Reply

MICHAEL E. MANN

Department of Meteorology, and Earth and Environmental Systems Institute, The Pennsylvania State University, University Park, Pennsylvania

SCOTT RUTHERFORD

Department of Environmental Science, Roger Williams University, Bristol, Rhode Island

EUGENE WAHL

Division of Environmental Studies and Geology, Alfred University, Alfred, New York

CASPAR AMMANN

Climate and Global Dynamics Division, National Center for Atmospheric Research, Boulder, Colorado

(Manuscript received 31 March 2006, in final form 24 October 2006)

Mann et al. (2005, hereafter MRWA05) examined the performance of the Regularized Expectation Maximization (RegEM) climate field reconstruction (CFR) technique, which has been favored in recent proxy-based climate reconstruction by Mann and coworkers (Mann and Rutherford 2002; Rutherford et al. 2003, 2005; MRWA05; Zhang and Mann 2005). MRWA05 demonstrated that the method yields skillful reconstructions using synthetic proxy ("pseudoproxy") datasets with similar attributes to actual proxy networks, derived from a simulation of the past millennium using the National Center for Atmospheric Research (NCAR) Climate System Model version 1.4 (CSM 1.4) coupled model. They consequently concluded that surface temperature reconstructions resulting from the application of this method to actual proxy data (e.g., Rutherford et al. 2005) are likely to yield realistic reconstructions within estimated uncertainties. Zorita et al. (2007, hereafter ZVS07) appear to challenge the findings of MRWA05, though they have not, as best as we can discern, demonstrated fault with any of the methods or calculations of that study. As outlined below, we reject—by explicit demonstration—the claims made by ZVS07.

Corresponding author address: Michael Mann, Department of Meteorology, The Pennsylvania State University, 503 Walker Building, University Park, PA 16802-5013.
E-mail: mann@psu.edu

DOI: 10.1175/JCLI4172.1

Von Storch et al. (2006, herafter VS06) argued that real-world proxy-based CFR reconstructions are likely to underestimate low-frequency variability, based on experiments using pseudoproxy networks derived from a millennial simulation of the GKSS ECHAM and the global Hamburg Ocean Primitive Equation (ECHO-G) coupled model. Yet they considered only the more primitive EOF-based CFR method of Mann et al. (1998, hereafter MBH98), long since supplanted by the RegEM CFR approach in all recent work by Mann and collaborators. Wahl et al. (2006) have moreover challenged the VS06 calculations, arguing that that they suffer from an artifact of an originally undisclosed procedure used by VS06 in which data were detrended prior to calibration. Wahl et al. (2006) note that such a procedure a priori removes the primary pattern of low-frequency variability from the surface temperature data.

ZVS07 argue that the skillful results of the MRWA05 experiments are somehow an artifact of the use of a long, combined nineteenth–twentieth century (1856–1980) rather than a short twentieth-century-only (1900–80) calibration interval. More indirectly, they suggest that behavior peculiar to the specific (NCAR CSM 1.4) model simulation used by MRWA05 and not common to their own (GKSS ECHO-G) simulations might be involved in the skillful MRWA05 outcome. Additionally, ZVS07 suggest (and argue more strenuously in VS06) that the results presented by MWRA05 may represent an artifact of an inappropriate model for the

