Laboratory studies of dust devil sediment flux: Comparison with data from Gusev Crater, Mars

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Introduction. Although dust devils are common atmospheric phenomena on Earth and Mars, they are not completely understood. Sediment flux estimates for Earth, and especially Mars, are important for deciphering the complex nature of the dust cycle and have implications for the global weather patterns on Mars. Previous measurements of sediment flux on Earth are limited to work done by Metzger [1], in which 5 dust devils were sampled. On Mars, the best estimates of sediment flux were conducted optically by Greeley et al. [2], with the *Mars Exploration Rover, Spirit*. Greeley et al., [2] reported dust devil sediment fluxes ranging between 3.9×10^{-9} and 4.59×10^{-4} kg m^{-2} s^{-1} – five orders of magnitude. Sediment flux in dust devils is controlled by the interplay between lift forces from surface shear stresses from the motion of air across the surface and the "ΔP-effect" of the low pressure core on the loose sediment. Core pressure drops in natural dust devils tend to be between 0.01 to 1.0% of ambient pressure for Earth and Mars. Balme and Hagermann [4] suggested that the lifting potential of the "ΔP-Effect" allows grains to be lifted when the pressure force to gravity force ratio is greater than or equal to 1, which means smallest grains (dust and fine sand) would be the most affected by the presence of a low-pressure core. In this abstract we report of experiments that explore the interplay between these two lifting mechanisms for flat surfaces and three different roughnesses over a range of particle sizes and densities.

Approach. We used the Arizona State University Vortex Generator (ASUVG), presently situated at the Planetary Aeolian Laboratory (PAL) at NASA Ames Research Center to allow low-pressure Mars-analog studies. Pressure profiles for a range of ASUVG settings allowed characterization of the vortex parameters (maximum tangential velocity, core radius, and maximum ΔP) for the four surfaces (no roughness, low, medium, and high roughness). The pressure profiles consisted of time averaged pressure measurements from 13 pitot ports on the test bed, which could be related to the tangential velocity and core radius by assuming cyclostrophic balance. Plots of tangential velocity as a function of radius were fit to the Lamb-Oseen vortex equation.

Mass-loss measurements were taken as a function of vortex size and speed, and time, which allowed the calculation of the sediment flux (kg m^{-2} s^{-1}). Sediments in this study included samples ranging in composition (silica, walnut shells, aluminum oxide, chromite, clay), density (~1300-4800 kg m^{-3}), and particle size (~2-1500µm). The same mass-loss experiments were then repeated for different sediments over 4 different surfaces (no roughness, low, medium, and high roughness).

The roughness beds were constructed with circular wooden elements glued to the test surface in regular arrays. Aerodynamic roughness values were approximated using the ratio of the height (H) to the spacing (D) of the elements. This parameter serves as a surrogate for the aerodynamic roughness length and a good classifier for the differences in roughness.

Laboratory data were compared to the recent measurements of dust devils over the last two martian summers, from Gusev Crater, Mars obtained by the *Mars Exploration Rover, Spirit.*

Results and Discussion. Sediment flux for laboratory conditions (all roughnesses) ranged from 9.42×10^{-6} to $\sim1.0\times10^{0}$ kg m^{-2} s^{-1} for core radii, 0.027 to 0.055 m (terrestrial ambient) and 0.048 to 0.075 m (low-pressure) with corresponding maximum tangential velocities, ~1.0 to 8.0 m s^{-1} (terrestrial ambient) and ~17.0 to 45.0 m s^{-1} (low-pressure). Maximum pressure drops were between 0.02 to 1.53 mbar (~0.01-0.2% of ambient) for terrestrial conditions and 0.02 to 0.50 mbar (0.2-5% of ambient) for the low-pressure cases (Figure 1).

In all cases, sediment flux remained constant. However, maximum tangential velocity was reduced as core radii increased. This suggests that vortices expand to encompass the roughness elements that are significant compared to the size of the core. The lack of apparent change in sediment flux is due to the capability of the vortex generator to run at a wide range of core pressures for the same-sized vortex. In order to achieve similar fluxes, the higher roughness bed required larger ΔP and hence higher velocities, to accommodate for the loss of energy to the surface as a result of the increased roughness.

Roughness elements in these experiments represent the first attempt to simulate the interaction of surface roughness with dust devil flow. The scale for these elements would represent large boulder fields in natural equivalents. For the low roughness case, roughness elements ranged from ~6 to 16% of the vortex sizes used. Medium roughness ranged from ~11 to 16%, and the high roughness case ~8 to 11% of the size of the vortices used in the experiments. For the majority of dust devils on Earth and Mars this would equate to small to large boulders in the smallest cases and upwards of small hills or hummocks for the largest cases.

