A STEREOPHOTOCLINOMETRY MODEL OF A PHYSICAL WALL REPRESENTING ASTEROID BENNU K. L. Craft[1*], O. Barnouin[1], R. Gaskell[2], E. Palmer[2], J. Weirich[2], M. Perry[1], B. Bierhaus[3], R. Olds[3], M. Daly[4], D. Lorenz[5], and D. Lauretta[6], [1]Johns Hopkins University Applied Physics Laboratory (11100 Johns Hopkins Rd., Laurel, MD 20723), *Kate.Craft@jhuapl.edu, [2]Planetary Science Institute, Tucson, AZ, [3]Lockheed Martin, Littleton, CO. [4]York Univ. Ontario CA., [5]SGT/GSFC, Greenbelt MD. [6]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ.

Introduction: Launched on 8 September 2016, the Origins, Spectral Interpretation, Resource Identification, and Security–Regolith Explorer (OSIRIS-REx) began a two-year cruise to the asteroid (101955) Bennu to return the first pristine samples of carbonaceous material from the surface of a primitive asteroid. Bennu is one of the most exciting, accessible, volatile, and organic-rich remnants from the early solar system, as well as one of the most potentially hazardous asteroids known, due to potential impact with Earth. OSIRIS-REx will spend over a year characterizing the surface and orbital environment of Bennu. Twelve candidate sample sites will be characterized with OSIRIS-REx's instrument suite. The Altimetry Working Group (AltWG) is responsible for producing Digital Terrain Models (DTMs) using both imaging and laser altimetry data that are essential for understanding the candidate sites and assessing their viability and value for sampling. These DTMs will also be used by the OSIRIS-REx spacecraft to navigate autonomously using Natural Feature Tracking (NFT), developed by Lockheed Martin Space Systems [1, 2]. The AltWG uses stereophotoclinometry (SPC; [3]) to generate these DTMs from images collected by the OSIRIS-REx Camera Suite (OCAMS). Here, we present an evaluation of SPC using a physical wall constructed to simulate Bennu's surface.

Figure 1. The Lockheed Martin wall imaged for use by the SPC method to generate a digital terrain and albedo map of the surface for later use with NFT.

Methods: For the purpose of this test, Lockheed Martin (LM) built a physical representation of a 3 m x 3 m section of Bennu's surface. The wall characteristics were determined from assessments of the surface properties of Eros and Itokawa, and the surface was constructed with shotcrete embedded with rocks of specified sizes. Paint was used to make its absolute albedo similar to Bennu's at about 3%, with some local variation. Images were taken at a specific time of month when the sunlight illumination in Denver matched those projected to occur at Bennu during the OSIRIS-REx encounter and at several times of day (7:00am; 9:00am; 11:00am; 2:00pm; and 5:30pm), a range of azimuths (-60°, -45°, -30°, 0°, 30°, 45°, 60°) and elevations (-10°, 0°, 10°, 20°, 35°). These imaging conditions represent a best case scenario of what the conditions may be during the mission and provide best case results for what SPC might produce. Images of the LM wall were obtained with pixel sample resolutions of 0.5 to 3.0 cm per pixel (Figure 1).

Prior to their use in the SPC process, all the wall images had a flat field removed and the camera distortion field accounted for. In addition, the position and pointing of the camera for each image were assumed to be known perfectly relative to the LM wall, contrary to expected flight conditions for the actual mission, which will have orbit determination and pointing errors. SPC, therefore, was not used to refine the position and pointing of the camera. The delivered SPC-derived wall model had a ground sample distance (GSD) of 5 mm.

The SPC model was compared to a LM wall model obtained using a commercial laser altimeter. This first ground truth altimetry model sampled the wall at ~1.5 mm. However, artifacts were found within this model, including floating local surfaces that made initial comparison between this and the SPC wall model problematic. The artifacts were corrected and a clean, closed mesh ground-truth model was created, hereafter called the Corrected Lidar Model (CLM). The CLM was then sampled at 2.5 mm (rather than the original 1.5 mm) across a smaller 2.9 m area, in order to eliminate the raised edges of the wall that were a product of the wall construction and also caused comparison issues.

Before any comparisons were undertaken, any translational or rotational differences between the two surface models were minimized using an Iterative Closest Point (ICP) algorithm [e.g. 4, 5]. The iterative closest point used about half of the 1 x 10^6 grid points contained in the Gaskell SPC-model. Increasing the number of points from 0.3 x 10^6 to 0.5 x 10^6 for ICP showed little improvement suggesting that any differences in the surface models obtained between the SPC model and the CLM could not be attributed to any misalignments between the models.

