A CONTROVERSY IN THE RATE OF WARMING IN THE ATMOSPHERE

➔ Temperature Changes Vary By Altitude

The changes in temperature that have occurred as a result of the human influence on climate are not uniform, varying from location to location, as well by altitude. For example, measurements show that during the latter part of the 20th century the temperature has changed by differing amounts at various altitudes above the surface (Lanzante et al. 2006). The reasons why this should occur are fairly well understood and climate models are invaluable tools in this endeavor.

The figure at the right shows temperature changes for the latter part of 20th century at various levels in the atmosphere as projected by a GFDL climate model (Santer et al. 2006). Various factors important to the climate system, which change over the course of time, act in concert to cool the stratosphere while warming the layer below it, the troposphere. One noteworthy aspect of the pattern is that for most latitude zones the largest warming occurs not at the surface, but at some considerable altitude above (about 8-10 km).

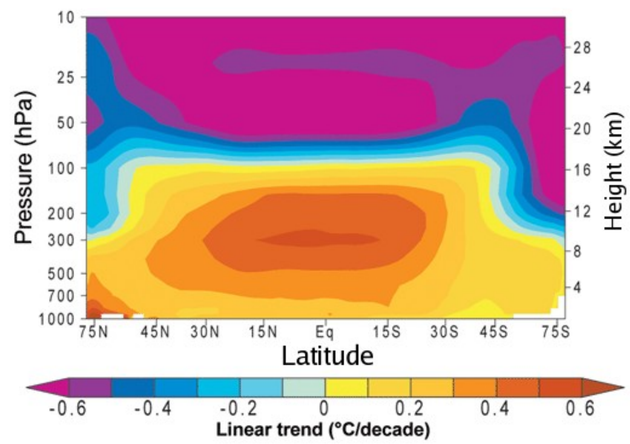
➔ The Ensuing Controversy

A controversy developed about 20 years ago upon the release of the first temperature record derived from satellite measurements intended for use in monitoring climate. Temperature trends derived from the satellite record showed little or no warming of the atmosphere, in contrast to measurements from the surface that showed considerable warming. Independent measurements from weather balloon thermometers were found to be consistent with the satellite measurements.

This finding, that the surface was apparently warming more than the atmospheric layer above seemed to fly in the face of climate model projections that suggested the opposite should be happening! This led some to question the fundamental validity of the climate models that form the basis for "greenhouse warming" projections of future climate.

TAKE HOME POINTS

- **About 20 years ago it was first discovered that the surface appeared to be warming faster than the atmosphere above.**
- **Since this relationship is opposite to that expected by climate models, some skeptics questioned the validity of future "greenhouse warming" projections.**
- **Recent studies, based on the latest information, conclude that there is no inconsistency between climate models and temperature measurements regarding the warming rates of the surface vs. the atmosphere.**



Temperature change over the time period 1979 to 1999 as simulated by the GFDL CM2.1 climate model. The change is expressed as a linear trend (in degrees C per decade) and has been averaged over all locations (longitudes) for each latitude. Cooling is seen in the stratosphere (purple and blue), due mostly to ozone depletion there, while warming is found in the layer below, the troposphere (brown, orange and yellow), due primarily to increases in carbon dioxide and other greenhouse gases. Note that for most latitudes the largest warming occurs well above the surface (innermost brown/orange contour). This figure was adapted from Fig. 5.7C of Santer et al. (2006).

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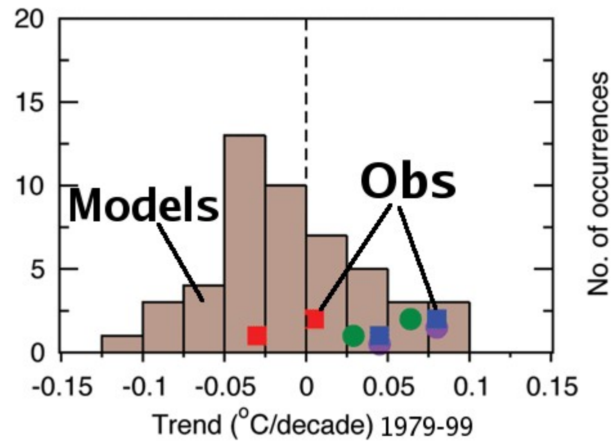
➔ Towards A Resolution Of The Controversy

Since the initial time many studies have addressed this controversy. The discrepancy has been largely resolved beginning with Karl et al. (2006), a report conducted for the Climate Change Science Program (CCSP). This report analyzed the latest climate model results, representing a substantial increase in the number and scope of projections than were previously available, utilized several new or revised sets of observations, and incorporated the latest findings on errors in those observations.

The CCSP assessment asserts that there is no longer a conflict between observed temperature changes and those from climate models regarding the difference in warming between the surface and the atmosphere aloft, when considering temperatures averaged over the globe. This is illustrated by the figure at the right in which trends from various observed datasets, represented by symbols, are superimposed upon a bar-graph of similar trends from a collection of climate model simulations. Note that the observations fall within the range of values produced by the climate models. More recently Santer et al. (2008) extended the main CCSP report conclusion to dispel the discrepancy in the tropics as well.



