Landslide Scaling Across The Solar System

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1 Scientific Motivation – TODO need citations

Landslides are fundamental surface processes that play an important role in sediment transport and landscape evolution. One approach to understand the factors that govern them is to study the statistics of landslide catalogs, collections of mapped landslides in a particular region. This allows for examination of how, for example, landslide volume scales with area or landslide frequency varies with size. This method has been used extensively for landslides on Earth, both for specific time periods (such as landslides triggered by a specific earthquake or storm) and geographic regions. It has allowed scientists to characterize the different processes that are responsible for terrestrial landslides as well as predict the occurrence rates of hazardous events.

With the advent of high-resolution imagery we have observed landslides on many non-Earth bodies, including the Moon, Mars, Venus, Mercury, and various asteroids. For some of these locations, researchers have used mapping techniques developed on Earth to create landslide catalogs. Examining the difference in landslide scaling relations across these bodies gives us a way to study the impact of gravity, the atmosphere, subsurface fluids, and the geologic environment on landslide properties.

2 Previous Work – TODO be more specific

(Brunetti et al., 2015) compiled small catalogs of landslides on crater slopes of the Moon and Mercury, tracking area and location. They then compared the frequency-area distribution of their catalog to local terrestrial catalogs from Italy and New Mexico. Additionally, they examined how landslide area scaled with crater diameter and area.

(Crosta et al., 2018) created a comprehensive landslide catalog for Mars and compared landslides within different geological settings. They also hypothesized about different terrestrial analogs for these features.

3 Existing Landslide Catalogs – TODO discuss how I loaded the data for each catalog

3.1 Mercury

Researchers have mapped landslides on crater slopes on Mercury (Brunetti et al., 2015). They used imagery from the Mercury Dual Imaging System (MDIS; 250 m/pixel). A DEM was not available for Mercury when they conducted their study. They compiled a catalog of 58 landslides in 38 craters.

3.2 Earth

There is an abundance of mapped landslide catalogs on Earth. I will not analyze all existing catalogs but will instead include several that represent diverse climatic, hydrologic, and geologic settings.

3.2.1 Washington State

The Washington State Geologic Survey has mapped landslides throughout the state to better understand the risks they pose to people and infrastructure (Washington Geological et al., 2017). To identify and map landslides they use orthoimagery and DEMs generated from high-quality lidar data (max of 2 m/pixel) collected by aerial surveys. This represents the current highest resolution approach to mapping landslides.

3.3 The Moon

Similarly to Mercury, landslides have been mapped on crater slopes on the Moon (Brunetti et al., 2015). Their study only considered landslides over 10^6 m^2. To identify and map landslides, they used imagery from the Wide Angle Camera on the Lunar Reconnaissance Orbiter Camera (100 m/pixel), as well as a global DEM (100 m grid size). They found 60 landslides in 35 craters.

3.4 Mars

Thanks to the availability of high resolution imagery, researchers have undertaken a project to globally map landslides on Mars (Crosta et al., 2018). They analyzed the planet over latitudes from $-60°$ to $+60°$ and only mapped landslides greater than 10^5 m^2. To globally identify landslides they used imagery from the High Resolution Stereo Camera on Mars Express (18 m/pixel), the Mars Orbital Camera (1.5–12 m/pixel), and the Context Imager (5–6 m/pixel) as well as 400 m gridded topography from the Mars Orbital Laser Altimeter (MOLA). To locally map landslides they used HiRISE imagery (0.3 m/pixel) and DEMs from HRSC (50–150 m grid size) and MOLA (463 m grid size) when the HRSC-derived DEM was not available. Their final catalog contains 3,000+ landslides.

3.5 Ceres & Vesta – TODO

(Parekh et al., 2021) both compiled previous work and

4 Scaling Analyses

4.1 Landslide Frequency vs. Area

A common technique when analyzing landslide catalogs is to examine the relationship between landslide frequency and area (Malamud et al., 2004; Stark and Hovius, 2001).

Let A be the landslide area. Then a probability density function $p(A)$ is defined such that that probability of a landslide occurring within a range of areas $A_{\min}$ to $A_{\max}$ is given by

$$Pr[A_{\min} \leq A \leq A_{\max}] = \int_{A_{\min}}^{A_{\max}} p(A) dA.$$

It is common to plot $p(A)$ as a function of A on a log-log scale. These plots have a characteristic shape, as illustrated by Figure 1. TODO: Talk about regions of frequency-area plot, what explanations people have given for them.

