CORRECTIONS TO THE MANN et. al. (1998) PROXY DATA BASE AND NORTHERN HEMISPHERIC AVERAGE TEMPERATURE SERIES

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ABSTRACT

The data set of proxies of past climate used in Mann, Bradley and Hughes (1998, “MBH98” hereafter) for the estimation of temperatures from 1400 to 1980 contains collation errors, unjustifiable truncation or extrapolation of source data, obsolete data, geographical location errors, incorrect calculation of principal components and other quality control defects. We detail these errors and defects. We then apply MBH98 methodology to the construction of a Northern Hemisphere average temperature index for the 1400-1980 period, using corrected and updated source data. The major finding is that the values in the early 15th century exceed any values in the 20th century. The particular “hockey stick” shape derived in the MBH98 proxy construction – a temperature index that decreases slightly between the early 15th century and early 20th century and then increases dramatically up to 1980 — is primarily an artefact of poor data handling, obsolete data and incorrect calculation of principal components.

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Key words: hockey stick, multiproxy method, global temperature history, IPCC, climate change, data quality.

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1. INTRODUCTION.

In a widely cited paper, Mann, Bradley and Hughes (1998, hereafter MBH98) constructed a temperature history of the Northern Hemisphere for the period 1400-1980. The result was the well-known "hockey stick"-shaped graph suggesting that the climate of the late 20th century is unusual compared to the centuries preceding it. This temperature history was extended to the period 1000-1399 in Mann, Bradley and Hughes (1999), who claimed that "temperatures in the latter half of the 20th century were unprecedented" and that "even the warmer intervals in the reconstruction pale in comparison with mid-to-late 20th-century temperatures". The temperature history was given bold prominence by the Intergovernmental Panel on Climate Change (2001) where it appears in Figures 2-20 and 2-21 in Chapter 2 of the Working Group 1 *Assessment Report*, Figure 1b in the Working Group 1 *Summary for Policymakers*, Figure 5 in the *Technical Summary*, and Figures 2-3 and 9-1B in the *Synthesis Report*. Referring to this figure, the IPCC *Summary for Policymakers* (p. 3) claimed it is likely "that the 1990s has been the warmest decade and 1998 the warmest year of the millennium" for the Northern Hemisphere. The IPCC view of temperature history has in turn been widely disseminated by governments and used to support major policy decisions.[1]

MBH98 applied 112 proxies and historical temperature measurements in what they called a "multiproxy approach" to construction[2] of a temperature index from 1400 to 1980. Although the "multiproxy" approach was apparently a novelty within the climatological community, the same algebraic and statistical methods are commonly used in economics, business and elsewhere in the social sciences, though the terminology differs from discipline to discipline.[3]

Upon request, Professor Mann instructed an associate to supply the collated proxy set, together with applicable weights, to the first author. When attempting to replicate MBH98 principal component (PC) calculations, an extremely low (6%) explained variance for those in the Texas-Mexico dataset was noticed, leading to a close examination of the data collation. Anomalous start years (see details below) were noticed and it was verified that these occurred only in MBH98 data and were not due to collation errors on our part. Explained variance improved significantly by moving the MBH98 data one year later, confirming that an MBH98 collation error had almost certainly occurred. We then noticed copy errors in the 1980 values for these series and stretches of identical values in other places in the database. This led to a systematic comparison of MBH98 data to original data, identifying obsolete versions and undisclosed truncation of time series. Independent calculations of the proxy principal components convinced us that those in MBH98 were erroneous we updated and corrected the database and then applied MBH98 methodology, as publicly disclosed, to construct a temperature index from 1400 to 1980. The newly calculated temperature index (see Figure 7) contradicts the MBH98 assertion of late 20th century uniqueness. We find that the particular "hockey stick" shape derived by MBH98 is primarily an artefact of poor data handling and use of obsolete proxy records.

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[1] See, for instance, the Government of Canada web site
http://www.climatechange.gc.ca/english/issues/what_is/index.shtml.

[2] MBH98 refers to the index resulting from their calculation as a "reconstruction." This is a misnomer since it is a novel index, rather than the recomputation of something previously observed. Therefore it will be referred to herein as "construction."

[3] For a critique of applying stationary linear maps to nonstationary phenomena like climate see Essex and McKitrick (2002) chapter 5.

2. ERRORS AND DEFECTS IN THE MBH98 PROXY DATA BASE

The term “proxy” denotes some physical data or measurement that can potentially serve as an indirect record of local temperature conditions, including tree ring widths and densities, coral δ^{18}O, δ^{13}C and calcification rates, ice core δ^{18}O, melt percentages and so forth. Thirteen MBH98 series are based on instrumental temperature records and are not, strictly speaking, “proxies”. For consistency with MBH98, we will use the term “proxy” to include these series.

We will denote a proxy series with the prefix ‘#’, i.e. proxies #1—#112. Twenty-two of the 112 proxies date back as far as 1400, while all 112 are available as of 1820. Twenty-three MBH98 proxies cease to be available in the 1970s. Thirty-one of the 112 proxies are principal components (PCs) from tree ring datasets, of which 28 were PCs calculated by MBH98 themselves from 300 tree ring datasets. Three are PCs from 14 Texas-Oklahoma sites, 9 are PCs from 20 Texas-Mexico sites, 9 are PCs from 232 International Tree Ring Data Base (ITRDB) US/Canada tree ring sites, 3 are PCs from 18 South American sites and 4 are from 16 Australian sites. Inconsistently, individual US, Canadian and Mexican tree ring sites are included separately in the list of 112 proxies rather than being incorporated into the PCs for that area (see e.g. Appendix, #49, #51-61, #106.) More information about the proxies is available at the Supplementary Information web site (see Appendix).

The database used by MBH98 contains the errors and defects listed below. We detail each of these points in this section, then in Section 3 we show how correcting these errors and defects affects the calculation of the Northern Hemisphere average temperature index using MBH98 methodology.

(a) unjustified truncation of 3 series;
(b) copying 1980 values from one series onto other series, resulting in incorrect values in at least 13 series;
(c) displacement of 18 series to one year earlier than apparently intended;
(d) unjustified extrapolations or interpolations to cover missing entries in 19 series;
(e) geographical mislocations and missing identifiers of location;
(f) inconsistent use of seasonal temperature data where annual data are available;
(g) obsolete data in at least 24 series, some of which may have been already obsolete at the time of the MBH98 calculations;
(h) listing of unused proxies;
(i) incorrect calculation of all 28 tree ring principal components.

(a,f) Series #10 and #11 (Central England and Central Europe air temperatures respectively) use June-July-August averages. This raises three concerns: annual data were available in the primary sources; other station temperature series used by MBH98 (#21- #31), where identified, are annual; and MBH98 claims to calculate an annual temperature index. The Central England Temperature series is truncated at 1730 rather than the available 1659 in source data, which removes a major late 17th century cold period (see Supplementary Information). Series #10 has a 1987 value which is 0.43 deg C higher than in the source data though this does not appear to affect any calculations discussed herein. Central Europe (#11) is truncated at 1550 rather than the available 1525, which removes the warmest temperatures in the series (compare Figure 1 Top and Bottom panels). #11, which is an exceptionally long series of direct temperature information, also shows a notable lack of 20th century uniqueness. In series #100, MBH98 also crop two very high values from the start of the series. These truncations are not justified and were not disclosed by MBH98.

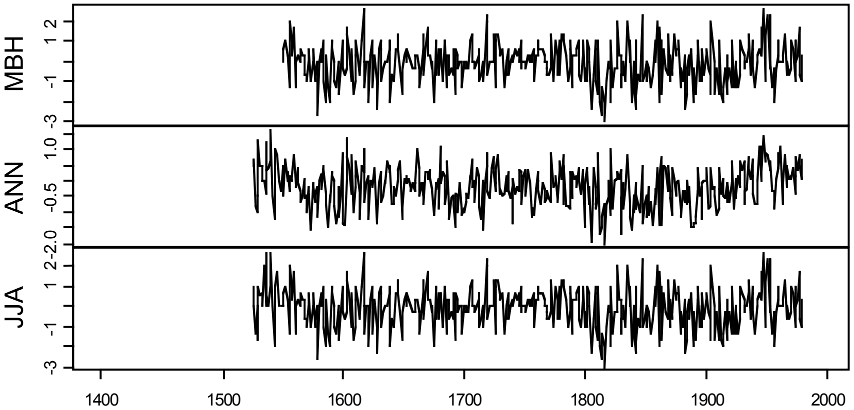

Figure 1. Temperature anomalies (C) by year for (Top panel) Central European historical air temperatures, MBH98 series #11; those differ from (Middle panel) Central European historical (Annual) from 1525-1979, which would be more relevant for inclusion in the calculation of an annual index; (Bottom panel) Central European historical (June-July-August) from 1525-1979, which matches, in the period of overlap, the incomplete record used by MBH98.

(b,c) In the MBH98 collated data set the 1980 values for series #72-#80, which are the 9 Texas-Mexico principal components computed by MBH98, are identical to 7 decimal places, an obviously impossible result (see Table 1) and therefore an error.

The 1980 values are likewise identical in the 3 Vaganov principal components (series #81-#83) and 4 of the 9 ITRDB US principal components computed by MBH98 (series #84, #90, #91 and #92); see Table 2. Interestingly, all but two of these series as collated in the MBH98 database begin in years ending in *99 or *49, rather than the apparently intended *00 and *50, and appear to have been displaced one year backward in collation. This suggests a simple clerical error, in which the series in question were copied into a file at the wrong row, then a 1980 value was filled in from an adjacent cell. Series #85-#89 commence in 1499, but lack the telltale 1980 value. The displacements will result in any extreme year in the past being one year off in these datasets, attenuating its effect in the compilation. The copy errors constitute a significant fraction of the MBH98 dataset for 1980 – the final year of the MBH98 proxy-constructed index.[4]

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[4] To access the underlying data consult the supplementary information sources listed in the Appendix.

Table 1. Identical 1980 values (bold) in Texas-Mexico series in MBH98 data set.

Directory: TREE/STAHLE/SWM/BACKTO_1700

MBH Series #:	**#72**	**#73**	**#74**	**#75**	**#76**	**#77**	**#78**	**#79**	**#80**
Record Name:	**pc01.out**	**pc02.out**	**pc03.out**	**pc04.out**	**pc05.out**	**pc06.out**	**pc07.out**	**pc08.out**	**pc09.out**
1976	-0.04758900	0.09825240	-0.01345320	0.01161880	0.01822490	0.03648180	0.04604640	-0.04273910	0.00526230
1977	0.02738590	-0.11581500	0.02995960	0.01370230	0.03782570	0.00327476	0.07170230	0.03729640	-0.10195200
1978	0.09249040	-0.00125138	0.08667150	0.07659540	0.02200060	0.04614070	0.03223540	0.02464170	0.02726110
1979	-0.01054950	-0.17253000	-0.00999568	-0.04078750	0.09144420	-0.00608904	-0.00508424	-0.03537360	-0.08408310
1980	**0.02303040**	**0.02303040**	**0.02303040**	**0.02303040**	**0.02303040**	**0.02303040**	**0.02303040**	**0.02303040**	**0.02303040**

Table 2. Identical 1980 values (bold) in Vaganov PCs and 4 ITRDB PCs in MBH98 data set.

Directory: TREE/VAGANOV/BACKTO_1750 TREE/ITRDB/NOAMER/BACKTO_1750

MBH Series #:	**#81**	**#82**	**#83**	**#84**	**#90**	**#91**	**#92**
Record Name:	**pc01.out**	**pc02.out**	**pc03.out**	**pc01.out**	**pc07.out**	**pc08.out**	**pc09.out**
1976	-0.03291460	0.02597240	0.01647480	0.00888690	0.10327000	0.18590800	0.03833640
1977	0.01170380	-0.09346030	-0.01559880	0.02153980	0.10721500	0.13304000	0.00842804
1978	0.05759400	-0.02107700	-0.13369700	0.02241670	0.11963800	0.12615900	0.01346540
1979	-0.11100000	-0.07345260	0.02438820	0.04898920	0.13681500	0.16866300	0.02801240
1980	**-0.04063530**	**-0.04063530**	**-0.04063530**	**0.04345260**	**0.04345260**	**0.04345260**	**0.04345260**

Table 3. Filled data series (bold) in MBH98 data set. NaN denotes a missing value, although values beyond 1980 are not relevant to the calibration interval.

Directory: TREE/MANNETAL97							
MBH98 Series #:	**45**	**46**	**51**	**52**	**54**	**56**	**58**
Record Name:	**cpatagonia.dat**	**npatagonia.dat**	**treeline1.dat**	**treeline10.dat**	**treeline2.dat**	**treeline4.dat**	**treeline6.dat**
1970	16.79999900	0.85000002	1.27000000	0.61400002	1.10500000	0.99900001	1.35900000
1971	15.50000000	-1.10000000	1.40900000	0.46000001	1.41199990	1.42200010	1.30300000
1972	15.90000000	0.17000000	1.25700000	0.83399999	1.38800000	1.22200000	1.38800000
1973	15.50000000	0.63999999	1.10700000	0.56199998	1.19700000	1.07100000	1.46000000
1974	16.70000100	**-0.43000001**	1.13300000	**1.10400000**	1.14400010	1.13500000	1.62899990
1975	14.90000000	**-0.43000001**	0.93199998	**1.10400000**	**1.36600010**	**1.22400000**	1.61300000
1976	14.70000000	**-0.43000001**	1.16100000	**1.10400000**	**1.36600010**	**1.22400000**	1.17600000
1977	16.10000000	**-0.43000001**	**1.58500000**	**1.10400000**	**1.36600010**	**1.22400000**	**1.57300000**
1978	**15.10000000**	**-0.43000001**	**1.58500000**	**1.10400000**	**1.36600010**	**1.22400000**	**1.57300000**
1979	**15.10000000**	**-0.43000001**	**1.58500000**	**1.10400000**	**1.36600010**	**1.22400000**	**1.57300000**
1980	**15.10000000**	**-0.43000001**	**1.58500000**	**1.10400000**	**1.36600010**	**1.22400000**	**1.57300000**
1981	**15.10000000**	NaN	NaN	NaN	NaN	NaN	NaN
1982	**15.10000000**	NaN	NaN	NaN	NaN	NaN	NaN

Table 4. Filled data (bold) in MBH98 data.

Directory:	TREE/ITRDB/SOAMER/BACKTO_1600			TREE/ITRDB/AUSTRAL/BACKTO_1750			
MBH98 Series #:	**93**	**94**	**95**	**96**	**97**	**98**	**99**
Record Name:	**pc01.out**	**pc02.out**	**pc03.out**	**pc01.out**	**pc02.out**	**pc03.out**	**pc04.out**
1970	-0.05519220	0.03191820	-0.00840994	0.07964660	-0.03334510	0.00628749	0.03972250
1971	0.04456720	0.02654390	0.06869810	0.05834090	0.03159730	0.01390980	-0.00292208
1972	-0.03087120	0.03992700	0.00302668	0.15582700	0.07014980	0.03358720	-0.07598700
1973	-0.02466770	0.11485700	-0.05301170	0.18438500	0.04514380	-0.04919020	-0.05758820
1974	0.03531060	0.07091270	0.00376018	0.11299600	0.01402680	-0.00682486	-0.10635300
1975	0.04918980	0.07842340	-0.02821910	0.16178501	0.02186560	0.02133480	0.00791537
1976	**0.04792530**	**0.07830090**	**-0.02856930**	**0.16103400**	**0.08604140**	**0.05941720**	**-0.05302600**
1977	**0.04792530**	**0.07830090**	**-0.02856930**	**0.16103400**	**0.08604140**	**0.05941720**	**-0.05302600**
1978	**0.04792530**	**0.07830090**	**-0.02856930**	**0.16103400**	**0.08604140**	**0.05941720**	**-0.05302600**
1979	**0.04792530**	**0.07830090**	**-0.02856930**	**0.16103400**	**0.08604140**	**0.05941720**	**-0.05302600**
1980	**0.04792530**	**0.07830090**	**-0.02856930**	**0.16103400**	**0.08604140**	**0.05941720**	**-0.05302600**

(d) MBH98 insert extrapolated, interpolated or copied values during the critical calibration period into 19 series. We refer to these as “fills” hereafter. In the data set provided to the authors, the following 17 series contain end-of-sample fills for one or more years including 1980: #6, #45, #46, #50-#52, #54-#56, #58, #93-#99. Series #53 was filled for 4 years at its beginning and series #3 for 16 years in the calibration period. In the case of #3, MBH98 inexplicably replaced available source values for 1962-64 with filled values. For examples see Tables 3, 4 and 5.

