PREFACE

Report Motivation and Guidance for Using this Synthesis/Assessment Report

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A primary objective of the U. S. Climate Change Science Program (CCSP) is to provide the best possible scientific information to support public discussion and government and private sector decision-making on key climate-related issues. To help meet this objective, the CCSP has identified an initial set of 21 synthesis and assessment products that address its highest priority research, observation, and decision-support needs. This Synthesis/Assessment Report, the first of the 21 Reports, focuses on understanding the causes of the reported differences between independently produced data sets of atmospheric temperature trends from the surface through the troposphere to the lower stratosphere.

This topic is relevant to policy-makers because previous discrepancies between surface and tropospheric temperature observations challenged the correctness of climate model simulations and the reality of greenhouse gas-induced global warming. As described in the Executive Summary, considerable progress has been made in resolving many of these earlier discrepancies.

Background

Measurements of global surface air temperature show substantial increases over the past several decades. In the early 1990s, data from the National Oceanic and Atmospheric Administration's (NOAA's) polar orbiting satellites were analyzed for multi-decadal trends. These initial analyses indicated that global-mean temperatures in the troposphere showed little or no increase, in contrast with surface air measurements from ships, land-based weather stations, and ocean buoys. This result led some to question the reality and/or the cause of reported global-mean surface temperature increases, on the basis that human influences, thought to be important contributors to observed change, were expected to increase temperatures both at the surface and in the troposphere, with the largest increases expected in the tropical troposphere. This led to an intensive effort by climate scientists to better understand the causes of the apparent differences in the reported rates of temperature changes between the surface and the troposphere.

Scientists analyzing the data knew that there were complex and unresolved issues related to inadequacies of observing systems that could lead to misleading impressions or misinterpretation of the data. There were also uncertainties in our understanding of how the climate might respond to various forcings, as is often assessed through the use of climate models. In an attempt to resolve these issues, in 2000 the National Research Council (NRC) specifically addressed the issue of temperature trends in the troposphere and at the surface. In its Report, the NRC concluded that "the warming trend in global-mean surface temperature observations during the past 20 years is undoubtedly real and is substantially greater than the average rate of warming during the twentieth century. The disparity between surface and upper air trends in no way invalidates the conclusion that surface temperature has been rising." The NRC further found that corrections in the Microwave Sounding Unit (MSU) processing algorithms brought the satellite data record into slightly closer alignment with surface temperature trends. They concluded that the substantial disparity that remained probably reflected a less rapid warming of the troposphere than the surface in recent decades due to both natural and human-induced causes.

In 2001, the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report devoted additional attention to new analyses of the satellite, weather balloon, and surface data to evaluate the difference in temperature trends between the surface and the troposphere. Similar to the NRC, the IPCC concluded that it was very likely that the surface temperature increases were larger and differed significantly from temperature increases higher in the troposphere. They concluded, "during the past two decades, the surface, most of the troposphere, and the stratosphere have responded differently to climate forcings because different physical processes have dominated in each of the regions during that time." (IPCC, Climate Change 2001: The Scientific Basis, Chapter 2, p. 122-123; Cambridge University Press).

Focus of this Synthesis/Assessment Report

The efforts of the NRC and IPCC to address uncertainties about the temperature structure of the lower atmosphere *(i.e.,* from the surface through the lower stratosphere) have helped move us closer to a comprehensive understanding of observed trends of temperature. Although these documents provided a great deal of useful information, full resolution of the issue was hampered by the complexities of the climate system coupled with shortcomings of the available observing systems. To more fully address remaining fundamental questions, a broader examination has been undertaken here to answer the following questions:

1) 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?

2) What kinds of atmospheric temperature variations can the current observing systems measure and what are their strengths and limitations, both spatially and temporally?

3) What do observations indicate about the changes of temperature in the atmosphere and at the surface since the advent of measuring temperatures vertically?

4) What is our understanding of the contribution made by observational or methodological uncertainties to the previously reported vertical differences in temperature trends?

