SLOPES OF DUNE SLIP FACES ON THE EARTH AND MARS: M. A Kreslavsky[1] and A. I. Ermakov[2], [1]Earth and Planetary Sciences, University of California, Santa Cruz, CA, 95064, USA, mkreslav@ucsc.edu, [2]Earth and Planetary Sciences, University of California, Berkeley, CA, 94720, USA

Introduction: Slip faces on lee sides of dunes are tilted at the dynamic angle of repose of sand. The angle of repose of terrestrial sand is known to be rather well constrained (30° – 35°) and slightly vary depending on shape and friction coefficient of sand particles. Sand avalanches developing on the slip faces are slow, therefore dynamic, inertial effects in their propagation are minor, and the difference between the static and dynamic angles of repose is expected to be minor. At the particle contact, the maximum tangential static friction force is proportional to the normal pressure force, which is proportional to gravity. Due of this, at the first approach, the static angle of repose is expected to be independent on gravity, and the dune slip faces on Mars are expected to be as steep as on the Earth with all other parameters being equal (e.g., [1]). On the other hand, experiment on low-gravity airplane flights [2] showed that at reduced gravity the static angle of repose is steeper, dynamic angle of repose is gentler. Applicability of those experiments to natural dunes is questionable because of significant difference in environments: dynamic nature of rotating drum experimental settings and mobilization of granular medium due to airplane vibration might play some role. This makes it interesting to compare actual slip faces of dunes on the Earth and Mars. We have preliminary shown that the slip face slopes on both planets are the same [3]. Here we report on a more detailed study of this topic.

Earth: Lidar data provide precise topography measurements with better than 1-m spatial resolution. Repeating lidar surveys of White Sands dune field (WSD) in New Mexico, USA was used to crack changes in active dunes [4]. We used lidar data available from http://opentopography.org to calculate topographic gradients at 4 m baseline and local 2D slopes (absolute value of topographic gradient). **Fig. 1** shows slope-frequency distributions calculated for the same 6 km^2 sample area in the dune field from the data [5-8] obtained on different dates. In the topographic data acquired on Jan 24, 2009 [5] (bold cyan line in Fig. 1) we see a sharp distribution spike centered at 32.5° slope, which corresponds to slip faces. All resolved slip faces were facing NE (**Fig. 2**), consistent with persisting SW winds in the region [4]. On Sep. 26, 2009 [6] such distribution spike was completely absent (red curve in Fig. 1), and slopes steeper than 30 deg were infrequent. This was related to winds of atypical direction in Aug. and Sept. 2009, according to meteorological data [4]. We ensured that the striking difference in the slope distribution is not an observational artefact. The slip faces were restored by the next survey on June 6, 2010 [7] (thin black curve in **Fig. 1**); their orientation was very similar (but not identical) to the original one (**Fig. 2**). One more data set obtained on Aug. 8, 2015 [8] (green curve in Fig. 1) shows less expressed slip faces compared to those in 2010. This example illustrates how easily bulk statistics applied to the high-quality lidar data can reveal interesting information about dunes.

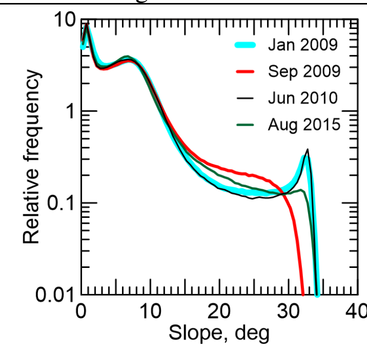

Fig. 1: Slope-frequency distribution for White Sands Dunes on different dates

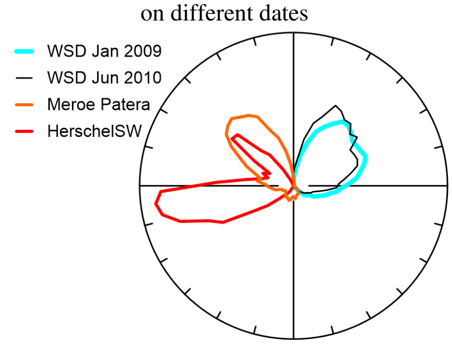

Fig. 2: Orientation-frequency distribution of slip faces (slope >30°) for White Sands Dunes on different dates and for two sites on Mars.

We compare in **Fig. 3** slopes in WSD (2010 data set, thin black curve, the same as in Fig. 1) with slopes calculated in the same way for a 6 km^2 sample from Great Sand Dunes (GSD) in Colorado, USA (lidar data from [9]). GSD also show a sharp peak in the slope-frequency distribution, which corresponds to slip faces of the dunes, however, this peak is at 29.5°. Due to high lidar data precision and involvement of a huge number of individual slope measurements, the typical slopes of the slip faces are very well defined; the uncertainty in the estimate of the typical slip-face steepness is less than 0.3°, and the systematic difference of 3° between WSD and GSD is reliably measured. Other sample areas within active parts of the WSD and GSD consistently give slip face steepness within 0.5° of 32.5° and 29.5° respectively. Thus, there is a systematic difference in slip face slopes between WSD and GSD. It is likely related to the difference in dune material: GSD sand is dominated by quartz, while WSD contains much gypsum.

