Correcting the MSU Middle Tropospheric Temperature for Diurnal Drifts

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Abstract-- Channel 2 of the 9 Microwave Sounding Units (MSUs) flown on NOAA polar orbiting platforms provides a 23-year time series of middle-tropospheric temperature. These measurements may be of sufficient quality for climate studies if intersatellite calibration offsets and drifts can be accurately characterized and removed. One of the most important and difficult to characterize sources of long-term drift in the data is due to the evolution of the local observing time due to slow changes in the orbital parameters of each NOAA platform, which can alias diurnal temperature changes into the long-term time series. To account for this effect, we have constructed monthly diurnal climatologies of MSU Channel 2 brightness temperature using the hourly output of a general circulation model as input for a microwave radiative transfer model. We report the results of this calculation, and validate the result by comparing with MSU observations.

I. INTRODUCTION

Satellite measurements of the Earth's microwave emission are a crucial element in the development of an accurate system for long-term monitoring of atmospheric temperature, providing global spatial and temporal coverage at much higher densities than attainable with *in situ* observations. The Microwave Sounding Units (MSU) operating on NOAA polar-orbiting platforms have been the principal sources of satellite temperature profiles to date, with measurements of microwave radiance in four channels ranging from 50.3 to 57.95 GHz on the lower shoulder of the Oxygen absorption band. These four channels measure the atmospheric temperature in four thick layers spanning the surface through the stratosphere. The measurements extend over more than two decades, beginning in January 1979 and continuing through the present. The application of the MSU time series by Christy and Spencer [1,2,3,4] to studies of climate change has played a high-profile and controversial role in the debate over the presence and magnitude of anthropogenic warming signals. In an effort to validate these results, we are performing an end-to-end independent analysis of the middle tropospheric data from MSU Channel 2.

An important component of this analysis is to account for long term drifts in the measurements that arise from drifts in local measurement time that can alias the local diurnal cycle into the long term record. Spencer and Christy [4] accounted for these drifts by noting systematic differences between measurements made as the instrument scanned across the satellite sub-track, and thus made measurements at different local time. This method has the drawback that due to sampling noise, zonal averages must be used to determine the slope of the diurnal cycle at a given measurement time accurately enough to perform the correction. This results in inaccuracies when the diurnal correction is used to produce a gridded map of decadal trends, since different locations within the same zonal band can have very different diurnal cycles. In this work, we use a new method based on a general circulation model, the NCAR community climate model (CCM3) [5] to calculate a five year climatology of local diurnal anomalies in the brightness temperature for each of the 6 cross-track view angles measured by the MSU instrument We performed a special analysis run of the CCM3 where the results for 5 years (1979-1984) were output on an hourly time scale.

II. DIURNAL BRIGHTNESS TEMPERATURE CLIMATOLOGY

Each hour, the CCM3 model produces atmospheric temperature and humidity profiles and surface temperatures on a 128 x 64 (T42) grid of earth locations. Each profile and surface temperature is used as input to our microwave radiative transfer and surface emissivity models [6] to calculate MSU channel 2 brightness temperature for each of the 6 distinct MSU view angles. For the oceans, we use a comprehensive surface model that includes the effects of wind-induced surface roughness and the variation of emissivity with sea surface temperature. For land, we assume a constant emissivity of 0.95. This procedure results in a 5-year time series of brightness temperatures for each grid point and view angle. To produce a monthly climatology, the time series for each location is divided into months, and the mean diurnal anomaly for the specific location, month, and view angle is computed. We then resample the gridded climatology onto the 144 x 72 grid we use for representing the MSU data.

