

SYSTEMATIC ELEVATION BIAS IN LUNAR SOUTH POLE TOPOGRAPHY DERIVED FROM CLEMENTINE IMAGERY. M. R. Rosiek, R. Kirk, and E. Howington-Kraus United States Geological Survey, Astrogeology Team, Flagstaff AZ 86001, (e-mail: mrosiek@usgs.gov).

Introduction: During the Clementine Mission both oblique and vertical multispectral images were collected. The oblique and vertical images from a single spectral band collected during the same orbit form a stereo pair that can be used to derive the topography. These stereo pairs are being used to derive the topography of an area (90°S - 65°S latitude) surrounding the lunar South Pole. Work on the lunar North Pole topography will start after completion of the South Pole topography [1,2]. This report describes a systematic error in the elevation data and a proposed method to eliminate the systematic error.

Clementine Data: In 1994, the Clementine spacecraft acquired digital images of the Moon at visible and near infrared wavelengths [3]. Stereo pairs consisting of oblique and vertical images were obtained with the ultraviolet-visible (UVVIS) camera. The UVVIS camera image size was 384x288 pixels with five spectral bands and one broad band. The 750 nm band stereo pairs are the image source for this study. The ground sample distance (GSD) for oblique images ranges from 300 to 400 meters. The GSD for the vertical images, acquired at the end of an orbit, is slightly larger and ranges from 325 to 450 meters. Using the formula for stereo height accuracy [4] an estimate of height accuracy is 180 m. This formula is $IFOV_{max}/(K \cdot B/H)$ with $IFOV_{max}$ defined as Maximum Instantaneous Field of View, B/H is the base-to-height ratio, and K is an estimate of pixel measurement accuracy on the imagery.

The Clementine laser altimeter (LIDAR) data were used previously to produce a global topographic model of the Moon [5]. The model has a vertical accuracy of approximately 100 m and a spatial resolution of 2.5°. Altimetry data were collected between 79°S - 81°N [5].

A global image mosaic of the Moon was produced from the 750 nm Clementine data [6,7]. The mosaic includes high resolution, oblique and vertical images. Match points were picked to tie the imagery together, and the camera pointing angles were adjusted to align the imagery. This produced a seamless image mosaic with latitude and longitude information but no information on the elevation [6,7].

Analytical Aerotriangulation: The imagery and support information were downloaded to our digital photogrammetric workstation from the Integrated Software for Imagers and Spectrometers (ISIS) system. The support data included the camera location and pointing angles. Match points used to produce the image mosaic also were downloaded. The camera angles were adjusted to account for the elevation of the match points. This was accomplished with the Multi Sensor Triangulation (MST) software from LH Systems SOCET Set software package [8.] The revised camera angles allowed for the derivation of digital elevation models (DEMs) from the stereo pairs.

Initial estimates. The match point latitude and longitude from the global image mosaic are used for an initial estimate of the horizontal position. The elevations of the match points were estimated from the altimetry data. These match points were used as control points in the analytical triangulation.

Stereo Adjustment. In forming the Clementine Mosaic over 3,600 images and 29,000 match points were used in the southern polar region, an area defined as 64°S to 90°S. A subset of images (983 images) and the match points (973 control points) were selected for processing. The MST software was used to add match points with the criteria that each image should have 9 match points distributed throughout the image. This process added 1,226 tie points. Tie points have estimates for their ground location based on the estimated position and attitude of the camera.

For the adjustment procedure an iterative least squares solution is used; this allows the camera angles and match point ground locations to change during the adjustment. The final root mean square (RMS) error of the match points is 0.68 pixels. Generally, a value of below one pixel is acceptable.

Elevation extraction: The SOCET Set software provides an automated routine to extract elevation data. For every stereo model, a correlation point was determined every 1 km in ground distance.

