Asymmetric Space Weathering on Lunar Crater Walls with an Updated Crater List

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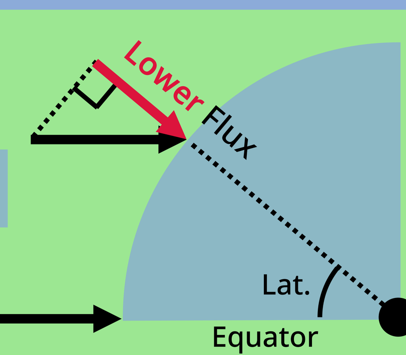
ABSTRACT

- The lunar surface progressively becomes darker in reflectance, redder in color, and smaller in particle size as a result of sputtering from solar wind particles and micrometeoroid bombardments.
- The degree of space weathering is a measure of how long the lunar regolith has been exposed to the surface and the exposure time provides crucial information on the evolution history of the lunar regolith.
- To understand the degree of space weathering on the Moon, we utilized wall-quadrants of 26,802 craters with an updated lunar crater list and studied the relative degree of space weathering between the opposing walls.
- By analyzing differences in optical properties between the north and south wall, we find a latitudinal asymmetry between the northern and southern hemispheres in the degree of space weathering.
- Then, it is analyzed more specifically by subdividing the latitudinal results into diameter, slope, and depth-to-diameter.

1. INTRODUCTION

What Happened on the Lunar Surface?

At higher latitudes, lunar regolith has brighter reflectance less red less mature caused by lower flux.



Which space weathering agents enter along the ecliptic plane and affect soil maturation more? Solar wind particles or Micro-meteorites?

Aug. 2023

Hemingway et al. (2015) Icarus

Solar wind particles enter along the ecliptic plane! Reduced flux should occur both at swirls and toward higher latitudes.

Aug. 2015

Jeong et al. (2015) ApJS

Micro-meteorites (as well as solar wind particles) enter along the ecliptic plane! Grain size monotonically increases as the latitude increases.

Nov. 2015

Sim et al. (2017) GeoRL

Solar wind particles weather the lunar regolith more than micro-meteorites! Pole-facing walls are brighter and less red (i.e. less mature) than their equator-facing counterparts as latitude increases.

Nov. 2017

Trang et al. (2019) Icarus

Both of them, but it is difficult to estimate what affects more... Nanophase and microphase iron abundances are lower at higher latitudes, which suggests lower solar wind and micro-meteoroid impact flux at these latitudes.

Nov. 2018

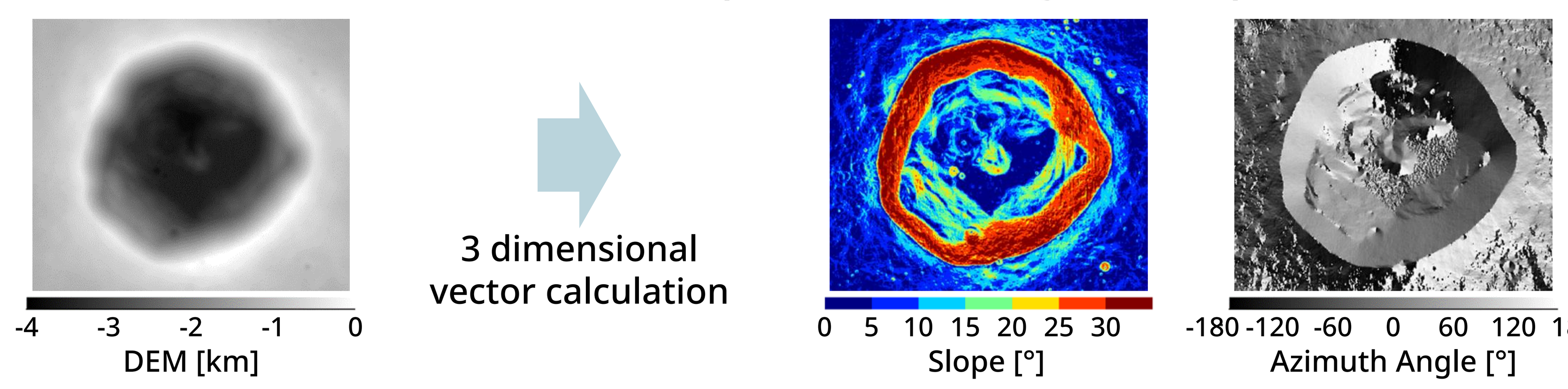
We are carrying on with Sim et al. (2017) with more craters. Thanks a lot for your research!