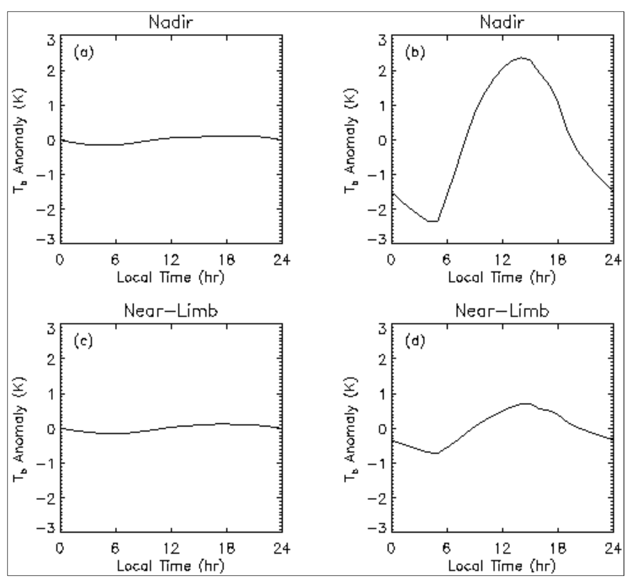

Fig. 1. Example simulated MSU Channel 2 diurnal cycles calculated from hourly CCM3 output. These diurnal cycles are for the month of June. (a) and (c) are for a 2.5 x 2.5-degree box in the tropical Pacific, centered at 178.75 W, 1.25 N. (b) and (d) are for a 2.5 x 2.5 degree box in the western United States., centered at 113.75 W, 38.75 N.

In Fig. 1, we show four examples of the brightness temperature diurnal cycle anomalies calculated using the above methods for two locations on the earth, and for the nadir and near-limb view angles. In Fig. 1, (a) and (c), we show the diurnal cycle for a location in the equatorial Pacific for the nadir and near-limb view angles. Both show a similar diurnal cycle, indicating that the calculated diurnal cycle over the oceans is mostly due to warming in a thick layer of the atmosphere, and suggesting that near-surface warming is not important. Note that the lower boundary condition for the model over the ocean is a weekly sea surface temperature analysis that is constant on the diurnal time scale, so we do not expect to see a surface diurnal cycle in these data. The validity of this assumption is supported by sea surface temperatures retrieved from the TRMM Microwave Imager (TMI). These show very little diurnal variation (< 0.5K), except in regions of very low (< 3 m/s) wind speed [7], which occur rarely.

Fig. 1 (b) and (d) are for a location in the western United States. The land location, relatively dry atmosphere, and summer time period result in a large diurnal cycle in the simulated brightness temperatures. In contrast to (a) and (c), there is significant reduction in amplitude of the near-limb view relative to the nadir view indicates that in this case, a significant portion of the MSU channel 2 diurnal cycle is due to surface warming. The surface signal is attenuated by the longer path through the atmosphere for the near-limb view.

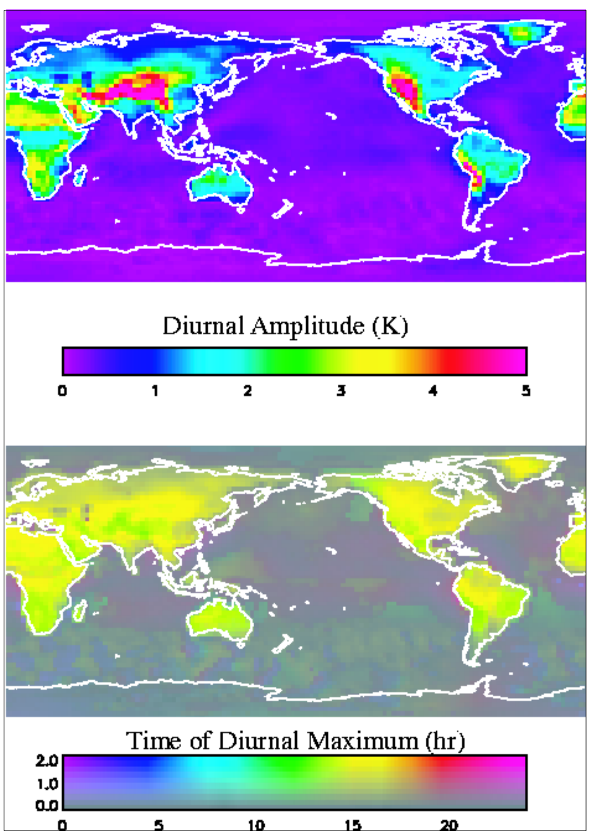

Fig. 2 (top) Mean simulated MSU Channel 2 diurnal amplitude for the June, nadir view. (bottom) Mean local time of simulated diurnal maximum, with the amplitude of the diurnal cycle denoted by the saturation of the color (this is done so the reader is not confused by anomalous diurnal maxima caused by noise in regions with a very small diurnal amplitude).

