Controls on the spacing and size of Martian polar dunes from a buried ice table.

Serina Diniega[1], Shane Byrne[2], and Karl Glasner[3], [1]Program in Applied Mathematics, The University of Arizona, 617 N. Santa Rita Ave., P.O. Box 210089, Tucson, AZ 85721-0089 (serina@math.arizona.edu), [2]Dept. of Planetary Sciences, The University of Arizona, [3]Dept. of Mathematics, The University of Arizona

Introduction

Many barchan dune corridors appear to contain dunes of stable size and spacing [1], and dune fields often exhibit regular patterns [2, 3] with apparent characteristic size and spacing (figure 1). It is still an open question as to what sets this characteristic scaling – local conditions such as topography or sand supply, or common dynamic processes such as those relating to saltation. Additionally, it is unknown whether the characteristic scaling is dependent on the initial dune size and spacing or on environmental conditions and dune interactions that vary in time and/or space.

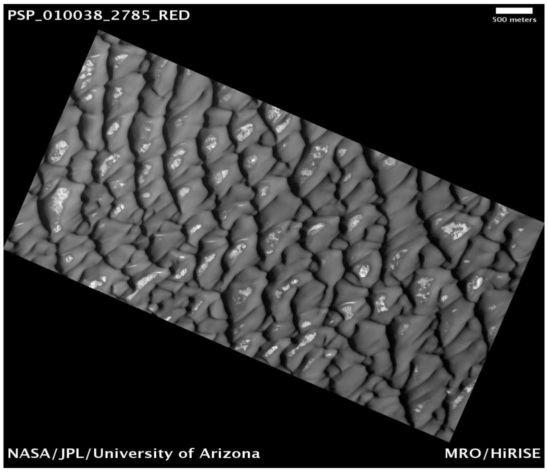

Figure 1: This image (HiRISE PSP_010038_2785; 81.2^{o}N, 180.2^{o}E) shows a Martian polar dune field, where most dunes appear to be the same size.

Hersen et al. [4] showed analytically that individual dunes which evolve only through sand flux will eventually coalesce into a small number of large dunes without a characteristic scaling. Hersen and Douady [1] showed analytically that collisions between dunes could be a viable sand redistribution process, and Diniega et al. [5] used a multiscale model to show that in fact dune collisions will stabilize a modeled dune field as long as a sufficient number of dune collisions redistribute sand from the larger to the smaller dune (figure 2). Elbelrhiti et al. [6] observed that additional stochastic processes, such as variations in wind strength and direction, destabilize large dunes and thus can play a role in size selection in dune fields.

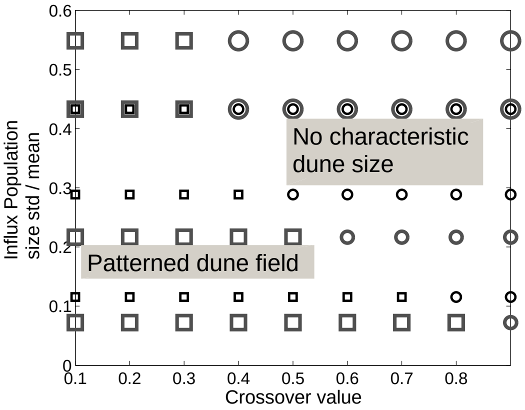

Figure 2: Plot from Diniega et al. [5], which shows the 2D dune field model end state as a function of two model parameters: the minimum size ratio between the colliding dunes where sand is redistributed from the larger dune to the smaller dune for all higher size ratios (crossover value), and the standard deviation/mean ratio of the sizes of the influx dunes. The two possible end states are: patterned (squares) fields with a characteristic dune size, or fields with a few dunes which grew much larger than their neighbors and thus did not exhibit any characteristic scaling (circles). The boundary between the regions corresponding to each end state is independent of other model parameters, including mean influx dune size (40m^2 = small point markers vs. 100m^2 = large point markers).

In current investigations, we aim to consider the effect of topography on dune size and spacing, both during dune initialization and subsequent evolution.

Topographical controls

Most contemporary dune models have considered dune initiation and evolution over flat surfaces. These studies have shown that there is a minimal dune size at which dunes will form [7, 8], but have not yielded a characteristic final size for dunes. In this study, we will investigate the effect of isolated and periodic topology on dune formation and evolution. If an effect is found, we aim to quantify how the characteristic scaling of dunes is influenced by the shape of the topography.