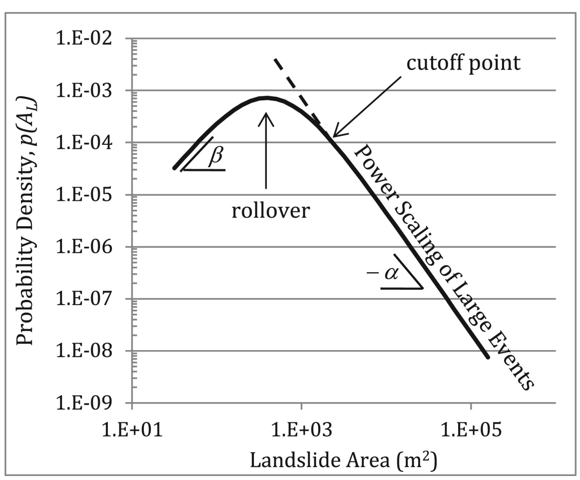

Figure 1: Typical landslide frequency-area relationship, taken from (Tebbens, 2020).

This probability density function can estimated from the finite samples in a landslide catalog using kernel density estimation. I used the implementation in `scikit-learn` with a Gaussian kernel and Scott's method for estimating the bandwidth. Due to the wide range of landslide areas, I performed the kernel density estimation in log space.

Figure 2 shows the frequency-area relationship for all included landslide catalogs.

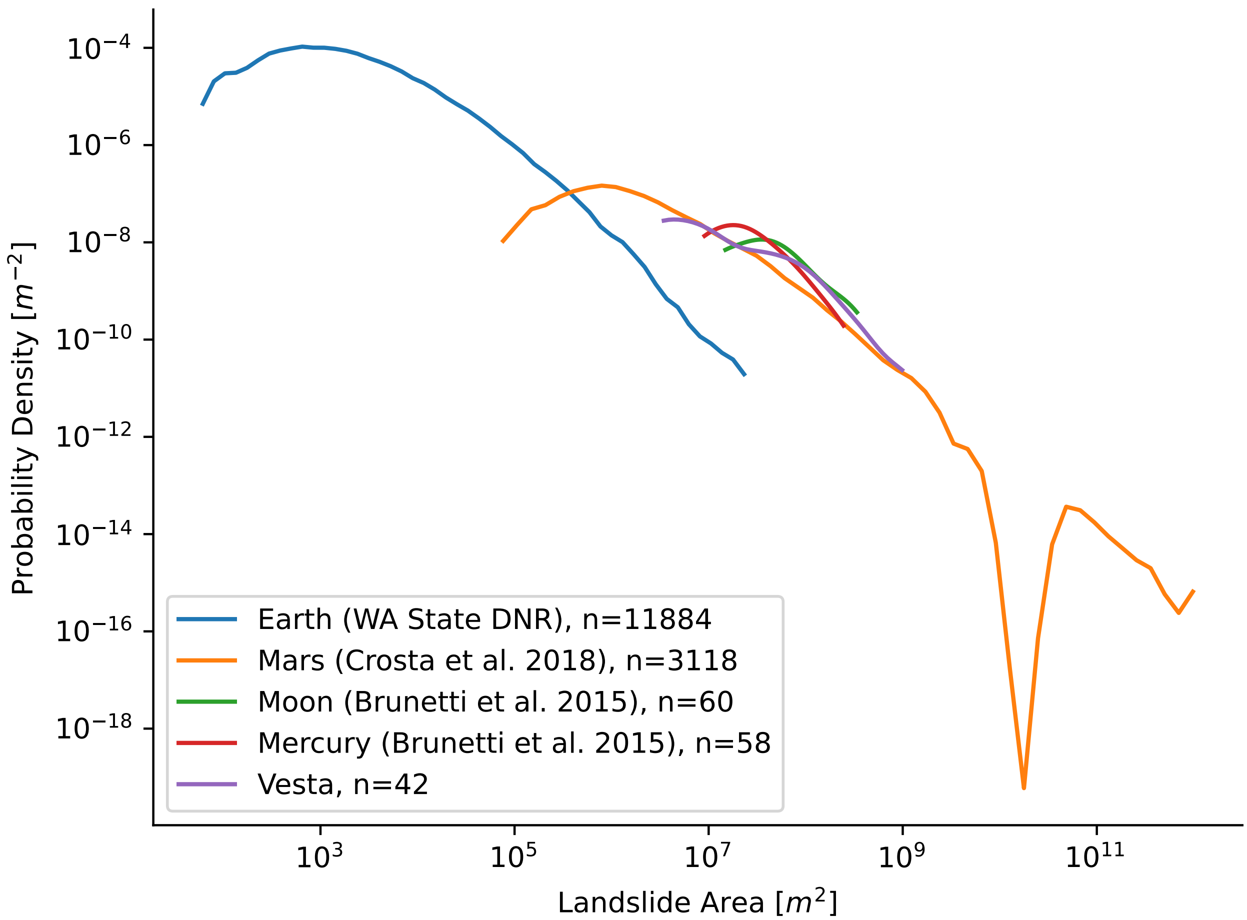

Figure 2: TODO

4.2 TODO: H/L Ratio? – Describes mobility

5 Discussion

6 Conclusions

7 References

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