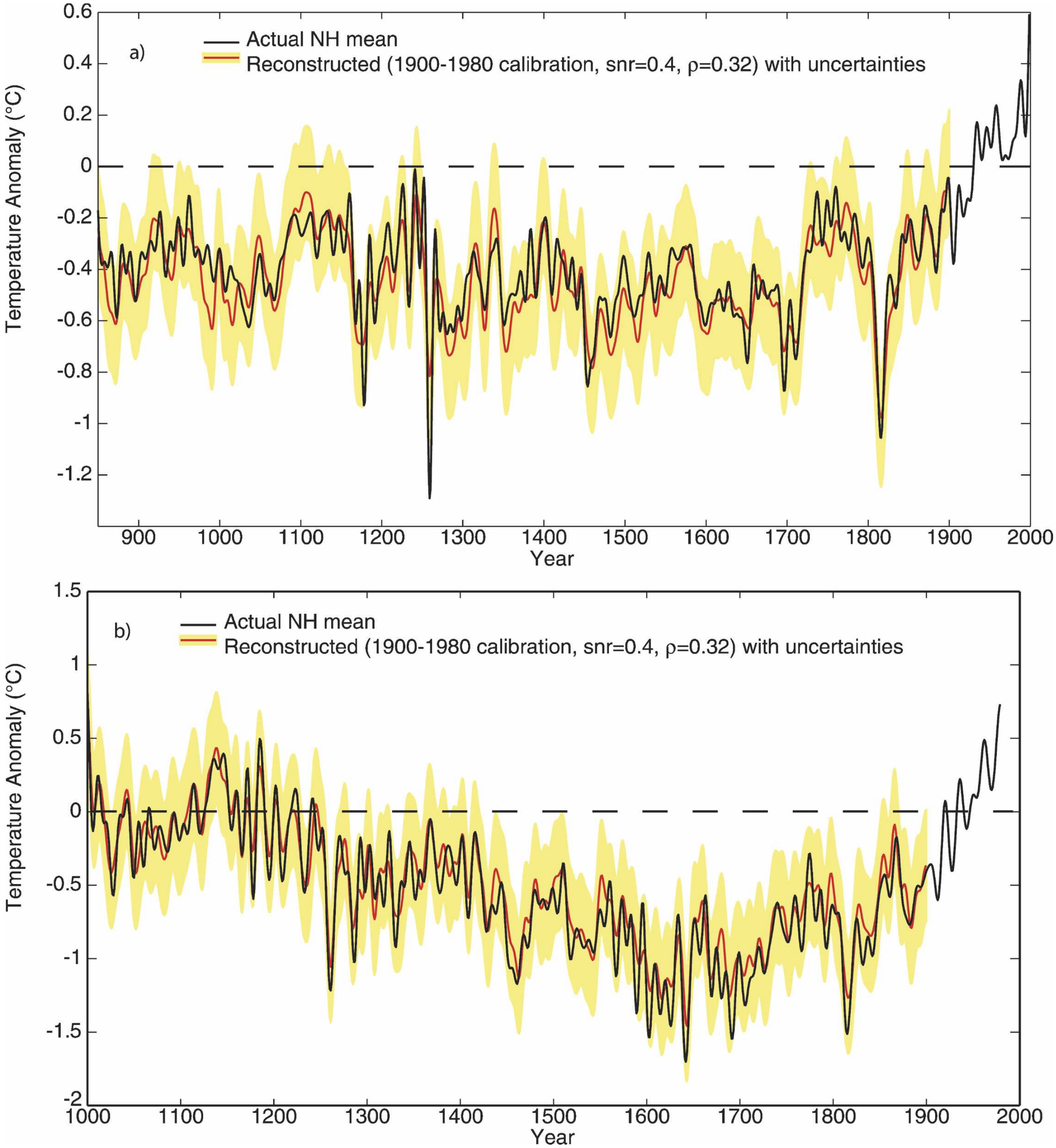

FIG. 1. Reconstruction of Northern Hemisphere mean temperature based on RegEM CFR reconstructions using pseudoproxy networks taken from (a) NCAR CSM 1.4 and (b) GKSS ECHO-G Erik simulations. In both cases, the pseudoproxy network locations correspond to the 104 unique locations used by MBH98, a proxy SNR = 0.4, red proxy noise with noise autocorrelation $\rho = 0.32$, and a 1900–80 calibration interval is used. Self-consistent uncertainties in the reconstructions are estimated from the unresolved residual variance during an 1856–1899 "validation" interval and are indicated by shading (95% uncertainty region). Actual model NH series is shown for comparison (black). All series are decadally smoothed.

proxy noise, and that poorer results would be achieved if proxy noise was assumed to be spectrally "red" rather than "white" (as assumed in previous studies such as M05 and VS06). We use the results of recent RegEM experiments described in detail by Mann et al. (2007) to demonstrate the incorrectness of these claims.

We have applied the RegEM procedure to surface temperature reconstructions using pseudoproxy net-

