Role of pore pressure gradients in geophysical flows over permeable substrates

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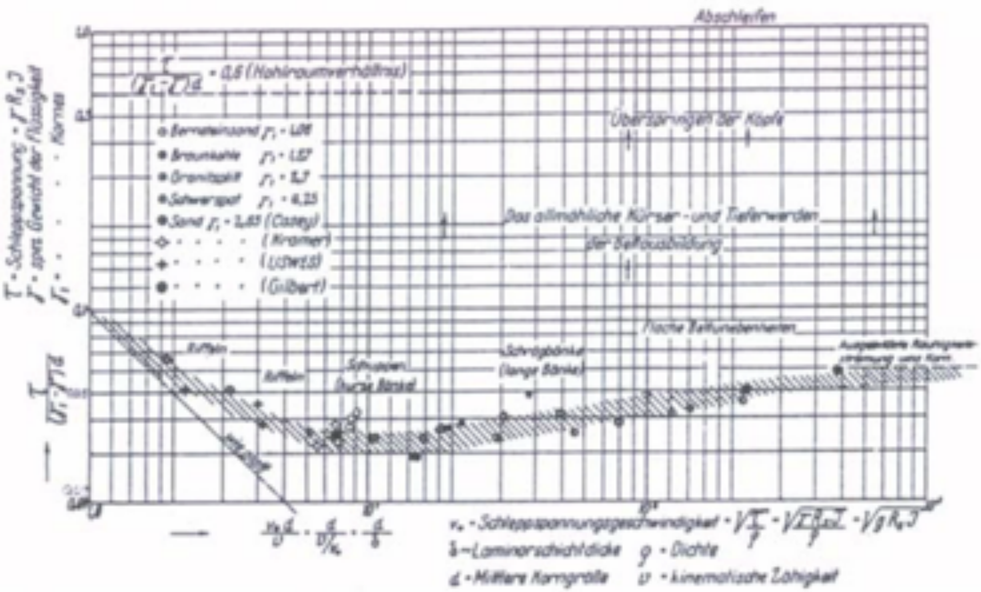
Shields, A. (1936). Anwendung der Aehnlichkeitsmechanik und der Turbulenzforschung auf die Geschiebebewegung, Mitteilungen der Preußischen Versuchsanstalt für Wasserbau 26. Berlin: Preußische Versuchsanstalt für Wasserbau.

Shields erosion



Schleppspannungsbeiwert $\frac{\tau}{(\gamma_1-\gamma)\,d}$ gegen die Reynold'sche Zahl des Kornes $\frac{v_* d}{\nu}$.

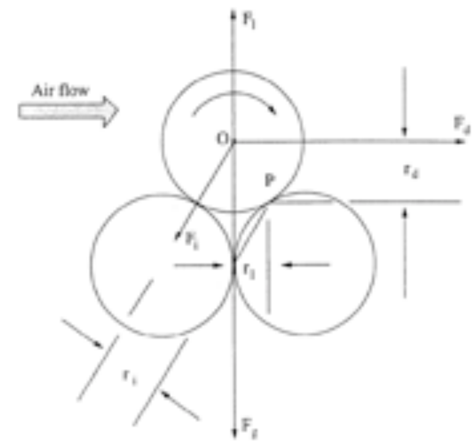


Figure 1. Forces acting on a particle resting on the surface under the influence of an airstream, including the aerodynamic drag F_d, the aerodynamic lift F_l, the gravity force F_g, the moment F_m, and the cohesive force F_i; r_d, r_l, r_m, and r_i are moment arm lengths associated with F_d, F_l and F_g, F_m, and F_i, respectively. O is the center of gravity of the particle, and P is the pivot point for particle entrainment.

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Flow over porous media

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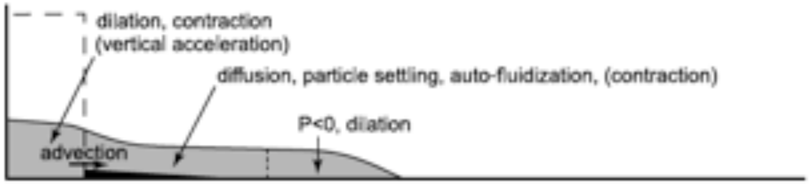