Aug. 2023

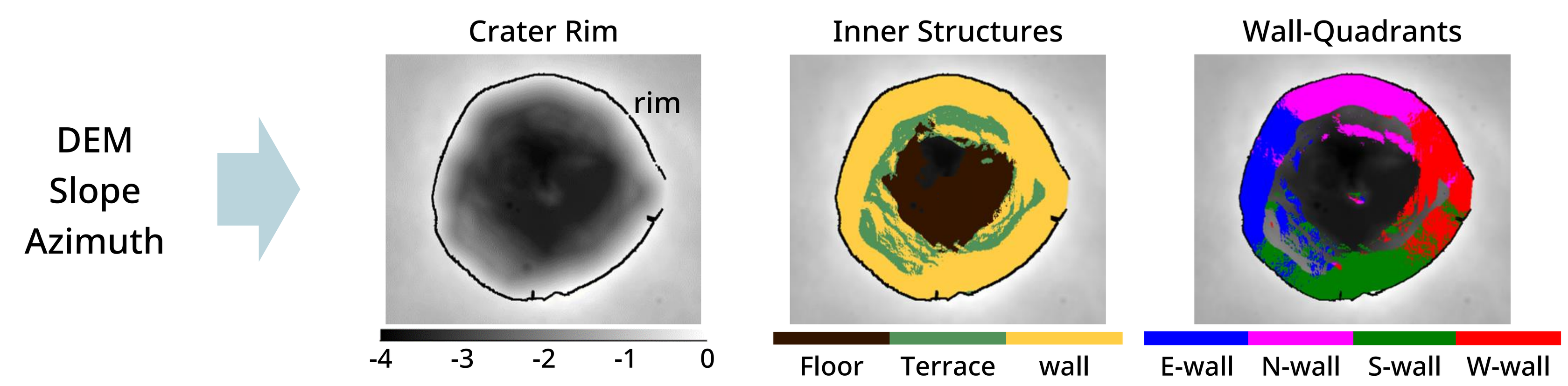
3. METHODS

We improved the analysis methods of Sim et al. (2017).

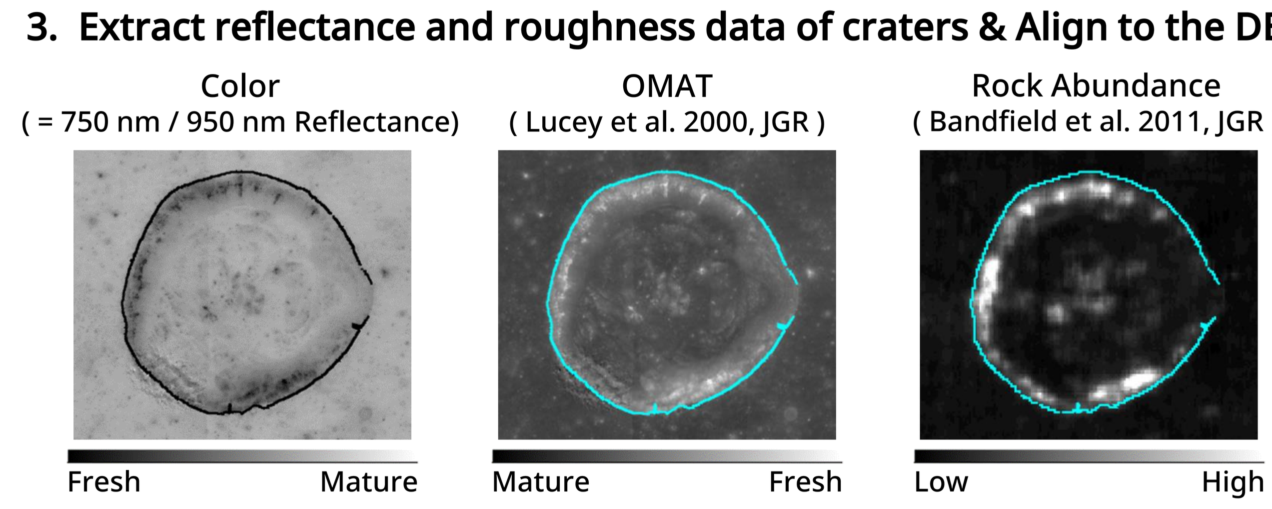
1. Extract the DEM of craters & Produce slope and azimuth angle of each pixel.



