CALIBRATION OF THE CLEMENTINE NEAR INFRARED CAMERA: READY FOR PRIME TIME, P. G. Lucey[1], J. Hinrichs[1], C. Budney[1], G. Smith[1], C. Frost[1], B. R. Hawke[1], E. Malaret[2], M. S. Robinson[3], B. Bussey[4], T. Duxbury[5], D. Cook[6], P. Coffin[3], E. Eliason[3], T. Sucharski[3], A.E. McEwen[7], C.M. Pieters[8], 1) Hawaii Institute of Geophysics and Planetology, University of Hawaii at Manoa, 2525 Correa Rd. Honolulu HI 96822 [lucey@pgd.hawaii.edu], 2) ACT Corp 112 Elden St. Suite K Herndon, VA 22070, 3) Northwestern University, 1847 Sheridan, Evanston, IL 60208., 4) ESTEC, ESA, Noordwijk NL, 5) Jet Propulsion Laboratory, 6) Astrogeology Team, U.S. Geological Survey, 2255 North Gemini Drive, Flagstaff, AZ 86001, 7) Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721-0092, 8) Department of Geological Sciences, Brown University, Providence RI 02912.

During early May 1994, the Clementine spacecraft occupied a polar lunar orbit for two months and obtained millions of images of the lunar surface with a suite of imaging instruments [1]. One of these instruments was a near infrared framing camera, designated the NIR Camera, known informally as the NIR, and more informally by other names. The NIR was built jointly by the Lawrence Livermore National Laboratory and Amber Engineering of Goleta Ca. The NIR camera obtained images of nearly the entire lunar surface in 6 wavelengths: 1.1, 1.25, 1.5, 1.99, 2.6 and 2.7 μm. The first five filters had 60 nm bandpasses while the 2.7 μm data has an effective bandpass of about 300 nm. Each frame obtained was 256 by 256 elements, with a field of view of 5.6 degrees and an IFOV (the field of view of individual pixels) of .38 mrad The NIR angular, and therefor spatial, resolution of the NIR camera is somewhat lower than that of the UVVIS camera at .25 mrad, with a maximum spatial sampling of 150m/pixel. The coverage of the Moon by the NIR camera is close to 100% and is essentially identical to that of the UVVIS camera.

The camera was based upon a 256 by 256 element indium antimonide detector array produced by Amber which offers sensitivity from 1 to beyond 5 μm. In order to eliminate thermal background from the instrument and spacecraft the camera was equipped with a cooled shortpass filter which rejected thermal radiation beyond about 2.75 μm.

Scientific use of the data from this instrument has been hampered by calibration difficulties with a number of sources. These problems include a large and time variable offset which makes accurate color ratio or spectral data impossible to obtain without correction. In addition the camera has four types of spatial nonuniformity corrections which must be determined and applied to achieve acceptable performance. Further, the camera equation postulated by LLNL scientists has numerous constants which must be determined prior to radiometric calibration. Some of these "constants" are also time variable. There is good evidence that the camera suffers from stray light effects, though to a lesser and qualitatively different degree than the UVVIS camera. NIR phase and photometric functions must be determined for which no publish estimates are available.

Many of the problems were manifest during the course of the mission and in post analysis. The camera model developed based on laboratory calibrations consistently overestimated the exposure times required to keep the camera from saturating indicating the presence of a background source of signal unaccounted for based on laboratory calibrations. While obtaining data for about 2 hours during each 5 hour Clementine orbit, the array was operated at 77K using a closed cycle Stirling cryocooler. To conserve power, the cooler was not routinely operated during the balance of each orbit. Observations of space while the camera was cooling to operating temperatures revealed that much more time was required for the data to stabilize than was observed in the laboratory under similar conditions. Observations of deep shadows near the lunar poles consistently returned much lower calibrated values than observations of space made prior to and following the mapping phase of each orbit. Calibrated data obtained of space are highly correlated with the temperature of the NIR camera electronics and cryocooler. Mosaics of NIR data corrected for gain, exposure and offset consistently showed mismatches across boundaries between changes in camera state in terms of these parameters. The NIR optics exhibit significant pincushion distortion which must be removed prior to image registration, and a different scale than the UVVIS camera which must also be characterized prior to registration.

