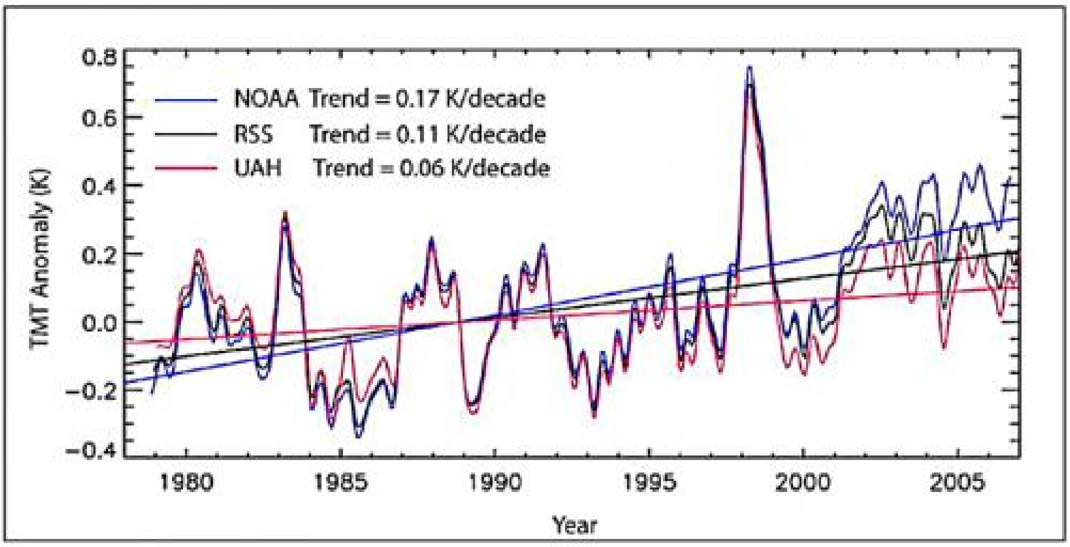
Toward a global microwave standard

February 6 2012, by David Walker



Long-term datasets from three different sources - the National Oceanic and Atmospheric Administration (NOAA), Remote Sensing Systems (RSS), which analyzes microwave data from NASA satellites, and the University of Alabama at Huntsville (UAH) - show different temperature trends in the middle troposphere.

Much of what is known about decadal climate change – and much of what appears on the evening weather forecast as well – comes from satellite-based remote sensing of microwave radiation at different levels in the Earth's atmosphere. Microwave measurements are generally reported as the apparent temperature of the object being monitored. Yet, at present, there is no accepted brightness-temperature (radiance) standard for microwaves that can be used for authoritative calibration of microwave sensors, for resolving discrepancies between readings from different satellites, or for comparing one program's results with another's.

Weather and climate uses for microwave remote sensing measurements require that the observed temperature be accurate within 1 kelvin or less. But existing measurements cannot be made with that accuracy or reliability. "Right now," says David Walker, Project Leader for Microwave Remote Sensing in PML's Electromagnetics Division, "new data coming from nominally identical instruments can differ by as much as a couple of kelvin."

"People have gotten remarkably good results from satellite microwave monitoring," Walker says, "but it takes a tremendous amount of post-processing of data and some recalibration tricks. And there's still much more uncertainty than we would like." For example, 30 year datasets from three separate, reputable sources show temperature trends in the middle troposphere that differ by a factor of three in magnitude, due in part to differences in the input data from various sensors. (See Figure 1) A significant contributor to these differences is the lack of reliable calibration for the initial measurements.

Such discrepancies could have a detrimental effect on the Global Earth Observation System of Systems, the forthcoming worldwide network of existing and planned observing systems, one major goal of which is to "promote common technical standards so that data from the thousands of different instruments can be combined into coherent data sets." Establishing internationally recognized, traceable microwave brightness-temperature standards would be enormously useful for minimizing uncertainty in remote-sensor readings and for reconciling instrument records over periods of years or decades. Another critical need is to protect against "data gaps" – non-overlapping data records from different instruments – caused by instrument failure (including launch failure), project delays due to technical or budgetary issues, and other factors.

