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Flume experiments on the initiation and evolution of transverse bedforms

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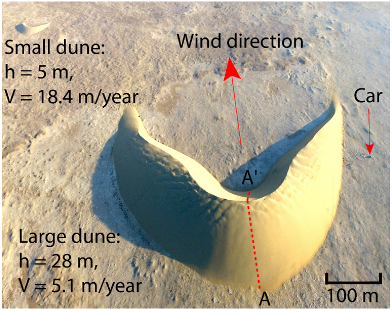
Pair of barchan dunes, Umm Said desert, Qatar



Credit: Sylain Michel

Height $\sim O(1-10)$ m

Wind ripples, Sistan, Afghanistan

Credit: Eugen Karl Kempf

Height $\sim O(1-10)$ cm

Sediment transport

If $\tau > \tau_c$ then transport is possible

Mass conservation

$$\frac{\partial z}{\partial t} + \frac{\partial q}{\partial x}$$

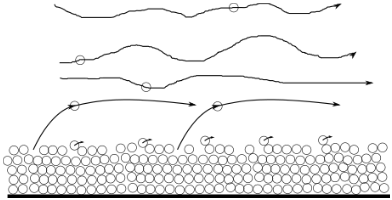
Sediment transport

$$q_{sat} = q_{sat}(\tau - \tau_c)$$

Transient relaxation

$$L_{sat}\frac{\partial q}{\partial x} = q_{sat} - q$$

General equations valid for different modes of transport



Differences:

- Functional form of transport law
- Physical origin of L_{sat}

Mode of transport determined by flow and particle Reynolds numbers

$$Re = \frac{UD}{\nu}, \quad Re_p = \frac{Ud}{\nu}$$

Aeolian and subaqueous comparison

Aeolian dunes:

- Typical wind speed
  - $U \sim O(10)$ m s^{-1}
- Kinematic viscosity of air
  - $\nu \sim O(10^{-5})$ m^2 s^{-1}
- Grain size
  - $D \sim O(10^{-3})$ m

Subaqueous ripples:

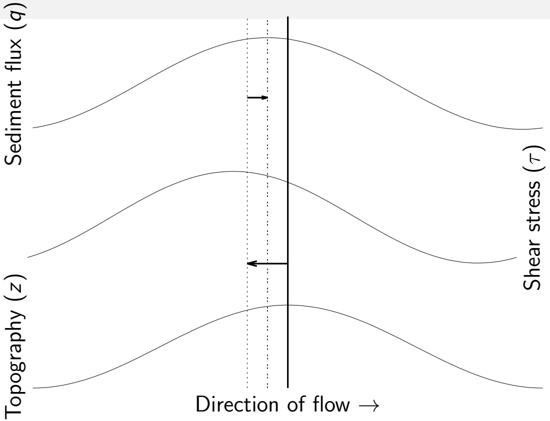
- Typical flow speed
  - $U \sim O(1)$ m s^{-1}
- Kinematic viscosity of water
  - $\nu \sim O(10^{-6})$ m^2 s^{-1}
- Grain size
  - $D \sim O(10^{-3})$ m

$$Re_{\mathrm{p}} \sim \frac{(10\mathrm{m\ s^{-1}})(10^{-3}\mathrm{m})}{10^{-5}\mathrm{m^2\ s^{-1}}} = 10^3$$

$$Re_{\mathrm{p}} \sim \frac{(1\mathrm{m\ s^{-1}})(10^{-3}\mathrm{m})}{10^{-6}\mathrm{m^2\ s^{-1}}} = 10^3$$

Similar Re_{p} suggest subaqueous flume experiments can provide insights on aeolian dunes

Initiation of transverse bedforms



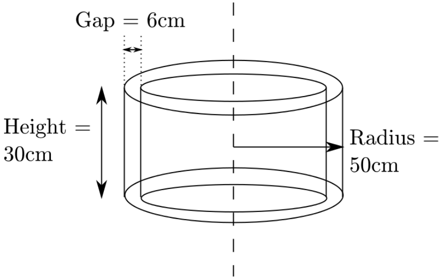
L_{sat} delays transport response

Phase shift between topography and shear stress

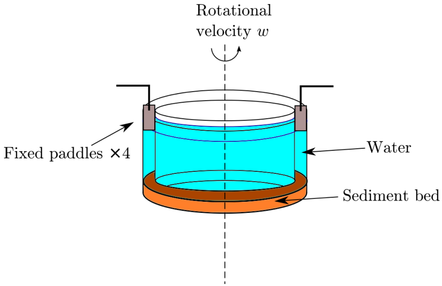
Causes small disturbances to grow and propagate

Initial λ set by saturation length

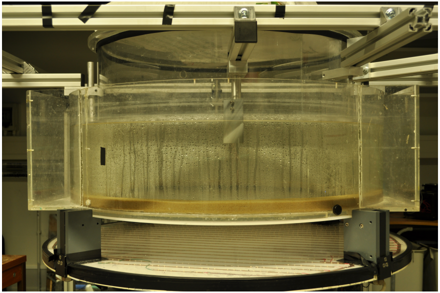
Experimental system - Annular flume



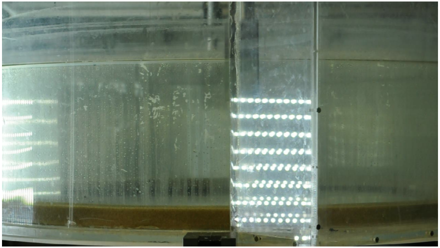
No need to replenish - can perform long term experiments