Table 5. Filled series (bold) in data for MBH98 PCs.

MBH98 Series #:	**51**	**54**	**56**	**58**	**53**
Record Name:	**ak031**	**ak032**	**cana157**	**cana153**	**cana036**
1400	NA	NA	NA	NA	**0.723**
1401	NA	NA	NA	NA	**0.723**
1402	NA	NA	NA	NA	**0.723**
1403	NA	NA	NA	NA	**0.723**
1404	NA	NA	NA	NA	**0.723**
1405	NA	NA	NA	NA	0.874
1406	NA	NA	NA	NA	1.026
1407	NA	NA	NA	NA	1.029
1408	NA	NA	NA	NA	1.203
1409	NA	NA	NA	NA	1.055
1970	1.270	1.105	0.999	1.359	1.376
1971	1.409	1.412	1.422	1.303	1.554
1972	1.257	1.388	1.222	1.388	1.463
1973	1.107	1.197	1.071	1.460	1.618
1974	1.133	1.144	1.135	1.629	1.483
1975	0.932	**1.366**	**1.224**	1.613	1.743
1976	1.161	**1.366**	**1.224**	1.176	1.577
1977	**1.585**	**1.366**	**1.224**	**1.573**	1.583
1978	**1.585**	**1.366**	**1.224**	**1.573**	1.851
1979	**1.585**	**1.366**	**1.224**	**1.573**	1.618
1980	**1.585**	**1.366**	**1.224**	**1.573**	2.204

Series #50 is especially noteworthy. The values of series #50 for the entire period from 1962 to 1982 are copied from series #49 (see Table 6). Although MBH98 attribute both series #49 and #50 to Fritts and Shao (1992), series #49 is actually derived from Briffa *et al.* (1992).

Table 6. Final 20 values in MBH98 Series #49 and #50 are identical.

Directory: TREE/MANNETAL97

MBH98 Series #:	**49**	**50**
Record Name:	**trd.dat**	**trw.dat**
1958	0.38000000	0.34000000
1959	-0.15000000	0.45000000
1960	0.280000000	0.020000000
1961	0.120000000	0.550000010
1962	**-0.039999999**	**-0.039999999**
1963	**0.600000020**	**0.600000020**
1964	**-0.779999970**	**-0.779999970**
1965	**-0.800000010**	**-0.800000010**
1966	**0.289999990**	**0.289999990**
1967	**-0.230000000**	**-0.230000000**
1968	**-0.949999990**	**-0.949999990**
1969	**0.910000030**	**0.910000030**
1970	**0.319999990**	**0.319999990**
1971	**0.110000000**	**0.110000000**
1972	**-0.020000000**	**-0.020000000**
1973	**-0.010000000**	**-0.010000000**
1974	**-0.079999998**	**-0.079999998**
1975	**-0.680000010**	**-0.680000010**
1976	**-0.090000004**	**-0.090000004**
1977	**0.150000010**	**0.150000010**
1978	**-0.140000000**	**-0.140000000**
1979	**0.020000000**	**0.020000000**
1980	**-0.239999990**	**-0.239999990**
1981	**-0.010000000**	**-0.010000000**
1982	**0.059999999**	**0.059999999**

These fills are neither required nor justified statistically and exceed MBH98 disclosure. There is no disclosure of the extent of data filling or its potential impact on the constructed temperature index in the text of the *Nature* article and, their supplementary web page (http://www.ngdc.noaa.gov/paleo/ei/data_supp.html) says only “Small gaps have been interpolated. If records terminate slightly before the end of the 1902-1980 training interval, they are extended by persistence to 1980.” Inconsistently, however, series #11, #102, #103, #104, #106 and #112 terminate prior to 1980 but were not filled in the MBH98 dataset. The fills in 1980 are pervasive: at least 30 (and up to 36) proxies in 1980 have values arising from copy errors or extrapolation.

(e) Geographical mislocations and missing attributions occur in the MBH98 data. For example, MBH98 use 11 precipitation series, for which they cite Jones and Bradley (1992) (hereafter “JB92”). JB92 (Table 13.3) lists 17 precipitation series, of which 12 are digitally published at the World Data Center for Paleoclimatology (http://www.ngdc.noaa.gov/paleo/paleo.html, hereinafter denoted WDCP). In only two MBH98 precipitation series (#35 and #37) did the correlation between JB92 and MBH98 data exceed 0.9, permitting a reasonably secure identification of locations; other correlations were less than 0.5 excluding the possibility of identification. The JB92 series for Paris, France (48.8N, 2.5E) can be identified with MBH98 series #37 both from the high correlation and the identity of starting date (see Figure 2, which graphs both these series). However, MBH98 series #37 is located at the grid-box centred at 42.5N, 72.5W near Boston, Massachusetts.

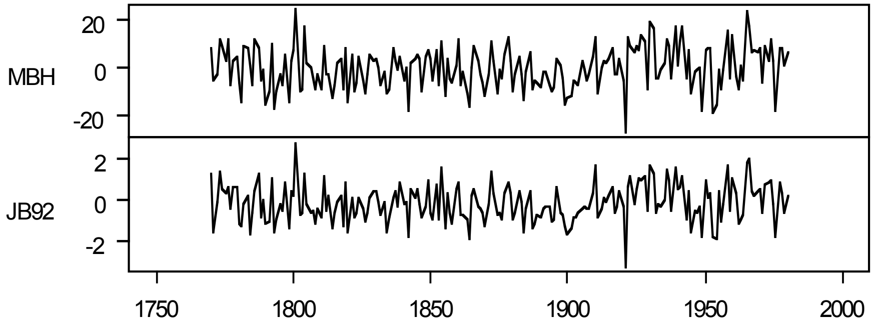

Figure 2. (Top) Station precipitation with erroneous location given as 42.5N, 72.5W in MBH98 (series #37); (Bottom) the record corresponds instead to that of JB92 Paris, France (48.8N, 2.5E) JB92 is scaled to a 1901-1950 reference period (i.e. subtracting the 1901-50 mean and dividing by the 1901-50 standard deviation). MBH98 appear to have a scale error by a factor of 10.

Two MBH98 precipitation series are in India and derive from an unreported source, since no Indian locations are listed in JB92. The other 7 MBH98 precipitation series derive either from unreported sources, from the 5 JB92 series not digitally published at WDCP or have been heavily transformed in collation. Two of the MBH98 temperature grid-box series had no locational counterparts in JB92 (Table 13.1): series #26 (52.5N, 17.5E grid-box) and series #29 (62.5N, 7.5E grid-box). In addition, MBH98 series #20 (Central Greenland ice core) is materially mislocated to the north and west. On comparison with source data, it can be seen that MBH98 have also reversed the geographical locations of series #46 and #47.

(g) Digitally published versions at the World Data Center for Paleoclimatology (WDCP, http://www.ngdc.noaa.gov/paleo/paleo.html) supercede the versions used by MBH98 for the following 24 series: #1, #2, #3, #6, #7, #8, #9, #21, #23, #27, #28, #30, #35, #37, #43, #51, #52, #54, #55, #56, #58, #65, #105 and #112. A listing of FTP sources is provided in the Appendix and details for each of the above series, including comparisons of different data editions, is provided in the Supplementary Information. (Since many datasets used by MBH98 remain digitally unpublished, this listing is only from datasets where a comparand was identified.) For the purposes of this study, it is immaterial whether the MBH98 datasets were obsolete as at the time of publication of MBH98 or whether they have become obsolete subsequently. However, at least some datasets used by MBH98 were already obsolete in 1998. In response to an inquiry about series #51- #61, WDCP confirmed that the updated versions for four of the series were available as early as 1991-1992. [WDCP, pers. comm., Sept. 2003].

In some cases, the differences between MBH98 and updated series were isolated; in other cases, the differences were systematic. As an example of relatively isolated differences, MBH98 series #28 corresponds closely to a Z-transformation (subtracting the mean, dividing by the standard deviation) of the JB92 Leningrad series for most of its history, but there are major and puzzling discrepancies in the 1760s, including a discrepancy of over 4 degrees C in 1764 (see Figure 3). As with the Central European temperature series (and other long temperature series), the 20th century values are not unique.

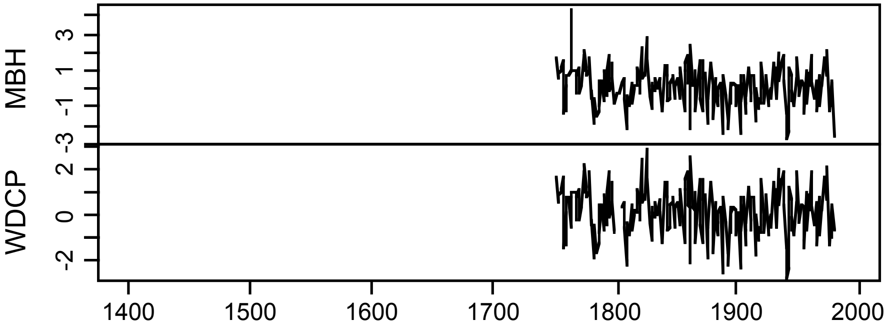

Figure 3. (Top) Station temperature for grid box 75.5N, 32.5E from MBH98 (series #28); (Bottom) Leningrad temperature from JB92 at WDCP (anomaly from 1951-1970).

As an example of systematic differences, MBH98 series #56 (Twisted Tree, Heartrot Hill, a northern treeline ring width series) used an early version of site data with values only up to 1975 and with MBH98 fills from 1976 to 1980. The updated version now at WDCP has data up to 1992 (see Figure 4) and differs quite dramatically from the MBH98 series. The MBH98 version of series #56, like MBH98 versions of many northern treeline series (#51-#58, #60-#61) shows an *increased* ring width index in the 1902-1980 period. However, in the WDCP series, there is a dramatic and sustained *reduction* in ring widths in the 1980s, with a complete reversal of the increases in the first decades of the century. This pattern occurs in other series updated into the 1990s (series #51 and #54) and was apparent by 1984 in the northerly series #59 (Hornby Cabin) (see Supplementary Information). The later edition of #56, presumably for quality control reasons, discontinued some early estimates made in the first edition.

(h) Five series purportedly in the multiproxy network (fran003, ital015, ital015x, spai026 and spai047 in the MBH98 list “ITRDB –Miscellaneous”) cannot be located in either the MBH98 collated set or the proxy PC compilations.

(i) Of the 112 proxies in MBH98, 28 are principal components calculated by MBH98 from International Tree Ring Data Base (ITRDB) site chronologies stored at WDCP for the sites listed in MBH98 Supplementary Information (see http://www.ngdc.noaa.gov/paleo/ei/data_supp.html) for the following five different regions: Texas-Oklahoma, Texas-Mexico, North America, South America and Australia-New Zealand. The principal component calculations have two types of problems: first, MBH98 does not establish consistent rules for inclusion or exclusion of sites in regional aggregates and, second, the MBH98 principal components fail to maximize explained variances.

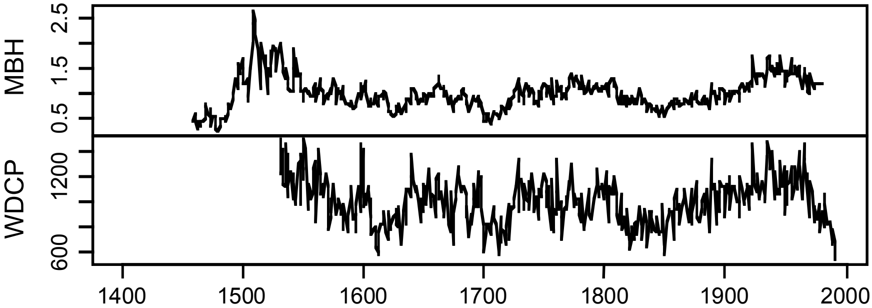

Figure 4. (Top) Twisted Tree, Heartrot Hill (northern treeline) ring width index from MBH98 (series #56) (1459-1975 plus 5 fills at end); (Bottom) Twisted Tree, Heartrot Hill ring width index from WDCP (1530-1992). MBH have divided WDCP values by 1000. Neither series is Z-transformed.

As to the first problem, MBH98 do not provide justification for excluding the Texas-Oklahoma and Texas-Mexico sites from the North American compilation. Similarly puzzling are the occurrences of other sites as individual proxies rather than being incorporated into the regional PC groups. Series #106 occurs within the Texas-Mexico region; series #49-64 are all North American sites or reconstructions; series #46-47 are within the South American region and series #43 and #45 are reconstructions within the Australia-New Zealand region.

The second problem was determined indirectly as the MBH98 principal component calculations are unpublished. We collated the source data from WDCP for all sites listed in MBH98 (except, immaterially, one MBH98 US site which could not be identified in the WDCP database). The collations are available in Supplementary Information. The start dates of the MBH98 PC's are not consistent with those of available data. In 12 cases, MBH98 commenced their calculation after the date in which all records were available (e.g. Australia-New Zealand region where MBH98 commenced in 1750, although a start date of 1625 was possible.) In 16 cases, MBH98 commenced their PC index in a period *prior* to that available in the data (e.g. Texas-Mexico). Because standard PC algorithms fail in the presence of missing data, an important part of the methodology—namely how missing data were treated in the PC calculation—remains unexplained in MBH98.

We computed all 28 PCs, together with their explained variances, using a standard principal component algorithm for the maximum period in which all records were available within each region. For comparison, weighting factors for the MBH98 PCs eigenvectors were computed which maximized the explained variance of the underlying ITRDB data, and the resulting explained variance was compared to our own computations using a standard algorithm. In all cases, explained variance for the recomputed PCs exceeded that for the MBH98 PCs (see Table 7). Indeed it was the observation of the unusually poor fit between the MBH98 Texas-Mexico PCs and the underlying ITRDB data that led to the detailed audit undertaken in this paper.

Table 7. 5 Regions in which MBH98 computed principal components. Each column shows the number of source sites listed by MBH98, the number found at WDCP; the number of PCs extracted; the dates spanned at WDCP and in the MBH98 PCs; the explained variance of each group.

REGION:	Texas-Oklahoma	Texas-Mexico	ITRDB North America	South America	Australia-. NZ
# of Source Sites Listed	14	20	232	18	16
# at WDCP	14	20	231	18	16
# of MBH PCs	3	9	9	3	4
WDCP Available Period	1698-1980	1760-1977	1619-1971	1568-1972	1625-1974
MBH PC Start	1-3: 1700	1: 1400 2: 1499 3-4: 1599 5-9: 1699	1-2: 1400 3-6: 1499 7: 1599 8-9: 1749	1-2: 1600 3: 1750	1-4: 1750
MBH PC End[5]	1980	1979	1980	1976	1976
Explained Variance: MBH	32%	6%	14%	26%	38%
Recalculated	39%	76%	40%	35%	46%

Figure 5 shows the MBH98 and re-calculated Australian PC1. The Australian PC1 is one of relatively few MBH98 series that shows anomalous 20th century behaviour and which closes on a dramatic "uptick". The correct computation shows that this feature of this particular MBH98 series is entirely an artefact of incorrect calculation.

