Comment on "Testing the Fidelity of Methods Used in Proxy-Based Reconstructions of Past Climate": The role of the standardization interval

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Mann et al. [2005] (hereinafter M05) conclude that they "*find no evidence for the suggestion that real-world proxy-based temperature reconstructions are likely to suffer from any systematic underestimate of low-frequency variability*." This conclusion is based on multiple pseudo-proxy experiments using the NCAR CSM millennial integration and the climate field reconstruction (CFR) method known as regularized expectation maximization (RegEM) [*Schneider*, 2001]. RegEM was used by *Rutherford et al.* [2005] (hereinafter R05) to reconstruct historical Northern Hemisphere climate from the *Mann et al.* [1998] proxy network, which prompted the follow-up study by M05 to test, in part, the veracity of the R05 millennial climate reconstruction. We have used the publicly available codes published by R05 and M05 to perform a new suite of pseudo-proxy reconstructions with the CSM data. Our findings contradict the M05 conclusion and highlight an important methodological choice that was different from R05, not reported by M05, and has significant impacts on the derived reconstructions.

Testing climate reconstruction methods with simulated climates relies on proper application of real-world constraints. For instance, it is important to perturb pseudo-proxy networks with realistic noise models such that the noise is representative of actual proxy records. A variety of colored noise models have been adopted [*Mann and Rutherford*, 2002; *von Storch et al.*, 2004, 2006; M05], but these may not fully mimic the non-linear, multivariate, non-stationary characteristics of noise in many proxy series [e.g. *Jacoby and D'Arrigo*, 1995; *Briffa et al.*, 1998; *Esper et al.*, 2005; *Evans et al.*, 2002; *Anchukaitus et al.*, 2006]. Therefore, improving the representation of noise in pseudo-proxy networks is an ongoing and important area of research. What is more obvious, however, is that the methodological constraints of real-world climate reconstructions must be preserved in pseudo-proxy tests if they are to have any direct applicability to actual reconstructions of historical climate. Using information or techniques that would never be possible in real-world settings sheds little light on climate reconstruction methods. The principal motivation of this comment is to note that M05 used information prior to the period of widespread observational evidence, thereby significantly affecting the outcome of their reconstructions.

RegEM requires an input data matrix that is a composite of both instrumental and proxy data. A time-by-space matrix for the instrumental data is first formed in which rows correspond to years in the calibration and reconstruction periods, and columns correspond to grid cells in the instrumental field. For instance, a reconstruction for the Eq-70° N region of the NH on a 5°x5° latitude-longitude grid and spanning A.D. 850-1980 would fill a matrix of 1131 rows by 1008 columns. This matrix of course would be initially empty, except for the instrumental data in the calibration period (rows 1007-1131 for an 1856-1980 calibration interval). The second part of the composite matrix is formed from the proxy data, comprising a matrix of 1131 rows and n columns, where n is the number of proxies (104 in the case of M05). Thus, the instrumental and proxy matrices are concatenated by column and comprise the input matrix for the RegEM algorithm (Figure 1).

As is standard with most reconstruction procedures, the instrumental and proxy data are standardized to eliminate differences in their relative units and for the calculation of the covariance matrix (here we define the standardization of a time series as both the subtraction of the mean and division of the standard deviation over a specific time interval). It is typical to standardize over a common interval, e.g. the calibration period for both the instrumental and proxy data; calibration interval standardization is the convention used by R05. By contrast, M05 standardized the instrumental and pseudo-proxy data over the full model period (see Figure 1). This was accomplished for the instrumental portion by standardizing the full-model field and then truncating the data prior to the calibration interval. While such a decision may sound benign, it amounts to knowing the mean and standard deviation of the target field prior to the calibration interval – a luxury that would obviate the need for a reconstruction in the first place. This unrealistic approach in the M05 method makes their pseudo-proxy test inapplicable to proxy-derived reconstructions of past climate. Perhaps most importantly in the present context, however, is the fact that the choice of standardization has large impacts on the characteristics of the reconstructions derived from the CSM pseudo-proxy tests.

