STEREOPHOTOCLINOMETRY MODELS IN SUPPORT OF THE OSIRIS-REX MISSION. E.E. Palmer[1], J.R. Weirich[1], O.S. Barnouin[2], R.W. Gaskell[1], P. Antreasian[3], C. Adam[3], J. Leonard[3], M.M. Al Asad[4], M.G. Daly[5], M.E. Perry[2], M.C. Nolan[6], D.S. Lauretta[6], and the OSIRIS-REx Team. [1]Planetary Science Institute, Tucson, AZ, USA (epalmer@psi.edu); [2]The Johns Hopkins University Applied Physics Laboratory, Laurel, MD, USA; [3]KinetX Inc., Simi Valley, CA, USA; [4]Department of Earth, Ocean and Atmospheric Sciences, University of British Columbia, Vancouver, BC, Canada; [5]The Centre for Research in Earth and Space Science, York University, Toronto, ON, Canada; [4]Lunar Planetary Laboratory, University of Arizona, Tucson, AZ, USA.

Introduction: The shape model of asteroid (101955) Bennu is an essential deliverable for the science and operations of the OSIRIS-REx mission. Many key science products use the shape model to compute local topography, adjust for geometric factors (incidence and emission angles), and provide global context. Due to the low gravity of Bennu, traditional navigation techniques using only Radiometric data cannot provide the navigation accuracies required by the OSIRIS-REx mission design. Optical images correlated with a shape model provide a body-fixed navigation solution with the accuracies required for small body exploration.

The shape model is a critical component of this effort because it is the "roadmap" from which navigation is conducted.

For the OSIRIS-REx mission, we use stereophotoclinometry (SPC) software created by Gaskell [1] to generate the shape model that is used for both science and navigation. This technique has been used to support science on several objects: Phoebes, Tethys, Eros, Itokowa, Vesta, Ceres, and most recently Ryugu with the Hayabusa2 mission.

Operational Use of Shape Models: As the spacecraft imagery improved during Approach, we generated improved SPC-derived shape models as needed by operational requirements. Evaluation of the model's accuracy is an important part of this effort and is discussed in [2]. There several stages of the mission operations that require a shape model, and the fidelity of the model evolved throughout these stages (Table 1).

Distant Approach. The navigation team began operations using the ground-based radar shape model [3]. When Bennu became a disk-resolved object, the navigation team used the radar shape model to conduct centroiding for position determination.

Approach: 8 to 23 November 2018. Once the OSIRIS-REx spacecraft was within 200 km of Bennu, the image pixel size became large enough to make accurate shape models that improved upon the radar shape model. We used rotation "movies" with images every 10° using a limb-based model generation tool called LIMBER. This tool detected limbs within images and generated a point cloud of Cartesian points that were turned into a shape model by generating a spherical harmonic solution that minimized the residuals, or by connecting the limb points with spline smoothing. The estimated vertical accuracy of the first model was 3-4 m with a pixel size between 2.5 m and 1.6 m.

At this point, we used traditional SPC techniques [1, 4] of solving for the topography of a small surface patch (maplet) using photoclinometry and its position in 3D space using stereogrammetry. In these early models, the topographic accuracy of the limb-based models was better than the corresponding SPC models, but the SPC shape model included albedo (surface brightness). The albedo is very important for landmark-based navigation because it greatly improved the identification of the control points (landmarks).

Close Approach: 25 November to 2 December 2018. Once the pixel scale of the images was better than 2 m/pixel, we generated the shape model using the full SPC technique [1]. These images had sufficient resolutions for shape modeling but the entire Approach phase of the mission occurred with the spacecraft near the equator and therefore has incomplete viewing geometries. Thus, the quality of the model was limited to about 2 m with limited fidelity in the polar regions.

Preliminary Survey. The next improvement of the shape model occurred during Preliminary Survey. This mission phase consisted of three passes over the north pole, with the first and third pass collecting 75-cm/pixel images. Following the north pole passes, OSIRIS-REx flew over the equator to get higher-phase-angle images (both morning and afternoon) and then completed a pass over the south pole, collecting data both before and after closest approach. This model had a 75-cm ground sample distance (GSD) and was provided to facilitate the transition to landmark navigation during Orbital A. The uncertainty of the model was estimated at 1.5 m.

Orbital A. During Orbital A, the navigation team focused on the operational evaluation of the SPC model. This analysis used NavCam images, Doppler, landmark-based navigation solutions, and gravity data to identify the quality of the shape model in regards to the following:

1. Center of mass and center of figure offset: The SPC shape model is centered at the center of mass

of Bennu. The navigation team estimated an offset of 1 to 2 m between the center of figure and center of mass. This offset was incorporated into the shape model because even a small offset results in larger residuals in the navigation solution.

2. Size bias: Because SPC updates both the position of the landmarks and the spacecraft position, the overall model size is affected by the uncertainty in the spacecraft position. Orbiting Bennu will allow the navigation team to identify remaining size bias.

3. Final pole determination: With the high resolution data from Orbital A OpNav images, the right ascension, declination, and rotational period will be calculated and published in an updated SPICE kernel and fed back into the shape modeling process. Currently a pole correction of less than 1/2° in RA and Dec is expected.

4. Quality of landmarks. During Orbital A, the NavCam will be used to provide the imagery with a field of view that completely covers Bennu. The SPC model has several hundred landmarks that the navigation team identifies in each NavCam image. When these landmarks are identified on the shape model, it provides an estimate for the spacecraft position. A correct shape model and landmark detection results in a consistent orbit that reflects gravity variations and small-forces, such as the solar wind. Errors in the model result in a poor fit to the data or a non-continuous flight path. These results are used to correct the shape model.

Conclusion: After using the images from Approach, Preliminary Survey, and preliminary navigational analysis during Orbit A, the Altimetry Working Group produced a 75cm GSD shape model for use during operations and science use. This model has an uncertainty of approximately 1 m.

References: [1] Barnouin O. S. et al. (2018) *AGU Fall Meeting, P33C-3835*. [2] Al Asad M. et al. (2019) *LPSC 50.* [3] Nolan M.C. et al. (2013) *Icarus, 226,* 629–640. [4] Palmer, E. (2016) *Earth & Space Sci*, 3, 488-506.

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Table 1. Data used and performance of SPC shape model

Shape Model	Dates	Distance [km]	Pixel Size [m]	Uncertainty [m]
Approach	8-22 Nov	162-100	2.2-1.4	4
Close Approach	25 Nov - 7 Dec	82-23	1.1-.3	2
Preliminary Survey-draft	4-16 Dec	11-7	.8-.5	1.5
75 cm	all	all	all	1.0