Two-Phase continuum Models for Geophysical Particle-Fluid Flows, Max Planck Institute, Dresden, 2016

Relaxation Processes in Aeolian Transport

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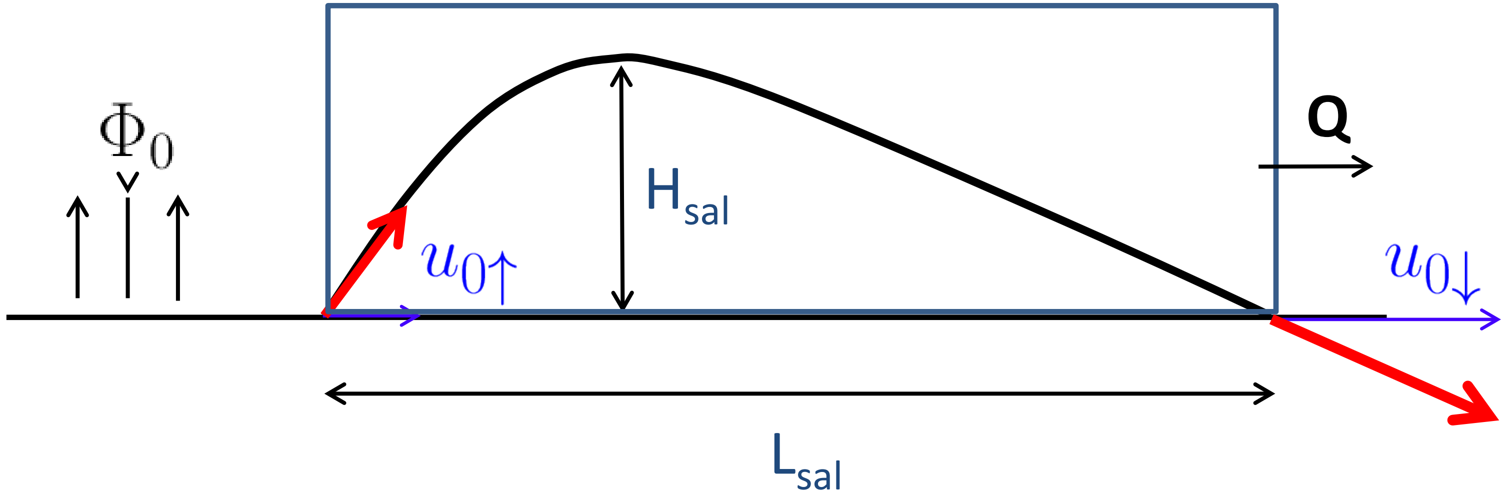
Characteristic Lengths of Saltating Particle

Transport Law



Momentum Balance: $$\tau_{grain} = \Phi_0(u_{0\downarrow} - u_{0\uparrow})$$

and $\tau = \rho_f u^{*2} = \tau_{fluid} + \tau_{grain}$

Mass Balance: $$Q = L_{sal} \times \Phi_0$$

$$Q = \frac{L_{sal}}{u_{0\downarrow} - u_{0\uparrow}}(\tau - \tau_{fluide})$$

Bagnold Transport Law

Bagnold (1941) Hypothesis: $\tau_{fluid} = 0$ (at z = 0)

