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Highs and Lows of Temperature [1]

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Any assessment of global climate change requires substantial temperature records that researchers must build from the ground up. Historically, scientists assembled these from thermometer measurements made at the Earth's surface since the last century. Over the past six years, however, two scientists have constructed an 18-year atmospheric temperature record from satellite data.

Temperature measurements from satellites are an intriguing piece of the global warming puzzle.

"Global warming is a huge puzzle, and we've got a very important piece of the puzzle," said Roy Spencer of NASA's Marshall Space Flight Center and the Global Hydrology and Climate Center. Spencer's puzzle piece is the new satellite record, which he compiled with the help of John Christy of the University of Alabama in Huntsville. The record, which suggests that the Earth's atmosphere is more complex than previously thought, is invaluable for its precision but controversial when compared with the surface record.

Over the past century, temperature measurements made at the Earth's surface indicate warming of about 1 degree Fahrenheit, a trend that has been increasing in rate over the last two decades. For 1979 through 1996 -- the period covered by Spencer and Christy's satellite record -- the surface and atmospheric records are not in agreement. For this period of overlap, the surface record indicates warming at about 0.24 degrees F (0.14 degrees Celsius) per decade, while the satellite record shows the atmosphere cooling at about 0.07 degrees F (0.04 degrees Celsius) per decade, according to Christy.

"That decoupling between the surface and the troposphere above is a feature of the atmosphere that's very intriguing. We can't explain it yet, and certainly models haven't been able to reproduce it," said Christy. "We don't expect the temperature trends to continue to diverge," added Spencer. "We think that the amount of divergence so far is possibly real but we wouldn't expect it to go on indefinitely. At some point, it becomes physically unrealistic. We would expect them to be much closer to each other in another five or 10 years."

Although they are complementary, historical thermometer measurements and the satellite record constitute fundamentally different ways of looking at the planet's temperature, Christy said. While the thermometer data are temporally extensive, the satellite data are evenly distributed and cover remote parts of the planet not covered by thermometers.

The two temperature records were the subject of much discussion in a special session on global warming at the American Meteorological Society's February 1997 meeting. The following month, two National Center for Atmospheric Research scientists added new dimension to the ongoing discussion by challenging the integrity of the satellite record itself.

The divergence of the surface and satellite records may not be resolved until this most recent challenge is answered. Nevertheless, in June 1996 the international entity charged by the World Meteorological Organization and the U.N. Environment Programme with assessing climate change concluded that the imprint of human activity on climate can be clearly seen. Citing trends observed in the surface record (and modeling observations), the Intergovernmental Panel on Climate Change (IPCC), said "The balance of evidence suggests that there is a discernible human influence on global climate."

However, because the satellite record does disagree with the temperature trends seen in the surface record, the satellite data have been widely covered by the popular press and discussed in policy circles. The data are often cited by those who dispute the 1996 IPCC statement or the veracity of global temperature increases shown by the surface record.

While waiting for the two temperature records to converge, climate change scientists are deliberating another interesting feature apparently revealed by the satellite record: the atmosphere's vertical complexity. The satellite record indicates warming in the upper troposphere (a region extending from approximately five to eight miles above the Earth's surface), but a slight cooling trend in the lower troposphere and a rather large cooling trend in the lower stratosphere.

Atmospheric temperatures may owe their vertical variation, in part, Christy said, to the forces that produce them. They are driven from below by sea surface temperatures, affected from above by aerosols from volcanoes, and influenced by other factors, including the loss of atmospheric ozone. Before Christy and Spencer compiled the satellite record, the only available atmospheric temperature measurements were taken by thermometers sent aloft on weather balloons.

In 1990, Spencer and Christy developed the technique with which scientists were first able to glean accurate estimates of global atmospheric temperatures from satellite measurements. The technique derives temperatures from satellite measurements of microwave radiation emitted by molecular oxygen. The measurements have been made by Microwave Sounding Units (MSUs) flown on NOAA satellites since 1979. The temperature data sets that Spencer and Christy retrieved from MSU data consist of precise global monthly temperature determinations for the troposphere and lower stratosphere.