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Two examples

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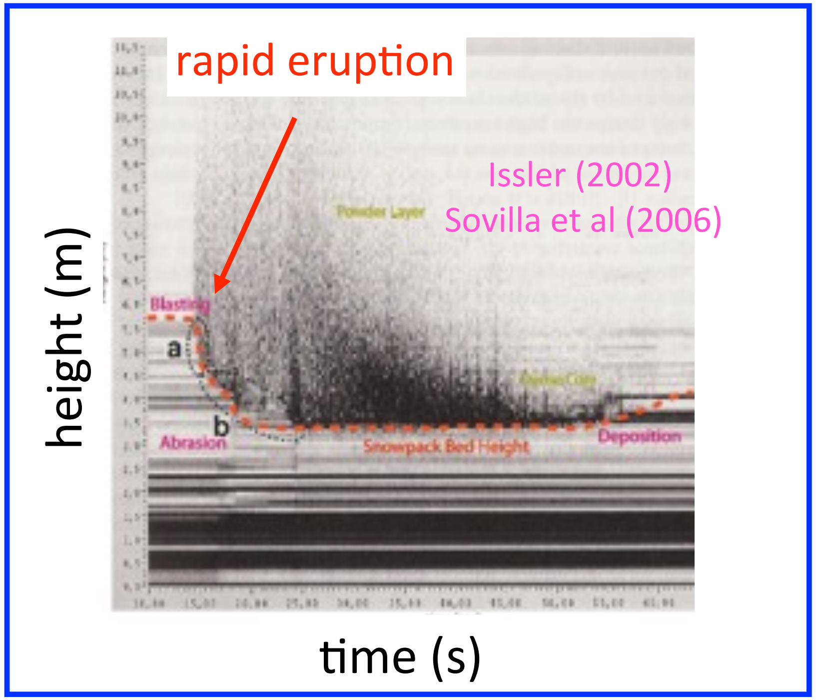
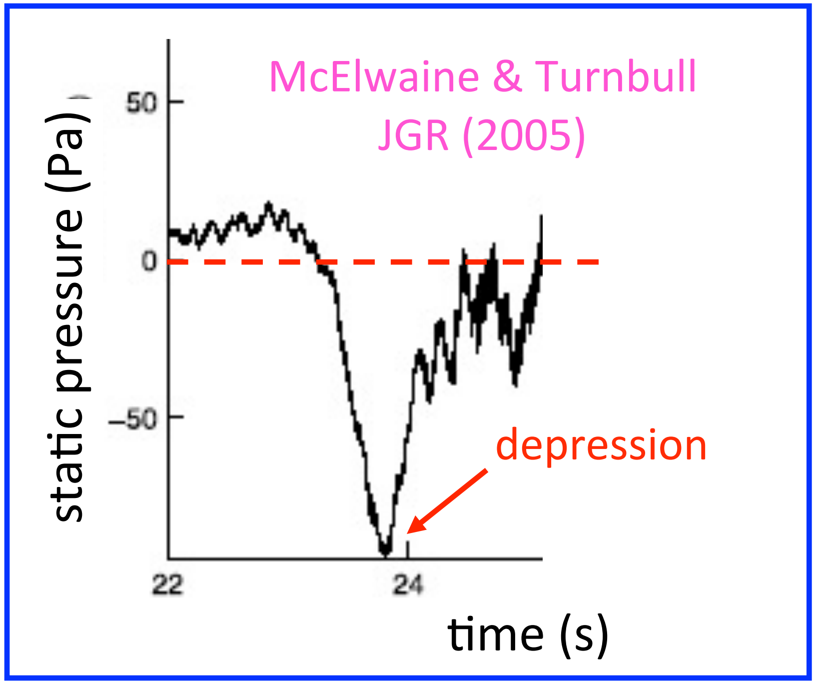
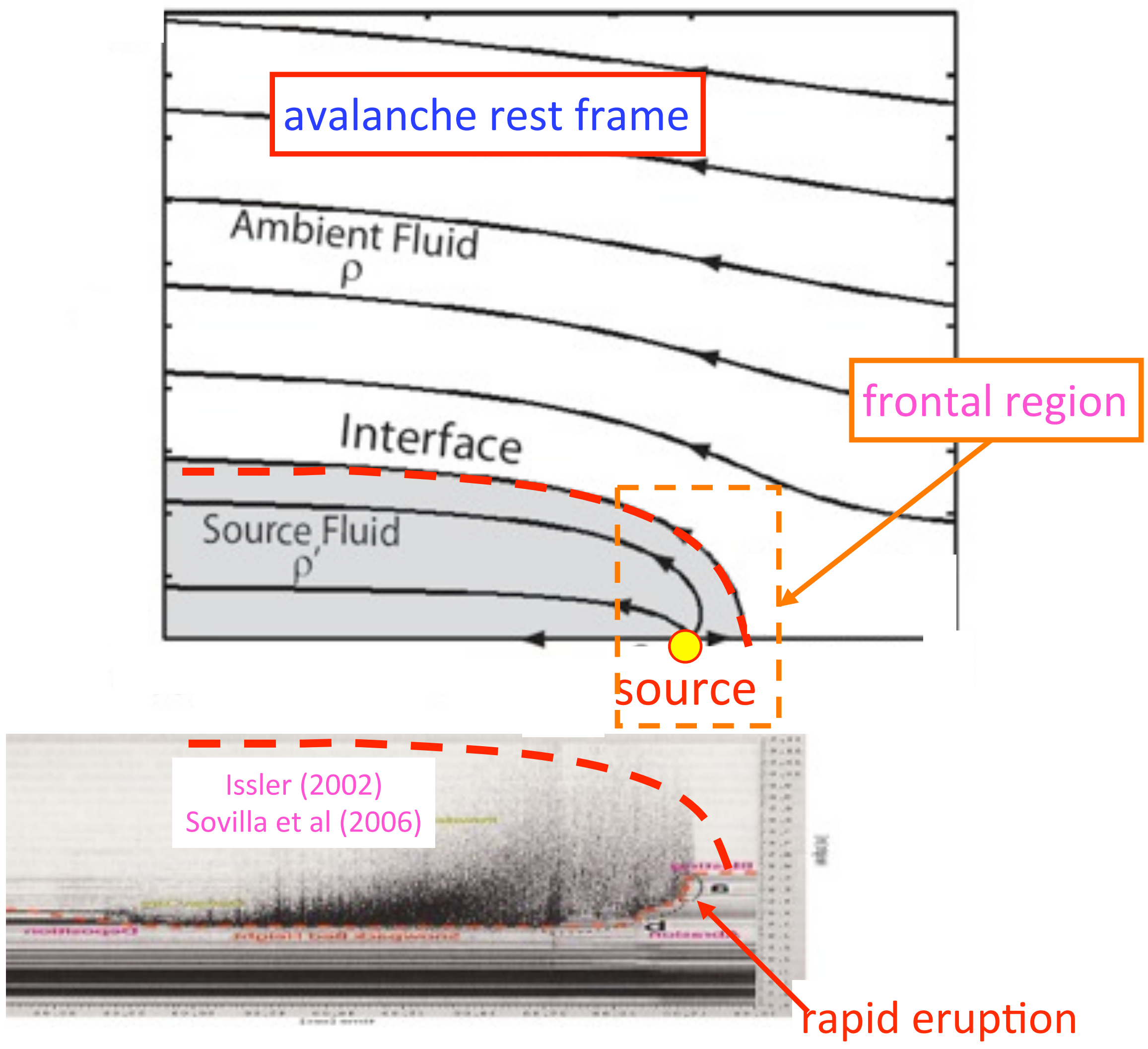
Eruption current