$$Q = \frac{L_{sal}}{u_{0\downarrow} - u_{0\uparrow}} \tau$$

Bagnold Law

$L_{sal} \propto u^{*2}/g$ and $u_{0\downarrow}, u_{0\uparrow} \propto u^*$ ⇒

$$Q \propto \frac{\rho_f}{g} u^{*3}$$

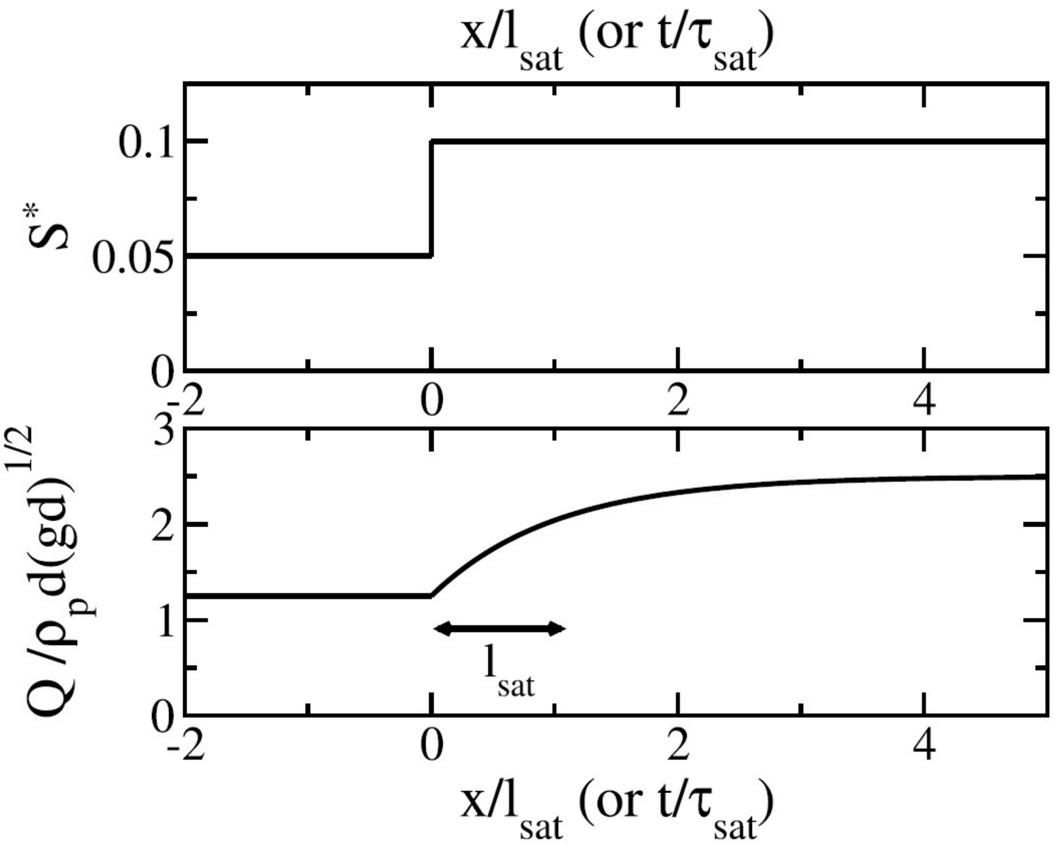
Owen (1964) Hypothesis: $\tau_{fluide} = \tau_d = \rho_f u_d^{*2}$ (at z = 0)

Modified Bagnold Law

⇒

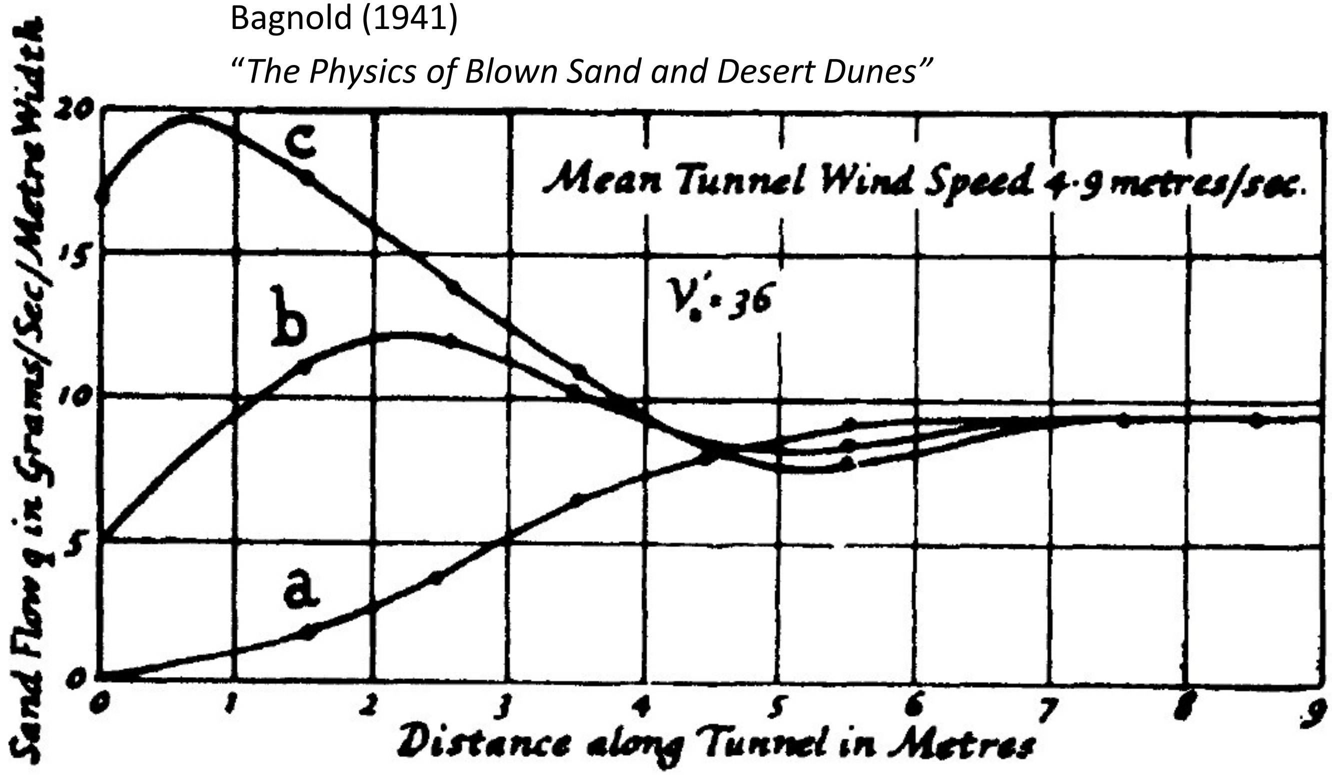
$$Q \propto \frac{\rho_f}{g} u^* (u^{*2} - u_d^{*2})$$

