IMAGE CROSS CORRELATION AS A MEASUREMENT OF SHAPE MODEL QUALITY. E. E. Palmer[1], J. R. Weirich[1], T. Campbell[2], O. S. Barnouin[3], M. G. Daly[4], and D. S. Lauretta[2], [1]Planetary Science Institute, Tucson, AZ (epalmer@psi.edu), [2]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ; [3]The Johns Hopkins University Applied Physics Laboratory, Laurel, MD; [4]The Centre for Research in Earth and Space Science, York University, Toronto, Ontario, Canada.

Introduction: Origins, Spectral Interpretation, Resource Identification, and Security-Regolith Explorer will use Stereophotoclinometry [1] (SPC) to generate the shape model of its target, Bennu. This shape model will be used to aid navigation and science processing [2].

The Altimetry Working Group has conducted numerous tests to evaluate the accuracy and performance of SPC in preparation for mission operations when OSIRIS-REx arrives at Bennu. The testing used several truth models that simulated both substantially rough and less rough shape objects with surface albedo, and also included navigational errors to identify SPC's robustness to meet the OSIRIS-REx accuracy requirements [3].

The main metric for the quality of a shape model is to subtract the generated model from the truth model (from which the simulated images were generated), and calculate the root mean squared differences of every vertex (RMS). Subtracting two models is the main tool that is typically used to evaluate two different shape models, such as what was done for Vesta [4]. For a global model, especially one built with direct measurement such as a laser altimeter, it provides a strong measurement of the model.

Limitations of RMS. During testing, we identified two limitations with the RMS technique for its use operationally.

Truth Model. Tests that are done on simulated objects with a truth model allow an extensive level of evaluation; however, this cannot be done during flight operations because there is no truth model available. Model accuracy can only be estimated using internal consistency checks.

To minimize these limitations, OSIRIS-REx will separately generate shape models using both a laser altimeter and SPC, so they can be compared [2]. While this improves our confidence in the shape model, as well as provides an indication of the uncertainty, it still does not fully establish if the model is correct.

High Resolution DTMs. During testing, we noted that adding additional images resulted in a better representation of the topography and albedo, but this was not always reflected in the RMS score.

We determined that this was because SPC generates an integrated solution where all topographic points and images influence on one another. As such, small errors in one region can generate a small slope variation that creates a regional offset, i.e. most of the object is closely aligned, but a whole region may be tens of centimeters higher than the truth model due to a slight error in the slope for the topography surrounding that region. This type of error can exist for stereophotogrammetry and laser altimetry, depending on how the navigation error is removed.

For the most part, these regional mismatches with the truth model are a reflection of navigation and camera errors that are not removed. The errors drive mismatches captured by RMS measures of accuracy, which becomes the limit to the quality of the shape model.

However, SPC is able to generate topography with a ground sample distance that matches the image pixel size itself. This high resolution topography typically has a higher fidelity than the RMS score indicates. This is because the topography in a mismatched region contains details of the topography that better represent the surface than indicated by the RMS error, i.e., the local topography can be excellent even though that entire region is offset from the truth by tens of centimeters.

Normalized Cross Correlation. For navigation purposes, the important metric of DEM quality is the ability to predict spacecraft imagery to compare with observation. Thus, rather than use numerical measures of the shape accuracy (such as RMS height difference described earlier), we began using a normalized cross correlation of spacecraft images compared to synthetic images rendered from the generated shape model [6]. Cross correlation is the key component of the SPC's automated alignment process [1], and is also being used separately by the Lockheed's Natural Feature Tracking [6] to provide backup navigation to the Touch-and-Go maneuver for OSIRIS-REx [7]. The use of cross-correlation in SPC supplements other internal SPC metrics, and greatly improve our ability to assess the performance of a shape model in flight. In flight, we will cross-correlate spacecraft imagery with simulated imagery generated from the derived shape model. In testing, the "spacecraft imagery" is simulated from the truth model. We specifically use a different set of simulated truth images than were used to generate the model for the comparison. This approach to testing provided the most realistic assessment, and was found to generate reliable, consistent and useable results.

