Maintaining and Improving Upper Air Temperature Records

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1. What are the key challenges or questions for Earth System Science across the spectrum of basic research, applied research, applications, and/or operations in the coming decade?

Projection of future changes in climate due to the accumulation of anthropogenic gases and aerosols in the atmosphere is one of the grand challenges of the Earth science community. These projections are typically made with sophisticated computer models of the general circulation of the coupled atmosphere-ocean system. The ability of such models to capture key features of the present-day and historical climate is a necessary but not sufficient condition for enhancing confidence in the reliability of model projections of 21st century climate change. To perform meaningful model evaluation studies, the best possible measurements of the climate system over the longest possible period are required. Temperature is the fundamental climate variable most directly affected by the accumulation of greenhouse gases in the atmosphere, and has significant impacts on many different aspects of human society and ecosystems. Ensuring a continuous record of temperature is critical to characterizing our changing climate, and enabling climate model evaluation.

2. Why are space-based observations fundamental to addressing these challenges/questions?

The temperature at Earth's surface is well represented by in situ measurements, with records dating back more than a century. In contrast, systematic measurements of the "upper air" temperature above Earth's surface only began in the last 70 years. Beginning in the late 1940s, measurements of atmospheric temperature were made from a sparse but expanding network of radiosonde (weather balloon) launch stations. The limited coverage of this network, particularly over the oceans, makes analyses of global-scale changes difficult or impossible. Starting in late 1978, the coverage problem was solved by the advent of microwave sounders. These satellite-based instruments continuously monitor atmospheric temperature with near-global coverage. Satellite temperature measurements remain a crucial resource for tracking global-scale changes in the temperature of planet Earth, for separating an anthropogenic signal from natural variability [e.g. *Santer et al.*, 2013], and for evaluating climate models.

Unfortunately, the satellite sounder record is plagued with its own inhomogeneities. These include calibration drifts and instrument non-linearity, drifts due to changing local measurement time (diurnal cycle drifts), and uncertainty associated with the measurement frequency changes that occurred with crossover from the last MSU instrument (NOAA-14) to the first AMSU Instruments (NOAA-15, AQUA, and NOAA-16). Over time, our understanding of these problems has improved, but the issues are still far from settled, largely due to the complex interplay between the individual problems described above.

The largest source of uncertainty is in the adjustments made to account for changing measurement time. This uncertainty arises from uncertain estimates of the diurnal cycle in the troposphere and (for tropospheric channels) of the microwave emissions from Earth's surface [*Mears et al.*, 2011]. Current versions of the sounder-based datasets account for the diurnal cycle by either using diurnal cycles deduced from model output (with well-documented flaws) or by attempting to derive diurnal cycle from the satellite measurements themselves (an approach plagued by sampling issues and possible calibration drifts). Each of these methods has strengths and weaknesses, but neither has sufficient accuracy to construct an unassailable long-term record of atmospheric temperature change.

A second issue is uncertainty due to the change in measurement frequencies that occurred with the transition from MSU to AMSU. The channels used for tropospheric measurements (MSU channel and AMSU channel 5) are significantly different between the two satellites. The same applies to the channels employed for lower stratospheric measurements (MSU Channel 4 and AMSU channel 9). Because the last MSU and the early AMSU satellites made measurements at different local times, it is difficult to obtain absolute intercalibration of these instruments without more accurate knowledge of the diurnal cycle at each frequency.

Different research groups have employed different strategies for addressing these uncertainties, resulting in an ongoing controversy regarding the size and spatial structure of long-term trends in tropospheric temperature [*Thorne et al.*, 2011]. Our goal is to design a mission to improve the accuracy of adjustments for non-climatic artifacts in satellite temperature retrievals. A successful mission will have two important outcomes. The first outcome is the continuation of an accurate temperature record into the future. The second key outcome is that the results from our proposed mission will greatly improve the cross-calibration of the previous MSU, AMSU, and ATMS instruments, thus reducing the observational uncertainty in estimates of the changes in upper air temperature since late 1978.

The long-term trends in global middle tropospheric temperature estimated by different groups are in the range 0.05 to 0.15 K/decade, with an estimated uncertainty in the Remote Sensing Systems dataset of 0.042 K/decade. For a typical satellite, the effect of the diurnal cycle leads to a drift of approximately 0.1K over its lifetime. Over the land, current model based diurnal adjustments appear to remove about ½ of this drift, leaving about 0.05K of residual drift. Over the ocean, the diurnal drift is at least 5 times smaller, but its structure is largely unconstrained by current observations. If the residual drift for both land and ocean is reduced to 0.01K, the effect of the diurnal drift would no longer dominate the uncertainty. For our proposed mission to measure the diurnal cycle, the dominant source of error is aliasing of daily to monthly scale variability into the derived diurnal cycle. Simulation studies demonstrate that this can be minimized by using two intercalibrated satellites making measurements 4 times per day.

3. Why are these challenges/questions timely to address now especially with respect to readiness?

Recent technology advances in miniature radiometers, ultra-stable calibration assemblies, and dedicated launches for relatively small payloads now enable a new class of relatively inexpensive small satellites that can now be launched into optimum orbits to make measurements of the diurnal cycle of upper-air temperature feasible. Our simulations show that two single-instrument microwave satellites in high-inclination and relatively rapidly precessing (instead of slowly precessing) orbits, combined with measurements from existing and planned weather-satellite instruments, could provide both global coverage and accurate diurnal cycle sampling to meet critical climate requirements that are currently unaddressed, as elaborated above. With channels duplicating the small number of MSU and AMSU channels that are used for climate trends, the uncertainty associated with surface emission could be significantly reduced.

References:

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