Saturation Length



Bagnold (1941)

"The Physics of Blown Sand and Desert Dunes"



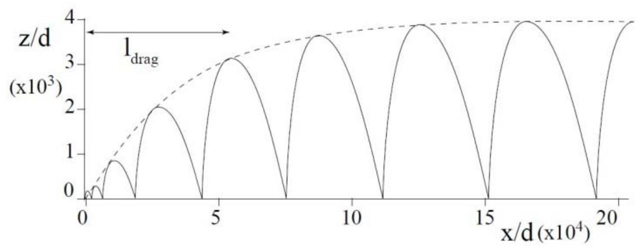
« *It can be said that any change in the rate of of sand flow produces a fluctuation down-wind of it consisting of at least one cycle of removal followed by deposition* »

Lag length is linked to minimum size of initial dunes

Possible Physical Mechanisms Responsible for Saturation Length

- Grain hop length (Saltation length, L_{sal}) (Charru, 2006)

- Length needed to accelerate new grains (drag length, $L_{drag} = \frac{\rho_{sand}}{\rho_{air}} d$) (Andreotti et al., 2002 and 2007; Hersen et al., 2002)



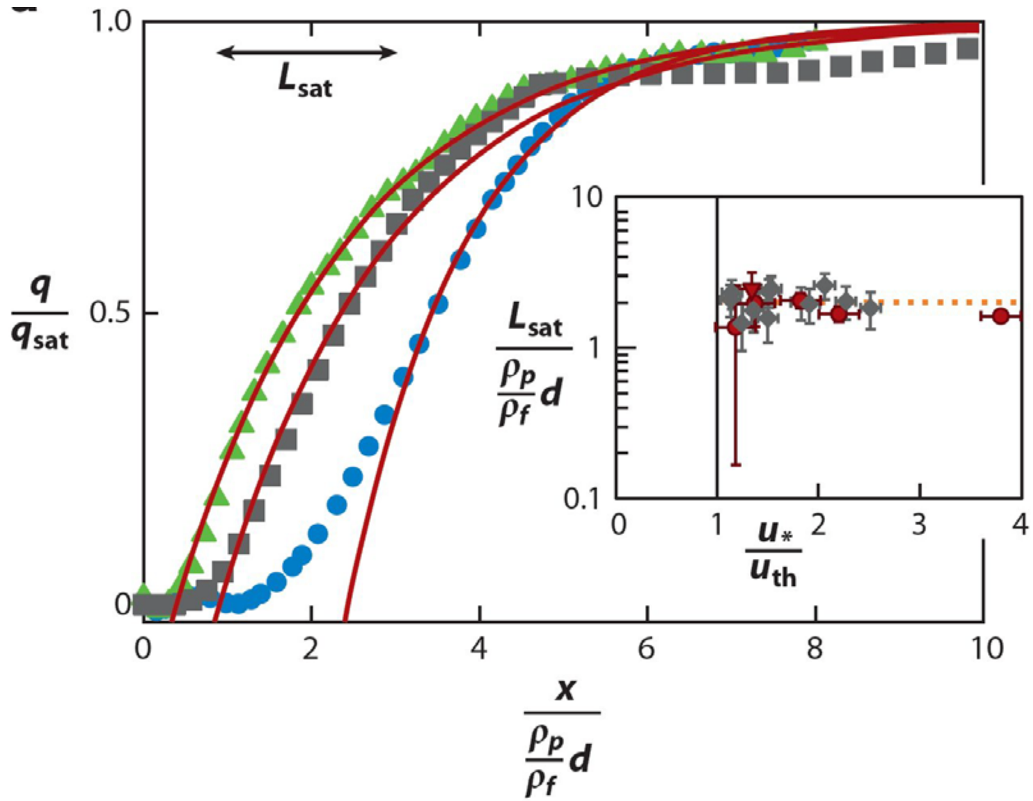
(Andreotti et al., Eur. Phy. J. B 28, 2002)

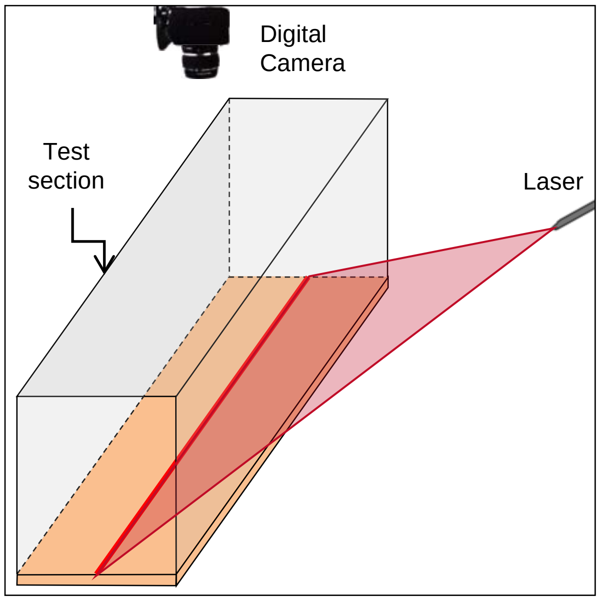
- Length needed to expel new grains from the sand bed (Sauermann et al., 2001; Parteli et al., 2007)

