THRESHOLD FOR SAND MOBILITY ON MARS CALIBRATED FROM SEASONAL VARIATIONS OF SAND FLUX.
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Introduction Coupling between surface winds and saltation is a fundamental factor governing geological activity and climate on Mars. Saltation of sand is crucial for both erosion of the surface and for the emission of finer (dust) particles into the atmosphere. Wind tunnel experiments and theory based on assumed interparticle cohesion along with measurements from surface meteorology stations and modeling of wind speeds suggest that winds should only rarely move sand on Mars. Whereas wind-induced dust emission has been observed to dominate large dust storm onset, evidence for currently active dune migration has only recently accumulated. Crucially, the frequency of sand-moving events and the implied threshold wind stresses for saltation have remained unknown. Here, we present detailed measurements over Nili Patera dune field based on HiRISE images, demonstrating that sand motion occurs daily throughout much of the year and that the resulting sand flux is strongly seasonal. Analysis of the distinctive seasonal variation of sand flux suggests an effective threshold for sand motion for application to large scale model wind fields (1-100 km scale) of 0.01 ± 0.0015 N/m^2.

Seasonal sand flux measurements: We examine a time-series of HiRISE images [1] of the Nili Patera dune field (8.8°N, 67.3°E) over the course of a Mars year to determine the seasonal distribution of sand transport. Nine optical images at 25 cm pixel scale were acquired at the eastern (upwind) edge of the dune field covering an area of ~ 43 km^2. The migration of the sand ripple laying on top of the dunes is measured using the Co-registration of Optically Sensed Images and Correlation (COSI-Corr) methodology [2]. For each pair of images, a “difference” image is constructed that represents the magnitude of ripple migration during the analyzed time interval. In a second step, we apply a principal component-based analysis which takes into account the uncertainties assigned to each local measurement. In practice, we use the first 2 components, which are able to account for more than 80% of the original data variance. This approach produces a time-series of ripple migration images with non-correlated noise filtered out (Fig. 1). We estimate next the average sand flux over each time interval based on ripple migration [3].

We observe a sustained sand flux throughout the year with a strong seasonal variation: during the southern summer period, which includes perihelion, the flux is about three times larger than during the northern summer. All the analyzed pairs show evidence of significant ripple migration, even two pairs of images taken only 17 or 16 days apart. Over these two consecutive periods the average flux is different by a factor of two, suggesting that while sand-moving wind events were probably numerous during both of these short time periods, the variability in frequency, duration, and/or strength of these winds must have been large (Fig. 2). However, the south-westward direction of the flux, indicated by the migration direction of the sand ripples, is stable over the year, indicating a fairly constant direction of sand-moving winds.

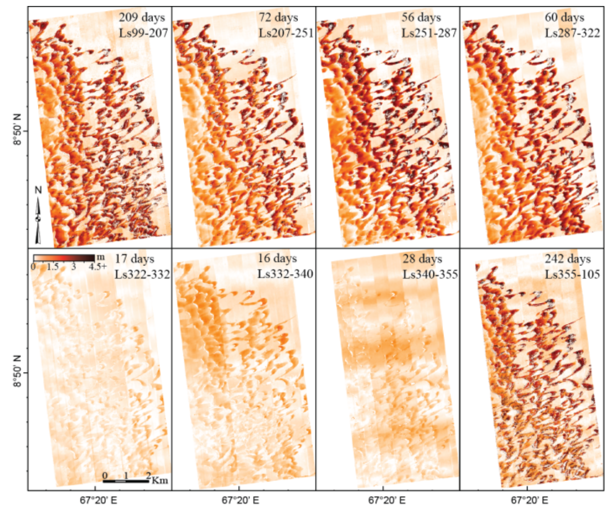

Figure 1: Time-series of the ripple displacement maps over the course of one Mars year at Nili Patera dune field.