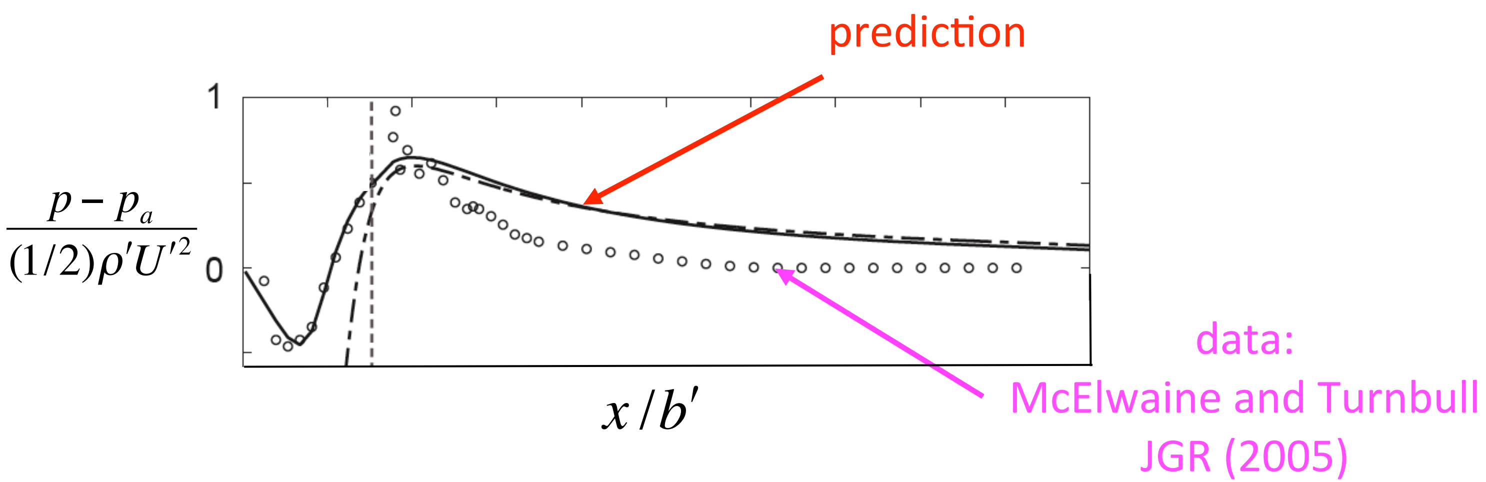


Eruption current =
a gravity current driven by massive frontal eruption

Eruption current frontal region



Static pressure in the cloud



pressure p, air density ρ, cloud density ρ'
stagnation-source distance b'
fluidized depth h'

$$\frac{p - p_a}{(1/2)\rho' U'^2} = \frac{2(x/b') - 1}{(x/b')^2 + (h'/b')^2}$$

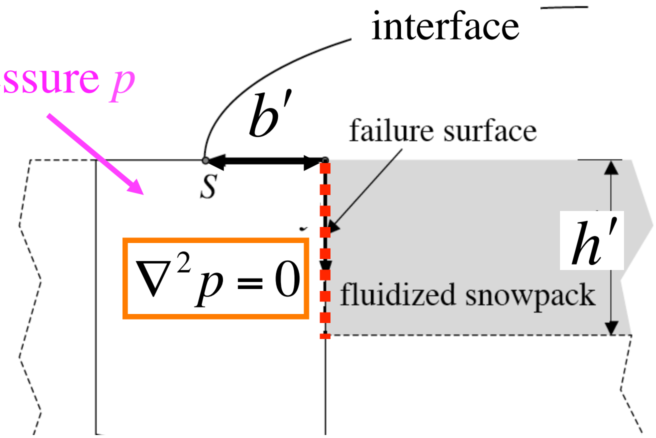
$\Rightarrow$ surface pressure time - history