- Length needed for the negative feedback of transport on the wind to take place (Andreotti, 2004)

Relaxation is limited by the slowest of these processes

The saturation length controls the initial size of sand dunes emerging from a flat sand bed (Andreotti et al., 2002)





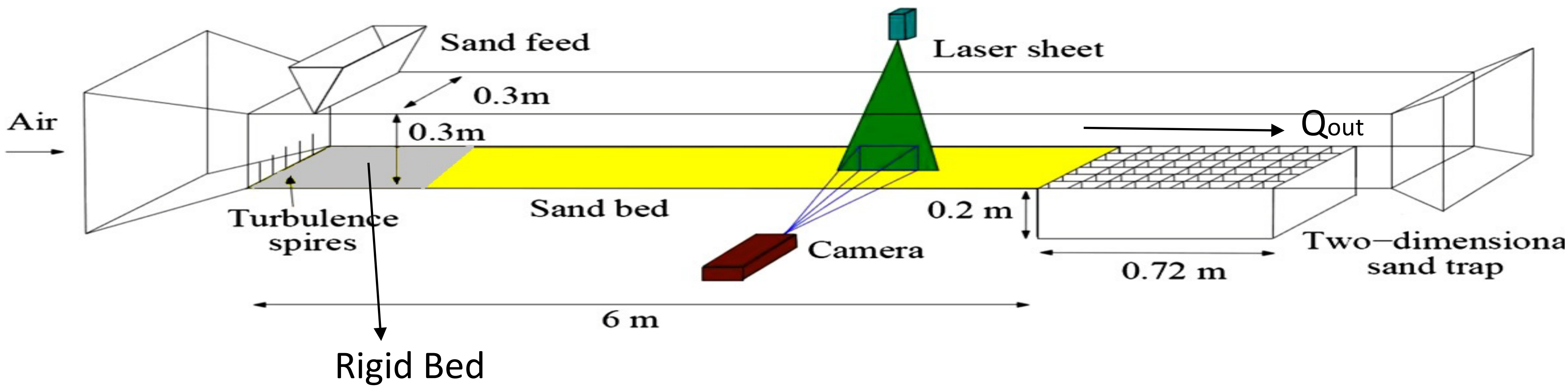
Charu et al, Ann. Rev. (45), 2013
Andreotti et al, Geomorphology (123), 2010

$$Q(x) = -\int_0^x \partial_t h(\xi) d\xi$$

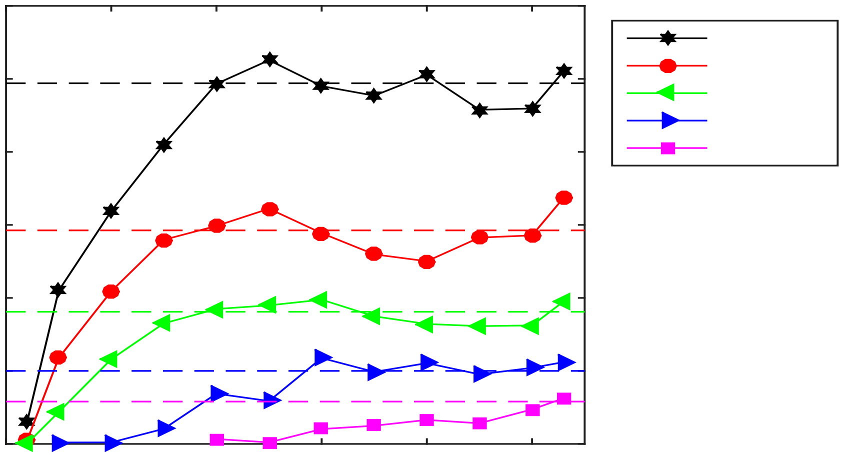
$$L_{sat} \approx 0.55cm$$

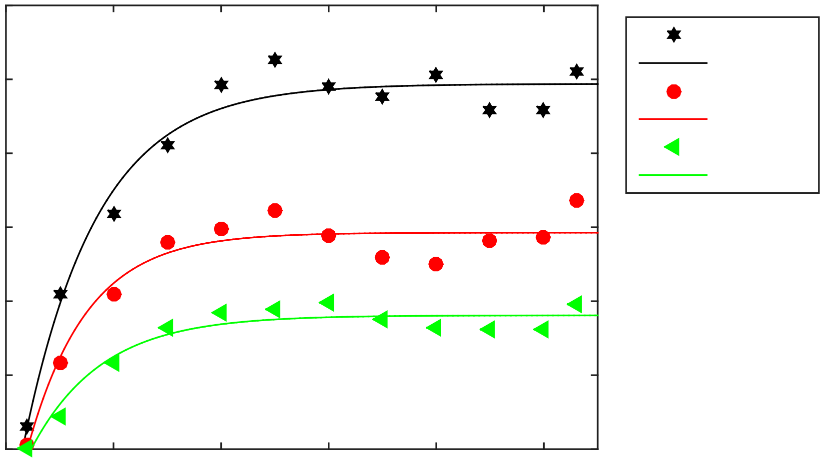
$$\frac{L_{sat}}{\frac{\rho_{sand}}{\rho_{air}} d} \approx 2$$

