PREDICTIONS OF RIPPLES AND DUNES IN WATER AND PLANETARY ENVIRONMENTS. O. Duran Vinent[1], B. Andreotti[2], P. Claudin[3] and T. Pähtz[4]. [1]Department of Ocean Engineering, Texas A&M University, College Station, TX, USA, [2]Laboratoire de Physique de l'Ecole Normale Supérieure (LPENS), UMR 8023 ENS-CNRS, University Paris-Diderot, Paris, France, [3]Laboratoire de Physique et Mécanique des Milieux Hétérogènes, PMMH UMR 7636 CNRS, Paris, France, [4]Institute of Port, Coastal and Offshore Engineering, Ocean College, Zhejiang University, 866 Yu Hang Tang Road, 310058 Hangzhou, China.

Introduction: Duran Vinent et al. (2019) [1] introduced a hydrodynamical model to explain the formation, and predict the initial wavelength, of bedforms in water and air. They identified two types of bedforms created by a hydrodynamic instability in the limit of large flow thickness: those that induce an inertial hydrodynamic response and those that induce a turbulent hydrodynamic response. They were separated by a gap in wavelength explained in terms of a hydrodynamic anomaly that leads to a shift of the position of the maximum shear stress from upstream to downstream of the crest. This anomaly gradually disappears when the bed becomes hydrodynamically rough. These bedform types were consistent with subaqueous ripples and dunes, which then represent a suitable reference to classify bedforms in other environments. Their result was robust, regardless of the details of sediment transport and bed segregation, as it arises from a hydrodynamic mechanism that has been directly evidenced and characterized in well-controlled experiments. For monodisperse sand and non-suspended transport in the limit of large flow thickness, the parameter space physically relevant to determine the bedform morphology is based on two strongly correlated dimensionless numbers, the particle Reynolds number and the transport saturation length rescaled by the viscous length. The particle Reynolds number quantify the hydrodynamic roughness and controls the appearance of the hydrodynamic anomaly. The rescaled saturation length depends on the dominant mode of sediment transport and determines the initial wavelength. The occurrence of ripple-like and dune-like bedforms is controlled by two different thresholds: the rough transition at particle Re ≈ 20 and the stabilizing effect of transport relaxation at a rescaled saturation length ≈ 1000. Whenever ripples are present, the size of the viscous sublayer ν/u^* determines the scale of the maximum size of the steady-state ripples and the minimum size of the emerging dunes. When only dunes are possible, their minimum size scales with the transport saturation length.

This unifying framework allowed to understand planetary bedforms and suggested a correspondence between bedforms in different environments based on the formation mechanism. However, predictions were strongly dependent on the parametrization of the transport saturation length and the transport threshold.

Here we use recent transport simulations at the scale of individual grains [2,3] to obtain a relation for the transport cessation threshold for arbitrary planetary conditions and derive an expression for the saturation length for bedload (water) and saltation (air). In a first approximation, we assume the saturation length during bedload equals the average hop length, whereas during saltation we assume the saturation length is proportional to the average hop length. The average hop length is then obtained from numerical transport simulations [3] as function of the Shields number, the particle to fluid density ratio and the rescaled grain diameter.
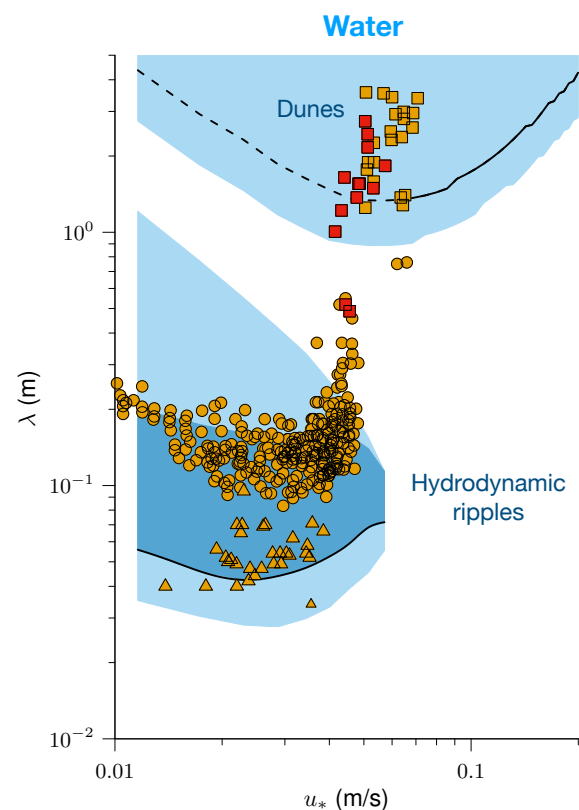

