LLNL-TM-409572

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Information Regarding Synthetic Microwave Sounding Unit (MSU) Temperatures Calculated from CMIP-3 Archive

B.D. Santer

January 5, 2008

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

1. Introduction

Since the late 1960s, scientists have performed experiments in which computer models of the climate system are run with human-caused increases in atmospheric concentrations of greenhouse gases (GHGs). These experiments consistently showed that increases in atmospheric concentrations of GHGs should lead to pronounced warming, both at the Earth's surface and in the troposphere. The models also predicted that in the tropics, the warming of the troposphere should be larger than the warming of the surface.

Observed estimates of surface temperature changes are in good agreement with computer model results, confirming the predicted surface warming. Until several years ago, however, most available estimates of tropospheric temperature changes obtained from satellites and weather balloons (radiosondes) implied that the tropical troposphere had actually cooled slightly over the last 20 to 30 years, in sharp contrast to the computer model projections.

For nearly a decade, this apparent disconnect between models and reality has been used by some scientists to claim that: 1) the Earth's surface is not warming, and the surface thermometer record is incorrect; 2) human-caused changes in greenhouse gases have no effect on climate; 3) computer models have no skill in simulating the observed temperature changes in the tropics, and therefore cannot be used to predict the climatic response to further increases in greenhouse gases.

PCMDI's primary mission is to evaluate and improve climate models. It is thus of considerable interest to determine whether there is or is not a fundamental discrepancy between modeled and observed trends in tropospheric temperatures and in lower tropospheric lapse rates. PCMDI staff have been involved in this area of research for over 10 years.

2. Comparing Modeled and Satellite-Derived Tropospheric Temperature Changes

Since 1979, Microwave Sounding Units (MSU) on polar-orbiting satellites have measured the microwave emissions of oxygen molecules in the atmosphere, which are proportional to atmospheric temperatures. Measurements of microwave emissions made at different frequencies can be used to obtain information about the temperatures of broad atmospheric layers. Most attention has focused on estimates of the temperatures of the lower stratosphere and mid- to upper troposphere (T_4 and T_2, respectively) as well as on a retrieval of lower tropospheric temperatures (T_{2LT}) (1, 2, 3, 4, 5). Here, we confine our attention to T_2 and the T_{2LT} retrieval.

To facilitate comparison between tropospheric temperatures changes obtained from climate models with changes estimated from satellite-borne MSU instruments, we used a static, global-mean weighting function approach. In this approach, the profile of discrete pressure-level atmospheric temperature data at each model grid-point is convolved with a profile of pressure weights. There are two separate profiles of pressure weights – one for T_2, and one for the T_{2LT} retrieval. These static weighting functions were obtained for standard atmospheric conditions, as described in (4). They were provided by John Christy at the University of Alabama at Huntsville.

The static weighting function approach is a standard method for deriving "synthetic" MSU temperatures from radiosonde soundings (4, 6), reanalysis products, or climate model data. The implementation of this approach is fully described in (6). The approach does not account for spatial differences in surface emissivity (between land, ocean, and sea-ice), or for variations in atmospheric moisture as a function of space and time (6). At large spatial scales (global and hemispheric averages), the decadal-timescale tropospheric temperatures trends estimated with the static weighting function approach are very similar to those obtained with a full radiative transfer code (6).

3. CMIP-3 data analyzed

Three recent studies involving PCMDI authors have relied on synthetic MSU temperatures calculated from the so-called CMIP-3 archive (7, 8, 9). The acronym "CMIP" stands for Coupled Model Intercomparison Project (10). In phase 3 of this project, a number of different climate model experiments were performed in support of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) (11). The CMIP-3 database is openly available to scientific researchers around the world for non-commercial use. For instructions on how to access the CMIP-3 data, refer to (12). Currently, over 2,400 groups have registered to use CMIP-3 model output.

In a paper published in *Science* in 2005 (7), PCMDI scientists computed synthetic MSU temperatures from the CMIP-3 "20c3m" experiment. In this experiment, nearly two dozen different climate models were forced with estimates of historical changes in both anthropogenic and natural external factors. The *Science* paper examined a set of 49 simulations of 20th century climate change performed with 19 different computer models (13).

