authorizing our access to the tunnel. EDF also provided lake-level data.

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Climate Reconstructions: Low-Frequency Ambition and High-Frequency Ratification

PAGES 113, 120

The assessment of past temperature variations and the magnitude and characteristics of recent warmth relative to warm periods in pre-industrial times—for example, during the Medieval Warm Period (MWP)—have critical implications for understanding and quantifying the forcing of climate in natural and anthropogenic conditions. The desire to benchmark past climate variability of the northern hemisphere has resulted in four millennial-length temperature reconstructions with annual resolution [*Briffa*, 2000; *Esper et al.*, 2002; *Jones et al.*, 1998; *Mann et al.*, 1999].

These records, however, provide different perspectives on the above issues. For example, the temperature amplitude reconstructed by *Esper et al.* [2002] is about 1°C, approximately twice that of *Mann et al.* [1999] and *Jones et al.* [1998]. Additionally, *Briffa* [2000] and *Esper et al.* [2002] display a pronounced MWP followed by a significant 200–300-year-long cooling trend associated with the Little Ice Age. Such a trend is broadly absent in *Mann et al.* [1999] and *Jones et al.* [1998].

To reconcile the apparent discord between these reconstructions, hypotheses have been put forth that point to potential limitations in the ability of the individual records to capture climate variability (items i and iii, below), and also, hypotheses suggesting that discrepancies may result from differences in what the reconstructions represent (items ii and iv, below). Briefly, these hypotheses are:

(i) Insufficient data used in *Esper et al.* [2002] to provide reasonable estimates of past temperature variability [*Mann and Hughes*, 2002].

(ii) Differences in the spatial coverage of regional proxy records used in *Esper et al.* [2002] and *Mann et al.* [1999]. It was suggested that the presence or absence of tropical data could explain trend and amplitude discrepancies between these records [*Esper et al.*, 2002].

(iii) The use of different tree ring de-trending methods and their varying abilities to retain millennial-scale variations. This limitation might apply to reconstructions [e.g., *Mann et al.*, 1999] where constituent records are not specifically processed to preserve low-frequency climate information [*Esper et al.*, 2002].

(iv) Seasonality explained by the reconstructions–growing season weighted when using only tree ring data [*Briffa*, 2000; *Esper et al.*, 2002] or more annually weighted when using combinations of various proxies (e.g., corals, ice core $\delta^{18}O$, tree rings; *Jones et al.* [1998]; *Mann et al.* [1999]) [*Esper et al.*, 2002; *Mann and Hughes*, 2002].

To help address these hypotheses, we have removed the millennial-scale variations from the reconstructions (Figure 1). It is apparent that once these lowest-frequency trends have been removed, the four reconstructions possess rather similar variations at multi-decadal to centennial wavelengths. To our knowledge, these similarities have not been mentioned in comparisons of these records, and they exist despite the relatively few data (numbers provided in the figure) and the different methodological approaches used for reconstruction development.

However, due to the limited number of millennial-length records, and regions from which such records are developed, all of these reconstructions draw data from the same proxy pool and are therefore not truly independent assessments of climate variation. Overlap varies from reconstruction to reconstruction, although data from Tornetraesk and the Polar Urals are used in all four records discussed here. These tree sites are, for example, two of the six locations in *Esper et al.* [2002] and two of the seven predictor locations in *Mann et al.* [1999] that have data at the beginning of the last millennium.

Even though for these two sites *Mann et al.* [1999] used maximum latewood density data, and *Esper et al.* [2002], as for all sites, used ring width data, Tornetraesk and the Polar Urals represent the vast majority of data overlap between these two reconstructions. While it can be difficult to quantify the exact weighting and influence of individual series in reconstructions, we can survey the primary impact of shared data by developing reconstructions with and without these two sites. To do so, the arithmetic mean of the linear and nonlinear curves was calculated, as shown in *Esper et al.* [2002] with the full *Esper et al.* [2002] data set (EsperFULL) and a subset in which the Tornetraesk and Polar Urals data have been excluded (EsperSUB). After removing the millennial-scale variations from these records as in Figure 1, EsperFULL and EsperSUB correlate at 0.94 (1000–1980 period). The EsperFULL record correlates at 0.44 and the EsperSUB at 0.41 with the *Mann et al.* [1999] record (1000–1980 period), respectively. During the 1000–1500 period, when the two tree sites are a larger percentage of the available data, similar values of 0.44 and 0.43, respectively, are obtained.