5) How well can the observed vertical temperature changes be reconciled with our understanding of the causes of these changes?

6) What measures can be taken to improve the understanding of observed changes?

These questions provide the basis for the six main chapters in this Synthesis/Assessment Report (the chapter numbers correspond to the question numbers above). They highlight several of the fundamental uncertainties and differences between and within the individual components of the existing observational and modeling systems. The responses to the questions are written in a style consistent with major authoritative international scientific assessments (*e.g.*, IPCC assessments, and the Global Ozone Research and Monitoring Project of the World Meteorological Organization [WMO]). The Executive Summary, which presents the key findings from the main body of the Report, is intended to be useful for those involved with policy-related global climate change issues. The Chapters supporting the Executive Summary are written at a more technical level suitable for non-climate specialists within the scientific community and well-informed lay audiences.

The Synthesis/Assessment Report is structured so as to compartmentalize, as much as possible, the answers to each of the six questions (above). However, given the interconnected nature of the questions, this is not entirely possible, or desirable. Occasionally topics extraneous to a particular chapter are mentioned in passing to make an important point or alert the reader to some issue(s) covered elsewhere in the report. However, as a general rule, in the interest of brevity this report does not always explicitly refer the reader to another chapter. The reader is advised to keep this in mind and refer to Table 1 (next page.) for guidance on locating the discussion of particular issues.

To help answer the questions posed, climate model simulations of temperature change based on time histories of important forcing factors have been compared with observed temperature changes. It is recognized that in a system containing internally generated variations, it is unrealistic to expect models to exactly replicate observed changes. If the ensemble of simulations replicates important aspects of the observed temperature changes (*e.g.*, global mean, tropical mean) this increases confidence in our understanding of the observed temperature record and reduces uncertainties about projected changes. If not, then this implies that the time histories of the important forcings are not adequately known, all of the important forcings are not included, the processes being simulated in the models have flaws, the observational record is incorrect, or some combination of these factors is present.

This CCSP Synthesis/Assessment Report assesses the uncertainties associated with the data used to determine changes of temperature, and whether such changes are consistent with our understanding of climate processes. This requires a detailed comparison of observations and climate models used to simulate observed changes, including an appreciation of why temperatures might respond differently at the surface compared to various layers higher in the atmosphere.

This CCSP Report also addresses the accuracy and consistency of the temperature records and outlines steps necessary to reconcile differences between individual data sets. Understanding exactly how and why there are differences in temperature trends reported by several analysis teams using different observation systems and analysis methods is a nec-

Table 1. Guide to readers to identify Chapter emphasis. The Executive Summary ties together all these aspects of the Synthesis/Assessment Report.

Report Section	Observations	Observational Uncertainty	Processes	Models	Comparing Model Simulations & Observations	Statistical Analysis
Chapter 1	secondary		primary			
Chapter 2		primary				
Chapter 3	primary					
Chapter 4		primary				
Chapter 5			secondary	primary	primary	secondary
Chapter 6		primary			secondary	
Appendix	secondary					primary

essary step in resolving previously identified discrepancies between observations and model simulations.

New observations and analyses since the IPCC and NRC Reports

Since the IPCC and NRC assessments, there have been intensive efforts to create new satellite and weather balloon data sets using a range of approaches. Having multiple tropospheric temperature data sets provides the opportunity for much greater understanding of observed changes and their uncertainty than was possible in the previous assessments. In addition, for the first time, a suite of models simulating observed climate since 1979 (when satellite data began) has provided a unique opportunity to inter-compare observed trends from various data sets with model simulations using various scenarios of historical climate forcings. Taken together, these advances lead to a greater understanding of the issues. The process of producing this Report has stimulated additional research and analysis on these topics, and helped to move the science forward.

