VERIFICATION OF AUTOMATICALLY MEASURED BOULDER POPULATIONS IN HIRISE IMAGES

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Introduction: Images taken by the High Resolution Imaging Science Experiment (HiRISE) show that meter-scale boulders and blocks, as observed by landers and rovers, are present across the entire surface of Mars [1], [2]. Quantifying estimates of these boulder populations, including their size and location, can address several outstanding questions regarding pedogenesis, surface weathering, impact processes, and mass wasting processes [3], [4]. In addition, surface analysis of hazards, such as boulders, is essential to identifying future landing sites [5]. However, manual measurement of boulder populations is time intensive, and is impractical to apply at large scales (e.g. more than a few square km of surface area). In order to examine large boulder populations, we have developed a Python-based algorithm to automatically identify, locate, and measure boulders in remote images of planetary surfaces. This set of tools and programs is collected in a python library called the Martian Boulder Automatic Recognition System (MBARS).

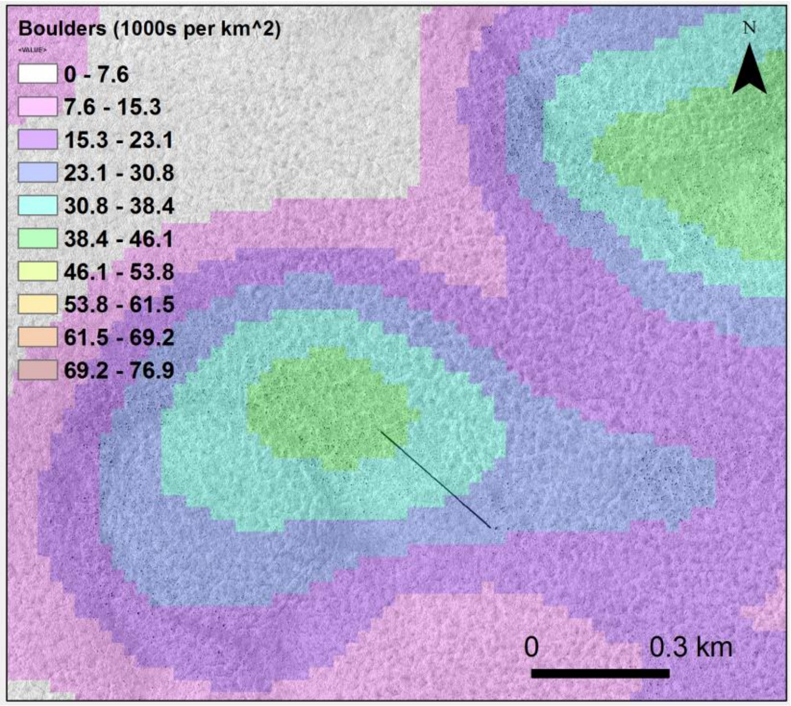

Figure 1. Map of boulder density (>1m) overlain on HiRISE image TRA_000828_2495 with boulder locations generated by MBARS. The map shows the clear trend of higher boulder densities near impact craters. MBARS is designed to ignore data errors, such as the one in the center of the image.

MBARS is designed to be an open-source system where the user is not involved in any evaluative decisions regarding the detection and measuring of boulders. This independence distinguishes MBARS from previous applications of similar methodology [1] and will make MBARS more usable by unskilled users. In addition, we have avoided relying on proprietary software (i.e. ArcGIS) instead using python and code that can be freely modified, customized, or improved by its users. These factors combined will make MBARS an accessible tool to analyze boulder populations on Mars at all levels of research and mission planning.

Methodology: The approach used in MBARS to identify and measure boulders is largely based on the methodology published by Golombek et. al (2008) [1]. In brief, this method isolates shadows (cast by boulders or other terrain) from the image and calculates the width and height of the object casting the shadow. Further details of how this method is applied in MBARS can be found in our previous abstract [6].

Results: At the current stage of development, MBARS is able to measure the diameter, location, and height of boulders in a single HiRISE image far faster than manual measurements. The processing time can vary greatly depending on the density of boulders in the image. As a benchmark, HiRISE image TRA_000828_2495, with ~230,000 detected boulders can be processed in approximately 2 hours when single-threaded on a computer with 3.6 GHz processor and 16 GB of RAM. The rate of boulder detection, ~31 boulders/sec, far outpaces human capabilities even at this early stage. The record of boulder locations and physical morphometry (height, width, etc.) is the key deliverable from MBARS. Tools within MBARS can analyze this record or export it to GIS-ready data tables enabling further analysis (e.g. Figure 1).

At this time, MBARS can also calculate vital parameters such as the cumulative fractional area of boulders and rock abundances (RA) (Figure 2). With conservative estimates of uncertainty, the rock abundance in a given image can be constrained to roughly ± 10%, though this varies with boulder density.

