Are reconstructed pre-instrumental hemispheric temperatures consistent with instrumental hemispheric temperatures?

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[1] Reconstructions of Northern Hemisphere near-surface temperatures from climate 'proxy' data such as tree rings, ice cores, and corals, suggest that late 20th century Northern Hemisphere mean warmth is anomalous in the context of the past several centuries and likely at least the past two millennia. Though substantial uncertainties in the paleoclimate reconstructions exist, these findings add to the evidence for a discernible human influence on climate. Here we use our simple climate model with six radiative-forcing reconstructions and climate sensitivity determined from instrumental temperatures over 1861 to 1997 to simulate the forced pre-instrumental hemispheric-average temperatures from 1500 to 1895. The model-simulated pre-instrumental temperatures indicate that the proxy temperature reconstructions are consistent with the instrumental temperatures in the Northern Hemisphere, but are too warm in the Southern Hemisphere. *INDEX TERMS:* 0370 Atmospheric Composition and Structure: Volcanic effects (8409); 1610 Global Change: Atmosphere (0315, 0325); 1620 Global Change: Climate dynamics (3309); 3309 Meteorology and Atmospheric Dynamics: Climatology (1620); 3344 Meteorology and Atmospheric Dynamics: Paleoclimatology. **Citation:** Andronova, N. G., M. E. Schlesinger, and M. E. Mann (2004), Are reconstructed pre-instrumental hemispheric temperatures consistent with instrumental hemispheric temperatures?, *Geophys. Res. Lett.*, *31*, L12202, doi:10.1029/2004GL019658.

1. Introduction

[2] The question of how sensitive the climate system is to natural and anthropogenic disturbances has more than a century of history. The development of longer instrumental records of near-surface air temperature (NSAT), estimations of the natural and anthropogenic radiative forcing at either the top of the atmosphere or the tropopause, and mathematical climate models have facilitated answering some aspects of this question [*Barnett et al.*, 1999]. In particular, experiments with the atmospheric general circulation models coupled with the ocean [*Tett et al.*, 1999; *Stott et al.*, 2000; *Mitchell et al.*, 2001] showed that forcing from anthropogenic activities, with additional input from variations in solar and volcanic forcing and natural variability, has been the main driver of climate change during the past century. *Andronova and Schlesinger* [2000] used their simple climate model and concluded that: (1) the observed warming during 1904–1944 and cooling during 1944–1976 were not human induced; (2) The observed warming during 1976–1990 was equally due to humans and a residual, most likely a natural temperature oscillation in the North Atlantic Ocean [*Schlesinger and Ramankutty*, 1994]; (3) the observed warming during 1856–1990 was predominantly human induced; hence (4) it would not be prudent to expect continued year-after-year warming in the near future and, in so doing, diminish concern about global warming should global cooling instead manifest itself again, as it did during 1944–1976.

[3] The recent development of: (1) long pre-instrumental NSAT records from climate 'proxy' data such as tree rings, ice cores, and corals [*Briffa*, 2000; *Briffa et al.*, 2001; *Crowley and Lowery*, 2000; *Esper et al.*, 2002; *Jones et al.*, 1998; *Mann et al.*, 1999; *Overpeck et al.*, 1997]; and (2) estimates of the historical radiative forcing have made it possible to investigate further the roles of humans and natural forcings in climate change. In particular, using the Northern Hemisphere NSAT data of *Jones et al.* [1998], *Mann et al.* [1999], and *Briffa* [2000] and a simple energy-balance model with fixed climate sensitivity of 2.0°C, *Crowley* [2000] concluded that the pre-industrial period of Northern Hemisphere NSAT can be explained by the variation in both solar and volcanic activities. *Crowley* [2000] also found that the difference between the reconstructed temperature change and that simulated by the simple climate model (SCM)–the "un-explained natural variability", is similar to that simulated by general circulation models. Later *Hegerl et al.* [2003] applied a multiple regression method to detect the response of the paleo temperatures simulated by a zonal energy-balance model to anthropogenic and natural climate forcings in the paleo-reconstructions of Northern Hemispheric temperature. That study found agreement with the previous finding of *Crowley* [2000] about the role of volcanoes and the sun in climate variability, and thus indirectly supported the assertion of the recent strong influence of human activity on climate during the industrial era.