This Report includes recent analyses of and corrections to data sets that have helped resolve inconsistencies among observational data sets and between observations and models. The science of upper air temperatures is a rapidly evolving field. During the preparation of this Report, new findings were published and are now included in the current draft. For example, a recent article demonstrated an error in the method used in the original satellite data set to correct for diurnal cycle errors due to satellite orbital drift. When corrected, the data set yielded greater warming in the lower troposphere. Since it was possible for the error to be rectified fairly quickly, a new version of this data set was available for this Report. At the same time, another research team produced its first version of satellite-derived lower tropospheric temperatures, and yet another team updated its tropospheric temperature time series. All these results are included in this Report and are compared to a suite of recent climate model simulations. The authors certainly expect that new data and discoveries that follow the release of this Report will further improve our understanding.

Factors that guided the authors in the selection of the climate records considered extensively in this Report were: (a) publication heritage, (b) public availability, (c) use by the scientific community at-large, (d) updates on a monthly basis, and (e) period of record beginning in 1979 or earlier. The climate records considered in this Report are also global in scope.[1]

[1] Most analyses undertaken to date have considered temperature trends at the global scale or large-regional scale *(e.g.,* the tropics). Because this report was charged with assessing the current state of the science, it also necessarily focuses on these large scales. It is at these scales that the apparent discrepancies in temperature trends were first reported. We also currently have most capability in simulating climate at these scales. Until we can reconcile our understanding on the very large scales, little scientific value will be added by considering finer regional details. This does not imply that future analyses should not consider finer regional scales for a complete understanding of relative temperature trends at the surface and in the troposphere.

The three surface analyses that were used have many publications that describe their construction methods. These data sets are readily available and are widely used. Two of the three satellite data sets used, while relatively recent, are based on a heritage of published versions that have incorporated new adjustments as discoveries have been made. Each of these data sets allows ready access to the public and has been used in several research publications. A third, more recently developed data set has been updated during the preparation of this Report. Two data sets used were based on weather balloon data. One of these data sets publicly appeared in 2005, but the authors had made the preliminary versions and methodology available to scientists as early as 2002 and have built upon the extensive experience acquired from previous versions of these data sets. Another data set has a heritage dating back several decades and was recently updated.

The models selected for comparison with observations were those models available to the author team during the course of this assessment. They represent the state-of-the-science from every major global climate modeling center in the world. The model simulations selected include a large fraction of those that were run for the Fourth Assessment Report of the IPCC, due to be published in 2007. The simulations are freely available, and details regarding access to the model data can be obtained from the Program for Climate Model Diagnosis and Intercomparison (http://www.pcmdi.11n1.gov/ipcc/about_ipcc.php). The data used in this report are also openly available and a list of web sites where they can be obtained is included in Chapter 3.

How to use this Synthesis/Assessment Report

This Report promises to be of significant value to decision-makers, and to the expert scientific and stakeholder communities. Readers of this Report will find that new observations, data sets, analyses, and climate model simulations enabled the Author Team to resolve many of the issues noted by the NRC and the IPCC in their earlier Reports. This Synthesis/Assessment Report already has had an important impact on the content of the draft to the Fourth Assessment Report of the IPCC, due to be published in 2007.

This Synthesis/Assessment Report exposes the remaining differences among different observing systems and data sets related to recent changes in tropospheric and stratospheric temperature. Discrepancies between the data sets and the models have been reduced and our understanding of observed climate changes and their causes has increased. Given this, there is no longer sufficient evidence to conclude that there exists any notable discrepancy between our understanding of recent global average temperature changes and model simulations of these changes. This represents a schange from conclusions of earlier reports (see above) and should constitute a valuable source of information to policymakers.

In addition, we expect the information generated here will be used both nationally and internationally, *e.g.*, by the Global Climate Observing System (GCOS) Atmospheric Observation Panel to help identify effective ways to reduce observational uncertainty. The findings regarding observations and comparisons between models and observations of lower stratospheric temperature trends may also be useful for future WMO/United Nations Environment Programme (UNEP) Ozone Assessments.

Some terms used in the Report may be unfamiliar to those without training in meteorology; a glossary and list of acronyms is included at the end of the Report. In addition, the table on page X defines defines the terminology used in this Report for the layers of the atmosphere.

