TES Calibration Update

Joshua Bandfield
December 2004

Summary of Known Calibration Errors

Space View

Starting on OCK 12581, the normal MGS mapping orientation was rotated 16 degrees as a fuel saving measure. As a result, TES could no longer use the -90 pointing angle for the space view used for calibration because a portion of Mars could find its way into the field of view (FOV). With this spacecraft orientation change, the space view was switched to a +74 pointing angle, which would ensure that Mars would not enter into the TES FOV for the space calibration observations. Unfortunately, the TES pointing mirror is only designed to clear the shroud from pointing angles of -90 to +70. Observations that stepped the mirror at 1 degree intervals confirm that all 6 detectors from the spectrometer do not experience vignetting to a pointing angle of no more than +72. At the pointing angle of +74 used for TES OCKS 12581-26794, TES detectors 3 and 6 detect an additional 4.5×10^{-7} and 2×10^{-7} W cm^{-2} sr^{-1} cm^{-1} respectively between 400 and 800 cm^{-1} (Figure 1). This effect is less for detectors 2 and 5 (1×10^{-7} W cm^{-2} sr^{-1} cm^{-1}) and is not detected in TES detectors 1 and 4. There does not appear to be any effect on the TES visible and thermal bolometers. The result is an apparent negative radiance for cold temperature observations, such as space, polar caps, and the Martian atmosphere.

The magnitude of this error on the calibrated radiance data is dependent on the wavenumber and magnitude of radiance of the target. The largest errors are near 600 cm^{-1} and for cold targets. Polar/nighttime surface temperature determination and atmospheric temperature retrievals are significantly affected and warm surface temperature atmospheric opacity retrievals and spectroscopy are not affected in a significant manner. There are several reasons for this, including the magnitude of the error diminishes with increasing signal, the relative proportion of the error is smaller with increasing signal, and radiance is a power function of temperature.

Temperature errors at 667 cm^{-1} for an average of all 6 detectors are -3 K, -4 K, and -8 K for 200, 180, and 150 K temperatures respectively. At 250-450 cm^{-1} these errors are somewhat lower; -2 to -4 K.

COBE

An additional source of calibration error is a slightly changing FOV as a function of TES mirror pointing angle. Special observations of space at different pointing angles indicate a variable apparent radiance that is a relatively smooth function of wavenumber and pointing angle (the term COBE is used to describe this). This effect appears to have remained largely unchanged over the course of the mission, though it is not possible to completely isolate its effects in later orbits (Figure 2).

The magnitude of this effect is <±1 x 10^{-7} W cm^{-2} sr^{-1} cm^{-1}. Using the standard pointing angles of -90 for calibration observations and 0 for nadir observations, the effect on calibrated radiance is -1 x 10^{-7} to 1.5 x 10^{-7} W cm^{-2} sr^{-1} cm^{-1} between 300 and 800 cm^{-1} and is <±1 x 10^{-7} W cm^{-2} sr^{-1} cm^{-1} for the average of all 6 detectors. The effect is larger for pointing angles of +74 and -16 for calibration and nadir observations respectively. The effect on calibrated radiance is 0-1.5 x 10^{-7} W cm^{-2} sr^{-1} cm^{-1} between 300 and 800 cm^{-1}. The average of all six detectors is 5-10 x 10^{-8} W cm^{-2} sr^{-1} cm^{-1}.

Time Variable Uncertainty

An additional source of error is apparent in data acquired on OCKS >~19000. This is a time variable effect that is apparently changing over the course of week to month long time spans. The nature of this error is similar to the COBE effect with a number of spectral features that can not be accounted for with simple combinations of blackbody radiance curves (Figure 3). The magnitude of this effect can be tracked by observing space at mirror pointing angles of +52, which were acquired as part of the standard limb observations when +74 space observations were being acquired (Figure 4). The magnitude of this effect is anywhere from -1 x 10^{-7} to 5 x 10^{-8} W cm^{-2} sr^{-1} cm^{-1} between 250 and 1000 cm^{-1}.

