Toward a unifying constitutive relation for sediment transport across environments

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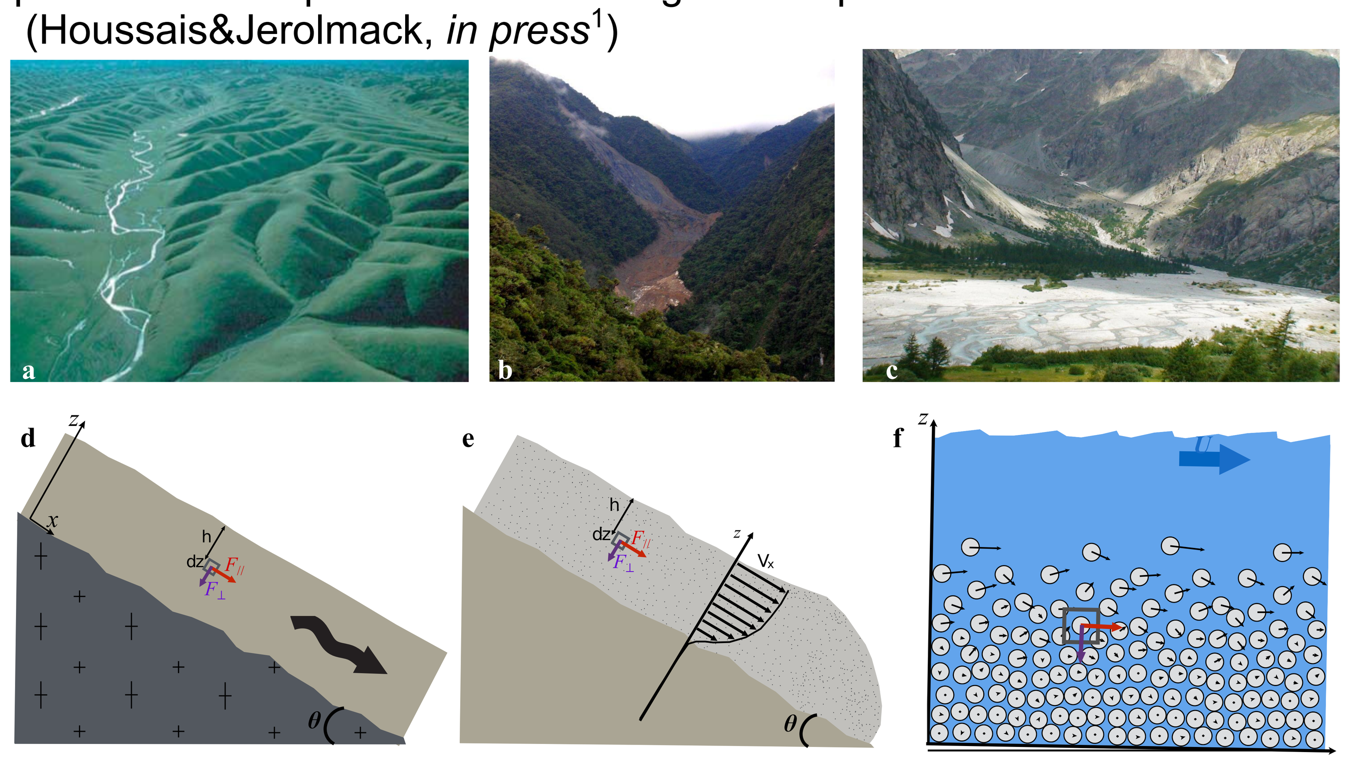
Abstract

« Landscape evolution models typically parse the environment into different process domains, each with its own sediment transport law: e.g., soil creep, landslides and debris flows, and river bed-load and suspended-sediment transport. Sediment transport in all environments, however, contains many of the same physical ingredients, albeit in varying proportions: grain entrainment due to a shear force, that is a combination of fluid flow, particle-particle friction and gravity. We present a new take on the perspective originally advanced by Bagnold, that views the long profile of a hillsope-river-shelf system as a continuous gradient of decreasing granular friction dominance and increasing fluid drag dominance on transport capacity. Recent advances in understanding the behavior and regime transitions of dense granular systems suggest that the entire span of granular-to-fluid regimes may be accommodated by a single-phase rheology. This model predicts a material-flow effective friction (or viscosity) that changes with the degree of shear rate and confining pressure. We present experimental results confirming that fluid-driven sediment transport follows this same rheology, for bed and suspended load. Surprisingly, below the apparent threshold of motion we observe that sediment particles creep, in a manner characteristic of glassy systems. We argue that this mechanism is relevant for both hillslopes and rivers. We discuss the possibilities of unifying sediment transport across environments and disciplines, and the potential consequences for modeling landscape evolution. »