2. Detect crater structures & Divide wall-quadrants using the topographic data.



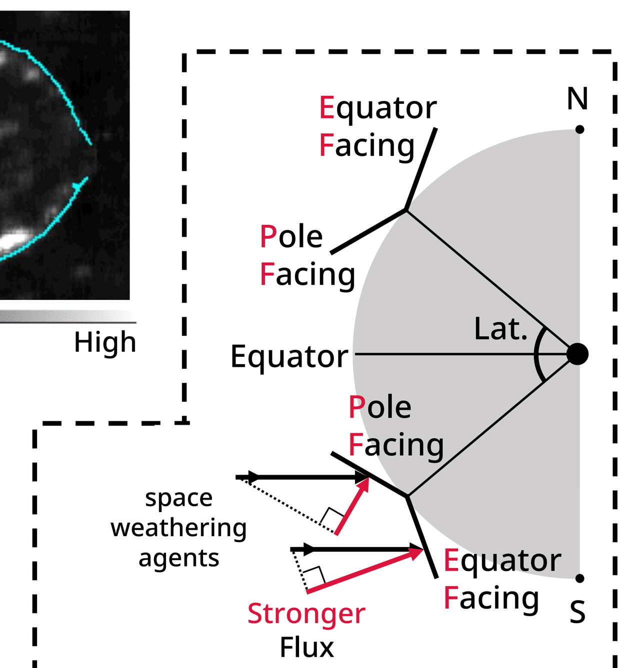
3. Extract reflectance and roughness data of craters & Align to the DEM data of them.



4. Analyze latitudinal trends using EF and PF walls.

Impact flux of space weathering agents is stronger on EF wall than on PF wall!

As latitude increases, flux difference of EF and PF wall increases. (= Δflux [$flux_{EF\ wall} - flux_{PF\ wall}$] increases.)



2. DATA

APRIM 2023 KORIYAMA, JAPAN

Lunar Crater Database

- We adopt the lunar crater database provided by Robbins et al. (2018) to consider more and smaller craters than Sim et al. (2017), which used lunar impact crater database provided by the Lunar and Planetary Institute (LPI).
- Our algorithm for detecting craters identifies craters with well-preserved inner structure, particularly outer rim and wall-quadrants.

	Sim et al. (2017)	This Study
Database	LPI (2015)	Robbins et al. (2018)
# of craters	1872 (of 8716)	26,802 (of ~1.3 million)
Information	Central Latitude & Longitude Diameter of Major/Minor-axis	
Diameter	5 ~ 120 km	2 ~ 120 km
Latitude	-50° ~ +50°	-60° ~ +60°

※ Craters smaller than 2 km in diameter cannot be recognized due to spatial resolution (~60 m/pixel) of lunar global map data, even though they are well-preserved.

Lunar Global Map Data

- DEM : the improved lunar digital elevation map created by the LOLA and SELENE Kaguya teams
- Reflectance : ultraviolet-visible (415, 750, 900, 950, 1001 nm) of SELENE multiband imager

Mission	LRO + SELENE	SELENE
Instrument	LOLA + Terrain Camera	Multiband Imager
Data Type	DEM	Reflectance (UV—Visible)
Resolution	~60 m/pixel	

※ All data cover latitudes within ±60°.

