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Introduction: The Altimetry Working Group (AltWG) of the Origins, Spectral Interpretation, Resource Identification, and Security-Regolith Explorer (OSIRIS-REx, [1]) mission is responsible for generating all of the mission’s global and local digital terrain models (DTMs). The AltWG also produces a suite of surface tilt maps and geodetic products (e.g. slope, gravity; see Figure 1) that use the mass of the asteroid determined via radio science (2-way tracking) to estimate a gravitational potential field or geoid. The geoid allows computing digital geopotential elevation maps that provide a measure of topography on other planetary bodies. The AltWG will also generate 1064-nm reflectance and relative albedo maps.

The AltWG products are critical for the science activities and sampling efforts of the OSIRIS-REx mission. Global products address the geological origin and evolution of the asteroid. For example, constraining its bulk density through a combination of precise volume measurements and the mass determination gives insight into the internal state of Bennu – whether or not it is a rubble pile – which relates to its collisional and tidal evolution. At local scales, the AltWG products provide context for understanding the surface processes that influence regolith development and evolution. High resolution (cm-scale) spatial measurements of surface topographic slopes, elevation, and vertical roughness within the sample ellipse (~25-m radius) are of sufficient resolution that we can measure the effects of granular surface flows. Driven by YORP spin-up or seismic shaking from impacts or tides, such flows could have influenced the regolith distribution on the asteroid [e.g., 2] and are key to interpret the samples returned to Earth accurately. The local AltWG maps of tilt, as well as the heights of any hazards, are necessary for finding the safest sampling site.

Here, we summarize how the AltWG produces both image- and altimeter-derived global and local DTMs. We review the observations collected by the OSIRIS-REx mission in support of the AltWG product development efforts. We provide a review of the expected quality of the DTMs as determined through testing.

DTM production: The AltWG uses two methods to construct the shape of Bennu. The first method uses images of Bennu with stereophotoclinometry (SPC; [3]). The second method uses data collected by OLA, a dual-transmitter, high-rate (10 kHz) scanning laser altimeter contributed to the mission by the Canadian Space Agency [4]. This instrument provides dense local 3-D point clouds that are tiled together to produce surface DTMs.

Stereophotoclinometry: SPC uses geometric stereo from imaging data to define the location in 3D space of the center pixel of many small DTMs or maplets spread across a target body. Observed brightness variations seen in these same images provide estimates of surface tilts and relative albedo across a maplet. These estimates make use of an appropriate photometric model—typically a modified Lommel-Seeliger function developed for the Moon [5]. SPC computes the surface tilt for each pixel in a maplet via a linear estimation solution that minimizes the residual of the summed square brightness at that pixel from at least five to a few hundred images. We obtain a global model by joining together the individual maplets. The resulting complete asteroid model is controlled by overlapping maplets, along with limb observations and the global stereo parallax of the center location of each maplet. These data constrain the tilt-to-height integrations that provide estimates of the global surface and spacecraft state. As a by-product of the SPC estimation process, we obtain solutions for the asteroid’s relative albedo, center of figure, pole location, wobble, and rotation state.

OLA processing: The AltWG has two approaches for tiling OLA scan data together: one uses a scale-invariant feature transform (SIFT; [6]) for generating matching features between OLA scans; the other makes use of the well-known Iterative Closest Point (ICP; [7]) algorithm. Both techniques minimize the differences between overlapping OLA scans to build up global and local DTMs.

This first approach is the baseline AltWG method for working with OLA data. In brief, we transform individual OLA scans into 2D images by generating a DTM and taking its Laplacian. The SIFT algorithm is then used to identify matching features. The matches are used to compute 3D rigid rotations and translations to match the overlapping OLA scans together. The adjustments are made iteratively across the asteroid until all the differences between OLA scans are minimized.
ICP is the backup approach employed by AltWG to develop OLA derived shape models. The ICP algorithm iteratively revises the transformation needed to minimize differences between two points clouds, using many if not all of the points. AltWG uses the root mean square difference between the points in the two clouds as its convergence criteria.

**Observations:** SPC products will be generated using the OCAMS narrow- (Polycam) and wide- (Mapcam) angle imagers. The data from initial phases of proximity operations (Approach and Preliminary Survey phases) provide the 75-cm ground sample distance (GSD) shape model. Images from the later (Detailed Survey) phase leads to a 32-cm GSD shape model and local 8-cm GSD DTMs. OLA data will be first collected in the Preliminary Survey phase to help validate the SPC 75-cm GSD shape model; later the Detailed Survey phase provides an OLA 75-cm GSD shape model. OLA data collected in the Orbital B phase yields an 8-cm GSD global model, while OLA Reconnaissance Phase ranging enables DTMs of the sample sites with <5 cm GSDs.

**Performance:** Tests using simulated OCAMs images with unknown pointing and position errors generated from a simulated high-resolution Bennu truth model indicate that SPC products are outstanding. Results show that we will generate a shape model with an RMS accuracy around 37 cm by the end of the Preliminary Survey phase. By the end of the Detailed Survey phase, we expect the 35-cm GSD shape models to differ on average from the truth by about 1.6 cm, with an RMS of 5 cm.

The OLA products using simulated OLA data with unknown pointing and spacecraft trajectory errors are equally good. The 75-cm GSD shape model produced at the end of the Detailed Survey phase differs on average from the truth model by 2 cm, with an RMS accuracy of 20 cm and a precision of 5 cm. The 8-cm GSD shape model generated at the end of the Orbital B phase differs on average from the truth by 0.7 cm, with an RMS accuracy of 8 cm and a precision of 1.2 cm. The reconnaissance sites <5-cm GSD DTMs are also accurate to 8 cm but have a precision of <1 cm.

**References:**


**Figure 1.** Examples of global products produced by the AltWG from stereophotoinmetry or OLA data. The shape model (a) comes with information on surface tilts (b through d) necessary for safe sampling and assessing surface sampleability, while geodetic products such as geopotential elevation (e) and gravitational acceleration (f) allow evaluation of the surface processes that are modifying Bennu.