Relaxation without sand supply



- ✓ sand of diameter d=200 μm
- ✓ For a given wind velocity, Erodible bed length varying
- ✓ Global sand flux measured (weigthed) Q_{out}



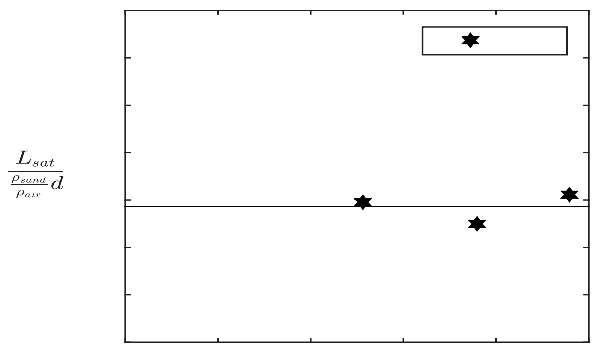


Shear Stress $\tau = \rho_f u^{*2}\ [N.m^{-2}]$

Shields Number $S = \dfrac{\tau}{(\rho_p - \rho_f)\ g\ d}$

$$\frac{Q_{out}}{Q_{sat}} = [1 - e^{-\left(\frac{x - x_0}{L_{sat}}\right)}]$$

Andreotti et al, Geomorphology (123), 2010



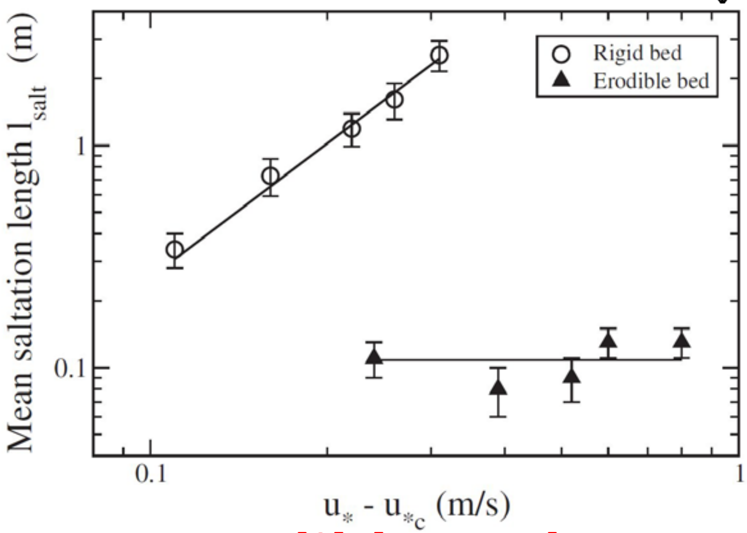
$$L_{sat} \approx 0.62cm$$

$$\frac{L_{sat}}{\frac{\rho_{sand}}{\rho_{air}} d} \approx 1.5$$

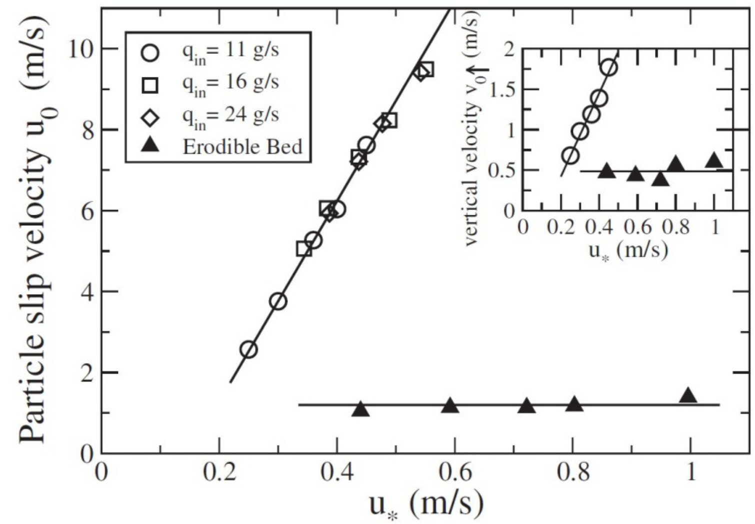
Relaxation from Rigid to Erodible Bed

Back to transport law

$$Q = \frac{L_{sal}}{u_{0\downarrow} - u_{0\uparrow}}(\rho_f u^{*2} - \rho_f u_d^{*2})$$