In Figure 2a we use the M05 pseudo-proxies to derive a suite of reconstructions in which the pseudo-proxy and instrumental data were standardized over the full target period (A.D. 850-1980); these are our reproductions of the M05 results for signal-to-noise ratios of infinity, 1.0, 0.5 and 0.25 and for a calibration period from A.D. 1856-1980. All of our reproductions of the M05 reconstructions correlate with the published time series at correlation coefficients larger than 0.997. We also note several aspects of the reconstructions in Figure 2a that were not reported in M05. Unlike R05, in which the entire Northern Hemisphere was used as a target domain, M05 used a restricted target domain comprising 669 grid cells out of the available 1008 in the Eq-70° N region (R05 excluded only 6 grid cells) [Scott Rutherford, 2006, personal communication]. We also plot for this comment the area-weighted reconstructions, pointing out that the M05 mean reconstructions were only normalized by the sum of the area weights, not weighted by them.

The results in Figure 2a reproduce the findings of M05, and imply that there are no significant or systematic biases in the RegEM reconstructions, relative to the mean CSM climate. In Figure 2b, however, we display reconstructions performed in exactly the same way as those in Figure 2a, but with standardizations restricted to the calibration interval, as in R05. Clearly the choice of standardization has a significant impact on the derived reconstructions – those in Figure 2b show large losses of variance and systematic warm biases in the RegEM reconstructions when realistic constraints are applied. In Figure 3 we summarize the means and variances of the reconstructions in Figure 2, during the reconstructed interval. For plotting purposes, we use the percent noise by variance as a measure of the noise in the pseudo-proxy series; 0, 50, 80 and 94% noise by variance corresponds to signal-to-noise ratios (by standard deviation) of infinity, 1, 0.5 and 0.25, respectively. The total variance in the M05 reconstructions is 2-4 times less than the actual modeled hemispheric mean, while the R05 version of the reconstructions are 2-11 times less. Similarly, the means of the M05 reconstructions match well the actual model mean, but the R05 reconstruction means become progressively warmer with added noise. These results suggest that RegEM is subject to the same warm biases and variance losses noted by *von Storch et al.* [2004, 2006].

Our conclusions have important implications regarding the performance of the RegEM CFR technique, and suggest that the R05 historical reconstruction likely underestimates climate variability during the last millennium. Given the similarity between the RegEM-derived reconstruction of R05 and that of the *Mann et al.* [1998] reconstruction, it is likely that the latter reconstruction also underestimates climate variability. Nevertheless, the noted problem in the RegEM CFR technique is not insurmountable and likely has reasonable solutions. Further research into this issue is highly warranted. Toward such ends, the codes and data used in this comment are available at http://www.ldeo.columbia.edu/~jsmerdon/jclimsupp2006.html.

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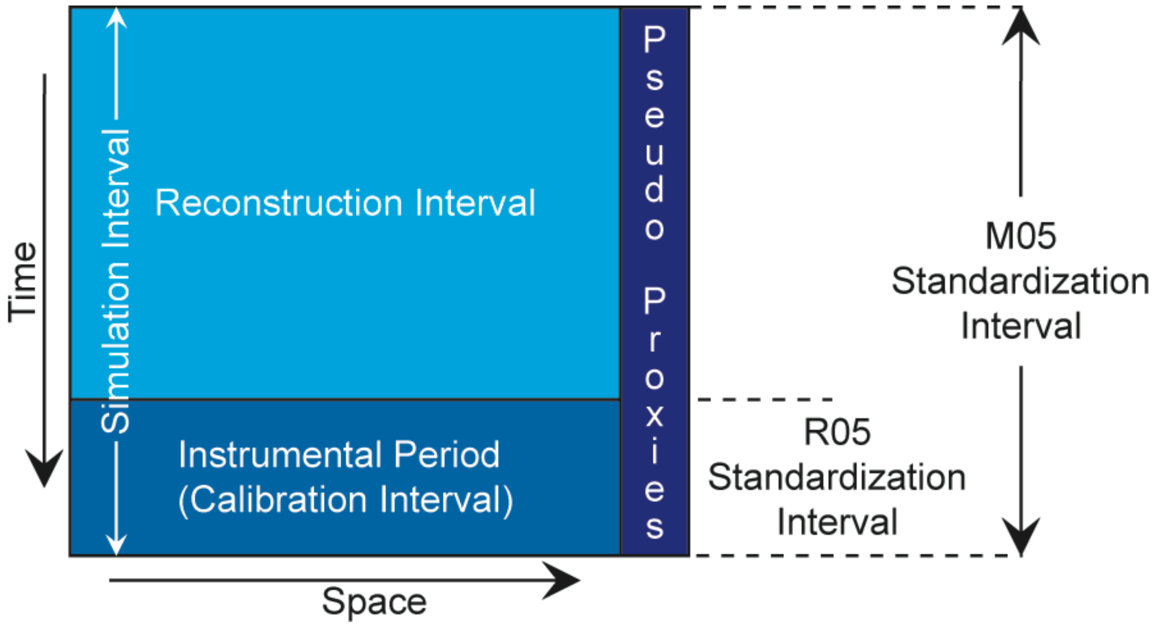
Figure 1. Standardization schemes used for the input matrix of RegEM in R05 and M05.