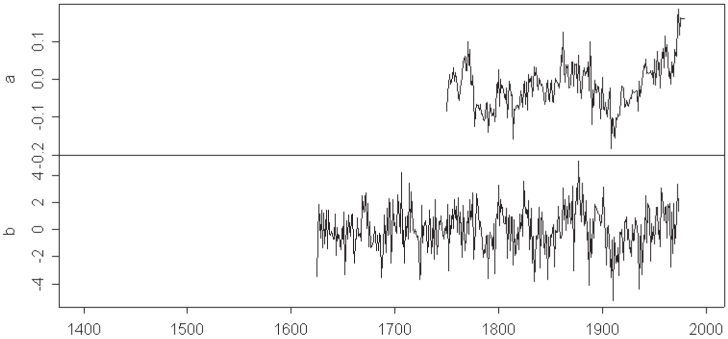

Figure 5. (a) Australia PC1 in MBH98 (series #96) graphed over time (b) PC1 for the MBH98 Australia dataset calculated using standard algorithm.

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[5] Excluding filled values

3. TEMPERATURE INDEX CONSTRUCTION USING CORRECTED DATA

A corrected and updated proxy database has been developed, in which the measures outlined above were adopted, including the following:

- the most recent editions of the MBH98 series have been used where identified and available;
- arbitrary MBH98 truncations and fills have been deleted;
- correct tree ring principal component calculations have been used.

We replicated the methodology of MBH98 as closely as we could using publicly available documentation and such private assistance as we were able to obtain.

MBH98 purports to establish relationships between the proxies and 16 temperature principal components calculated from the Climate Research Unit (CRU) instrumental temperature database, using a subset of 1,082 out of 2,592 cells and the 79-year period from 1902-1980 as a calibration period. These 16 temperature principal components are referred to as TPC1—TPC16. Prior to this calculation, the CRU data was scaled cellwise. We downloaded original temperature data from CRU and gridpoint locations from the MBH98 website and calculated scaling factors for downstream use in calculation of northern hemisphere temperature averages. Four MBH98 cells contained no observations in the CRU data and were excluded from all calculations.

Following the description of MBH98 procedures in their Supplementary Information, our construction is done piecewise for each of the periods listed in Table 8, using the roster of proxies available throughout the period and the selection of TPCs for each period listed in Table 8. There are slight discrepancies between 1500 and 1750 in the number of proxies which MBH98 reported to be available and the number actually available in the MBH98 data set (see columns 2-3).

The anomalous listing of TPCs 6 and 8 in the period 1750 to 1759 is assumed to be an erroneous rendering of TPCs 7 and 9, but there is little sensitivity to this assumption. Following MBH98, the number of TPCs used in the construction decreases from 11 in the latest period to 1 in the earliest period, as shown in Table 8.

Following MBH98 procedures as publicly disclosed, for each combination of proxy roster and TPC selection, the proxies were first calibrated against the temperature PCs in the calibration period of 1902-1980 and then the temperature PCs were constructed in each period using the proxy and TPC rosters prescribed by MBH98 for the period, together with weighting factors supplied to the authors by an associate of Prof. Mann. From these constructed PCs, using MBH98 eigenvalues and eigenvectors, gridded temperature series for 1,082 cells were obtained. From the cells in the northern hemisphere (excluding the four cells with no observations and hence no scaling factor), a northern hemisphere average temperature index was calculated. We have posted scripts for this construction in Supplementary Information.

It should be noted that each of the above steps in the MBH98 northern hemisphere temperature index construction is a linear operation on the proxies. Accordingly, given the roster of proxies and TPCs in each period, the result of these linear operations is a set of proxy weighting factors, which generates the NH average temperature construction. These weighting factors are not disclosed in MBH98.

Table 8. Intervals defining proxy groups and subset of temperature PCs used in coefficient fitting process.

Interval	No. of proxies reported available	No. found in data set	Number of Temp PCs fit to proxies	Temperature PC Identifiers
1400-1450	22	22	1	1
1450-1500	24	24	2	1,2
1500-1600	28	34	2	1,2
1600-1700	57	54	4	1,2,11,15
1700-1730	74	73	5	1,2,5,11,15
1730-1750	79	78	5	1,2,5,11,15
1750-1760	89	89	8	1-3,5,6,8,11,15
1760-1780	93	93	9	1-5,7,9,11,15
1780-1800	97	97	11	1-5,7,9,11,14-16
1800-1820	102	102	11	1-5,7,9,11,14-16
1820-1971	112	112	11	1-5,7,9,11,14-16
1972+	112	106-111	11	1-5,7,9,11,14-16

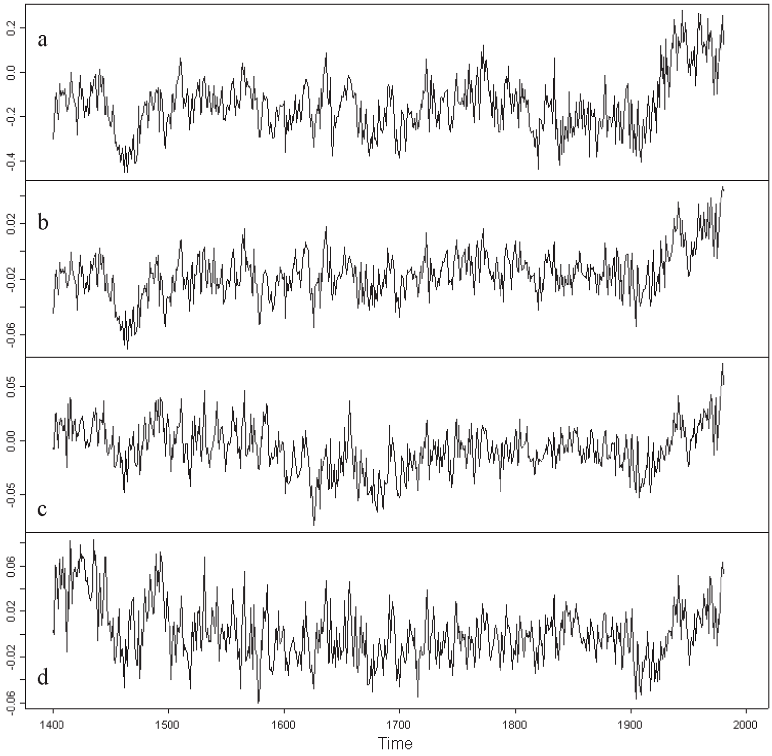

Figure 6. (a) MBH98 NH temperature series (deg C), 1400-1980, which relies heavily on (b) TPC1 from MBH98. (c) Authors' replication of TPC1 using MBH98 methods and data. (d) Authors' TPC1 using MBH98 methods but with data corrected as outlined in text.

The well-known "hockey stick" shape of the MBH98 northern hemisphere temperature index is shown in Figure 6a. It depends strongly on the temperature PC1 (Figure 6b) so we will illustrate its replication, although all TPCs were calculated and used in the NH construction. Our replication of TPC1 using the MBH98 method and data is shown in Figure 6c. Our version of TPC1 in Figure 6c is clearly similar to the calculation of MBH98 in Figure 6b (correlation 0.95 in the 20th century), indicating substantial success in replicating the MBH98 methodology, but some differences remain, possibly due to undisclosed variations in their procedures and assumptions. The TPC1 construction using corrected data is in Figure 6d, showing higher 15th century values than 20th century values, unlike the MBH98 TPC1.

Figures 7 and 8 show the impact of the corrections on northern hemisphere temperature construction. In Figure 7 the top line is the MBH98 construction (reproducing Figure 6a), while the bottom line shows the Northern Hemisphere multiproxy temperature index resulting from the application of MBH98 procedures on an updated and correctly collated assembly of the MBH98 library of proxy data. On the basis of corrected and updated data, 15th century values are higher than those in the 20th century, contradicting the MBH98 conclusion of a unique late 20th century climate. Figure 8 shows 20-year smoothed series for comparison.

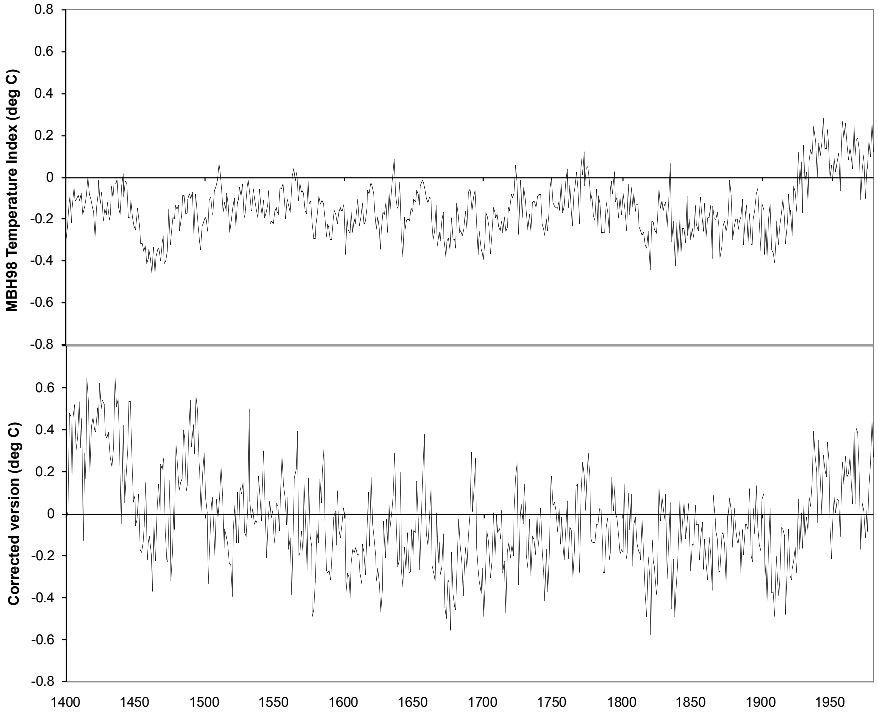

Figure 7. Temperature anomalies index (deg C) 1400-1980 for Northern Hemisphere average temperature construction from (top) Mann et. al. (1998); and (bottom) based on this work using corrected and updated data as outlined in text.

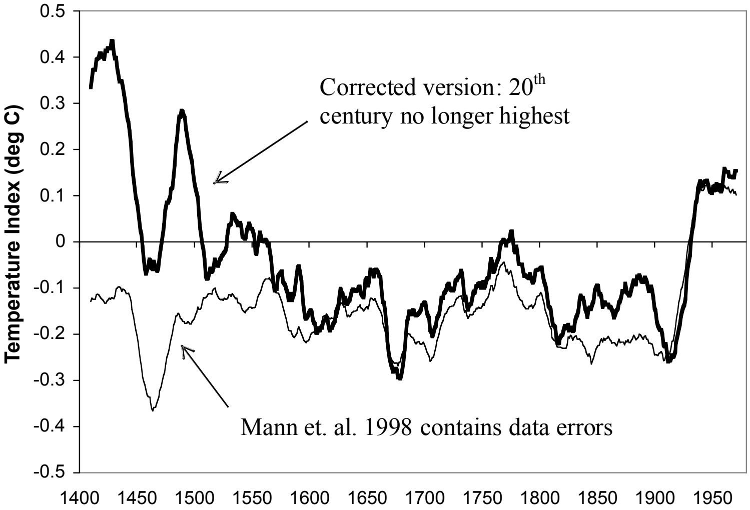

Figure 8. As Figure 7, using 20-year running mean to smooth.

4. CONCLUSIONS

The MBH98 hockey stick-shaped NH temperature index discussed here has been extremely influential in discussions of 20th century global warming. Together with a pre-1400 extension derived in Mann et. al. (1999) and a spliced instrumental temperature series, this index figured prominently in the IPCC Third Assessment Report (IPCC 2001) and numerous other publications. However, the dataset used to make this construction contained collation errors, unjustified truncation or extrapolation of source data, obsolete data, incorrect principal component calculations, geographical mislocations and other serious defects. These errors and defects substantially affect the temperature index.

Although not all of the dataset could be audited, it was possible to prepare a data base with substantially improved quality control, by using the most recent data and collating it correctly, by avoiding arbitrary filling in or truncation of data and by computing principal components using standard algorithms. Without endorsing the MBH98 methodology or choice of source data, we were able to apply the MBH98 methodology to a database with improved quality control and found that their own method, carefully applied to their own intended source data, yielded a Northern Hemisphere temperature index in which the late 20th century is unexceptional compared to the preceding centuries, displaying neither unusually high mean values nor variability. More generally, the extent of errors and defects in the MBH98 data means that the indexes computed from it are unreliable and cannot be used for comparisons between the current climate and that of past centuries, including claims like “temperatures in the latter half of the 20th century were unprecedented,” and “even the warmer intervals in the reconstruction pale in comparison with mid-to-late 20th-century temperatures” (see press release accompanying Mann et al 1999) or that the 1990s was “likely the warmest decade” and 1998 the “warmest year” of the millennium (IPCC 2001).

REFERENCES

Briffa, K.R., P.D. Jones, and F.H. Schweingruber, 1992, Tree-Ring Density Reconstructions of Summer Temperature Patterns across Western North America since 1600, *Journal of Climate*, Vol. 5, No. 7.

Essex, C. and R. McKitrick (2002). *Taken By Storm: The Troubled Science, Policy and Politics of Global Warming*. Toronto: Key Porter.

Fritts, H.C. & Shao, X.-M. (1992), Mapping climate using tree-rings from western North America, Dendroclimatic evidence from the northern Soviet Union, in *Climate since A.D. 1500*, (eds Bradley, R.S. & Jones, P.D., 269-294, Routledge, 1992).

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Jones, P.D. & Bradley, R.S. (1992) Climatic variations in the longest instrumental records, in *Climate Since A.D. 1500*, (eds Bradley, R.S. & Jones, P.D., 246-268, Routledge, 1992).

Mann, M.E., Bradley, R.S. & Hughes, M.K. (1998) Global-Scale Temperature Patterns and Climate Forcing Over the Past Six Centuries, *Nature*, No. 392, pp. 779-787, 1998.

Mann, M.E., Bradley, R.S. and Hughes, M.K., (1999). Northern Hemisphere Temperatures During the Past Millennium: Inferences, Uncertainties, and Limitations, *Geophysical Research Letters*, No. 26, pp. 759-762. See also press release at http://www.umass.edu/newsoffice/archive/1999/030399warming.html.

APPENDIX: SUPPLEMENTARY INFORMATION SOURCES

Supplementary information for this paper, including detailed information about all 112 proxy series, the computations and data used for the Figures, are available at
http://www.climate2003.com/index.html and
http://www.uoguelph.ca/~rmckitri/research/trc.html.

The supporting web site for the MBH98 paper is
http://www.ngdc.noaa.gov/paleo/ei/data_supp.html.

FTP References for Updated MBH98 Series. Column 1 is MBH98 series number. Column 2 is MBH98 series descriptor. Column 3 shows whether a digital update is referred to in the text. Column 4 shows the digital publication reference (see Supplementary Information). Column 5 is applicable line in multi-set FTP reference. NA- No digital publication located. NV- Digital publication located, but not compared.