4. RESULTS

Figure 1. Result of Sim et al. (2017)

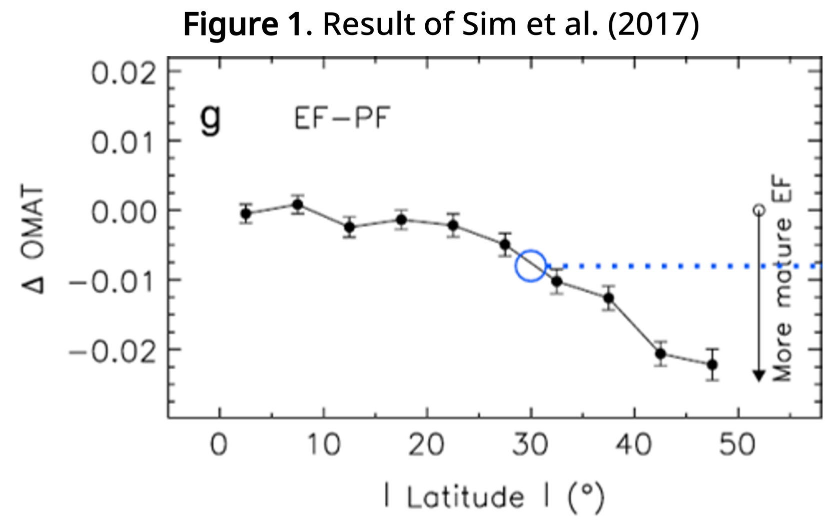
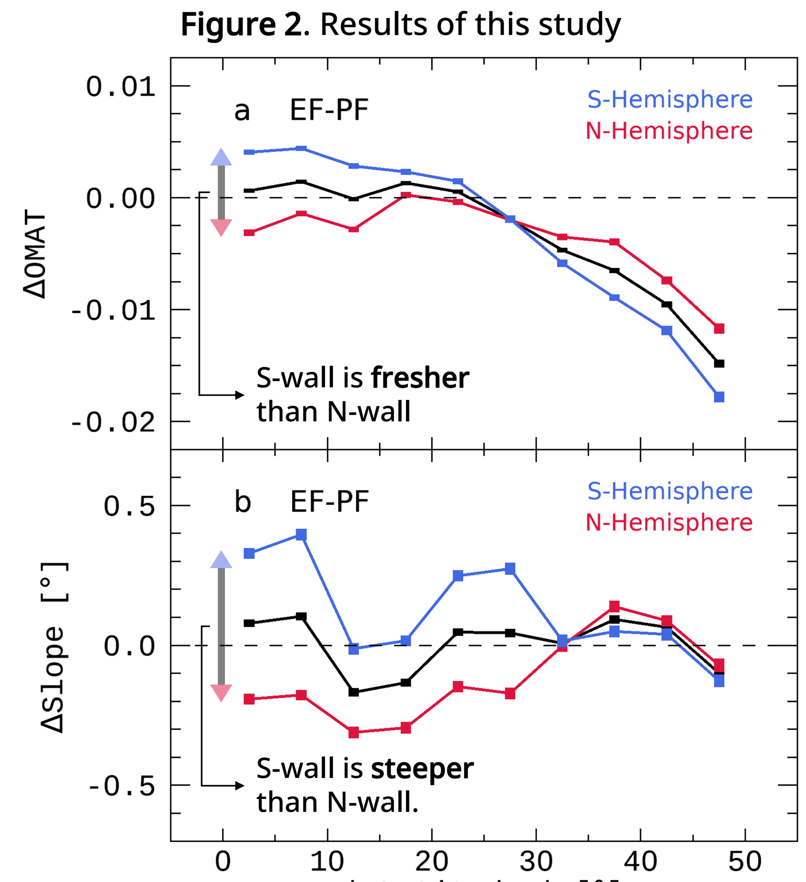


Figure 2. Results of this study



Latitudinal Trends of Δ (= [Equator Facing] – [Pole Facing])

