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A global catalogue of Ceres impact craters ≥ 1 km and preliminary analysis

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A B S T R A C T

The orbital data products of Ceres, including global LAMO image mosaic and global HAMO DTM with a resolution of 35 m/pixel and 135 m/pixel respectively, are utilized in this research to create a global catalogue of impact craters with diameter $\geq$ 1 km, and their morphometric parameters are calculated. Statistics shows: (1) There are 29,219 craters in the catalogue, and the craters have a various morphologies, e.g., polygonal crater, floor fractured crater, complex crater with central peak, etc.; (2) The identifiable smallest crater size is extended to 1 km and the crater numbers have been updated when compared with the crater catalogue ($D \geq 20$ km) released by the Dawn Science Team; (3) The *d/D* ratios for fresh simple craters, obviously degraded simple crater and polygonal simple crater are 0.11 ± 0.04, 0.05 ± 0.04 and 0.14 ± 0.02 respectively. (4) The *d/D* ratios for non-polygonal complex crater and polygonal complex crater are 0.08 ± 0.04 and 0.09 ± 0.03. The global crater catalogue created in this work can be further applied to many other scientific researches, such as comparing *d/D* with other bodies, inferring subsurface properties, determining surface age, and estimating average erosion rate.

1. Introduction

The geologically primitive dwarf planet Ceres, with approximately 940 km diameter and a mass of one third of the total mass of the asteroid belt, is an intact protoplanet since its formation, which is key to understand the origin and evolution of the solar system (Russell et al., 2004; Russell and Raymond, 2011). The Dawn spacecraft, chiefly equipped with Framing Camera (FC), Visible and infrared spectrometer (VIR) and Gamma Ray and Neutron Detector (GRaND), has mapped Ceres with Framing Camera at different orbital heights during the early approach phase, the Survey orbit, the High Altitude Mapping Orbit (HAMO) and the Low Altitude Mapping Orbit (LAMO) after orbit insertion on March 6, 2015 (Russell et al., 2016).

FC images reveal the surface of Ceres is heavily cratered with a large variety of crater morphologies, e.g., bowl shaped craters, polygonal craters, floor-fractured craters (Hiesinger et al., 2016). Cratering is one of the most important processes that greatly shaped the surface of Ceres, and the morphology and distribution of the craters can provide insights into geological settings, subsurface properties, and even the evolution history of Ceres. Therefore, crater catalogue with morphometric properties have significant scientific application potentials for the research of Ceres, which is impossible to accomplish before the Dawn mission. Though studies on craters at a global scale for Ceres have been done by the Dawn Science Team (Hiesinger et al., 2016; Marchi et al., 2016), the spatial resolution of the base map for constructing their crater catalogues is about 135 m/pixel (Roatsch et al., 2016b).

In this research, the recently released global LAMO image mosaic and global HAMO DTM derived from FC images with a resolution of about 35 m/pixel (Roatsch et al., 2017) and 135 m/pixel respectively are utilized comprehensively to construct a global crater catalogue with diameter $\geq$ 1 km, and crater morphometric parameters are further measured and calculated. Preliminary analyses of their spatial distribution characteristics and morphometric parameters are also included in this research. We hope this global crater catalogue for Ceres can contribute to the community and be used broadly in the future.

2. Datasets and methodologies

2.1. Datasets

The datasets used in our research are global mosaic products from the Dawn mission, which is the first spacecraft to orbit separately two extraterrestrial bodies: Vesta and Ceres

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(Russell et al., 2016). After orbital insertion on March 6, 2015, the framing camera onboard Dawn had imaged Cerean surface through a clear filter and 7 narrow-band filters covering the wavelengths from the visible to the near-infrared, at different orbital heights under various viewing angles and illumination conditions (Sierks et al., 2011). Global image mosaics of different resolutions have been produced from these collected images, including global survey mosaic with a resolution of about 400 m/pixel (Roatsch et al., 2016a), global HAMO mosaic with a resolution of about 135 m/pixel (Roatsch et al., 2016b), global LAMO mosaic with a resolution of about 35 m/pixel (Roatsch et al., 2017). In addition, about 2350 clear filter images acquired from HAMO in six different cycles, each of which is optimized for stereo photogrammetry, are used to construct digital terrain models (DTMs). A global HAMO DTM, formatted as image where the DN values give the height in meters above a reference sphere of 470 km, is generated with a lateral spacing of about 135 m/pixel and a vertical accuracy of about 10 m. The DTM covers approximately 98% of Ceres surface, with only few permanently shadowed areas near the poles interpolated (Preusker et al., 2016). Hence, the global LAMO mosaic and global HAMO DTM, both of which provided in equidistant cylindrical projection, are the highest resolution cartographic products available at present, and are the two most important basemaps to map craters on Cerean surface and to calculate their morphometric parameters in this research. The inappropriate illumination geometry and the permanently shadowed areas of the mosaics (Schorghofer et al., 2016) have influence on crater identification on polar regions and will be discussed in Section 3.2.2.

