Comment on "Ground vs. surface air temperature trends: Implications for borehole surface temperature reconstructions" by M. E. Mann and G. Schmidt

David S. Chapman, Marshall G. Bartlett, and Robert N. Harris

Department of Geology and Geophysics, University of Utah, Salt Lake City, Utah, USA

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[1] Changes in the Earth's surface temperature over time can be constructed from historical records of surface air temperature (SAT) [e.g., *Jones et al.*, 1999], from analysis of temperature proxies [e.g., *Mann et al.*, 1998], and from direct measurement of temperature in boreholes with computation of ground surface temperature (GST) histories that are consistent with the SAT record [e.g., *Huang et al.*, 2000; *Harris and Chapman*, 2001]. There is considerable interest in comparing these methods because the amount of warming since about 1500 A.D. inferred from borehole temperature studies is about 0.4°C greater than the warming inferred from proxy studies [*Harris and Chapman*, 2001].

[2] *Mann and Schmidt* [2003] argue that snow cover decouples air and ground temperatures, degrading recovered climate signals from borehole temperatures and thereby providing a partial explanation for the discrepancy between hemispheric borehole and proxy reconstructions. Their argument is based on a GISS ModelE GCM simulation of the latter half of the 20th century. From their interpretation of model results they conclude: (1) "...ground surface temperature in the Northern Hemisphere closely tracks surface air temperature only during the warm-season" [*Mann and Schmidt*, 2003, paragraph 10], (2) changing cold season snow cover provides a source of bias in interpreting climatic changes from GST changes, and (3) "...[snow cover] and pre-conditioning by prior warm season SAT also exhibiting a sizable and, in places, dominant influence." [*Mann and Schmidt*, 2003, paragraph 1] These three assertions raise serious questions about how closely GST changes track SAT changes at frequencies relevant to climate change studies and, by extension, the basis for interpretation of GST changes from boreholes.

[3] We have been working on the same question as Mann and Schmidt - the fidelity of GST and SAT tracking, in particular the effect of seasonal snow cover on this tracking. But our analysis, based not on model simulation but on analysis of measurements of GST and SAT at observatories and compiled in regional data collections, lead us to very different conclusions. We believe that analysis of GST and SAT data shows: (1) GST tracks SAT extremely well at time scales that are appropriate for climate change considerations. Although at each location there is an offset between mean annual ground and air temperature [*Powell et al.*, 1988] with ground temperature generally warmer by 1 to 3°C, and significant seasonal differences in the offset [*Baker and Ruschy*, 1993; *Putnam and Chapman*, 1996], measurements strongly indicate that GST tracks SAT changes at periods of years to decades [*Chapman and Harris*, 1993]. (2) Snow cover can either warm or cool the ground relative to a "no snow" case and need not lead to any bias. (3) Finally, our observations have not revealed any physical process that would explain the supposed pre-conditioning of GST by a prior season SAT. Our conclusions about GST and SAT are, therefore, opposite to those of *Mann and Schmidt* [2003]. We suggest the differences are based in a bias, not inherent in SAT and GST phenomena, but in selective and inappropriate presentation of model results by Mann and Schmidt. Rather than restate conclusions from our own observations, we show that, analyzed in an appropriate way, the *Mann and Schmidt* [2003] model results support rather than contradict findings from field observations.

[4] Borehole temperatures respond to an integrated, continuous time series of temperature at the Earth's surface [*Harris and Chapman*, 1998]. Furthermore, the process of heat conduction smoothes out high frequency temperature fluctuations so subsurface temperature profiles contain information on average surface temperatures over decade to century time scales, depending on the depth of a particular anomaly. It is these characteristics, direct measurement of temperature, sensitivity to a continuous rather than a discontinuous or seasonal time series, and low-pass filtering that make borehole temperature analysis such a useful complement of climate change studies. When *Mann and Schmidt* [2003] break their model output time series into warm season and cold season series their results may be of interest to seasonal investigations but have little relevance to, and are misleading in, the comparison of GST and SAT tracking.

[5] Figures 1a and 1b shows the model simulation results of Mann and Schmidt partitioned into separate seasonal time series, warm-season (April–September) and cold-season (October–March) half years. Interesting features in these seasonal comparisons are: (1) warm-season GST inter-annual variability is slightly greater than cold-season GST variability (standard deviations of the inter-annual

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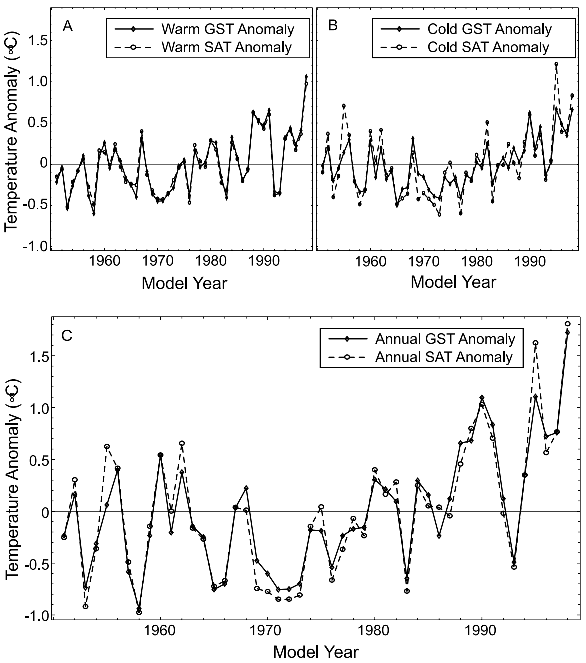