Series #	MBH98 Description	Ref	Digital Publication	Line
1	Burdekin River Coral Fluorescence	Yes	ftp://ftp.ngdc.noaa.gov/paleo/coral/west_pacific/great_barrier/burdekin_2001.txt	47
2	Great Barrier Reef Coral Thickness Index	Yes	ftp://ftp.ngdc.noaa.gov/paleo/coral/west_pacific/great_barrier/aims10coreavg.txt	
3	Galapagos Urvina Bay UR-86 dO18	Yes	ftp://ftp.ngdc.noaa.gov/paleo/coral/east_pacific/urvcomp.txt	
4	Red Sea, Aqaba Core 18 dO18	No	ftp://ftp.ngdc.noaa.gov/paleo/coral/red_sea/aq18-18o.txt	
5	Red Sea, Aqaba, Core 18 dC13	No	ftp://ftp.ngdc.noaa.gov/paleo/coral/red_sea/aq18-13c.txt	
6	Espiritu Santu, Vanuatu dO18	Yes	ftp://ftp.ngdc.noaa.gov/paleo/coral/west_pacific/vanuatu_annual.txt	
7	New Caledonia dO18	Yes	ftp://ftp.ngdc.noaa.gov/paleo/coral/west_pacific/nc_published_1992-1657_qtr.txt	
8	Gulf of Chiriqui, Panama dO18	No	ftp://ftp.ngdc.noaa.gov/paleo/coral/east_pacific/secas-10yr-iso.txt	
9	Gulf of Chiriqui, Panama dC13	No	ftp://ftp.ngdc.noaa.gov/paleo/coral/east_pacific/secas-10yr-iso.txt	
10	Central England Historical	Yes	http://www.metoffice.com/research/hadleycentre/CR_data/Daily/HadCET_act.txt	
11	Central Europe Historical	Yes	ftp://ftp.ngdc.noaa.gov/paleo/climate1500ad/ch6.txt	
12	Quelccaya Summit dO18	No	ftp://ftp.ngdc.noaa.gov/paleo/icecore/trop/quelccaya/q83cor1.txt	
13	Quelccaya Summit Accum. (m)	No	ftp://ftp.ngdc.noaa.gov/paleo/icecore/trop/quelccaya/q83cor1.txt	
14	Quelccaya Ice Core 2 dO18	No	ftp://ftp.ngdc.noaa.gov/paleo/icecore/trop/quelccaya/q83summ.txt	
15	Quelccaya Ice Core 2 Accum (m)	No	ftp://ftp.ngdc.noaa.gov/paleo/icecore/trop/quelccaya/q83summ.txt	
16	Dunde Ice Core dO18	NA	NA	
17	West Greenland Ice Melt (pct)	NA	NA	
18	Svalbard Ice Melt, 5-yr avg ("pct)	NA	see ftp://ftp.ngdc.noaa.gov/paleo/climate1500ad/ch26.txt	
19	Penny, Baffin Island dO18	NA	NA	
20	Central Greenland (Stack) dO18	NA	NA	
21	Station temperature 42.5N, 92.5W	Yes	ftp://ftp.ngdc.noaa.gov/paleo/climate1500ad/ch13.txt	2370
22	Station temperature 47.5N, 2.5E	NA	NA	
23	Station temperature 47.5N, 7.5E	Yes	ftp://ftp.ngdc.noaa.gov/paleo/climate1500ad/ch13.txt	780
24	Station temperature 47.5N, 12.5 E	NA	NA	
25	Station temperature 47.5N, 17.5E	NA	NA	
26	Station temperature 52.5N, 17.5E	NA	NA	
27	Station temperature 57.5N, 17.5E	Yes	ftp://ftp.ngdc.noaa.gov/paleo/climate1500ad/ch13.txt	272
28	Station temperature 75.5N, 32.5E	Yes	ftp://ftp.ngdc.noaa.gov/paleo/climate1500ad/ch13.txt	1289

29	Station temperature 62.5N, 7.5E	NA	NA	
30	Station temperature 62.5N, 12.5E	Yes	ftp://ftp.ngdc.noaa.gov/paleo/climate1500ad/ch13.txt	52
31	Station temperature 62.5N, 42.5E	NA	NA	
32	Station Precipitation 12.5N, 62.5E	NA	NA	
33	Station Precipitation 17.5N, 72.5E	NA	NA	
34	Station Precipitation 37.5N, 77.5W	NA	NA	
35	Station Precipitation 42.5N, 2.5E	Yes	ftp://ftp.ngdc.noaa.gov/paleo/climate1500ad/ch13.txt	3650
36	Station Precipitation 42.5N, 7.5E	NA	NA	
37	Station Precipitation 42.5N, 72.5W	Yes	ftp://ftp.ngdc.noaa.gov/paleo/climate1500ad/ch13.txt 3848	
38	Station Precipitation 47.5N, 2.5E	NA	NA	
39	Station Precipitation 47.5N, 12.5E	NA	NA	
40	Station Precipitation 52.5N, 12.5E	NA	NA	
41	Station Precipitation 52.5N, 2.5W	NA	NA	
42	Station Precipitation 57.5N, 7.5W	NA	NA	
43	Tasmania T-reconstruction	Yes	ftp://ftp.ngdc.noaa.gov/paleo/treering/reconstructions/tasmania/tasmania_recon.txt	
44	Java	NA	NA	
45	New Zealand T-reconstruction	Yes	ftp://ftp.ngdc.noaa.gov/paleo/climate1500ad/ch24.txt	65
46	cpatagonia 41S!	Yes	ftp://ftp.ngdc.noaa.gov/paleo/climate1500ad/ch23.txt	187
47	npatagonia 38S!	No	ftp://ftp.ngdc.noaa.gov/paleo/climate1500ad/ch23.txt	236
48	Upper Kolyma River, Russia T	NA		
49	Western North America T (MXD)	No	ftp://ftp.ngdc.noaa.gov/paleo/treering/reconstructions/westnamerica/briffa1992/briffa1992.txt	
50	Western North America T (RW)	NV	ftp://ftp.ngdc.noaa.gov/paleo/treering/reconstructions/westnamerica/readme_westnamerica_recons.txt	
51	Treeline, 412 Alaska	Yes	ftp://ftp.ngdc.noaa.gov/paleo/treering/chronologies/northamerica/usa/ak031.crn	
52	Treeline, Fort Chimo PQ	Yes	ftp://ftp.ngdc.noaa.gov/paleo/treering/measurements/northamerica/canada/cana002.crn	
53	Treeline, Gaspe PQ	Yes	ftp://ftp.ngdc.noaa.gov/paleo/treering/measurements/northamerica/canada/cana036.crn	
54	Treeline, Arrigetech AK	Yes	ftp://ftp.ngdc.noaa.gov/paleo/treering/measurements/northamerica/usa/ak032.crn	
55	Treeline, Sheenjek R, Alaska	Yes	ftp://ftp.ngdc.noaa.gov/paleo/treering/chronologies/northamerica/usa/ak033.crn	
56	Treeline, TTHH Canada	Yes	ftp://ftp.ngdc.noaa.gov/paleo/treering/chronologies/northamerica/canada/cana157.crn	
57	Treeline, Mackenzie Mts, Canada	No	ftp://ftp.ngdc.noaa.gov/paleo/treering/chronologies/northamerica/canada/cana154.crn	

58	Treeline, Coppermine R, Canada	Yes	ftp://ftp.ngdc.noaa.gov/paleo/treering/chronologies/northamerica/canada/cana153.crn
59	Treeline, Hornby Cabin, Canada	No	ftp://ftp.ngdc.noaa.gov/paleo/treering/chronologies/northamerica/canada/cana155.crn
60	Treeline, Churchill, Canada	No	ftp://ftp.ngdc.noaa.gov/paleo/treering/chronologies/northamerica/canada/cana158.crn
61	Treeline, Castle Penin, Canada	No	ftp://ftp.ngdc.noaa.gov/paleo/treering/chronologies/northamerica/canada/cana159.crn
62	Precip-Recon- SE USA-NC	NA	NA
63	Precip-Recon- SE USA –SC	NA	NA
64	Precip-Recon – SE USA -GA	NA	NA
65	Mongolia, Tarvagatny Pass	Yes	ftp://ftp.ngdc.noaa.gov/paleo/treering/chronologies/asia/mong003.crn
66	Yakutia, Russia T-reconstruction	NA	NA – but compare to ftp://ftp.ngdc.noaa.gov/paleo/treering/chronologies/asia/russ142w_crns.crn
67	Fennoscandia T-reconstruction	NA	NA – but compare to ftp://ftp.ngdc.noaa.gov/paleo/treering/chronologies/europe/swed019x_crns.crn
68	Northern Urals T-reconstruction	NA	NA
69	USA, OK PC1	NA	NA
70	USA, OK PC2	NA	NA
71	USA, OK PC3	NA	NA
72	Mexico PC1	NA	NA
73	Mexico PC2	NA	NA
74	Mexico PC3	NA	NA
75	Mexico PC4	NA	NA
76	Mexico PC5	NA	NA
77	Mexico PC6	NA	NA
78	Mexico PC7	NA	NA
79	Mexico PC8	NA	NA
80	Mexico PC9	NA	NA
81	Vaganov12 Chronologies PC1	NA	NA
82	Vaganov 40 Chronologies – PC1	NA	NA
83	Vaganov 58 Chronologies PC1	NA	NA
84	USA PC1	NA	NA
85	USA PC2	NA	NA
86	USA PC3	NA	NA

87	USA PC4	NA	NA
88	USA PC5	NA	NA
89	USA PC6	NA	NA
90	USA PC7	NA	NA
91	USA PC8	NA	NA
92	USA PC9	NA	NA
93	South America PC1	NA	NA
94	South America PC2	NA	NA
95	South America PC3	NA	NA
96	Australia PC1	NA	NA
97	Australia PC2	NA	NA
98	Australia PC3	NA	NA
99	Australia PC4	NA	NA
100	CHIN04	Yes	ftp://ftp.ngdc.noaa.gov/paleo/treering/chronologies/asia/chin004.crn
101	CHIN04X	No	ftp://ftp.ngdc.noaa.gov/paleo/treering/chronologies/asia/chin004x.crn
102	FRAN009	No	ftp://ftp.ngdc.noaa.gov/paleo/treering/chronologies/europe/fran009.crn
103	FRAN010	No	ftp://ftp.ngdc.noaa.gov/paleo/treering/chronologies/europe/fran010.crn
104	FRAN011	No	ftp://ftp.ngdc.noaa.gov/paleo/treering/chronologies/europe/fran011.crn
105	INDI008X	Yes	ftp://ftp.ngdc.noaa.gov/paleo/treering/chronologies/asia/indi002x.crn
106	MEXI001	No	ftp://ftp.ngdc.noaa.gov/paleo/treering/chronologies/northamerica/mexico/mexi001.crn
107	MORO003	No	ftp://ftp.ngdc.noaa.gov/paleo/treering/chronologies/africa/morc011.crn
108	MORO007	No	ftp://ftp.ngdc.noaa.gov/paleo/treering/chronologies/africa/morc001.crn
109	MORO008	No	ftp://ftp.ngdc.noaa.gov/paleo/treering/chronologies/africa/morc014.crn
110	SPAI011	No	ftp://ftp.ngdc.noaa.gov/paleo/treering/chronologies/europe/spai011.crn
111	SPAI012	No	ftp://ftp.ngdc.noaa.gov/paleo/treering/chronologies/europe/spai012.crn
112	SWED002B	Yes	ftp://ftp.ngdc.noaa.gov/paleo/treering/chronologies/europe/swed002.crn

THE M&M CRITIQUE OF THE MBH98 NORTHERN HEMISPHERE CLIMATE INDEX: UPDATE AND IMPLICATIONS

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ABSTRACT

The differences between the results of *McIntyre and McKitrick* [2003] and *Mann et al.* [1998] can be reconciled by only two series: the Gaspé cedar ring width series and the first principal component (PC1) from the North American tree ring network. We show that in each case MBH98 methodology differed from what was stated in print and the differences resulted in lower early 15th century index values. In the case of the North American PC1, MBH98 modified the PC algorithm so that the calculation was no longer centered, but claimed that the calculation was "conventional". The modification caused the PC1 to be dominated by a subset of bristlecone pine ring width series which are widely doubted to be reliable temperature proxies. In the case of the Gaspé cedars, MBH98 did not use archived data, but made an extrapolation, unique within the corpus of over 350 series, and misrepresented the start date of the series. The recent Corrigendum by Mann *et al*. denied that these differences between the stated methods and actual methods have any effect, a claim we show is false. We also refute the various arguments by Mann et al. purporting to salvage their reconstruction, including their claims of robustness and statistical skill. Finally, we comment on several policy issues arising from this controversy: the lack of consistent requirements for disclosure of data and methods in paleoclimate journals, and the need to recognize the limitations of journal peer review as a quality control standard when scientific studies are used for public policy.

1. INTRODUCTION

The Northern Hemisphere temperature index of *Mann et al. [1998, "MBH98"]*, together with its extension in *Mann et al. [1999]*, was adopted by the Intergovernmental Panel on Climate Change *[IPCC, 2001]* as the canonical temperature history of the Northern Hemisphere. It is the authority for claims that the 1990s were the warmest decade of the millennium and its influence on the public's attitude towards climate change and climate change policy has been enormous, and was recently reinforced by its usage in the Arctic Climate Impact Assessment *[ACIA, 2004*].

In *McIntyre and McKitrick [2003*, "MM03"], we attempted to replicate the results of MBH98 and encountered many data and methodological problems, some of which had a significant effect on the central MBH98 conclusions concerning the uniqueness of the late-20th century climate. In response to MM03 and subsequent submissions and correspondence to *Nature*, Mann et al. have provided new information about MBH98, including an extensive archive of data and methods at the Supplementary Information (the "Corrigendum SI") to *Mann et. al., [2003, 2004a, 2004c*, the "Corrigendum"], an extensive archive of data and methods at a University of Virginia FTP site, *[Mann, 2002-2004]* and various written responses to our work *[Mann et al. 2003, 2004a, 200b, 2004d]*. Unfortunately Mann et al. have refused to provide the source code used to generate their results, other than the limited (but essential) programs used for tree ring principal components (PCs). They have also refused to provide supporting calculations for the individual calculation steps in MBH98, especially the controversial step from 1400-1450 (the "AD1400 step"). We made unsuccessful appeals to both *Nature* and the U.S. National Science Foundation, which funded MBH98, to compel release of this material.

Because of this obstruction, not all the problems in MBH98 can be resolved. However, we believe that we have sufficient information in hand to:

(1) completely reconcile the differing results of MM03 and MBH98;
(2) establish the non-robustness of MBH98;
(3) reject the temperature reconstruction in MBH98.

The results presented here do not contradict the results of MM03, but are a logical development of the issues first raised therein.

In order to establish our results, we have attempted to emulate all aspects of MBH98. Much of the controversy in the response to our first article on MBH98 pertained to the accuracy of our emulation. We have followed all published information on the MBH98 procedures, and any remaining differences likely cannot be addressed without disclosure of the actual MBH98 code. However, none of the points established herein are affected by the remaining secrecy surrounding MBH98 computational details (for full details of our emulation, including R code, see the Supplementary Information). We anticipate that there will be critical interest in the emulation itself and we will address these matters in a separate paper.

One of the points of view advocated in this article is that individual data series matter in the MBH98 results. We disagree with the view that problems with individual series simply get washed out in a multiproxy study. In the context of the MBH98 methodology this optimistic assumption is untenable.

Section 2 explains the sources of difference between MM03 and MBH98. Section 3 considers the issue of the robustness of MBH98 results. Section 4 discusses particular issues concerning bristlecone pine and cedar proxies, which are central to the matters in this paper. Section 5 deals with some remaining counter-arguments from Mann *et al.* and Section 6 offers concluding comments.

2. RECONCILING MM03 AND MBH98

Differences between MM03 results and MBH98-type results can be reconciled through variations in the handling of only two series, the Gaspé "northern treeline" series and the first principal component (PC1) from the North American proxy roster (NOAMER). The changes are illustrated in Figure 1 below.