Lab vortices are considerably smaller than their natural counterparts, although mechanically they behave similarly. Comparison of the lab data to the field for Earth and Mars allows estimation of the strengths of the martian dust devils observed over the last two summers in Gusev Crater. Of the 700+ observed dust devils from *Spirit*, similar ranges in fluxes are observed as in the lab: ~5-6 orders of magnitude. Lab observations suggest that smaller vortices tend to have higher fluxes when all else is equal [5]. ASUVG data plot linearly with natural cases on log-log plots, suggesting a simple scaling relationship with core radius (Figure 2). The 5-order of magnitude spread in the data shows variations in either the strength of individual core pressures or variations in the surface roughness. Considering the floor of Gusev is relatively flat (minor differences in roughness of similar scale to lab roughnesses) over the area where dust devils were observed, variations in dust devil flux are probably due to variations in strengths of the core pressure.

Observations of dust devils in Gusev Crater present the opportunity to study sediment flux more quantitatively on Mars. However absence of wind velocity and atmospheric pressure measurements hinders the complete comparison of laboratory studies to the field. Ideally comparison of lab roughnesses should be scaled to measurements of surface roughness from the site in question. HiRISE data now available for Gusev Crater should make this possible in the near future. At the meeting we will report additional results on further comparisons to the surface properties in Gusev Crater.

References.

[1] Metzger, (1999) PhD Dissertation, UNR; [2]Greeley et al., [2006], JGR, doi:10.1029/2006JE002743; [3] Greeley et al., [2003] JGR, doi: 10.1029/2002JE001987; [4] Balme and Hagermann [2006], GRL, doi:10.1029/2006GL026819; [5] Neakrase et al., [2006], GRL, doi: 10.1029/2006GL026810

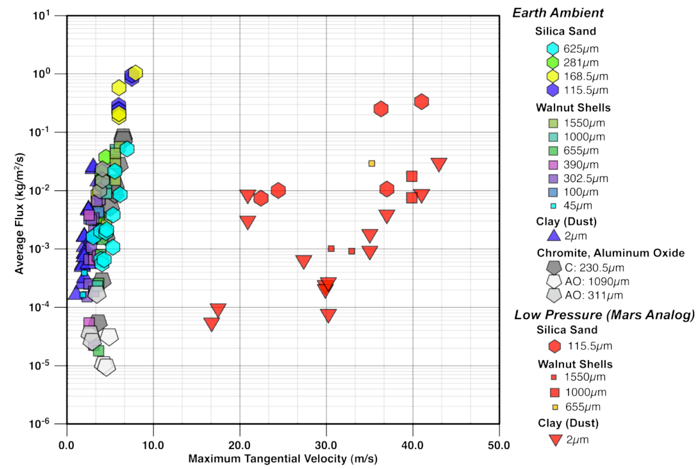

Figure 1. Average flux vs. maximum tangential velocity for vortices moving over a range of sediments used in lab, under terrestrial ambient and low-pressure (Mars analog) conditions.

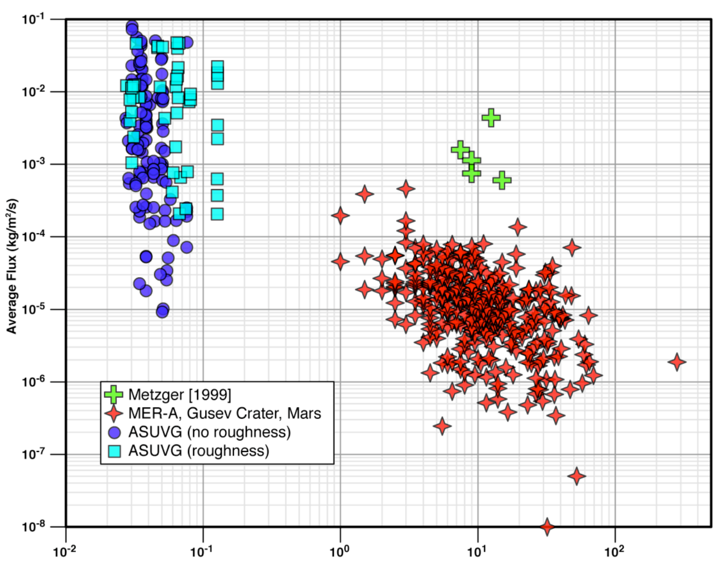

Figure 2. Plot showing all laboratory flux data including roughness points as a function of core radius, compared to [1] data for terrestrial dust devils and [2] data for Gusev Crater, Mars.