MEASUREMENT OF HIGHLAND POND MELT VOLUMES FROM LRO NAC DEMS P. Mahanti[1], K. Burns[1], T. Tran[1], M.S. Robinson[1], [1]Lunar Reconnaissance Orbiter Camera, School of Earth and Space Exploration, Arizona State University, Tempe,AZ,USA; pmahanti@asu.edu;

Introduction: Lunar Reconnaissance Orbiter Camera (LROC) Narrow Angle Camera (NAC)[1] meter scale images reveal a large region (more than 3000 square km, at 41°N, 167°E) containing hundreds of young discrete smooth deposits ('ponds'). Smooth plains in this region appear to have formed from viscous fluid ponding. NAC stereo-pairs acquired in this region were used to obtain Digital Elevation Models (DEM) at 2 meters/pixel [2].

In this work we describe image analysis procedures used to estimate the melt pond volumes within the craters. The problem involves obtaining the volume of the filled portion of a crater by inferring the DEM of unfilled crater. Polynomial fitting is used to accomplish this task. Also the variation of the pond volume with pond area is analysed.

Obtaining NAC DEMs: The two LRO-NAC's are designed to provide 0.5 m resolution panchromatic images covering a 2,500 m swath width, for a combined coverage of 5,000 m, at an altitude of 50 km. Each camera has its own optics that are aligned to overlap by 135 pixels in the cross-track direction and are offset from each other by 185 pixels in the down-track direction [1]. Although they were initially not designed as a stereo system, they can obtain stereo pairs through images acquired from two orbits (with at least one off-nadir slew) with similar lighting conditions. Typically the two observations that form a geometric stereo pair have different slew angles ranging from zero to twenty degrees [3]. To obtain an accurate DEM, the convergence angle between the two images should be between 12°-35° for images with a 0.5 pixel scale [4]. Off-nadir rolls interfere with the data collection of the other instruments, so during the nominal mission LROC slew opportunities are limited to three per day [1].

DEM data analysis and image processing: The DEM data analysis was done in three stages. In the first stage, portions of the DEM were isolated to allow for ease of processing in melt pond volume calculations. Slope maps were generated with the NAC DEMs to identify the boundary between ponded material and the surrounding crater wall. A box was drawn around the area that accurately represented the crater definition and encapsulated the ponded area. The coordinates of the box were exported to crop individual ponds from the larger DEM.

In the second stage the individual cropped regions were processed. Using the slope map and the DEM, the pond perimeter was defined interactively with the help of image processing code developed using the Image Processing Toolbox in Matlab 7 (Mathworks Inc.). Once the pond perimeter was defined this was used to crop and remove the DEM data in corresponding isolated DEM portions generated in the first stage. This DEM with a 'hole' in the center was then fitted smoothly by a 4th order 2-dimensional polynomial, with residuals less than 3 percent and a root-mean-square error less than 0.5m in most cases. It may be noted that the re-meshing of the cropped polynomial fit depends on the nature of the slope in the surrounding areas. While the fitting error could be reduced by using higher-order polynomials, this is avoided to prevent over-fitting.

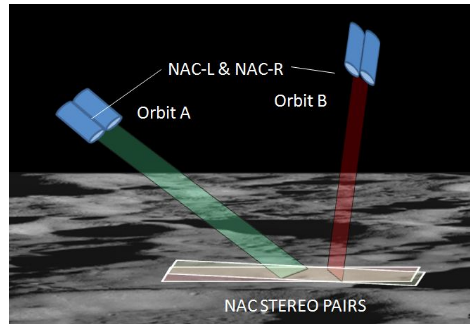

Figure 1: Imaging geometry for obtaining a NAC stero pair. Images are obtained by both NAC left and right cameras in two different orbits.

The final stage involved subtracting the DEM with the pond ('filled' crater) from the fitted DEM made in the previous stage without the pond ('unfilled' crater) to get the volume of the melt pond. care was taken to avoid problems at the pond boundary which could be caused during the polynomial interpolation process.

Variation of Pond Volumes with Pond area: Pond volume was plotted against the pond area and was fitted with a quadratic function. The fitting results indicate that highland pond volumes could be inferred successfully from the pond areas. Also, it was found that the pond volumes showed excellent linear behavior when plotted against the product of the pond area and the maximum depth of the pond. The maximum depth of the pond was estimated from the recovered DEM of the 'unfilled' pond region. The offset of the linear fitting is very small which leads to an approximation of the pond volume as $\frac{1}{2}ph$ where p is the area of the pond and h is the maximum height.

