QUANTIFYING DUNE INTERACTIONS ON PLANETARY SURFACES: EXPLORING PATTERN DEVELOPMENT DEPENDENCE ON ENVIRONMENTAL CONDITIONS. M. C. Marvin[1], A. Gunn[1,2], M. Day[3], and M. G. A. Lapôtre[1], [1]Department of Geological Sciences, Stanford University, Stanford, CA, USA (mcmarvin@stanford.edu). [2]School of Earth, Atmosphere & Environment, Monash University, Clayton, VIC, Australia. [3]Department of Earth, Planetary, and Space Sciences, UCLA, Los Angeles, CA, USA.

Introduction: Windblown bedforms are found on many planetary surfaces and are one of the most common landforms in the Solar System. Dunes and ripples have been identified on Venus, Earth, Mars, Titan, Pluto, and the 67P/Churyumov-Gerasimenko comet [1-3]. Dune morphology evolves in conjunction with formative winds and sediment availability (e.g., transverse dunes form under high sediment availability and unidirectional winds). Dunes are a sediment sink and hold a large sand volume relative to that entrained in a given transport event. Thus, the integrated effect of formative winds and sediment supply over relatively long (often > 1 kyr) timescales is reflected in dune morphology. Superimposed bedforms have a shorter reconstitution time and their orientation reflects higher frequency (e.g., seasonal) or more recent transport events. Consequently, bedform analyses offer a chance to interpret current and past planetary environmental conditions [4].

Dune fields are complex systems in which patterns emerge as dunes interact in a self-organizing manner. [5–6]. Previously, it was determined that dune fields with longer wavelengths, λ (m), have lower densities of interactions (where two or more dune crestlines are within 10% of the mean wavelength from each other) and dune defects (the pair of terminations of a given dune) [4,7]. Furthermore, it was suggested that dune-interaction density might enable scientists to decipher the age or maturity of planetary dune fields, and they are readily observable from orbital imagery.

Quantitative dune pattern analyses are typically performed from one of two parameters: defect density, ρ (the number of termination pairs per unit crest length, in m^{-1}) [4] or the interaction density, I (number of interactions per unit area, in m^{-2}) [7]. Both ρ and I roughly scale with λ^{-2} [7]. It was proposed that the dependency of I on λ did not vary across planets but that crescentic and linear dunes followed different relationships [7]. However, previous studies have defined the extent over which dune-interaction density as a function of dune wavelength – a method which can be demonstrated to inherently lead to $I \propto \lambda^{-2}$ and may yield different proportionality constants for crescentic and linear dunes [8]. Conversely, the average number of interactions per dune, α, is scale-independent [8] and may be used as quantitative metric to disentangle the role of environmental conditions on dune pattern development [8].

A scale-independent approach to quantifying dune interactions: Counting areas are selected by identifying a dune-field region with homogenous wavelengths and generating a circle of one-half the surface area of that region. This approach decorrelates the surface area of the counting polygon from dune wavelength and eliminates any bias related to dune migration direction relative to the shape of the counting area.

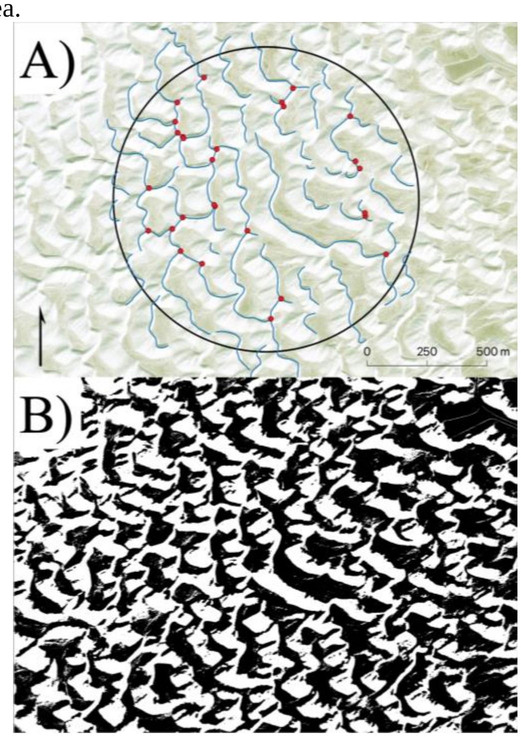

Figure 1: (A) Dune crestlines (blue lines), counting area (black circle), and interactions (red dots) at White Sands National Park. (B) Binary thresholding of dune field imagery, with white denoting sand cover and black interdune areas.

We count the number of dunes, N, as a decimal value (with only the fraction of a dune's crest length located within the circle counted; Fig. 1A). Dune interactions are defined as points where dune crestlines are within < 10% of the average λ from each other [7], which itself was determined from >35 crestline-normal measurements of λ per field and buffer polygons around all crestlines.