This effect can also be detected in nadir observations of cold surfaces, such as polar caps. There are two distinctive spectral features present at 750 and 1000 cm^{-1} that are distinct in the TES spectra of low temperature surfaces. Unfortunately, the pattern of the effect in the +52 space observations does not correlate with nadir (-16) observations acquired during the same period. This indicates that there is some pointing mirror dependency to this effect which makes it difficult to use the +52 space observations to track the magnitude of this effect. In the example shown in Figure 5, the effect is prominent in the polar cap observations and changes by ~1.5 x 10^{-7} W cm^{-2} sr^{-1} cm^{-1}. During the same period, the +52 space observations indicate that there is little, if any of this effect (the negative radiance is due to the +74 space observations described above) and no significant change is present.

Random noise

The magnitude of random, low spectral frequency noise has increased over the course of the TES mission. TES is known to be sensitive to vibrations caused by solar panel and high gain antenna movements and the magnitude of these effects appear roughly proportional to the speed of the movements. There are other possible sources of vibration on the MGS spacecraft, including reaction wheels, the TES pointing mirror, etc… that may also be the source of this noise. This noise is random between ICKs, but is correlated between detectors and is not reduced significantly with an average of all 6 detectors.

While individual ICKs may be averaged to reduce this error, a limiting factor is the error present in the calibration observations. Until, OCK 22601, 3 ICKs of data were collected for space and reference observations. These observations are averaged and any noise and error present is mapped into the calibrated radiance data. The number of observations was increased to 7 for the space observations after OCK 22601. The standard deviation of the error present in cold temperature observations is reduced from a peak of 1.8 x 10^{-7} W cm^{-2} sr^{-1} cm^{-1} to 1.4 x 10^{-7} W cm^{-2} sr^{-1} cm^{-1} (Figure 6). At 667 cm^{-1}, this corresponds to a 5, 3, and 2 K error for a 150, 180, and 200 K target respectively for the 3 ICK calibration observations and a 4, 2, 1.5 K error for the 7 ICK calibration observations. These errors are taken from OCK 25850-25950 data. The magnitude is less early in the mission but has not been tracked or determined here. These errors will be present in individual spectra or averages from within an orbit, but will be significantly reduced if data is averaged over multiple orbits (and multiple calibration observations).

Summary of Observations

To summarize, there are four known nonrandom sources of error in the TES data that can significantly affect the retrieval of cold surface temperatures and atmospheric temperature profiles; 1) the use of an improper pointing angle for space calibration observations from OCKs 12581 to 26795; 2) COBE effects present in the data from the start of the mission, which are more prominent in the +74 space calibration observations; 3) a time and pointing angle variable uncertainty that became prominent in OCKs >19000; 4) a random noise present at significant levels in the data that is mapped into the instrument response function.

Proposed Changes to Calibration Routine

Past Data

The radiance inaccuracies due to 1 and 2 listed above can be corrected in a relatively simple manner. It is currently assumed that observations of space are a zero radiance target. The calibration software will be modified to change this assumption to a constant radiance as a function of wavenumber and detector. This radiance will be obtained from large averages of -90 space calibration observations acquired after OCK 16887 but before the time variable radiance error appeared in the data near OCK 19000. These -90 observations were acquired on the night time side of the planet when the MGS spacecraft was reoriented to nadir pointing for reaction wheel desaturation events. The dataset has been reprocessed using only +74 space observations to allow the -90 space observations to be calibrated relative to the +74 observations. The large averages will reduce to insignificant levels the sample to sample random noise of the instrument as well as the noise described in 4 listed above.

The result of this correction will be to modify the calibration scheme to closely resemble the traditional -90 space calibration observations taken up until OCK 12581. This achieves two results; 1) the TES calibrated radiance data is consistently calibrated throughout the mission and within each orbit with a nadir equator crossing reorientation; 2) Nadir (and the similar pointing angle of -16) observations have minimal COBE and no vignetting effects relative to the -90 space observations.

At this time, there is no method for extracting the magnitude of the time variable radiance as a function of pointing angle. While its effects can be detected and identified, any reasonably simple tracking and correction method is likely to contain significant inaccuracies. Radiance errors due to random noise can be reduced by averaging data from multiple orbits. Vicarious corrections can be applied to the data, but once again, there is no systematic correction proposed at this time.