The normalized cross correlation technique calculates the correlation score between two images, that is to say, the pixel-to-pixel relative brightness agreement. It also can be used to determine the best fit location between the two images. This can be used to solve for a more accurate spacecraft position and pointing than that determined using traditional navigation techniques.

In the SPC processing, we have begun to use the cross correlation score as an indicator of how well the model is performing. The cross correlation score runs between 0 and 1, with 1 being a perfect match of the images. We have seen that resampling the same data can reduce the correlation score from 1.00 to around 0.85 to 0.90, depending how extensive the resampling is. A good model produced afterward, should at least have a score of 0.7, with 0.8 or above to be the goal for SPC.

We present an example how cross correlation works in Figure 1 and 2. In figure 1, we show an image derived from our test 'truth' model. It represents the type of image we anticipate obtaining at Bennu. Figure 2 shows the simulated image derived, using a suite of other simulated spacecraft imagery collected during proximity operations at Bennu. The cross-correlation score is excellent at 0.79. The accuracy measurements are also excellent at 7.2cm RMS. This result shows how effective the cross-correlation is in ensuring the in-flight quality of the model.

Conclusion: Cross correlation as implemented by the SPC team of the AltWG provides is an excellent technique to ensure the quality of the shape model. It will be one of the main approaches used to ensure that the models derived for navigation and science at Bennu will achieve all mission requirements, and ensure safe sampling of the asteroid.

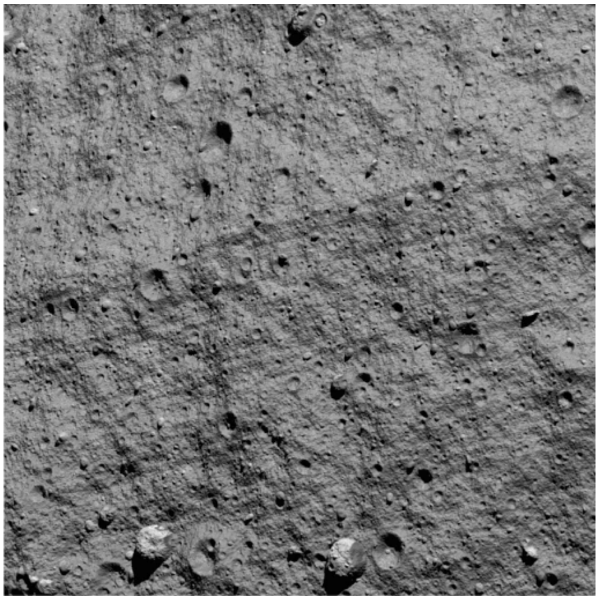

Figure 1 - Spacecraft image. This image is considered "truth".

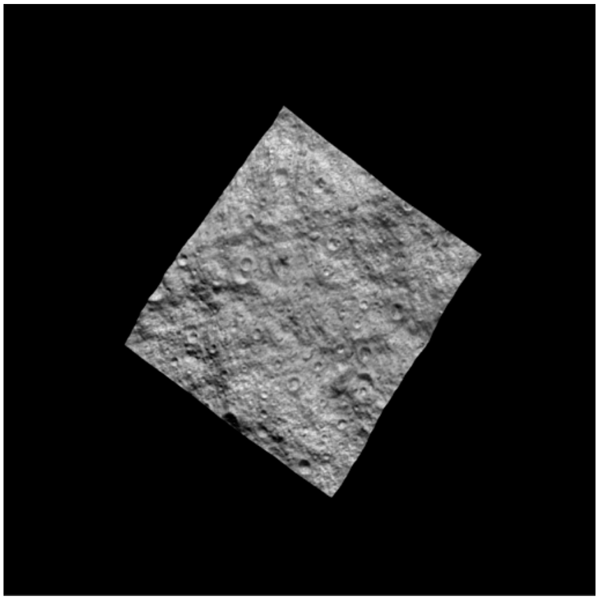

Figure 2 - Simulated image from the generated shape model. The normalized cross correlation routine determines both the best match for this image within the image in Figure 1, as well as the location of this best match.

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Acknowledgments: This work was supported by NASA contract NNM10AA11C.