Saltation transport on Earth

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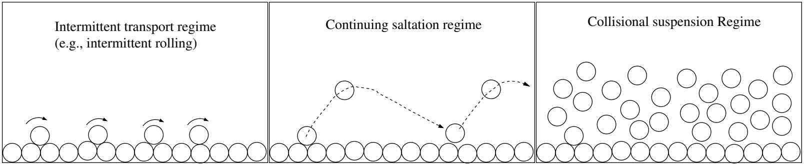
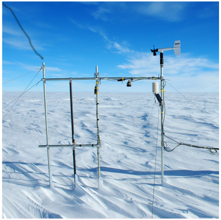
Saltation Transport

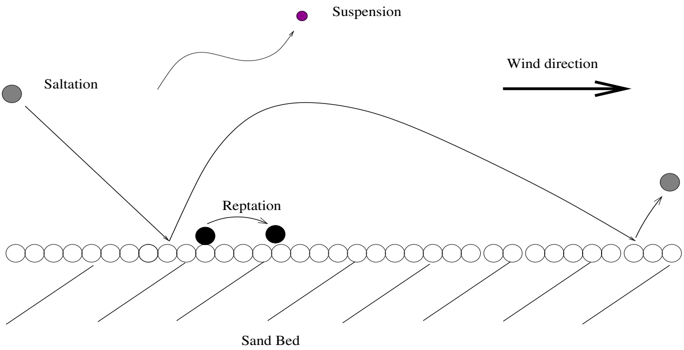
- Different regimes of transport



- Saltation transport (sand in air, snow in air, sediment in rivers)



Aeolian saltation transport (Bagnold, 1941)



- Aeolian sand : size $d \approx 0.2\,mm$ and density $\sigma = \rho_p/\rho_{air} = 2200$
- Transport mode : Saltation (successive jumps)

Dimensionless numbers

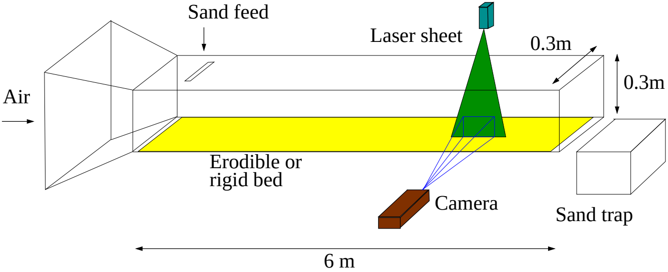
- Dimensionless numbers for wind blown on Earth
  - Shields number : $S^* = \rho_f {u^*}^2/(\rho_p - \rho_f)gd \approx 0.01 - 0.1$
  - Density ratio : $\sigma = \rho_p/\rho_f \approx 2000$
  - Reduced gravity : $g' = (1 - 1/\sigma)g \approx g$
  - Particle Reynolds number : $R_p = d\sqrt{g'd}/\nu \approx 1$
  - Stokes number : $St = \sigma R_p \approx 2000$
  - Rouse number : $Rouse = v_t/\kappa u^* = St/\kappa\sqrt{\sigma S^*} \approx 10 - 50$

Outline

- Wind-tunnel experiments : Erodible versus Non-erodible beds
- Impact law at the bed : Erodible versus Non-erodible beds
- Two-phase modeling with two-way coupling
- Conclusion

Wind-tunnel experiments

- 6m wind-tunnel (LTeN, Nantes) *(Ho D. PhD thesis, 2012)* :

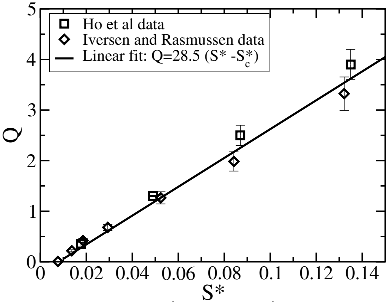


- Sand : $d \approx 0.2\,mm$ and $\rho_p \approx 2650\,kg/m^3$
- Instruments : Particle Tracking Velocimetry, Pitot tubes, Sand trap

