COMPLETION OF THE UNIFIED LUNAR CONTROL NETWORK 2005 AND TOPOGRAPHIC MODEL. B. A. Archinal, M. R. Rosiek, R. L. Kirk, and B. L. Redding. U. S. Geological Survey (2255 N. Gemini Drive, Flagstaff, AZ 86001, USA, barchinal@usgs.gov).

Introduction: We have completed a new general unified lunar control network and lunar topographic model based on Clementine images. This photogrammetric network solution is the largest planetary control network ever completed. It includes the determination of the 3-D positions of 272,931 points on the lunar surface and the correction of the camera angles for 43,866 Clementine images, using 546,126 tie point measurements. The solution RMS is 20µm (= 0.9 pixels) in the image plane, with the largest residual of 6.4 pixels. We are now documenting our solution [1] and plan to release the solution results soon [2].

Previous Networks: In recent years there have been two generally accepted lunar control networks. These are the Unified Lunar Control Network (ULCN) and the Clementine Lunar Control Network (CLCN), both derived by M. Davies and T. Colvin at RAND. The original ULCN was described in the last major publication about a lunar control network [3]. Images for this network are 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 published information on the network is available.

The CLCN was derived from Clementine images and measurements on Clementine 750-nm images. The purpose of this network was to determine the geometry for the Clementine Base Map [4]. The geometry of that mosaic was used to produce the Clementine UVVIS digital image model [5] and the Near-Infrared Global Multispectral Map of the Moon from Clementine [6]. Through the extensive use of these products, they and the underlying CLCN in effect define the generally accepted current coordinate system for reporting and describing the location of lunar features. The CLCN is described in print only briefly [7]. See [8] for ULCN and CLCN files.

Our efforts have merged these two networks into an improved ULCN.

ULCN 2005 Features: The primary difference between our new network and the previous ones is that we solve for the radii of the control points. This avoids distortion of horizontal positions (of about 7 km average, and up to 15 km or more [9-11]) present in the CLCN primarily due to its points being constrained to the surface of a sphere of radius 1736.7 km. This is possible since the overlapping Clementine images do provide stereo information. The expected precision of such information is on the order of several hundred m, but these data appear to be compatible with Clementine LIDAR ([12], previously the most accurate elevation data); the mean absolute difference between our values and the LIDAR values is ~700 m. This difference is larger than expected and under investigation, but it shows that radii are being recovered at that accuracy or better. Thus, a by-product of this network is a global lunar topographic model that is denser than that provided by LIDAR and of similar accuracy, and denser than any other lunar topography information except that provided in limited areas ([10, 13-25]). This radius information is also defined in a consistent, full, absolute, 3D system. This is the only lunar topographic model positioning where both heights and horizontal positions are estimated in a globally-consistent system. See Figure 1 for a representation of this topographic model.

A second significant feature of the ULCN 2005 is that we have constrained the camera angles to their values as measured during the mission, supposedly with an accuracy of 0.03º [16]. We have used a constraint of 1º, with angles that show changes of more than 0.6º allowed to change freely, on the assumption they are from angle measurement blunders (a few angles change by up to ~25º , probably due to unaccounted for spacecraft operations). We believe this provides significant improvement in the horizontal accuracy of the network (and therefore improves the vertical accuracy, which is coupled), because from an average altitude of 640 km, the implied horizontal position accuracy due to this 0.03º a priori information is 335 m. Since 99% of the angles change less than 0.45º, this and the 640 km altitude would also imply that even if the a priori angles were perfect, the greatest 3σ horizontal error in our solution is 5.1 km. This also assumes that the spacecraft positions – which we do not adjust – are perfectly accurate. Obviously this is not the case, but the cited errors [17] in the orbit positions (at least radially) are ~100 m, which when RSS added to the pointing errors, would still cause a maximum of a few hundred m additional errors. The change (and therefore improvement) in camera boresight positions between the CLCN and ULCN 2005 is represented in Fig. 2.

A third feature is that we identified a majority of the original ULCN points on Clementine images and included measurements of them in the new ULCN 2005. 1261 points are measured, with 754 of them having two or more measurements. This therefore allows for the direct incorporation of the ULCN into the new ULCN 2005. We have done so by weighting the ULCN points appropriately (0.18-5 km horizontally, 2-6 km vertically) for the accuracies as described in [1]. 124 ULCN points, which had particularly high residuals, were interpreted as misidentified points or points where the original ULCN was in error and weighted the same as non-ULCN points (2° and 10 km, effectively free).