Influence of evolving topography

Recently, interest has risen in studying dune evolution in polar regions, as many Martian dunes are found near the poles and their apparent slow migration rates are perhaps due to interactions between nivean and aeolian processes. Bourke et al. [9] investigated the influence of niveo-aeolian deposits, and Zeng et al. [10] considered the effect surface fractures have on dune initiation and distribution. We hypothesize that the intrusion of subsurface ice into dunes may also influence dune formation and evolution. Feldman et al. [11] has shown, by matching neutron current measurements with two-layer models of the surface, that there may exist an ice-rich (and immobile) subsurface layer with an $\sim$ 6cm relatively desiccated (and mobile via saltation) sublimation lag in the polar regions of Mars, which includes areas where dune fields are observed.

Using a basic linearized dune evolution model (similar to that outlined in Andreotti et al. [12]), we add in an evolution equation for the topography. This equation assumes that the subsurface ice layer is continuously evolving towards an equilibrium depth, via equations and rates such as those given in Hudson et al. [13]. Although estimates of subsurface ice migration rates are much lower than saltation rates, it is estimated that Martian winds are rarely high enough to initiate and sustain saltation [8]. If this is the case, then the very long timescales estimated for Martian dune evolution and migration are comparable to estimates for significant subsurface ice layer evolution [13].

First, we will try to estimate, through computational and analytical methods, the magnitude of ice layer migration rates (relative to saltation rates) that would be necessary for interaction between these two processes, as well as the timescales over which observable surface differences would occur. We will then numerically model 2D dune evolution (figure 3), and compare dune shapes, sizes, and spacings with HiRISE images of Martian polar dune fields.

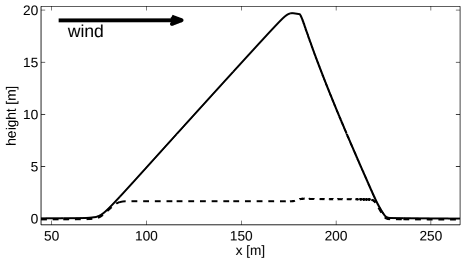

Figure 3: Sample figure from dune and ice layer evolution model; the solid line is the dune topography (initialized as a triangular heap), and the dashed line is the subsurface ice layer (initialized as a flat plane at 0 m, with an equilibrium depth of 10 cm). In this model run, the subsurface ice migration rate was chosen to be comparable to the saltation rate, resulting in the ice table intruding into the dune and slowing saltation near the dune foot.

References

[1] P. Hersen and S. Douady. Collision of barchan dunes as a mechanism of size regulation. *Geophysical Research Letters*, 32:L21403, 2005.
[2] G. Kocurek and R. C. Ewing. Aeolian dune field self-organization – implications for the formation of simple versus complex dune-field patterns. *Geomorphology*, 72:94–105, 2005.
[3] M. A. Bishop. Point pattern analysis of north polar crescentic dunes, Mars: A geography of dune self-organization. *Icarus*, 191:151–157, 2007.
[4] P. Hersen, K. H. Andersen, H. Elbelrhiti, B. Andreotti, P. Claudin, and S. Douady. Corridors of barchan dunes: stability and size selection. *Physical Review E*, 69(1):011304–1 – 12, January 2004.
[5] S. Diniega, K. Glasner, and S. Byrne. Long-time evolution of models of aeolian sand dune fields: influence of dune formation and collision. In *Geomorphology, special edition: Planetary Dunes Conference Proceeding*, in review.
[6] H. Elbelrhiti, P. Claudin, and B. Andreotti. Field evidence for surface-wave-induced instability of sand dunes. *Nature*, 437:720–722, 2005.
[7] P. Claudin and B. Andreotti. A scaling law for aeolian dunes on Mars, Venus, Earth, and for subaqueous ripples. *Lunar and Planetary Science Letters*, 2006.
[8] E. J.R. Parteli and H. J. Herrmann. Dune formation on the present Mars. *Physical Review E*, 76:041307–1–16, 2007.
[9] M. C. Bourke, K. S. Edgett, and B. A. Cantor. Recent aeolian dune change on Mars. *Geomorphology*, 94:247–255, 2008.
[10] Z. Zeng, H. Xie, S. J. Birnbaum, S. F. Ackley, and L. Liu. A structural solution for the formation of dunes in the Martian polar region. In *Lunar and Planetary Institute Conference Abstracts*, page 2050, 2008.
[11] W. C. Feldman, M. C. Bourke, R. C. Elphic, S. Maurice, T. H. Bandfield, T. H. Prettyman, B. Diez, and D. J. Lawrence. Hydrogen content of sand dunes in Olympia Undae. *Icarus*, 196:422–432, 2008.
[12] B. Andreotti, P. Claudin, and S. Douady. Selection of dune shapes and velocities, Part 2: A two-dimensional modeling. *The European Physical Journal B*, 28:341–325, 2002.
[13] T. L. Hudson, O. Aharonson, N. Schorghofer, C. B. Farmer, M. H. Hecht, and N. T. Bridges. Water vapor diffusion in Mars subsurface enviroments. *Journal of Geophysical Research*, 112:E05016, 2007.