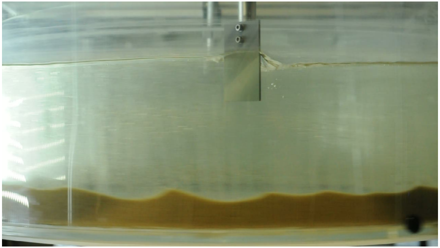
Small gap-radius ratio leads to transverse bedforms



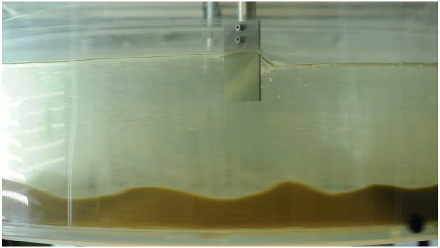
Example experiment



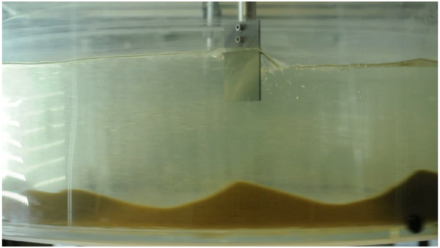
$t = 0$ s



$t = 100$ s



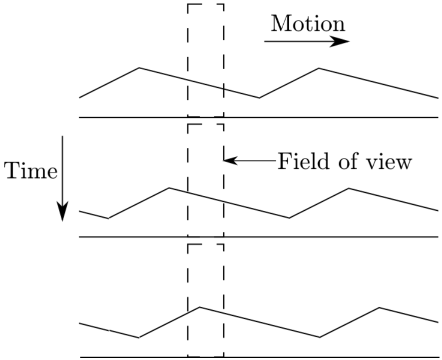
$t = 200$ s



$t = 300$ s

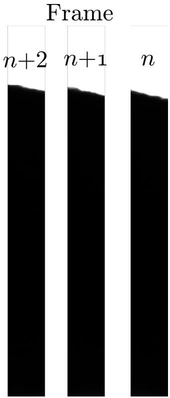
Data aquisition

Photograph thin area as tank rotates past



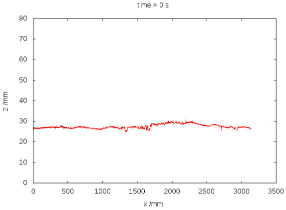
Frame rate = 200 fps

Spatial resolution = 14 mm px^{-1}

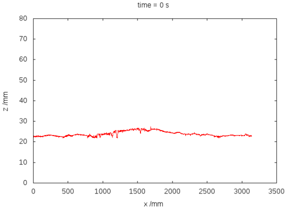


Results - Profile evolution

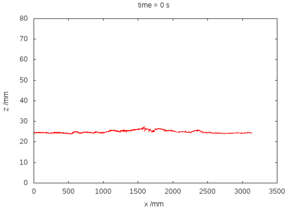
$U = 0.55 \text{ m s}^{-1}$



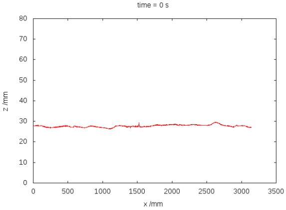
$U = 0.60 \text{ m s}^{-1}$



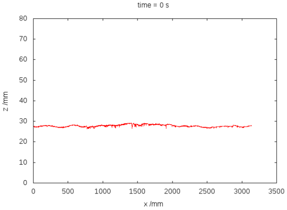
$U = 0.65 \text{ m s}^{-1}$



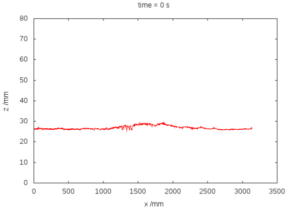
$U = 0.70 \text{ m s}^{-1}$



$U = 0.75 \text{ m s}^{-1}$

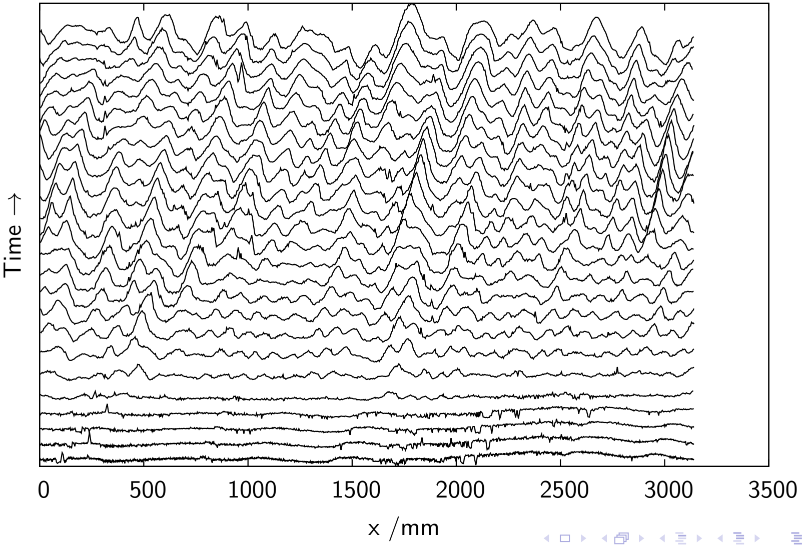


$U = 0.80 \text{ m s}^{-1}$



Results - Initial formation

$U = 0.85$ m s^{-1}, 4 s intervals for 100 s



Results - Growth

$U = 0.7$ m s^{-1}, 45 s intervals for 900 s