CHALLENGES AND SUCCESSES OF IN-FLIGHT LROC WAC DARK CALIBRATION. A. K. Boyd[1], P. Mahanti[1], D.C. Humm[2], M.S. Robinson[1], LROC Operations Team. [1]School of Earth and Space Exploration, Arizona State University, Tempe, AZ, 85287. [2]Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Road, Laurel MD, 20723 (Aaron.Boyd@asu.edu)

Introduction: The Lunar Reconnaissance Orbiter Camera Wide Angle Camera (LROCWAC) [1] acquired its first useful images 20 September 2009 and has been imaging almost continuously since that date, witnessing over 35 lunations and acquiring over 195,000 images. The radiometric accuracy of the WAC images is maintained by the WAC image calibration process. In the absence of light, the WAC charged-coupled device (CCD) response is a combination of the inherent bias and the dark current. This response in the absence of light is captured as a dark image which is then used in the calibration process. In equational form, the simplified WAC image calibration process is

$$\text{Calibrated\_Obs} = \frac{\text{Observation} - \text{DarkSignal}}{\text{NonUniformityMatrix}} \quad (1)$$

Both focal plane array (FPA) temperature and integration time affect the CCD dark signal during the acquisition of dark observations. The exposure range of 10ms to 60ms and FPA temperature range of $-30°$C to $5°$C for observations were investigated in this study. In addition, parameters controlling the WAC background offset also effect the dark observations. This work describes the methods used in collecting and analyzing the dark image data for calibration.

Data Collection and Processing: The flight calibration software uses dark images synthesized from a stack of dark observations with no illuminated terrain, and acquired under similar imaging conditions (temperature and background offset value) as the raw observation to be calibrated. Accordingly, dark observations are acquired throughout the nightside with several different exposures to increase the sample size of all temperature and exposure bins. While the temperature values for the dark observations are contiguous (and dependent on the spacecraft orbital position), the WAC has flown with only three different background offset values for onboard bias (56, 64, and 68). In addition, there are 4 basic imaging modes for the WAC resulting in independent sets of calibration files for each background offset value and imaging mode (see [1] for modes).

Building the Dark Library: The lower temperature extreme of the WAC FPA occurs while imaging the terminator (high spacecraft β angle). It is necessary to include as many observations closest to the terminator with no illuminated terrain to create an all-inclusive data set. Due to the difficulty of manually checking the nearly 46,000 WAC dark observations for illuminated scenes, a process enabling automatic identification and

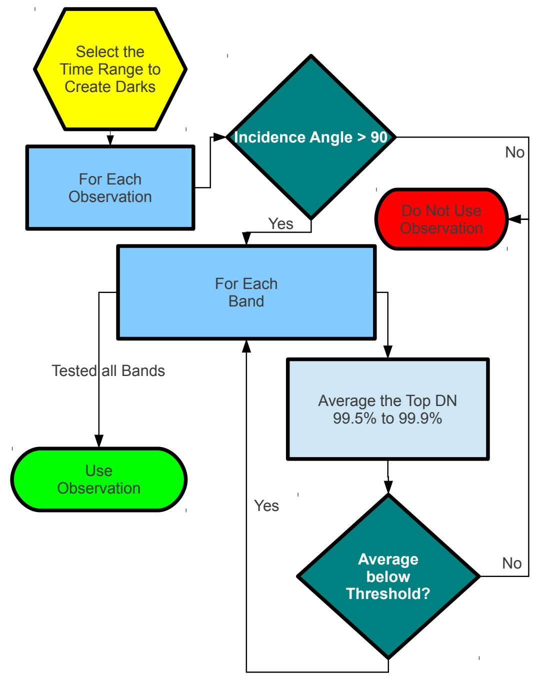

Figure 1: Dark observation selection routine for inputs to the calibration files

exclusion of observations with illuminated terrain [Fig. 1] was developed. The selected dark observations [Fig. 2] are then used to create a calibration image library.

The 32 frame long dark calibration images used by the WAC calibration software are calculated from dark observations, binned by 3 month periods and 3°C FPA temperatures.

The first frame of each calibration image is a mean of the first frames from observations in the bin, the second frame of the calibration image is a mean of all the second frames from the observations in the bin, etc. up to 31, and the 32nd frame of each calibration image is a mean of all remaining frames from the observations in each bin.

Dark observations for the WAC are dynamic; cosmic rays and radiation have been seen in WAC images and have had pervasive, but temporary effects observations. Temporal binning the dark observations during the synthesis of a composite dark image lessens the impact of random events on calibration.

Using the Dark Library: Dark subtraction frames are calculated from selected 32 frame long dark calibration images from the dark library, using interpolation in detector temperature followed by interpolation in time between the first and last frame of the image to be calibrated.

