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Earth is Warmer, Has the Atmosphere Warmed Too?

Research Teams Still Differ on Atmospheric Warming, But Why is now Becoming Clear

A dilemma has bedeviled Earth science for the last 25 years. You might think the atmosphere must be warming if the surface of the Earth (where people read thermometers) is warming, but *you might well be wrong*. The "ocean of air" should warm as fast as the surface does, since that is an expected part of the "greenhouse effect", which explains why carbon dioxide (CO_2) may be raising global temperatures. Since CO_2 absorbs outgoing thermal radiation from the Earth's surface, and re-radiates it back to Earth, you might expect that gas (and the surrounding air) to warm up in step with the surface. Nearly all climate *models* predict this behavior. But Planet Earth does not behave this way! Data from weather balloons and satellites suggest that the lower atmosphere either has not warmed at all, or has warmed much less than the Earth's surface over the last quarter century of truly global measurements.

This is perplexing enough to Earth scientists, but there's more . . . . We can use either weather balloons or satellites to measure the temperature of the lower atmosphere. The technology of weather balloons is simple and the data exist for about 70 years. Bur since balloons are launched only from land areas (30% of the Earth), their data cannot give a global picture. Weather satellites do observe the temperature of the whole globe, but have done so only since 1978. Data from both sources are seriously flawed for detecting long-term climate changes. Which source should you trust?

Also, the two main research teams that specialize in measuring the temperature of the atmosphere with satellite data do not agree on the rate that the atmosphere is warming, or even (until recently) if it is warming at all. In the past year, their differences have narrowed. Reasons for arriving at different temperature trends are becoming clear, but much remains uncertain on the whole question.

The Tiros-N weather satellite was the first to measure the temperature of the free atmosphere

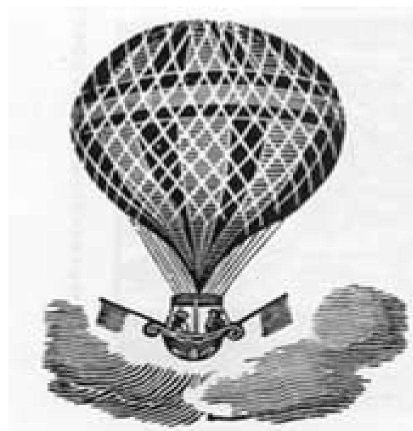
As the Surface warms, the Atmosphere does not?

A panel of the National Academy of Sciences concluded [1] that part of the difference in temperature trend between surface and atmosphere was real. While the surface warmed roughly one-third degree C from 1979 to 2000 (the estimates ranged from 0.11° to 0.20°C per decade), the lower atmosphere warmed by 0.0° to 0.10°C per decade in these 20 years. Either the atmosphere did not warm, or it warmed only half as fast, at best. The Panel was at a loss to explain the difference, or indeed if it was real. Either errors in measurement or errors in sampling the atmosphere could largely be responsible for the discrepancy. Finally the models which have been simulating a warming atmosphere could be erring in their temperature trends.

The National Academy cautioned that uncertainties in the trends were almost as large as the disparities between the surface and the lower atmosphere. Notably, it added that a 20 year trend is not long enough to represent any changes in the atmosphere that might be due to human influences, especially changes involving greenhouse warming.

In the same year (2000) four scientists wrote a major review of the evidence on this issue for the Bulletin[2] of the American Meteorological Society. They concluded that the satellite trend was upward but small (+0.04°C per decade). It was not significantly different from zero, and also did not differ significantly from the trend given by weather balloons (+0.03°C per decade).

Is 20 years too short to conclude anything about a climate trend? Well, we can look at the balloon data over the 40-plus years since 1958. That temperature trend was definitely upward, and more importantly, the lower atmospheric trend (+0.10 °C per decade) was actually a bit greater than the surface trend (+0.06 °C per decade), both given in the year 2001 Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)[3]. What happened was the surface neither warmed nor cooled from the 1950s to 1975, while the atmosphere did warm; then their roles appear to have reversed, at least after 1978. That reinforces what the National Academy said: just wait, the true trend will eventually emerge.



