Analytical Mesoscale Modeling of Aeolian Sand Transport

Marc Lämmel, Anne Meiwald, Klaus Kroy

UNIVERSITÄT LEIPZIG

GeoFlo16 — Dresden

GIF

Analytical Mesoscale Modeling of Aeolian Megaripples

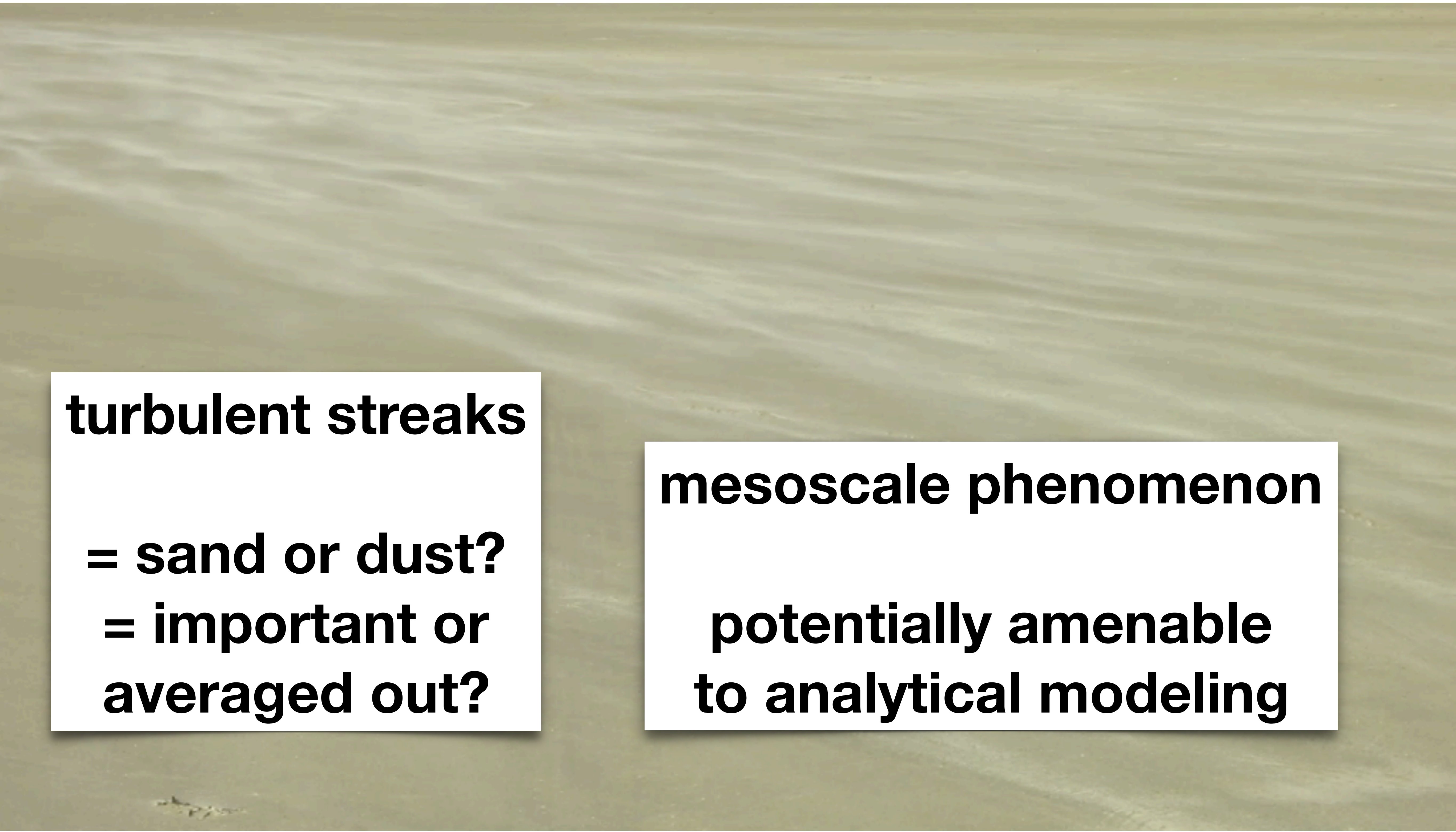
Marc Lämmel, Anne Meiwald, Klaus Kroy

UNIVERSITÄT LEIPZIG

GeoFlo16 — Dresden

GIF

Aeolian Sand Transport