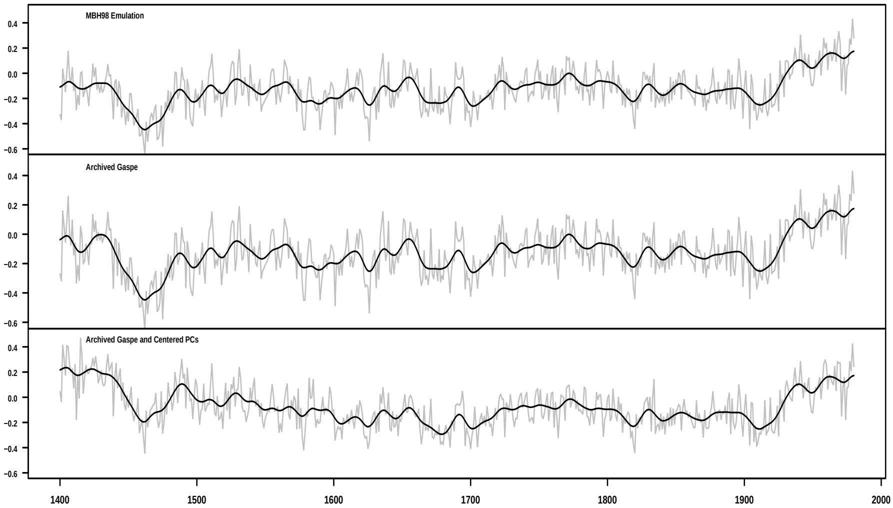

Figure 1. NH Temperature Index. Top panel: MBH98 emulation; middle panel: using archived Gaspé version; bottom panel: using centered PC algorithm.

The top panel shows our emulation (version 3) of MBH98, which implements new information from the Corrigendum SI. Relative to the MBH98 reconstruction, it has a Reduction of Error ("RE") statistic of 0.83 in the 1400–1901 period (R^2 – 0.68) – both values lower than our version 2 emultion without the Corrigendum SI information.

The middle panel ("Archived Gaspé") shows the effect of merely using the version of the Gaspé series archived at WDCP, rather than the version as modified by MBH98, accounting for a material change in the early 15th century. The only difference between the two series is the extrapolation of the first four years in MBH98. Under MBH98 methods, a series had to be present at the start of a calculation step in order to be included in the interval roster. In only one case in the entire MBH98 corpus was this rule broken – where the Gaspé series was extrapolated in its early portion, with the convenient result of depressing early 15th century results. This extrapolation was not disclosed in MBH98, although it is now acknowledged in the Corrigendum *[Mann et al., 2004c]*. In MBH98, the start date of this series was misrepresented; we discovered the unique extrapolation only by comparing data as used to archived data. There are other considerations making this unique extrapolation singularly questionable. The Gaspé series is already included in the NOAMER principal components network (as cana036) and thus appears twice in the MBH98 data set, and the extrapolation, curiously, is only applied to one of the columns. The underlying dataset is based on only one tree up to 1421 and only 2 trees up to 1447. *Jones and Mann [2004]* point to the need for "circumspect use" of tree ring sites with few early examples. The early portion of the series fails standard minimum signal criteria [e.g. *Wigley et al. 1984]* and indeed fails the data quality standards Mann et. al. themselves listed elsewhere. The early portion of the series was not used by the originating authors *[Jacoby and d'Arrigo, 1989; D'Arrigo and Jacoby, 1992]*, whose analysis only begins effective 1601. In fact, *Jones and Mann [2004]* do not use the Gaspé series as an individual proxy and only use the Jacoby-d'Arrigo northern treeline composite when it is adequately replicated after 1601.

The bottom panel ("Archived Gaspé and Centered PCs") shows the additional effect of using conventional (centered) PC methods and is virtually identical to MM03. MBH98 had stated that they used "conventional" principal components (PC) calculations. A conventional PC calculation applies standardization in which the columns are centered by subtracting their mean, which is done for the calculations in the bottom panel. Stepwise PC series are used (extending the NOAMER network back to AD1400), thereby avoiding the main criticism leveled against MM03.

Once again, MBH98 contained a misrepresentation, this time about their PC method. After the University of Virginia FTP site was made publicly available following MM03, by examining PC series archived there and, by examining source code for PC calculations,[1] we were able to determine that MBH98 had not carried out a "conventional" PC calculation, but had modified the PC algorithm, by, among other things, subtracting the 1902-1980 mean, rather than the 1400-1980 column mean, prior to PC calculations, so that the columns were no longer centered on a zero mean in the 1400–1980 step. By this procedure, series are more decentered, and their variance more inflated, the larger is the difference between the series mean and the mean of the 20th century subset. The effect of this transformation would have been mitigated if they had carried out a singular value decomposition on the covariance matrix, but they carried it out on the de-centered data matrix. We have shown elsewhere that this method re-allocates variance so that the PC algorithm then strongly over-weights hockey stick-shaped proxies and that it is so efficient in mining a hockey stick shape that it nearly always produces a hockey-stick shaped PC1 even from persistent red noise [*McIntyre and McKitrick, 2005;* discussed in *Muller, 2004*].

This observation has received a considerable amount of publicity and some observers have misunderstood the point. While we have made scripts available at our FTP site, for greater certainty, we show here the relevant R functions, which were used

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[1] See weights in ftp://holocene.evsc.virginia.edu/pub/MBH98/TREE/ITRDB/NOAMER/pca-noamer.f. This program has 588 lines of Fortran code, of which the first 323 lines are particular to the PC calculations and the final 265 lines is an SVD routine. The 1902–1980 mean is removed in lines 168–173 as follows:

```
168 c   remove 1902–19xx mean from training data
169 c
170     do i=nlow,nhigh
171        iyear = i-nlow+1
172       aprox(iyear.j)=aprox(iyear.j)-roxave(j)
173       end do
```

for these results and which show algorithmically exactly what Mann and we are doing. We emphasize that we are able to exactly replicate Mann's PC calculations with these scripts and that, in unpublished material at *Nature*, Mann has replicated our PC calculations. Although many readers may not be familiar with R *[R Development Core Team, 2004]*, we strongly believe that the provision of source code in the actual language is an essential part of ensuring replicable results and that there is sufficient commonality in source codes that the following code will illuminate the issues even for persons who are unfamiliar with the language. We have also chosen to highlight source code in the running text rather than a footnote, because source code issues turn out to be an essential finding. The detrended standard deviation was calculated with the following function:

```
sd.detrend<-function(x) { t<-c(1:length(x)) ; fm<-lm(x~t); sd.detrend<-
    sd(fm$residuals); sd.detrend }
```

The MBH98 transformation was calculated with the following function:

```
mannomatic<-function(x, M=78) {N<-length(x);  xstd<- (x- mean( x[(N-
    M):N]))/sd(x[(N-M):N]);
 sdprox<-sd.detrend(xstd[(N-M):N]); mannomatic<- xstd/sdprox; mannomatic }
```

The main effect of this transformation is through the de-centering, rather than the difference between detrended and undetrended standard deviations, which, in this case, is empirically rather slight. A default value of 78 for M is used to simplify use for the 1902–1980 calibration period, which is M+1 years long.

The North American tree ring network for the AD1400 step was collected into one matrix *Tree*, in this case of dimension 581x70. A matrix *Tree.mannomatic* transformed according to MBH98 was obtained through applying the above function to the matrix as follows:

```
Tree.mannomatic<-apply(Tree,2,mannomatic)
```

By applying the svd function in R, a singular value decomposition corresponding exactly to the archived results (eigenvalues, eigenvectors and PC series) at the University of Virginia FTP site[2] was obtained:

```
PCA.mannomatic.svd<-svd(Tree.mannomatic)
```

We have reported that this algorithm nearly always yields hockey-stick shaped series from persistent red noise networks [*McIntyre and McKitrick, 2005;* also see below]. In response, some readers have expressed incredulity about whether our methods

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[2] Directory <ftp://holocene.evsc.virginia.edu/pub/MBH98/TREE/ITRDB/NOAMER/BACKTO_1400>, PCs at pc01.out, …; eigenvectors at eof01.out,…eigen.out contains percentage variance for each eigenvalue of total variance rather than actual eigenvalues.

accurately reflect actual MBH98 methods. For this specific point – the replication of tree ring PC calculations, we re-iterate that we have *exact* replication of MBH98 PCs and that the above method, however implausible it may seem on first principles, is the method that was used in MBH98 tree ring PC calculations.

While PC algorithms are related to SVD algorithms, they are not exactly the same. We were able to replicate the above results with a PC algorithm, only by specifying an uncentered option as follows:

```
PCA.mannomatic.prcomp<-prcomp(Tree.mannomatic, center=FALSE)
```

A different protocol is used for reporting eigenvalue information in the *svd* and *prcomp* algorithms, but the results are identical, allowing for the protocol.[3]

The method which we used in MM03, MM04a and MM04b can be shown by the corresponding command, displaying two differences clearly – not using the transformed data; and the use of a *centered* method.

```
PCA.centered<-prcomp(Tree, center=TRUE)
```

The default value is center=TRUE and the result would also have been realized by:

```
PCA.centered<-prcomp(Tree)
```

A centered calculation is clearly what one would expect in a "conventional" calculation. A centered calculation on the de-centered matrix is a possible variation, which can be implemented through:

```
PCA.mannomatic.centered<-prcomp(Tree.mannomatic, center=TRUE)
```

In this case, the calculation is done on the covariance matrix of the transformed data and produces an intermediate result (in terms of the hockey stick shape of the PC1).

We see no advantage to the MBH98 approach of using hundreds of lines of Fortran text to carry out the above functions, thereby opening up the possibility of error, since it can be easily done in a few lines of high-level programming languages, as shown above. While the MBH98 procedure may have originated as a programming error, the Corrigendum did not admit any error and seemed to take the position that the above method was intentional (even though it was undisclosed and tends to produce hockey sticks). Be that as it may, the key difference turns out to be not the stepwise principal components method, as claimed in *Mann et al. [2003]*, but the use of an uncentered algorithm on de-centered data. Together with the MBH98 use of a non-archived version of the Gaspé series (containing a unique extrapolation), this fully reconciles MM03 and MBH98 results.

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[3] PCA.mannomatic.svd$d = PCA.mannomatic.prcomp$sdev *sqrt (N-1), where N is the number of years in the calculation. PCA.mannomatic.svd$u[,k]=PCA.mannomatic.prcomp$x[,k]/(sqrt(N-1) *PCA.mannomatic.prcomp$sdev[k]).

3. EFFECT OF SLIGHT VARIATIONS ON 15TH CENTURY TEMPERATURE RESULTS

We presented these results in a slightly different form in *McIntyre and McKitrick [2004a, 2004b]*. In response to these results (and to MM03), *Mann et al. [2004a, 2004b, 2004d]* argued that they can still obtain MBH98-type results under other conditions. While we differ with Mann et al. on the issue of which methodological assumptions are "correct", if the assumptions are specified sufficiently precisely, there is surprising consensus on the actual effects. Slight variations of methods and data lead on the one hand to MM-type results (with a 15th century higher than the late 20th century) or on the other hand to MBH-type results (with a 15th century lower than the late 20th). These can be summarized as follows.

Variants on the NOAMER PC1 (After Removing the Gaspé Series Extrapolation)

- In the MBH98 de-centered PC calculation, a small group of 20 primarily bristlecone pine sites, all but one of which were collected by Donald Graybill and which exhibit an unexplained 20th century growth spurt (see Section 5 below), dominate the PC1. Only 14 such chronologies account for over 93% of the variance in the PC1,[4] effectively omitting the influence of the other 56 proxies in the network. The PC1 in turn accounts for 38% of the total variance. In a centered calculation on the same data, the influence of the bristlecone pines drops to the PC4 (pointed out in *Mann et al., 2004b, 2004d).* The PC4 in a centered calculation only accounts for only about 8% of the total variance, which can be seen in calculations by Mann et al. in Figure 1 of *Mann et al. [2004d]*.
- If a centered PC calculation on the North American network is carried out (as we advocate), then MM-type results occur if the first 2 NOAMER PCs are used in the AD1400 network (the number as used in MBH98), while MBH-type results occur if the NOAMER network is expanded to 5 PCs in the AD1400 segment (as proposed in *Mann et al., 2004b, 2004d)*. Specifically, MBH-type results occur as long as the PC4 is retained, while MM-type results occur in any combination which excludes the PC4. Hence their conclusion about the uniqueness of the late 20th century climate hinges on the inclusion of a low-order PC series that only accounts for 8 percent of the variance of one proxy roster.
- If de-centered PC calculation is carried out (as in MBH98), then MM-type results still occur regardless of the presence or absence of the PC4 if the bristlecone pine sites are excluded, while MBH-type results occur if bristlecone pine sites (and PC4) are included. Mann's FTP site *[Mann, 2002–2004]* actually contains a sensitivity study on the effect of excluding 20 bristlecone pine sites[5] in which this adverse finding was discovered, but the results were not reported or stated publicly and could be discerned within the FTP site only with persistent detective work.
- If the data are transformed as in MBH98, but the principal components are calculated on the covariance matrix, rather than directly on the de-centered data, the

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[4] See <ftp://holocene.evsc.virginia.edu/pub/MBH98/TREE/ITRDB/NOAMER/BACKTO_1400/eof01.out>

[5] See <ftp://holocene.evsc.virginia.edu/pub/MBH98/TREE/ITRDB.NOAMER/BACKTO_1400-CENSORED>

results move about halfway from MBH to MM. If the data are not transformed (MM), but the principal components are calculated on the correlation matrix rather than the covariance matrix, the results move part way from MM to MBH, with bristlecone pine data moving up from the PC4 to influence the PC2. In no case other than MBH98 do the bristlecone series influence PC1, ruling out their interpretation as the "dominant component of variance" *[Mann et al, 2004b]*

- If no North American PC1 is used at all in the AD1400 calculations (which occurs if PC calculations are done over the maximum period in which all sites are available, as done in MM03), then MM-type results occur under both centered and decentered PC calculations, with and without bristlecone pines.

Variants on the Gaspé Series (After Applying Centered PC Method on NOAMER)

- If the archived version of the Gaspé series is used, MM-type results occur. If the early (pre-1447) portion of the site chronology with less than 3 trees is not used [see discussion in *Jones and Mann, 2004*], MM-type results occur. If the duplicate version of the Gaspé series used as an individual proxy is not used (while continuing the use of the Gaspé series in the NOAMER network with or without the extrapolation), MM-type results occur. MBH-type results occur only if a duplicate version of the Gaspé series is used as an individual proxy and the portion of the site chronology with 1–2 trees is used and if the first four years of the chronology are extrapolated under an ad hoc procedure not otherwise used in MBH98. *Mann et al. [2004a, 2004b]* justified the extrapolation as a means of maintaining representation of northern treeline series in this interval. If representation is achieved by use of the updated version of the Sheenjek River series (which meets replication standards in the 15th century), then MM-type results occur.

Variants on the Entire Procedure

- If, as is suggested in *Mann et al. [2004a, 2004b]*, no PC calculations are applied to the North American and Stahle/SWM networks and the sites are instead used as individual proxies (while otherwise carrying on with MBH98 methods), then MBH-type results are obtained regardless of whether the Gaspé series is duplicated or extrapolated. In this case, the MBH temperature reconstruction becomes little more than an index of bristlecone pine growth. However, if the bristlecone pine sites are excluded from this network, then MM-type results are obtained.

We emphasize the consensus between ourselves and Mann et al. on the results of sufficiently well-defined calculations. The PC calculations themselves are replicated between parties to complete accuracy. Differences remain in the emulations of NH temperature (given the PC series), but *Mann et al. [2003]* showed a calculation with high early 15th century results if the North American PC1 were unavailable; the comments in *Mann et al. [2004b]* about the effect of the PC4 confirm this overall agreement if assumptions are sufficiently well defined.

