ASSESSING THE VARIABILITY AND RELATIVE ACCURACY OF DIGITAL TERRAIN MODELS OF EUROPA.
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Motivation and Approach: Evaluating the three-dimensional characteristics of surfaces in the outer solar system has been vital to unravelling their geologic history. On Europa, topographic information (from either stereogrammetry or photoclinometry) has been critical to evaluating the formation of bands and ridges [1, 2, 3], chaos [4, 5], dark spots (maculae) [6], and pits and uplifts [7]. Additionally, it has been used to constrain the thickness of the elastic lithosphere [8, 9], test for true polar wander [10, 11] and lateral variations in ice shell thickness [12], and determine the properties of the ice shell [13]. However, such topographic information must be used cautiously. In the inner solar system, laser altimeter or radar data often provides robust surface heights, and permits digital terrain models (DTMs) generated from image data to be confidently tied to ground [e.g., 14]. In the outer solar system, however, altimeter data generally does not exist, imaging data sets are limited (resulting in non-ideal stereo pairs), and image resolution is typically several orders of magnitude coarser than image data from the Mars High Resolution Imaging Science Experiment (HiRISE) or Context Camera (CTX) images. DTMs produced for bodies in the outer solar system therefore have greater degrees of uncertainty both in absolute and relative height determination.

Here we describe an analysis of DTMs of Europa that will provide crucial insight into to the relative uncertainty (often much greater than the formal error) associated with such DTMs. To do so, we are deriving DTMs of Europa from Galileo data using the stereogrammetric software SOCET SET® [15] and Ames Stereo Pipeline (ASP) [16, 17]. 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. Additionally, our newly generated DTMs will be compared to existing DTMs provided by our collaborators. We emphasize that 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."

To date we have completed four DTMs for Europa using SOCET SET®: two for the crater Pwyll (Fig. 1), one for the crater Cilix, and one for Agenor Linea. A SOCET SET® DTM of Conamara Chaos, and ASP DTMs of each location are currently in progress.

A Preliminary Case Study: We began our investigation by qualitatively assessing the variability between two DTMs that were both created using SOCET SET®, but with different methodologies: one using a dependent relative solution, and the other using an independent relative solution. In the former, the nadir most image (based on reconstructed SPICE) is held fixed, whereas in the latter all images are adjusted independently. Both solutions are "relative" in that they are not tied to a reference ground.

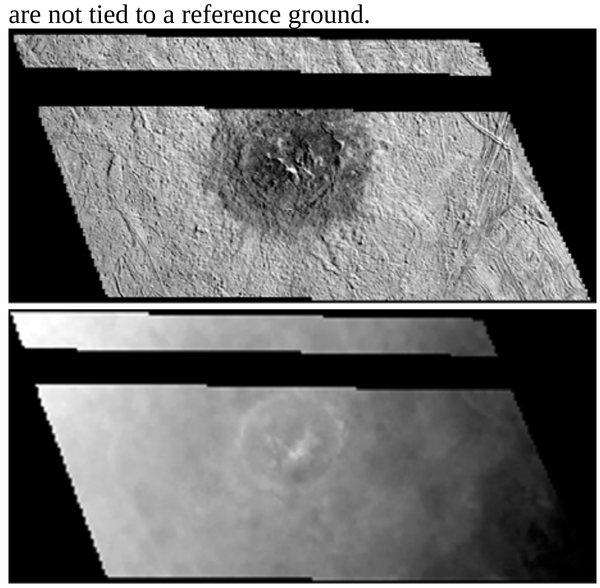

*Figure 1: **Top)** Orthoimage of Europa's Pwyll crater at 125 m/pixel. The black band across the image is due to data loss during transmission. **Bottom)** DTM of Pwyll produced from two images at 245 m/pixel and one at 125 m/pixel. The DTM has a resolution of 750 m/pixel. White regions are high, dark regions are low (total relief of 2.7 km). Shown is the independent relative solution (see text).*

The independent relative solution is shown in Fig 1 for Europa's Pwyll crater. Comparison of the DTM to the associated orthoimage suggests good agreement between the derived relative topography (at 750 m/pixel) and the image itself (at 125 m/pixel). Both the rim and central peak of the crater are clearly visible in the DTM, including the morphological complexity of the crater structures. Additionally, a prominent double ridge is visible in the topography (far right), as is a high-standing, tabular feature and associated north-south trending ridge at left. Interestingly, the DTM has a regional tilt (downward to the bottom right), which is seen in both the independent and dependent solutions. We have not yet determined if this slope is real – doing so may not be possible without ground information.