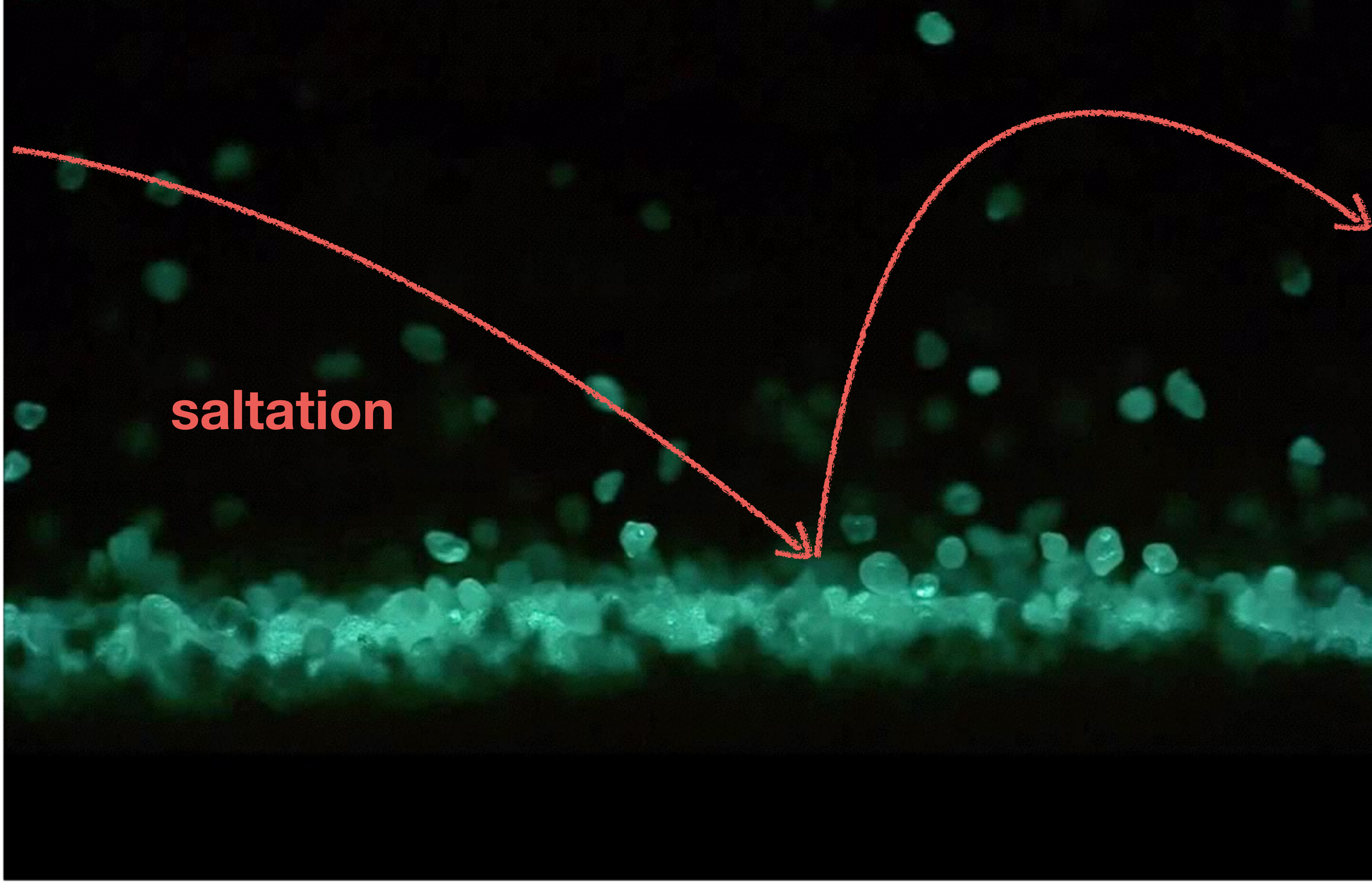
turbulent streaks

= sand or dust?
= important or averaged out?

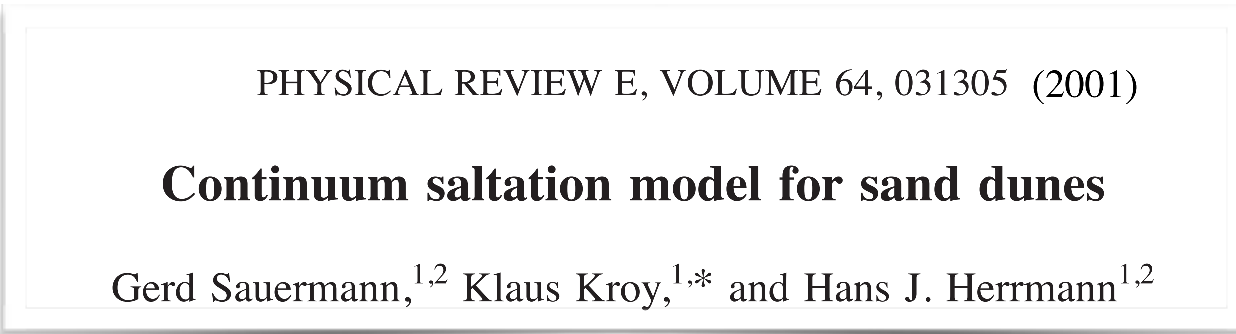
mesoscale phenomenon

potentially amenable to analytical modeling

mean-field model

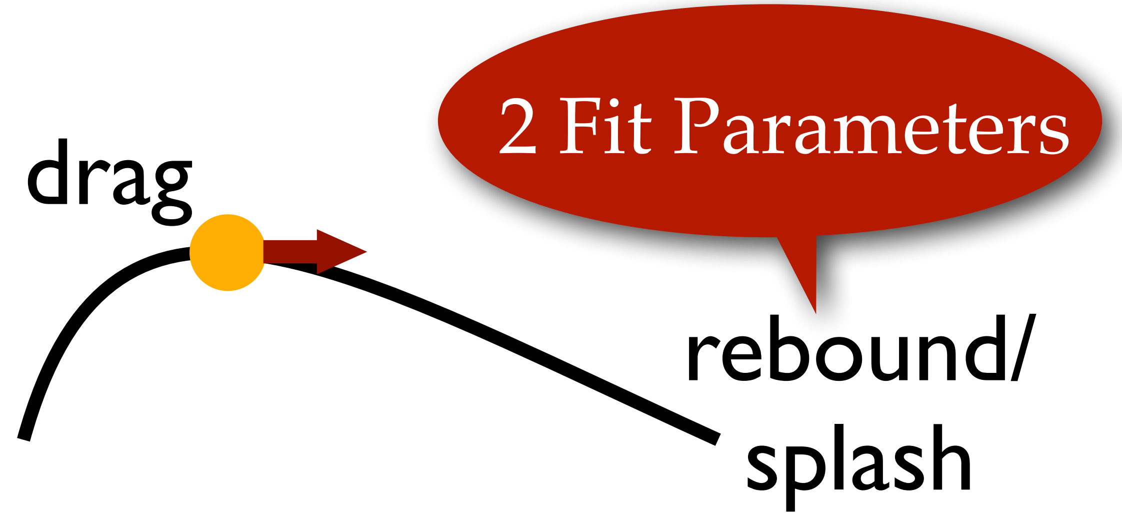


mean-field model


PHYSICAL REVIEW E, VOLUME 64, 031305 (2001)

