HOW WELL DO WE KNOW EUROPA'S TOPOGRAPHY? ASSESSING VARIABILITY IN DIGITAL TERRAIN MODELS.

M. T. Bland[1], D. Galuszka[1], D. P. Mayer[1], R. A. Beyer[2], R. L. Kirk[1], P. M. Schenk[3], R. L. Fergason[1]. [1]USGS Astrogeology Science Center, Flagstaff AZ (mbland@usgs.gov), [2]The SETI Institute, Mountain View CA. [4]Lunar and Planetary Institute, Houston TX.

Motivation and approach: Topographic information (from either stereogrammetry or photoclinometry) has been critical to evaluating the formation of Europa's surface features [e.g., 1, 2, 3], constraining the thickness of the elastic lithosphere [4], testing for true polar wander [5] and lateral variations in ice shell thickness [6], and determining the properties of the ice shell [7]. It will also be critical for landing future spacecraft on the surface. However, available topographic information must be used cautiously because digital terrain models (DTMs) produced for Europa have greater degrees of uncertainty in both absolute and relative height determination than those recently produced for the Moon, Mars, and Mercury. We lack altimeter data for Europa (thus an accepted "ground truth" dataset such as provided by Mars Orbiter Laser Altimeter data for Mars is absent), imaging data sets are limited (resulting in non-ideal stereo pairs), and image resolution is typically several orders of magnitude coarser than is used for landing site evaluation on Mars or the Moon.

To evaluate the true uncertainty in our knowledge of Europa's topography we are deriving DTMs from *Galileo* data using the stereogrammetric software SOCET SET® [8] and Ames Stereo Pipeline (ASP) [9, 10, 11]. We have also acquired DTMs from collaborator P. Schenk (processed in the Z3 stereogrammetric software (LPI)) [12]. These DTMs are assessed for quality, and then compared to each other to determine the degree of variability between DTMs produced from the same data, but from different techniques and users. Our goal is not to determine which DTMs are "correct" or "better." Rather we are assessing the degree of variability in DTMs produced from challenging data sets that cannot be tied to an independently derived reference "ground truth" dataset.

To date we have completed SOCET SET® DTMs for four regions (Pwyll crater, Cilix crater, Agenor Linea, and "the wedges") and ASP DTMs for two regions (Pwyll and Cilix). We have also constructed an extensive suite of ASP DTMs to understand how choices made during DTM creation affect their quality. Here we limit our discussion to the DTMs of Cilix crater, which provide a useful, illustrative example.

The Cilix stereo dataset: The *Galileo* spacecraft acquired two moderate resolution image sets of Cilix crater, a 15-km diameter crater in Europa's equatorial region. One is a single frame at 110 m/pixel, the other set is sequence of 16 frames covering the region at 63 m/pixel. The pair is suitable, although not ideal, for stereo processing. The base-height ratio is 1.2 (ideally <1), the resolution ratio is 1.75 (ideally <2.5), and the difference in illumination is near 0 (ideal). The expected vertical precision (EVP) is 15 m. Photogrammetric control of the two images is challenging, as the images are *a priori* mis-registered by 25 km. Figure 1 shows hillshades generated from the DTMs created by SOCET SET® and ASP.

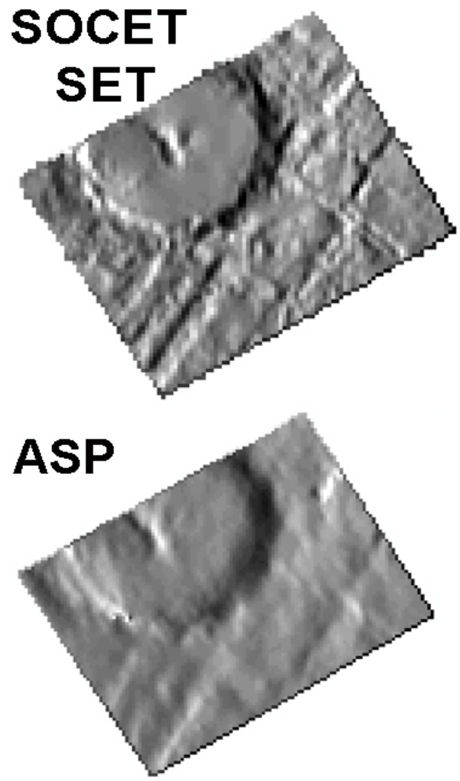

Figure 1: Hillshades from DTMs of Cilix crater generated using SOCET SET® (top) and ASP (bottom). Cilix is 15 km in diameter.

SOCET SET® and ASP comparison: The DTMs shown in Fig. 1 have obvious differences. The SOCET SET® DTM captures greater small-scale detail then the ASP DTM. We co-aligned the DTMs using ASPs pc_align function and subtracted them to identify regions of difference (Fig. 2). Maximum elevation differences are ±150 m (10x the EVP), and primarily due to small-scale features such as crater rims and double ridges. Individual topographic profiles suggest, however, that the measured depth of Cilix is similar in the two DTMs (Fig. 3). This suggests that, despite failing to resolve small features, the ASP DTM agrees with SOCET SET® at scales of 10s of kilometers.

