

A GLOBAL CATALOG OF LUNAR GRANULAR FLOW FEATURES. V. T. Bickel¹, S. Loew¹, J. Aaron², N. Goedhart¹, ¹ETH Zurich (valentin.bickel@erdw.ethz.ch), CH, ²WSL, CH.

Introduction: Mass wasting is one of the major drivers of lunar landscape evolution. Currently known mass wasting processes and features include rockfalls [1], landslides, slumps, creep [2], and granular flows [3] (Fig. 1). Detailed analysis of these features provides insights into the endo- & exogenic activity and dynamics of their host body – without requiring a landed mission or distributed, global geophysical network. Lunar mass wasting features were studied in the past using either manual [2,3] and/or automated approaches [1]. The most recent studies suggest that the main, global short- and long-term drivers of lunar mass wasting are meteoritic impacts at various scales, in combination with solar-driven thermal fatigue, while seismicity might contribute locally [1,4].

In contrast to other lunar mass wasting processes and features, little is known about the overall distribution and characteristics of lunar granular flows. Earlier studies identified granular flows in a few impact craters within the Schrödinger basin [5] and the equatorial regions [2,3]. [3] further suggested a granular flow classification system, although this might be subject to an unknown observational and/or geographic bias.

This work seeks to train, validate, and deploy a convolutional neural network (CNN) to consistently map granular flow features on a global scale, enabling the study of those features – as well as their drivers – on an unprecedented scale.

Methods: We trained an off-the-shelf CNN (RetinaNet) with a ResNet101 backbone [6,7] and a total of 6,248 positive and 1,200 negative training labels that were created by a human operator. We used a testset with 331 labels to quantify the CNN's performance using a bootstrapping approach (drawing 80% of the testset over 500 iterations). Our CNN achieves a mean recall (R_{test}) of 0.61 and a mean precision (P_{test}) of 0.78, with a mean average precision (AP) of 0.55, at a network confidence threshold (CT) of 0.5.

The CNN was used to scan a total of 149,079 LRO NAC (Lunar Reconnaissance Orbiter Narrow Angle Camera) images that cover the lunar surface between 60°N and S. The image selection algorithm exclusively used images with incidence angles <60° to minimize the number and extent of shadows, while minimizing image spatial over- and underlap. We used a total of 10

cloud (virtual) machines (Google Cloud Platform) with a total of 10 NVIDIA T4 GPUs, for a total of ~3 weeks.

Preliminary results: Our CNN identified a total of 44,785 granular flow feature candidates at CT 0.4, which were reduced to 28,101 granular flows following removal of false positives by a human operator. We chose CT 0.4 to maximize the recall of the CNN, at the cost of an increased number of false positives. Our catalogue has increased the number of mapped and recorded lunar flow features by a factor of ~50 or more. Figure 1 shows the distribution (heatmap) of the mapped granular flow features. Our preliminary analysis suggests that:

- Granular flows appear to be heterogeneously distributed over the lunar surface
- The density of features appears to be highest in Copernican-aged craters, but there are flow hotspots in very old craters as well (Imbrian-aged)
- Mare regions on the nearside appear to host an increased number of flow features
- Features appear not to be co-located with Apollo-era seismicity and/or visible tectonic features (lobate scarps, wrinkle ridges, graben, etc.)
- The spatial distribution of granular flows and rockfalls [1] is significantly different, potentially indicating different long- and/or short-term drivers.

The analysis of the new catalog has just started – future investigations will further correlate the new catalog with other, existing catalogs [1], a geologic map, and additional thermophysical datasets.

Acknowledgments: This work is supported by a Google Cloud Research Grant. VTB thanks the Moon Trek team for granting access to the NAC image archive via the Moon Trek API.