Difference in global temperature change between the surface and the layer above it (up to an altitude of approximately 15 km) for the time period 1979 to 1999. The change is expressed as a linear trend (in degrees C per decade). Positive values indicate more warming at the surface than aloft. The histogram bars are based on the collection of 49 climate model simulations, while the symbols show results based on individual observed datasets. Squares and circles denote satellite and weather balloon measurements, respectively; different colors denote different datasets, with two variants of each. This figure was adapted from Fig. 5.3F of Santer et al. (2006).

➔ Lessons To Be Learned

In retrospect, the controversy erupted for two main reasons. First, there were unrecognized errors in the observations. Although some errors remain, these have been corrected to a considerable extent and the nature of the errors is much better understood. Second, uncertainty that arises from random variations in short-term climate was not well taken into account. Large increases in computing power since have enabled this source of uncertainty to be explored using repeated climate model simulations (i.e. ensemble experiments). With continuing work involving both models and observations, any remaining differences between the two should be further reduced in the future.

➔ Some Related References

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From The IPCC AR4 Summary For Policymakers…
"New analyses of balloon-borne and satellite measurements of lower- and mid-tropospheric temperature show warming rates that are similar to those of the surface temperature record and are consistent within their respective uncertainties, largely reconciling a discrepancy noted in the TAR" **Available online at http://www.ipcc.ch**

➔ The Climate Model Projections

The climate model projections come from a set of experiments intended to approximate climate during the end of the 20th century and were performed in support of the IPCC Fourth Assessment (AR4). They were produced by 19 groups from 9 different countries. Since some groups contributed more than one simulation, a total of 49 experiments were available. For details see Santer et al. (2006).

These experiments incorporate historical changes in the most important "forcing" factors, both natural and human-induced, believed to influence climate. These include carbon dioxide and other "greenhouse gases", stratospheric ozone, as well as particles injected into the stratosphere by volcanic eruptions. Various other factors, for example changes in solar output, are considered as well.

➔ The Pattern Of Vertical Temperature Change

The combined effect of all major forcings yield stratospheric cooling, driven primarily by depletion of ozone there, and warming in the layer below, the troposphere, due largely to increases in carbon dioxide and other greenhouse gases (Ramaswamy et al. 2006). Climate models simulations show the largest warming well above the surface for many latitude zones, particularly the tropics, where the maximum occurs at about 8-10 km above the surface. This elevated warming is due to a process known as convection, which is characterized by strong upward and downward vertical motions and is also the driving force behind thunderstorms. By contrast, in polar regions, where vertical motions are inhibited, the largest warming is seen at the surface.

➔ The Observations

The observed temperature data incorporate measurements from thermometers: (1) housed in instrument shelters near the ground, (2) attached to weather balloons, and (3) on-board earth-orbiting satellites. Unfortunately, when the instruments or procedures used to take the measurements are changed, they can corrupt the data used to assess climate change. For example, if an old thermometer is replaced and the new one has a reading that is consistently lower, it will appear that the climate has cooled. In order to remove such artificial changes from the temperature record it is necessary to perform adjustments that cross-calibrate data from one measurement system to its successor.

Due to various complications, determining the proper procedure for performing cross-calibrating adjustments is often not straight-forward. Typically, separate teams of analysts approach the problem differently, yielding different climate trends. For technical reasons it is easier to make such adjustments for surface data than for the data aloft from balloons or satellites, so the former are considered much more reliable than the latter two.

➔ Interpreting The Range Of Results

Evaluation of climate models and observations is facilitated by comparing the range of results obtained from models with a similar range obtained from observations. Model experiments produce a range of results due to uncertainties that arise for a variety of reasons including the fact that: (a) each model is formulated differently, (b) climate forcings that drive the model are not known precisely, with different estimates from different research groups, and (c) "climate noise" varies from simulation to simulation. Climate noise is what the climate system does naturally, and randomly, in the absence of any climate change. For example, by chance an El Nino may occur at the beginning of a model simulation, resulting in warming, yielding a false impression of cooling associated with climate change thereafter.

While uncertainty in the observations may arise from climate noise, the overwhelming concern is associated with adjustments made to construct the observed datasets. Since trends derived from the different datasets can lead to substantially different conclusions, it is prudent to consider trends from all credible observed datasets collectively.

The conclusion that there is no important difference between models and observations regarding the difference in warming between the surface and the atmospheric layer above (Karl et al. 2006; Santer et al. 2008) stems from the fact that the range of results from models and observations show a considerable overlap. Prior to these works far fewer climate model results and observed datasets were available, and the range for both was less, yielding little or no overlap. Newer satellite and balloon datasets indicate more warming of the lower atmosphere than the earlier datasets. This demonstrates that our earlier incomplete knowledge of various factors led to the apparent controversy.

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