Introduction: The Origins, Spectral Interpretation, Resource Identification, and Security–Regolith Explorer (OSIRIS-REx) mission will return the first pristine samples of carbonaceous material from the surface of a primitive asteroid, (101955) Bennu[1]. Launched on 8 September 2016, OSIRIS-REx will arrive at Bennu in August 2018, acquire a sample in July 2020, and return the sample to Earth in September 2023.

The Altimetry Working Group (AltWG) produces local and global topographic maps (digital terrain maps or DTMs) both for science objectives [2] and for incorporating into the Natural Feature Tracking (NFT) [3, 4] used to autonomously guide OSIRIS-REx to the sample location on Bennu’s surface. The AltWG generates the DTMs using two independent processes and datasets: stereo-photoclinometry (SPC) processing [5, 6] of image data from OCAMS and processing of range data obtained by the OSIRIS-REx Laser Altimeter (OLA). Here, we describe the process developed to determine Bennu’s topography from a set of OLA point clouds that are range measurements containing uncertainties in both amplitude and surface location. The SPC process is described in a complementary abstract [6].

OLA processing: Altimetry data processing contains several steps, including an iterative loop that repeats the same processing steps several times to sequentially generate products of increasing fidelity. The input data are the level-2 (L2) OLA measurements, which are body-fixed, 3-D point clouds. Simulated data are derived for a true mission scenario, based on a manufactured ‘truth shape’ and include realistic spacecraft position and pointing uncertainties. After faulty range errors are purged from the data, the remaining L2 data are ported from binary tables to an SQLite database that facilitates searches during subsequent processing steps.

Figure 1. A shaded relief map from simulated OLA data obtained after adjustment to minimize the effects of spacecraft position and pointing errors. The colors show the residual topographical error or mean difference between overlapping OLA tracks, a measurement that would be available in flight. The magnitudes of these errors are similar to those obtained by comparing the initial OLA shape model to the truth shape. The scale is in kilometers; all of the dark blue points have errors less than 10 cm. The X marks the low-error area chosen as the reference to begin a second set of local strip adjustments.
We create an initial, low-resolution global DTM from the OLA data. The process uses the Generic Mapping Tool (GMT [7]) and several other AltWG processing software programs. Unadjusted OLA measurements are collected in a global grid generated over the surface. GMT blockmedian and the GMT surface algorithms compute median heights over a grid in ~10m bins and perform a spline fit to these, producing an initial global terrain model.

The next step is to adjust each OLA scan so that the difference between the first estimated global model and each OLA scan is minimized. We use an Iterative Closest Point (ICP) algorithm for this purpose. After this first adjustment, the adjusted OLA scans are used to build a new global shape model, and the errors between individual scans are assessed in bins of 1 m (Figure 1). This first iteration reduces errors by a factor of three.

The next step adjusts individual OLA scans to remove additional errors and to increase the spatial resolution. This requires selecting several anchor points (such as the X in Fig. 1) that have good agreement between the overlapping scans and therefore represent regions that have minimal errors. Each of the overlapping OLA scans or “strips” at an anchor point are adjusted as a unit, using a different variant of ICP, translating and rotating the entire point cloud together. These entire-cloud adjustments are enabled by the small errors (20µrad) in the relative knowledge of the OLA mirror position [8]. The new, adjusted locations and orientations of the strips are then used as new anchors, continuing until all of the strips have been adjusted, and a new global DTM is produced. Figure 2 shows the result of one iteration. We repeat this process, reducing errors and improving resolution with each iteration until achieving the desired accuracy.

Once complete, the AltWG team then produces a global shape model and a suite of local surfaces and tilt maps. Combining OLA data with the SPC products generates the final, highest-fidelity version of these products [9].

Quality assessment: Particularly during the iterative portion of the process, we require one or more methods to assess the quality or accuracy of the strip adjustments and the DTM products. This output is also a formal requirement: the DTM accuracy must be 14 cm or less to meet the needs of NFT.

During software development, we compare the DTMs to the truth shape that was used to build the simulated data. A simple technique such as calculating the RMS for each facet provides a preliminary assessment but is insensitive to some errors. A more-complex assessment such as cross correlation provides a better measure of accuracy [3, 6, 10].

In flight, without the availability of a truth shape, the quality can only be evaluated using the data themselves. The standard deviation between adjusted OLA scans and the RMS between each scan and the final global model both provide useful metrics. Since the final adjustments in the OLA scans represent the errors in spacecraft position and attitude, they can also be assessed by the navigation team for their feasibility. We evaluate these techniques and report on their robustness for use in flight.


Figure 2. Portions of the locations of the point clouds of two overlapping OLA scans of Bennu, one point cloud in red and one in green. a) After constructing the initial global model. The green points are the anchor scan and the red are to be adjusted. b) After the first strip adjustment (adjusted points in white).