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Surface Temperatures of (101955) Bennu Observed by OSIRIS-REx

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1. Introduction

NASA's OSIRIS-REx spacecraft arrived at its target asteroid, (101955) Bennu, in December 2018. The primary objective of the mission is to return a pristine sample from Bennu to address some of NASA's (and humanity's) fundamental questions: How did the Solar System form? How did life evolve in the Solar System? Are asteroids harbingers of life or death—or both? [1]

Before picking up the sample from the surface, OSIRIS-REx will have spent more than a year characterizing the surface with cameras, spectrometers, and the laser altimeter that are onboard the spacecraft [1]. Surface temperatures at multiple local times of day, orbital positions, and viewing geometries are among the important quantities to be determined and mapped. Global and local surface temperatures inform maps of sampleability, spacecraft safety, and science value of the surface, and temperatures also affect compositional interpretation of measured spectra.

2. Methods & Observations

The primary data set for determining surface temperatures consists of infrared (6–100 μm) spectra from the OSIRIS-REx Thermal Emission Spectrometer (OTES) [2]. OTES is a point spectrometer with a FOV of 8 mrad, leading to a spatial resolution of ~40 m during the main global mapping phase, when the spacecraft is 5 km above the surface. The long-wavelength end of spectra obtained by the OSIRIS-REx Visible and InfraRed Spectrometer (OVIRS; 0.4 to 4.0 μm) [3] is also dominated by thermal emission. As a result, the OVIRS spectra can also be used to determine temperatures. OVIRS is a point spectrometer with a FOV of 4 mrad and a resulting spatial resolution half that of OTES.

During the Detailed Survey phase of the mission in spring 2019, the spacecraft observed Bennu from various stations above different latitudes and local times of day. OTES collected data during all of these stations and OVIRS during most. The Equatorial Stations sub-phase (April 25 to June 6) is designed for global mapping of Bennu at seven different local times of day. Next, the Orbital B phase of the mission will return temperatures at higher spatial resolution (~10 m for OTES) near the terminator. Finally, the Reconnaissance phase will observe potential sample sites at even higher spatial resolution. Several off-nadir OTES and OVIRS observations are included to investigate the dependence of thermal emission on viewing geometry.

The thermal radiance of Bennu exceeds reflected radiance for wavelengths longer than ~3 to 3.4 μm, depending on local temperature and illumination. To properly interpret reflectance spectra, we model and subtract the thermal continuum from OVIRS spectra. In addition to the thermal continuum, spectral features in emission can partially or fully fill in absorption bands if the thermal radiance is significantly higher than reflected radiance (generally 6 to 10 times). This thermal fill-in effect must also be taken into account in detailed band analysis.

3. Results

From data returned by OTES and OVIRS during the first seven weeks of Detailed Survey, we have constructed multiple maps for different times of day and viewing geometries. An example from observations taken during nadir-relative north-south scans when the spacecraft was above the equator at 12:30 pm local time is shown in Figure 1.

Temperatures generally agree with predictions made using the thermophysical properties derived from Approach-phase observations [4]. Some spots, mostly associated with certain boulders, have higher temperatures than predicted, which we interpret as due to lower thermal inertia than the average surface of Bennu (see [5] for thermal inertia maps and [6] for an overview of possible physical interpretations).

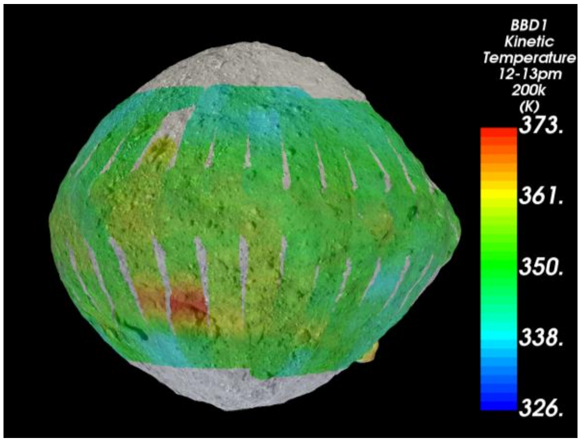

Figure 1. Temperature map of Bennu from observations on March 7, 2019. The spacecraft was positioned above the equator at ~12:30 pm local time, and the OTES spots mapped are those with local solar times between 12:30 and 1:30pm.

The initial attempt at removing the thermal contribution from OVIRS spectra uses a single-temperature blackbody fit to the thermal radiance. After thermophysical analysis has been completed for each observation, we can directly model the distribution of temperatures within each OVIRS spot. We will compare the two approaches in terms of final depth and shape of the broad hydration feature detected on Bennu [7].

To assess potential fill-in of absorption bands by thermal emission, we constructed an artificial spectral model of Bennu in which the reflectance spectra had a 6% absorption due to organics at 3.4–3.5 μm. We then constructed an emissivity spectrum for the same mixture of materials. Band contrast is generally reduced in emissivity as compared to reflectance [8], and in this case the emissivity features have a contrast that is about 0.1 times the contrast of the features in reflectance. We then convolved the reflectance and emissivity spectra with reflected and thermal continuum fluxes computed across the surface of Bennu at different times of day and summed these for the total radiance spectrum that would be measured by OVIRS. The final measured absorption band depth remains largely unchanged on the coldest parts of the surface, but is substantially reduced in the hottest regions (equatorial and mid-latitudes in the afternoon). For broad features, variable amounts of thermal fill-in at different wavelengths could affect the measured band shape as well as depth.

4. Summary and Conclusions

We will present additional temperature measurements of Bennu by OSIRIS-REx and discuss the effects of thermal emission on the interpretation of the measured spectra.

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