CERES' GLOBAL SURFACE ROUGHNESS: IMPLICATIONS FOR SUB-RESOLUTION COLD TRAPS.

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Introduction: The roughness of a planetary surface contains a record of the processes that have shaped that object. For airless bodies like the dwarf planet Ceres, the number of processes acting to alter its terrain is relatively small; relief-creation from impact cratering (and more rarely cryovolcanism [1]) and relief-reduction from diffusive mass-wasting. This permits a detailed study of geologic history from topographic datasets. Quantitative characterization of the surface roughness provides information about the relative effectiveness of the processes that formed and shaped the crust [2,3].

Knowledge of processes that explain surface roughnesses can lead to predictions of surface properties below the resolution of observations. The existence of ice deposits in observed permanently shadowed regions (PSRs) [4] depends heavily on surface roughness in the polar regions [5]. Cold traps too small to observe may also exist [6] and could be characterized by a model of landscape evolution calibrated to explain Cerean roughness at larger scales. For Ceres, such a study is now possible due to comprehensive stereo coverage from the Dawn Framing Camera's Low Altitude Mapping Orbit [7,8].

Here we present global maps of various roughness parameters and preliminary analysis of their implications for the history and present state of Ceres' surface, similar to previous studies using altimeter data for the Moon [9], Mercury [10], and Mars [2].

Finally, we discuss application of these results to the calibration of a landscape evolution model, which allows us to study Ceres-like synthetic surfaces at scales below the resolution limit of Dawn's instruments.

Data: A global shape model for Ceres has been produced from Dawn Framing Camera images and radiometric tracking data using the stereophotoclinometry method [11,12]. The Framing Camera topography obtained during Dawn's Low-Altitude Mapping Orbit has a resolution of ~140 m [1,11]. The resulting 3D shape model of [12] has height accuracies of better than 30 m. For our analysis, we sampled the shape model on a global grid of 10000 by 5000 points to generate a DTM.

Roughness Analysis: This Ceres global DTM was used to produce high-resolution slope and roughness maps (Figures 1 and 2). Due to sub-optimal lighting conditions near the poles, the data quality in those regions is poor. Therefore, our maps only display latitudes between -80º and +80º. Within this area, roughness statistics were computed for a moving 5ºx5º (~1600 km^2) window. Projection effects were mitigated by reprojecting each rectangular window using an equidistant cylindrical projection, resulting in a resolution of about 300 m/pixel.

For each window, the median bidirectional slope is computed using elevation differentials in the x- and y-directions (Fig. 1).

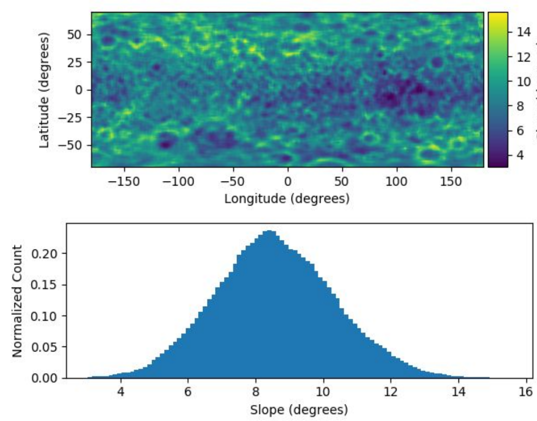


Figure 1. Median global slope map and distribution for Ceres

The global distribution of slopes is peaked around 8º suggesting that much of the surface is relatively smooth over length scales of approximately 300 m. However, the heavily cratered nature of Ceres is evident in the small fraction of slopes greater than 12º. These steep slope faces, found often on the walls of impact craters may augment the thermally stable locations for ice deposits in permanently shadowed regions [4,5].

The power spectrum of the topography was characterized with a 2D Fourier Transform of the moving window. A line was then fit to the radially-averaged FT in log-log space (Fig. 2).

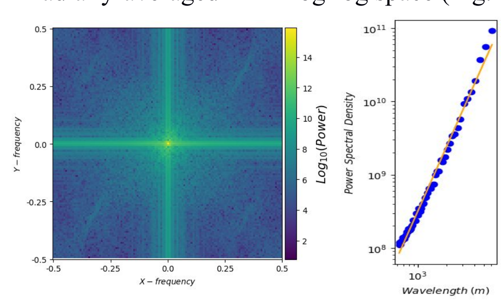


Figure 2. a) 2D Fourier Transform of an elevation grid. b) 1D radial average of a) and linear fit

This fit is performed for each window in the DTM and the slope, β, is used to represent the surface roughness for that region. The global map of this parameter is shown in Figure 3.