Wind shear stress threshold constrain: We use the observed seasonal evolution of the sand flux to estimate an effective wind stress threshold. To do so, we simulate the seasonal evolution of sand flux using a numerical atmospheric model, and adjust the stress threshold used in the sand flux equation such that the predicted seasonal flux variation matches the observed one. Our numerical modeling of the wind field uses the MarsWRF system [4], a multiscale, nonhydrostatic Mars atmospheric model based on the NCAR Weather Research and Forecast (WRF) system. The model was sampled in seasonal windows over the annual cycle, with near-surface winds, densities, and wind stresses output every Martian minute (1/1440th of a Martian day or sol; see also Methods) on a grid spacing scale of 120 km (O[120 km]). A variety of sand transport laws have been proposed which relate the sand flux to the wind stress, τ, in excess of some threshold wind stress, τ_s. To investigate the sensitivity of our analysis to the chosen law, we predict the sand flux, q, using four different equations. Because we are matching the seasonal variation of flux (i.e., the relative flux, rather than the absolute magnitude of flux at a given time) the constants at the start of the equations are factored out:

$$q \propto \rho u^{*2}(u^* - u_t^*) \quad [5]$$

$$q \propto \rho(u^{*2} - u_t^{*2})^{1.2} \quad [6]$$

$$q \propto \rho u_t^*(u^{*2} - u_t^{*2}) \quad [7]$$

$$q \propto \rho(u^{*3} - u_t^{*2}/u^*)(\alpha + \gamma\, u_t^*/u^* + \beta\, u_t^{*2}/u^{*2}) \quad [8]$$

where u_t^* is the threshold velocity calculated from the atmospheric density, ρ , and stress threshold $\tau_s = \rho(u_t^*)^2$.

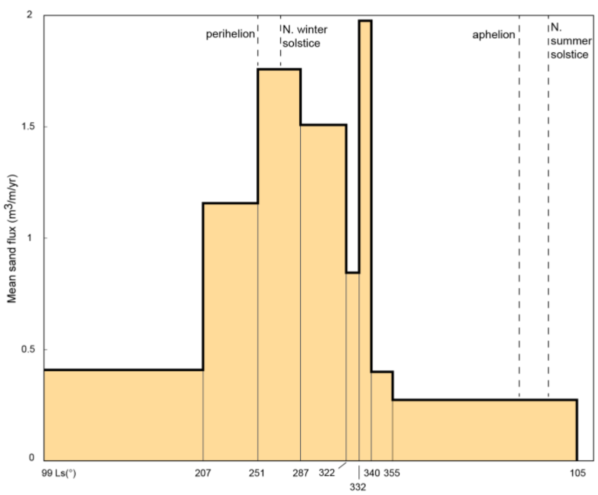

Figure 2: Sand flux seasonal variation.

The seasonal evolutions of sand flux at O[120km] for the four sand flux formulations are predicted for 25 values of the stress threshold ranging from 0.001 to 0.025 N/m^2, with a step of 0.001 N/m^2. The most noticeable aspects of these results are the similarity of the predicted sediment fluxes between the four transport laws tested, and that a strong seasonal variation is predicted in all cases. However, the observed ratio of the summer to winter sand flux is globally reproduced in the predictions for only a limited range of threshold stresses. If the threshold is larger than 0.015 N/m^2, the predicted summer flux drops to nearly zero and the predicted ratio of winter to summer sand flux is significantly too large. Conversely, if the stress threshold is smaller than 0.05 N/m^2, the predicted ratio of winter to summer sand flux is too small, less than half the ratio observed. The shear stress threshold for sand motion is thus estimated to be $\tau_s = 0.01 \pm 0.0015\ N/m^2$ for simulation at a grid scale of O[1-100 km].

Discussion: The value of stress threshold inferred should be interpreted as the effective threshold for the instantaneous mean wind over scales up to a few degrees. This threshold is much lower than would be expected for turbulence-resolving models, wind tunnel experiments, or lander-based local *in situ* observations, and this study does not address the nature of the mapping from O[1-100 km] scales to the local scale (O[1-1000m]) which may vary spatially with factors such as the interparticle cohesion, grain size or surface roughness. However, the estimation of the O[1-100 km] threshold stresses estimated here is relevant to estimate dust lifting, sand motion, dune formation, and aeolian erosion based global and mesoscale models.

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Note: This material is subject to press embargo.