Testimony of Richard A. Muller

14 November 2011

I am a Professor of Physics at the University of California at Berkeley, and I am the co-founder of the Berkeley Earth Surface Temperature Study, an independent research effort organized under the auspices of the Novim Group in Santa Barbara, California. I devoted over a decade of my research to climate change, particularly in paleoclimate; I've published papers on climate change in the most prestigious journals including Science, Nature, Paleoceanography, and Geology, and I'm the lead author of a major technical book on paleoclimate (published in 2000). For more bio, see the Appendix. In my testimony today I represent myself and the Berkeley Earth study, and not the University of California, Novim, or any other organization.

Prior to our Berkeley Earth work, three major groups had made estimates of global warming based on thermometer records. These were teams at NOAA, NASA, and the HadCRU group in the UK. Details can be found in our papers online at BerkeleyEarth.org.

The Berkeley Earth project was organized to address four legitimate criticisms of the prior work:

1. **Data selection bias**. The prior groups used fewer than 20% of the available stations, in recent years fewer than 10%. Did their station selection lead to an exaggeration of global warming?

2. **Urban heat islands**. We know that cities warm much more than rural areas, but this is not because of greenhouse warming. Did the inclusion of urban heat islands lead to an exaggeration of the greenhouse warming estimates?

3. **Station quality bias**. 70% of the stations used were ranked poor or bad by NOAA standards. Did nearness to buildings and other heat sources exaggerate global warming?

4. **Data adjustment bias**. The other three groups adjusted the data at times when there seemed to be a station or instrument change effect. Many of these adjustments were done by hand and are not reproducible. Did such "homogenization" exaggerate global warming?

Note that by "global warming" I am referring to the physical warming of the land surface of the Earth, and not to the human component of that warming.

The details of our answers are in four papers submitted to peer-reviewed journals, and available in preprint form at our website, www.BerkeleyEarth.org. The conclusions are based on careful analysis and solid analytical methods, and were a surprise to me.

Prior to the Berkeley Earth study, I had concluded that the only evidence for global climate change that could be compared in a quantitative way to theoretical predictions of the global climate models were the thermometer records. Other evidence, including

changes in hurricanes, tornadoes, heat spells, polar melting, and sea level rise, did not allow a quantitative comparison to the computer model calculations, and was tarnished by cherry-picking bias. The Berkeley Earth study provides a careful and precise measurement of the land temperature rise that can be compared directly to theory. We did not make an independent assessment of the theory, although we note below that future theoretical work needs to include intrinsic variability of ocean currents.

What did we do differently from the prior groups? (not part of verbal testimony)
--We developed an analysis method based firmly in the best statistical practices that enable us to use virtually all of the available data, 96%, vs the less than 20% used by prior groups. In particular, our method allows the inclusion of short records.
--We avoided manual adjustments to the data. When there were changes in temperature measurement methods, instead of "correcting" the data were automatically split and considered to be from separate stations.
--We performed no "gridding" to average nearby stations, but instead used an optimal method (called Kriging in the statistics literature) that takes into account correlations between nearby stations, and to make certain that the entire land surface was given equal weight in the final result. This method and use of the larger data set together are responsible, in part, for our improved uncertainties compared to the prior work.
--Uncertainties were calculated by subdividing the data set into smaller groups and then intercomparing them, a method that avoids the need for station error estimates.
--We studied station quality and the urban heat island by subdividing the data into groups that were expected to show differences. Our ability to handle small data sets with fragmented data allowed us to reach definitive conclusions on these issues.

Conclusions. Berkeley Earth were able to derive a good estimate of the Earth's average land temperature back to 1800, about 55 years earlier than the prior groups had done. The Berkeley Earth reconstruction for the period subsequent to 1956, when the IPCC says that the human component becomes detectable, shows an average land surface temperature rise of 0.9 ºC = 1.6 ºF, with an error uncertainty of ± 5%. This rise agrees with that previously estimated by NOAA, with a recent estimate made by NASA, and is about 0.2ºC warmer than the HadCRU result.

Our conclusions to the four key criticisms listed at the beginning of this testimony were no, no, no, and no. This means that the list of potential biases had not unduly influenced the results that had been published by the prior groups.