Eleven of these 19 models performed multiple realizations of the 20c3m experiment (see Appendix A). For any given model with multiple 20c3m realizations, the applied external forcings do not vary from realization to realization – the only variation between realizations is in the initial conditions of the coupled atmosphere-ocean system (14).

The same set of 49 simulations of 20th century climate change was examined in the first Synthesis and Assessment Product of the U.S. Climate Change Science Program (CCSP) (2, 8) and in a paper published in 2008 in the *International Journal of Climatology* (9).

The 49 simulations used in the *Science* paper (7), the first CCSP Report (2, 8) and the *International Journal of Climatology* paper (9) are explicitly identified in Appendix A.

4. Calculation of indices

Gridded monthly-mean synthetic MSU T_2 and T_{2LT} temperatures were calculated from each of the 49 simulations of historical climate change. At each grid-point, temperatures were expressed as anomalies relative to climatological monthly means over the period January 1979 through December 1999 (15). From these gridded fields of monthly-mean anomaly data, ten different spatially-averaged indices were computed. Spatial averaging involves appropriate area-weighting. The indices are for the following domains:

1. Global
2. Northern Hemisphere
3. Southern Hemisphere
4. Northern Hemisphere high-latitudes (60°N-90°N)
5. Northern Hemisphere mid-latitudes (30°N-60°N)
6. Northern Hemisphere low latitudes (0°-30°N)
7. Southern Hemisphere high latitudes (60°S-90°S)
8. Southern Hemisphere mid-latitudes (30°S-60°S)
9. Southern Hemisphere low latitudes (0°-30°S)

10. Tropics (20°N-20°S)

5. Output files of synthetic MSU temperatures

There are a total of 98 ASCII files containing synthetic MSU temperatures from 49 simulations of 20th century climate change (16). Each file contains 29 header lines. Thirteen columns of data follow the header lines. The first three columns are an integer counter over the total number of months, and two "time counters". The next 10 columns are the time series of monthly-mean, spatially-averaged anomaly data.

The ASCII files for different models can be of different length, since individual modeling groups often chose different start dates and end dates for their 20c3m experiments.

The file names encode information about the data stored in the file. Consider, for example, the file name:

tam2_CCSM3.0_VSGSuO_b30.030a_mm_ci_aw_r1979_1999_nofilt.d

This encodes the following information:

tam Climate variable considered (tam = temperature, atmosphere)

2 MSU channel 2 (*i.e.*, T_2; mid- to upper troposphere)

CCSM3.0 Climate model analyzed (NCAR Community Climate System Model, version 3.0)

VSGSuO_b30.030a Experiment analyzed

mm Type of temporal averaging: Monthly mean data

ci Type of data: Climate indices

aw Data are area weighted

r1979_1999 Reference period for calculation of anomalies nofilt No temporal filtering of output data

Several points should be noted about this encoding system. First, tam2 and tam6 are the designations for T_2 and T_{2LT} data, respectively (17). Second, the model names and experiment names that are encoded in the file names are not identical to the model and file names used in the official CMIP-3 archive (18). The reason for this difference in names is that some of the synthetic MSU calculations performed at PCMDI were completed before "official" model and experiment names were decided upon. The Table in Appendix A enables users of the synthetic MSU data to identify (in the official terminology of the CMIP-3 database archived at PCMDI) the models and experiments from which the T_2 and T_{2LT} data were calculated.

6. Referencing the synthetic MSU temperatures

Publications using any or all of the synthetic MSU T_2 temperatures and/or the synthetic T_{2LT} temperatures described in this document should reference these datasets as follows:

"Synthetic MSU temperatures from 49 simulations of 20th century climate change were calculated as described in Santer, B.D., *et al*., 2008: Consistency of modeled and observed temperature trends in the tropical troposphere. *International Journal of Climatology*, **28**, 1703-1722, doi:10.1002/joc.1756."