Future Data

The +74 space observations have been changed to +68 to prevent any of the shroud from entering into the detector FOV's. COBE effects will remain at a magnitude similar to the +74 observations. These will be obtained using early in mission +60 COBE observations because of their low noise. The calibration software will be modified to include these radiance values for the space calibration observations.

An additional improvement in accuracy may be obtained by increasing the number of ICKs used for space calibration observations. This number is currently at 7 but an additional degree of accuracy (at 150 K) may be obtained by doubling the number to 14 ICKs.

Figures

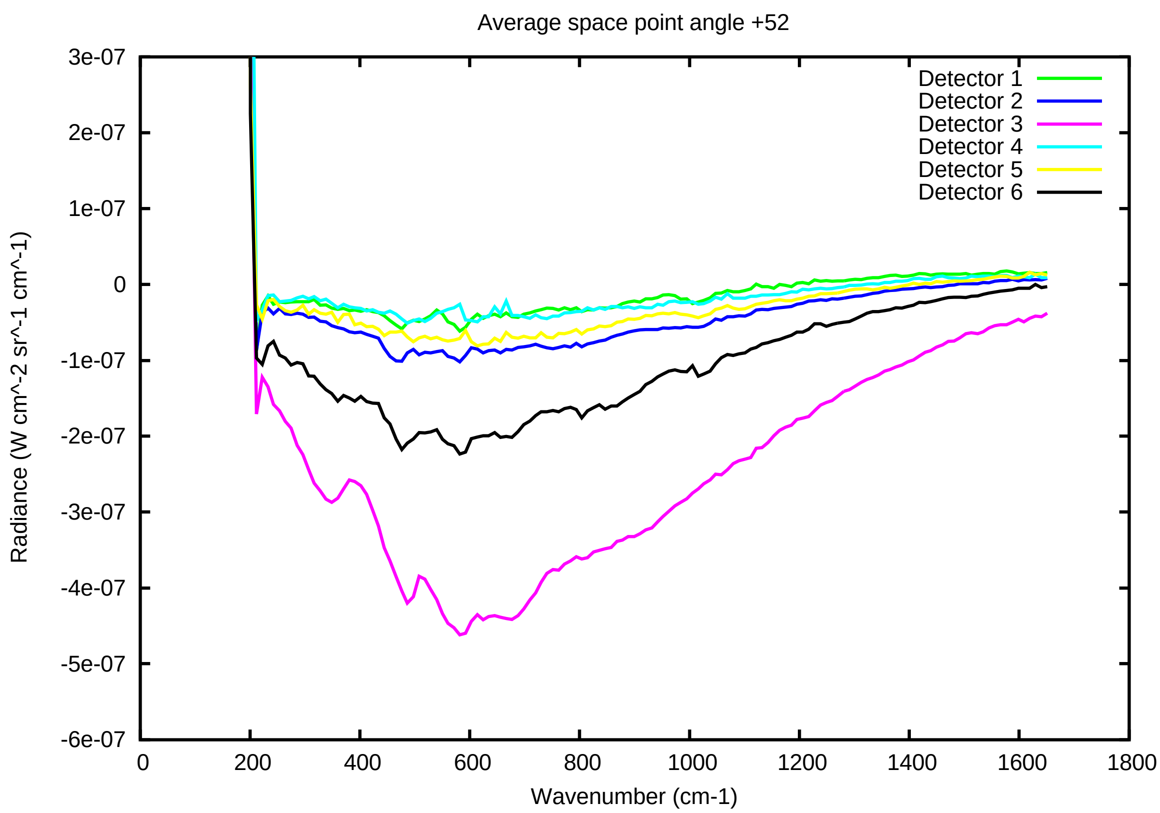

Figure 1: Average (OCKs 12586-17000) calibrated radiance for TES pointing angle of +52 calibrated using +74 space calibration observations. Negative radiances are a result of a portion of the TES shroud in the field of view for space calibration observations. Detectors 3 and 6 are significantly affected and detectors 1 and 4 display no significant effect.