Initial Results: Data were collected from 572 stereo models and the imagery was from 50 different orbits. Errors were summarized by number of points, RMS, standard deviation, bias, and percentage of points that were blunders (Table 1). For overlapping models within an orbit, the RMS and bias error are similar. For elevation errors in overlapping orbits, the bias error drops to 104 m.

Table 1 - Average of errors (Models: n=572, Orbits: n=50)

	Points	RMS	St. Dev.	Bias	% Blunders
Models	1801	836m	155m	812m	1.8%
Orbits	20073	314m	292m	104m	2.2%

We initially believed that the biases between stereo models were caused by tilts in the models, but, in general, triangulation errors do not result in DEMs that are tilted in the flight direction. While editing and merging the elevation data, we realized that the bias errors have an extremely systematic pattern: within pairs of overlapping models, within an orbit, the one closer to the pole is invariably higher. Furthermore, the magnitude of the bias is nearly identical in overlaps within different orbits but at the same latitude. The merged set of all DEMs therefore contains concentric "cliffs" corresponding to the latitudes where individual models join.

Discussion: We believe that the systematic elevation errors just described are a result of the relatively weak geometry of the image set, which limits the success of our

LUNAR TOPOGRAPHIC MAPS. M. R. Rosiek, R. Kirk, and A. Howington-Kraus

analytical triangulation. Successive stereo models within each orbit generally overlap as noted, but the region of overlap is extremely narrow, so that match points chosen in the overlap region are nearly collinear. When initial estimates for camera pointing come from the adjustment used to make the Clementine global mosaic, initial elevation values for the tie points tend to be lower near the pole than away from it (Figure 1). When initial pointing angles are taken from before the adjustment for the global mosaic, initial elevation values for the tie points that are higher near the pole (Figure 2). The least squares weighting scheme can be set to have the adjusted tie points elevation close to the altimetry data (Figure 3), yet the systematic bias is still in the data.

The systematic and significant biases between adjacent DEMs provide strong evidence of what the correct elevation relation between these models is, even if the triangulation process is inadequate to derive camera angles consistent with this result. We believe that adjustment of the overlapping DEMs to minimize the biases between them will yield a correct (as far as that is possible) DEM for the whole polar region. Furthermore, this calculation can be carried out in a way that is mathematically objective and that yields camera angles consistent with the DEM solution.

One can readily imagine a simple, ad hoc method of reducing offsets in the merged DEM: starting at some latitude in each orbit (e.g., 71°S, where confidence in both the altimetry data and the stereo geometry is high) and working inward and outward, add or subtract a constant elevation from the adjacent DEM to bring it into agreement with the starting model. Then adjust the elevation of the third model to bring it into agreement with the second, and so on. Because the latitudinal offsets are similar from one orbit to the next, adjusting each orbit independently in this way should yield reasonably good agreement between as well as within orbits. This is similar to the approach employed by Dr. Tony Cook [9]. Given the presence of other error sources in the DEMs, however, a better approach is to determine a vertical correction for every individual DEM in the polar region simultaneously, in such a way as to minimize the sum-squared offsets both within and between orbits. Software to perform this calculation is available in ISIS: the program EQUALIZER is designed to give a simultaneous least-squares estimate of the best brightness and contrast corrections to images in a mosaic, based on their relative

brightness and contrast where they overlap. Treating the DEM segments as images (so that “elevation” becomes “brightness”), this program performs the needed calculation. The result will be a mosaic of images with equalized brightness (i.e., a composite DEM with equalized elevations). To obtain camera angles consistent with this DEM solution, we plan to run a second analytic triangulation in which the elevations of control points are constrained to agree with the equalized DEM. Since the DEM itself has been made to agree with the elevation data where the two overlap, the result will be a set of camera angles that are both internally consistent and consistent with the altimetry. As a check on the validity of these camera angles, new stereo models derived by using them should be free of systematic elevation biases where they overlap. We plan to present the DEM that results from this procedure in our poster.

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