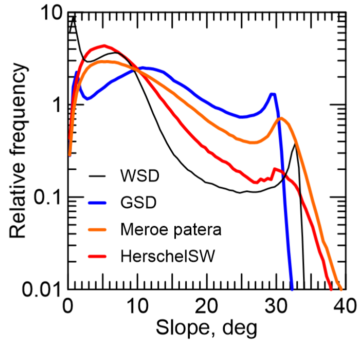

Fig. 3: Slope-frequency distribution for two terrestrial and two martian dune fields.

Mars: Large topographic data sets suitable for analogous analysis of dune slip face slopes on Mars are digital terrain models (DTMs) obtained by photogrammetric processing of stereo pairs of images [10] obtained by HiRISE camera onboard MRO orbital mission to Mars. Although such DTMs have 1-m sampling, their actual resolution is usually worse and highly inhomogeneous; vertical precision is also worse than for lidar. Typically, the DTMs are unsuitable for systematic statistical studies of the dune slip faces. The steep slip faces often cast shadows, which makes stereo-derived DTM quality very low locally. Even if illuminated, the slip faces are usually featureless, therefore, there are no explicit or implicit tie points for stereo processing in the middle of slip faces. Sometimes, bad DTM quality is obvious just from visual inspection of shaded relief DTM rendition; sometimes DTM looks good, and special assessment of the source stereo images is needed to understand that the DTM is unreliable. Reliable slip face slope retrievals are never possible at high latitudes and for east-faced slip faces because of shadows (all low- and mid-latitude HiRISE images are taken under afternoon illumination, that is from the west or northwest or southwest, and east-facing steep slopes are in shadow.) Our analysis of HiRISE DTM quality showed that actually only west-facing steep slopes at low and mid-latitudes can be reliably analyzed. This excludes the majority of martian dune fields from the analysis.

We found a few HiRISE DTMs of sufficient quality with abundant west-facing slip faces. One of them (7.2°N 67.8°E) [11] is located in Syrtis Major, in a barchanoid field traveling from Meroe Patera westward. A slope-frequency distribution for a 6 km^2 sample area is shown in **Fig. 3** (orange line). The distribution peak reflecting the slip faces is clearly seen and centered at ~31°. This peak is much wider than analogous peaks for terrestrial dune fields WSD and GSD (Fig. 3). At least partly this is caused by worse precision of HiRISE DTM in comparison to terrestrial lidar data. Azimuth distribution of the slip face orientation (**Fig. 2**) is narrower than for terrestrial dunes. Data imperfections would cause distribution widening rather than narrowing. For barchans, even if they are forming under stable winds, the slip faces on the horns deflect significantly from the downwind direction. It is probable that in the case of Meroe Patera dunes slip faces associated with barchanoid's horns are too short and are not sufficiently resolved in 4 m baseline slope data.

Another analyzed HiRISE DTM (16.3°S 128.3°E) [12] covers a part of a dune field in an unnamed 60-km crater superposed on SW rim of Herschel basin in Terra Cimmeria. The slope-frequency distribution for a 6 km^2 sample (red in **Fig. 3**) shows a peak at ~30° rather similar to the Meroe Patera dunes. Azimuth distribution (**Fig. 2**, red curve) shows two sharp maxima. It is not clear, whether this indeed reflects two slightly different dominating wind directions, or it is just noise (which is possible because the total area of slip faces here is small), or it is some observational artefact.

Conclusions:

1. High precision, resolution, and quality of terrestrial lidar data enable accurate informative statistical analysis of dune slip faces. Martian HiRISE DTM only occasionally can be used to study slip faces.

2. There is a minor but accurately measured systematic difference in the slip face slopes (and the dynamic angle of repose) between WSD and GSD sands potentially caused by differences in sand material.

3. The presence of slip faces varies in time at a time scale of months.

4. We did not observe systematic difference in the slip face slopes (and the dynamic angle of repose) between martian and terrestrial dunes.

References: [1] Melosh, H. J. (2011). Planetary surface processes. Cambridge Univ. Press. [2] Kleinhans M. et al. (2011) JGR 116, E11004. [3] Ermakov A. I. et al. (2019) JGR 124, 14–30. [4] Pedersen et al. (2015) Earth Surf. Process. Landforms 40, 925–941. [5] DOI: 10.5069/G9Q23X5P [6] DOI: 10.5069/G9ZK5DMD [7] DOI: 10.5069/G97D2S2D [8] http://opentopo.sdsc.edu/usgsDataset?dsid=USGS_LPC_NM_WhiteSands_2015_LAS_2017 [9] http://opentopo.sdsc.edu/ usgsDataset?dsid=CO_San-Luis-Valley_2011 [10] Kirk R. (2008) JGR 113, E00A24. [11] https://www.uahirise.org/dtm/dtm.php?ID=ESP_051084_1875 [12] https://www.uahirise.org/dtm/dtm.php?ID=PSP_004350_1635