[4] Recently, proxy-based hemispheric temperature reconstructions have been extended back to AD 200 for both the Southern and Northern Hemispheres [*Mann and Jones*, 2003]. The uncertainties are considerably larger for the Southern Hemisphere estimates, owing in large part to the sparseness of the available long proxy series. The sparse available network leads to large uncertainties, as diagnosed from the calibration period residual variance [*Mann and Jones*, 2003]. Accordingly, here we use our simple climate model with six radiative-forcing reconstructions and climate sensitivity determined from instrumental temperatures over 1861 to 1997 to simulate the forced pre-instrumental hemispheric-average temperatures for the Northern and

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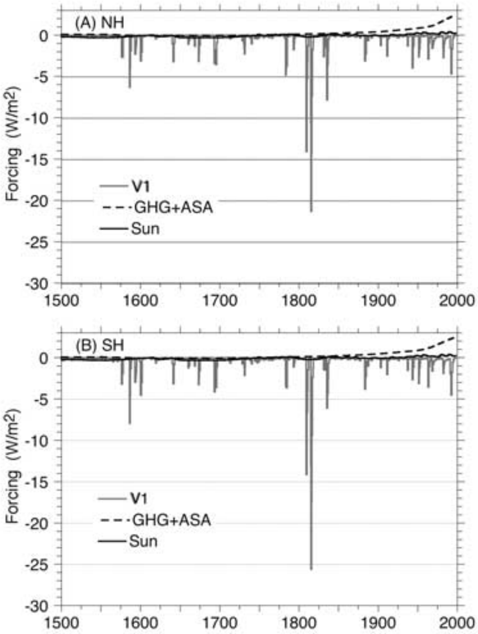

Figure 1. Radiative forcing for the Northern Hemisphere and the Southern Hemisphere greenhouse gases (GHG), anthropogenic sulfate aerosol (ASA), sun and volcanoes (V1).

Southern Hemispheres from 1500 to 1895. The first section describes the method, the second section presents our results, and the third section gives our conclusions.

2. Method

[5] Here we use a simple climate model (SCM) to simulate the hemispheric-mean temperature for the Northern and Southern Hemispheres [*Andronova and Schlesinger*, 2000, 2001]. The same hemispheric radiative forcing factors are used as in *Andronova and Schlesinger* [2001] (Figure 1), (1) the greenhouse-gas forcing (G) from 1500 to 1764 from *Crowley* [2000] and from 1765 to 1997 from *Harvey* [1997] due to the increasing concentrations of CO_2, methane, N_2O, and chlorofluorocarbons; (2) tropospheric ozone (T) beginning in 1860 because of anthropogenic emissions of NO_x and volatile organic compounds [*Stevenson et al.*, 1998]; (3) the clear air (direct) plus cloudy air (indirect) radiative forcing by sulfate aerosols (A) beginning in 1857 that are created in the troposphere from anthropogenic SO_2 emissions which forcing depends on $F^{dir}_{ASA}(1990)$, which we estimate as described below, and $F^{ind}_{ASA}(1990) = 3F^{dir}_{ASA}(1990)/8$ the latter as given by *Harvey et al.* [1997]; (4) the solar forcing (S) from 1500 to 1609 from *Crowley* [2000] and from 1610 to 1997 from *Lean et al.* [1995];. and (5) the volcanic radiative forcing (V1) beginning in 1500 estimated for the optical depths of *Robertson et al.* [2001] for stratospheric sulfate aerosols created from SO_2 gas injected into the stratosphere by major volcanic eruptions following the method described by *Andronova et al.* [1999]. For comparison, over the industrial period we use a different reconstruction of the volcanic forcing (V2) starting in 1850 calculated by *Andronova and Schlesinger* [1999] for the optical depths of *Sato et al.* [1993]. For comparison, over the paleo-period we used the global forcing from 1500–1850 calculated by *Crowley* [2000] (V3). The radiative forcing for the Northern and Southern Hemispheres is the same for G, S and V3, but is different for T, A, V1 and V2.

[6] The SCM is used to simulate the monthly temperature changes from 1500 to 1997 for six combinations (models) of the radiative forcing factors: GT, GTA, GTAS, GTAV1, GTAV2, GTAV3, GTASV1, GTASV2, and GTASV3. We chose the starting year as 1500 because there is no volcanic radiative forcing reconstruction for both the Southern and Northern Hemispheres prior to 1500. For each radiative-forcing model (RFM) the optimal values of ΔT_{2x} and $F^{dir}_{ASA}(1990)$ are determined by an optimization procedure that maximizes the probability that the simulated and observed temperature records are close to each other (maximum likelihood method) over 1861 to 1997 between the simulated and instrumental [*Jones and Moberg*, 2003] global-mean annual temperature departures and between the simulated and observed interhemispheric difference in annual temperature departures [*Andronova and Schlesinger*, 2000].

