A REVISED PLANET-WIDE DIGITAL ELEVATION MODEL OF THE MOON. M. R. Rosiek[1], A. C. Cook[2], M. S. Robinson[3], T. R. Watters[4], B. A. Archinal[1], R. L. Kirk[1], and J. M. Barrett[1], [1]USGS Astrogeology Team, 2255 N Gemini Drive, Flagstaff, AZ 86001 (mrosiek@usgs.gov), [2]School of Computer Science and IT, University of Nottingham, Nottingham, NG8 1BB, United Kingdom (acc@cs.nott.ac.uk), [3]School of Earth and Space Exploration, Box 871404, Tempe, AZ 85287-1404, [4]Center for Earth and Planetary Studies, Smithsonian Institution, PO Box 37012, National Air and Space Museum, MRC 315, Washington, DC 20013-7012.

Introduction: We present work in progress on revising two lunar Digital Elevation Models (DEMs) that were generated from Clementine [1] ultraviolet-visible (UVVIS) camera along track stereo coverage [2]. A 69% complete, locally detailed "planet wide" [3] DEM (1 km/pixel) was generated at the Center for Earth and Planetary Studies, National Air and Space Museum, Washington D.C. in May 2000 and shall be referred to as NASM1KM. A nearly complete "global" [4] (5 km/pixel) DEM of the Moon was derived from this product in January 2002 and shall be referred to as NU5KM. It was found however that these products did not register spatially [5, 6] with the earlier USGS Clementine Basemap Mosaic (CBM) [7].

NASM1KM and NU5KM DEMs: The NASM1KM DEM was derived by automated stereo matching of ~700,000 Clementine UVVIS image (100-150 m/pixel) stereo pairs using a patch-based correlation stereo matcher [8]. A stereo correlation matcher patch radius of 7 pixels was used and the corresponding matched image coordinate pairs were passed through a stereo intersection camera model using JPL Clementine SPICE data and the NAIF toolkit [9] to produce height measurements. It was assumed that the specifications for spacecraft position and orientation [1, 10] were sufficiently accurate that derived spatial positions would be good to within 1 km on the surface; any residual spatial errors would manifest themselves in height offsets of the tiles rather than tilts. Fitting the small DEM tiles to absolute height LIDAR points helped compensate for low frequency height offsets between tiles. Where LIDAR data were not available tile offsets were adjusted, iteratively, or as a last resort data were fitted to a 0.25° per pixel smoothed LIDAR DEM [9]. The 1 km pixel size in the DEM was chosen to match the image resolution and correlation patch size. Although there was good overlapping coverage of the DEM poleward of +/-60˚ in latitude, at lower latitudes the coverage became "checkerboard-like" in appearance. The NU5KM DEM was generated using a larger 5x5 km DEM pixel size, hence many of the gaps were filled in, and the overall topographic noise was suppressed.

Why a Revision is Needed: Analysis of the NASM1KM DEM indicated some DEM tile offsets were larger than expected from nominal camera pointing errors. These were probably caused by spacecraft camera position and orientation error outliers and also by a small quantity of unfiltered unreliable LIDAR measurements. In addition, when the NASM1KM DEM was overlaid with the UVVIS CBM [7] a local spatial registration difference between the DEMs and the CBM of +/-1 to 15 km was found. A similar effect had been noticed previously when comparing a Clementine HiRes camera image mosaic [11] to the CBM. No absolute ground control points (i.e. laser retro reflector points on the near side) exist for the lunar far side, making global assessment of the accuracy of any lunar control network difficult. Bore sighted centers for Clementine UVVIS images derived from mission produced NAIF archived spacecraft position and orientation data were compared with image centers derived from the Clementine Lunar Control Network (CLCN) [12] photogrammetrically adjusted pointing (using an assumed fixed radius of 1737.4 km). Offsets are typically <1 km within the CLCN absolute control net region (enclosed within +/-40° E/W and N/S region on the near side), worsening up to approximately 10 km in the vicinity of the 90°W and 90°E longitude lines (albeit smaller near the poles), and then reducing to <1 km towards the center of the far side. The 750 nm CBM (upon which all other UVVIS and NIR mosaics are registered) shows several km-scale discrepancies in absolute spatial position with respect to the earlier Unified Lunar Control Net (ULCN) [13]. These errors seem to have arisen for several reasons, including that only a few (22) near side points were fixed to ULCN positions, plus the images were small and therefore not well-suited for global control (43,871 images were required to cover the entire Moon). In addition, the camera angle adjustments were unconstrained, and most importantly the tie points were all constrained to lie on a mass-centered sphere with a radius of 1736.7. These limitations resulted in a poorly constrained fit in regions where there was no absolute control (i.e. the whole far side and much of the near side outside of the absolute control area) and in regions of large elevation differences from the mean radius (i.e. south pole Aitken basin).