These results also show that the effects of individual series are not necessarily washed out in a multiproxy method of MBH98 type, contrary to suggestions in *Zorita et al. [2003]*[6] and *von Storch et al. [2004]*[7].

In response to a reader's suggestion, we performed a sensitivity test in which we arbitrarily increased the ring widths of all non-Graybill (50 of 70) sites by +0.5 (index units) in the first half of the 15th century, and then re-calculated the PC1 under MBH98 methodology. The purpose is to evaluate how well the added variance is retained in the final temperature index. We provide the exact script here both to describe the calculation exactly and because the results are initially very counter-intuitive and have provoked some disbelief.

```
Tree.adj<- Tree                                        #creates mirror object for testing
Tree.adj[1:50,!graybill]<- Tree.adj[1:50,!graybill]+0.5  # adds 0.5 to all non-Graybill sites (mean is 1)
Tree.adj.mannomatic<- apply(Tree.adj,2, mannomatic)    # applies MBH98 transformation to columns
PCA.adj.mannomatic<-svd(Tree.adj.mannomatic)           #svd on data matrix
PC1.adj.mannomatic<- PCA.adj.mannomatic$u [,1]         #selects PC1 from svd model
```

The results of this calculation are shown in Figure 2 together with the results from a centered calculation (all results smoothed). For a centered calculation, the increased ring widths for the first 50 years lead to an increase in the PC1 as expected. However, under the MBH98 de-centered method the *increased* ring widths for 50 non-Graybill sites in the early 15th century causes a significant *decrease* (!) in the early 15th century PC1. *Carried forward through to Northern Hemisphere temperature calculations, these increased ring widths would be construed by the MBH98 method as evidence of* ***colder*** *temperatures in the early 15th century.*

This rather perverse result nicely illustrates a problem of mechanically applying a numerical algorithm like PC analysis without regard to whether it makes sense for the underlying physical process. PC methods are indifferent to the orientation (up or down) of a series – the difference is merely the presence or absence of a negative sign. A vivid example in this context is the archived PC1 for *Mann et al. [1999]*,[8] which is upside-down as archived, but which was flipped for presentation purposes in *Mann et al. [1999]*. Under the MBH98 algorithm, the addition of the extra values in the first half of the 15th century causes the algorithm to flip the series upside-down so that they match as well as possible to the bristlecone pines, whose hockey stick pattern is

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[6] "MBH98's method yields an estimation of the value of the temperature PCs that is optimal for the set of climate indicators as a whole, so that the estimations of individual PCs cannot be traced back to a particular subset of indicators or to an individual climate indicator. This reconstruction method offers the advantage that possible errors in particular indicators are not critical, since the signal is extracted from all the indicators simultaneously."

[7] "The optimized temperature fields target the whole available proxy network at a given time, so that the inclusion of a few instrumental data sets in the network should have little influence on the estimated fields, unless the instrumental records are explicitly overweighted. The advantage is that the method is robust against very noisy local records. This contrasts with direct regression methods, where the estimated temperature fields are the predictands of a regression equation. In this case a few instrumental records, highly correlated to the temperature fields, may overwhelm the influence of proxy records with lower correlations in the calibration period."

[8] ftp://ftp.ngdc.noaa.gov/paleo/contributions_by_author/mann1999/proxies/itrdb-namer-pc1.dat>.

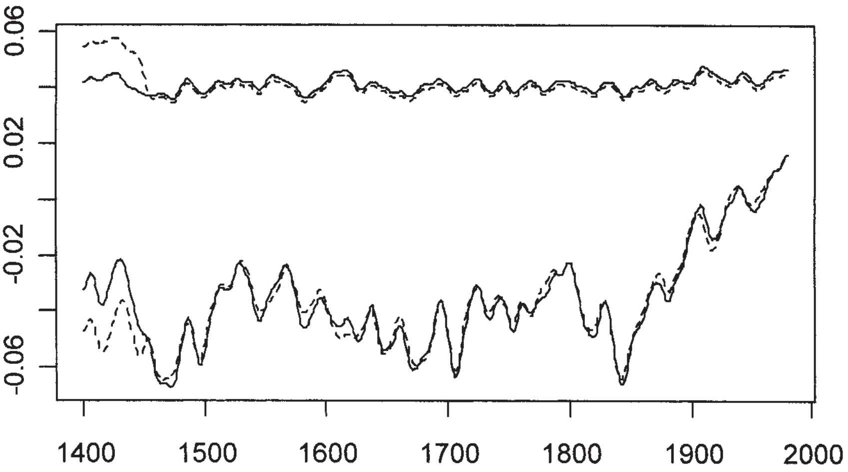

Figure 2. North American AD1400 PC1. Above: PC1 using centered calculations; below: MBH98 PC1 using decentered method. Solid-base case; dashed – with arbitrary addition of 0.5 to non-Graybill sites from 1400–1450. 25-year smoothing is applied.

imprinted on the PC1. This does not occur using a centered algorithm.

4. ROBUSTNESS

The sensitivity of 15th century results to such slight variations of method and data show a fundamental instability in MBH98 results, related especially to the presence or absence of bristlecone pines and Gaspé cedars. This flatly contradicts some claims by Mann et al. about the robustness of MBH98 results. MBH98 stated the following:

> **the long-term trend in NH is relatively robust to the inclusion of dendroclimatic indicators in the network**, suggesting that potential tree growth trend biases are not influential in the multiproxy climate reconstructions. (p. 783, emphasis added)

This was stated in even stronger, and equally misleading, terms in *Mann et al. [2000]* as follows:

> We have also verified that possible low-frequency bias due to non-climatic influences on dendroclimatic (tree-ring) indicators is not problematic in our temperature reconstructions….**Whether we use all data, exclude tree rings, or base a reconstruction only on tree rings, has no significant effect on the form of the reconstruction for the period in question.** … These comparisons show no evidence that the possible biases inherent to tree-ring (alone) based studies

> impair in any significant way the multiproxy-based temperature pattern reconstructions discussed here. (http://www.ngdc.noaa.gov/paleo/ei/ei_nodendro.html, emphasis added)

The synopsis of results in Section 3 effectively disproves these claims, regardless of the point of view that one may take on questions such as whether 2 PCs or 5 PCs is "correct" for the AD1400 North American network. Each of the permutations discussed above is a sensitivity test much less draconian than excluding all tree rings. Both the Gaspé cedar series and the bristlecone pine series are obviously subsets of the dendroclimatic indicators and each has a significant effect on the 15th century results, as indeed do the specific methodological decisions (extrapolation, decentered PC calculations), which enhance the effect of these series.

Figure 3 may be helpful in illustrating exactly why these two series have such a dramatic impact on early 15th century results. The left panel is a scatterplot as follows. For each of the 22 proxies in the AD1400 roster we computed the correlation between each proxy and the temperature PC1 over the 1902–1980 interval (x-axis), and the difference between the 1902–1980 mean and the 1400–1450 mean, divided by the 1400–1980 standard deviation (y-axis). The 1902–1980 interval is the MBH98 calibration period and is the interval over which the mean is computed in the PC decentering. It can be shown that the PC weights for each proxy in the AD1400 network are closely related to the correlation with the temperature PC1. The difference of means is a measure of "MBH-ness" – series with a zero value are flat, while those with an absolute value in excess of 1 have a a hockey stick shape (sometimes upside-up and sometimes upside-down). The two points in the top right hand corner represent

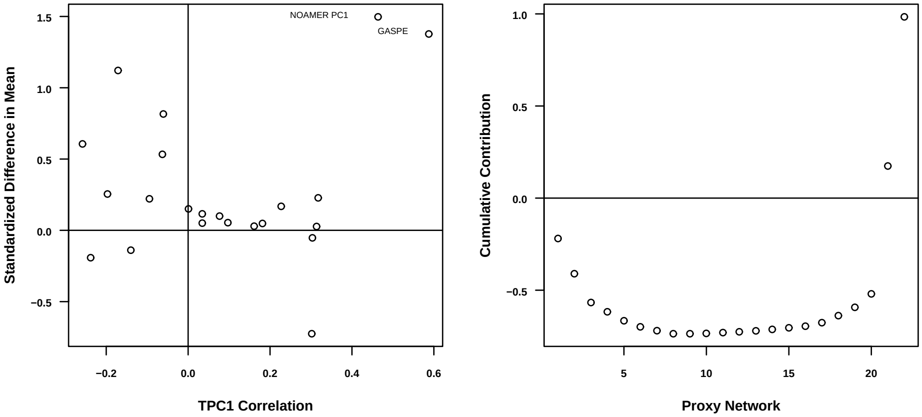

Figure 3. Left: Scatterplot with x-axis: correlation between AD1400 step proxies and the temperature PC1 in the calibration period 1902–1980; y-axis: difference between 1902–1980 mean and 1400–1450 mean divided by 1400–1980 standard deviation. right: cumulative contribution to standardized difference between 1902–1980 mean and 1400–1450 mean.

the MBH98 NOAMER PC1 and Gaspé tree ring series. Except for these two points there is an overall *negative* relationship between the difference of means and the correlation with temperature: i.e. hockey stick series fit the temperature data relatively poorly in the calibration interval. But the NOAMER PC1 and Gaspé series are such influential outliers that they reverse this pattern for the model as a whole.

In the right panel the 22 series in the AD1400 step are introduced sequentially into the multiproxy calibration model, with the Gaspé and NOAMER PC1 series introduced last. The standardized difference between the 1902–1980 mean NH temperature and the 1400–1450 mean NH temperature is computed at each step. The relatively high 1902–1980 temperature in MBH98 (i.e. the hockey stick shape) results entirely from the contributions of the two final, outlier values.

If the same calculations are carried out using centered principal components calculations and the Sheenjek River series is used as a northern treeline proxy instead of the Gaspé series, as represented in Figure 4, there are no longer two outlier series, resulting in the 1400–1450 mean temperature being higher than the 1902–1980 mean temperature.

Some consternation has been expressed by critics of MM03 that its high early 15th century values are inconsistent with other supposedly independent temperature reconstructions. However, the MM results are obtained from the same underlying proxy set as MBH98. The influence of the two outlier series can be seen in a different way in Figure 5, which shows a simple comparison of the mean of Gaspé and NOAMER PC1 against a weighted average of 6 series used in the AD1400 network

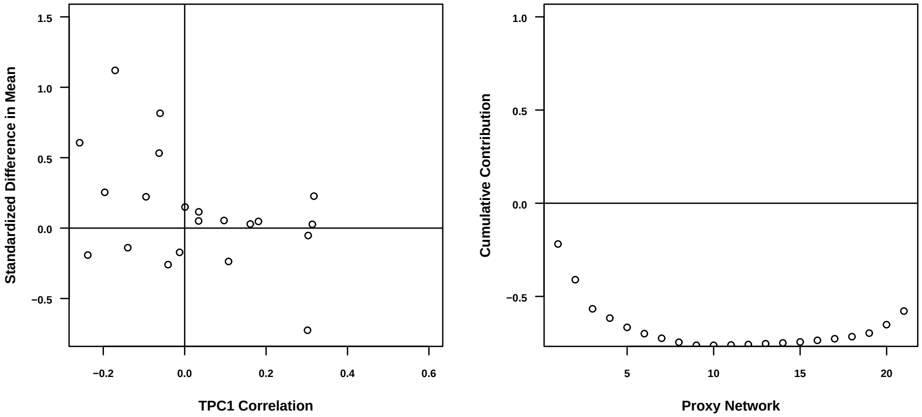

Figure 4. As with Figure 3, but with centered PC calculations and Sheenjek River. Left: Scatterplot with x-axis: correlation between AD1400 step proxies and the temperature PC1 in the calibration period 1902–1980; y-axis: difference between 1902–1980 mean and 1400–1450 mean divided by 1400–1980 standard deviation. right: cumulative contribution to standardized difference between 1902–1980 mean and 1400–1450 mean. The 1400–1450 mean temperature is now higher than the 1902–1980 mean temperature.

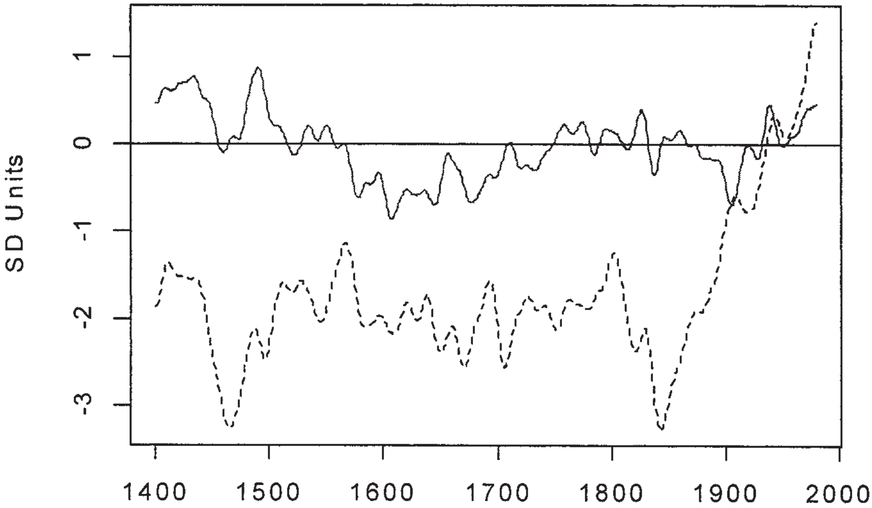

Figure 5. Solid: Weighted average of 6 MBH98 AD1400 step proxies: 4 Quelccaya series (averaged to one series), Tornetrask temperature reconstruction and Tasmania temperature reconstruction; Dashed – average of MBH98 NOAMER PC1 and Gaspé. All series smoothed with 25-year Gaussian filter.

(and often used in other multiproxy studies). The weights are calculated as follows: equal weight is given to the Tornetrask and Tasmania series, while each of the 4 constituent Quelccaya series are given a quarter-weight, reversing the sign for the accumulation series. All series are standardized. The strong negative bias of the two outlier series is evident, as is the closer relationship of the 6 series average to the MM-type reconstruction.

5. BRISTLECONE PINES AND GASPÉ CEDARS

Although considerable publicity has attached to our demonstration that the PC methods used in MBH98 nearly always produce hockey sticks, we are equally concerned about the validity of series so selected for over-weighting as temperature proxies. While our attention was drawn to bristlecone pines (and to Gaspé cedars) by methodological artifices in MBH98, ultimately, the more important issue is the validity of the proxies themselves. This applies particularly for the 1000–1399 extension of MBH98 contained in *Mann et al. [1999]*. In this case, because of the reduction in the number of sites, the majority of sites in the AD1000 network end up being bristlecone pine sites, which dominate the PC1 in *Mann et al. [1999]* simply because of their longevity, not through a mathematical artifice (as in MBH98).

Given the pivotal dependence of MBH98 results on bristlecone pines and Gaspé cedars, one would have thought that there would be copious literature proving the validity of these indicators as temperature proxies. Instead the specialist literature only raises questions about each indicator which need to be resolved prior to using them as temperature proxies at all, let alone considering them as uniquely accurate stenographs of the world's temperature history.