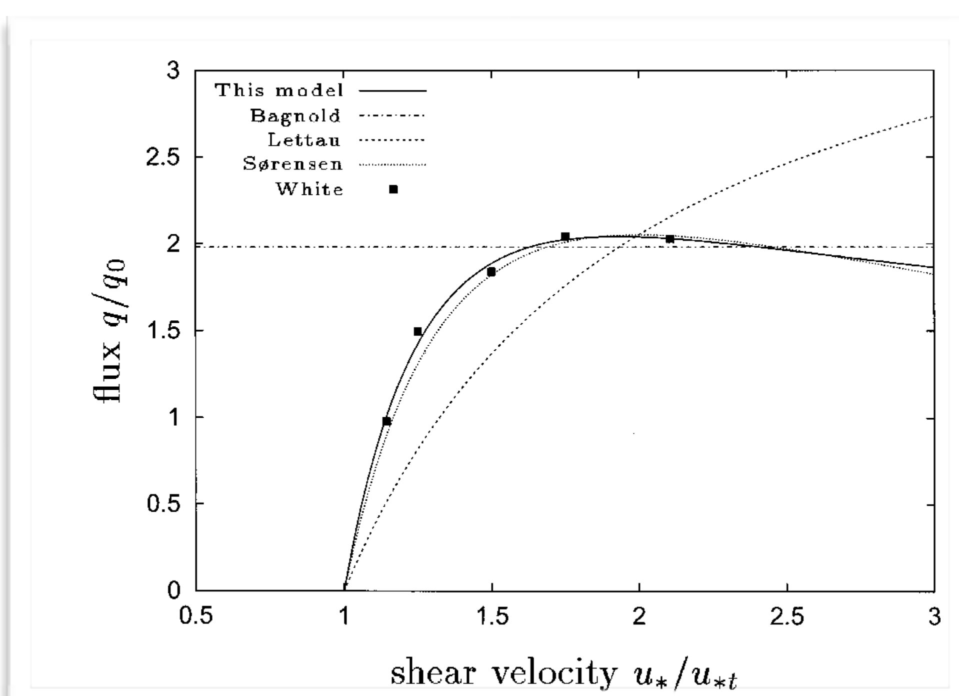
Continuum saltation model for sand dunes

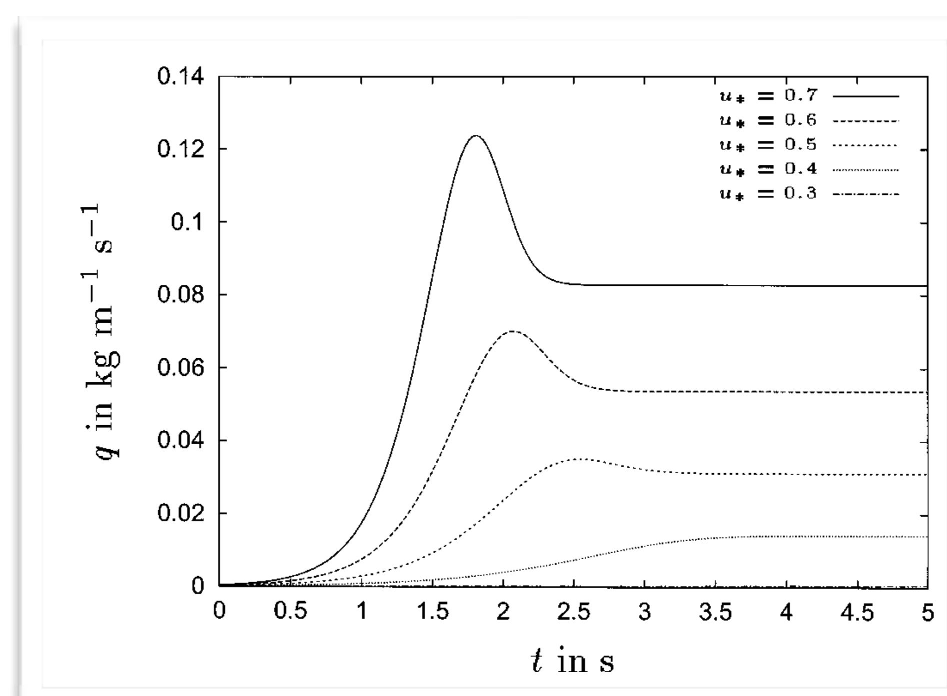
Gerd Sauermann,[1,2] Klaus Kroy,[1,*] and Hans J. Herrmann[1,2]



