MECHANICS OF MARINE RIPPLES AND IMPLICATIONS FOR PLANETARY ANALOGS.

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Introduction: Sand ripples are small bedforms that are widely distributed across the sea floor and in fluvial channel beds. Ripples are formed by waves and currents, and ripple spacing is governed by flow intensity. This relationship makes ripples a useful (paleo) flow indicator of flow depth, wave period, and flow velocity on Earth as well as on other planets.

What governs ripple spacing? Many studies have shown that spacing correlates with the wave orbital diameter [1], grain size, and shear velocity [2], however a full mechanistic explanation is still incomplete. A mechanistic explanation is necessary to appropriately reconstruct ripple (paleo) environments we cannot recreate in laboratory environments on Earth.

In addition to ripple spacing, many ripples also display characteristic patterns as they evolve in response to changes in flow conditions. A mechanistic perspective of ripple shape might explain the origin of observed ripple features that predominantly occur during periods of flow adjustment.

Methods: Here we use a lattice Boltzmann numerical flow model (LBM) to study the flow mechanisms that control ripple spacing [3]. The LBM solves the Boltzmann equations and uses an LES formulation to efficiently investigate flow and turbulent dynamics and their interaction with a rippled bed morphology. We drive the LBM with either an oscillatory flow or a unidirectional flow.

To investigate how ripple patterns adjust to changing flow conditions, we combine the LBM with laboratory flume experiments. In the laboratory flume we use a wave paddle to produce oscillatory flow conditions [3].

We also combine the LBM with data from a tripod located in ~4 m water depth offshore of Martha's Vineyard, MA [4]. This field study uses ADCP, rotary sidescan sonar, and pressure sensors to measure ripple geometry and tidal and wave-driven flows continuously for 50 days. With the LBM we reproduce key elements of the flows observed in this field study to investigate the detailed flow mechanics controlling ripple spacing and ripple adjustment.

Results: With the LBM we ran different combinations of oscillatory flows and ripple spacings (Fig. 1). We find that the separation zone that develops on both sides of the ripple crest during each orbital cycle is key in controlling ripple spacing. The separation vortex drives flow and sediment from the trough between two ripples up towards the ripple crest. When the ratio between the orbital diameter and ripple wavelength is 0.65 – the observed equilibrium spacing [1] – we find that the sepearation vortex flow up to the ripple crest is maximized (Fig. 1d). We suggest that this feedback drives orbital wave ripples to their equilibrium spacing [3].

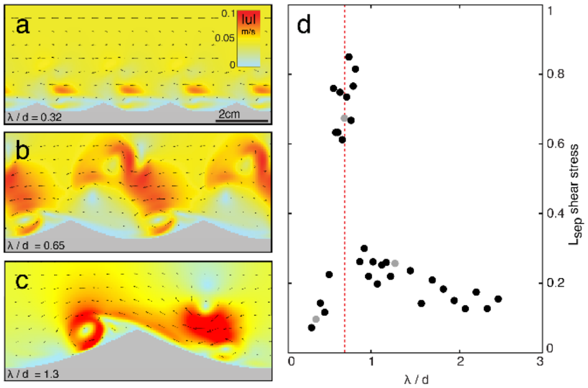

Fig. 1: Wavelength selection for orbital wave ripples. **(a-c)** panels show flow velocity magnitude and structure for different ripple sizes and identical flow conditions. (**d**) separation zone shear stress directed towards the ripple crest for different orbital diameter (d) and ripple spacing (λ) combinations. Figure from [3].

In oscillatory flow laboratory experiments where we impose a sudden decrease in wave period (and therefore orbital diameter), we find that ripples adjust by forming new ripples on the flanks of existing ripples. These new ripples then migrate into each trough.

In flume experiments where we impose an increase in wave orbital diameter, we find that the originally straight ripple crests buldge and become increasingly sinuous before breaking up to form larger ripples. Combining these experiments with the LBM, we find that if orbital diameters are too large for a ripple spacing (λ/d < 0.65, Fig 1a), ripples buldge because their crests preferentially migrate to a neighbouring crest that is closer. This crest instability ampliflies any initial perturbation in the original ripple pattern and can lead to the observed breakup and bulging of ripples [3].

Investigating the spacing for ripples under tide-driven (~ unidirectional) flow in our LBM, we ran model simulations with different flow velocities and different ripple spacings. We find that the shear stress at the ripple crests, a proxy for migration rate, depends on the spacing between ripples. If two ripples are spaced relatively far apart, the shear stress at the downstream crest decreases, which would correspond to a decrease in the downstream ripple migration rate and the spacing between the two ripples. This suggested feedback leads to a ripple spacing that is dependent on flow velocity and also shows similar scaling to the field observations of tide-driven bedforms.

Conclusion: We report on model experiments, flume studies, and field observations of sand ripples in oscillatory (waves) and unidirectional (tidal) flow environments. By combining the LBM with ripple observations, we can infer physical mechanisms governing observed ripple shapes. Firm understanding of these physical mechanisms can lead to better ripple-derived (paleo) flow reconstructions of distant environments. For example, we envision LBM simulations with reduced gravity or different fluid densities to investigate altered dynamics of flow separation behind ripple crests and their effect on wave ripple spacing.

References:

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