KEYNOTE

A unified model of bedforms across the turbulent roughening transition

B. Andreotti, *Laboratoire de Physique de l'Ecole Normale Supérieure*
O. Duran, *Department of Ocean Engineering, Texas A&M University*
A. Fourrière, *BGR - Federal Institute for Geosciences and Natural Resources*
P. Claudin, *Laboratoire de Physique et Mécanique des Milieux Hétérogènes*

ABSTRACT The emergence of bedforms as result of the coupling between fluid flow and sediment transport is a remarkable example of self-organized natural patterns. The size of subaqueous and aeolian bedforms generated by unidirectional water or wind flows, like ripples, dunes or compound bedforms, have been shown to depend on grain size, water depth and flow velocity. In the last decade, this variety of morphologies, previously classified according to their size, has gradually been understood in terms of mechanical and hydrodynamical mechanisms. Do ripples and dunes form by linear instability or nonlinear processes like pattern-coarsening? What determines their time and length scales, so different in air and water? What are the similarities and differences between aeolian and subaqueous patterns? What is the influence of the mode of transport: bedload, saltation or suspension? Can bedforms emerge under any hydrodynamical regime, laminar and turbulent?

Guided by these questions, a unified description of bedform growth and saturation will be discussed, with emphasis on the hydrodynamical regime in the inner layer and the relaxation phenomena associated with particle transport. It provides a physical explanation for bedform formation that disentangles the different regimes and show that the transition from ripples to dunes is associated, under water, with an anomalous hydrodynamic response to relief in the range of wavelength exciting the turbulent transition. This anomaly gradually disappears in the rough regime. The model is tested using a quantitative, yet reductionist, numerical model that couples hydrodynamics over a modulated bed to sediment transport and resolves both initial and mature bedforms. Numerical predictions are tested for subaqueous and aeolian bedforms, for which all components of the theory are independently calibrated. The resulting classification of hydrodynamical regimes provides a new mechanistic framework to compare ripples and dunes in different environments.

Finally, the effect of the free surface will be discussed, comparing ripples (downstream propagating transverse bedforms), chevrons and bars (bedforms inclined with respect to the flow direction) and anti-dunes (upstream propagating bedforms), and focusing on the mechanisms involved in the early stages of their formation. In the subcritical regime (Froude number F smaller than unity), the same instability produces ripples or chevrons depending on the influence of the free surface. The transition from transverse to inclined bedforms is controled by the ratio of the saturation length Lsat, which encodes the stabilising effect of sediment transport, to the flow depth H. These results suggest that alternate bars form in rivers during flooding events, when suspended load dominates over bed load. In the supercritical regime F > 1, the transition from ripples to anti-dunes is also controlled by the ratio Lsat/H. Anti-dunes appear around resonant conditions for free surface waves, a situation for which the sediment transport saturation becomes destabilising. This resonance turns out to be fundamentally different from the inviscid prediction. Their wavelength selected by linear instability mostly scales on the flow depth H, which is in agreement with existing experimental data.

REFERENCES

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