Appendix A: Model 20c3m runs analyzed

Model name in file with synthetic MSU data	Official model name in CMIP-3 archive	Experiment name and realization number in file with synthetic MSU data	Official experiment name and realization number in CMIP-3 archive	No. of 20c3m realizations
CCCMA3.1	CGCM3.1(T47)	20c3m_run1	20c3m_run1	1
CCSM3.0	CCSM3	VSGSuO_b30.030a/b/c/d/e	20c3m_run1/2/3/4/5	5
CNRM3.0	CNRM-CM3	20c3m_run1	20c3m_run1	1
CSIRO3.0	CSIRO-Mk3.0	20c3m_run1	20c3m_run1	1
ECHAM5	ECHAM5/MPI-OM	VSGSuO_run1/2/3	20c3m_run1/2/3	3
GFDL2.0	GFDL-CM2.0	CM2Q-d2-AllForc_h1/h2/h3	20c3m_run1/2/3	3
GFDL2.1	GFDL-CM2.1	CM2.1U-d4-AllForc_h1/h2/h3	20c3m_run1/2/3	3
GISS_AOM	GISS-AOM	A1-20C3M-run1/2	20c3m_run1/2	2
GISS_EH	GISS-EH	A1-20C3M-run1/2/3/4/5	20c3m_run1/2/3/4/5	5
GISS_ER	GISS-ER	A1-20C3M-run1/2/3/4/5	20c3m_run1/2/3/4/5	5
HADCM3	UKMO-HadCM3	20c3m_run1	20c3m_run1	1
HADGEM1	UKMO-HadGEM1	20c3m_run2	20c3m_run1 (19)	1
IAP_FGOALS1.0	FGOALS-g1.0	20c3m_run1/2/3	20c3m_run1/2/3	3
INMCM3.0	INM-CM3.0	20c3m_run1	20c3m_run1	1
IPSL_CM4	IPSL-CM4	20c3m_run1	20c3m_run1	1
MIROC3.2_T106	MIROC3.2(hires)	VSGSuO_run1	20c3m_run1	1
MIROC3.2_T42	MIROC3.2(medres)	VSGSuO_run1/2/3	20c3m_run1/2/3	3
MRI2.3.2a	MRI-CGCM2.3.2	20c3m_run1/2/3/4/5	20c3m_run1/2/3/4/5	5
PCM	PCM	VSGSuO_B06.57/59/60/61	20c3m_run1/2/3/4	4
				49

End notes

[1] The designations T_4 and T_2 reflect the fact that the original MSU measurements employed MSU channels 4 and 2 (subsequently replaced by equivalent data from other channels in the latest Advanced Microwave Sounding Units). The bulk of the microwave emissions monitored by channel 4 is from roughly 14 to 29 km above Earth's surface (150 to 15 hPa). Channel 2 primarily samples emissions from the surface to 18 km (75 hPa). The T_{2LT} retrieval is constructed using the outer and inner "scan angles" of channel 2, and is a measure of temperatures from the surface to 8 km (350 hPa). For further details of the atmospheric layers sampled by MSU, see (2).

[2] Karl TR, Hassol SJ, Miller CD, Murray WL (*eds*). 2006. *Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences*. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. National Oceanic and Atmospheric Administration, National Climatic Data Center, Asheville, NC, 164 pp.

[3] Spencer, R.W., and J.R. Christy, 1990: Precise monitoring of global temperature trends from satellites. *Science*, **247**, 1558-1562.

[4] Spencer, R.W., and J.R. Christy, 1992: Precision and radiosonde validation of satellite grid-point temperature anomalies, Part I, MSU channel 2. *Journal of Climate*, **5**, 847-857.

[5] Spencer, R.W., and J.R. Christy, 1992: Precision and radiosonde validation of satellite grid-point temperature anomalies, Part II, A tropospheric retrieval and trends during 1979-90. *Journal of Climate*, **5**, 858-866.