From the general similarity in Figure 1 and the above comparison, we conclude that, at least for the multi-decadal to centennial variations, the data utilized are sufficient to derive similar temperature histories. With this being said, and with regard to argument (i), the substantial low-frequency difference between the linear and nonlinear groups during the 11th and 12th centuries in *Esper et al.* [2002] indicates that the transition from the MWP into the Little Ice Age is not necessarily well understood or captured in this record [*Esper et al.*, 2002; Fig. 2a].

The commonality between the detrended series (Figure 1) further indicates that differences in spatial coverage of the proxies—e.g., including the tropics [*Mann et al.*, 1999], or not including the tropics [*Esper et al.*, 2002]; hypothesis (ii)—likely has minimal impact on multi-decadal to centennial wavelength differences between the records. Coherence in these shorter wavelengths implies that millennial-scale differences between the reconstructions should be even smaller due to difference in location, as the spatial autocorrelation of temperature fields extends to greater distances when increasing lengths of time are considered [*Karl et al.*, 1994]. The observational (land and sea surface) annual temperature records averaged over the full northern hemisphere and averaged over the 20–90°N latitudinal bands demonstrate the insignificance of including/excluding lower-latitude data as they correlate at 0.97 over the 1856–2000 period. Standard deviations for these data are 0.25 and 0.28°C, respectively, showing that slightly more variability might be inherent in a record that does not contain tropical data, and/or is calculated over a smaller spatial domain. However, these differences in variability are not large enough to substantially account for the significant amplitude and trend differences between the large-scale reconstructions.

Having shown that the data and space-related hypotheses (i and ii) are of secondary importance, we now show the different de-trending