Ho et al, PRL (106), 2011



Erodible Bed

$$L_{sal} \not\propto u^*$$

$$u_{0\downarrow}, u_{0\uparrow} \not\propto u^*$$

$$Q \propto \rho_f \sqrt{d/g}(u^{*2} - u_d^{*2})$$

Rigid Bed

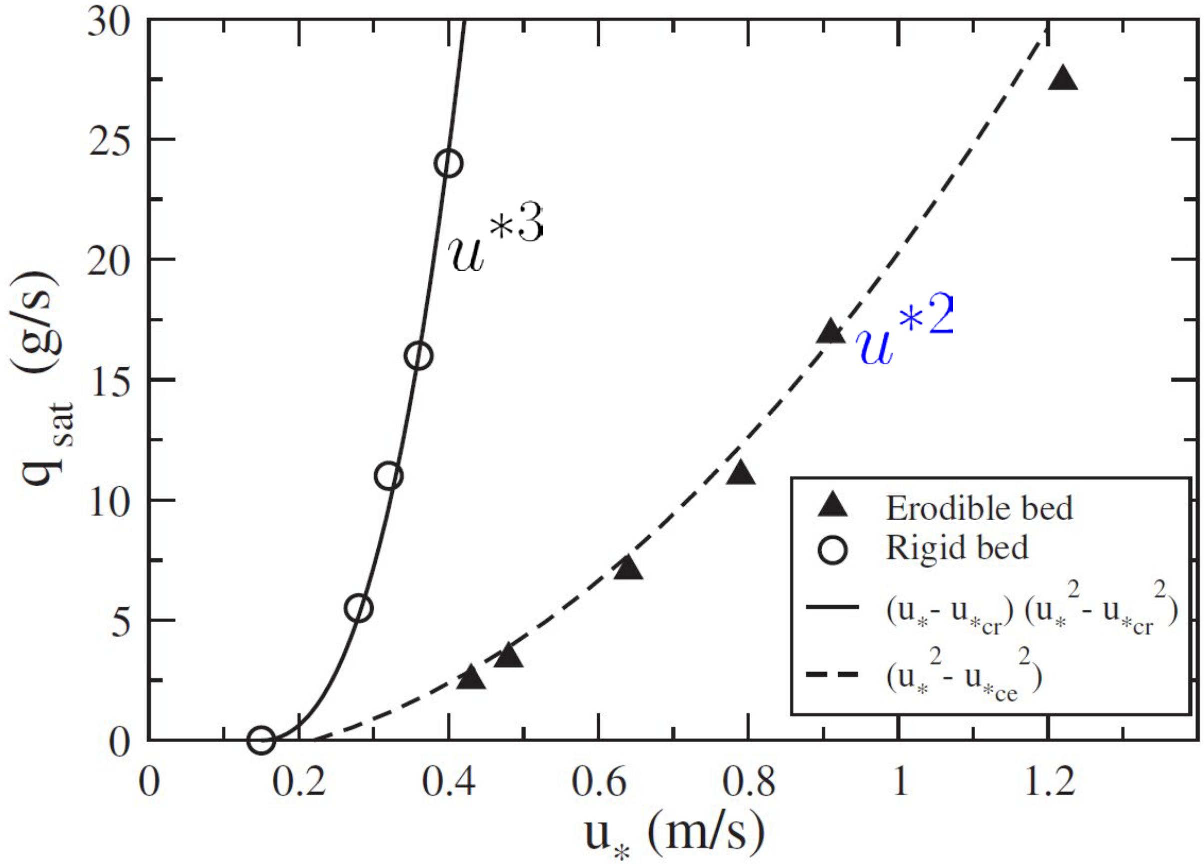
$$L_{sal} \propto u^{*2}/g$$

$$u_{0\downarrow}, u_{0\uparrow} \propto u^*$$

$$Q \propto \frac{\rho_f}{g}(u^* + u_d^*)(u^{*2} - u_d^{*2})$$

Transport Flux

Ho et al, PRL (106), 2011



$Q_{érodible} \propto (u^{*2} - u_d^{*2})$ **and** $Q_{rigide} \propto (u^* + u_d^*)(u^{*2} - u_d^{*2})$