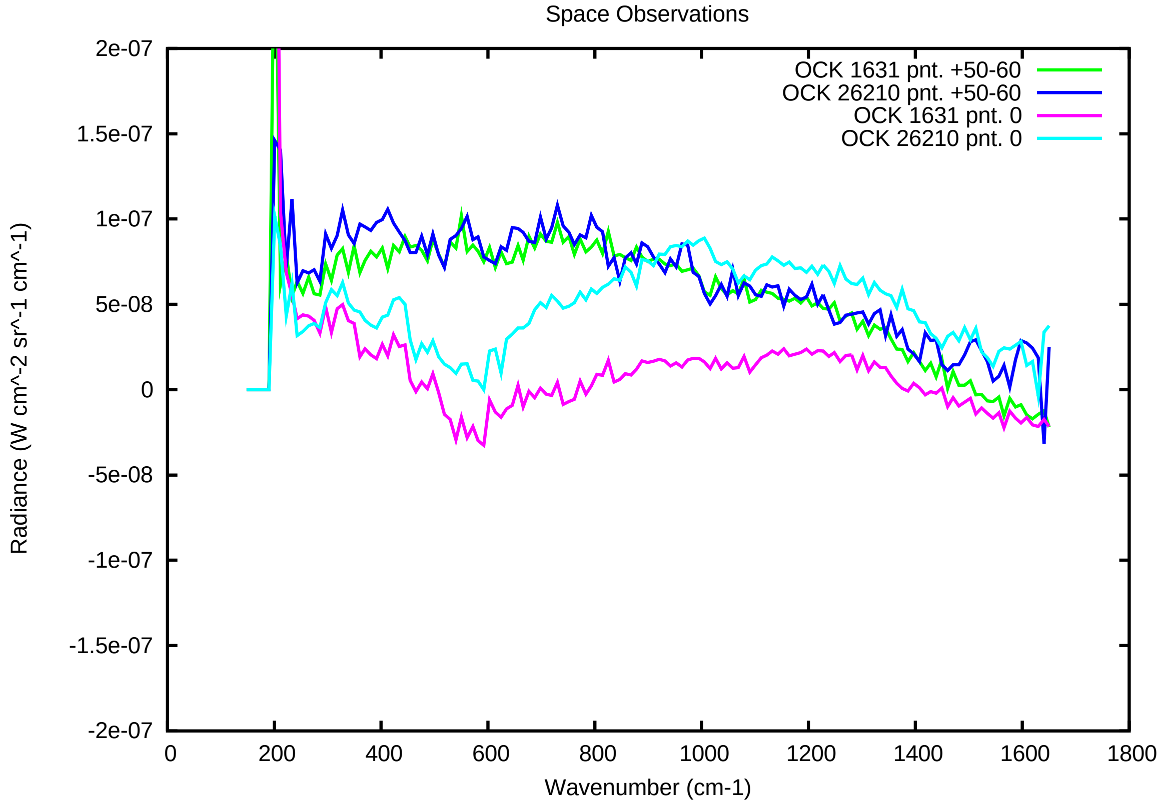

Figure 2: Space observations at pointing angles of 0 and +50-60 at OCKs 1631 and 26210. The finer spectral structure remains largely unchanged. It is unclear if the difference between the 0 pointing angle observations is due to changes inherent to this effect. It is likely unrelated because of the limited number of observations and the inability to isolate other sources of error for the OCK 26210 data.