3. Results

[7] The values of ΔT_{2x}, $F_{ASA}(1990) = F^{dir}_{ASA}(1990) + F^{ind}_{ASA}(1990)$, and the root mean square difference (RMS) for the Northern and Southern Hemispheres over 1895–1997 are displayed in Figures 2a–2d for the different RFMs. For GT, ΔT_{2x} = 1.10°C, which is very close to the value obtained when there is no net feedback in the climate system [*Schlesinger*, 1985]. For GTA, ΔT_{2x} = 4.25°C. This nearly fourfold increase in ΔT_{2x} from GT is required for the SCM to reproduce the observed global-mean temperatures (GMTs) for the decreased net radiative forcing caused by the negative sulfate forcing. In this light the result for GT may be interpreted as the case for which the positive radiative forcing by carbonaceous aerosol balances the negative radiative forcing by the sulfate aerosol forcing. For GTAS, ΔT_{2x} = 2.48°C. This 42% decrease in ΔT_{2x} from GTA is required for the SCM to reproduce the GMTs for the increased net radiative forcing caused by the positive solar forcing during the period of instrumental temperature observations. Including the V1 volcanic forcing reduces ΔT_{2x} for GTAV1 compared to GTA but increases ΔT_{2x} for GTASV1 compared to GTAS. Including the V2 volcanic forcing, instead of V1 slightly reduces ΔT_{2x}. Figure 3b shows that $F^{dir}_{ASA}(1990)$ is rather insensitive to the RFM. Figures 2c and 2d show that except for the two RFMs that include V2, the RMS between the simulated and instrumentally observed temperature departures is smaller in the Southern Hemisphere (SH) than in the Northern Hemisphere (NH). It can be seen that no RFM yields the minimum RMS for both the NH and SH, although GTAS comes close with the smallest NH RMS + SH RMS of 0.14°C. With the exception of GTAV1, all of the RFMs have NH RMS + SH RMS that are within 0.035°C of the value for GTAS. Thus the correct radiative forcing model cannot be determined from this analysis. Reducing the uncertainty in ΔT_{2x} requires reducing the uncertainty in the radiative forcing by the sun, anthropogenic aerosols and volcanoes.

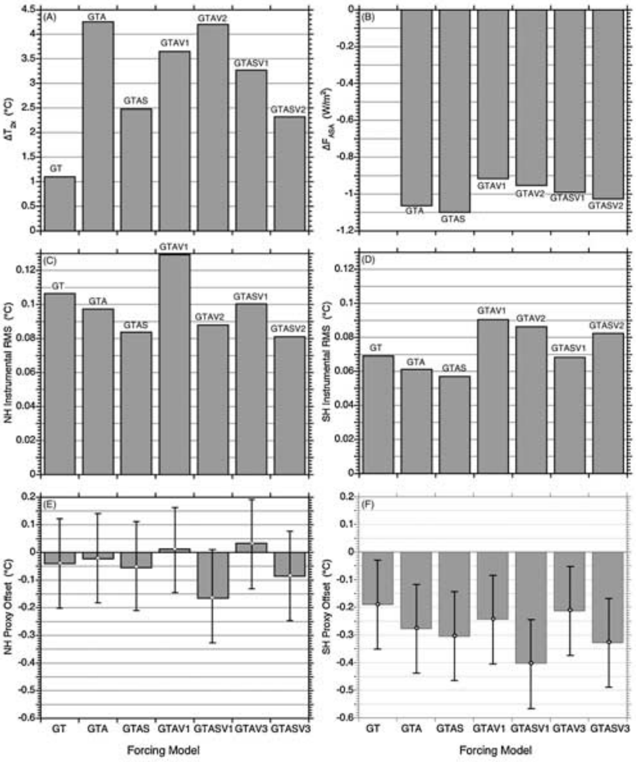

Figure 2. Climate sensitivity (A), anthropogenic sulfate aerosol radiative forcing in reference year 1990 (B), root-mean-square difference between the simulated and instrumental temperatures for the Northern Hemisphere (NH) (C) and Southern Hemisphere (SH) (D), and the difference between the proxy and simulated temperatures averaged over 1500 to 1895 for the NH (E) and SH (F) with one sigma uncertainty showed by bars.

[8] Ten-year running means of the resulting simulated temperatures are presented in Figure 3 together with reconstructed proxy and instrumental temperatures. It is seen that the simulated temperatures for the Southern Hemisphere are offset below the proxy temperatures, while this is not the case for the Northern Hemisphere. Figures 2e and 2f show the difference between proxy and simulated temperatures averaged from 1500 to 1895 for both hemispheres. The offset ranges from −0.17°C to 0.03°C for the Northern Hemisphere and −0.40°C to −0.19°C for the Southern Hemisphere. Thus the proxy temperatures are consistent with the simulated temperatures in the Northern Hemisphere but not in the Southern Hemisphere.