Difference maps were then produced showing the magnitude of topography differences (Figure 2). Histograms of the difference distributions were generated and the RMS, skew and Kurtosis for these distributions were computed. Further, spectral correlations between the SPC-derived model and the CLM were calculated using a form of normalized correlation called admittance that highlights differences between the two models at different wavelengths (Figure 3). Spectral similarities between the models were obtained from coherency which measures the extent to which the CLM may be predicted from the SPC-derived model by an optimum linear least squares function.

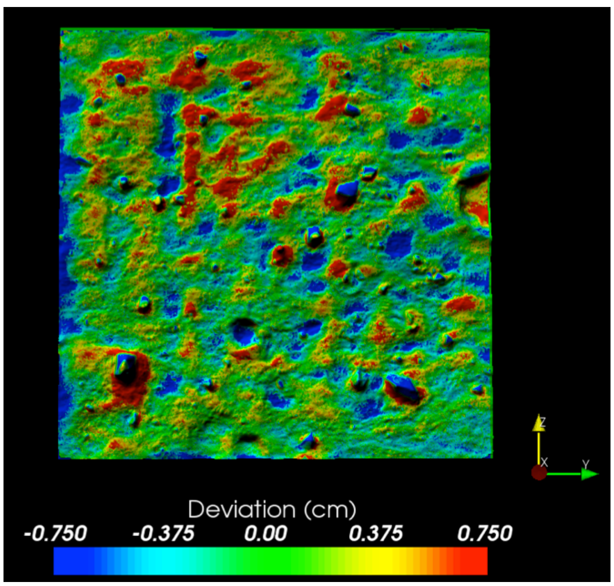

Figure 2. Shaded relief of the SPC model showing the deviations between the SPC model and the CLM. The maximum differences measure -2.6 cm and 3.4 cm. The RMS difference equals 0.42 cm.

Results: High-level findings reveal that in general the differences between the SPC-model and CLM are small, with an RMS difference of ~0.42 cm, where the vast majority of difference measure less than 0.5 cm. There are some maximum topographic differences up to 3.4 cm specifically around large surface rocks. This agreement is excellent given that images used to build the SPC-derived model had pixels scales ranging from 0.5 to 3 cm.

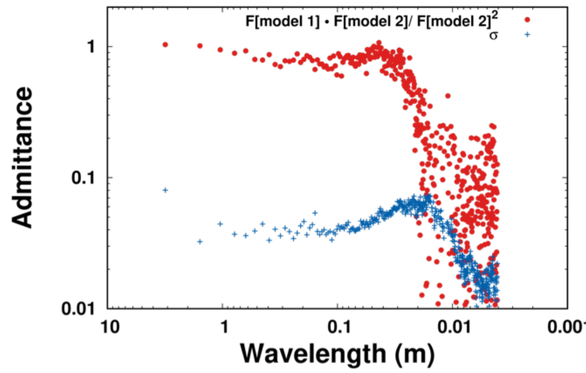

Figure 3. Spectral admittance (red) comparison of the digital terrain model derived from SPC with the CLM. Results indicate the correlation of the values in the SPC-derived model vs. the CLM as a function of the wavelength. Perfect correlation is indicated with an admittance = 1. The blue values give the admittance 1-sigma uncertainty at each wavelength.

Spectral correlation and coherency assessments show that the SPC model process generates a good product at long wavelengths (GSD) from 3 m down to about 0.05 m. The analysis reveals that the SPC model lacks significant high frequency signal below 0.03 m. There does appear to be a slight decrease in the correlation between the topography of the CLM and the SPC derived model for wavelengths between 0.5 m and 0.04 m, which seems to correlate with an ~0.4 m wave-like artifact present in the SPC model, that lies along the N-S axis. This artifact is known to occur when uniform maplet tiling is used in SPC when going across the wall from left to right. A more random generation of these tiles, and the use of a few large but low resolution maplets placed across the surface would mitigate this effect. The availability of limb data obtained during the mission is also expected to remove such wavy artifacts.

References: [1] Olds R. et al. 2015. AAS 15-124. [2] Mario and Debrunner, AAS 16-087. [3] Gaskell, R.W. et al., 2008. *Meteoritics and Planetary Science*, 43(6), pp.1049–1061. [4] Besl, P. J. and N. D. McKay (1992), In P. S. Schenker (Ed.), P*roc. SPIE, Vol. 1611*, pp. 586–606. [5] Chen, Y. and G. Medioni (1992), *Image and Vision Computing*, *10*(3), 145–155.

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