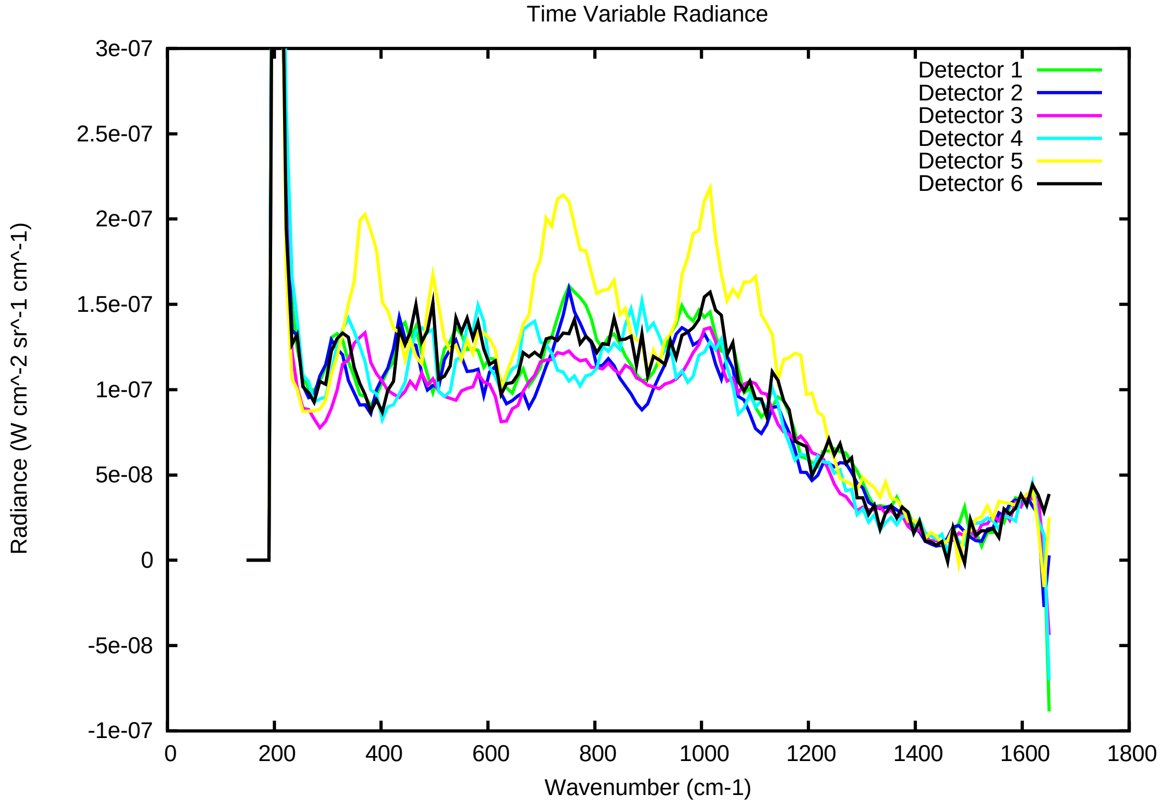

Figure 3: Difference in space radiance between averages of OCKs 23972-24905 and 24998-25549. All data were taken from a pointing angle of +52 using +74 space calibration observations.