Conclusion: DEMs made from NAC stereo-pairs at 2m/pixel were utilised to estimate melt pond volumes in the highland region. Slope maps were used to identify the pond extents and interactive image processing algo-

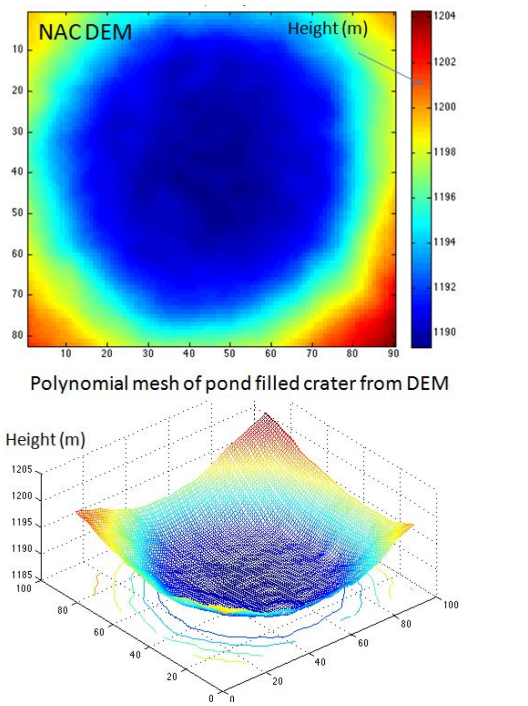

Figure 2: An example NAC DEM and its 3-dimensional polynomial mesh. The 'base' of the mesh is the top layer of the melt pond.

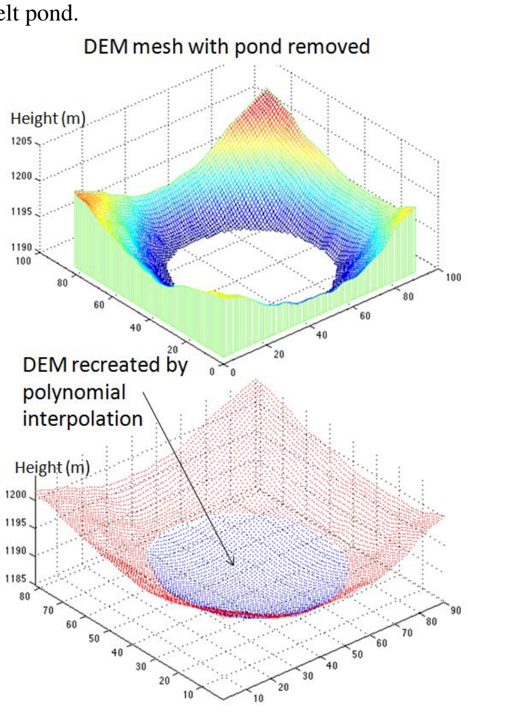

Figure 3: Stage 2 of the DEM data analysis and processing. The top image shows the true DEM mesh with the pond region cropped creating a 'hole' in the DEM. The bottom image shows the polynomial fit of the cropped region with the 'hole' interpolated by fit to surrounding crater slopes.

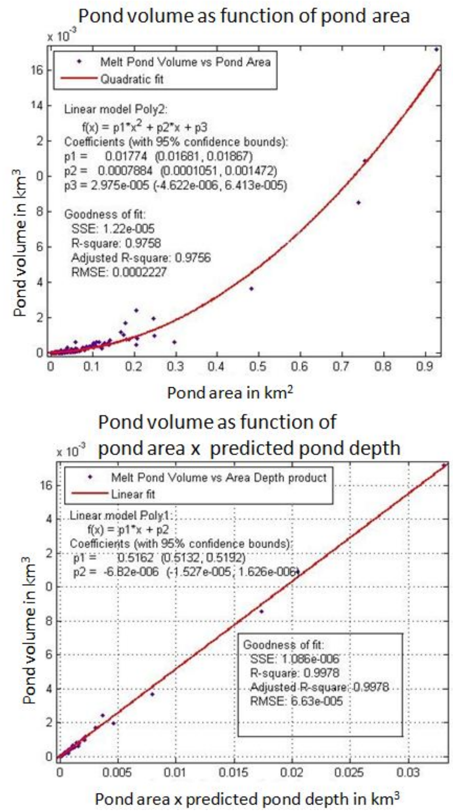

Figure 4: Pond melt volume as a function of pond area (top plot) and pond area and estimated depth product (bottom plot). Note the high concentration and more variation of points at lower pond volumes.

rithms were utilized to recover the DEMs without the filled pond and this was then employed to calculate the volume of the melt. It was found that the pond volumes could be expressed as a quadratic function of the pond area or as a linear function of the product of pond area and predicted pond depth to a high degree of accuracy. A comparison of different polynomial mesh interpolation methods which potentially could lead to improvements in pond volume computation would be pursued as future work.

References: [1] M. Robinson, et al. (2010) *Space science reviews* 150(1):81. [2] M. Robinson, et al. (2011) in *Lunar and Planetary Institute Science Conference Abstracts* vol. 42 2511. [3] R. Beyer, et al. (2010) in *Lunar and Planetary Institute Science Conference Abstracts* vol. 41 2678. [4] A. Cook, et al. (1996) *Planetary and space science* 44(10):1135.