Porous snow pack

$$u = -\frac{K}{\mu}\nabla p$$

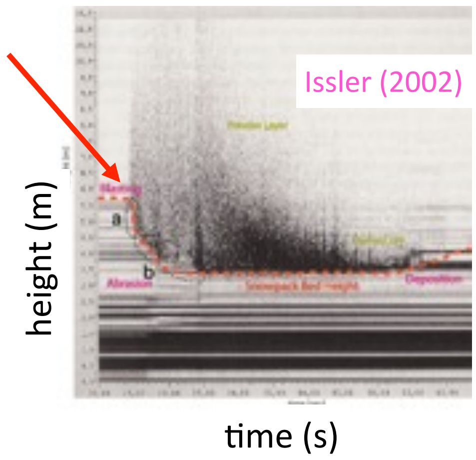
$$\nabla \cdot u = 0$$

$$\nabla^2 p = 0$$

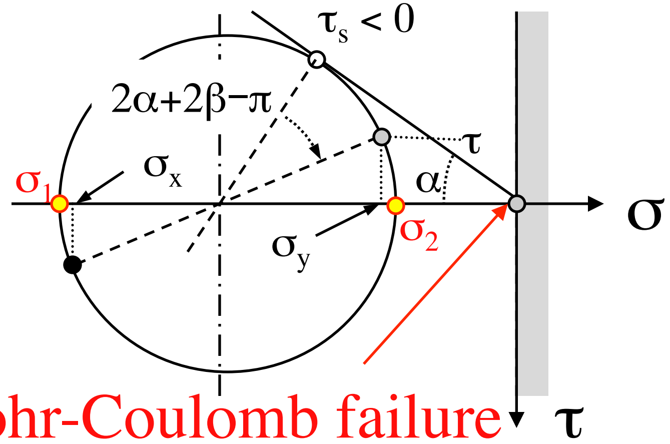


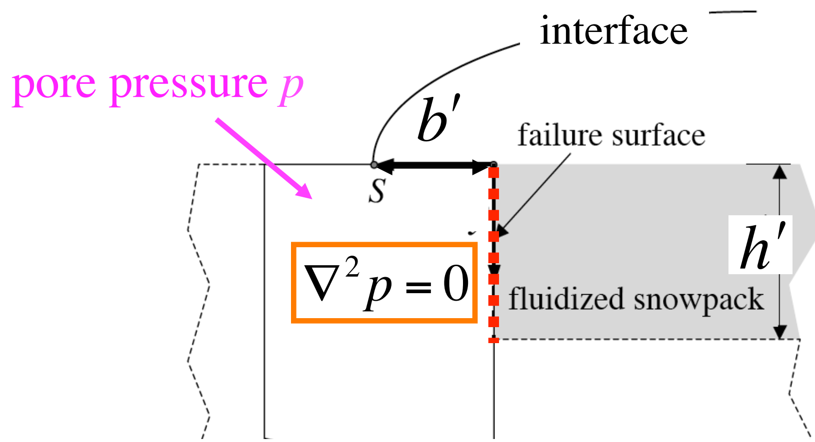
Pore pressure gradients defeat cohesion

rapid eruption



Fluidization

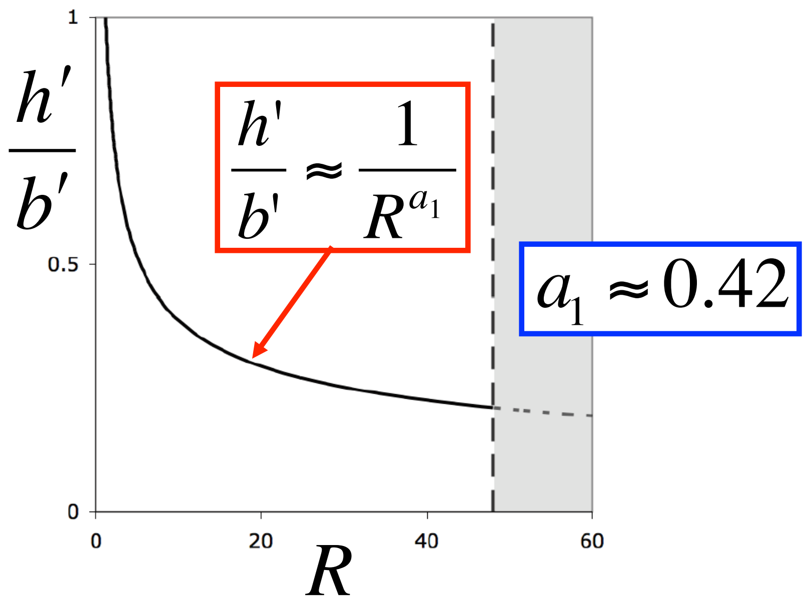