To integrate a wide variety of information, this Report also uses a lexicon of terms (See Fig. 1) to express the team's considered judgment about the likelihood of results. Confidence in results is highest at each end of the spectrum. Unless qualified by these expressions of likelihood, all statements are implied to be certain.

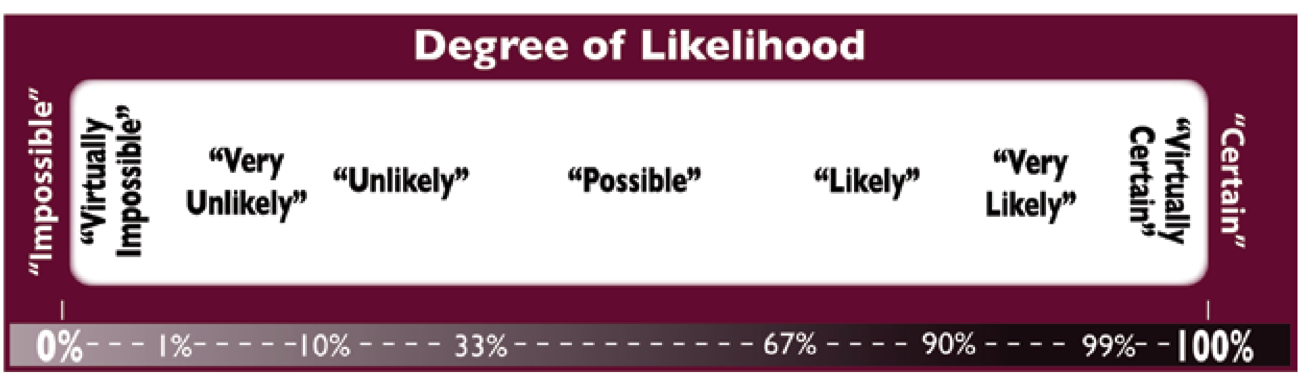

Figure 1.

The Synthesis/Assessment Product Team

A full list of the Author Team (in addition to a list of lead authors provided at the beginning of each Chapter) is provided on page II of this Report. The focus of this Report follows the Prospectus guidelines developed by the Climate Change Science Program and posted on its website at http://www.climatescience.gov.