We compiled λ, α, I, crestline density (crest length per area, m^{-1}), sinuosity (length of crestline over end-to-end straight-line distance), and crestline azimuth for 35 dune-fields: 19 terrestrial dune fields (7 fields of crescentic dunes, 5 of linear dunes, and 5 fields with large compound dunes) and 15 martian dune-fields (10 crescentic and 5 linear, where five of the crescentic fields are in craters). We note that "linear" here refers to the geometry of individual crest segments, such that network dunes were counted as "linear." Furthermore, we derived the fractional sand cover within the counting area through binary thresholding of imagery within each counting area image (Fig. 1B); a sand cover of 1 implies the entire counting area is fully covered in windblown sand and values < 1 imply interdune areas are not covered with loose sand.

Preliminary results: We find that, when the size of the counting area is not correlated with dune wavelength, I still roughly decreases as λ^{-2} but trends for crescentic and linear dunes cannot be distinguished. We find that the average number of interactions per dune, α, does not significantly vary with crestline density (a proxy for dune density), percent sand cover (a proxy for sediment availability), or with the variance in crestline sinuosity (a proxy for the complexity of the wind regime; Fig. 3).

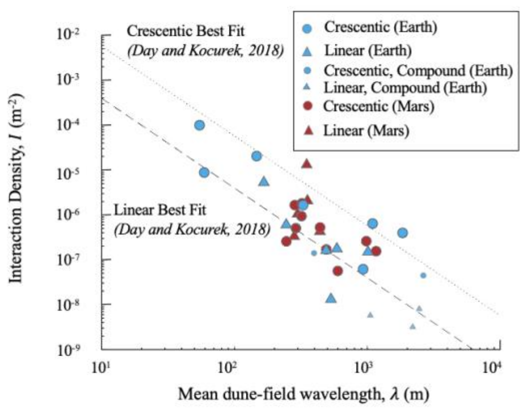

Figure 2: Interactions per area (m^{-2}) as a function of mean dune wavelength. Best fit lines for crescentic and linear dunes from [7] are shown for comparison.

Future Work and Conclusions:

Our proxies for dune density and sand availability (crestline density and sand cover) suggest that either these parameters do not exert a first-order control on α, or they are poor proxies for dune density and sediment availability. For example, crestline density does not incorporate any information about dune width, even though the latter influences the likelihood of two neighboring dunes to interact for a given spacing between their respective crests. The lack of a relationship between sinuosity variance and α is also surprising as, intuitively, dune-fields containing more sinuous dunes should lead to more dune interactions. Although such a trend might be gleaned for linear dunes, it is not observed for crescentic ones (Fig. 3). However, crestline sinuosity does not uniquely reflect the complexity of the wind regime. Further analyses, including of dune-crestline azimuth and of wind-data from global circulation models on Earth and Mars, will be performed. These preliminary analyses of terrestrial and martian dune fields, in study areas where environmental conditions are better constrained, will serve as a jumping-off point for future analyses of dune interactions on Venus, Titan, and Pluto.

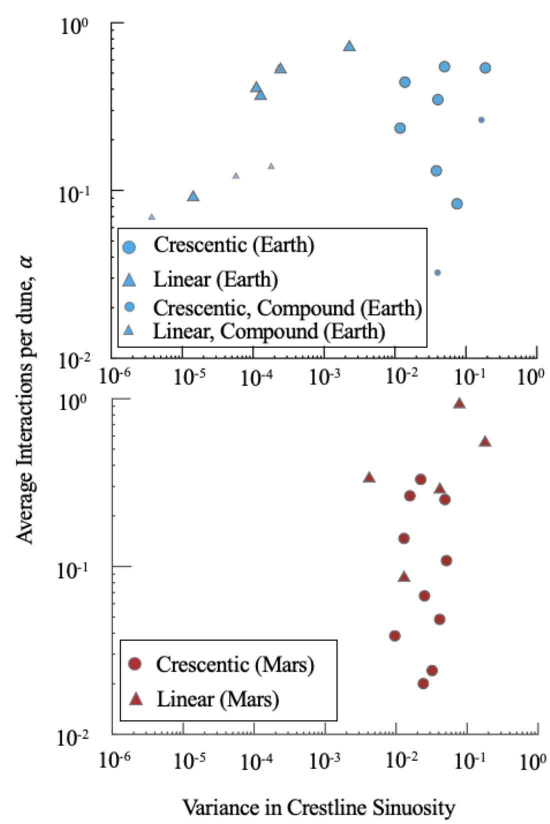

Figure 3: Average number of interactions per dune as a function of the variance in dune crestline sinuosity on Earth and Mars.

References: [1] Bourke M.C. et al., (2010) *Geomorphology, 121(1-2)*, 1-14. [2] Telfer M.W. et al., (2018) *Science, 360(6392)*, 992–997. [3] Thomas N. et al., (2015) *Astro. Astrophys., 583*, A17. [4] Ewing R.C. et al., (2015) *Nature Geoscience, 8(1)*, 15-19. [5] Werner B.T. (1997) *Geology, 23*, 1107–1110. [6] Werner B.T. and Kocurek G. (1999) *Geology, 27*, 727–730. [7] Day M. and Kocurek G. (2018) *Geology, 46*, 999–1002. [8] Marvin M. C. et al., (2021) *LPSC, 52*.