Quaternary Science Reviews 24 (2005) 2164–2166

Viewpoint

Climate: past ranges and future changes

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Received 15 May 2005; accepted 8 July 2005

Abstract

Comparison of large-scale temperature reconstructions over the past millennium reveals agreement on major climatic episodes, but substantial divergence in reconstructed (absolute) temperature amplitude. We here detail several research priorities to overcome this 'amplitude desideratum', and discuss the relevance of this effort for the prediction of future temperature changes and the meaning of the Kyoto protocol.

Persisting controversy (Regalado, 2005) surrounding a pioneering northern hemisphere temperature reconstruction (Mann et al., 1999) indicates the importance of such records to understand our changing climate. Such reconstructions, combining data from tree rings, documentary evidence and other proxy sources are key to evaluate natural forcing mechanisms, such as the sun's irradiance or volcanic eruptions, along with those from the widespread release of anthropogenic greenhouse gases since about 1850 during the industrial (and instrumental) period. We here demonstrate that our understanding of the shape of long-term climate fluctuations is better than commonly perceived, but that the absolute amplitude of temperature variations is poorly understood. We argue that the knowledge of this amplitude is critical for predicting future trends, and detail four research priorities to solve this incertitude: (i) reduce calibration uncertainty, (ii) preserve 'colour' in proxy data, (iii) utilize accurate instrumental data, and (iv) update old and develop new proxy data.

When matching existing temperature reconstructions (Jones et al., 1999; Mann et al., 1999; Briffa, 2000; Esper et al., 2002; Moberg, et al., 2005) over the past 1000 years, although substantial divergences exist during certain periods, the timeseries display a reasonably coherent picture of major climatic episodes: 'Medieval Warm Period', 'Little Ice Age' and 'Recent Warming' (Fig. 1). However, when calibrated against instrumental temperature records, these same reconstructions splay outwards with temperature amplitudes ranging from ~ 0.4 to 1.0 °C for decadal means (Moberg et al., 2005). Further, a comparison of commonly used regression and scaling approaches shows that the reconstructed absolute amplitudes easily vary by over 0.5 °C, depending on the method and instrumental target chosen (Esper et al., 2005). Overall, amplitude discrepancies are in the order of the total variability estimated over the past millennium, and undoubtedly confuse future modelled temperature trends via parameterisation uncertainties related to inadequately simulated behaviour of past variability.

Solutions to reduce calibration uncertainty include the use of pseudo-proxy experiments (Osborn and Briffa, 2004; von Storch et al., 2004) derived from ensemble simulations of different models (Knutti et al., 2002; Stainforth et al., 2005) to test statistical calibration methods, e.g. principal component (Cook et al., 1994) and timescale-dependent (Osborn and Briffa, 2000)

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0277-3791/$ - see front matter
doi:10.1016/j.quascirev.2005.07.001

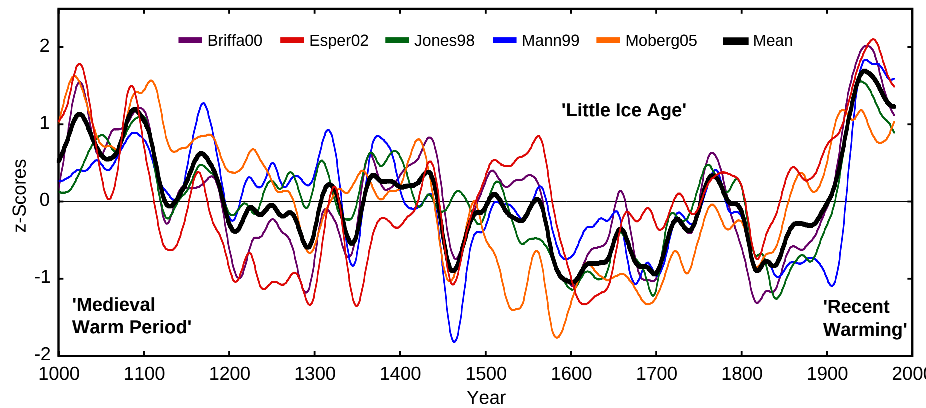

Fig. 1. Course of temperature variations. Large-scale temperature reconstructions scaled to the same mean and variance over the common period 1000–1979 AD, and their arithmetic mean. The normalisation highlights the similarity between the records, but broadly ignores the differing calibration statistics with instrumental data, and their particular 'shapes' and distribution of variance, e.g. during the instrumental and pre-instrumental periods. The average correlation between the original reconstructions is 0.47, and 0.64 after smoothing (as done in the figure using a 40-year low-pass filter). Lag-1 autocorrelations range from 0.52 (Jones98) to 0.93 (Moberg05; with no variability <4 years represented).

regression. Such analyses, however, should mimic the character of empirical proxy data, e.g. the decline of replication (numbers of sites, quality per site) back in time, and the addition of noise typical to empirical proxy data (i.e., not just white; Mann and Rutherford, 2002). Further, reconstructions from areas such as Europe (Luterbacher et al., 2004; Xoplaki et al., 2005), where long instrumental series and high densities of proxy records exist, allow extended calibration periods and increased degrees of freedom enabling the assessment of robust relationships at all timescales (i.e., low and high frequency), both critical to reduce calibration uncertainty. Subsequent comparison of such regional records with hemispheric reconstructions that can be downscaled should provide greater understanding of reconstructed amplitudes at larger spatial scales.