$$Q_{rigide} \gg Q_{érodible}$$

FIELD STUDY – TRANSPORT OVER BARCHAN

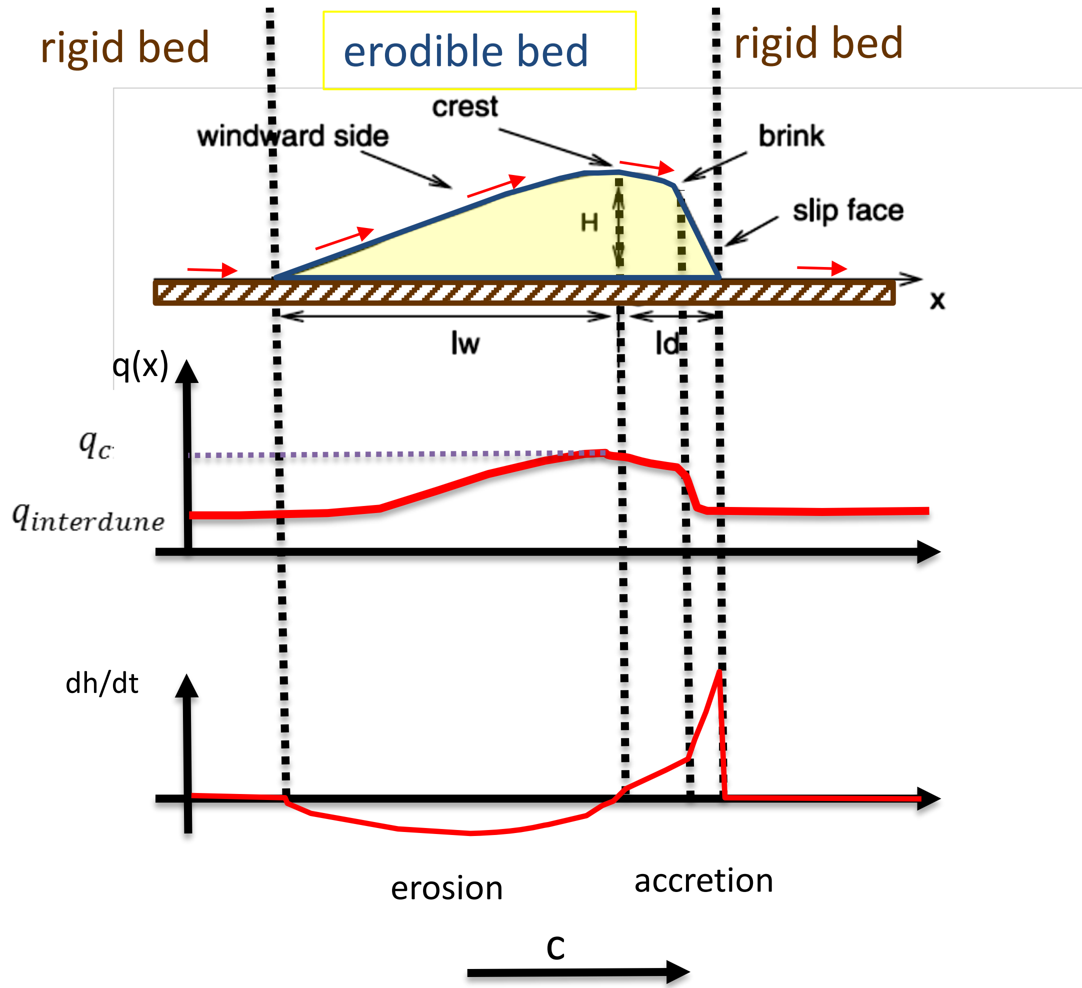
boundary condition

topography

horizontal flux

net erosion

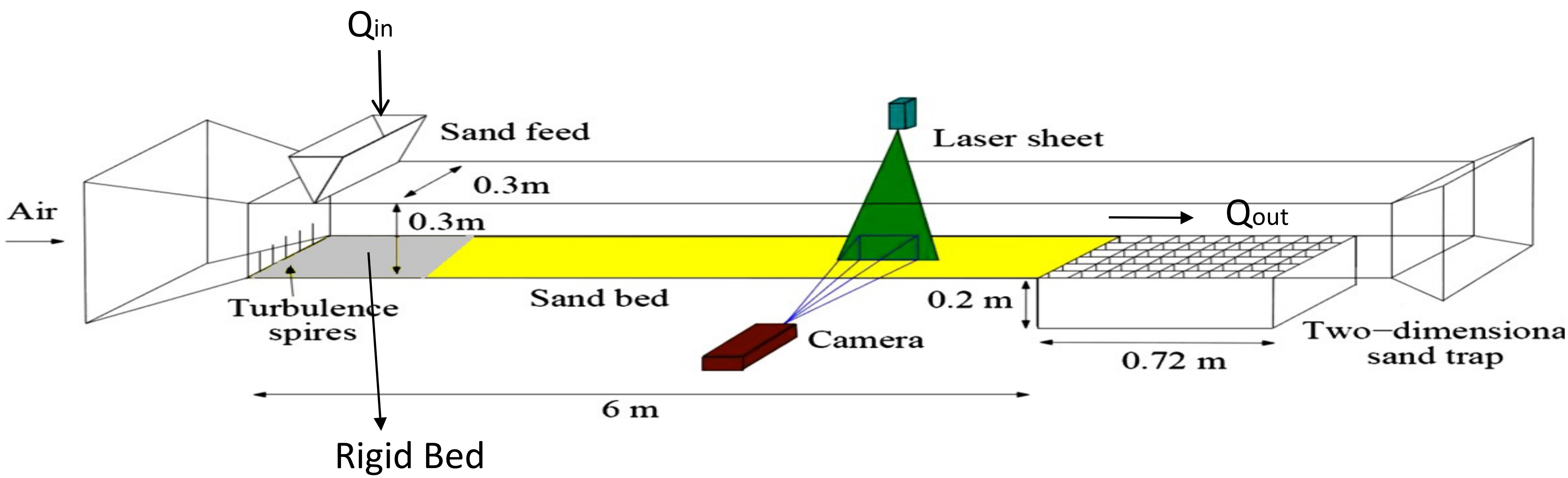
dune celerity



$$\rho . H . C = q_{trap} = q_c - q_{interdune}$$

Saltation over rigid bed is one of the component of barchan dynamics

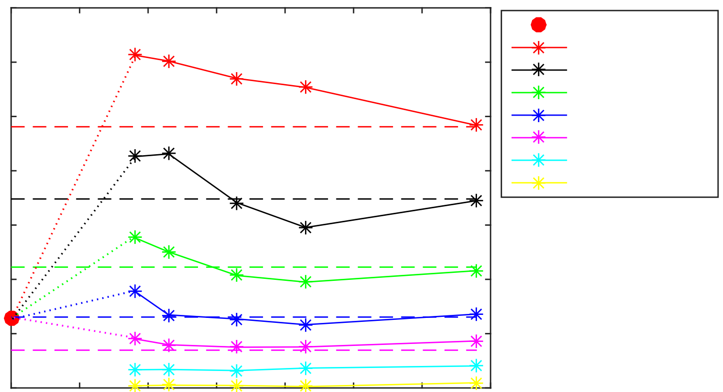
Relaxation with sand supply

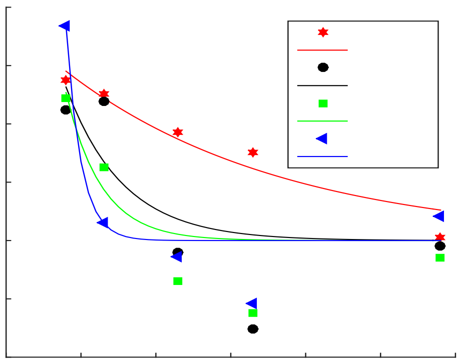


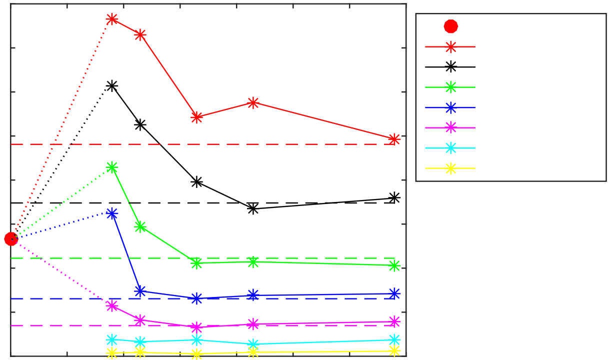
- ✓ sand of diameter d=200 μm
- ✓ For a given wind velocity and sand supply flux, Erodible bed length varying