References: [1] Bickel et al. (2020) *Nature Comms.* [2] Xiao et al. (2013) *Earth and Planetary Science Letters.* [3] Kokelaar et al. (2017) *JGR Planets.* [4] Bickel et al. (2021) *JGR Planets.* [5] Kumar et al. (2013) *JGR Planets.* [6] Lin et al. (2017) *Arxiv.* [7] He et al. (2015) *Arxiv.*

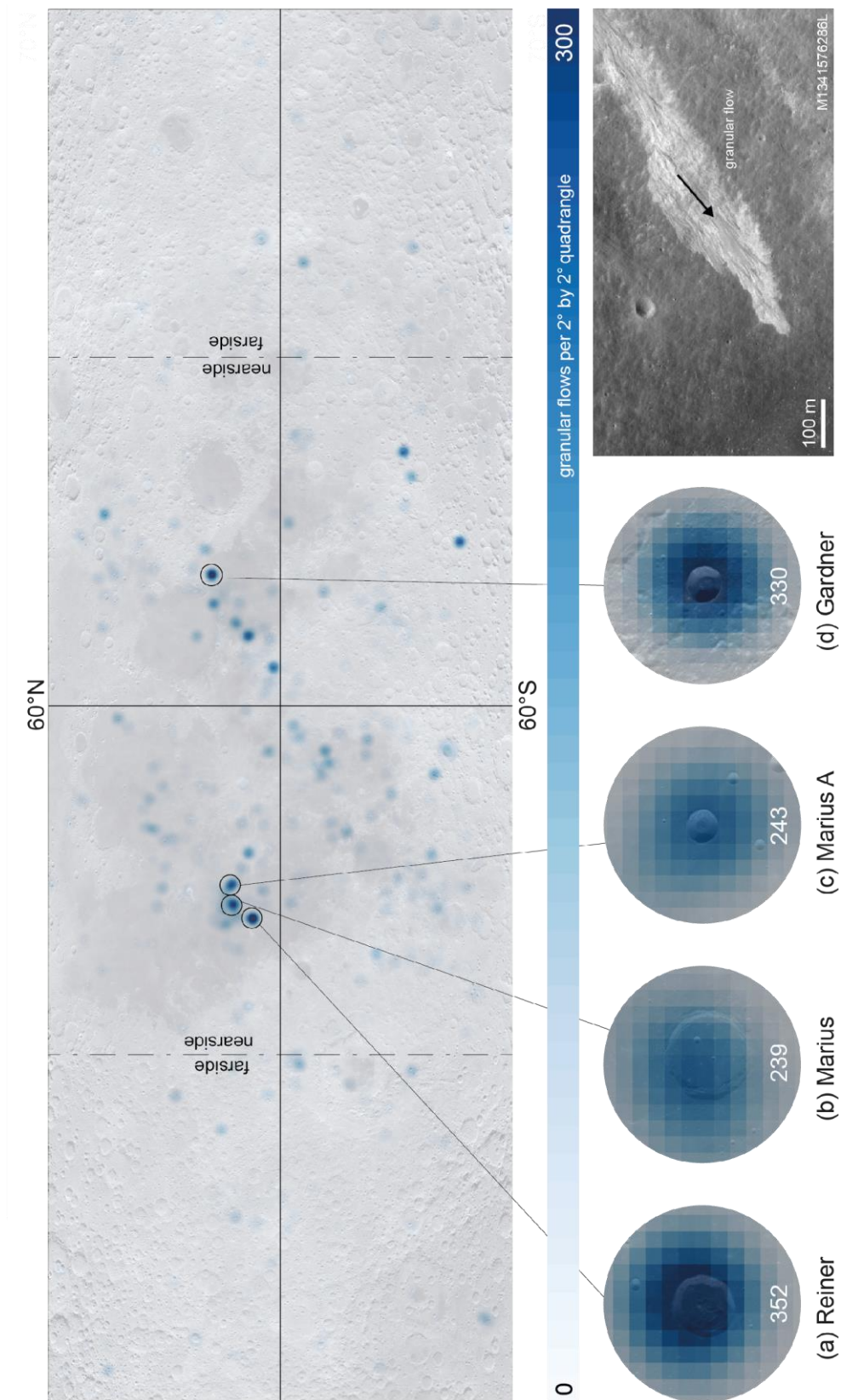


Figure 1. Granular flow feature spatial density map (# features per 2° by 2° quadrangle), Moon2000 equirectangular projection; WAC global mosaic in the background. Inset shows a typical granular flow feature (LROC/GSFU/ASU).