In doing this study, we were able to reach several other important conclusions:

1. **Human component**. Although we did not address this directly, we found compelling evidence that Atlantic Ocean variability plays a bigger role in land temperature change than had previously been recognized, from the early 1800s up to the present. Future estimates of the human component of global warming must take into account that some of the rise might be due to natural variability in the deep-sea conveyor belt currents (the thermohaline circulation), the same phenomenon that gives rise to the Gulf Stream.
2. **Volcanoes.** We identified the coldest year in our record as 1809, and only subsequently learned that there was a great volcanic eruption that year, comparable in magnitude to the eruption of Tambora in 1815 that led to the "year

without a summer." This substantiates the role of volcanic eruptions in short-term cooling.

3. **Warming was underway by 1800,** in disagreement with the famous "hockey stick" graph of the 2001 IPCC report. We also find that the early 1800s were considerably cooler than the hockey stick graph showed.

Transparency. We have merged the data from 15 sources and placed combined set online in a unified format easy for others to use. Merging the data was extraordinarily difficult (1.6 billion records in over a dozen formats, many duplicates and gaps); absence of a merged database had previously been a barrier to entry for other scientists. (Our lead scientist, Robert Rohde, deserves most of the credit for this accomplishment.) We expect that our new merged database will lead to a broader scientific involvement in the study of global warming. In the spirit of transparency, we have also placed our key analysis program (over 20,000 lines of code) online for scrutiny by others. The temperature data are now available online at BerkeleyEarth.org.

Greenhouse Theory. *The Berkeley Earth project did not directly study the greenhouse warming theory or the global climate models, except to the extent (mentioned above) that I conclude that natural variability in the oceanic currents needs to be included in future estimates of the human component.*

Climategate. *We made no study of the proxy data (tree-rings, corals, other indirect measures of climate) that were relevant to the "Climategate" issue.*

Reductions in emissions. *Berkeley Earth did not study methods to reduce greenhouse gas emission, but I have a personal comment. Most of the future greenhouse gases will be emitted by developing nations, and they can't afford to follow our example if the method we use is expensive. The best hope lies in energy conservation, efficiency, extended use of natural gas, solar, wind, and nuclear power. We need vigorous programs in all of these.*

Future work. The next phase of the Berkeley Earth project will be a study of ocean surface temperatures.

Financial Support
The Berkeley Earth Project was supported by:
The Lee and Juliet Folger Fund ($20,000)
William K. Bowes, Jr. Foundation ($100,000)
Fund for Innovative Climate and Energy Research (created by Bill Gates) ($100,000)
Charles G. Koch Charitable Foundation ($150,000)
The Ann & Gordon Getty Foundation ($50,000)
We have also received funding from a number of private individuals, totaling $14,500 as of June 2011.
All donations were provided as unrestricted educational grants, which means the donor organizations have no say over how we conduct the research or what we publish.
This work was also supported in part by the Director, Office of Science, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231 ($188,587)

Appendix: Biography for Richard A. Muller

Richard Muller has over 140 scientific publications in physics, astrophysics, and geophysics.

He is well known as the founder of the Berkeley project to study the expansion of the Universe, which led to a Nobel Prize (this year) for his former graduate student and post-doc Saul Perlmutter. Previously he had founded a project to measure the radiation from the Big Bang that led to a Nobel Prize (2006) for his post-doc George Smoot.

Muller is the inventor of Accelerator Mass Spectrometry, now the primary method used around the world for radiocarbon dating. He has other extensive experimental and theoretical work in particle physics, astrophysics, and geophysics. He spent over a decade studying paleoclimate, climaxing in a technical book, "Ice Ages and Astronomical Causes," coauthored by geophysicist Gordon MacDonald.

Muller is a Fellow of the American Association of Arts and Sciences, of the California Academy of Arts and Sciences, of the American Physical Society, and of the American Association for the Advancement of Science. He received a MacArthur Foundation Prize, the Alan T. Waterman Award of the National Science Foundation, and the Texas Instruments Founders Prize. Newsweek cited him as one of the top 25 Innovators in the United States, and The Atlantic Monthly listed him as one of 21 "Brave Thinkers" (along with President Obama and Steve Jobs). He has numerous awards for teaching excellence, and was voted a "campus hero" for having helped students "beyond the call of duty."

For 34 years he was a Jason advisor to the US government on national security. He has written eight books, including the bestseller "Physics for Future Presidents" based on his course at Berkeley voted by students as the "best class" on the Berkeley Campus. His new book, "Energy for Future Presidents" will be published this Spring. He and his daughter Elizabeth founded the Berkeley Earth Surface Temperature Project in 2009.