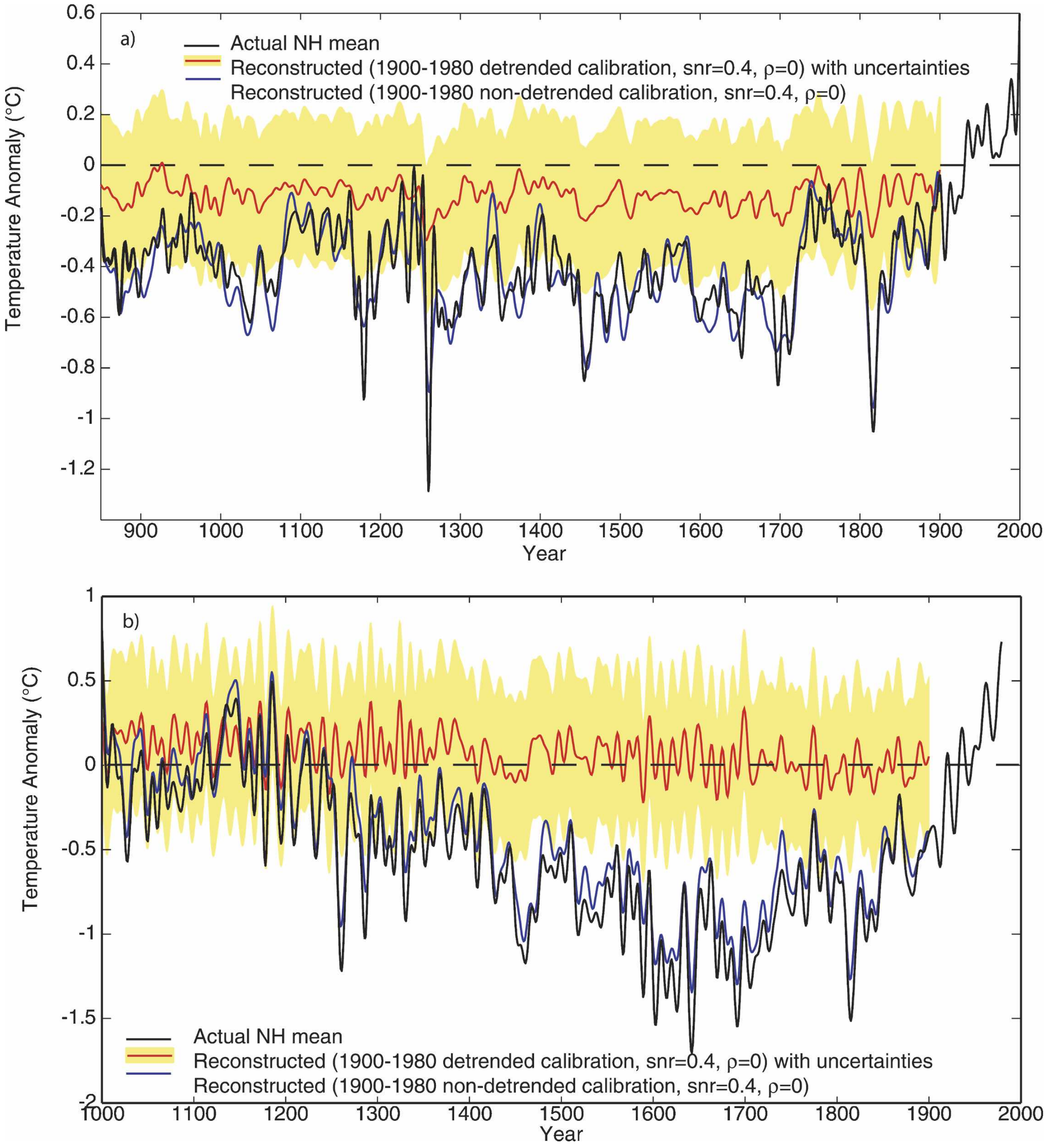

FIG. 2. Same as in Fig. 1, but using white proxy noise and comparing results based on standard RegEM CFR procedure (blue) and procedure similar to that of VS06 in which the predictand (surface temperature field) is detrended over the calibration period prior to performing the reconstruction.

works diagnosed from two different model simulations, the NCAR CSM 1.4 coupled simulation used by MRWA05, and the GKSS ECHO-G "Erik" simulation used by VS06. The pseudoproxy networks, as with ZVS07, have the spatial distribution of the full MBH98 proxy network. The reconstructions are based on use of the "short" (1900–80) calibration interval, and a *lower* signal-to-noise ratio (SNR) than used by ZVS07 (we employed an SNR = 0.4 corresponding to average proxy/temperature correlations of $r = 0.37$, while ZVS07 used SNR = 0.5, corresponding to an average $r = 0.44$). We furthermore allowed that the proxy noise be red as in VS06, using a noise autocorrelation coefficient $\rho = 0.32$ estimated from the actual MBH98 network (see Mann et al. 2007 for details). For both simulations, the RegEM reconstructions are observed to closely track the actual model temperature histories, with the reconstructions lying entirely within the self-consistently estimated uncertainties (Fig. 1). The most striking feature—the cold temperatures of the fifteenth–nineteenth centuries associated with pronounced anomalous negative radiative forcing by a combination of solar irradiance reduction and active explosive volcanic aerosol forcing—is well captured in both cases.

Osborn et al. (2006) have shown that the anomalous initial warmth and much of the subsequent long-term cooling trend in the Erik simulation is an artifact of inappropriate model initialization, whereby anthropogenic levels of greenhouse gas concentrations were imposed as a preanthropogenic initial condition. In MRWA05, we speculated that the unphysical drift resulting from this initialization might degrade CFR performance in tests using the Erik simulation, since the drift pattern might not be captured over the modern training intervals used for calibration. As the Erik simulation data have now recently been released, we have been able to test this assertion. As evident from Fig. 1, the drift does not appear to pose any particular problem for the RegEM CFR method.