Pore pressure gradients defeat cohesion

$$R \equiv \frac{2\rho_c g b' \mu_e}{\rho' U'^2}$$

snowpack density ρ_c, friction μ_e



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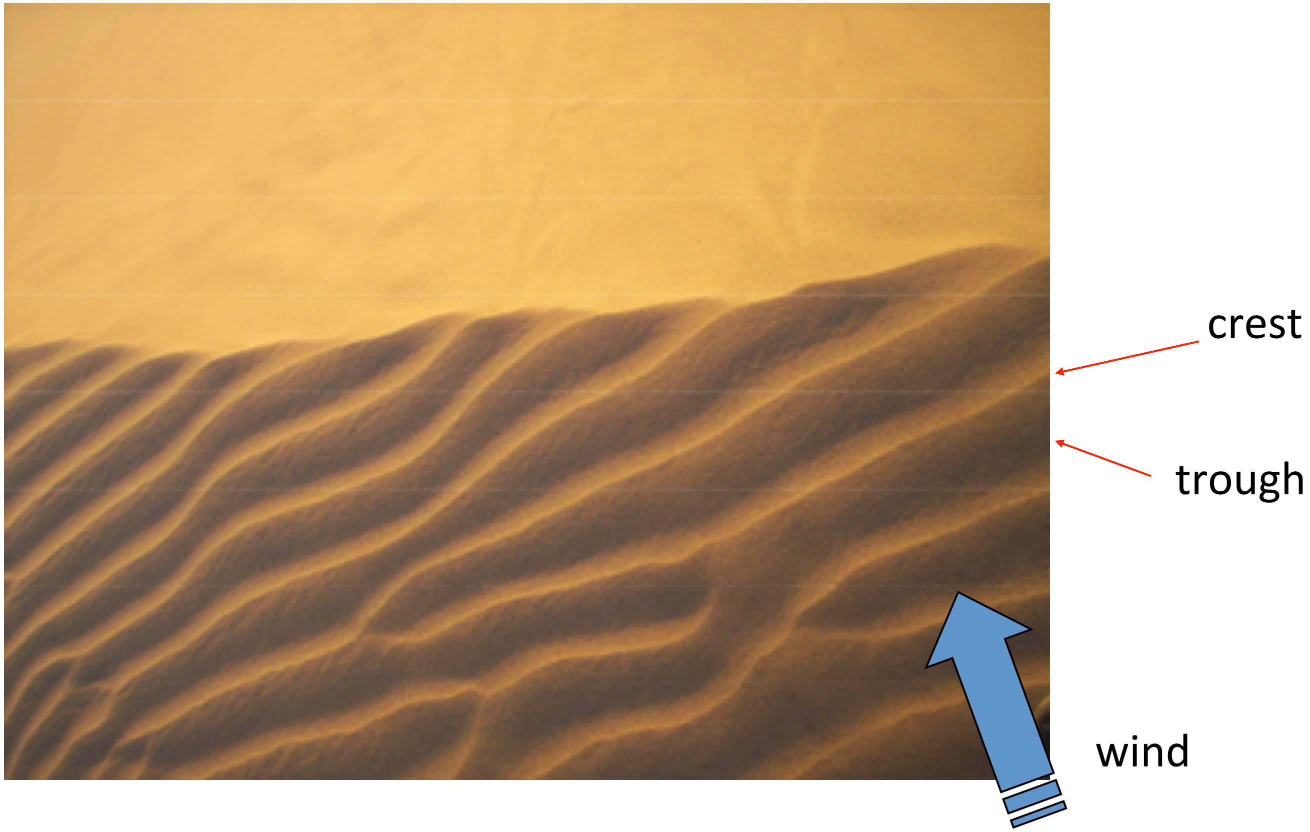
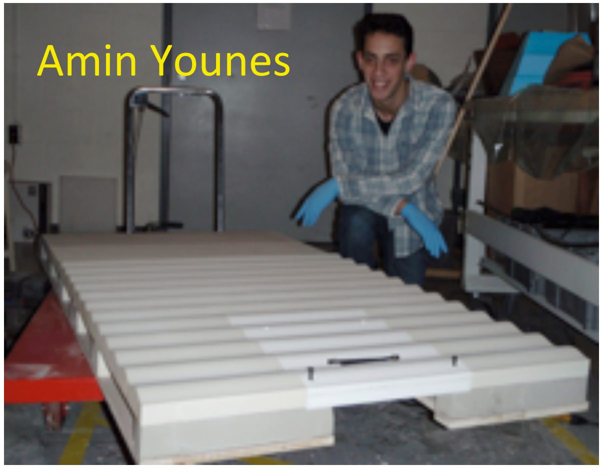
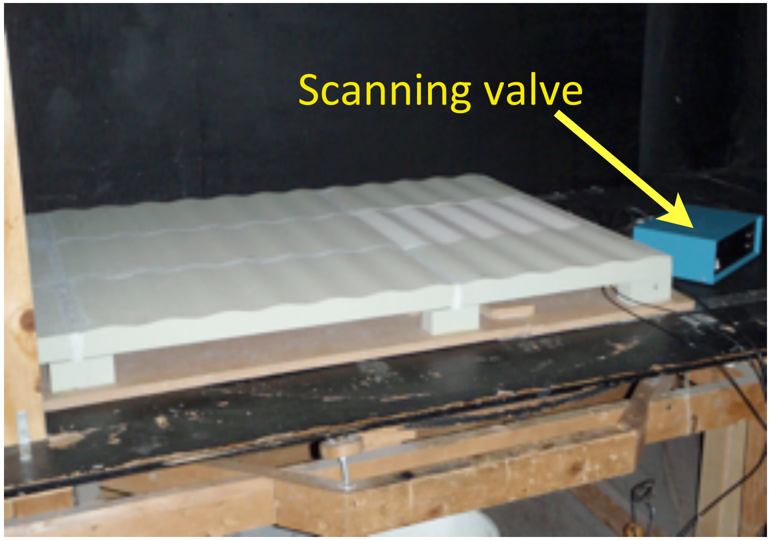
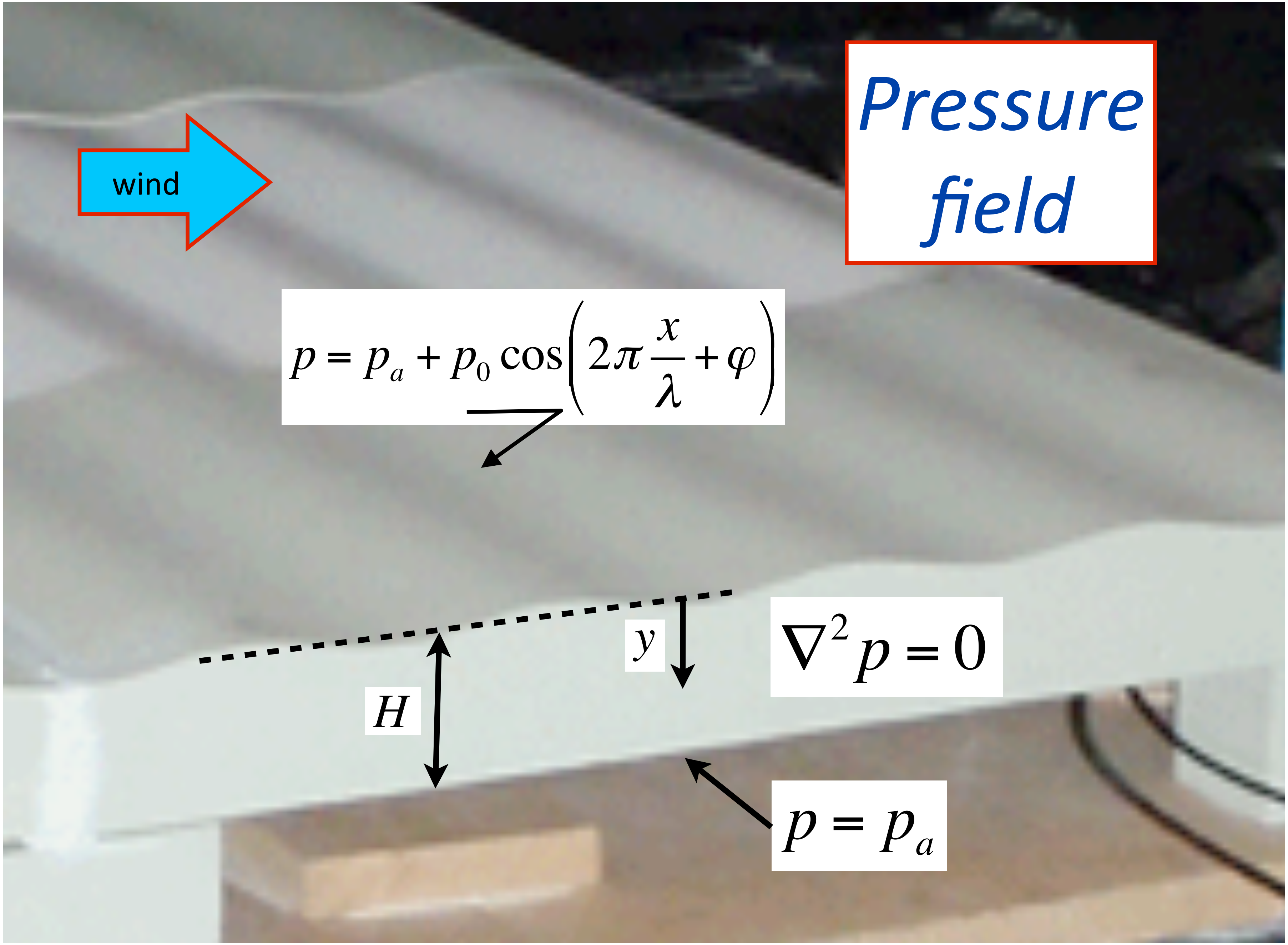
Sand ripples