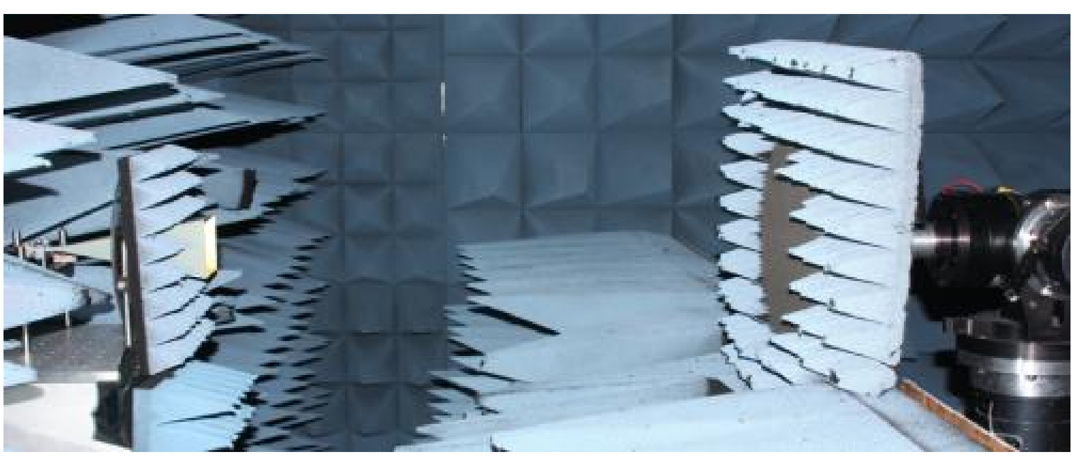
To solve general measurement problems such as this, the international scientific community has adopted the International System of Units (SI). By providing a robust way to ensure that measurements can be traced back to the SI, it is possible to ensure quantitative equivalence of measurements made by different instruments, in different places, and at different times. To attack that microwave measurement problem, Walker and colleagues are developing a system of SI-traceable radiometric measurements that can be used to determine the brightness temperature (T_B) of a microwave source, which can then be used as the basis for determining the temperature of any "grey body," including the Earth's atmosphere, land, and sea surfaces. (T_B is the temperature at which an ideal blackbody would have to be to emit the same radiance that arrives at the sensor.) Satellites do not measure temperature directly; instead they measure the amount of radiation incident on their sensors at various key wavelengths and sometimes polarizations associated with different meteorological phenomena and different sections of the atmosphere or surface. Those data are then processed by different groups using various methods to yield temperature equivalents.

NIST waveguide radiometers. The cryogenic primary standards are encased in the blue cylinders.

A T_B standard can take the form of either a source (radiance standard) or a receiver (irradiance standard, also called a "radiometer"). Creating a fully traceable radiance T_B standard requires a microwave source of well-known and independently verifiable brightness. PML is working on this type of standard in collaboration with researchers at the University of Colorado and NASA Goddard Space Flight Center. While significant progress has been made towards that goal, the final realization is still to come.

A fully traceable standard for receiving (irradiance), by contrast, requires a standard radiometer (see Figure 2) and a radiometer antenna that is characterized to high accuracy. This realization of a T_B standard has recently been demonstrated at NIST. The crucial advancement is the ability to perform the measurements in free space without having to characterize the antenna beam pattern separately. Walker's group has devised a way to determine the beam efficiency (fraction of the total antenna power pattern subtended by the target) of a microwave receiver antenna, and therefore determine the T_B of the blackbody target, by varying the target temperature and measurement distances from the antenna. (See Figures 2 and 3.) The result to date is an uncertainty of 0.7 K in the frequency range of 18 GHz to 26.5 GHz. That degree of accuracy is well within the permissible uncertainty range for a number of environmental parameters, including troposphere, stratosphere, precipitation, and water vapor.

The new method, tested at PML's anechoic chamber in Boulder, CO, used a blackbody target 33 cm in diameter and a rectangular horn antenna. (See Figure 3) The target temperature, monitored with calibrated thermometers embedded in the backside, was increased in approximately 10 K increments from 296 K to 352 K. Distance from target to receiver was varied from 50 cm to 500 cm. Three frequencies (18 GHz, 22.5 GHz, and 26 GHz) were measured in each configuration. The data – "we took a lot of data," Walker says – produced plots with relatively limited uncertainties, and the new technique circumvents problems in conventional methods related to precise knowledge of the antenna pattern for all possible directions. In all, "this procedure is well-suited for pre-launch calibration of blackbody targets at microwave frequencies," the team concludes in a forthcoming paper.



In NIST's anechoic chamber in Boulder, CO, the receiver (with attached horn-like waveguide) at left measures radiance from the blackbody target (disk-shaped object) at right at a distance of approximately 1.5 m. Actual temperature of the blackbody target is measured with multiple platinum resistance thermometers.

Any progress is welcome. "Although the majority of satellite data are taken at optical frequencies," Walker explains, "microwave readings provide information that is not available through optical measurements. For example, microwave monitoring provides total, continuous coverage of the Earth because microwave sensors can 'see' through clouds. Moreover, microwaves provided quantitative information about the moisture content in the atmosphere, which serves as an essential check on other measurements.

"For example, radar altimetry from satellites in space is used to determine sea-level changes with an accuracy of a few millimeters . Those measurements depend critically on understanding and quantifying the moisture-dependent atmospheric path-delay variations, which can be as large as a few centimeters. The path-delay measurement is made using passive microwave radiometry, which NIST's research addresses."

Provided by National Institute of Standards and Technology

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