In Fig. 2, we show maps of the diurnal amplitude and the local time of diurnal maximum for the month of June for the nadir view. In general, the simulated diurnal cycle has the largest amplitude in high altitude regions, where the surface is less obscured by atmospheric absorption, and in dry regions, which have large near-surface diurnal cycles due to nighttime radiative cooling. In the regions with the largest amplitudes, the brightness temperature peaks shortly after local noon, while land regions with smaller amplitudes peak a few hours later. Low- and mid-latitude ocean regions tend to peak even later in the day, though with much reduced amplitude. When a similar map is plotted for the near-limb view, the diurnal amplitude for land regions is significantly reduced, indicating that much of the channel 2 diurnal cycle for these regions is due to surface heating.

III. Validating the CCM3-based Diurnal Climatology.

Before using the above diurnal cycle to correct long term time series of MSU brightness temperatures, we need to test its validity to the extent possible. To do this, we can use the measured MSU brightness temperatures. A straightforward way to do this that reduces the effects of long-term trends being aliased to the diurnal cycle is to compare ascending and descending measurements of the same earth location during the same time period. (Sampling of the diurnal cycle performed by the MSU series of instruments is insufficient to map the complete diurnal cycle in detail.) The difference between ascending and descending node measurements can be compared to similar differences calculated using the

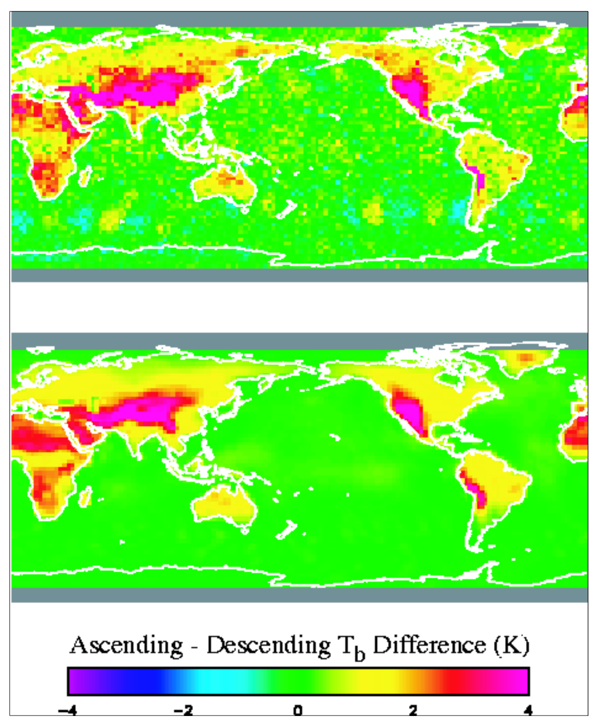

Fig. 3. (top) ascending-descending channel 2 brightness temperature differences for the entire MSU dataset for the central 5 fields of view, the month of June, and for ascending node equatorial crossing times between 15:00 and 16:00. The roughly periodic variation visible in the southern oceans is due to sampling effects. (bottom) Same as (top), except simulated using the CCM3 diurnal climatology.

CCM3 simulated diurnal cycles. The ascending and descending measurements are separated by ~12 hours near the equator, declining to ~10 hours at 65 N or 65 S.

We have assembled monthly averages of ascending and descending MSU measurements, binned into hourly bins by the local equatorial crossing time for the ascending node. When the entire MSU data set is used, there is a significant amount of data in 5 bins for most months-- those centered at 14:30,15:30,16:30,19:30 and 20:30 local time.