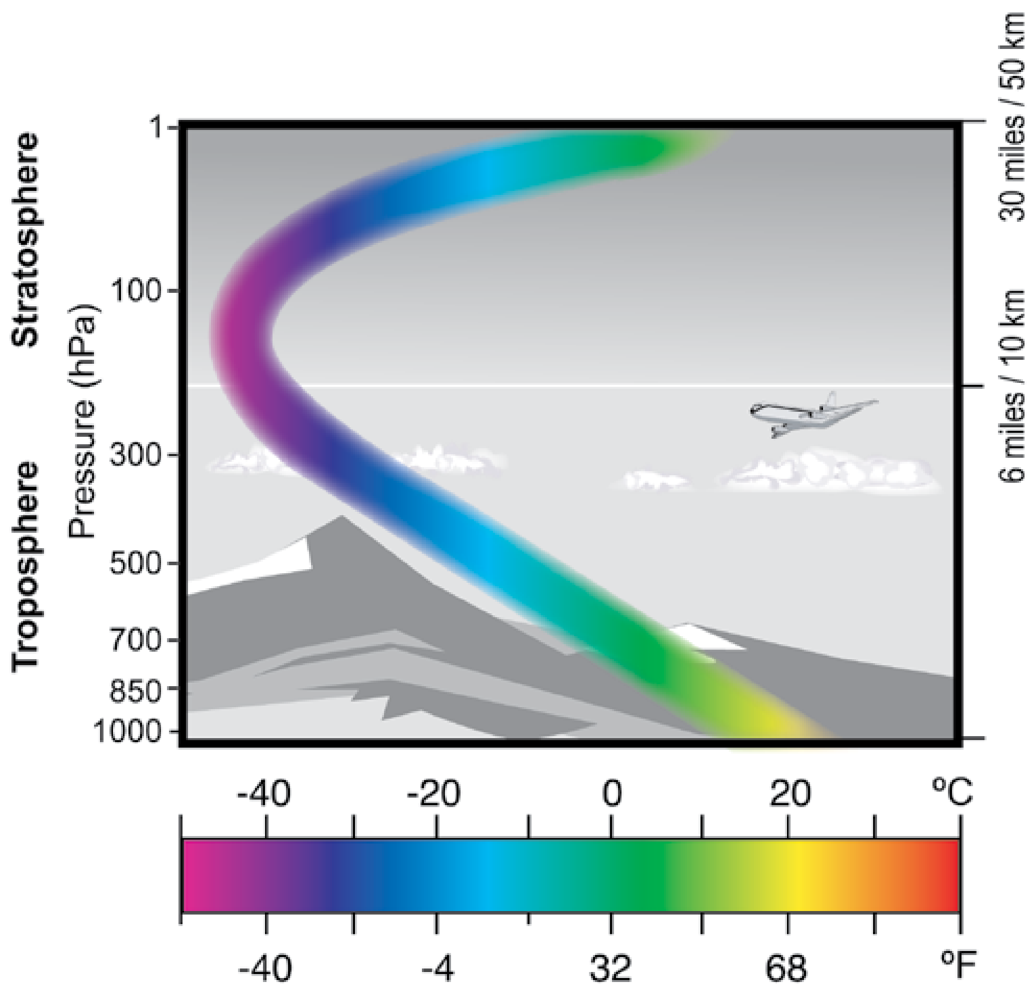

Figure 2. The illustration shows the layers of the atmosphere of primary interest to this Synthesis/Assessment Report. The multi-colored line on this diagram indicates the variations in temperature with altitude. The table on the following page defines the terminology used in this Report for the layers of the atmosphere.

Table 2. Abbreviated terms: Subscript "S," refers to the Surface. Subscripts "2" and "4" refer to MSU data from channels 2 and 4. Subscript "2LT" refers to a modification of channel 2 data to focus more directly on the Lower Troposphere and reduce the influence of stratospheric temperatures on channel 2 data. Subscripts "850–300" and "100–50" are specific atmospheric layers sampled by radiosondes. Subscript "*G" refers to a combination of channel 2 and channel 4 data derived by Fu and co-workers, applicable to global averages, and "*T" refers to applicable tropical averages. For the model-observation comparisons, the observation-based definitions were used as listed in the Table.

Terms for Layers of the Atmosphere Used in this Report

Common Term	Abbreviated Term for the temperature of that layer	Main region of Influence	Approximate altitude. (For satellite products: altitude range of bulk (90%) of layer measured)	Lower and upper pressure level boundaries
Surface	T_S	Air: Just above surface Water: Shallow depth	Surface Air: Land: 1.5 m above surface; Ocean: ship deck-height (5 – 25 m) above surface (NMATs). Surface Water: 1 - 10 m depth in ocean (SSTs)	Surface (or ~1000 hPa at sea level)
Lower Troposphere	T_{2LT}	Lower to Mid-Troposphere	Sfc – 8 km	Sfc – 350 hPa
Troposphere (radiosonde)	$T_{(850\text{-}300)}$	Troposphere	1.5 – 9 km	850 – 300 hPa
Troposphere (satellite)	T^*_G	Troposphere	Sfc – 13 km	Sfc – 150 hPa
Tropical Troposphere (satellite)	T^*_T	Troposphere (tropics only)	Sfc – 16 km	Sfc – 100 hPa
Mid Troposphere to Lower Stratosphere	T_2	Mid and Upper Troposphere to Lower Stratosphere[2]	Sfc – 18 km	Sfc – 75 hPa
Lower Stratosphere (satellite)	T_4	Lower Stratosphere	14 – 29 km	150 – 15 hPa
Lower Stratosphere (radiosonde)	$T_{(100\text{-}50)}$	Lower Stratosphere	17 – 21 km	100 – 50 hPa

[2] Only about 10% of this layer extends into the lower stratosphere.