Detailed comparison of the two SOCET SET®-derived DTMs of Pwyll provides a starting point for assessing the variability inherent in DTMs of Europa. In a statistical sense, the two DTMs are very similar. The dependent and independent solutions have elevation means of -53 m and -53 m, medians of 16 m and 13 m, standard deviations of 578 m and 546 m, total relief of 2833 m and 2687 m, and skew of -0.36 and -0.36, respectively. However, the statistical similarity belies important differences between the two. Figure 2 shows a difference map (independent minus dependent) for the two DTMs. Substantial differences in rim and central peak height are clearly evident, as are more modest differences in the (possibly artificial) regional slope. The prominent double ridge also clearly stands out. Differences are generally less than ±150 m, although maximum differences are ± 300 m. This maximum difference is an order of magnitude more than the expected vertical precision (EP) based on the image resolution and stereo geometry (here ~23 m).

Figure 3 shows the how the variability in the DTMs affects a measurement of potential scientific interest: the central peak height. The two topographic profiles shown (one each from the independent and dependent DTM) were each extracted along the same transect. The profile from the independent DTM yields an average central peak height of 574 m, whereas the profile from the dependent DTM solution yields 487 m, a difference of 87 m. In this case the difference in central peak height is 4x greater than the formal EP. Rim heights are more similar, but even these vary by ~50 m. Such variability may result from differences in post locations (e.g., posts missed the highest point) or the refined image positions used in the independent solution.

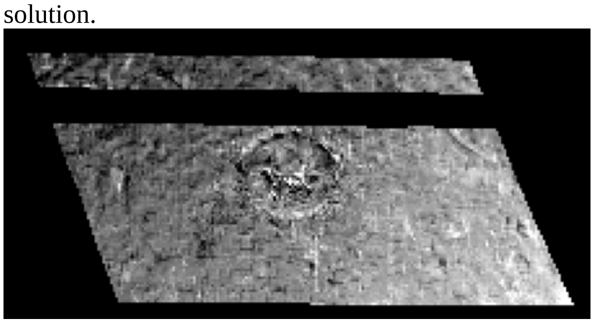

Figure 2: Difference map for the independent and dependent relative solutions (Independent-Dependent). Differences in the crater rim and central peak are typically ~150 m or less.

Preliminary Conclusion: Our preliminary investigation has shown that even two DTMs produced with the same imaging data and the same software show substantial variability in derived topography. In the case of Europa's Pwyll crater, relative topography cannot be known to better than ~100 m. Given that the imaging data used here is typical of Europa, care must be used when interpreting small-scale features on Europa.

Future Direction: We will soon expand our analysis to compare DTMs generated using SOCET SET® to those generated using ASP and a third hybrid stereo/photoclinometry method [4,5,6,7,10,11]. Additionally, we will compare DTMs produced by different analysts with different experience levels. This analysis will better characterize the uncertainties involved in utilizing DTMs produced from low-resolution data without a ground for science and mission planning. The work will result in a "best practices" for producing DTMs from such data.

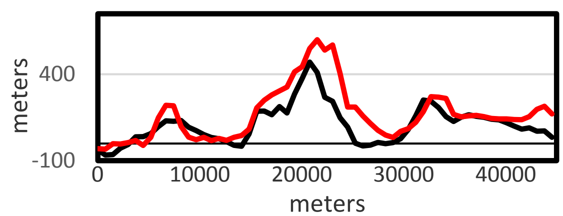

Figure 3: Comparison of the crater topography derived from each DTM. Red and black curves are the independent and dependent relative solution from SOCET SET®, respectively. The independent solution yields a central peak height ~100 m greater than the dependent solution: an uncertainty of ~20%.

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