The ascending and descending monthly averaged maps are then differenced for each crossing-time bin and we calculate maps of ascending-descending simulated brightness temperature differences with the same local (zonally dependent) observation times as the MSU difference. A comparison of these two sets of maps provides a validation of the diurnal variations simulated by CCM3. To reduce problems associated with sampling, we have combined the central 5 fields of view into a single map, after adjusting each measurement to the nadir view using our radiative transfer and surface models. In Fig. 3 we show as an example the comparisons between the measured and simulated ascend-descending differences for the 15:30 crossing-time bin for the month of June. We plot maps of the observed and simulated differences, and a comparison of zonal averages for land and ocean separately. The agreement between the overall pattern and amplitude in most areas gives us confidence that the CCM3 model accurately represents MSU channel 2 diurnal cycle. The model appears to slightly overestimate the diurnal cycle over tropical forests (visible in tropical Africa and the Amazon Basin) and slightly underestimate the diurnal cycle in some high latitude land areas (visible in northwestern Canada and eastern Siberia). These discrepancies are not large enough to significantly change the diurnal correction applied to the MSU data.

Comparison of the ascending-descending difference for other crossing time bins and months show similar agreement, with the correlation coefficient between measured and simulated maps (spatially smoothed with a boxcar smooth of width 22.5 degrees to reduce sampling noise) remaining above 0.8 except for the crossing time bin centered at 20:30 local time. For this crossing time, the correlation coefficient is ~0.7 due to the increased relative importance of sampling noise since the signal amplitude has been reduced by approximately a factor of 4 for this later time.

IV. Correction Applied to the MSU Time Series

Using the diurnal climatology simulated from CCM3, we can adjust all MSU measurements to the same local time so that drifts in the measurement time no longer affect any deduced long term trends. The adjusted brightness temperature T_{Adj} is given by

$$T_{Adj} = T_{Meas} - T_{Sim}(t_{Meas}) + T_{Sim}(t_{Ref})\,. \qquad (1)$$

Here, T_{meas} is the measured brightness temperature, $T_{Sim}(t)$ is the simulated diurnal anomaly at time t, t_{Meas} and t_{Ref} are the measurement and reference time. In practice, the simulated brightness temperatures are obtained by interpolating monthly gridded climatology both spatially and temporally. In Fig. 4 we plot the global correction applied to the time series for each satellite to account for drifts in measurement time, as well as the Local Equator Crossing Time (LECT). The local reference time is chosen to be 12:00 noon for all satellites and both ascending and descending node. The choice of these times has little effect of the long term trends, since the effect of choosing a different time is to add the same periodic signal with a constant offset to all satellites.

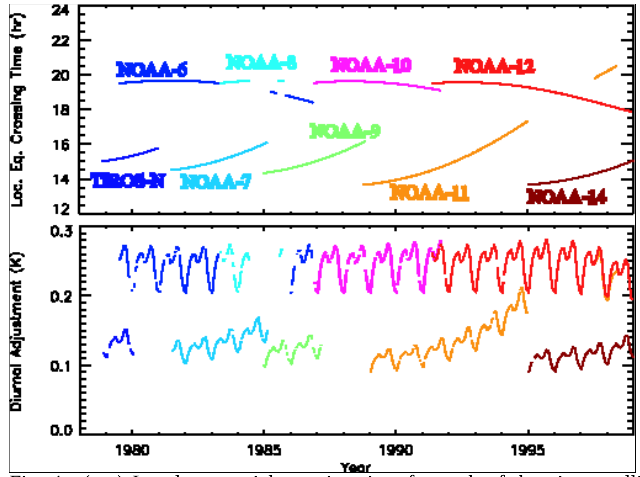

Fig. 4. (top) Local equatorial crossing time for each of the nine satellites. (bottom) Global diurnal correction applied to each satellite to account for drifts in local measurement time.

The most important diurnal drift correction is that for NOAA-11, since this satellite underwent the largest drift in LECT during the time period shown, though the corrections for NOAA-7, NOAA-12 and NOAA-14 are also important. Depending on the techniques used to merge the time series for each satellite together, this diurnal correction increases the resulting global decadal trends by 0.02 to 0.05 K/decade, with the largest effect on trend over land.

Acknowledgment

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