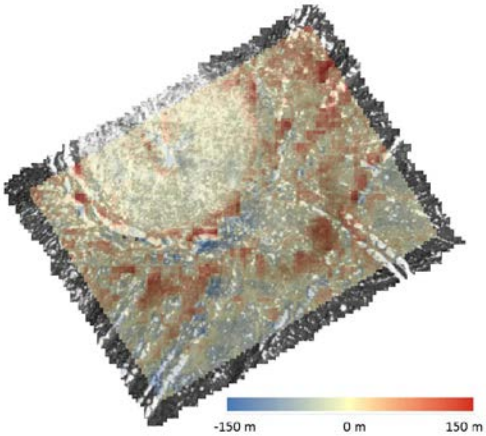

Figure 2: Difference map (colors) for ASP-SOCET (red=ASP is higher, blue=SOCET is higher) overlain on the SOCET-derived orthoimage.

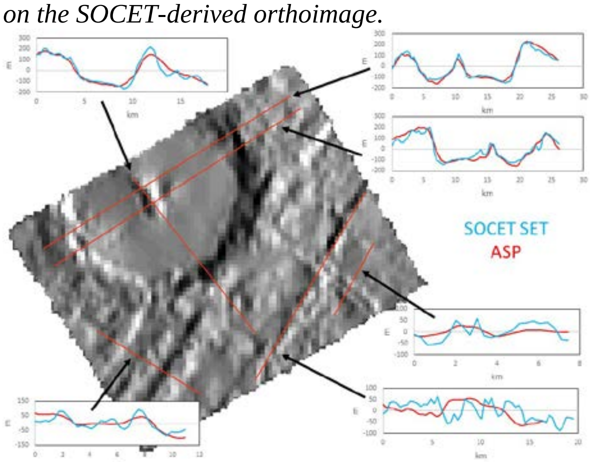

Figure 3: Paired profiles (red lines on hillshade) from SOCET (blue) and ASP (red) DTM. Although ridges aren't resolved (profiles bottom right), profiles of the crater itself are broadly in agreement (upper profiles).

We also examine the adirectional slopes derived from each DTM. The SOCET SET® DTM has higher maximum (23.4° vs. 23.1°) and mean (4.2° vs. 3.0°) slopes then the ASP DTM.

Effect of parameter choices: Because ASP DTMs can be generated quickly relative to SOCET SET®, it permits the user to evaluate how parameter choices affect DTM quality. To this end, we generated 48 ASP DTMs of Cilix (Fig. 4) that varied the size of the correlation kernel, subpixel refinement, and pre-filter kernel (three key parameters in ASP). We find that for this stereo pair, increasing the correlation kernel size and subpixel refinement degrades DTM quality (fewer features are resolved); although too small a correlation kernel excessively amplifies noise. A pre-filter kernel of 1.4-1.5 is ideal. We are currently evaluating whether the "ideal" values depend on the specific image pair.

Conclusions and future direction: Our analysis thus far indicates variability between DTMs of ~10x the formal EVP. Much of this results from the finer details resolvable with SOCET SET's manual editing capability; however, in some locations it remains unclear which DTM reproduces the "correct" relative elevation, indicating substantial uncertainty in Europa's actual topography. Utilizing ASP's new photoclinometry tools may better resolve smaller-scale features and bring the two DTMs into better agreement. We continue to generate and evaluate DTMs for Europa, with emphasis on statistical assessments of the topography, slope vs. baseline analysis, creation of multi-image stereo sets in ASP, comparisons with collaborator DTMs, and writing a "best practices" document.

Acknowledgements: This work is supported by NASA PDART #NNH16AC37I. References to commercial products are for identification purposes and do not imply an endorsement by the U.S. Government.

References: [1] Nimmo, F. et al. (2003a) *Icarus 166*, 21-23. [2] Schenk, P. and Pappalardo, R. (2004) *GRL 36*, L16202. [3] Schmidt, B. E. et al. (2011) *Nature 479*, 502-505. [4] Hurford, T. et al. (2005) *Icarus 177*, 280-296. [5] Schenk, P. et al. (2008) *Nature 453*, 368-371. [6] Nimmo, F. et al. (2007) *Icarus 191*, 183-192. [7] Nimmo, F. and Schenk, P. (2006) *J. Struct. Geo. 28*, 2194-2203. [8] Kirk, R. L. et al. (2009) *LPSC* 40 #1414. [9] Broxton, M, J. and Edwards, L. J. (2008) *LPSC* 39 #2410. [10] Moratto, Z. et al. (2010) *LPSC* 41 #2364. [11] Beyer R. A. et al. (2017) http://doi.org/10.5281/zenodo.581187. [12] Schenk, P. and Nimmo, F. (2018) in prep.

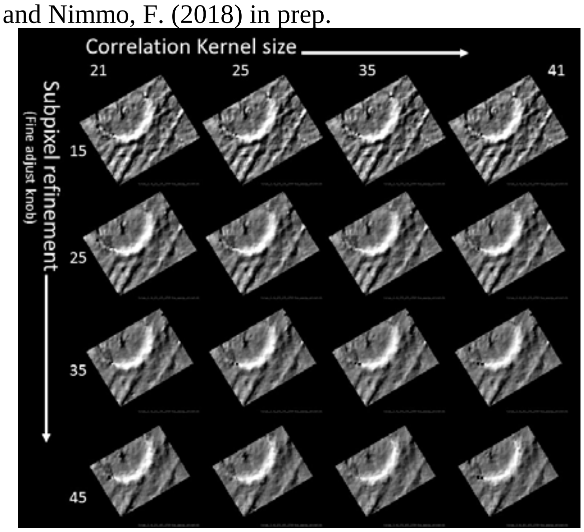

Figure 4: Subset of the 48 ASP DTMs generated to evaluate how a user's parameter choices affects the DTM produced.