Balloon data: too messy for climate purposes

Clearly the warming trend at the surface, as measured by thermometers, has been greater than the trend in the lower "free atmosphere" in the last 20 years. We use the phrase "free atmosphere" to mean all of the atmosphere except the few hundred meters (or feet) just above the Earth's surface. By "lower atmosphere", we mean the lowest 8 kilometers (5 miles) of the free atmosphere, where two-thirds of the weight of the air is found, and where all weather occurs. For the past 70 years, weather balloons have been the standard tool for observing the free atmosphere. But detecting a trend is difficult because instruments and observing practices have changed a lot, especially in some parts of the world. Last year J.R. Lanzante and colleagues wrote in the Journal of Climate[4] that these changes have severely compromised the value of balloon data for determining temperature trends. Nevertheless, they made valiant efforts to correct the data from a 40 year period. Their corrections made the balloon data more like the satellite data (see below) for the period after 1978, which lends confidence to their corrections. The trends they found in the lower atmosphere were positive but mixed: the Northern Hemisphere warmed primarily after 1980, the Southern Hemisphere before 1980, and the Tropics only in the late 1970s.

While the 20-year record of temperature trends from satellites and (apparently) balloons shows either no trend or a small warming trend, the 40-year trend from balloons (as flawed as it is) does show warming of the atmosphere, perhaps as much as the 40-year warming at the surface.

Satellite measurements are global, but the record is short

Truly global coverage began in 1979 when weather satellites began to measure atmospheric temperatures with microwave sensors. But again, detection of a trend has not been easy, the National Academy found. Some of the many sources of error include:

♦ On a single satellite, the calibration changes as the satellite ages;

♦ As the satellite orbit decays, the local time of observation changes slowly. Daily temperature changes (morning warm-up, evening cool-down) become mixed with year-to-year changes in the data. This effect requires elaborate correction.

♦ Eleven different satellites have been used, each having a unique calibration. To combine data from all of them, researchers have computed "offsets" between two satellites that observed the same place at the same time. Usually one year of overlap is needed to compute a reliable inter-satellite offset. But in 1985-86, the NOAA-9 satellite overlapped its successor by only 85 days. That introduced much uncertainty in interpretation of the trend since then.

Discovery and correction of errors in the satellite data has been ongoing for the last 14 years. That's why estimates of the temperature trends have been revised so often.

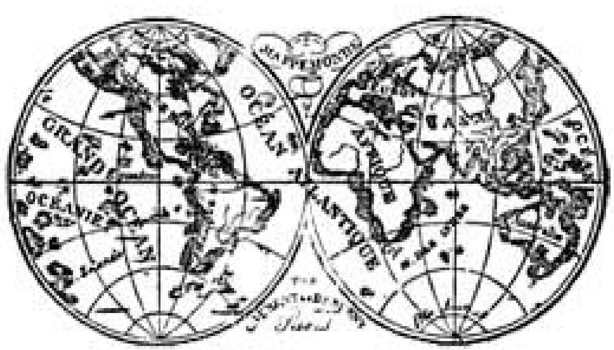
What trend is seen in the satellite data?

The research teams that analyzed the 20 year record of satellite data have come up with different trends. A team under John R. Christy at the University of Alabama in Huntsville (UAH) has been publishing estimates since 1990. Last year his team published new estimates[5] of the uncertainty and the trend in satellite-based temperatures. The new uncertainty is ±0.05°C per decade while the new trend is +0.06° per decade (a warming) for the lower atmosphere. Note that the uncertainty is almost as large as the trend, but the trend is indeed positive. It is still only half as large as the trend at the surface. Three years earlier in 2000, Christy's team had reported the same trend (+0.06°C) but with a larger degree of uncertainty, so that the trend was not significantly different from zero.