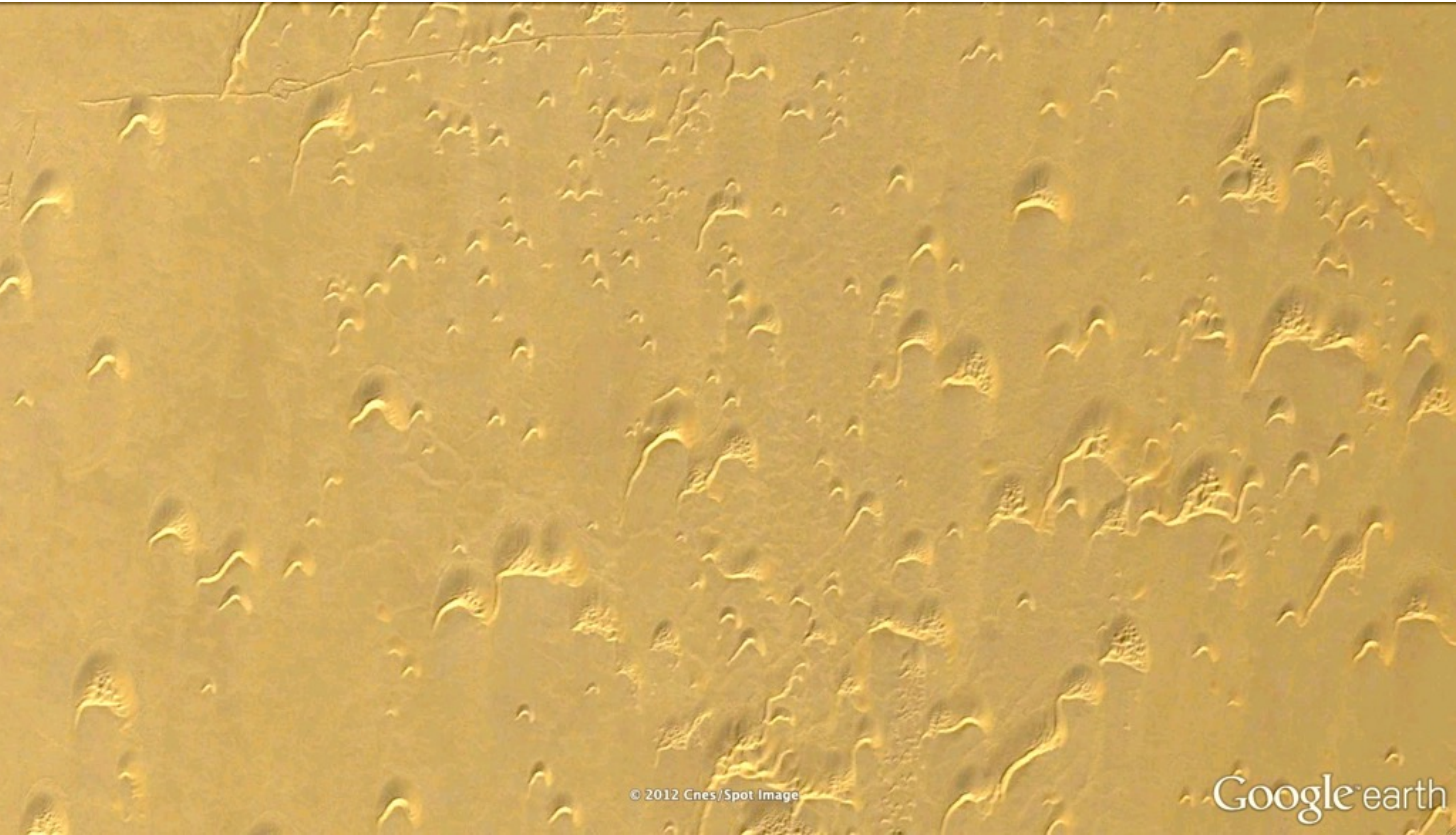
depth-averaged saturated flux/u_*^3

saturation transients (mesoscale)