Figure 2. RegEM reconstructions of the CSM mean NH climate using (a) the M05 convention, which standardized the instrumental and proxy data over the entire simulation interval, and (b) the R05 standardization convention, which standardized the instrumental and proxy data over the 1856-1980 calibration interval.

Figure 3. Comparison of RegEM reconstructed means and variances during the reconstruction interval (850-1855 A.D.).



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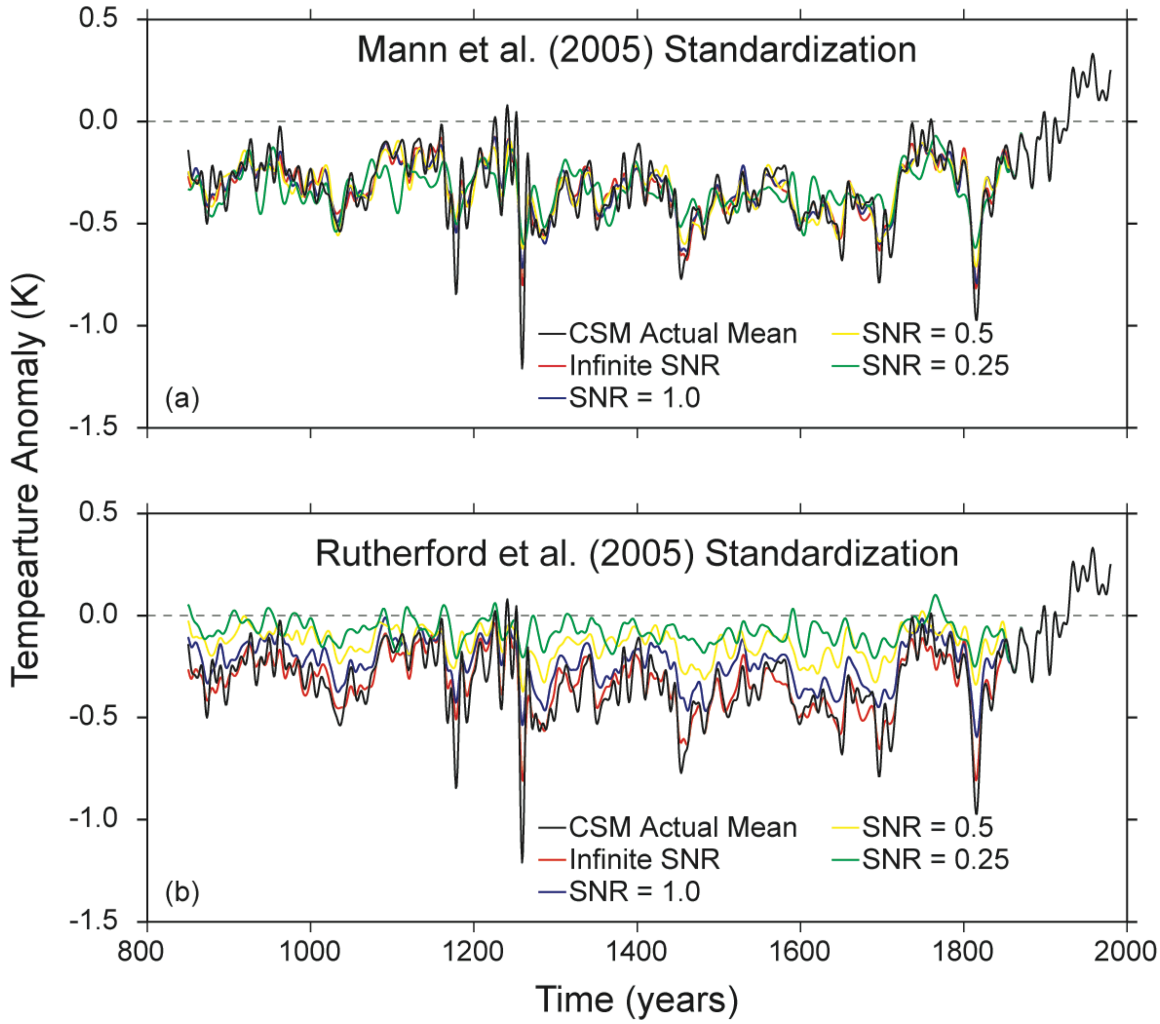