5.1 Bristlecone Pines

There has been an undoubted increase in bristlecone pine ring widths in the 20th century. *Graybill and Idso [1993]* explicitly stated it is greater than could be explained by temperature. Ironically, *Mann et al. [1999]* (referring to the bristlecone pine sites) admits the same thing:

> A number of the highest elevation chronologies in the western U.S. do appear, however, to have exhibited long-term growth increases that are more dramatic than can be explained by instrumental temperature trends in these regions. (p. 760)

The anomalous 20th century growth rate for bristlecone pines is illustrated in Figure 6, which compares the standardized MBH98 PC1 (dominated by bristlecone pines) to the *Briffa et al. [1992a]* North American temperature reconstruction (using tree rings from many species), which is used in MBH98 itself, as well as *Jones and Bradley [1993]*, *Jones et al. [1998]* and *Jones and Mann [2004]*. There is little visual relationship. The correlation between the two series in the MBH98 calibration period of 1902–1980 is 0; the RE statistic for the MBH98 PC1 as a predictor for the Briffa temperature reconstruction in a verification period of 1600–1901 is –7.7, showing no skill whatsoever. Thus, whatever "dominant component of variance" *[Mann et al., 2004a]* is supposedly captured in the MBH98 PC1 has apparently escaped detection in the Briffa reconstruction. The strong negative bias of the MBH98 PC1 is evident in comparison to the Briffa reconstruction. The strong negative bias of the MBH98 PC1 is also evident in periods where we have instrumental records in North America. There is no reason to believe that average temperatures in the 18th century were negative 3 standard deviation units.

Despite the reliance of MBH98 on the North American PC1, the validity of this series as a temperature proxy was not independently established in peer-reviewed literature. Co-author Hughes stated later *[Hughes and Funkhouser, 2003*] that the anomalous growth rate of bristlecone pines was a "mystery", which should have raised questions about the PC1. The strong difference between the Briffa re-construction, comprised of many species, and the MBH98 PC1 (representing only bristlecone pines) should also have raised questions about whether there may be species-particular effects related to any of the numerous unusual features of bristlecone pines.

We surveyed the literature on bristlecone pines and report here on many peculiarities pertaining to this species, which should be clearly addressed prior to relying on the MBH98 PC1 for policy purposes.

Bristlecones are famously long-lived, but despite this, do not appear to senesce *[Lanner and Connor, 2001; Connor and Lanner, 1991]*. They occur in an unusual strip bark form, where the bark in most long-lived trees dies around the circumference except for a small strip on one side. Unlike most pines, they continue to respire during the winter thereby consuming photosynthate *[Schulze et al., 1967]*.

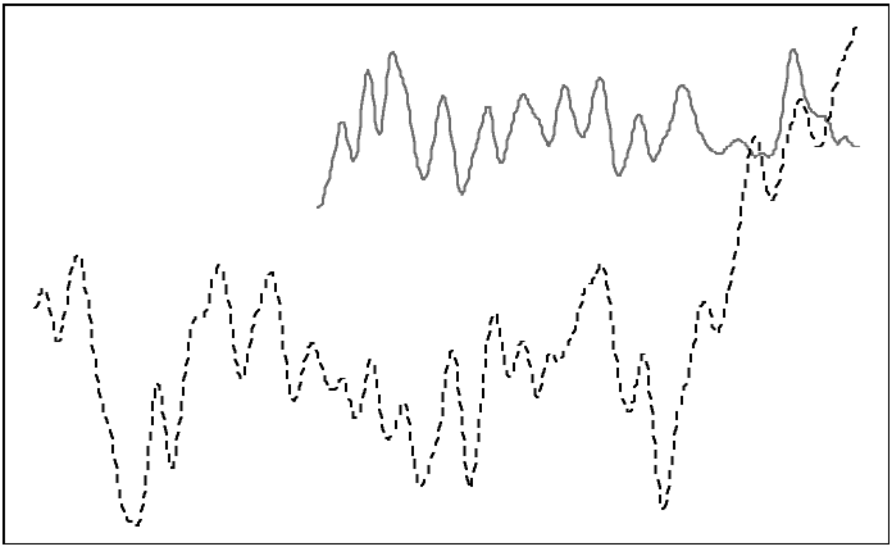

Figure 6. Solid: North American temperature reconstruction of Briffa et al. [1992a]. Dashed: the MBH98 North American PC1. All series smoothed with a 25-year Gaussian filter. Both series are standardized by subtracting the 1902–1980 mean and dividing by the 1902–1980 standard deviation (re-scaling is not an issue here, since the PC calculations have already been done.)

Tree lines at bristlecone pine sites were significantly higher in the past, especially during the Holocene Optimum about 6000 years ago, but also during the medieval period *[LaMarche and Mooney, 1967; LaMarche, 1973]*. In 1957, bristlecone pines in the Campito Mountain area were not reproducing *[Billings and Thompson, 1957]*, indicating that more favourable conditions than the 1950s were required for bristlecones pine to become seedlings.

The Sheep Mountain series, ca534, is the top-weighted series in the MBH98 NOAMER PC1[1] receiving 390 times the weight of the least-weighted series. *LaMarche, Fritts, Graybill and Rose [1984]* (all authors listed for emphasis) argued that the anomalous 20th century growth in bristlecone pines was attributable to CO_2 fertilization, using Sheep Mountain as an example. In the 1980s, Donald Graybill followed up at the other bristlecone pine sites, collecting the samples which later comprised the NOAMER PC1. Graybill specifically sought out strip bark samples and reported that strip bark forms had much stronger 20th century growth than entire bark forms at the same site *[Graybill and Idso, 1993]*. More recently, *Bunn et al. [2003]* confirmed higher growth in strip bark forms than entire bark forms at sites in Montana.

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[1] ftp://holocene.evsc.virginia.edu/pub/MBH98/TREE/ITRDB/NOAMER/BACK TO_1400/ECOF01.OUT and series identifications in ftp://holocene.evsc.virginia.edu/pub/MBH98/TREE/ITRD /NOAMER/ BACTO_1400/noamer-itrdb-ad1400

Brooks et al. [1996] also pointed out the impact of anthropogenic nitrogen on fertilization of high-altitude bristlecone pines, stating that:

> At these high-elevation catchments there has been a shift in ecosystem dynamics from an N-limited system to an N-saturated system as a result of anthropogenically-fixed N in wetfall and dryfall. Results from the Western Lakes Survey component of the National Surface Water Survey show that N saturation is a regional problem in the Colorado Front Range, with many lakes having (NO3-) concentrations greater than 10 meq/L. Foliar N to P ratios in Bristlecone Pine increase with elevation in the Colorado Front Range, indicating that at higher elevations P is translocated from foliar tissue more efficiently than N and that increasing atmospheric deposition of N with elevation is causing a change from N limitation to P limitation in the highest-elevation Bristlecone Pines.

Graybill and Idso [1993] attributed the anomalous 20th century growth of strip-bark forms to CO_2 fertilization There are some possible reasons why CO_2 fertilization may affect high-altitude strip bark forms more strongly than lower-altitude entire-bark forms and there is specific evidence for CO_2 fertilization for vegetation from the White Mountains, California, where important bristlecone pine stands are located *[Mooney et al., 1964]*. The response to changes of CO_2 concentration in controlled experiments is strongly non-linear and attenuates as CO_2 levels increase. CO_2 levels at the high altitudes of bristlecone pines (3000–3500 m) are significantly lower than at sea level and, at the lower CO_2 levels at high-altitude, the response to increased CO_2 levels is in a range with stronger response.

The general hypothesis of CO2 fertilization of tree growth has been hotly contested. Opponents [e.g. *Jacoby and D’Arrigo, 1997 and Graumlich, 1991]* have pointed to other sites which do not exhibit anomalous 20th century growth and argued that the anomalous growth effect is limited to high-altitude strip bark forms. More recently, *Schauer et al. [2001]* reported that trees with strip-bark have significantly lower pre-dawn water potentials during the driest part of the growing season relative to non-strip-barked trees. So the anomalous growth of strip bark trees may be related to effects differing from CO_2.

Whatever side one takes on the CO_2 fertilization debate is really immaterial. Even if one adopts the position of Jacoby and Graumlich – that the effect is limited to strip bark forms – since the NOAMER PC1 is comprised almost entirely of strip-bark forms it could easily be affected as a proxy, even under the limited position taken by Jacoby and Graumlich.

Mann et al. [1999] purported to adjust the NOAMER PC1 for CO_2 fertilization, by coercing the shape of the NOAMER PC1 to the Jacoby northern treeline reconstruction in the 1750–1980 period, arguing that the northern treeline series would not be affected by CO_2 levels. Once one gets into such ad hoc adjustments, many new questions need to be answered about the validity of the adjustment procedure. In the actual *Mann et al. [1999]* adjustment, the main adjustment for "CO_2 fertilization" takes place in the 19th century rather than the 20th century, with *Mann et al. [1999]* being forced into the counterintuitive position that the effect of CO_2 fertilization was somehow stronger in the 19th century but became attenuated in the 20th century, the exact opposite of the hypothesis of *LaMarche et al. [1984]* and later *Graybill and Idso [1993]*. If the differences between the northern treeline series and the bristlecone pines arise from some other factor (a couple of possibilities are discussed below), then the *Mann et al. [1999]* "adjustment" would have made the proxy record even more distorted. In MBH98, no such adjustment was made in the AD1400 period in any event. (It also appears that no such adjustment was made in *Mann and Jones [2003]* or *Jones and Mann [2004]*, but we are presently unable to confirm this.)

An important influence on these trees is precipitation. *Mann and Jones [2003]* point out the need to distinguish between temperature and precipitation effects, which may have a different expression. Within bristlecone pine literature, *LaMarche and Stockton [1974]* pointed out that high-altitude bristlecone pine stands have both a lower limit and upper limit and argued that bristlecone pine growth at the lower limit was controlled by precipitation and at the upper limit by temperature. *Hughes and Funkhouser [2003]* found regional correlations among high-altitude bristlecone pine growth, which they attributed to regional climate, but still concluded that the anomalous 20th century growth was a "mystery". Even in upper limit stands, the bristlecone pine stands in the PC1 are located in semi-arid regions and the bifurcation in *LaMarche and Stockton [1974]* may be overly simplistic. Studies of actual bristlecone pine growth have shown that it is limited by soil moisture *[Fritts, 1969; Beasley and Klemmedson, 1973]*. Even in higher stands, their principal botanical competition in many locations is with big sagebrush *[Wright and Mooney, 1965; Mooney et al., 1964]* with bristlecones outcompeting big sagebrush on moister dolomite substrate. This effect is vividly illustrated by Figure 2 of *Wright and Mooney [1965]*, where the sharp geological contact between the dolomite and sandstone is clearly shown by the change from bristlecone pines to sagebrush at the same elevation. The same effect is also perhaps shown in the charming 19th century painting (Figure 7), where a sharp change in vegetation at the same elevation is easily observed. There is evidence that higher moisture levels in the 20th century in the American Southwest accounted for high growth rates in New Mexico *[Grissino-Mayer, 1996; D'Arrigo and Jacoby, 1991]*, where two of the *LaMarche and Stockton [1974]* sites are located. The effect may extend to other locations. In the classical bristlecone pine sites of the White Mountains, where a weather station operated close to Sheep Mountain and Campito Mountain from 1954 to 1980, records show low ring widths correlate to drought, even in upper limit stands. *Mann and Jones [2003]* pointed out that precipitation proxies need to be carefully distinguished from temperature proxies and a complete demonstration that these effects have been separated in bristlecone pines is obviously required. *Williams [1996]* reported that a continuous climate record since 1951 at Niwot Ridge in the Colorado Front Range, near a bristlecone pine site, showed a decline in mean annual temperature and an increase in annual precipitation amount.

There is one other issue that needs to be canvassed and eliminated prior to reliance on bristlecone pines. The pulse in bristlecone pine growth is contemporaneous with a

Figure 7. 19th century painting showing bristlecone pines. Source: NOAA website. In the background, the pines reaching up the hill are almost certainly bristlecone pines on a dolomite substrate, with a sandstone substrate where there are no pines. Retrieved from <http://www.ngdc.noaa.gov/paleo/drought/drght_graumlich.html>

pulse in woody plant growth throughout the American Southwest, attributed to overgrazing by sheep in the late 19th Century (see Figure 8), which in turn followed the extension of the railroads *[Allen, 1998; Allen et al., 1998]*. Sheep differ from other species in that they will completely destroy grasslands by eating down to the roots, leaving barrens *[Allen, 1998]*. Although *Allen [1998]* only documented the expansion of pinyon pines and junipers into terrain formerly occupied by 19th century grasslands, Allen (2004, pers. comm.) did not exclude the possibility of a similar effect involved in anomalous 20th century growth for bristlecone pines, but was unaware of any studies on the topic. There is a published reference to the introduction of large commercial sheep flocks in the late 19th century in the White Mountains CA *[St. Andre et al. 1967]*, where the key sites of Sheep Mountain and Campito Mountain are located. The founder of the Sierra Club, John Muir, complained of the depredations of sheep in the Sierra Nevadas (adjacent to the White Mountains) as “hoofed locusts” *[Muir, 1911]*. Carl Purpus, a late 19th century botanical collector in the Sierra Nevadas, stated in 1896 that commercial flocks had cleaned out all grass to the top of Old Mt Whitney [present-day Mount Langley, which reaches 4,280 m] *[Ertter, 1988]*. Allen (pers. comm., 2004) said that there was a large commercial sheep trail at Jicarita Peak NM, another bristlecone pine site studied by *LaMarche and Stockton [1974]*. In severe high-altitude terrain, even after the departure of commercial flocks, a small population of bighorn sheep could prevent the re-establishment of grass (Leslie Thomas, Colorado Springs, landscape architect, pers. comm.) Since grass (and other herbs) compete with pines for scarce moisture, one can hardly exclude, on a priori basis, the possibility of a connection between anomalous 20th century growth rates of bristlecone pines and a growth release following 19th century overgrazing, as experienced elsewhere in the American Southwest.

Figure 8. Sheep grazing in ponderosa pine forests and grasslands near Flagstaff, AZ, ca. 1899. Image 21a by F.H. Maude, Cline Library Special Collections, Northern Arizona University. Retrieved from http://www.cpluhna.nau.edu/Change/grazing.htm

Finally, there may even be problems with the site chronologies as indexes of actual growth. *Cook and Peters [1997]* pointed out that conventional dendrochronology techniques resulted in a bias in 20th century results at Campito Mountain, one of the Graybill sites in the NOAMER PC1. Presumably the same effect applies to other bristlecone pine sites.

If the reader takes the (reasonable, we think) view that these unusual trees are not mystical antennae for an elusive "climate signal" missed by all other proxy indicators, then each of the above problems and issues must be dealt with systematically, prior to any reliance being placed on bristlecone pine ring widths as the dominant arbiter of world climate history.

4.2 Gaspé Cedar Series

The other critical series in MBH98 is the Gaspé cedar chronology. There are many interesting similarities between bristlecone pines and cedars. *Kelly, Cook and Larson [1992]* likened Eastern white cedars to bristlecone pines, pointing out the occurrence of strip bark forms and the apparent lack of senescence. Larson (pers. comm., 2004) stated that there is little aging effect in Ontario cliff cedars: they grow slowly when they are young and slowly when they are old.

There is virtually no site information on the Gaspé cedar series. *Sheppard and Cook [1988]* mentions the site, but is not a comprehensive publication. They commented on its "peculiar" growth spurt in the 20th century, but cautioned that there were no other northern white cedar chronologies available so it was not possible to say whether it was indicative of climatic conditions or some other influence. *Sheppard and Cook [1988]* referred to two other pending cedar studies, one in Maine and one in Michigan. The Maine series (Sag Pond) has been archived at WDCP and does not show any 20th century trend, while the Michigan series seems to have remained unpublished. *Archambault and Bergeron [1992]* published a cedar series from Lac Duparquet, Quebec, but it does not show any 20th century trend and the authors reported a positive correlation to precipitation and a negative relationship to June temperature. For Ontario cedars, *Kelly et al. [1994]* reported a strong negative relationship between temperature and observed growth rates in the 20th century.