(Houssais&Jerolmack, *in press*[1])



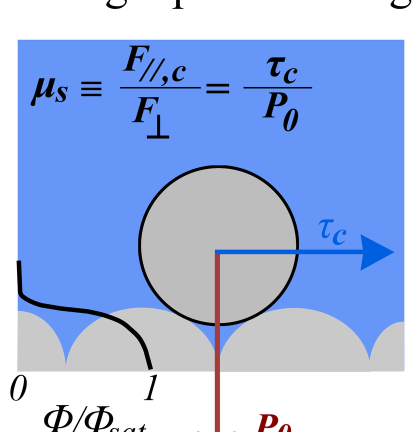
Submerged granular rheology

Effective friction coefficient $\mu \equiv \dfrac{\tau}{P_p}$ Viscous coefficient $I_v \equiv \dfrac{\eta_f \dot{\gamma}}{P_p}$

Confinement pressure $P_p(z) = P_0 + \int_z^{+\infty} (\rho_p - \rho_f) g \langle \Phi \rangle (z) dz$

$P_0 \propto$ normal stress due to a single particle weight

Critical stress condition ($\tau = \tau c$) at the bed surface:



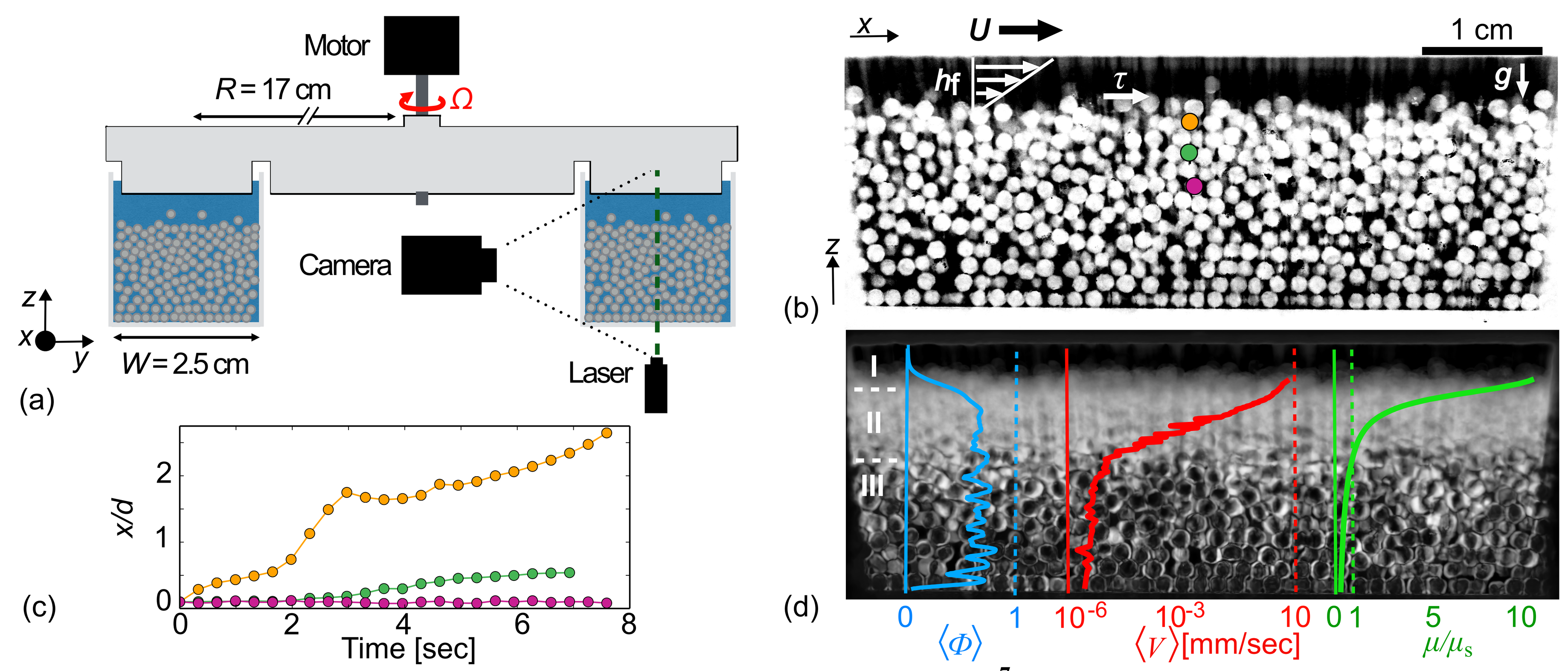
Unified rheology: (Boyer et al, PRL, 2011[4])

$$\mu(I_v) = \underbrace{\mu_s + \frac{\mu_d - \mu_s}{I_0/I_v + 1}}_{\text{Dense dry granular flow rheology}} + \underbrace{I_v + \frac{5}{2}\Phi_c I_v^{1/2}}_{\text{Dilute suspension flow rheology}}$$