Accurate preservation and assessment of low-to-high frequency variation ('colour') in proxy data, and a selected use of certain frequency bands that best fit those of instrumental data (Moberg et al., 2005), are further desirable when compiling large-scale reconstructions that seek to yield the true absolute temperature amplitude. This approach, however, requires a comprehensive examination of regional proxy data including the seasonality of temperature signals, and a selection of only those records that effectively capture low-frequency climate variation. Inclusion of regional tree ring records in which long-term trends are not preserved, should be avoided in efforts to reconstruct low frequency temperature variations (Esper et al., 2004; Melvin, 2004). In these data, such limitations primarily occur when age-related biases from tree-ring series are individually estimated and removed ('the segment length curse' Cook et al., 1995). Similar considerations apply to documentary evidence, long isotope records and other proxy sources that should, on a site-by-site basis, be examined for potential low-frequency limitations.

The instrumental target data chosen (Esper et al., 2005), and adjustments made to these data are also vital to the reconstructed amplitude. A recent analysis of a carefully homogenised instrumental network from the Alps and surrounding areas (Böhm et al., 2001), for example, shows the annual temperature trend over the last ca 110 years to be 1.1 °C–twice that observed over the same alpine gridboxes in the global dataset provided by the Climatic Research Unit (Jones et al., 1999). Such changes in the character of observational data, resulting from homogeneity adjustments and methodology differences (Moberg et al., 2003), directly affect the temperature amplitude in proxy-based reconstructions, since instrumental calibration sets the pulse in these paleorecords (Büntgen et al., 2005). Accurate instrumental data are therefore crucial to the reconstructed amplitude, and this again argues for regional studies where mutual verification between proxy and instrumental records is viable (Frank and Esper, 2005; Wilson et al., 2005).

Finally, more proxy data covering the full millennium and representing the same spatial domain as the instrumental target data (e.g., hemisphere) are required to solve the amplitude puzzle. The current pool of 1000-year long annually resolved temperature proxies is limited to a handful of timeseries, with some of them also portraying differing seasonal (e.g., summer or annual) responses. Furthermore, the strength of many of these local records and literally all tree ring chronologies varies and almost always declines back in time (Cook et al., 2004). The reasons are manifold and include dating uncertainty, loss of signal fidelity in the recent period, assumptions about signal stationarity, reduction of sample replication, etc., and are generally not considered in the uncertainty estimates of combined large-scale reconstructions. Also, data from the most recent decades, absent in many regional proxy records, limits the calibration period length and hinders tests of the behaviour of the proxies under the present 'extreme' temperature conditions. Calibration including the exceptional conditions since the 1990s would, however, be necessary to estimate the robustness of a reconstruction during earlier warm episodes, such as the Medieval Warm Period, and would avoid the need to splice proxy and instrumental records together to derive conclusions about recent warmth.

So, what would it mean, if the reconstructions indicate a larger (Esper et al., 2002; Pollack and Smerdon, 2004; Moberg et al., 2005) or smaller (Jones et al., 1998; Mann et al., 1999) temperature amplitude? We suggest that the former situation, i.e. enhanced variability during pre-industrial times, would result in a redistribution of weight towards the role of natural factors in forcing temperature changes, thereby relatively devaluing the impact of anthropogenic emissions and affecting future predicted scenarios. If that turns out to be the case, agreements such as the Kyoto protocol that intend to reduce emissions of anthropogenic greenhouse gases, would be less effective than thought. This scenario, however, does not question the general mechanism established within the protocol, which we believe is a breakthrough.

Acknowledgements

We thank Bernd Kromer, Jim Rose, Thomas Stocker and an anonymous reviewer for helpful comments. J.E., H.W. and J.L supported by the SNF (NCCR Climate), R.J.S.W. by the EC (Grant # EVK2-CT-2002-00160, SO&P), and D.C.F. by the SNF (Grant ♯ 2100-066628).

References

Böhm, R., Auer, I., Brunetti, M., Maugeri, M., Nanni, T., Schöner, W., 2001. Regional temperature variability in the European Alps 1760–1998 from homogenized instrumental time series. International Journal of Climatology 21, 1779–1801.

Briffa, K.R., 2000. Annual climate variability in the Holocene – interpreting the message from ancient trees. Quaternary Science Reviews 19, 87–105.