This tie to the ULCN and the use of Clementine a priori spacecraft data in the mean Earth/polar axis system also places our solution in the same system (see [3]).

Future Work: In the upcoming months we plan to finish the analysis of our ULCN 2005 solution, publish a paper describing it, and release the solution data on the web ([8]). Although difficult, given the lack of any higher accuracy data, we will attempt to quantify the horizontal and vertical accuracy of this network. We will provide the topographic information in various formats, and also provide information for converting CLCN coordinates and CLCN registered images to the new system. The Lunar Orbiter digital mosaics now being generated [18] will also be registered to this system. Finally, we plan to continue to improve this network by the addition of the direct use of Mariner 10, Galileo, and Lunar Orbiter image measurements, and Clementine stereo [10]. We will also add ties to the current absolute LLR and ALSEP network [19].

It will also be necessary to further update and improve this network with data from future missions. This is necessary so that these new datasets can be compared to prior data, particularly the Lunar Orbiter and Clementine multispectral products.

Acknowledgements: We acknowledge the efforts of Tim Colvin and the late Merton Davies of RAND for their development of the ULCN and CLCN and for the algorithms and software used. This work is partially funded through the NASA Planetary Geology and Geophysics Program.

References: [1] Archinal, B. A., et al. (2006). In preparation. [2] Archinal, B. A, et al. (2006). USGS Open File Report. In preparation. [3] Davies, M. E. et al. (1994) *JGR*, 99, E11, 23,211-23,214. [4] USGS (1997) Clementine Basemap Mosaic, *USA_NASA_PDS_CL_30xx*, NASA PDS. [5] USGS (1999) Clementine UVVIS Mosaic, *USA_NASA_PDS_CL_40xx*, NASA PDS. Eliason, E. M. et al. (1999), *LPS XXX*, Abstract #1933. [6]

USGS, in publication. Eliason, E. (2003), *LPS XXXIV*, Abstract #2093. [7] Edwards, et al. (1996), LPS XXVII, 335-336. [8] http://astrogeology.usgs.gov/Projects/ControlNetworks/.
[9] Malin, M. and M. Ravine (1998) *Clementine High Resolution Camera Mosaicking Project*, TR, Malin Space Science Systems San Diego. [10] Cook, A. C. et al. (2000), *JGR*, 105, E5, 12,023-12,033. [11] Cook, A. C. et al. (2002), *AGU Fall Meeting*, Abstract #P22D-09. [12] Smith, D. E. et al. (1997) *JGR*, 102, E1, 1591–1611. [13] Rosiek, M. R. et al. (1998), *LPS XXX*, Abstract #1853. Rosiek, M. R., and Aeschliman, R. A. (2001) *LPS XXXII*, Abstract #1943. Rosiek, M. R. et al. (2001) Planetary Mapping 2001, ISPRS WG IV/9, http://astrogeology.usgs.gov/Projects/ISPRS/MEETINGS/. [14] Margo, J-L. C. (1999) PhD Thesis, Cornell University. [15] Wu, S. S. C. and Doyle, F. J. (1990) in *Planetary Mapping*, R. Greeley and R.M. Batson, eds., CUP, 169–207. [16] Nozette, S., et al. (1994) *Science*, 266, 1835-1839. [17] Zuber, M. T., et al. (1994) *Science*, 266, 1839-1843. [18] Weller, et al., this conf. Also http://astrogeology.usgs.gov/Projects/LunarOrbiterDigitization/. [19] Davies, M. E. and Colvin, T. R. (2000), *JGR*, 105, E8, 20,277-20,280.