ULCN 2005: To correct this error a new lunar control network was developed. The Unified Lunar Control Network 2005 (ULCN 2005) [14] merged the ULCN and the CLCN and addressed the horizontal accuracy problems of the CLCN. The ULCN [13] was developed using images from the Apollo, Mariner 10, and Galileo missions, and Earth-based photographs. The importance of this network is that its accuracy is relatively well quantified and documented. The CLCN [12] includes measurements on 43,871 Clementine 750-nm images. The purpose of this network was to determine the geometry for the CBM [7].

The ULCN 2005 solution includes primarily 3 significant changes: 1) the camera angles were constrained to 1˚ of their a priori (NAIF) values, with angles changing by more than 0.6˚ left unconstrained, 2) the coordinates of identifiable ULCN points [13], with low errors, are constrained (0.18 – 5 km horizontally, 2-6 km vertically) in proportion to their reported accuracy, and 3) radii of all tie points are solved.

Analysis of the ULCN 2005 shows horizontal position changes from the CLCN on average of ~7 km with some changes of dozens of km. The ULCN 2005 solution is a true 3-D network, with recovered radii for all of the 272,931 control points in the network.

Update of Camera Angles to ULCN 2005: In order to revise the NASM1KM and NU5KM DEMs it was necessary to align the DEM tiles with the camera angles of images that were common between those used in the DEM construction and the 43,866 images used in the ULCN 2005. This correction enabled the topographic data to be recomputed based on the new camera angles and the previous line sample values for image matches. These topographic data were filtered: (1) to remove unrealistic topographic values (<-15 km or >15 km), (2) if the topographic value was not within 4 standard deviations of the height values in the stereomodel, (3) if the skew (separation distance at the point of intersection of two stereo projected rays) was greater than 2 km, and (4) if there were less than 100 points in the stereomodel.

After updating and filtering the topographic data there were 28,698 stereomodels left. These models were then adjusted to minimize the elevation differences between adjacent stereomodels and also the ULCN 2005 elevation values (see Table 1). Some stereomodels did not overlap with points in the ULCN 2005 network nor with a stereomodel that did overlap the ULCN 2005 network. This eliminated 140 stereomodels.

Mean offset	958 m
Mode	638 m
Standard Deviation	1212 m

94 % of the data is in the range -1500 to 2500 m

Table 1 *Offsets between ULCN 2005 and corresponding points in unfitted stereomodels used in NASM1KM.*

For 66% of the DEM tiles the elevation values have an expected vertical precision between 300 and 500 m, and another 30 % of the DEM tiles have an expected vertical precision between 500 and 1000 m.

Use of Data: Although the revised DEM generated from ULCN 2005 images has a 35% planet-wide coverage of the lunar surface, it is an improvement in spatial resolution over the smoothed laser altimeter DEM [9] where the mean spacing of LIDAR height measurements varied from ~20-100 km [15]. The revised DEM has potentially several uses: 1) for statistical studies on local surface roughness, 2) for determining regional limits for minimum altitudes for low orbiting spacecraft, 3) to assist in range binning for future LIDAR/RADAR experiments, 4) for crustal thickness measurements when used in conjunction with gravity data, 5) to identify previously unknown impact basins and to confirm/reject previously suspected impact basins, and 6) for use in determining limb slope and profiles for Earth-based occultation astronomers and for astronomers planning on using the limb to determine atmospheric point spread function for Earth-based diffraction limited imaging. The 1 km/pixel "planet-wide" DEMs can supply local topographic details and profiles to +/-100 m relative height accuracy within a stereomodel tile in areas of the Moon that existing LIDAR or shadow height measurements have been unable to measure. The revised data will be made available on an ftp site as a set of text values so analysts can process the data according to specific needs. The existing NASM1KM and NU5KM DEMs were used to identify 6 new basins [4], to confirm suspected basins, and to refine the knowledge of existing basins. However a lower resolution Galileo stereo image-derived DEM [15] has since cast doubt on the Sylvester-Nansen basin [16] at the north pole and this identification may have been an artifact of the mosaicking process. The revised DEMs, when completed, should clarify this discrepancy.

Future Work: There are another ~320,000 stereomodels that if funding were available could be aligned to the ULCN 2005 network. These stereomodels overlap existing updated stereomodels and so would bring surface coverage up to 69% at 1 km/pixel and nearly complete coverage at 5 km/pixel. They would also improve significantly the topographic signal to noise ratio and help to eliminate erroneous elevation values. Such a further improvement in the knowledge of lunar topography would be a valuable resource in the planning of the many upcoming lunar missions.

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