Wind tunnel experiments

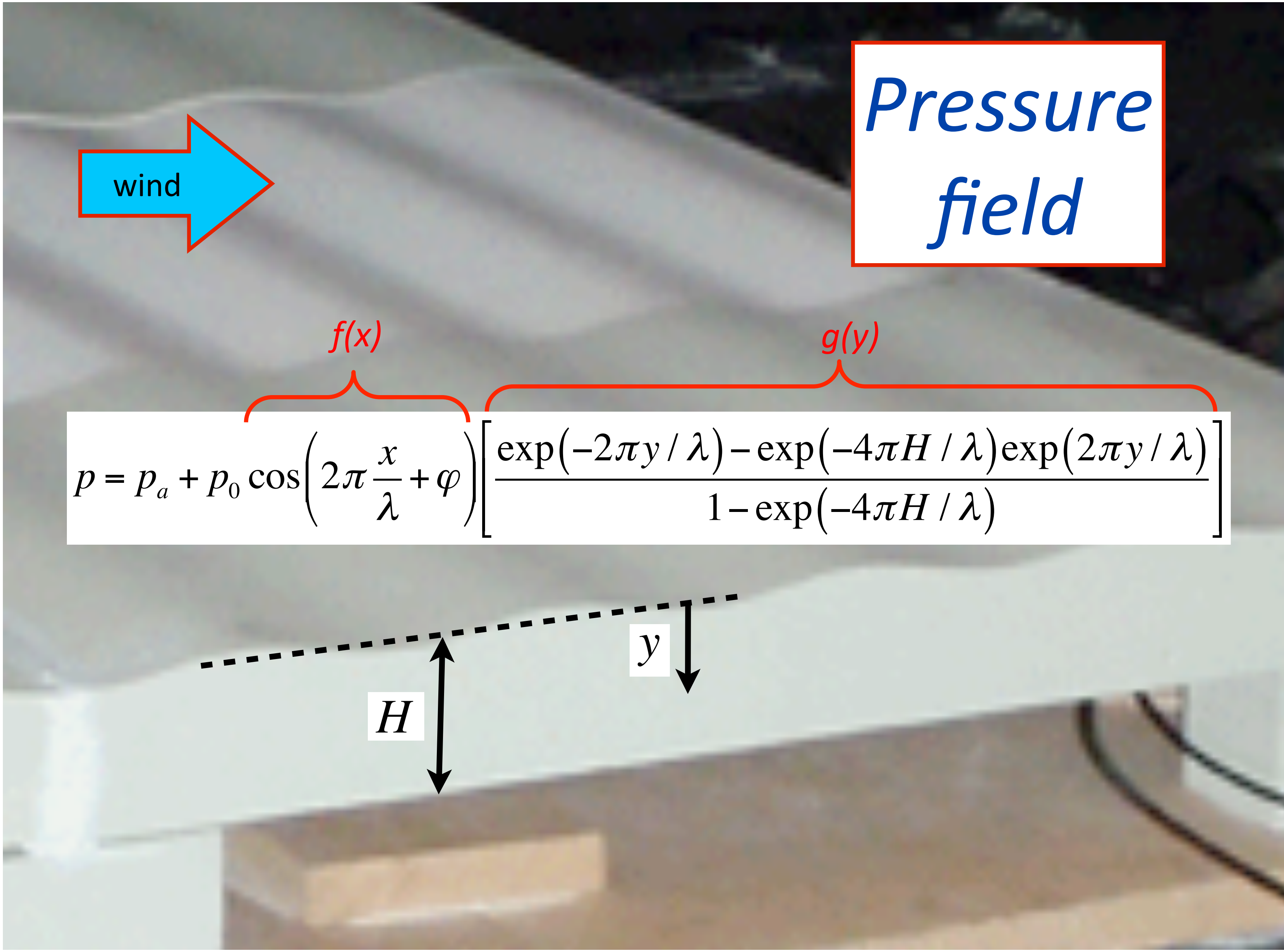




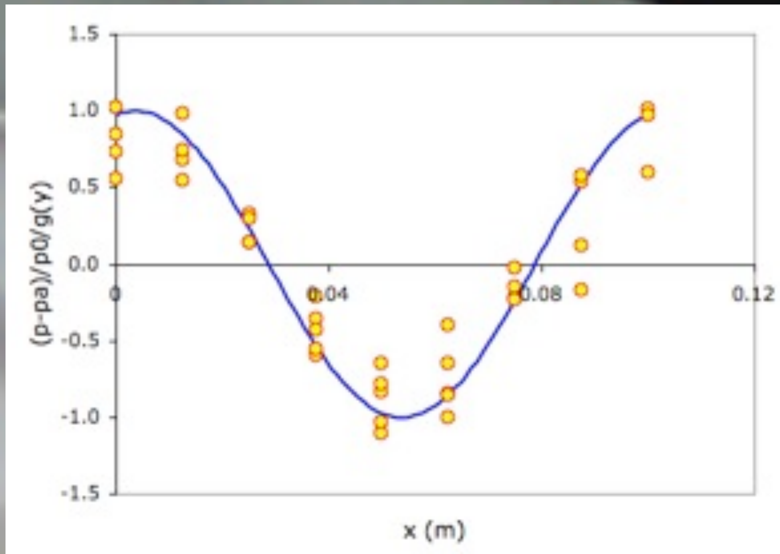

Pressure field
wind
$p = p_a + p_0 \cos\left(2\pi \frac{x}{\lambda} + \varphi\right)$
y
H
$\nabla^2 p = 0$
$p = p_a$

Pressure field

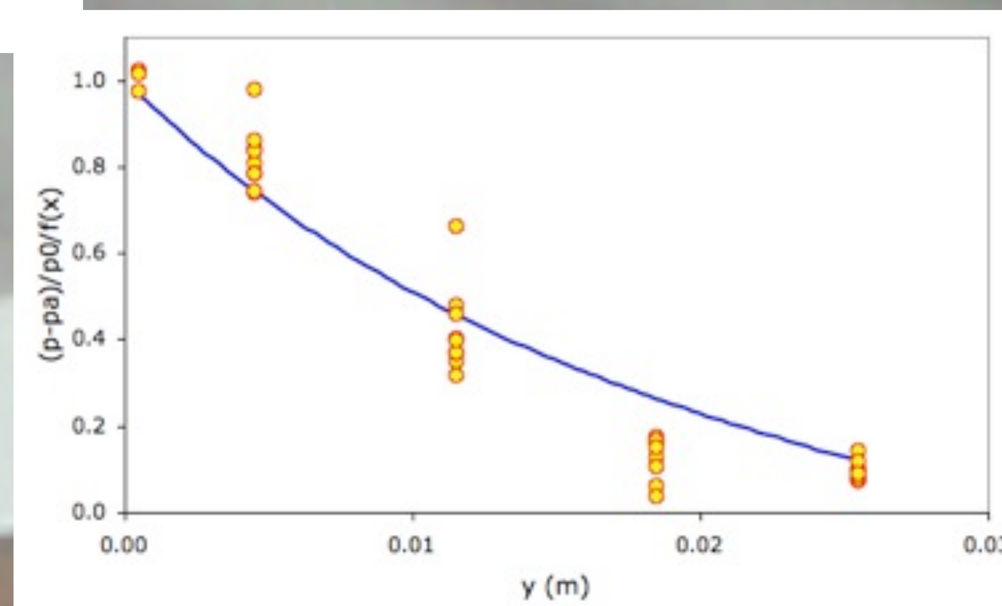
$$p = p_a + p_0 \cos\left(2\pi \frac{x}{\lambda} + \varphi\right)\left[\frac{\exp(-2\pi y/\lambda) - \exp(-4\pi H/\lambda)\exp(2\pi y/\lambda)}{1-\exp(-4\pi H/\lambda)}\right]$$