[6] Santer, B.D., J.J. Hnilo, J.S. Boyle, C. Doutriaux, M. Fiorino, D.E. Parker, K.E. Taylor, and T.M.L. Wigley, 1999: Uncertainties in observationally-based estimates of temperature change in the free atmosphere. *Journal of Geophysical Research*, **104**, 6305-6333.

[7] Santer, B.D., T.M.L. Wigley, C. Mears, F.J. Wentz, S.A. Klein, D.J. Seidel, K.E. Taylor, P.W. Thorne, M.F. Wehner, P.J. Gleckler, J.S. Boyle, W.D. Collins, K.W. Dixon, C. Doutriaux, M. Free, Q. Fu, J.E. Hansen, G.S. Jones, R. Ruedy, T.R. Karl, J.R. Lanzante, G.A. Meehl, V. Ramaswamy, G. Russell, and G.A. Schmidt, 2005: Amplification of surface temperature trends and variability in the tropical atmosphere. *Science*, **309**, 1551-1556.

[8] Santer, B.D., J.E. Penner, P.W. Thorne, W.D. Collins, K.W. Dixon, T.L. Delworth, C. Doutriaux, C.K. Folland, C.E. Forest, J.R. Lanzante, G.A. Meehl, V. Ramaswamy, D.J. Seidel, M.F. Wehner, and T.M.L. Wigley, 2006: How well can the observed vertical temperature changes be reconciled with our understanding of the causes of these changes? In: *Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences*. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research [Karl, T.R., S.J. Hassol, C.D. Miller, and W.L. Murray (eds.)]. National Oceanic and Atmospheric Administration, National Climatic Data Center, Asheville, NC, USA, pp. 89-108.

[9] Santer, B.D., P.W. Thorne, L. Haimberger, K.E. Taylor, T.M.L. Wigley, J.R. Lanzante, S. Solomon, M. Free, P.J. Gleckler, P.D. Jones, T.R. Karl, S.A. Klein, C. Mears, D. Nychka, G.A. Schmidt, S.C. Sherwood, and F.J. Wentz, 2008: Consistency of modelled and observed temperature trends in the tropical troposphere. *International Journal of Climatology*, **28**, 1703-1722. DOI: 10.1002/joc.1756.

[10] Meehl, G.A., C. Covey, T. Delworth, M. Latif, B. McAvaney, J.F.B. Mitchell, R.J. Stouffer, and K.E. Taylor, 2007: The WCRP CMIP3 multi-model dataset: A new era in climate change research. *Bulletin of the American Meteorological Society*, **88**, 1383-1394.

[11] IPCC, 2007: *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[12] See https://esg.llnl.gov:8443/about/registration.do

[13] These were the models and simulations available in the CMIP-3 archive in late 2004, at the time analyses for the 2005 Santer *et al*. *Science* paper (7) were being conducted. A larger number of 20c3m simulations is now available in the archive.

[14] As discussed in detail in (7) and (8), the modeling groups contributing to the CMIP-3 archive did not use the same external forcings.

[15] For example, the T_2 temperature at grid-point *x*, month *m*, and year *t* in the i^{th} realization of the 20c3m experiment performed with the j^{th} model is expressed as an anomaly with respect to the climatological monthly-mean T_2 temperature at grid-point *x* (for month *m*, realization *i*, and model *j*). The 252-month reference period used for anomaly definition is the period of maximum overlap between observed MSU T_2 and T_{2LT} data (which commence in January 1979) and most of the model 20c3m experiments in the CMIP-3 archive (which generally commence in the late 19th century and end in December 1999).

[16] 49 simulations of 20th century climate change × 2 MSU temperatures (T_2 and T_{2LT}).

[17] The designation “tam6” for T_{2LT} data is consistent with the terminology used by scientists at the University of Alabama at Huntsville.

[18] See http://www-pcmdi.llnl.gov/ipcc/time_correspondence_summary.htm for the official model designations.

[19] This mismatch in realization numbers occurs because the UKMO Hadley Centre provided PCMDI with data from addition 20c3m realizations which are not in the official CMIP-3 archive.