A second team at Remote Sensing Systems (RSS), Santa Rosa, California, just published a complete re-analysis of the satellite-based temperature data [6]. Using different methods than the group at UAH, the team concluded that the temperature trend is larger, a warming of +0.10°C per decade and that the uncertainty is rather less at ±0.02°C per decade. The estimates of the two teams overlap when you consider the level of uncertainty given by the "plus-or-minus" figures.

Using quite different techniques, K.Y. Vinnikov of the University of Maryland and N.C. Grody of NOAA computed a much larger warming for the atmosphere from the satellite data (in a recent issue of Science.[7]) Their value, from +0.22° to 0.26°C per decade, is more than twice the rate published by the RSS team, which had been the higher estimate.

Although the satellite measurements are global in extent, the short 20-year period raises another issue — do the results mean much for climate change? It does appear that the small change in the temperature of the atmosphere over the last 20 years is quite different from the change over the last 40 to 50 years. Further, the 20-year warming trend in the atmosphere is still no more than one-half the rate of warming at the surface, according to the RSS and the UAH groups.



Why different estimates for the same trend?

A valuable contribution of the RSS paper is an analysis of what contributed most to the different results of the two teams. The largest factor, RSS concluded, was the manner in which the two teams calibrated data from the "problem satellite", NOAA-9. This satellite served as a critical link between the earlier satellites before 1985 and the later ones after 1987. Abrupt changes in the raw data were found in those years, and RSS asserts that most of the discrepancy arises from different calibrations of the data from NOAA-9.

The geographic patterns of temperature changes produced by the teams are similar, although the globally averaged trends are different. For example, both the UAH and RSS teams show the greatest warming over continents. Christy's UAH team shows a lot of cooling over the remote southern oceans, which might be correct, as there is very little data at the surface to confirm a trend there. But another scientist has shown that Antarctic sea ice may affect the microwave satellite observations to produce a false cooling trend.

The teams regard the value of the balloon data differently. The UAH team has often compared their results favorably with the trends given by balloon data, while RSS has criticized a number of flaws in the balloon data set, and does not regard it as a "gold standard," in their words.

Another hypothesis, put forth in Geophysical Research Letters [8] by R. Lindzen and C. Giannitsis of MIT, is that the atmospheric temperature jumped in 1976, but the surface responded later (about ten years later) because the mass of the oceans retarded a quick temperature change. Several lines of evidence point to sudden changes in the climate in 1976—1978. If the temperature indeed jumped, it did so before satellites routinely measured temperatures, and so the jump may not have been observed.

If you can't measure the temperature, measure its effects !

Another, perhaps easier, way to track thermal changes in the lower atmosphere is to monitor the height of the tropopause, an invisible level which separates the lower atmosphere from the stratosphere. The tropopause generally lies at the level of the jet stream. Its height will increase if either the lower atmosphere warms or the stratosphere cools. Recently, B. Santer and 10 colleagues reported in Science [9] that many studies document an increase in the height of the tropopause level since 1979. They attribute the height change to both ozone loss in the stratosphere, which cools that layer, and to greenhouse gas increases, which would warm the lower atmosphere.

There is reason to be uncertain about all these data, and to be cautious in finding trends in the temperature of the lower atmosphere. The best evidence is that the "ocean of air" did warm somewhat over the last two decades of the 20th century, but much less than the surface warmed. Even though they ought to trend together over the long term, there is no reason that the Earth and the atmosphere must warm or cool at the same rate over any 20-year period. Since the trends of the last 20 years are different than the trends of the last 50, it seems likely that we will witness trends in the 21st century unlike any we have seen in the past. One hopes that the ability of "Science" to monitor what is really happening in the atmosphere will improve.

➤ On that note, see The Nation's Plan for Climate Change Science in this Newsletter.

CITATIONS

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8. “Reconciling observations of global temperature change,” by R.S. Lindzen and C. Giannitsis, *Geophysical Research Letters*, v. 29, no. 12, 1583.

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