Most of the problems are related to a major change in camera behavior post-launch. Several flight models of the camera failed during shake testing in a manner which indicates a likely source of many of the problems. The cooled thermal background rejection filter shares the same cold finger as the detector array and is held in front of the detector with a short cold snout which also serves as a light baffle. The adhesive bond holding the filter to the cold shield failed repeatedly during shake testing. The camera flown passed this test, after a few repairs, but we believe that the cold filter-cold shield failed on launch shock. While the detector array temperature rapidly reaches a stable operating temperature on cooling, the output of the detector remains high and does not drop and stabilize at a low value for 40 minutes after turn-on of the cooler. (Travis White, Lyn Pleasance, LLNL, personal communication) This indicates that the cold filter is in poor thermal contact with the cold finger causing a low cool-down time. This poor contact indicates a mechanical failure which may be admitting a broadband thermal light leak with the body of the camera as the source. This may also explain the high correlation of values obtained from observations of space with the NIR camera electronics and cryocooler and is the likely source of the time variable thermal background. This is our working hypothesis for the thermal background term: it is composed of two sources, one is steadily declining thermal emission by the cold filter during the early portion of each data take, and a thermal light leak due to mechanical failure of the cold filter bond.

Despite a careful calibration of gain values on the ground by Amber and LLNL personnel, the gain values did not correct overlapping frames obtained in flight well. Relatively minor adjustments of gain values greatly improve the gain normalization. We think the likely source is a change in the values of the resistors in the network which generate the gains in the vacuum thermal environment of the spacecraft. The ground gain calibration was not performed both in vacuum and under the same thermal conditions as obtained in flight.

Since the conclusion of the mission, the authors have been deriving corrections for most of these problems. To this end we assembled a number of tools to attack the problems. First, we produced global mosaics of NIR data treating each image as one pixel in the manner of [2]. The mosaics were constructed of each relevant calibration parameter such as gain state, exposure time, emission angle, phase angle, Moon-Sun distance, etc. so that different versions of the calibration could be tested rapidly. Second, we extracted the raw values for shadowed regions in the 80-90 latitude bin for each pole for each orbit. One constraint is that these data should go to zero. We extracted every image obtained of space during the course of the mission to obtain values of both global and pixel dependent terms. We obtained ground-based low phase angle global images of the Moon at 1.0, 1.1, 1.25, 1.5 and 1.99 μm as a spectral and phase function calibration reference. Finally, we are completing an atlas of extremely high quality groundbased spectra of lunar locations obtained by Hawke and coworkers and Pieters and coworkers. These 60-odd spectra will be used to “ground-truth” extracted Clementine NIR spectra.

The NIR calibration equations are as follows:

$$DN = G\left[\left(C_1 L_{Total} + C_2\right)t + C_3 + C_4\right] + C_5$$

Where:

$L_{total} = L_{lunar} + L_{background}$

and is the total radiance sensed by the system for each filter, and is composed of lunar signal, stray light, and thermal contamination background,

DN are the raw counts as derived from decompressed NIR images.

G is the gain which must be obtained from a lookup table using the gaincode found in the PDS label of each image.

C_5 is a digital offset. It is the DN value output when G (gain) is zero.

C_4 is an adjustable global analog offset which equals offset_id*V, where V=-0.91. Offset_id is obtained from the PDS label.

C_3 is the pixel dependent bias. It is the output of the analog signal chain with zero integration and Offset_id is zero.

C_2 is the pixel dependent dark current rate, that is the rate of accumulated signal in the absence of incident photons.

C_1 is the wavelength dependent, pixel dependent absolute calibration constant. In practice it can be broken into a pixel dependent term with mean value of unity (the “flat field”) and a global absolute calibration constant.

t is the integration time, obtained from the PDS label.

Rearranging, the calibration of DN to radiance is as follows:

$$L_{Total} = \left\{\left[\left(\frac{DN - C_5}{G} - C_4 - C_3\right)\Big/ t\right] - C_2\right\} C_1$$

We are in the process of finalizing the values and uncertainties for each of these constants. The value of $L_{background}$ is correlated with the NIR electronics temperature, excepting a narrow range of orbits during the first month of operation. We will use this correlation, tied to the values of deep polar shadows for each orbit, to provide the thermal background correction. We have derived bias, dark current, bad pixel fields and preliminary flat fields. Refined flat fields will be derived on completion of the calibration. The geometric distortion and UVVIS-NIR focal length and image rotation reconciliation are being finalized. Finally, we are refining the values of the NIR phase functions.

The final result of the calibration will be compared to the groundbased spectra as a consistency check. The final steps will be reporting of signal to noise ratios within each frame, and the global signal to noise ratios which include calibration uncertainties.

A set of CD’s will be produced with all relevant calibration data used in this project including groundbased observations, special observations culled from the larger data set including space-looks and derived products such as deep-shadow image histograms.

References: Nozette, S. et al., Science, 266, p1835, 1994; 2) Lucey P.G., et al., Science 266, p1855, 1994.