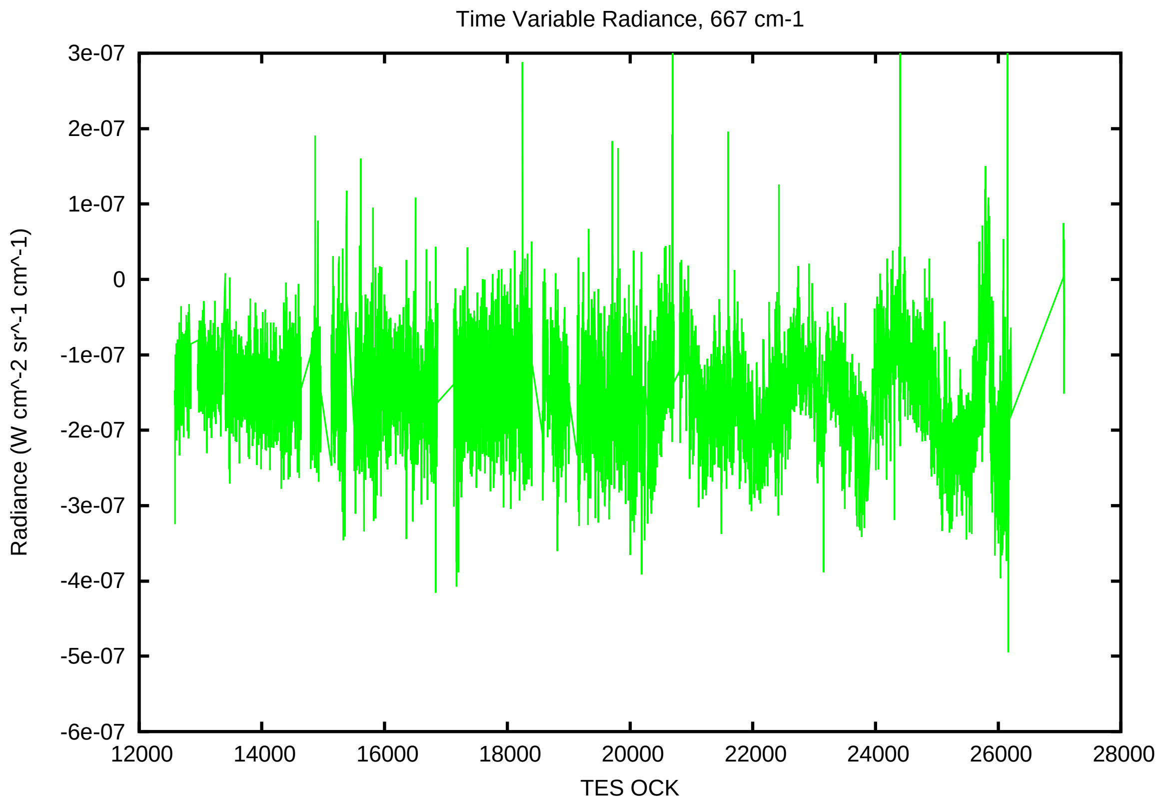

Figure 4: Orbit averaged radiance at 667 cm^{-1} and a pointing angle of +52 versus TES OCK.