Pressure field



$$h_0 / \lambda = 3\%$$



Toward fluidization

$$\text{body force} = -\nabla p + \rho_s \nu g$$

$$\text{fluidization} \Leftrightarrow \frac{\partial p}{\partial y} \geq \rho_s \nu g$$

$$p^* \equiv \left(\frac{p}{\rho u^2}\right)\left(\frac{\lambda}{h_0}\right)$$

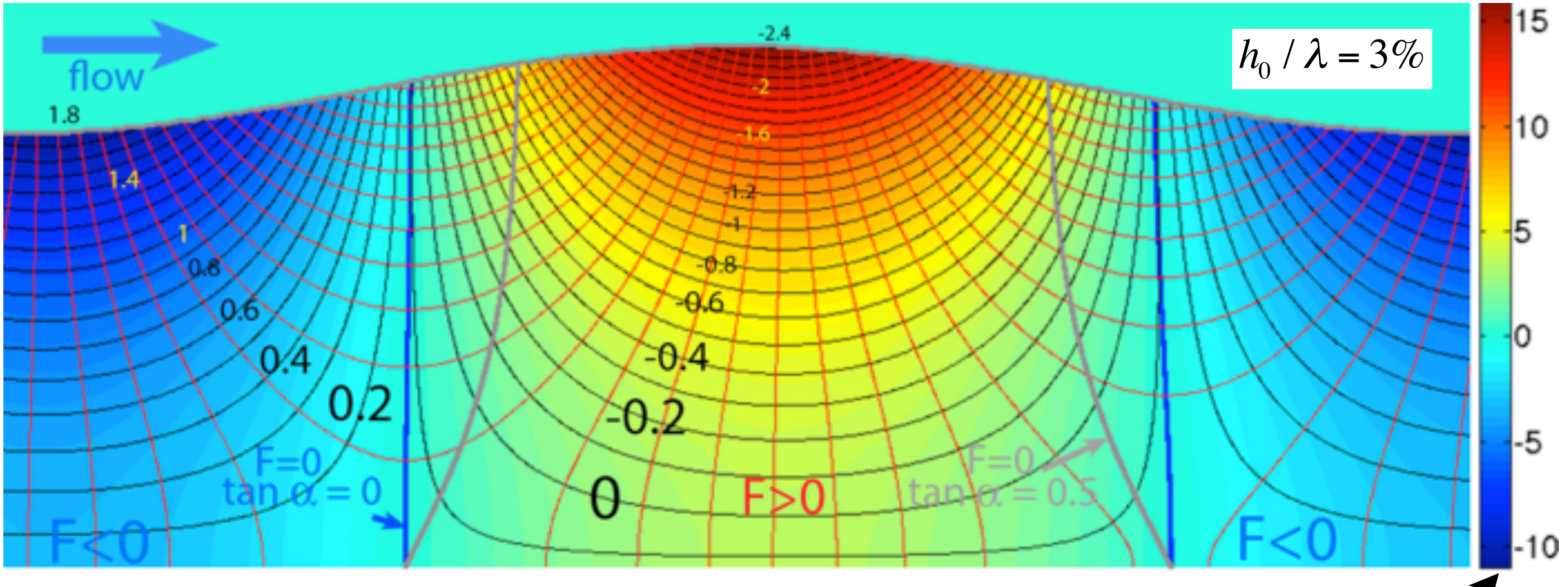
Jackson, P.S., and J.C.R. Hunt, Turbulent wind flow over a hill, Quart. J. R. Met. Soc. 101, 929-955 (1975).

