Coevolving aerodynamic and impact ripples on Earth: unifying bedforms on water, Earth and Mars

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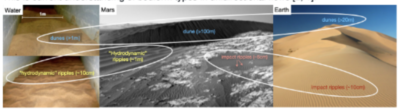
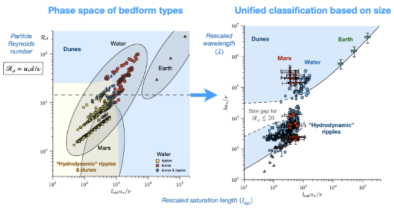
1. What we think we know

This is current understanding of bedform types in unidirectional flows [2, 1]:

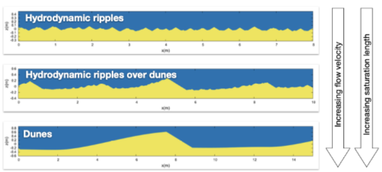


where **hydrodynamic ripples** are defined as the smallest bedforms of hydro(aero)dynamic origin, in contrast to the so-called **impact ripples** which arise from the interaction of hoping grains with the bed surface.

Theory – This classification was based on an improved understanding of the underlying physics. In agreement with the morphodynamic model [1], existing bedform data can be collapsed after rescaling all relevant lengths (grain size d, the transport saturation length l_{sat} and bedform wavelength λ) by the viscous length ν/u_*, where ν is the kinematic viscosity of the fluid and u_* is the friction speed in the fluid boundary layer. The transport saturation length l_{sat} is defined as the spatial lag between the bed shear stress and the transport rate.

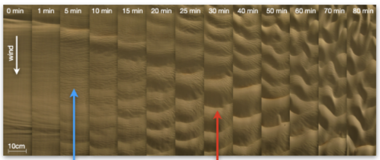


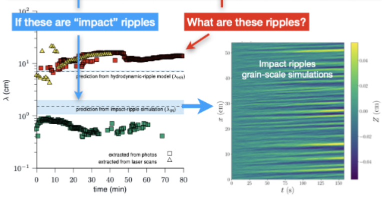
Here are examples of the bedform types for water using morphodynamic simulations:



2. New unexplained data

Recent wind tunnel experiments showed the co-evolution of **two** different small bedforms for fine spherical grains ($d \approx 90\mu$m) on Earth [3], instead of the expected single impact ripple.





5. Open questions

- Why most ripples on the field (unimodal sand) only seem to have a single length scale?
- Are ripples in the field "impact" or "hydrodynamic" ones?
- What is the role of grain size and shape, and flow velocity?
- What is the physical origin of the smaller saturation length?
- Is there a smaller saturation length on Mars as well?

References

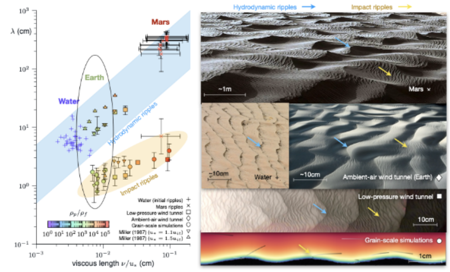
[1] Orencio Duran Vinent et al. "A Unified Model of Ripples and Dunes in Water and Planetary Environments". In: *Nature Geoscience* 12.5 (2019).

[2] M. G. A. Lapotre et al. "Large Wind Ripples on Mars: A Record of Atmospheric Evolution". In: *Science* 353.6294 (2016), pp. 55–58.

[3] Hezi Yizhaq et al. "Coevolving Aerodynamic and Impact Ripples on Earth". In: *Nature Geoscience* (2024), pp. 1–7. DOI: 10.1038/s41561-023-01348-3.

3. Interpretation as hydrodynamic ripples on Earth

A comparison with existing data for water and Mars, as well as new impact ripples simulations and new low-pressure wind tunnel experiments (for fine sand and flow velocities close to the transport threshold), suggests the larger ripple can be interpreted as a hydrodynamic ripple, clearly distinct from the new smaller impact ripple [3].



4. Proposed physical mechanism

But hydrodynamic ripples ($\lambda \sim 0.1$m) should not exist on Earth because $l_{sat} \sim 0.5$m and by definition $\lambda > l_{sat}$.
However, new evidence suggests the existence of a much smaller saturation length ~ 1cm (left panel), that can explain the data using linear instability analysis (right panel) [3].