Wind-tunnel experiments

- Erodible bed vs Rigid bed *(Ho et al., PRL 2011)* :

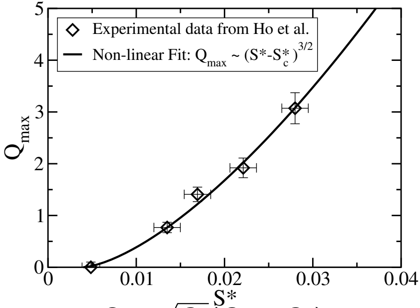
Erodible bed



$$Q \propto (S^* - S^*_c)$$

Linear law (Ho et al.)

Rigid bed



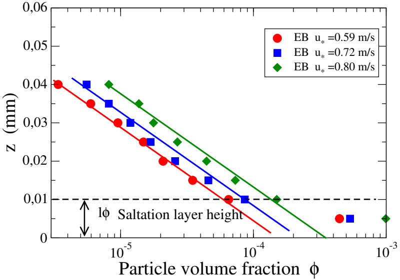
$$Q \propto \sqrt{S^*}(S^* - S^*_c)$$

Bagnold law

Particle concentration profiles

(D. Ho et al., PRL 2011)

Erodible bed

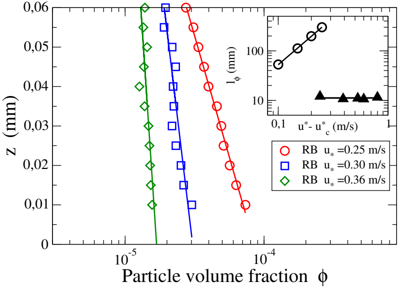


$$\phi(z) \approx \phi_0 e^{-z/l_\phi}$$

with $l_\phi \approx constant \approx 10\, mm$

and $\phi_0 \propto (S^* - S^*_c)$

Rigid bed : Fixed incoming mass flow rate



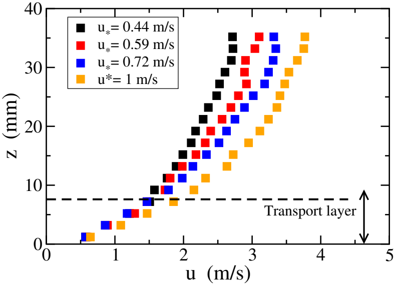
$$\phi(z) \approx \phi_0 e^{-z/l_\phi}$$

with $l_\phi \propto S^*$

Particle velocity profiles

(Ho et al, PRL 2011, Ho Phd Thesis 2012)

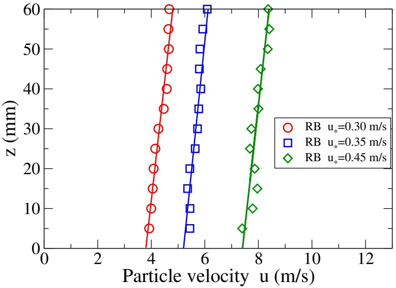
Erodible bed



Invariance of the velocity profile within the saltation layer

Slip velocity : $u_0 \approx constant$

Rigid bed



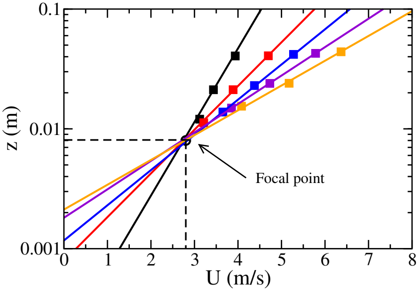
Increasing velocity with increasing flow strength

Slip velocity $u_0 \propto u^*$

Air velocity profiles

(Ho et al, PRL 2011, Ho Phd Thesis 2012)