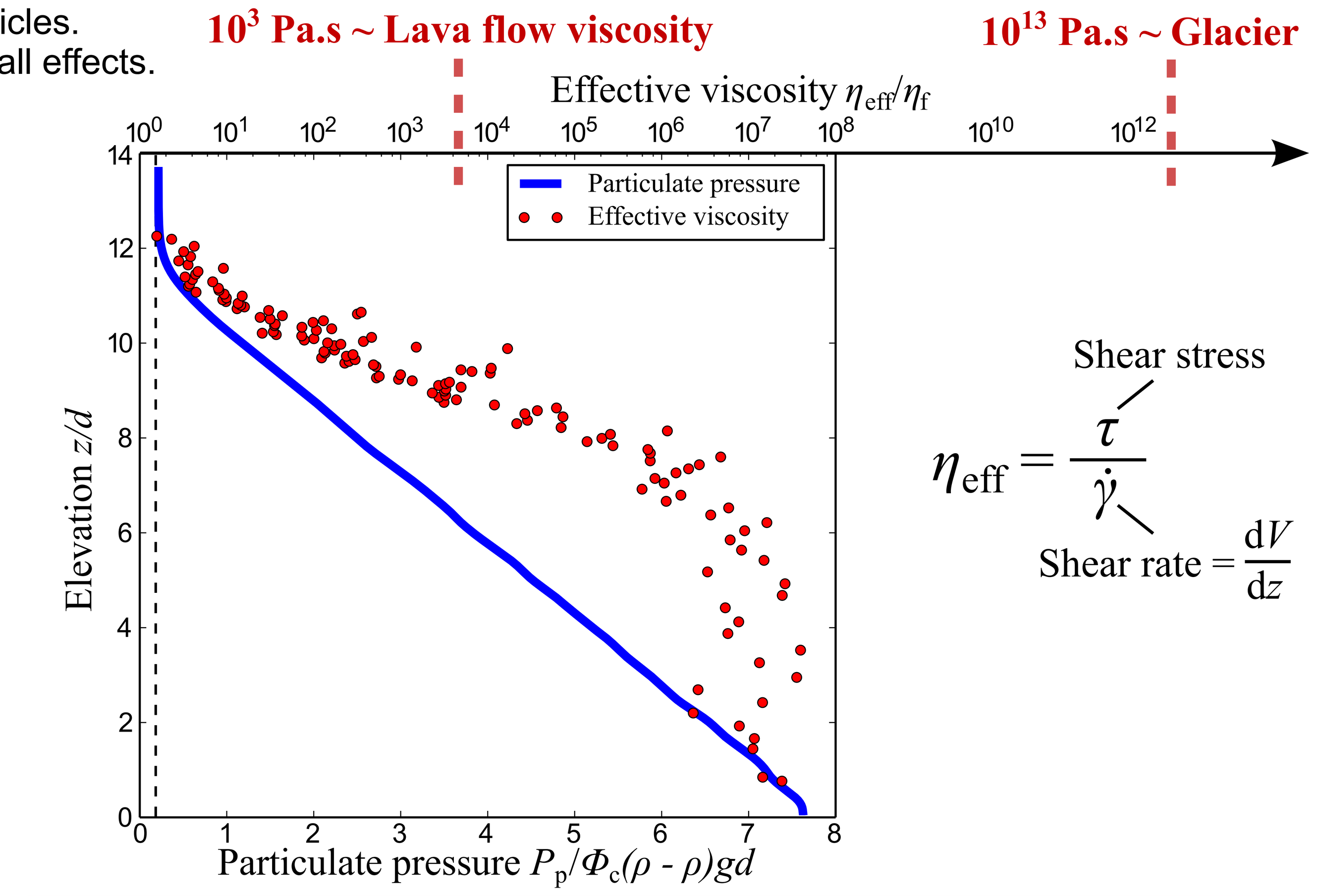
Dense dry granular flow rheology (GDR MiDi, 2004) Dilute suspension flow rheology (Einstein, 1905)