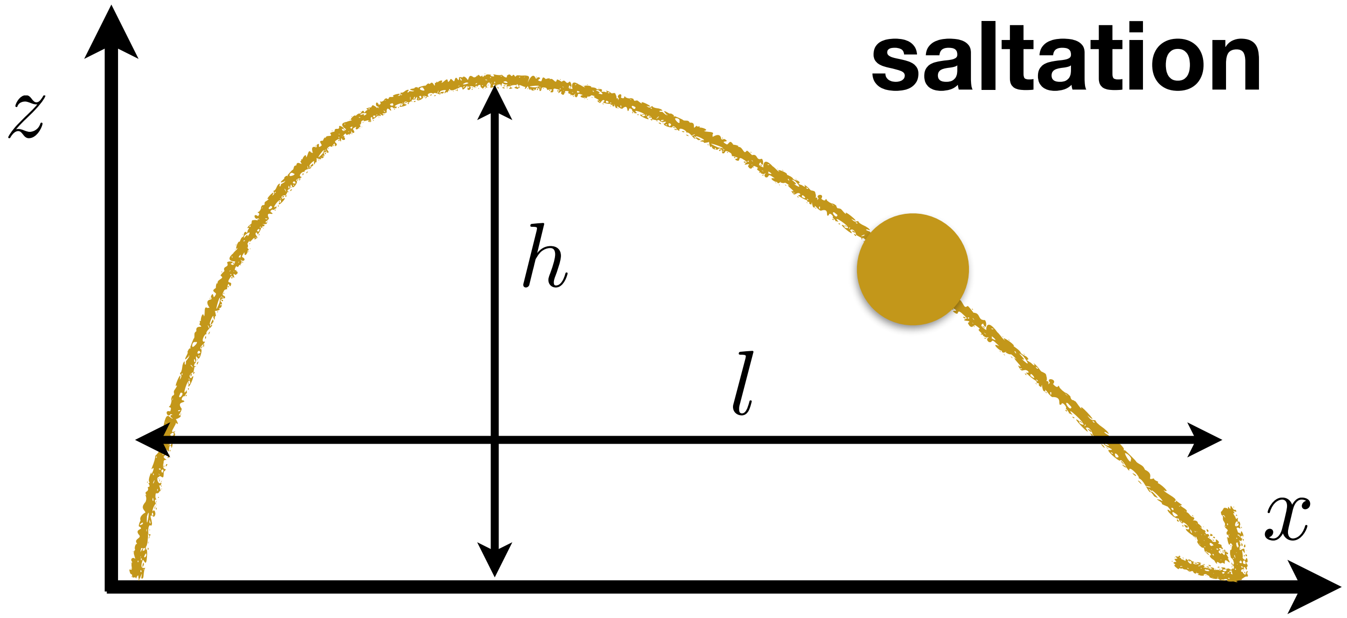


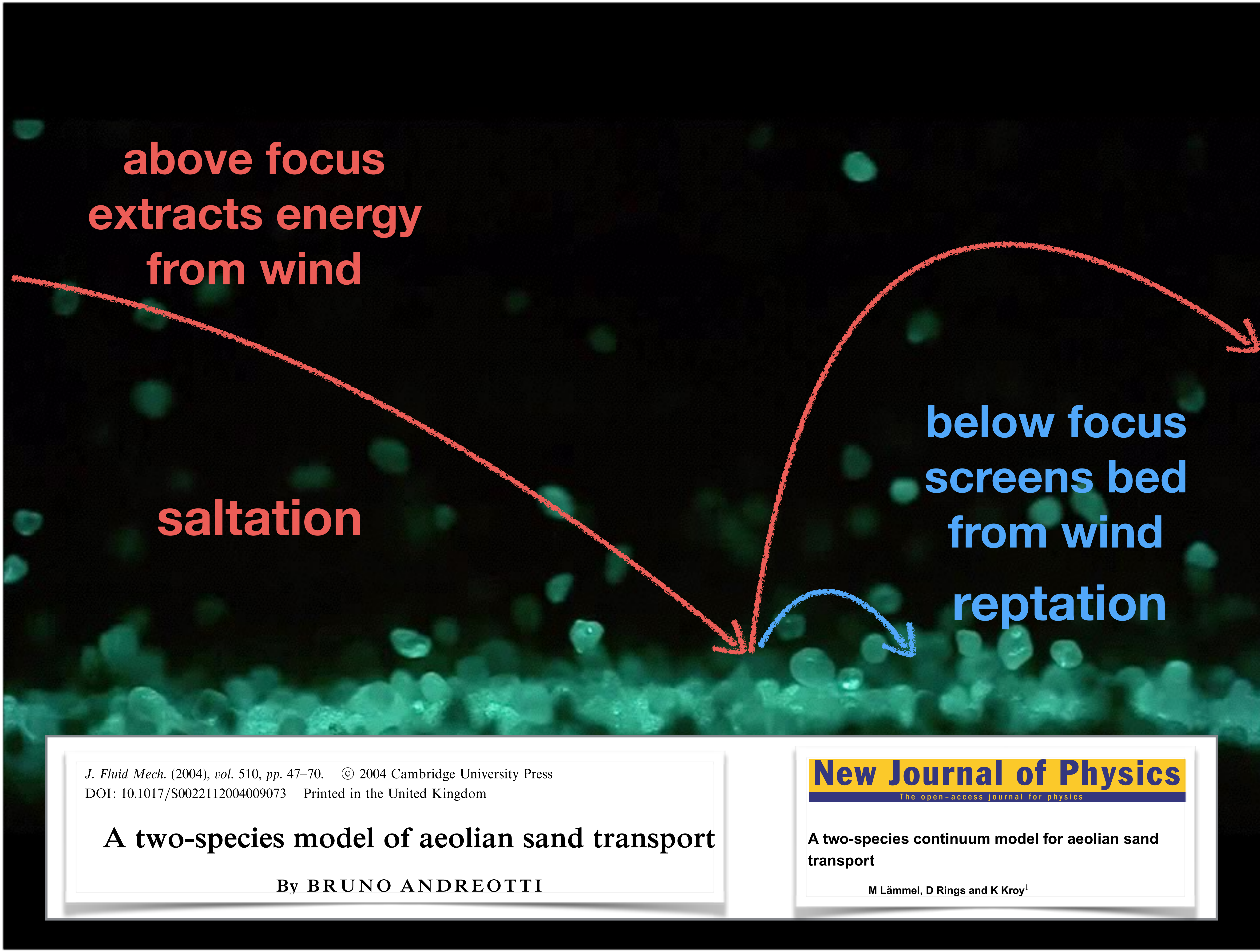


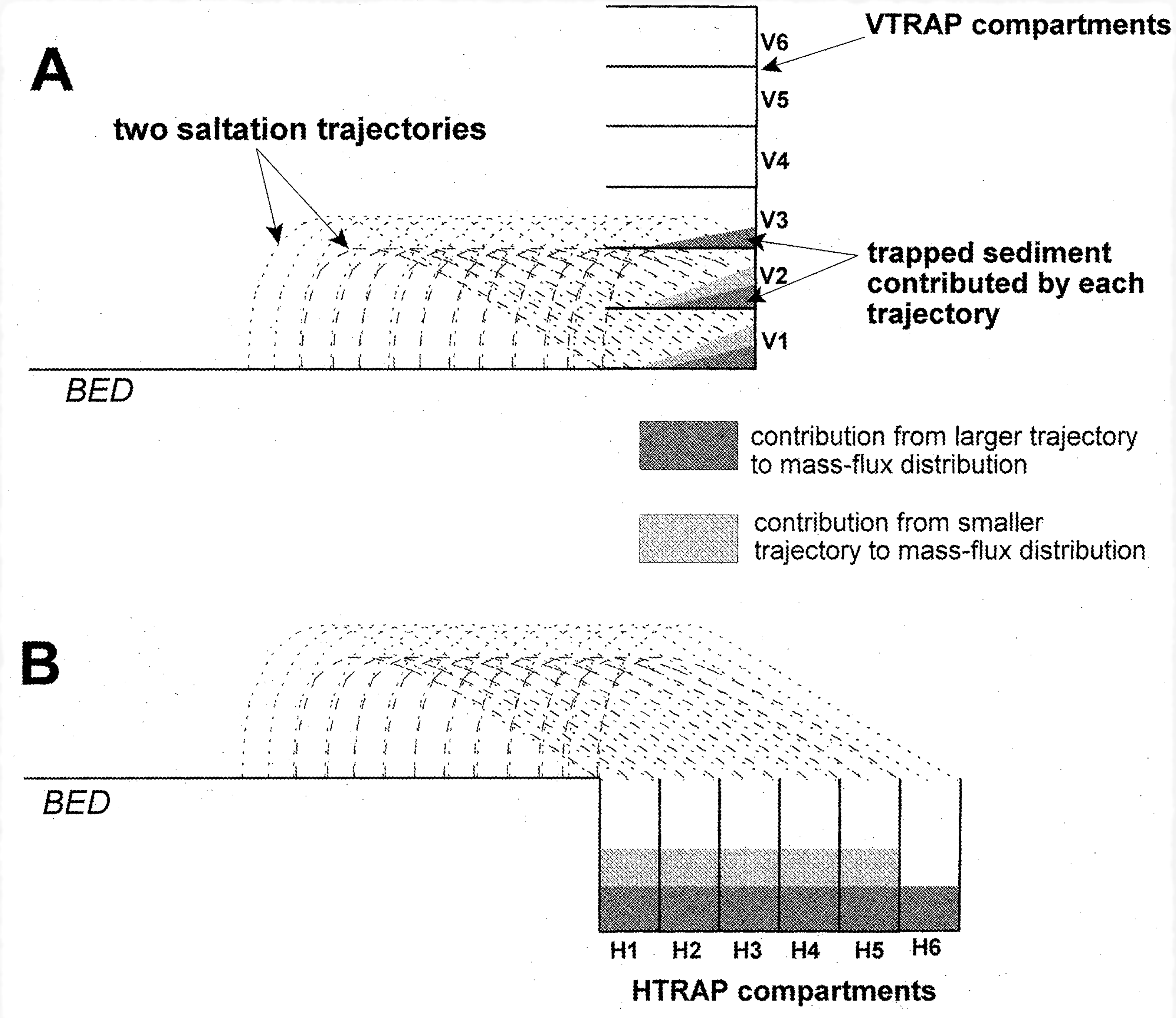
Aeolian Structure Formation



Mesoscale Phenomena




above focus
extracts energy
from wind
saltation
below focus
screens bed
from wind
reptation
J. Fluid Mech. (2004), vol. 510, pp. 47–70. © 2004 Cambridge University Press
DOI: 10.1017/S0022112004009073 Printed in the United Kingdom
A two-species model of aeolian sand transport
By BRUNO ANDREOTTI
New Journal of Physics
The open-access journal for physics
A two-species continuum model for aeolian sand transport
M Lämmel, D Rings and K Kroy[1]



J. Fluid Mech. (1964), *vol.* 20, *part* 2, *pp.* 225–242 225
Printed in Great Britain

Saltation of uniform grains in air

By P. R. OWEN
Department of Aeronautics, Imperial College, London

(Received 14 April 1964)

HEIGHT RESOLVED

- **particle concentration**
- **particle velocity**
- **particle flux**
- **hop length & height**
- **wind speed**