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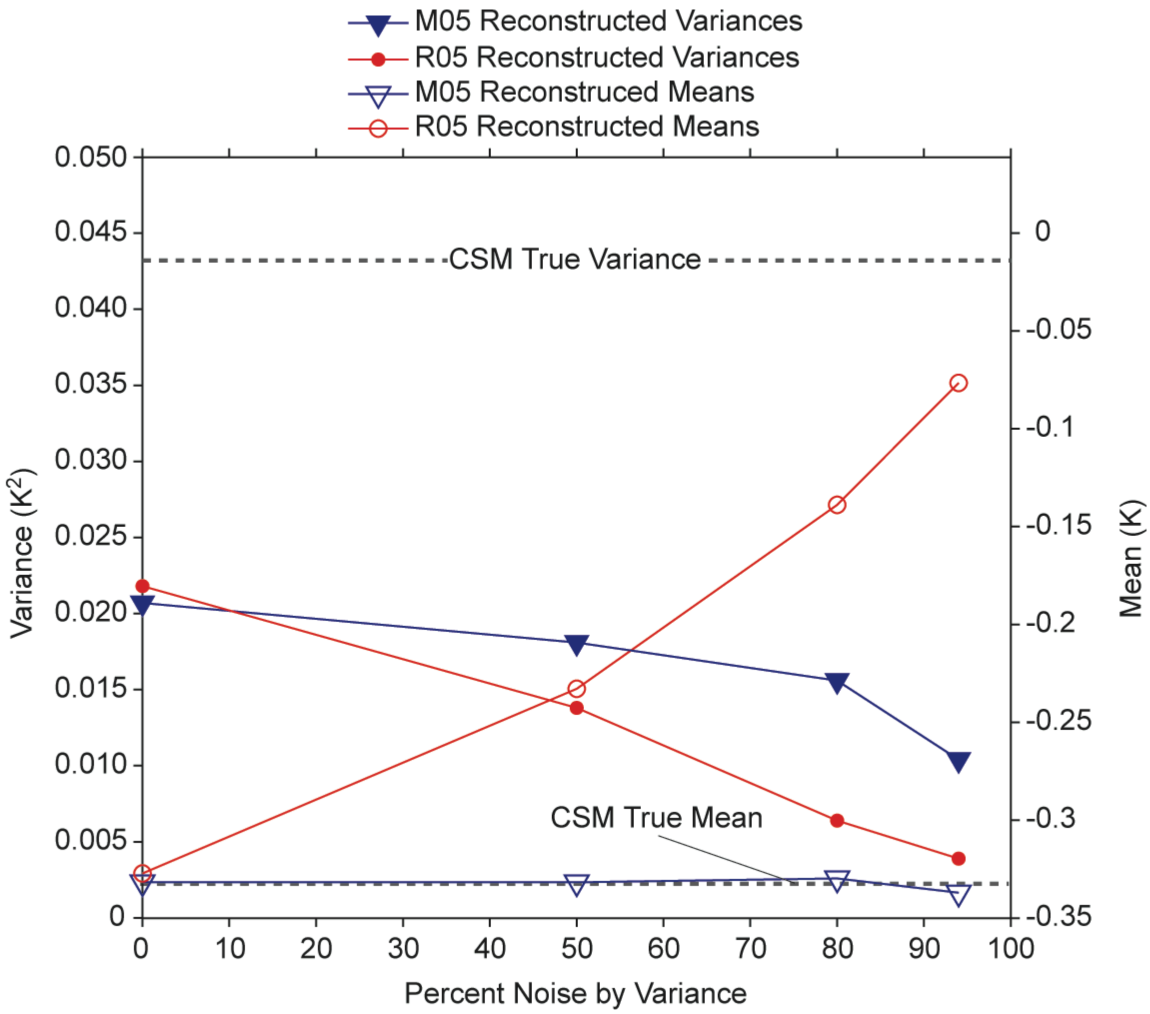

Figure 3. Comparison of RegEM reconstructed means and variances with those of the known CSM mean and variance during the reconstruction interval (850-1855 A.D.).