Figure 1. Northern Hemisphere mean surface air temperatures (SAT) and ground surface temperatures (GST) from the GISS ModelE GCM simulations of *Mann and Schmidt* [2003]. Panels A and B are the warm and cold season temperature anomalies, respectively, presented by *Mann and Schmidt* [2003] for the years 1951–1998. Panel C is the annual anomaly (October through September) constructed from the warm and cold season anomalies for the same period.

differences are 0.38°C and 0.31°C, respectively), (2) decadal SAT and GST trends in both warm and cold seasons are similar, (3) the effect of snow is variable, causing a condition where the cold-season GST is warmer than the SAT anomaly in 23 (48%) of the 48 model years (1951–1998) but cooler than the SAT anomaly in 25 (52%) of the model years. These separated seasonal anomalies, however are inappropriate for assessing how well ground temperature changes track air temperature changes for the purpose of studying climate change.

[6] A more appropriate comparison for testing bias in tracking is the continuous, annual time series of GST and SAT anomalies (calculated by averaging annual warm and cold season anomalies; the produced annual anomaly is for the period October to October, consistent with the model output provided by Mann and Schmidt) shown in Figure 1c. The two annual time series track extremely well, with a correlation coefficient $r = 0.97$. The annual ground temperature anomalies oscillate in magnitude with air temperature anomalies, and are greater than the air temperature anomaly in 21 of the modeled years, less than the air temperature anomaly in 14 years, and indistinguishably different (absolute difference <0.05°C) in the 13 remaining years. The inescapable conclusion from Figure 1c, both visually and statistically, is that in GISS ModelE GCM circulation simulations, ground temperatures closely track air temperatures at the annual time scales and longer. This result is confirmed by a recent simulation of the last millennium with a three-dimensional climate model driven by estimates of historical external forcings which shows that at climatically important time scales deep soil temperatures and SAT variations are "almost indistinguishable from each other" [*Gonzalez-Rouco et al.*, 2003].

[7] A second misleading analysis made by *Mann and Schmidt* [2003] concerns inappropriate use of end-points in reaching a numerical conclusion. In their paper, Mann and Schmidt focus on the model period 1971–1998 in which significant warming takes place. They state, "During a period of coincident surface warming and cold-season snow cover decrease in the model (1971–1998) mean [GST] increases are 0.2°C less than those in SAT, a consequence of greater exposure of the ground surface to winter cold air outbreaks. Interpretations of past SAT trends from borehole-based [GST] reconstructions may therefore be substantially biased by seasonal influences and snow cover changes." [*Mann and Schmidt*, 2003, paragraph 1] The 0.2°C difference in this period is misleading. It is based on using end points in computing changes in an oscillating time series, and is just bad science. For example, had they chosen the time period 1975–1996 the equally erroneous end-point analysis would have lead to an opposite conclusion that GST changes are 0.14°C more than the SAT changes. The correct analysis to investigate borehole-based GST bias combines the seasonal curves into a continuous, annual time series (Figure 1c) and asks whether there are significantly different trends over appropriate time periods. Over the time period of warming (1971–1998) the warming trends in GST and SAT are 0.59 ± 0.10 (sd) °C/decade and 0.61 ± 0.11 (sd) °C/decade respectively, not significantly different.

[8] The third misleading conclusion reached by *Mann and Schmidt* [2003] is that "[snow cover] and pre-conditioning [of the ground] by prior warm-season SAT exhibits a sizable and, in places, dominant influence" on cold season GST, ($r = 0.7$) thereby apparently degrading tracking between SAT and GST. [*Mann and Schmidt*, 2003, paragraph 1] The concept of a prior warm-season preconditioning was puzzling because, although temperatures below the ground surface are lagged by thermal diffusion (e.g., at about 7.5 m depth, temperatures are profoundly affected by surface temperature 6 months previously) the time lag at the ground surface is zero. The answer to this puzzle is that the GISS ModelE has persistence of seasonal trends. The correlation between cold and prior warm season SAT is also high ($r = 0.6$). Cold season GST responds to cold season SAT ($r = 0.9$) which is influenced by prior warm season SAT. The purported preconditioning of ground temperature is a by-product of this persistence.

[9] In conclusion, the *Mann and Schmidt* [2003] modeling study provides additional and strong support for field [*Harris and Chapman*, 2001] and observatory [*Putnam and Chapman*, 1996] studies that demonstrate how well ground temperature and air temperature changes track each other at time scales relevant to climate change reconstructions. These studies, showing good tracking of air and ground temperature, affirm that borehole temperature investigations remain an important complement in the arsenal of methods used to determine climate change.

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M. G. Bartlett, D. S. Chapman, and R. N. Harris, Department of Geology and Geophysics, University of Utah, 135 South 1460 East WBB 719, Salt Lake City, UT 84112, USA. (bartlett@mines.utah.edu)