- ✓ Global sand flux measured (weigthed)

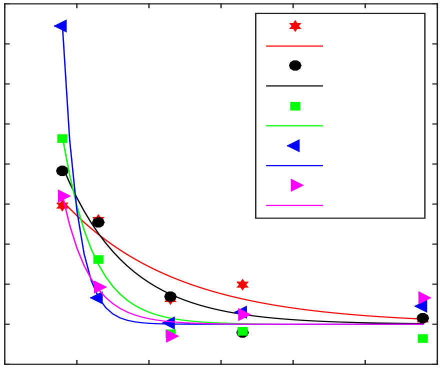
Relaxation with sand supply

$$\frac{Q_{out} - Q_0}{Q_{sat}} = \left(\frac{Q_{sat} - Q_0}{Q_{sat}}\right)\left[1 - e^{-\left(\frac{x}{L_{sat}}\right)}\right]$$

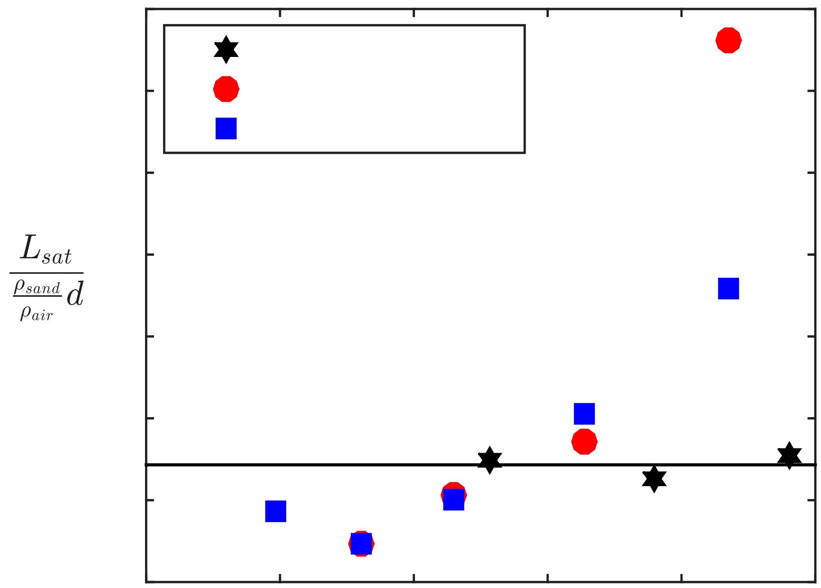








Evolution of Lsat with and without sand supply



Conclusions

- Relaxation length was measured with and whitout sand suply
  - Without sand supply, transport saturation seems governed by grains inertia
  - With sand supply, Lsat presents a variation with friction velocity