4. Conclusions

[9] In this paper we simulated the forced pre-instrumental hemispheric-average temperatures for the Northern and Southern Hemispheres from 1500 to 1895. Comparison of the simulated temperatures with reconstructed paleo temperatures for the Southern and Northern Hemispheres showed that the proxy temperatures are consistent with the instrumental temperatures in the Northern Hemisphere but not in the Southern Hemisphere. There the proxy temperatures are at least 0.2°C warmer than the simulated temperatures. This might indicate a missing feedback in the simple climate model or a missing forcing in the Southern Hemisphere. Alternatively, it may indicate that the proxy temperatures are biased too warm. If this is the case, then removal of the bias by reducing the mean Southern Hemisphere temperature over 1500 to 1895, by at least 0.2°C would reduce the global-mean temperature by at least 0.1°C. This would enhance the comparative global warmth of the 20th century relative to the proxy temperatures prior to the mid 19th century, thereby further strengthening the case for human-induced temperature changes during the 20th century.

[10] Finally we mention two additional findings. First, during the entire paleo-period (1500–1895) the standard deviation of the reconstructed NH temperature departures (0.065°C) is considerably smaller than the standard deviation of the reconstructed SH temperature departures (0.10°C), with their NH/SH ratio being 0.64. The variability of the simulated hemispheric temperature departures depends largely on the forcing model, but for any forcing model the variability of the simulated NH temperature departures is comparable or larger than the variability of the simulated SH temperature departures, with the NH/SH ratio varying from 1.12 for GT to 1.23 for GTASV1. For the paleo-period the only asymmetry in the forcing is for the volcanic forcing, as the solar and GHG forcings are the same for both hemispheres. But, there are large uncertainties in the estimated paleo volcanic forcing. Accordingly, the

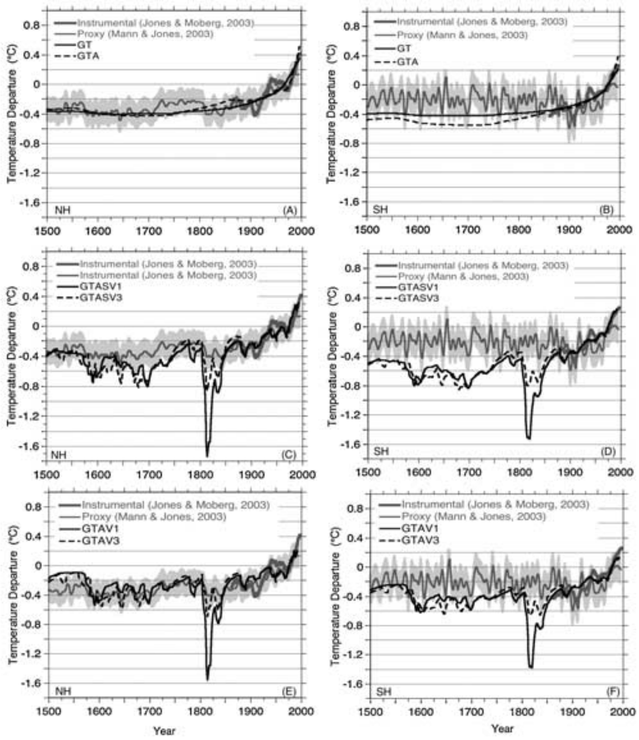

Figure 3. Ten-year running average temperature departures simulated by the simple climate model for the Northern Hemisphere (NH) and Southern Hemisphere (SH) for the radiative forcing models GT, GTA, GTAS, GTAV1, GTAV3, GTASV1 and GTASV3 in comparison with the ten-year running average instrumental and proxy temperature departures. The one sigma uncertainty of reconstructed data is shown by the shaded area.

difference in the variability between the reconstructed NH and SH temperature departures needs further consideration.

[11] It is known that there is a large sampling uncertainty in the SH reconstruction, attributed to the sparseness of currently available proxy data in the Southern Hemisphere [*Mann and Jones*, 2003]. Clearly an expanded network of high-quality Southern Hemisphere temperature proxy records could aid in diminishing this uncertainty.

[12] Second, Figure 3c shows that the simulated temperature departures for GTAV3 reproduce the reconstructed temperature departures starting from 1580 reasonably well. Thus it appears to be unnecessary to have a minimum in solar irradiance to explain the Little Ice Age in the NH.

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