



Temperature Trends in the Lower Atmosphere

Steps for Understanding and Reconciling Differences

U.S. Climate Change Science Program
Synthesis and Assessment Product 1.1

**DRAFT SUBSEQUENT
FROM PUBLIC REVIEW**

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Synthesis and Assessment Product 1.1
Report by the U.S. Climate Change Science Program
and the Subcommittee on Global Change Research

EDITED BY:

Thomas R. Karl, Susan J. Hassol,
Christopher D. Miller, and William L. Murray

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Previously reported discrepancies between the amount of warming near the surface and higher in the atmosphere have been used to challenge the validity of climate models and the reality of human-induced global warming. Specifically, surface data showed substantial global-average warming, while early versions of satellite data showed little or no warming above the surface. There is no longer evidence of such a discrepancy. This is an important revision to and update of the conclusions of earlier reports from the U.S. National Research Council and the Intergovernmental Panel on Climate Change.

Since those reports, errors have been identified and corrected in the satellite data and other temperature observations. These data now show global-average warming in the atmosphere similar to the warming observed at the surface and consistent with the results from climate models, although discrepancies remain to be resolved in the tropics. The recent evidence has increased confidence in our understanding of observed climatic changes and their causes.

RECOMMENDED CITATIONS

For the Report as a whole:

Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences. Thomas R. Karl, Susan J. Hassol, Christopher D. Miller, and William L. Murray, editors, 2006. A Report by the Climate Change Science Program and the Subcommittee on Global Change Research, Washington, DC.

For the Preface:

Karl, T.R., C. D. Miller, and W. L. Murray, editors, 2006: in *Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences*. T. R. Karl, S. J. Hassol, C. D. Miller, and W. L. Murray, editors. A Report by the Climate Change Science Program and the Subcommittee on Global Change Research, Washington, DC.

For the Executive Summary:

Wigley, T.M.L., V. Ramaswamy, J.R. Christy, J.R. Lanzante, C.A. Mears, B.D. Santer, C.K. Folland, 2006: Executive Summary in *Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences*. T. R. Karl, S. J. Hassol, C. D. Miller, and W. L. Murray, editors. A Report by the Climate Change Science Program and the Subcommittee on Global Change Research, Washington, DC.

For Chapter 1:

Ramaswamy, V., J.W. Hurrell, G.A. Meehl, 2006: Why do temperatures vary vertically (from the surface to the stratosphere) and what do we understand about why they might vary and change over time? in *Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences*. T. R. Karl, S. J. Hassol, C. D. Miller, and W. L. Murray, editors. A Report by the Climate Change Science Program and the Subcommittee on Global Change Research, Washington, DC.

For Chapter 2:

Christy, J.R., D.J. Seidel, S.C. Sherwood, 2006: What kinds of atmospheric temperature variations can the current observing systems detect and what are their strengths and limitations, both spatially and temporally? in *Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences*. T. R. Karl, S. J. Hassol, C. D. Miller, and W. L. Murray, editors. A Report by the Climate Change Science Program and the Subcommittee on Global Change Research, Washington, DC.

For Chapter 3:

Lanzante, J.R., T.C. Peterson, F.J. Wentz, K.Y. Vinnikov, 2006: What do observations indicate about the change of temperatures in the atmosphere and at the surface since the advent of measuring temperatures vertically? in *Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences*. T. R. Karl, S. J. Hassol, C. D. Miller, and W. L. Murray, editors. A Report by the Climate Change Science Program and the Subcommittee on Global Change Research, Washington, DC.

For Chapter 4:

Mears, C.A., C.E. Forest, R.W. Spencer, R.S. Vose, R.W. Reynolds, 2006: What is our understanding of the contribution made by observational or methodological uncertainties to the previously reported vertical differences in temperature trends? in *Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences*. T. R. Karl, S. J. Hassol, C. D. Miller, and W. L. Murray, editors. A Report by the Climate Change Science Program and the Subcommittee on Global Change Research, Washington, DC.

For Chapter 5:

Santer, B.D., J.E. Penner, P.W. Thorne, 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*. T. R. Karl, S. J. Hassol, C. D. Miller, and W. L. Murray, editors. A Report by the Climate Change Science Program and the Subcommittee on Global Change Research, Washington, DC.

For Chapter 6:

Folland, C.K., D. Parker, R.W. Reynolds, S.C. Sherwood, P.W. Thorne, 2006: What measures can be taken to improve the understanding of observed changes? in *Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences*. T. R. Karl, S. J. Hassol, C. D. Miller, and W. L. Murray, editors. A Report by the Climate Change Science Program and the Subcommittee on Global Change Research, Washington, DC.

For Appendix A:

Wigley, T.M.L., Appendix A: Statistical Issues Regarding Trends, in *Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences*. T. R. Karl, S. J. Hassol, C. D. Miller, and W. L. Murray, editors. A Report by the Climate Change Science Program and the Subcommittee on Global Change Research, Washington, DC.