Finally, we consider the impact of the detrending procedure used by VS06 and discussed earlier. ZVS07 conflate the methodological issue of detrending data prior to calibration with the phenomenological issue of whether the processes that introduce noise into proxy measurements of climate are spectrally white or red. Yet, these are entirely separate issues. We have shown above that the RegEM CFR method performs well in the presence of realistic proxy noise "redness." The inappropriate methodological step of detrending data prior to calibration, however, completely undermines CFR performance, irrespective of whether the noise is red or white. We repeated the analysis discussed above with both simulations, but employing white proxy noise and detrending—as in VS06—the model surface temperature field prior to calibration. The detrending procedure leads to a dramatic underestimate of the low-frequency variability in tests with both the NCAR and ECHO-G simulations, with the true history lying outside the estimated uncertainties of the reconstructions (Fig. 2). The correctly implemented (undetrended) RegEM procedure, however, yields remarkably skillful reconstructions in both cases. Wahl et al. (2006) emphasize that the detrending procedure used by VS06 is ill advised in CFR applications for physical reasons and is not motivated from a statistical standpoint for CFR methods. Given the clear failings of the procedure in this context, we are surprised that it was used in the first place (e.g., VS06), repeated by others (e.g., Burger et al. 2006), and is still now defended by ZVS07.

There is still significant progress to be made in the area of proxy-based reconstruction, and in the development of optimal statistical methods for performing such reconstructions. While we find little merit in the current criticism put forth by ZVS07, we do nonetheless share the view that a vigorous, good faith, community-wide effort to compare the relative strengths and weaknesses of competing paleoclimate reconstruction approaches should pave the way toward improved knowledge of past climate variability and change. Indeed, such an effort is currently being planned under the auspices of the International Past Global Changes/Climate Variability and Predictability (PAGES/CLIVAR) Intersection (Mann et al. 2006).

REFERENCES

Burger, G., I. Fast, and U. Cubasch, 2006: Climate reconstruction by regression. *Tellus,* **58A,** 227–235.

Mann, M. E., and S. Rutherford, 2002: Climate reconstruction using "Pseudoproxies." *Geophys. Res. Lett.,* **29,** 1501, doi:10.1029/2001GL014554.

——, R. S. Bradley, and M. K. Hughes, 1998: Global-scale temperature patterns and climate forcing over the past six centuries. *Nature,* **392,** 779–787.

——, S. Rutherford, E. Wahl, and C. Ammann, 2005: Testing the fidelity of methods used in proxy-based reconstructions of past climate. *J. Climate,* **18,** 4097–4107.

——, K. R. Briffa, P. D. Jones, T. Kiefer, C. Kull, and H. Wanner, 2006: Scientists convene to discuss climate variability of past millennia. *Eos, Trans. Amer. Geophys. Union,* **87,** 526–527.

——, S. Rutherford, E. Wahl, and C. Ammann, 2007: Robustness of proxy-based climate field reconstruction methods. *J. Geophys. Res.,* in press.

Osborn, T. J., S. C. B. Raper, and K. R. Briffa, 2006: Simulated climate change during the last 1000 years: Comparing the ECHO-G general circulation model with the MAGICC simple climate model. *Climate Dyn.,* **27,** 185–197.

Rutherford, S., M. E. Mann, T. L. Delworth, and R. Stouffer, 2003: Climate field reconstruction under stationary and nonstationary forcing. *J. Climate,* **16,** 462–479.

——, ——, T. J. Osborn, R. S. Bradley, K. R. Briffa, M. K. Hughes, and P. D. Jones, 2005: Proxy-based Northern Hemisphere surface temperature reconstructions: Sensitivity to methodology, predictor network, target season, and target domain. *J. Climate,* **18,** 2308–2329.

Von Storch, H., E. Zorita, J. M. Jones, F. Gonzalez-Rouco, and S. F. B. Tett, 2006: Response to comment on "Reconstructing past climate from noisy data." *Science,* **312,** 529c.

Wahl, E. R., D. M. Ritson, and C. M. Ammann, 2006: Comment on "Reconstructing past climate from noisy data." *Science,* **312,** 529b.

Zhang, Z., and M. E. Mann, 2005: Coupled patterns of spatiotemporal variability in Northern Hemisphere sea level pressure and conterminous U.S. drought. *J. Geophys. Res.,* **110,** D03108, doi:10.1029/2004JD004896.

Zorita, E., F. Gonzalez-Rouco, and H. von Storch, 2007: Comments on "Testing the fidelity of methods used in proxy-based reconstructions of past climate." *J. Climate,* **20,** 3693–3698.