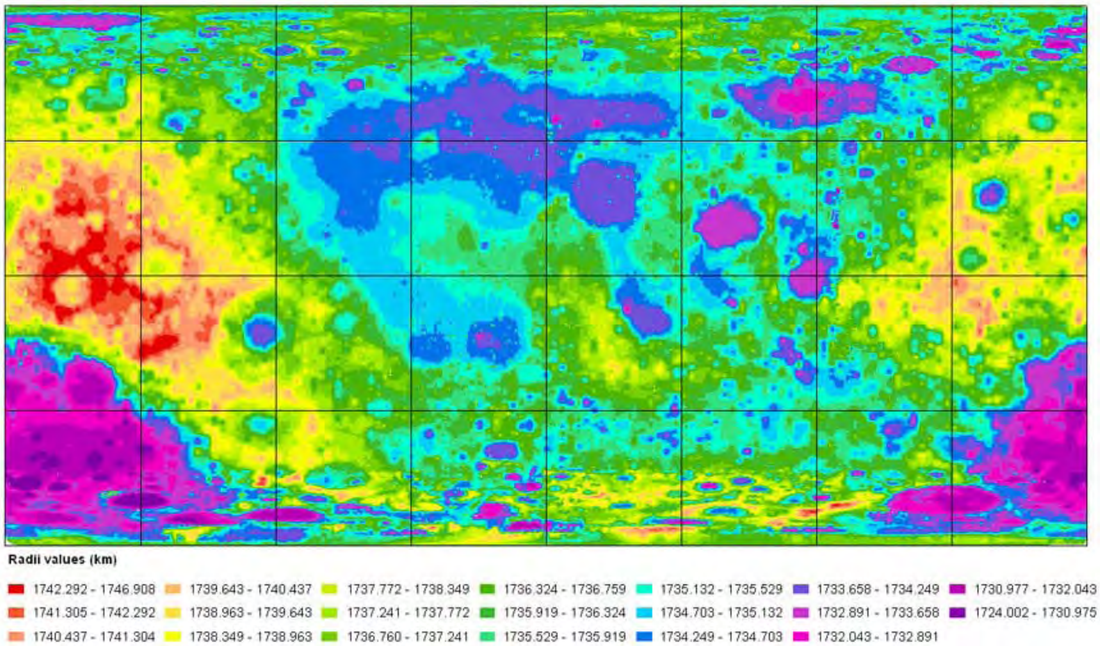

Figure 1: Topography (radii in km) derived from ULCN 2005 solution. Shown as a global rectangular projection with north up and east to the right, and 0° longitude at center, covering -85° to +85° latitude. This constitutes an improved lunar topographic model, the densest such global model existing, with radii uncertainties likely of several hundred m to 1 km or better.

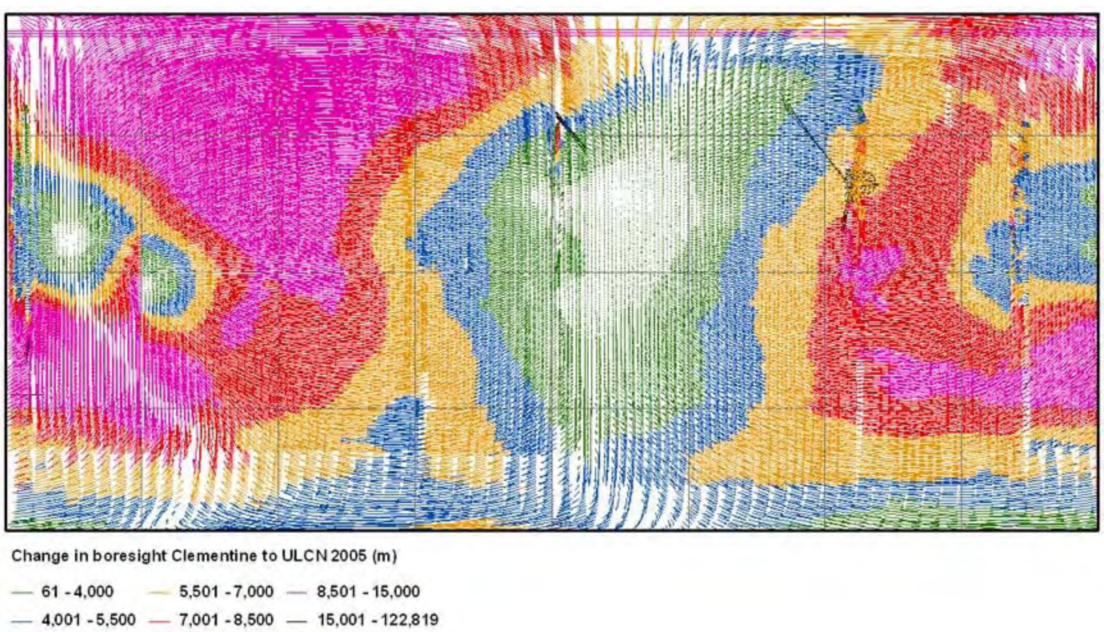

Figure 2: Horizontal change in image bore sight position of 43,866 images, in the sense of the ULCN 2005 solution minus the CLCN solution, demonstrating the horizontal position improvement of the ULCN 2005 over the CLCN. Shown as a global rectangular projection with north up and east to the right, and 0° longitude at center, covering -85° to +85° latitude.