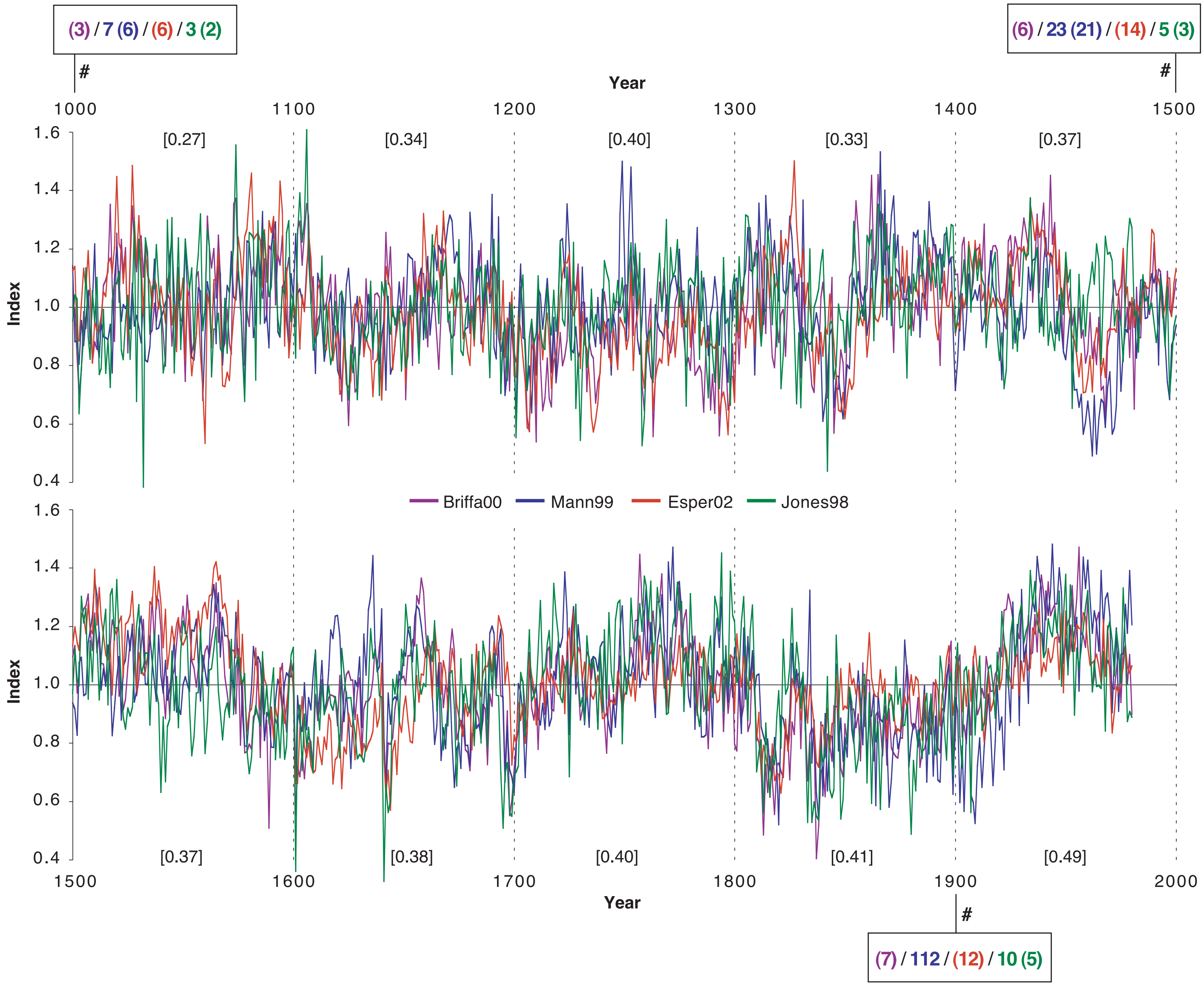

Fig. 1. Large-scale temperature reconstructions after millennial-scale variations have been removed by de-trending with a cubic smoothing spline with a 50% frequency-response cutoff width equal to 67% of the length of the common period (1000–1980): purple, Briffa *[2000]; blue,* Mann et al. *[1999]; red,* Esper et al. *[2002]; green,* Jones et al. *[1998]. The series are not smoothed to illustrate the full range of variability up to centennial scales. The inter-series correlations between all four reconstructions are 0.42 for non-smoothed data and 0.63 for 50-yr smoothed data, both calculated over the 1000–1980 period. Inter-series correlations for each century (1901–1980 for the 20th century) remain fairly high and stable over time (numbers provided in brackets). The lowest correlation (0.27) occurs in the 11th century, despite the fact that the relative data overlap (e.g., Torneträsk and Polar Urals tree ring data used in all reconstructions) is greatest during this early period. In boxes, the numbers of northern hemisphere regional proxy records considered in the large-scale reconstructions are provided for 1900, 1500, and 1000 (colors as for the curves). Values in parentheses indicate numbers of tree ring records. For* Mann et al. *[1999], 112 in 1900 includes records from the southern hemisphere, and the numbers for 1500 and 1000 include principal components derived from 21 western and 6 southern U.S. tree sites that are counted as two regional records.*

methods (iii) applied to tree ring data to retain millennial-scale variations, as a substantial argument to explain dissimilarities between the original records. The preservation of low-frequency, climate-related trends is very sensitive to the standardization applied [*Fritts*, 1976]. As such, methods to specifically retain these variations are required for reconstruction of longer wave length climate variations, as shown in one of the earliest tree ring-based northern hemisphere temperature reconstructions [*Jacoby and D'Arrigo*, 1989].

The application of different de-trending methods likely becomes more important toward the beginning of the reconstructions, where tree ring data dominate, and where possible long-term cooling trends that mirror long-term (tree age-related) noise trends are removed by traditional individual series de-trending methods [*Esper et al.*, 2002]. For example, regional tree ring records such as those from France [*Serre*, 1978] and Morocco [*Stockton*, 1988] represent a significant fraction of predictors available in the early periods of the *Mann et al.* [1999] reconstruction, when only few proxy series still remain (see the numbers in Figure 1). As used, they contain just one to a few trees in their earlier portions. The series from France, for example, contains one tree before 1043 and two trees before 1186. More important, in the case of the French record, the original tree ring data were de-trended so that no millennial-scale variation is preserved in the resulting chronology [*Mann et al.*, 1999].

The same de-trending limitation applies to the data obtained from the Atlas cedars of Morocco, another series spanning the entire millennium. However, this site is described as being precipitation-sensitive, and thus, also possesses variations that are generally "whiter" than temperature variations [*Stockton*, 1988]. It is thus not surprising that the temperature reconstructions possess different low-frequency characteristics when they rely on data that are variably limited in their ability to retain low-frequency climatic information. In general, this argument is relevant not only to the de-trending methods actually applied, but also to the appropriateness of the tree ring data themselves for the use of different de-trending methods. For example, it was recently demonstrated that age-related de-trending methods, as used in the *Esper et al*. [2002] record, may not be fully suitable if applied to ring width data from only living tree sites from which no relict or sub-fossil wood are available [*Esper et al*., 2003].

