GSICS Quarterly

A Lunar Eclipse Observation With AMSU-B

By Martin Burgdorf, Universität Hamburg, Niutao Liu, Fudan University, Stefan Buehler, Universität Hamburg, Ya-Qiu Jin, Fudan University, and Marc Prange, Universität Hamburg

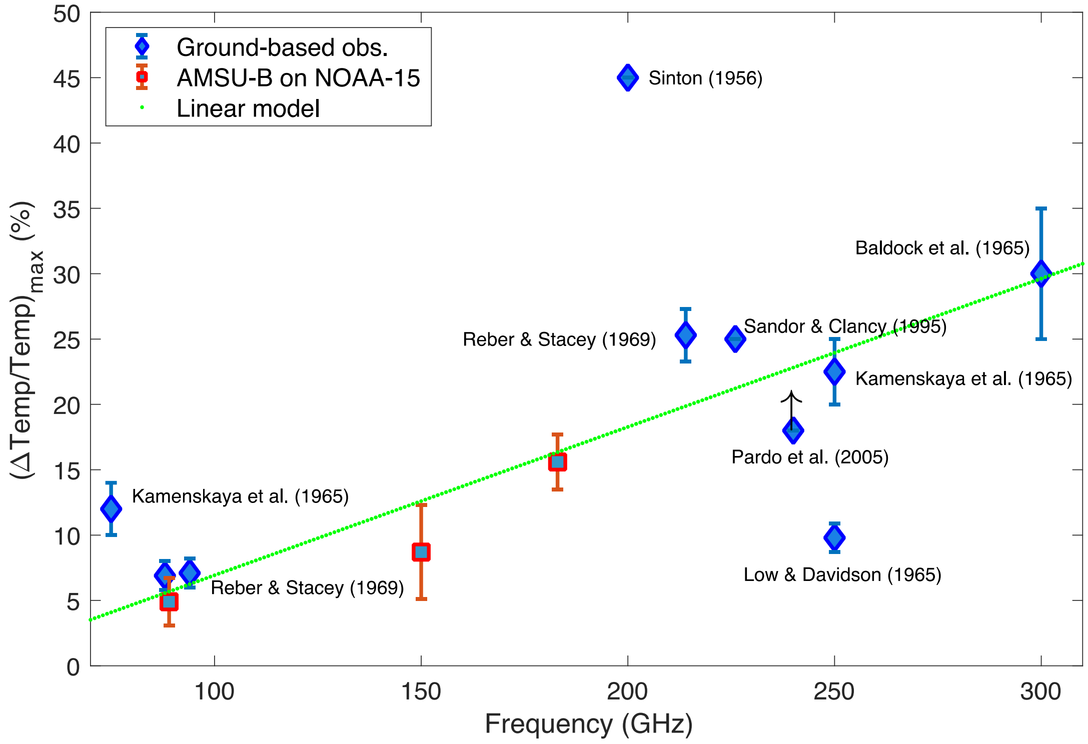
---

In order to establish the Moon as flux reference for the calibration of microwave sounders, it is important to have both an accurate radiative transfer model and a precise measurement technique for the spaceborne instruments. A lot of effort was invested during the last few decades on improving lunar models, but often the achievable calibration precision was limited by uncertainties of the observations – both with microwave and optical instruments. In order to demonstrate that observations of the Moon with microwave sounders are at least as accurate as the ones performed with ground-based radio telescopes, we have analyzed observations of the Moon that were taken with AMSU-B (Advanced Microwave Sounding Unit - B) on NOAA-15 during the total lunar eclipse of 2004 October 28. The Moon appeared in its DSVs (Deep Space View) once per orbit of the spacecraft over the whole duration of the eclipse. In each of these orbits, the Moon produced an anomaly in the counts of the DSVs that lasted several minutes and had the shape of a Gaussian. From the counts obtained before and after the Moon intrusion, it was possible to calculate the gain and then the radiance of the Moon in each channel, i. e. at 89, 150, and 183 GHz. The processing steps are listed as IDL commands in [1].

