1040 AD, at the 5% level (2-tailed). Likewise, the LIA was significantly cooler than the bimillennial average during most of approximately 1440-1740 AD.

The peak value of the MWP is 0.526 Deg C above the mean over the period (again as a 29 year mean, not annual, value). This is 0.412 Deg C above the last reported value at 1935 (which includes data through 1949) of 0.114 Deg C. The standard error of the difference is 0.224 Deg C, so that the difference is significantly non-zero at the 10% level ($t = 1.84$). While instrumental data are not strictly comparable, the rise in 29 year-smoothed global data from NASA GISS (http://data.giss.nasa.gov/gistemp) from 1935 to 1992 (with data from 1978 to 2006) is 0.34 Deg C. Even adding this rise to the 1935 reconstructed value, the MWP peak remains 0.07 Deg C above the end of the 20th Century values, though the difference is not significant.

The main significance of the results here is not the details of every wiggle, which are probably not reliable, but the overall picture of the 2000 year pattern showing the MWP and LIA timing and curve shapes. Future studies need to acquire more and better data to refine this picture.

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