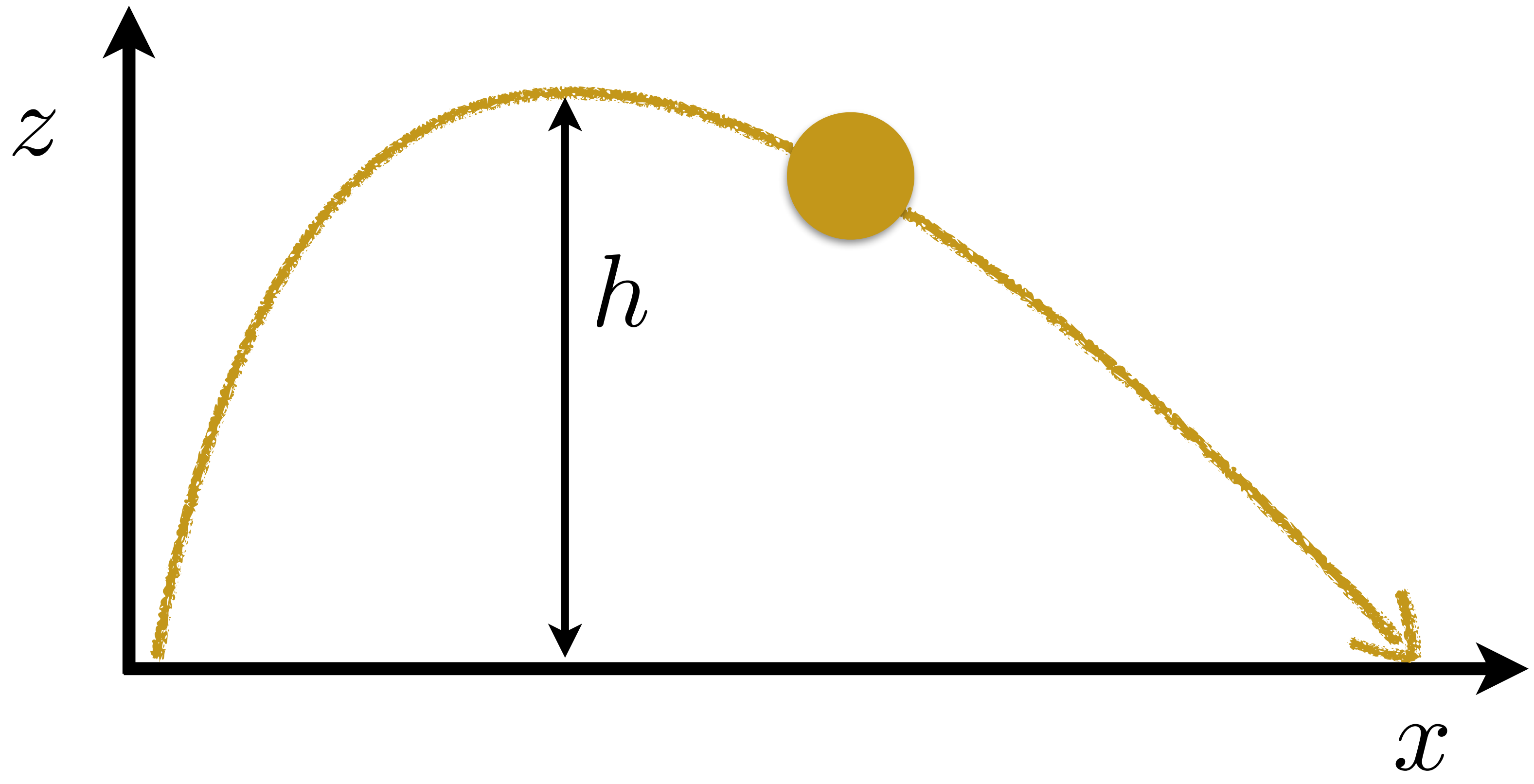
→ **DISTRIBUTIONS**

of grain trajectories

particle distribution

$$P(z, h)$$

Prob to observe particle
on trajectory of height h at z

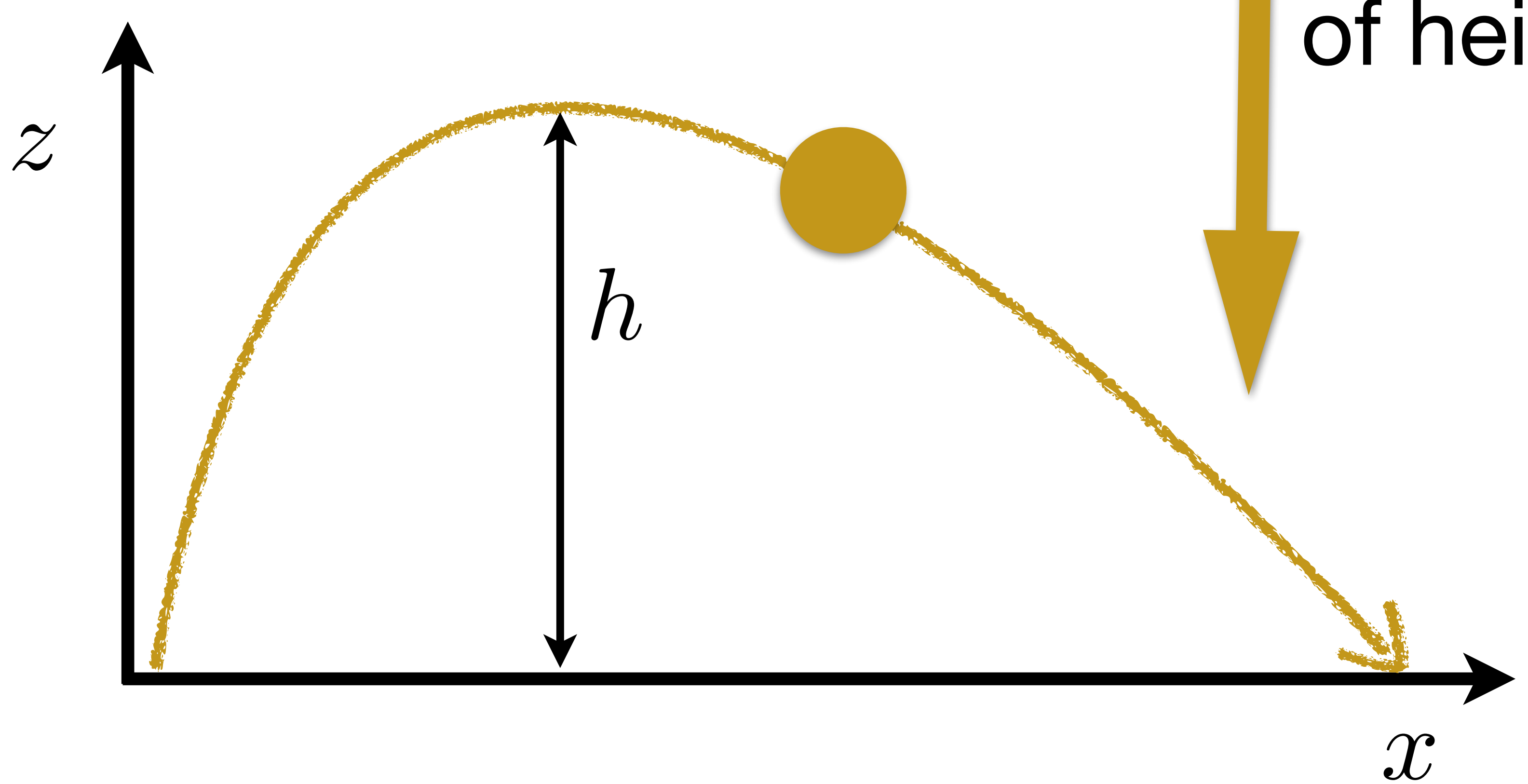


particle distribution

$$P_{\bar{h}}(z, h) = P(z|h)P_{\bar{h}}(h)$$

wind 2-spec

Prob for trajectory of height h