Cedar growth is optimal under cool and moist conditions *[Kelly et al., 1994; Matthes-Sears and Larson, 1990]* and declines both in very hot and very cold weather (an upside-down U). A similar upside-down U pattern has been reported for bristlecone pines and two other conifer species *[Schoettle, 2004].* In fact, the possibility of a quadratic ring width response to temperature has been recently posited by *D'Arrigo et al. [2004*] in connection with Twisted Tree Heartrot Hill. This possibility has far-reaching implications on the entire enterprise of estimating past temperatures from tree ring widths: with a quadratic (upside-down U) response, it is impossible to determine whether a past narrow ring width resulted from cold or hot weather.

We carried out our own comparison between gridcell temperature in the Gaspé area and Gaspé temperatures and did not find any correlation.

Cook and Peters [1997] discussed above, explored spurious end-of-sample growth bias as an artifact of tree-ring chronology de-trending. Amazingly, in addition to the Campito Mountain bristlecone pine site, their other main example was the Gaspé series (cana036). In order to eliminate this bias, the underlying tree ring chronologies would have to be re-calculated, a calculation which would have the effect of reducing its hockey-stick shape, with implications that stand alone from any of the other issues raised in this paper.

The Gaspé site was re-sampled in the early 1990s; we have seen a site chronology showing that the re-sampling did not replicate the previously reported 20th century growth spurt. However, the new data has not been published or archived, and the originating authors have refused to disclose the new data on the grounds that the older data "better" shows temperature and because their research is "mission-oriented". We have sought coordinates of the actual site in order to commission a re-sampling of the site, but we have not received this information despite repeated requests.

5. REFUTATION OF COUNTER-ARGUMENTS OF MANN ET AL.

We now turn to a discussion of recent arguments of *Mann et al. [2003, 2004a, 2004b, 2004d],* purporting to counter our various criticisms.

5.1 "Effective Omission" of Indicators

Mann et al. [2004a, 2004b] argued that our use of centered principal components calculations amounted to an "effective omission" of the 70 sites of the North American network. They showed that a calculation excluding the North American PC1 also resulted in MM-type results with high early 15th century values. Although the calculations to which they were referring (using centered PC methods) did *not* actually omit this network, since the results were similar to results without the PC1, Mann et al. argued that our calculations *effectively omitted* these indicators. This critique fails on several counts. First, the North American PC1 is only one of 22 series in the AD1400 step. A robust statistical method should be relatively insensitive to the presence or absence of one of 22 series. If centered principal components calculations are used, the temperature index is relatively insensitive to the presence or absence of the North American PC1. On the other hand, if de-centered principal components calculations are used, the results are very unstable to the presence or absence of the North American PC1. Robustness considerations therefore tend to support the use of a conventional centered PC method. Second, using the MBH98 decentered method, 14 bristlecone sites account for over 99% of the explained variance in the PC1. Using the terminology of Mann et al., under the decentered methodology, the other 56 sites are "effectively omitted" from the PC1, which is merely a carrier for the bristlecone pines. Using a centered methodology, the PC1 is relatively similar to the mean of all the series. Thus, we believe that it is more accurate to characterize MBH98 de-centering methods as "effectively omitting" the majority of tree ring sites.

Mann et al. [2004a, 2004b] also argued that use of the archived version of the Gaspé series amounted to an "effective omission" of the northern treeline series. *Jones and Mann [2004]* do not use the Gaspé series at all and only use the Jacoby northern treeline series in the relatively well-replicated portion after 1601. Simply applying the quality control criteria of *Jones and Mann [2004]* should not provoke complaints about "effective omission". Moreover, we have specifically maintained the number of northern treeline series in the AD1400 step, by using the updated version of the Sheenjek River series (which could have been used in 1997). Replication in the Sheenjek River series is much superior to that of the Gaspé series, which does not meet standard quality control criteria in its early portion.

5.2 Tendency of decentered PC methods to yield PC1 hockeysticks

In *McIntyre and McKitrick [2004a, 2004b],* we pointed out that the de-centered PC method used in MBH98 tends to produce hockey-stick shaped series. We have sharpened this result considerably in *McIntyre and McKitrick [2005]*. There we define a "hockey stick" as a series in which the 1902–1980 mean differs from the long-term mean by more than 1 standard deviation (σ). Applying the MBH98 decentered PC method to trendless red noise with persistence properties of the North American tree ring network (modeled as fractional processes), in 10,000 simulations we found that the 1902–1980 mean differed from the 1400–1980 mean by more than 1 σ over 99% of the time, (1.5 σ –72%; 1.75 σ –19% and 2 σ –0.2%). The hockey stick blades sloped up about half the time and down half the time, but the 1902-1980 mean is almost never within one σ of the 1400–1980 mean. PC series are unoriented so that no significance is attributed to the sign.

In their comment to the earlier version of this argument, Mann et al. [2004a, 2004b] argued that their PC series were simply linear combinations of the underlying proxies and that no pattern could be produced in the PC1 which was not in the underlying data. It is of course true that the PC series are linear combinations of the proxies, but it is evident that the de-centering process preferentially selects series with hockey-stick shapes and this over-weighting is what yields a pattern that is not representative of the underlying data. The exclusive selection of bristlecones into the PC1 should give rise to serious examination of why all other proxies are so efficiently discarded – a discussion which does not occur in MBH98.

5.3 Lack of a linear response to temperature in "key" proxies

In *McIntyre and McKitrick [2004b]*, in our criticism of bristlecone pines as an arbiter of world climate, we pointed out (as above) that a linear response to temperature had not been established for these sites (as seemingly required by MBH98). *Mann et al. [2004b]* replied that:

> MM04 demonstrate their failure to understand our methods by claiming that we required that "proxies follow a linear temperature response". In fact we specified (MBH98) that indicators should be "linearly related to one or more of the instrumental training patterns[2]", not local temperatures.

We doubt the authors really believe the idea of a temperature proxy exhibiting no relationship to local temperature makes much sense. It is instructive to compare this response to the policy articulated in *Jones and Mann [2004]*, which states:

> A number of other temperature reconstructions used in earlier multiproxy composites or in review papers [e.g., Jones et al., 1998; Mann et al., 1998a, 1999; Mann and Jones, 2003] are not included. This is because they are either less resolved than decadal resolution [e.g., Dahl-Jensen et al., 1998] or correlations with local grid box temperatures are not significant …

Jones and Mann [2004] do consider "climate field reconstructions" (CFRs), which appear to be similar to "instrumental training patterns" of MBH98. In this case, *Jones and Mann [2004]* argue that the CFRs should be shown to be similar to some aspect of local climate during some part of the year. This would seem to invite opportunistic use of either precipitation or temperature as a climate indicator, something for which they reproached *Soon et al. [2003].* But perhaps most telling is the comment of MBH98 co-author Hughes in *Hughes and Funkhouser [2003],* who did not attribute the bristlecone pine growth to an “instrumental training pattern”, but stated that their anomalous 20th century growth rate is a “mystery”.

5.4 Insignificant Values of Verification Statistics

Mann et al. [2004a, 2004b] have argued that, regardless of how they got their results, their reconstruction with decentered PC methods and extrapolation of the duplicate Gaspé series has greater “skill” than a reconstruction with centered PC methods and use of the archived version of the Gaspé series. Most dendroclimatic reconstructions provide a suite of verification statistics, including RE, R^2, CE, sign test and product mean test *[e.g. Cook et al, 1994]*. In MBH98, only the RE statistic is reported for steps prior to the AD1820 step, including the controversial AD1400 step. Mann et al. have not provided their own results for the other verification statistics or supporting calculations from which these statistics could be calculated, and have refused requests for this information. *McIntyre and McKitrick, 2005,* using Monte Carlo simulations, shows that the MBH98 benchmark for 99% significance for the RE statistic is substantially under-stated (0.0 in MBH98 versus a Monte Carlo estimate of 0.59) and that the R^2 and other verification statistics, which were not reported in MBH98, are statistically insignificant in the AD1400 step.

Mann et al. [2004b] contained a diatribe against the R^2 statistic. However, in other papers [e.g. *Mann and Jones, 2003],* when they were in his favour, Mann has reported R^2 statistics. In this case, we estimate the R^2 statistic as being only 0.02 – obviously well short of statistical significance and strongly indicating that even the lower level of RE significance discussed above is spurious.

5.5. “Confirmation” by other studies

Mann et al. [2003, 2004a, 2004b] argued that their results are similar to those of “independent” studies, such as *Jones, Briffa et al. [1998], Crowley and Lowery [2000], Briffa, Jones et al [2001], Mann and Jones [2003]* and *Jones and Mann [2004],* calculated with different proxies and different methods. This “similarity” is typically shown by “spaghetti” diagrams supposedly illustrating the similarity, rather than through detailed analysis.

These studies are hardly “independent”. If all the authors in the multiproxy articles are listed, one sees much overlapping. Mann himself was a co-author of two supposedly “independent” studies; his sometime co-author (as well as Bradley’s sometime co-author) Jones was co-author of two of the others. Even *Crowley and Lowery [2000],* where there is no apparent overlap, stated that they used data supplied by Jones. This hardly amounts to “independence” in any conventional use of the term.

Many proxies are re-used in these studies, a point which *Briffa and Osborn [1999]* acknowledged, as follows:

> An uninformed reader would be forgiven for interpreting the similarity between the 1000-year temperature curve of Mann et al. and a variety of others also representing either temperature change over the NH as a whole or a large part of it (see the figure) as strong corroboration of their general validity, and, to some extent, this may well be so.

> Unfortunately, very few of the series are truly independent: There is a degree of common input to virtually every one, because there are still only a small number of long, well-dated, high-resolution proxy records.

Briffa's Polar Urals and Tornetrask series [*Briffa et al., 1995; Briffa et al., 1992b* respectively] are recurrent proxies as is Cook's Tasmania reconstruction [*Cook et al., 1991, 1992*]. The North American PC1, criticized here, is used as a proxy in *Mann et al. [1999]*, *Mann and Jones [2003]* and *Jones and Mann [2004]*.

Most importantly, even if such articles generate similar results to MBH98, that does not prove that MBH98 results were calculated correctly. Mann et al. have to support MBH98 on its own terms; appeals to other results are completely irrelevant.

For rhetorical purposes, agencies like the IPCC may well turn to these other studies for support, if MBH98 can no longer be used, but the prominent reliance on MBH98/99 in the Third Assessment Report is a matter of public record and cannot now be undone. If there is any lesson from our work it is that, before making prominent use of these other studies, each one needs to be proven replicable. However critical we may be of MBH98, the disclosure for nearly all the other studies is significantly worse:

- After over 20 requests, Crowley (pers. comm., Oct. 2004) supplied smoothed and transformed versions of proxy data used in *Crowley and Lowery [2000]*, but stated that he could not find the actual data versions used so that these could be verified.
- A listing of the sites used in *Briffa et al. [2001]* has never been published or archived. The authors have not responded to requests for data.
- A listing of sites in *Esper et al. [2002]* is available, but the majority of site data is not publicly archived.
- Most of the data from *Mann and Jones [2003]* and *Jones and Mann [2004]* was eventually provided by Jones in July 2004. However, Jones was unable to provide the weightings used in the creation of the final results, as these were in the possession of co-author Mann.
- Of these studies, only *Jones et al. [1998]* has a relatively complete record.

None of these studies provides a careful, objective analysis of how the particular proxy records are selected from the thousands available, thereby leaving unanswered the possibility of cherry-picking. Replication is only the first step in assessment. One then has to assess the quality of the proxies actually used. For example, we have concerns about potential problems in Briffa's Polar Urals record *[Briffa et al., 1995]*, which has a very significant effect on medieval values in several of these studies. We intend to address these issues in the future.

6. DISCUSSION

There are many large issues at stake in this discussion, mainly because of the powerful role a handful of published paleoclimate studies are playing in policy decisions.

The ability of later researchers to carry out independent due diligence in paleoclimate is severely limited by the lack of journal policies or traditions requiring contributors to promptly archive data and methods. *King [1995]* has excellent comments on replication. In this respect, paleoclimate journal editors should consider changes taking place at some prominent economics journals. For example the *American Economic Review* now requires, as a precondition of publication, archiving data and computational code at the journal. This is a response to the critique of *McCullough and Vinod [2003]*, and earlier work by *Dewald et al. [1986]*. The files associated with paleoclimate studies are trivial to archive. In our view, if the public archive does not permit the replication of a multiproxy study, then it should be proscribed for use in policy formation *[McCullough and Vinod, 2003]*.

In addition, we are struck by the lack of policy both in paleoclimate publications and in climate policy reports (e.g. IPCC, ACIA) regarding the reporting of results adverse to their claims. While it may be assumed that results adverse to their claims would be generally disclosed, we are unaware of any paleoclimate journal which explicitly articulates this as a requirement to authors. In contrast, for a prospectus offering securities to the public, officers and directors are required to affirm that the prospectus contains “full, true and plain disclosure”, which requires the disclosure of material adverse results. In MBH98, there are a number of examples, where results adverse to their claims were not reported (and in some cases, actual misrepresentations), as listed below (most of which we have discussed passim above):

- MBH98 did not report the results adverse to their conclusions from calculations excluding bristlecone pines (contained in the BACKTO_1400-CENSORED directory).
- For steps prior to 1820, MBH98 did not report verification statistics other than the RE statistic. Unlike the above case, we cannot prove on the present record that Mann et al. had calculated these other statistics, but we consider it quite likely that these statistics were calculated and not reported. (In this case, we believe that diligent referees, even under the limited scope and mandate of journal peer review, should have requested the reporting of this information.)
- MBH98 did not report results from calculations using archived Gaspé tree ring data (which did not contain the extrapolation of early values). Again, while we cannot prove that they actually carried out calculations using the archived version, we find it inconceivable that this unique extrapolation would have been made without previously doing a calculation using the archived version. Although the Corrigendum (six years after the event) disclosed the existence of this extrapolation, it did not disclose its uniqueness or the actual effect of this previously undisclosed extrapolation, disclosure which we believe to be essential for full disclosure, since the very existence of the extrapolation had been hidden from referees and previous readers by a misrepresentation of the start date of this series.
- MBH98 incorrectly stated that conventional PC methods were used, which necessarily means centered calculations. This error in their prior disclosure should have been prominently disclosed in the Corrigendum together with its effects on PC calculations described, especially since it was at the heart of our submission then

under review at *Nature*. Mann et al. could then try to argue in that context that the effect was limited (an argument with which we obviously disagree). Instead, the prior incorrect disclosure was not mentioned at all in the printed Corrigendum; in the Corrigendum SI, the incorrect prior disclosure is not specifically mentioned; the method itself is acknowledged, but it is not prominent and even carries a denial that the method made any difference (a claim discussed at length above).

- The aggressive claims that MBH98 methods were “robust” (see discussion above) are extremely problematic. As noted above, Mann et al. had carried out a sensitivity study on the exclusion of the bristlecone pines and knew that their 15th century results were not robust to these sites. We also believe that they knew the instability regarding the Gaspé series (or else they wouldn’t have done the extrapolation.) We find it difficult to understand how the claims to robustness could have made under these circumstances.

We are also struck by the extremely limited extent of due diligence involved in peer review as carried out by paleoclimate journals, as compared with the level of due diligence involved in auditing financial statements or carrying out a feasibility study in mineral development. For example, “peer review” in even the most eminent paleoclimate publications, as presently practiced, does not typically involve any examination of data, replication of calculations or ensuring that data and computational procedures are archived. We are not suggesting peer reviewers should be auditors. Referees are not compensated for their efforts and journals would not be able to get unpaid peer reviewers to carry out thorough audits. We ourselves do not have explicit recommendations on resolving this problem, although ensuring the archiving of code and data as used is an obvious and inexpensive way of mitigating the problem.

But it seems self-evident to us that, recognizing the limited due diligence of paleoclimate journal peer review, it would have been prudent for someone to have actually checked MBH98 data and methods against original data before adopting MBH98 results in the main IPCC promotional graphics..

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