Büntgen, U., Esper, J., Frank, D.C., Nicolussi, K., Schmidhalter, M., 2005. A 1052-year alpine tree-ring proxy for Alpine summer temperatures. Climate Dynamics, doi:10.1007/S00382-005-0028-1.

Cook, E.R., Briffa, K.R., Jones, P.D., 1994. Spatial regression methods in dendroclimatology – a review and comparison of two techniques. International Journal of Climatology 14, 379–402.

Cook, E.R., Briffa, K.R., Meko, D.M., Graybill, D.A., Funkhouser, G., 1995. The 'segment length curse' in long tree-ring chronology development for palaeoclimatic studies. The Holocene 5, 229–237.

Cook, E.R., Esper, J., D'Arrigo, R., 2004. Extra-tropical northern hemisphere temperature variability over the past 1000 years. Quaternary Science Reviews 23, 2063–2074.

Esper, J., Cook, E.R., Schweingruber, F.H., 2002. Low-frequency signals in long tree-ring chronologies for reconstructing past temperature variability. Science 295, 2250–2253.

Esper, J., Frank, D.C., Wilson, R.J.S., 2004. Temperature reconstructions – low frequency ambition and high frequency ratification. EOS 85, 113–120.

Esper, J., Frank, D.C., Wilson, R.J.S., Briffa, K.R., 2005. Effect of scaling and regression on reconstructed temperature amplitude for the past millennium. Geophysical Research Letters 32.

Frank, D., Esper, J., 2005. Temperature reconstructions and comparisons with instrumental data from a tree-ring network for the European Alps. International Journal of Climatology (in press).

Jones, P.D., Briffa, K.R., Barnett, T.P., Tett, S.F.B., 1998. High-resolution palaeoclimatic records for the past millennium – interpretation, integration and comparison with general circulation model control-run temperatures. The Holocene 8, 455–471.

Jones, P.D., New, M., Parker, D.E., Martin, S., Rigor, I.G., 1999. Surface air temperature and its changes over the past 150 years. Reviews of Geophysics 37, 173–199.

Knutti, R., Stocker, T.F., Joos, F., Plattner, G.K., 2002. Constraints on radiative forcing and future climate change from observations and climate model ensembles. Nature 416, 719–723.

Luterbacher, J., Dietrich, D., Xoplaki, E., Grosjean, M., Wanner, H., 2004. European seasonal and annual temperature variability, trends, and extremes since 1500. Science 303, 1499–1503.

Mann, M.E., Rutherford, S., 2002. Climate reconstruction using 'pseudoproxies'. Geophysical Research Letters 29, doi:10.1029/2001GL014554.

Mann, M.E., Bradley, R.S., Hughes, M.K., 1999. Northern Hemisphere temperatures during the past millennium – inferences, uncertainties, and limitations. Geophysical Research Letters 26, 759–762.

Melvin, T.M., 2004. Historical growth rates and changing climate sensitivity of boreal conifers. Ph.D. Thesis, University East Anglia, Norwich (available at: http://www.cru.uea.ac.uk/cru/pubs/thesis/2004-melvin/).

Moberg, A., Alexandersson, H., Bergström, H., Jones, P.D., 2003. Were southern Swedish summer temperatures before 1860 as warm as measured? International Journal of Climatology 23, 1495–1521.

Moberg, A., Sonechkin, D.M., Holmgren, K., Datsenko, N.M., Karlèn, W., 2005. Highly variable northern hemisphere temperatures from low- and high-resolution proxy data. Nature 433, 613–617.

Osborn, T.J., Briffa, K.R., 2000. Revisiting timescale-dependent reconstruction of climate from tree-ring chronologies. Dendrochronologia 18, 9–25.

Osborn, T.J., Briffa, K.R., 2004. The real color of climate change? Science 306, 621–622.

Pollack, H.N., Smerdon, J.E., 2004. Borehole climate reconstructions – spatial structure and hemispheric averages. Journal of Geophysical Research 109, doi:10.1029/2003JD04163.

Regalado, A., 2005. The 'hockey stick' leads to a face of. The Wall Street Journal, February 14.

Stainforth, D.A., et al., 2005. Uncertainty in predictions of the climate response to rising levels of greenhouse gases. Nature 433, 403–406.

von Storch, H., Zorita, E., Jones, J.M., Dimitriev, Y., González-Rouco, F., Tett, S.F.B., 2004. Reconstructing past climate from noisy data. Science 306, 679–682.

Wilson, R.J.S., Luckman, B.H., Esper, J., 2005. A 500-year dendroclimatic reconstruction of spring-summer precipitation from the lower Bavarian forest region, Germany. International Journal of Climatology 25, 611–630.

Xoplaki, E., Luterbacher, J., Paeth, H., Dietrich, D., Steiner, N., Grosjean, M., Wanner, H., 2005. European spring and autumn temperature, variability and change of extremes over the last half millennium. Geophysical Research Letters 45 (in press).