Experimental apparatus and methods

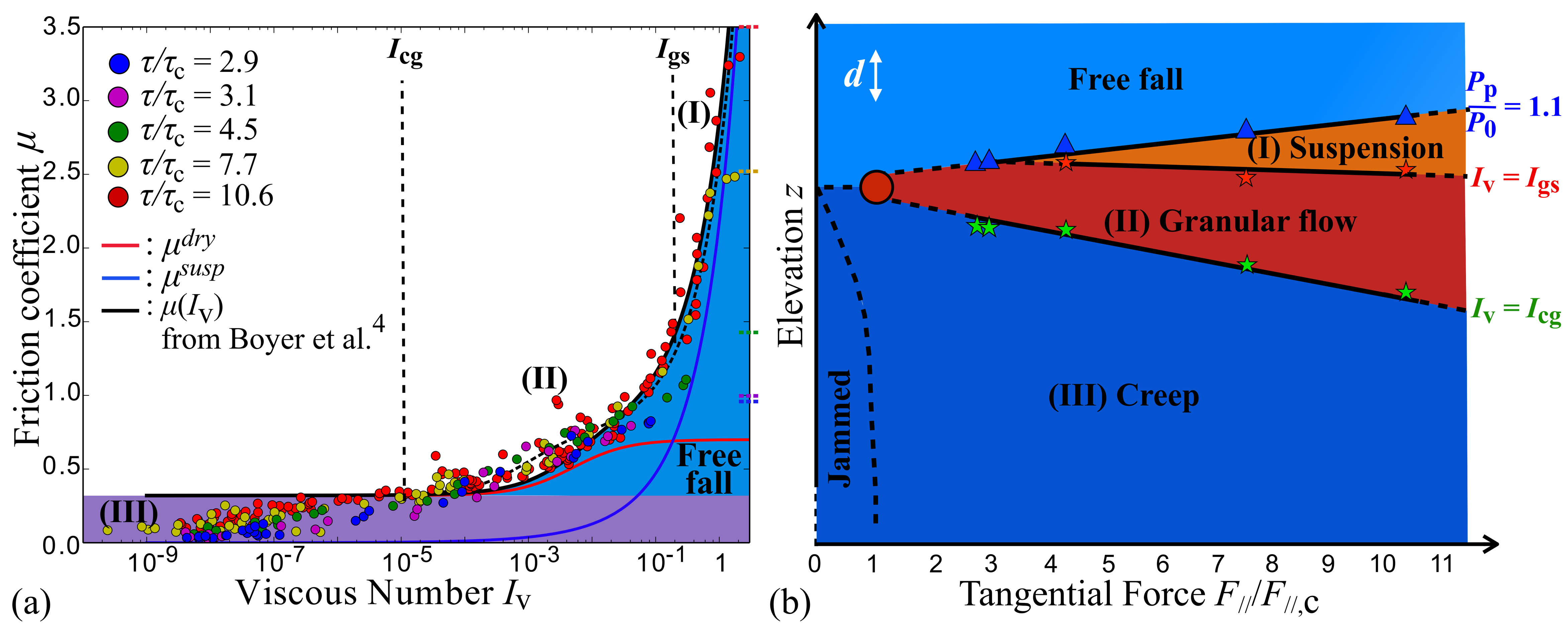
Couette cell experiment, where the rotating top plate shear a viscous oil (viscosity η_f), which shear at a constant shear stress τ a bed of plastic particles. Particles (of diameter **d**) and oil refractive indexes are matched, which allow us to image a vertical plan at the center of the channel, far from side wall effects. All particles position and sizes are tracked over hours via images analysis, and allow us to finely quantifiy the particle flow rheology.



10^{-7} **mm/sec ~ slow landslide** (Di Maio et al, *Eng. Geol.*, 2013)