Erodible bed

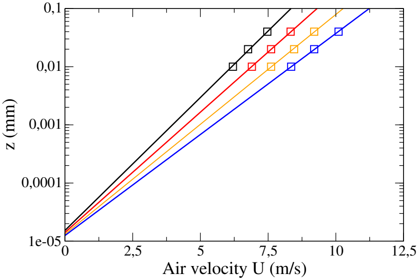


$U(z) \approx U_f + (u^*/\kappa)\ln(z/z_f)$

Bagnold focus point

$z_f \approx l_\phi \approx 10\,mm$ and $U_f = 5m/s$

Rigid bed



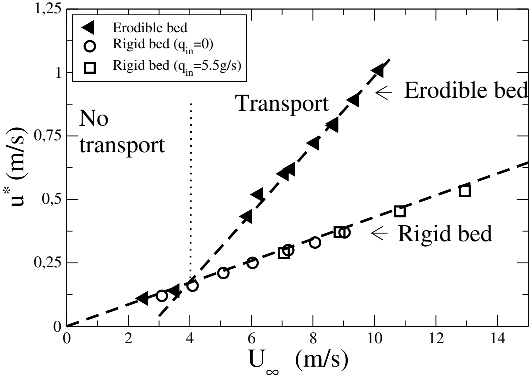
No feedback of the grains on the flow

No Bagnold focus point

Friction velocity $u^* = \sqrt{\tau / \rho_{fluid}}$

(Ho et al, 2011, Ho Phd Thesis 2012)

Air friction speed vs the nominal velocity U_∞

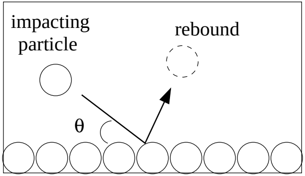


Non-erodible bed : $u^* \approx 0.045 U_\infty$

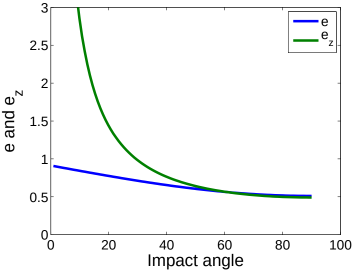
Erodible bed : $u^* = u^*_c + 0.13(U_\infty - U_c)$

Boundary conditions for Rigid beds

- Rigid Bed : rebound but no "Splash" (i.e., no particle ejection)
- Rebound law on a bumpy surface (Beladjine, PRE 2007)



Rigid and bumpy bed



$$
\begin{aligned}
e &= \xi^{+}(0)/\xi^{-}(0) = (A - B\sin\theta) \\
e_z &= -\xi_y^{+}(0)/\xi_y^{-}(0) = (A_z/\sin\theta - B_z)
\end{aligned}
$$

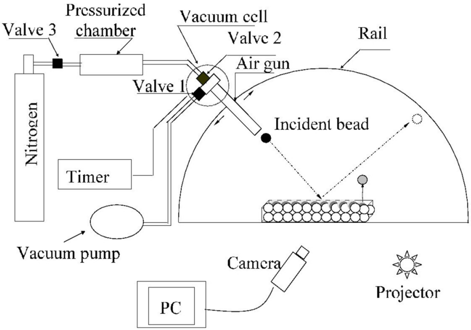
$A = 0.9$, $B = 0.4$, $A_z = 0.5$ and $B_z = 0$

(values obtained from D.E.M simulations with $e_n = 0.8$)

Boundary condition for Erodible beds

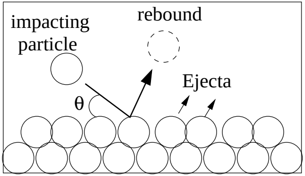
- Splash process investigated via a model collision experiment (Beladjine et al, PRE 2007)

  Particle parameters : $d = 6\,mm$ and $\rho_p = 1300\,kg/m^3$



Boundary condition for Erodible beds

- Ejection process (Beladjine, PRE 2007)



$$N_{tot} = N_{rebound} + N_{ej}$$

Ejection threshold ($N_{ej} > 0$) :

