

## IMPACT RIPPLES: EMERGENCE AND SCALINGS ACROSS ENVIRONMENTS

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**Introduction:** Spontaneous pattern formations in sediment are observed on Earth and other planetary bodies [1,2]. Bed formations on other planetary bodies come in a variety of shapes and sizes—often taking forms similar to ripples and dunes found on Earth. Understanding the dynamical mechanisms responsible for extra-terrestrial bedforms—i.e. which type of Earth bedform they dynamically correspond to—is essential for interpreting the environmental conditions on other planetary bodies. The spatial scale of emergent bedform contain implicit information about quantities such as fluid velocity, grain size, fluid-grain densities, etc.

*Impact ripples.* Among the most ubiquitous patterns to be observed in sand on Earth are aeolian impact ripples – periodic, centimeter-scale bedforms that emerge through the mechanism of grains impacting (and collectively entraining more grains from) the granular surface. Impact ripples, in wind-tunnel experiments and in the field, exhibit characteristics that are not consistent with what we expect based on text book understanding on aeolian transport. For example, impact ripple wavelengths were thought to be scale independent with respect to wind-speed [3]—but observations seem to show otherwise [4]. Additionally, the wavelengths that spontaneously emerge from a flatbed are larger than expected [4]—much larger than the average ejection length. And on Mars, bedforms with similar characteristics as impact ripples are observed to have a variety of wavelengths—from Earth sized (10's of cm) to orders of magnitude larger.

Our dynamical understanding of impact ripples is evolving [5]. In this context, controlled experiments, field observations and detailed numerical models can play a valuable role in predicting the emergent scales of bedforms across planetary environments, and in determining correlations between impact ripple characteristics (wavelength, propagation speed) and measurable quantities (wind speed, grain size, densities) with the hope to better understand this highly complex system.

**Numerical Simulations:** In recent years, the granular physics/sediment transport community has transitioned towards a molecular dynamics approach to the problem—developing comprehensive discrete element models (DEM's) to numerically simulate grain scale phenomena and conduct precise experiments. We have developed a DEM for sediment transport that quantitatively agrees with experimental transport data and is able to produce aeolian impact ripples who's

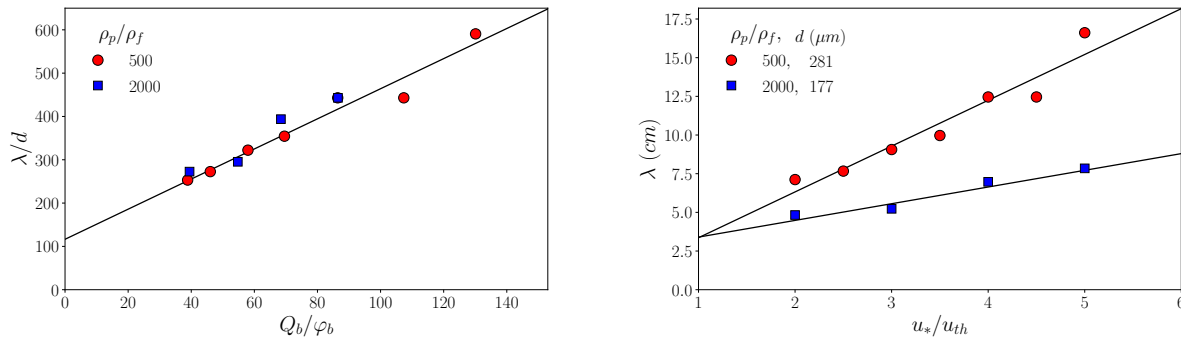
wavelengths and propagation speeds scale with wind speed in a way that is similar to observations in the field and in wind tunnel experiments [5]. Additionally, Durán et. al. (2014) [5] used this DEM to analyze what transport mechanisms might give rise to observed ripple scalings. They observed that emergent ripple wavelengths seem to scale with the ratio of the horizontal mass flux ( $Q$ ) to the erosion rate at the surface ( $\phi$ ). The DEM shows that this ratio is not constant with wind speed, as one might expect, but scaled approximately linearly with wind speed due to an unpredicted discontinuity in the scaling of the erosion rate at the surface [5].

Continuing the work of Durán et. al. (2014) [5], we use the DEM to conduct a series of numerical experiments in which we systematically vary key control parameters and observe the resulting ripple behavior. The goals of these simulations are: 1) verify the proposed ripple scaling with  $Q/\phi$ ; and 2) observe how well numerical ripples compare to existing field and experimental data under the same transport conditions.

Preliminary results show that simulated ripple wavelengths are comparable to experimental data in size, and they scale with wind speed similar to experimental data [4]. Additionally, ripple wavelengths under differing environmental conditions are seen to increase linearly with  $Q/\phi$  (Figure 1). We will present additional results and analysis for numerical experiments under a wide range of transport conditions to obtain statistically reliable relationships and comparisons to wind tunnel/field experiments.

## References:

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**Figure 1. Simulated Wavelengths:** Left panel shows wavelengths rescaled by grain diameter vs. the proposed scaling relationship, ratio of the horizontal flux to the erosion rate measured at the bed (subscript b). Right panel shows wavelength in centimeter units vs. the shear velocity/transport threshold ratio. Red (blue) symbols are for grain to fluid density ratio of 500 (2000). The right panel legend also shows the respective grain sizes in micrometers.