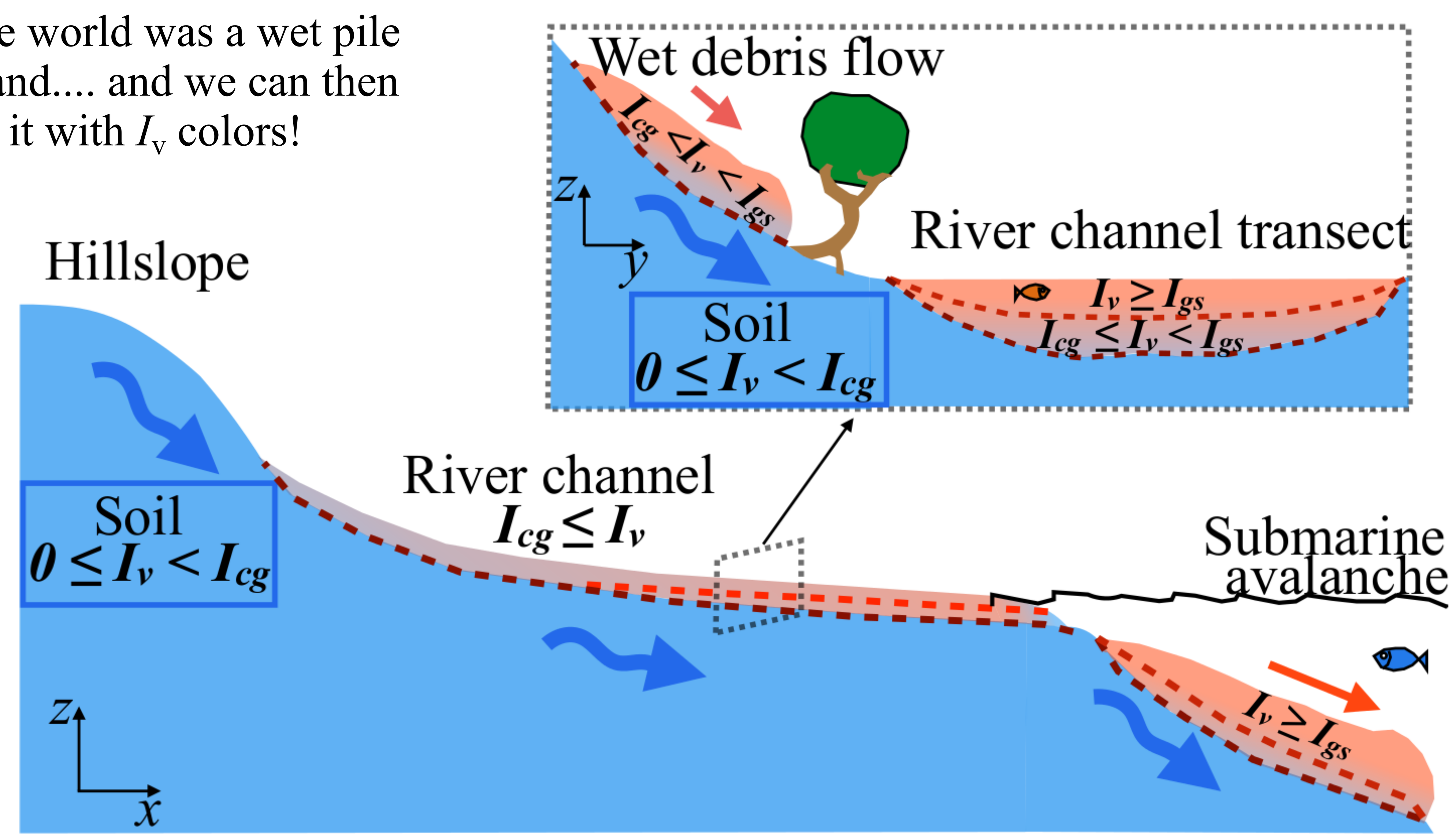


Results



Discussion

If the world was a wet pile of sand.... and we can then map it with I_v colors!



Conclusion and perspectives

- Rafined measurements of the vertical profiles of sediment concentration and velocity establish how to insert sediment transport in the general framework of complex fluid flow rheology[2,4].
- The different earth surface processes of sediment transport appear now as different regimes of a general framework. This open numerous perspectives, and in particular it strongly suggests to study transport big events as regime transitions[1,3].
- As a result of using the unified rheology, landscape evolution models could gain efficiency and accuracy while being more continuous.
- Creep regime and the transition from creep to granular flow (III→II) are still largely non-understood. Yet, they are crucial to study problems such as soils evolution, avalanche triggering and river beds' hysteresis.

The authors are currently inciting themselves and others to pursue novel investigations on this phenomenon.

Biblio

[1] **Houssais, Morgane, and Douglas J. Jerolmack. "Toward a unifying constitutive relation for sediment transport across environments." *Geomorphology* (in press).**

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[3] Houssais, Morgane, Carlos P. Ortiz, Douglas J. Durian, Douglas J Jerolmack. "Onset of sediment transport is a continuous transition driven by fluid shear and granular creep." *Nature communications 6* (2015).

[4] Boyer, Francois, Élisabeth Guazzelli, and Olivier Pouliquen. "Unifying suspension and granular rheology." *Physical Review Letters* 107.18 (2011).

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