Uncertainty of the Measured Brightness Temperature

The measurement of the relative drop in disk-integrated brightness temperature of the Moon during the eclipse has the advantage of being independent of the absolute flux calibration, which affects all observations in the same way. Another peculiarity of our observations of the Moon, however, introduces an additional uncertainty, and that is the distance of the Moon from the pointing direction of the deep space view. As the Moon fills only a fraction of the Gaussian beam, its signal decreases with increasing distance from the center of the beam. The Moon angle can be calculated with a program in the ATOVS and AVHRR pre-processing package, but the absolute pointing accuracy of the microwave sounders is only 0.2°, i. e. almost 20% of the FWHM of the beam. It is therefore necessary to determine the Moon angle in a more accurate way, and for this purpose we take advantage of the fact that there are four DSVs with slightly different pointing directions. The ratio of the maximum counts in the different DSVs is characteristic for the position of the Moon: In one orbit, two neighboring DSVs may produce very similar counts, indicating that the Moon is in the middle between them, and in the next orbit one DSV produces many more counts than its neighbors, indicating that the Moon is very close to this pointing direction. From comparing many observations of the full Moon without eclipse to a model, we found out how the measured counts depended on the position of the Moon relative to the four DSVs. From the random scatter of these counts we could determine the uncertainty of the measured brightness temperature: It is 5 K at 89 GHz for a single measurement with AMSU-B, when the Moon is in the center of a pointing direction, and somewhat larger, when the Moon falls in between two DSVs. For MHS (Microwave Humidity Sounder), the uncertainty is half as large.

By comparing the counts obtained from observations of the Moon during the eclipse to those without eclipse, but with the same Moon angle, we could calculate the maximum relative temperature drop at the different frequencies of AMSU-B. These values are shown in the figure, and they demonstrate that the reliability of the observations with NOAA-15 allows to identify outliers in the results obtained with astronomical radio telescopes at similar frequencies [2].



Maximum relative drop in effective temperature during different total lunar eclipses. Our results are shown as red rectangles.

Relevance to Detecting Calibration Trends

From comparing observations, where the Moon had different positions relative to the four DSVs, but the same phase angle, we could determine how the counts depend on the distance of the Moon from the pointing direction of the instrument. With this knowledge it is possible to calculate the brightness temperature from almost every appearance of the Moon in the DSV. There are about a hundred events like this per year, and the uncertainty of a single measurement is some 3K at 89 and 183 GHz for MHS. Hence one can detect a calibration trend of 0.1% between the first and last two years of the operational phase of a satellite. With a typical lifetime of ten years, this means that a trend of about 1%/decade in upper tropospheric humidity (for a typical UTH of 30%) can be detected, assuming that UTH is an exponential function of brightness temperature. This is smaller than the discrepancies between different moistening trends of UTH reported in the literature [3]. It will be interesting to check, whether these results were affected by calibration trends.

Summary

We demonstrate how the radiance of the Moon during a total eclipse can be measured very precisely with AMSU-B, and we identified several wrong results obtained in the past with astronomical radio telescopes at similar wavelengths. The small uncertainties we achieved suggest that by analyzing all observations of the Moon that happened with microwave sounders in the past, it will be possible to check for undetected calibration drifts in the moistening trends of the upper tropospheric humidity.

References:

[1] file to be made available in Zenodo

[2] Burgdorf, M., et al, 2023, Observation of a Lunar Eclipse at 89, 150, and 183 GHz, Planet. Sci. J., Vol. 4, 112, 10.3847/PSJ/acd76e.

[3] Shi, L., et al., 2022, Assessing the consistency of satellite-derived upper tropospheric humidity measurements, Atmos. Meas. Tech., Vol. 15, 6949–6963, 10.5194/amt-15-6949-2022.