Although the global warming puzzle obviously can't be solved with a single piece, the satellite record is "often used by others in an attempt to prove things we don't think can be proved [by the record]," said Spencer. "The record is short in the context of global warming, but it is the longest record we have from satellites. With it, we've been able to monitor changes in the climate system over very short time scales with high precision over the whole Earth, which thermometers can't do."

With its precision, the MSU data also offer distinct modeling advantages. Because models can experimentally identify what causes, or "forces" temperature changes, "a model that could reproduce a precise record like this would show us how the forcing worked on the atmosphere," said Christy.

Also, because the satellite data are precise, "they are quite valuable in defining small changes and showing us small responses to small forcings -- letting us judge how the entire globe might respond to changes in forcing," said Christy. (Such forcings include volcanic eruptions like that of Mount Pinatubo in 1991, which registers clearly in the satellite record as increased temperatures in the lower stratosphere.)

Finally, the satellite record will also assist models in understanding variability that occurs in places like the South Atlantic and South Pacific oceans, where temperatures have never been well-measured, Christy said.

Scientists assessing global climate change must consider that thermometer measurements historically made over land areas like the northern continents show more variability than temperature measurements made by either thermometers or satellites over the more stable oceans, Christy said. In the future, a complement of satellite and in-situ temperature measurements will address this concern. Satellite data provide accurate measures of temperature, but only for broad vertical layers. Because scientists need to know the temperature at as many levels as possible, the atmospheric record could be enhanced by thermometer measurements made from weather balloons in existing monitoring networks, said Christy.

In coming years, the MSU record will be extended by Advanced Microwave Sounding Units (AMSUs), to be launched on both the NASA Earth Observing System (EOS) PM satellite and NOAA-K satellites. In addition to monitoring the troposphere and lower stratosphere, the AMSU instrument will measure temperatures closer to the Earth's surface with more channels, less noise, and better spatial resolution, said Spencer.

Spencer and Christy will append AMSU data to the MSU record to make the world's longest satellite temperature record even longer. "We've demonstrated the MSU system's ability to monitor the climate quite precisely," Christy said, "and we expect only better information from the next generation of satellites. Our goal is to provide the most precise data possible, so that we can understand why this climate system does what it does."

What's Up with the Atmosphere?

The record compiled by Spencer and Christy consists of precise temperature data derived from Microwave Sounding Units (MSUs) flown on different satellites. In a letter to *Nature* (March 13, 1997), James Hurrell and Kevin Trenberth argue that the MSU record is suspect precisely because "there is no single satellite record," and thus, "different tropospheric measures of temperature from the MSUs contain different trends and different error characteristics."

Hurrell and Trenberth, of the National Center for Atmospheric Research (NCAR), concluded that although the MSU data are "excellent for examining interannual variability of tropospheric temperature," the MSU record

contains "spurious trends" produced by satellite measurement "noise," orbit inconsistencies, and errors introduced during transitions from one satellite to the next. After analysis of the satellite record with these concerns in mind, the NCAR scientists said that the satellite record actually shows slight warming rather than cooling trends in the atmosphere.

Spencer and Christy remain confident of the satellite record's integrity, and argue that sufficient temporal overlap of instruments occurs during satellite transitions. Moreover, the atmospheric temperatures are validated, they said, by thermometer measurements made from weather balloons called radiosondes. "A big strength of the MSU is that it's been independently validated by radiosondes. Wherever the MSU detected a radiosonde, a check of the two shows they're in substantial agreement," Christy said.

Spencer and Christy will soon respond to Hurrell and Trenberth's challenge. However, if Hurrell and Trenberth are right, the atmospheric and surface temperature record are not in disagreement after all, and those skeptical of global temperature increases shown by the surface record have lost the main ground from which they dispute "global warming."

The MSU data, which were previously archived at the former DAAC at the Marshall Space Flight Center, are now distributed by the Global Hydrology Resource Center at the Global Hydrology and Climate Center.

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