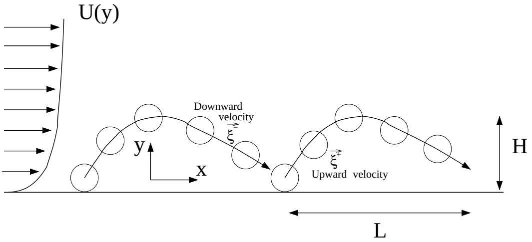
$$\xi_{imp} > \xi_c \approx 40\sqrt{g'd}$$

- Two saltation regimes :
  - Transport-limited regime : $\xi_{imp} < \xi_c$
    Splash is not triggered
    $\Rightarrow$ Transport similar to that on a rigid bed
  - Splash-limited regime : $\xi_{imp} \geq \xi_c$
    Splash is triggered
    Equilibrium state is bounded by the critical impact velocity $\Rightarrow \xi_{imp}^{eq} \propto \xi_c$

Periodic Saltation model

(Jenkins et al, POF 2014, Berzi et al., JFM 2016, JGR 2017)

- Simple two-phase modeling : two-way coupling
  -Fluid phase : RANS
  -Particle phase : Lagrangian approach with a non-linear drag
- Description of the saltation transport in terms of an unique periodic trajectory (instead of a distribution of trajectories)

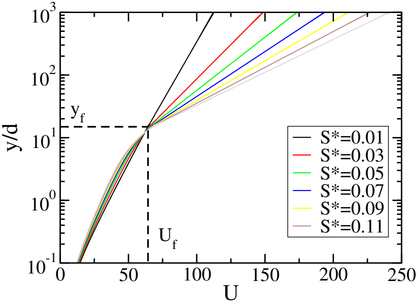


- Implementation of relevant boundary conditions at the bed deduced from the impact laws

Model predictions in the splash-limited regime

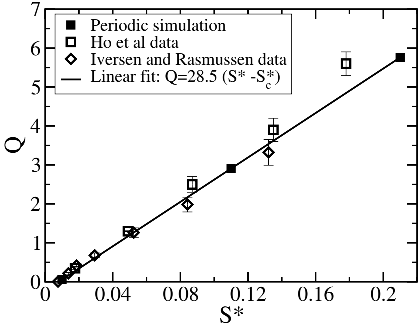
System parameters : sand grains in air
$R = 0.73$ ($d = 0.23\,mm$) and $\sigma = 2200$

- Bagnold focus point



Bagnold focus point

- Mass flow rate Q : Model vs Experiments



$$Q \propto (S^* - S_c)$$

Conclusion

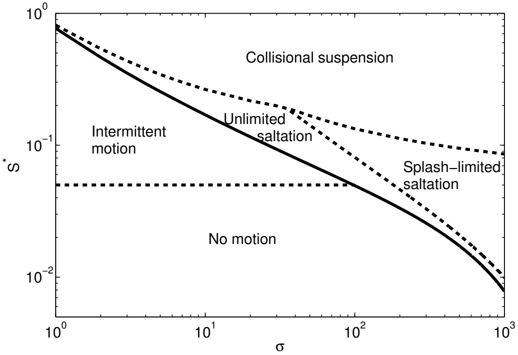
- Conclusion
  - Two different saltation regimes :
    -Transport-limited saltation : $Q \propto \sqrt{S^*}(S^* - S_c^*)$

    -Splash-limited Saltation : $Q \propto (S^* - S_c^*)$
  - Simple predictive model for saltation transport
  - Application to other planetary aeolian environments (Venus : $\sigma = 80$; Titan : $\sigma = 200$; Mars : $\sigma \approx 10000$))

Saltation regime map for various density ratio $\sigma = \rho_p/\rho_f$

- Regime map for saltation transport (Berzi et al. JFM 2016)

$St = \sigma R = 1000$



- Extra-terrestrial atmospheres : Venus ($\sigma = 80$) and Titan ($\sigma = 200$) $\Rightarrow$ Expected transition from transport- to splash-limited saltation