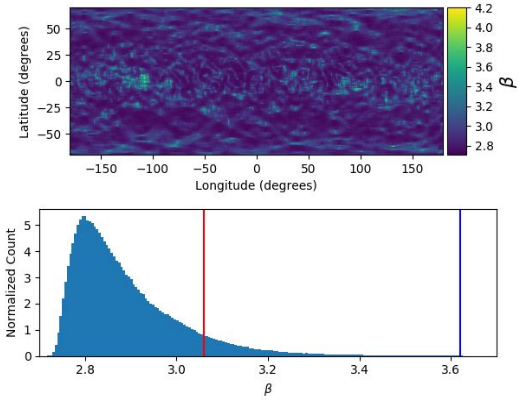
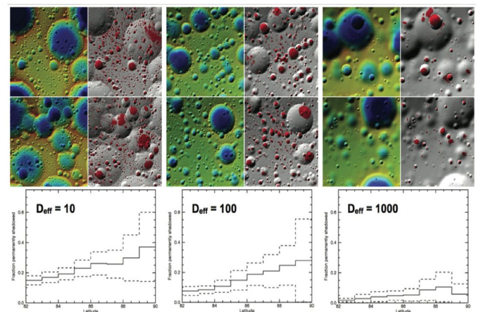


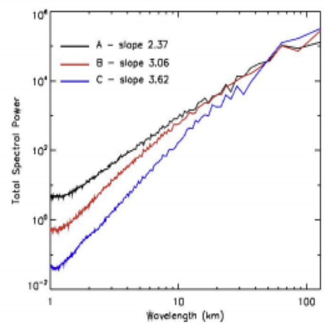
Figure 3. Map and global distribution of roughness parameter, β. Vertical lines correspond to the FT slopes of surfaces B & C in Fig. 4

Model Calibration: We are currently applying these surface roughness measurements to the calibration of a landscape evolution model (Fig 4 A-C) that will investigate surface ice deposits in permanently shadowed craters [4] and space weathering on airless bodies. The two most important processes in this model are relief-creation from impact cratering and relief-reduction from mass wasting (driven by micrometeorite bombardment) [13]. Downslope motion of material is computed via diffusion similar to the method of [14], and we employ accurate impactor population parameters to scale projectiles to final crater dimensions using pi-group scaling techniques [15] and realistic, size-dependent crater shapes [16]. This allows us to vary the source of impacting bodies (e.g. Main Asteroid Belt, near-Earth space, or the Kuiper Belt) and vary target properties such as strength, density and gravity.

Power spectra calculated from 2D Fourier Transforms can measure the roughness of the synthetic and real landscapes. Landscape diffusivity can be adjusted so that the power spectra of the model resembles that of Ceres. Figure 4D depicts how the power spectral slope differs for varying diffusion rates. Our retrieved diffusivities will be used in higher-resolution model runs over smaller areas to synthesize realistic topography below the resolution limit of the Dawn Framing Camera. Solar elevation calculations will determine the PSR fraction in our calibrated surfaces (e.g. Fig 4 A-C). We will take a Monte Carlo approach and simulate many landscapes to investigate what PSR fraction is typical and what role sub-resolution cold traps play in the total PSR area. These surfaces could also provide information about the characteristic geometry, e.g. depth-to-diameter ratio, of craters hosting PSRs and could be used to directly model temperatures within realistic synthetic craters.



(A-C)



(D)

Figure 4. (A-C) Model landscapes centered on Ceres' north pole with increasing diffusivity from left to right. Color represents elevation while red on the shaded maps shows PSRs. Plots show the average and range (over many random landscapes) of the fraction of PSR terrain vs. latitude.
(D) Power spectra of model terrains with the same diffusivities have clearly-distinguishable slopes.

Discussion: We present global maps of median bidirectional slope and Fourier Transform slope, β, for Ceres using Dawn topography data. By calibrating our landscape evolution model to the large-scale roughness of Ceres using these results, we can probe surface conditions below the resolution of Dawn instruments. We will discuss the application of this model to permanently shadowed regions and present preliminary analysis of calibrated, Ceres-like synthetic surfaces.

References: [1] Ruesch et al. *GRL* (2016). [2] Aharonson et al., *JGR*, 106, 23723-23735 (2001). [3] Smith et al., *Science*, 284, 1495-1503 (1999). [4] Platz et al., *Nature Astron.*, 1, 0007 (2016). [5] Rubanenko and Aharonson, *Icarus*, 296, 99-109 (2017). [6] Hayne et al., *JGR*, 120, 1567–1584, (2015). [7] Raymond et al, *Space Sci. Rev.*, 163, 487–510, (2011). [8] Raymond et al., *LPSC* (2016). [9] Rosenburg et al., *JGR*, 116, (2011). [10] Susorney et al., *JGR*, 122, 1372-1390, (2017). [11] Park et al., *Nature*, 537, 515–517 (2016). [12] Park et al., *EGU*, 3380 (2017). [13] Fassett, and Thomson, *JGR*, 119, 2255-2271 (2014). [14] Howard, *Geomorphology*, 91, 332-363 (2007). [15] Holsapple, *Annu. Rev. Earth and Planet. Sci*, 21, 333-373 (1993). [16] Richardson, *Icarus*, 204, 697-715 (2009).