The selection of dark calibration images is a two stage process. Calibration image detector temperatures that bracket the raw image detector temperature comprise the first selection criterion. Calibration images with time bins closest to the acquisition time of the raw image comprise the second selection criterion. Temperature bin sizes are 3°C. Time bins are generally confined from 0° to 90°β (3 months), which is the period of a temperature cycle for the spacecraft.

The first 31 frames of a WAC observation are calibrated using the first 31 frames of the temperature-bracketing dark calibration images. The 32nd and all remaining frames of a WAC observation are calibrated using the last frame of the temperature-bracketing dark calibration images. Temperature interpolation is applied to the library dark calibration images to generate a 32-frame dark subtraction image appropriate for the detector temperature of the first frame of the image being calibrated and similarly for the last frame. Then,time interpolation is applied to the two temperature-interpolated dark subtraction images to make a dark subtraction image appropriate for the time at which each frame was taken within the image being calibrated. Finally, only one frame of each dark subtraction image is actually subtracted in the calibration, namely the frame appropriate for the frame being calibrated.

During the mission, the FPA temperature has ranged from -38°C to +25°C, but for night side images the FPA temperature ranges only from -35°C to 6°C [Fig. 2,3]. Approximately 99.9% of the day side images fall into the latter temperature range. The dark subtraction on the other $\approx 0.1\%$ of day side images with detector temperature at extremes is done by extrapolating.

Observations on Dark Images: The onboard WAC bias is working as expected, and can be successfully commanded on the ground. The visible wavelengths of the WAC dark observations behave the same over the nominal temperature ranges and exposure times [Fig. 4].

Effects of Temperature: The WAC dark bias is inversely related to detector temperature [Fig. 3]. The KODAK KAI-1001 has insignificant dark current in relation to other electronics for the WAC, and the secondary electronics are what is thought to be the contributing factor to the noise as detector temperatures decrease.

Effects of Exposure Time: For WAC observations with exposure times between 10 ms and 60 ms there is no significant change in dark current [Fig. 3].

Conclusion: The WAC dark behaviour is well described and understood. The density and repeatability of dark observations continues to contribute to the success of the calibration.

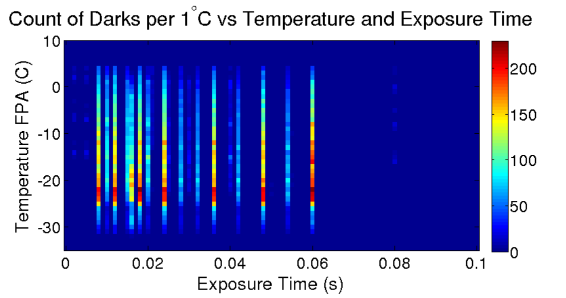

Figure 2: Number of dark observations vs exposure time and temperature. The total number of dark observations is 45,843 with highest density near -23°C for all exposure times.

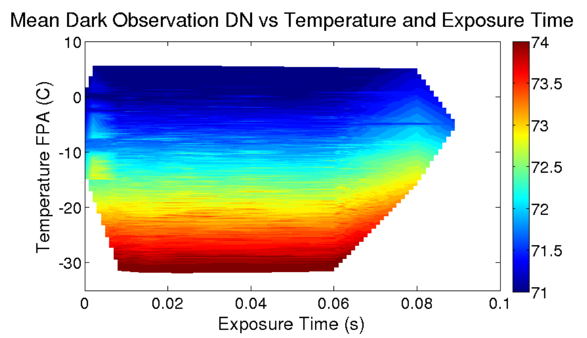

Figure 3: Mean dark observation DN vs exposure time and temperature for the 604 nm wavelength (all wavelengths are similar). The bias (background DN) removed on-board has been added back to the dark observations, allowing collective analysis of dark observations. Notice the near zero dependance on exposure time (dark current) for nominal WAC exposure times (10 ms to 60 ms).

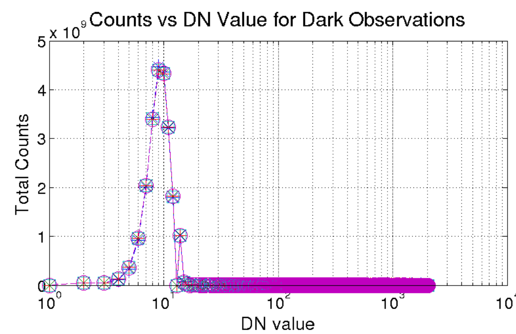

Figure 4: Aggregate histogram of WAC visible wavelengths from dark color observations with a background offset of 64. All wavelengths have similar dark current; this is expected, because all bands are on the same CCD and read out identically.

References: [1] M. Robinson, et al. (2010) *Space Sci Rev* 150(1):81.