Comparison & Verification: A variety of datasets are used to verify the results provided by MBARS both at the large (>1km) scale and the individual object scale. Our primary source of verification comes from previously measured boulder populations. Published results from algorithmic approaches [1], [2] as well as manually counted images are used to verify MBARS' results [7]. Since the shadow-detection method used by Golombek et. al. is also applied here, we expect that the results generated with the same method will be readily comparable to MBARS' results. Manually counted images, on the other hand, rely on trained human pattern recognition to identify boulders in the image. Due to such methodological differences, we do not expect the output of MBARS to match the manually interpreted results. Instead we compare derived parameters, such as the best fit RA, to check the accuracy of MBARS. Rock abundances from infrared observations (e.g. TES [8]) can also provide a comparison to rock abundances determined from HiRISE images. Figure 2 shows that MBARS results are consistent with manually counted results in preliminary tests.

In order to verify the accuracy and precision of MBARS when measuring individual objects, reliable measurements of individual rocks and boulders are needed. While these data are less abundant than larger-scale data, several avenues are still available, namely images from landers and rovers. While more recent landers have selected landing sites with low rock abundance, older landers such as the Viking 1,2 and Pathfinder missions landed in rock-dense areas and boulders in their immediate areas have been thoroughly examined and measured [9]. The areas around these landers provide a rare opportunity to view these rocks from multiple perspectives (i.e. from orbit and in situ) and can verify the accuracy of MBARS on an individual object scale.

References: [1] M. P. Golombek, et. al. *JGR*, 2008. [2] M. P. Golombek, et. al. *Int. J. Mars Sci. Explor.*, 2012. [3] T. de Haas, et. al. *GRL*, 2013. [4] T. C. Orloff, et. al. *JGR*, 2011. [5] K. Di, et. al. *Planet. Space Sci.* , 2016. [6] D. R. Hood, et. al., *49th LPSC*, 2018. [7] S. F. Sholes, et. al., *GSA Annual Meeting*, 2017. [8] S. A. Nowicki and P. R. Christensen, *JGR*, 2007. [9] H. J. Moore and J. M. Keller, 1991.

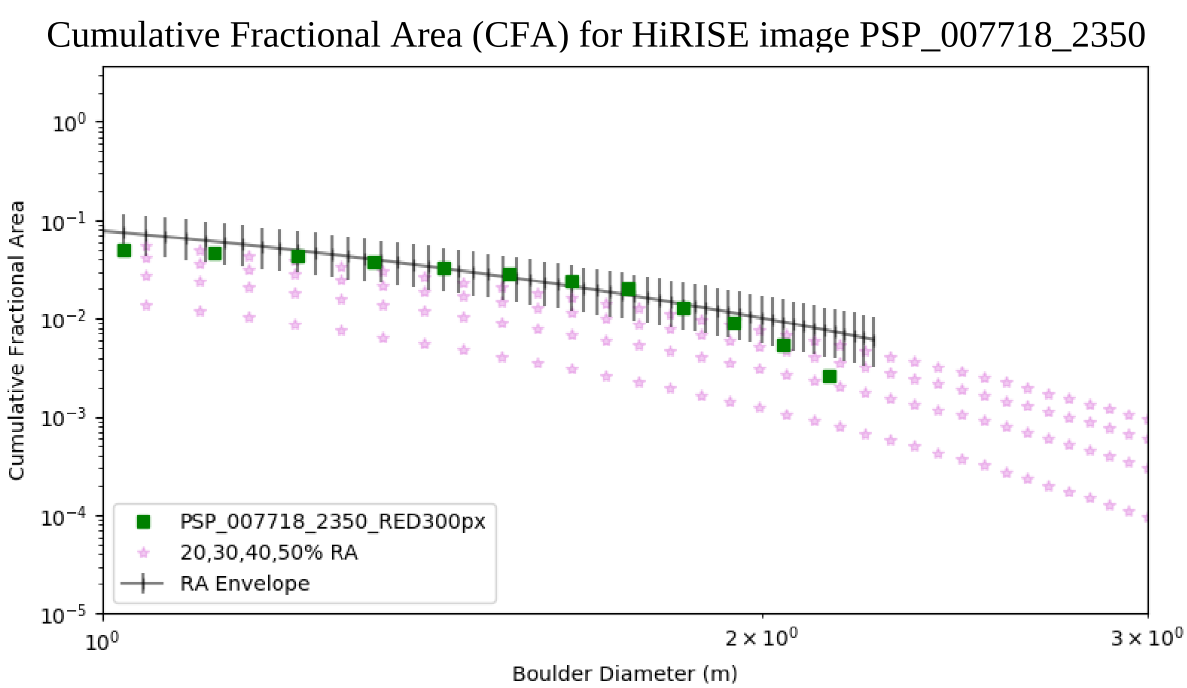

Figure 2. Cumulative fractional area plot for HiRISE image PSP_007718_2350 from MBARS results. The green stars show the average CFA for the entire image. The pink stars show reference CFAs for 10%, 20%, 30%, and 40% Rock Abundance. The black line shows the best fit RA for the image, 60%, while the vertical bars show the uncertainty of the RA, roughly ± 20%. Hand-counts of images within this HiRISE image give RAs of 50-70%, so the algorithm is in good agreement with manual measurements.