$$y^* \equiv \frac{y}{\lambda}$$

$$F \equiv \frac{\partial p^*}{\partial y^*} - \tan\alpha \left|\frac{\partial p^*}{\partial x^*}\right| \qquad R \equiv \frac{\rho u^2 h_0}{\rho_s \nu g \lambda^2}$$

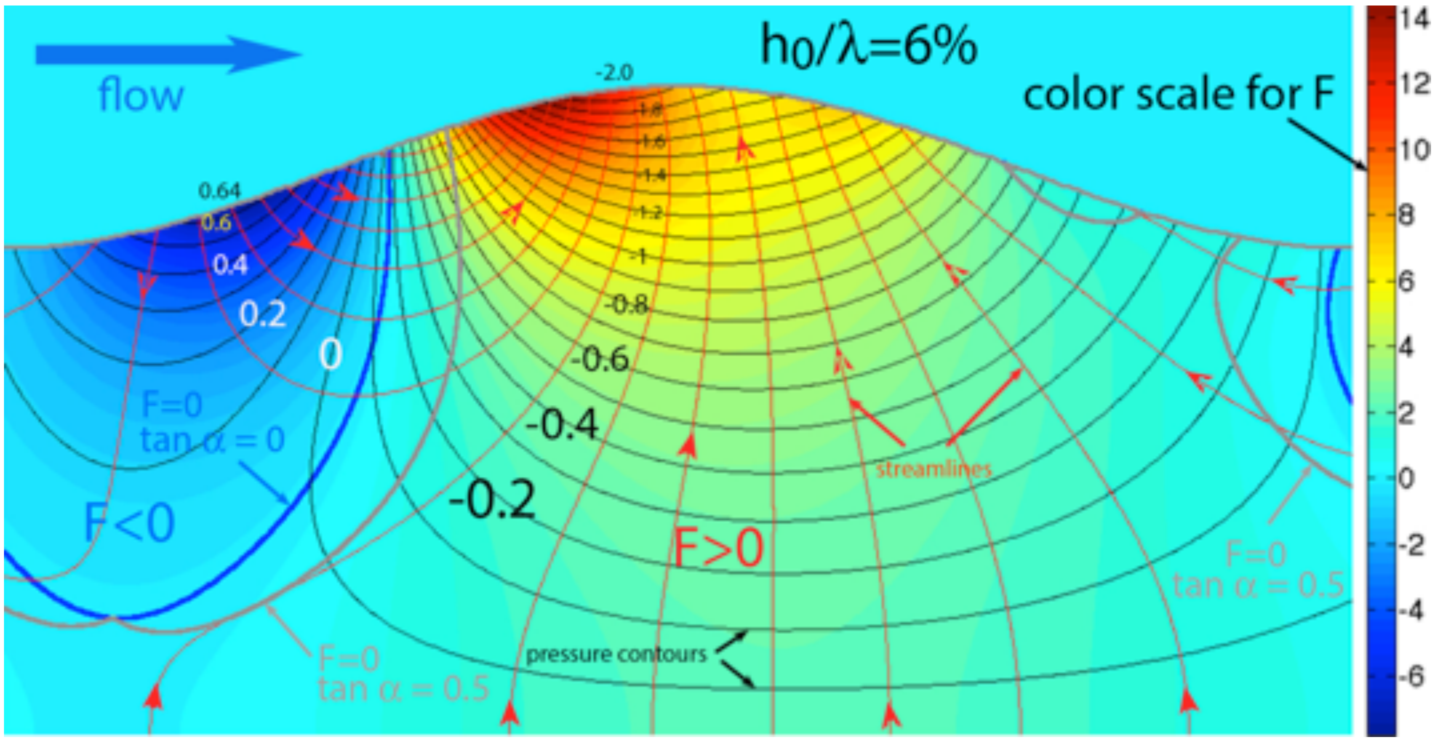
$$\text{fluidization} \Leftrightarrow F R \geq 1$$

Toward fluidization



$$F \equiv \frac{\partial p^*}{\partial y^*} - \tan\alpha \left| \frac{\partial p^*}{\partial x^*} \right|$$

Toward fluidization



$$\frac{h_0 d}{\lambda^2} > 0.003 \Rightarrow \nabla p \text{ matters more than Shields}$$

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Conclusions

Flow-induced pressure gradients
matter to sediment uplift
over permeable media

http://grainflowresearch.mae.cornell.edu/index.html