Finally, with regard to the different reconstructed seasons (hypothesis iv), scaling and correlation analyses indicate that the proxy-based records contain the greatest similarities to the large-scale observational temperature data at decadal and lower frequencies. For example, after applying a 20-year filter, the correlations between large-scale proxy and warm season and annual observational data are all greater than 0.8 and less than 0.3 for the low- and high-pass fractions, respectively. Yet, annual and warm season, weighted, large-scale observational data are practically identical, and correlate at 0.94 over the period 1856–2000 (April-September versus annual temperatures; averaged over the full northern hemisphere land and sea-surface areas). It is therefore difficult to statistically validate which temperature season a reconstruction actually represents on hemispheric scales. We further suggest that the change of proxy type mix, from multi-proxy in recent centuries to almost only tree ring records toward the beginning [e.g., *Mann et al*., 1999], likely causes a shift in the reconstructed seasonality toward warm season temperatures back in time.

From the comparisons shown here, we conclude that the various methods applied to de-trend tree ring data appear to most substantially account for the differing low-frequency trends between recently developed large-scale reconstructions of temperature over the past millennium. On theoretical grounds, the low-frequency trends obtained from these reconstructions, such as the long-term cooling trend into the Little Ice Age, differ in a way the de-trending methods applied therein predict that they should. However, it would be incorrect to assume that applying age-related de-trending methods, such as Regional Curve Standardization, by definition, ensures a more accurate reconstruction of temperature variability. The similarity of the large-scale reconstructions in the multi-decadal to centennial scales, even when data overlap is minimized, suggests that higher-frequency climate variations are generally better understood than lower-frequency variations. Yet, it is not entirely surprising that the large-scale reconstructions agree on higher frequencies, but disagree on lower frequencies, considering the dominance of tree-ring records, de-trending differences in the preservation of millennial-scale variations, and the shared seasonality toward warm season temperatures.

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Stable Water Usage, But Some Groundwater Concerns, USGS Report Indicates

PAGE 114

Water use in the United States has remained fairly stable since 1985, according to an 11 March report by the U.S. Geological Survey. The report, which estimates water use for the year 2000—the most recent available data—indicates that Americans used an estimated 408 billion gallons of water per day, an amount the agency said would fill 8 billion bathtubs daily.

This also translates into 1,430 gallons per person per day, when including electric power generation, irrigation, and personal use.

Water usage has remained stable for the past 15 years, even though the U.S. population has increased from about 250 million to 290 million. Since 1950, water use more than doubled, with much of that growth occurring in the 1960s and 1970s due to increases in population, electrical power generation, and expanded use of irrigation.

USGS hydrologist Susan Hutson, author of the report, said the message is one of "good news." She said the report indicates that the two largest categories of water use—thermo-electric power generation and irrigation—have been able to reduce their usage.

Robert Hirsch, USGS' chief hydrologist, said the report "shows that conservation does work" and that people can adapt to using resources more sustainably.

Hirsch also credited other factors for limiting the increase in water usage. "Driven by legislation and the development of new technology, water use for power production has been made more efficient, particularly since the passage of the [federal] Clean Water Act in 1972." He noted that over the past 50 years, power production has increased 15-fold, while water usage has increased just 5-fold.

Major water usage categories are thermo-electric power, which accounts for 48% of water withdrawals, irrigation at 35%, and public supply at 11%. The three largest water withdrawal states are California, Texas, and Florida, with the first two states plus Idaho topping the list for surface water usage. California, Texas, and Nebraska account for 38% of the nation's groundwater usage.

Trends in Groundwater Usage

The report provides some indications about groundwater usage trends, which Hirsch said is a cause for some concern in certain areas. "People are becoming more dependent on groundwater [as a water source]. That represents a number of scientific and management challenges," he said.

Drawdowns in groundwater have increased significantly for irrigation, as well as for some public water supplies in rapidly growing arid and coastal areas. In 1950, groundwater accounted for 23% of total irrigation water, while in 2000 it accounted for 42% of the total, according to the USGS. Hirsch said that saltwater intrusion is a common problem that arises from groundwater pumping in coastal areas. "We need to