- ΔOMAT of all craters (dark solid line in Figure 2a) is consistent with the previous study (Figure 1), it should be close to zero near the equator and increases toward higher latitudes.
- It means that incident angles of EF and PF walls are similar near the equator because space weathering agents are known to enter along the ecliptic plane.
- For the similar reason, Northern (N) and southern (S) hemispheres should be symmetrical. In Figure 2, red and blue solid lines represent the N and S hemispheres, respectively.
- We analyzed the ΔOMAT in N and S hemispheres separately in order to confirm the symmetry using more craters than the previous study.
- However, the ΔOMAT in the N (red solid line) and S (blue solid line) hemispheres are not close to zero near the equator and have opposite trends below 25° of latitude.
- ΔSlope also has the asymmetries and the opposite trends throughout the latitude.

More Detailed Analysis with Morphological Features of the Craters

- In Figure 3, We performed more specific analysis with three features that are diameter, slope, and depth-to-diameter (= d/D).
- Δ ~ 0 near 0 degrees in latitude regardless of diameter, slope, and d/D. It means that they are not causes of latitudinal asymmetry between N- and S-hemispheres.
  - In other words, the latitudinal asymmetry is likely to be caused by the space environment, not by natural processes on the lunar surface.
- We speculate that this unexpected result is caused by asymmetric impacts of meteoroids in the northern and southern hemispheres on the Moon.
- When meteoroids enter from the direction of the N hemisphere, probably 20 degrees or more in latitude, the S-wall of a crater experiences stronger impacts with more meteoroids than the N-wall near the equator.
  - The S-wall is fresher and steeper than the N-wall because the impacts excavate fresh regolith of the subsurface and small craters created by the impacts within the wall have steeper slope than their primary crater's wall.
- Merisio et al. (2023) show that subradiant positions of meteoroids are distributed along strips on the N hemisphere (between 0° and 45° in latitude). On the other hand, actual impacts location on the lunar surface are spread over wider regions.

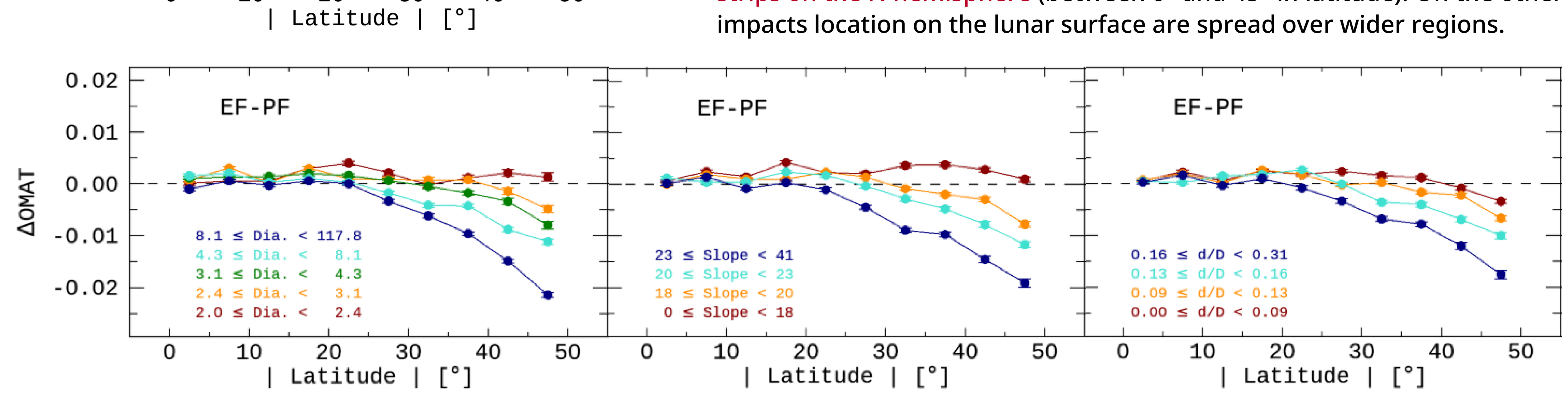


Figure 3. The results subdivided by diameter (left), slope (middle), and depth-to-diameter (right)