Fig. 1 Model prediction for ripples and dunes in water for d=200μm. Lines represents the initial ripple and dune sizes obtained from the dispersion relation. Shaded areas represent the range of sizes with positive growth rates. The darker shaded area represents the

region with the fastest growth rates. Symbols are experimental data for grain diameters in the range 100-300µm classified as: initial ripples (triangles), mature ripples (circles), dunes (squares) and dunes with superimposed ripples (dark squares).
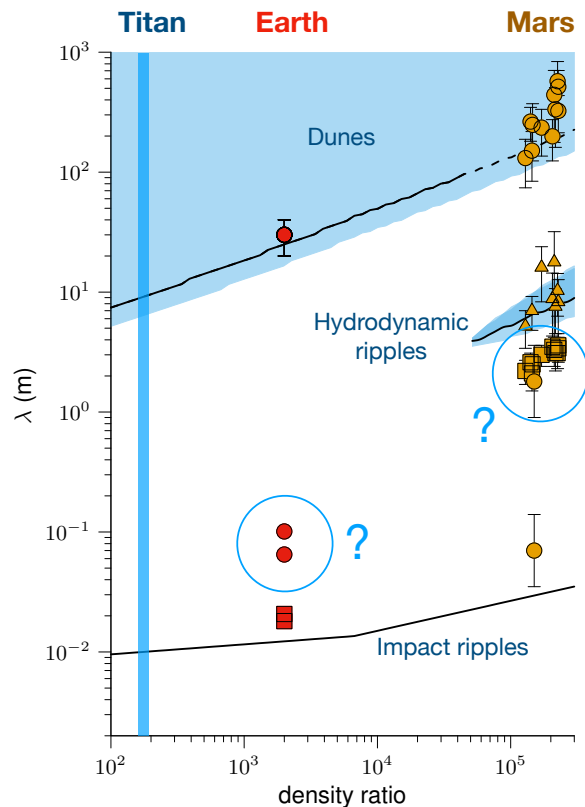

Fig. 2 Model predictions for different particle to fluid density ratios for d=120µm at the transport cessation threshold. Model predicts the initial size (lines) and region of positive growth rates (blue areas) for impact ripples, hydrodynamic ripples and dunes. For Earth (red symbols), data is selected to be relatively close to the threshold. For Mars (yellow symbols, [1]), data is classified as small ripples (lower circle), large ripples (squares), TARs (triangles) and dunes (upper circles). Shear velocity for Martian data is unknown. Blue circles represent bedforms that are not properly captured by our current models.

Predictions for water: Model predictions of initial bedform sizes are shown in Fig. 1 for grain diameter d=200µm. The model reproduces quite well the initial wavelengths of both ripples and dunes as well as the value of shear velocity at which ripples vanish, without any fitting parameter. In particular, the maximum ripple size seems to be captured by the condition that the growth rate is 10 times slower than the maximum

at the most unstable linear mode (boundary between the dark and light blue areas).

Predictions for planetary conditions: Fig. 2 shows model predictions for different density ratios at the transport cessation threshold. The model now has one fitting parameter, the proportionality constant between the saturation length and the average hop length, which is determined by measurements of the saturation length on Earth [1]. Furthermore, we also include predictions for impact ripples [4], whose initial size scales with the ratio of the transport rate and the surface erosion rate [4]. This ratio is estimated using transport simulations for planetary conditions (Fig.1).

The combined hydrodynamic and transport model captures the main bedform types, leads to novel predictions for bedforms in Titan (blue band in Fig. 2), and predicts the 5-10m bedforms found on Mars are not necessarily mega-ripples but are akin to water ripples [1] (thus we called then *hydrodynamic ripples*). However, it fails to reproduce the range of sizes of large ripples of Mars (1-3m) and our impact ripple model underpredict the size of typical impact ripples on Earth (around 10cm, red circles) by a factor of 10. This could point to a potential missing ingredient in our transport formulation.

References: [1] Duran Vinent, O., et al., (2019) *Nat. Geoscience*, 12(5), 345–350. [2] Pähtz, T. and Duran, O. (2020) *Phys. Rev. Lett.*, 124, 168001. [3] Pähtz, T. et al. (2022), arXiv, https://doi.org/10.48550/arXiv.2203.00562. [4] Duran, O., et al. (2014) *PNAS,* 111: 15665–68.