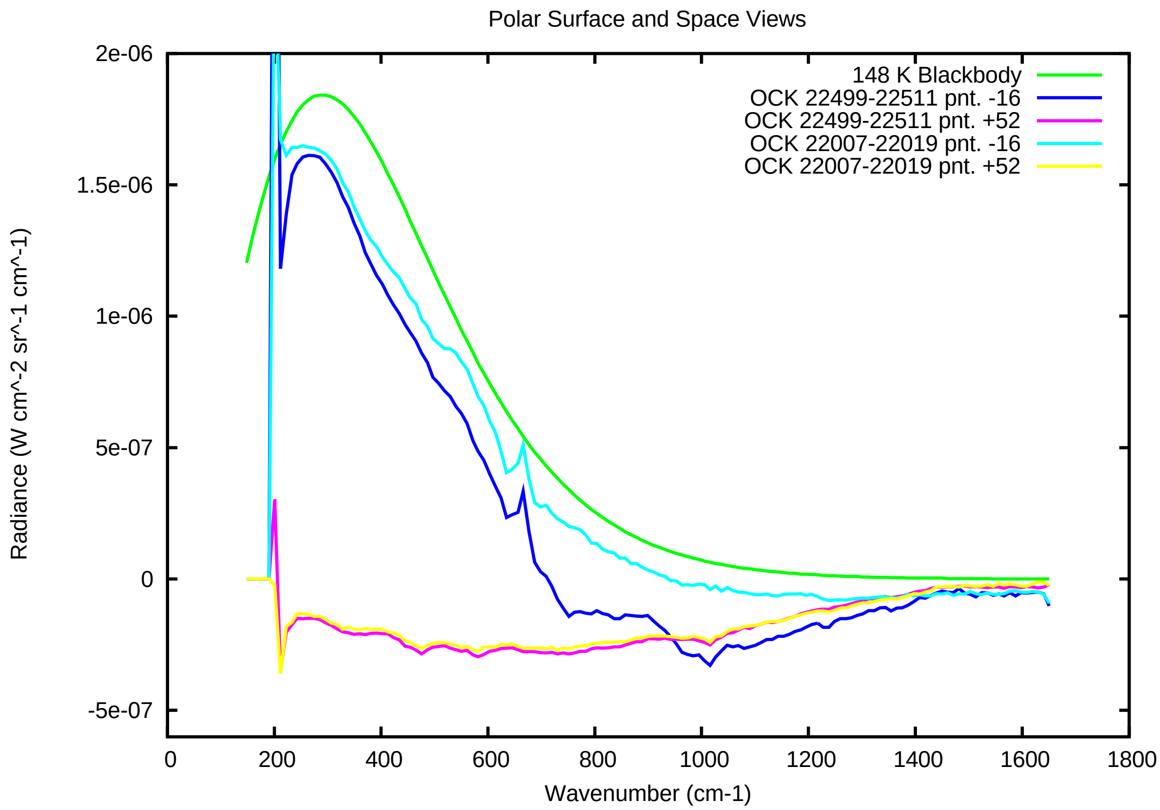

Figure 5: Calibrated radiance observations of space at a pointing angle of +52 and polar cap surfaces at a pointing angle of -16. All data are calibrated using space observations of +74 accounting for the overall low values relative to the 0 and 148 K blackbody radiance values. Major differences in radiance occur in the polar cap surface spectra due to the effects shown in figures 3 and 4. This is especially noticeable between 600 and 1200 cm^{-1}. Space observations do not display similar differences, though a similar spectral structure is present in data from other OCKs.

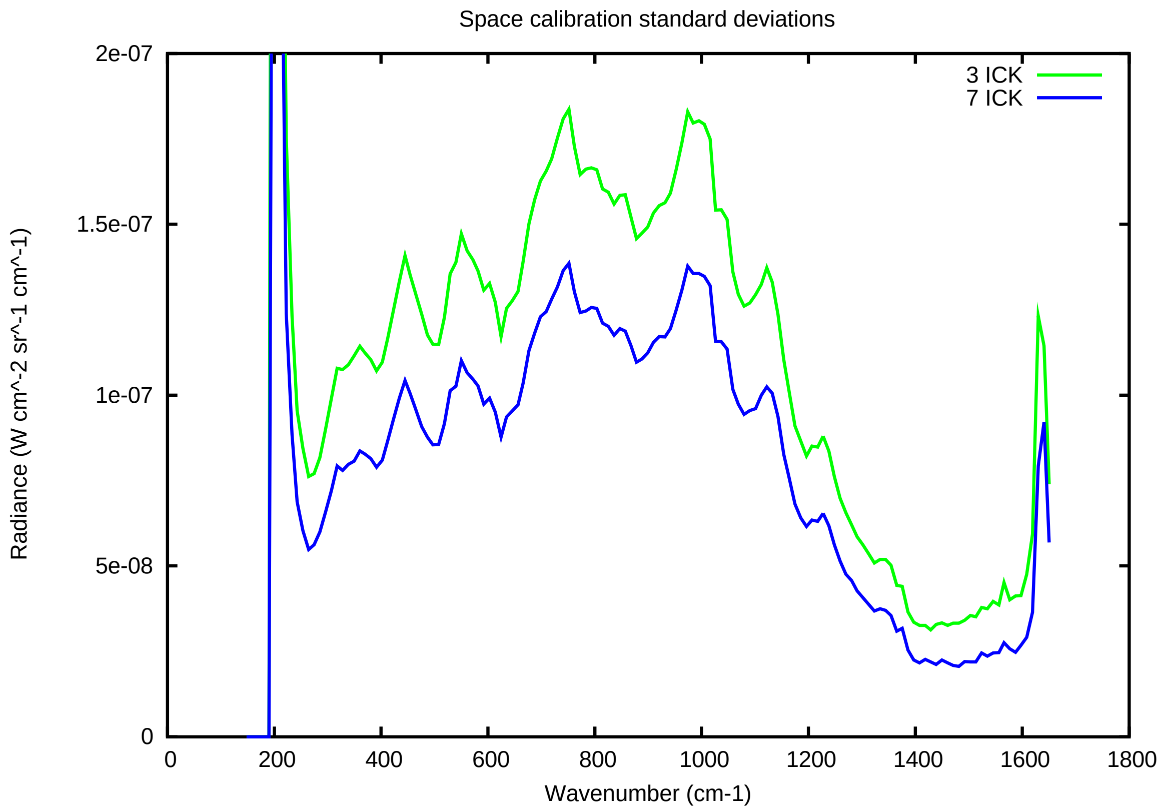

Figure 6: Standard deviations of 3 ICK and 7 ICK space calibration observations versus wavenumber. Data were taken from OCKs 25850 to 25950 at a pointing angle of -90 and calibrated using +74 space observations. These values are mapped into cold surface radiance observations.