2.2. Methodologies

2.2.1. Crater identification

The crater identification is the basis for further morphometric measurement and analysis. The crater identification procedure over the Cerean surface is performed manually with global LAMO mosaic as basemap in a geographic information system environment by using the CraterTools extension for ArcGIS, which helps to avoid errors of crater diameters and measurement area sizes related to map-projection induced distortions automatically (Kneissl et al., 2011). The craters are identified by their unique characteristics (e.g., presence of rim, circularity of the rim, etc.), and they are digitized by a three-point rim fitting method (Kneissl et al., 2011), so the resulted diameter is rim diameter in this research. The basemap for crater identification is shown in polar stereographic projection for single hemisphere areas poleward of 60° and the other areas is mapped in equidistant cylindrical projection.

2.2.2. Morphometric measurement

After the completion of crater extraction over Cerean surface, the morphometric parameters for each crater are measured based on the global HAMO DTM. Because of the limitation of the resolution (~135 m/pixel) of DTM, the smallest diameter of the crater that can be reliably resolved is ~ 1 km, or ~8 pixels across (Garvin and Frawley, 1998; Robbins and Hynek, 2012). Hence, the morphometric measurements are only applied onto those craters with diameter ≥ 1 km by following the algorithm shown in Fig. 1.

(1) *Crater selection* The craters ≥ 1 km in diameter in previous identification are selected for morphometric measurements (Fig. 2a). Within this step, obvious secondary craters that align in chains or form clusters are excluded for further calculation to preclude possible contamination on crater morphometric analysis, especially those secondaries around Occator, Dantu and Yalode identified by Scully et al. (2016)_ENREF_43 and Schmedemann et al. (2017).

(2) *Profile creation* Because there are many craters that cannot be perfectly fitted by a circle, so 8 profiles crossing the initial circle center of each crater are drawn starting from north with fixed interval angle 22.5° (Fig. 2b).

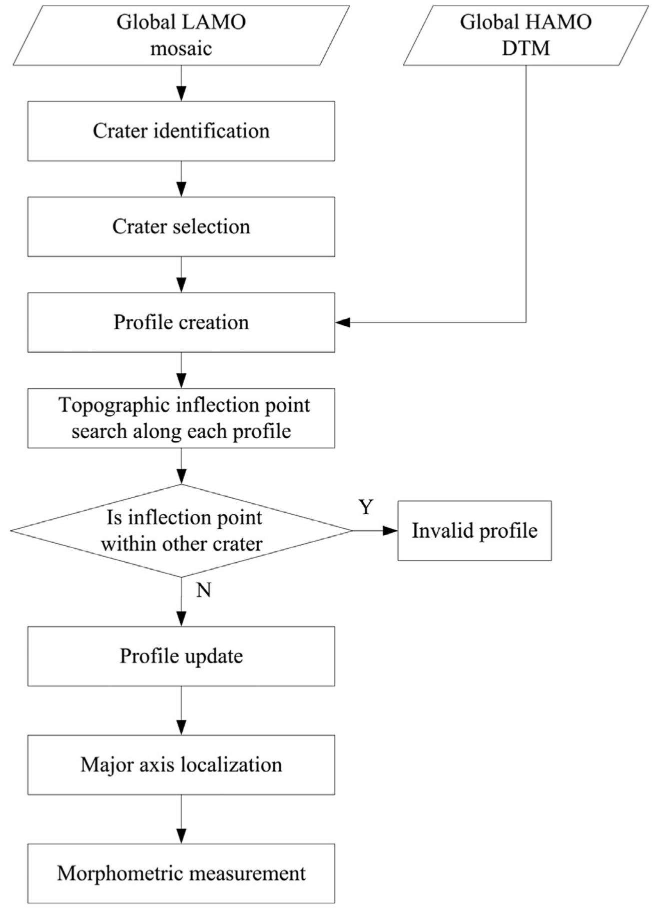

Fig. 1. Flow chart of crater extraction and morphometric measurement.

(3) *Profile update* Taking into account the uncertainty of the initial diameter measurement in CraterTools, the local topographic inflection point (local maxima) along the profile is found within 10% diameter on both sides of the initial circle (Fig. 2c), and the profiles are updated by connecting the two local maxima points in each previous profile. During this process, if any of the local maxima is within other crater, the relief along this profile is affected and the profile is marked as invalid. And if none of the local maxima can be found along the profile, this profile is also marked as invalid.

(4) *Major axis localization* Though the major axis within the updated 8 profiles can be determined, it may be not the real case, so it is named as 'pseudo major axis'. The exact major axis crossing the crater center is searched and localized within the current 'pseudo major maxis' and its left and right neighbors by binary search method with the search threshold is set to 1° The major axis localization procedure can make morphometric measurement more accurate and reliable, especially for fresh craters.

(5) *Morphometric measurement* The diameter of the crater measured by CraterTools is adopted in this research, the depth of the crater is defined as the average elevation difference between the rim and the floor of each profile, and the depth-to-diameter ratio (abbreviated as *d/D*) is defined as the ratio of the average depth to the diameter. During the morphometric measurement procedure, in order to avoid any influence of map projection and terrain relief, the coordinates of each crater are converted to local coordinate system (the origin is the crater center, *x* direction is local east, *y* direction is local north, and *z* direction is perpendicular to the