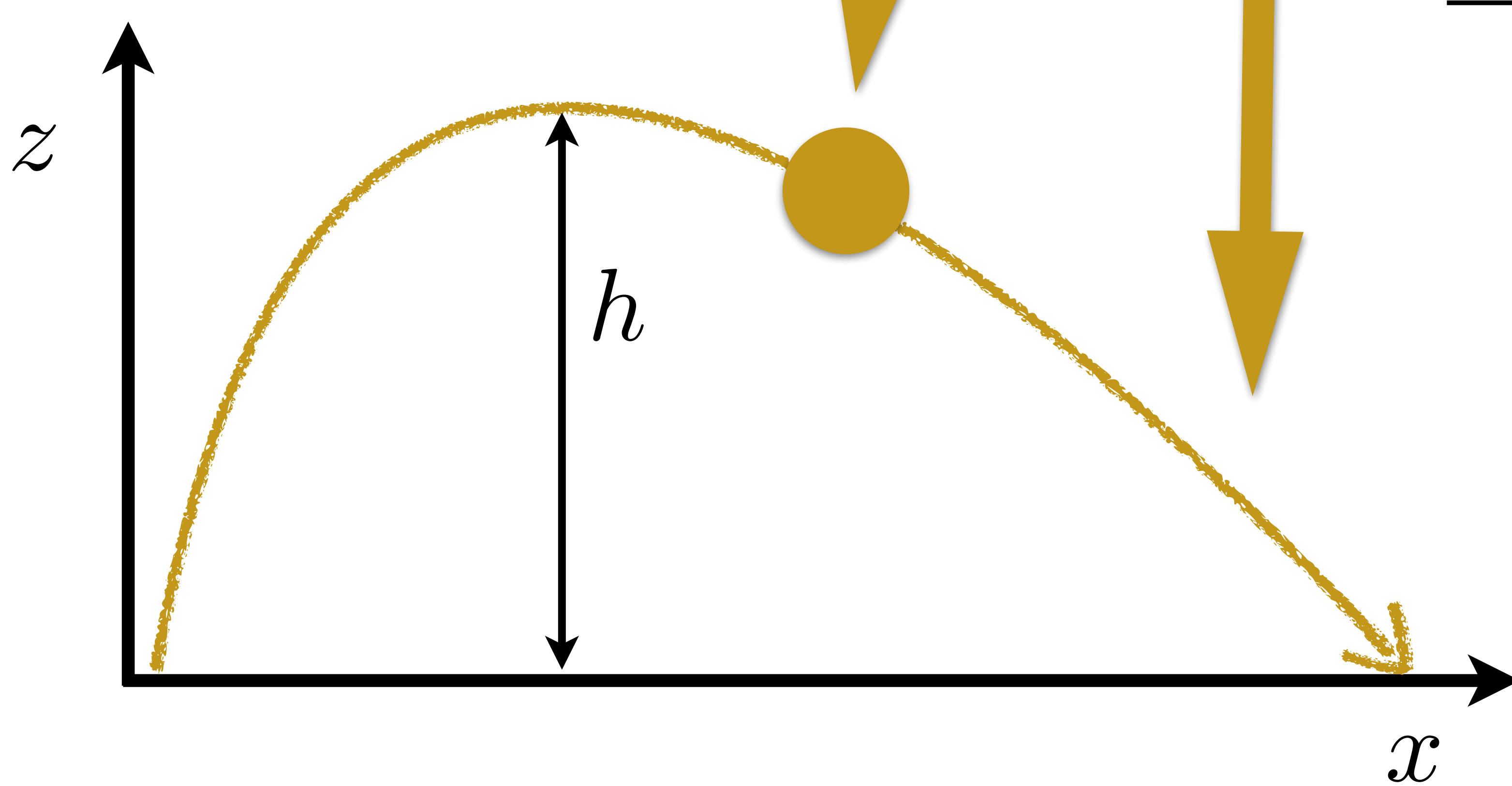


particle distribution

$$P_{\bar{h}}(z,h) = P(z|h)P_{\bar{h}}(h)$$

Prob for particle at z
if on this trajectory

$$\frac{e^{-h/\bar{h}}}{\bar{h}}$$

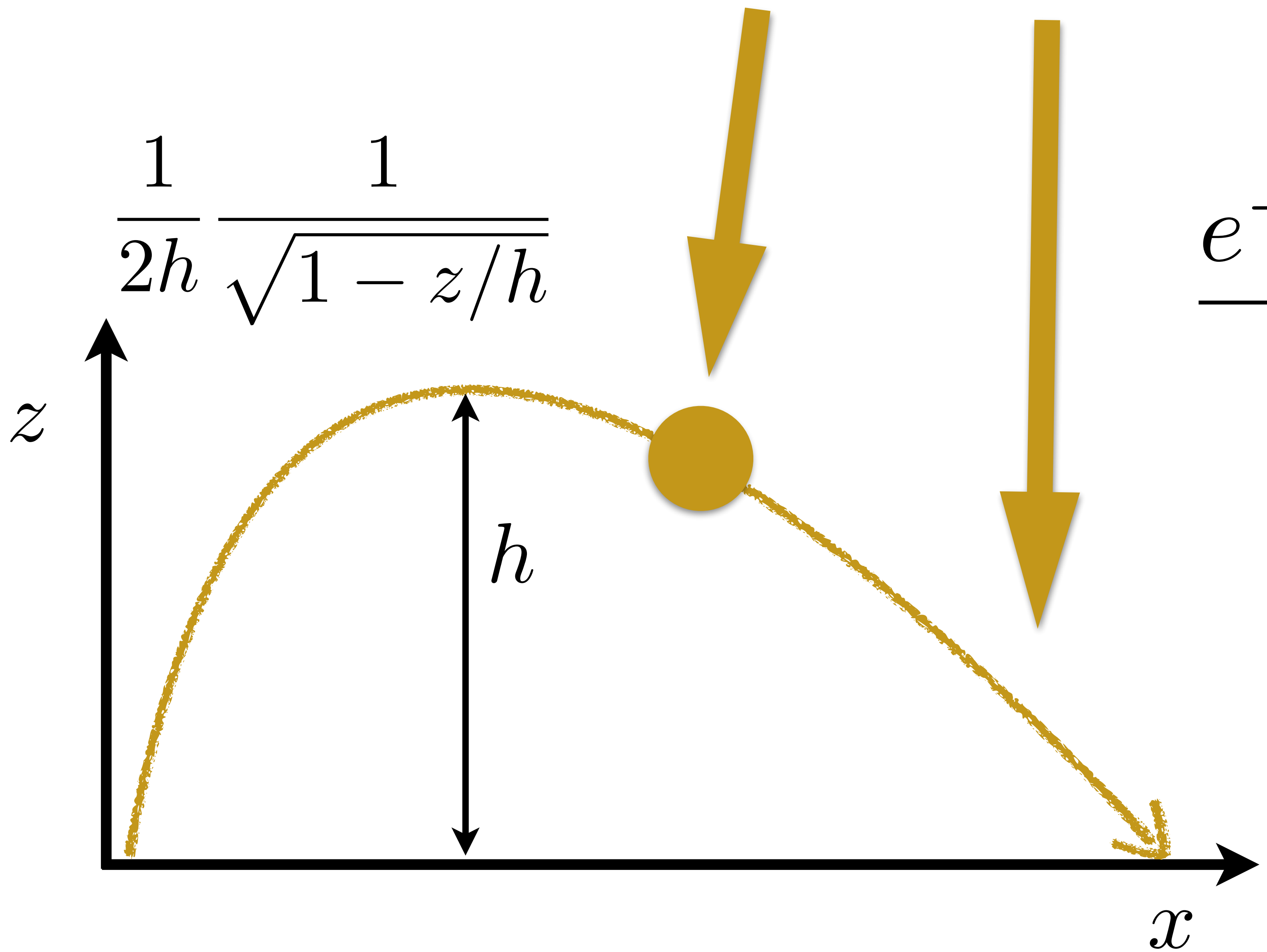


particle distribution

$$P_{\bar{h}}(z,h) = P(z|h)P_{\bar{h}}(h)$$

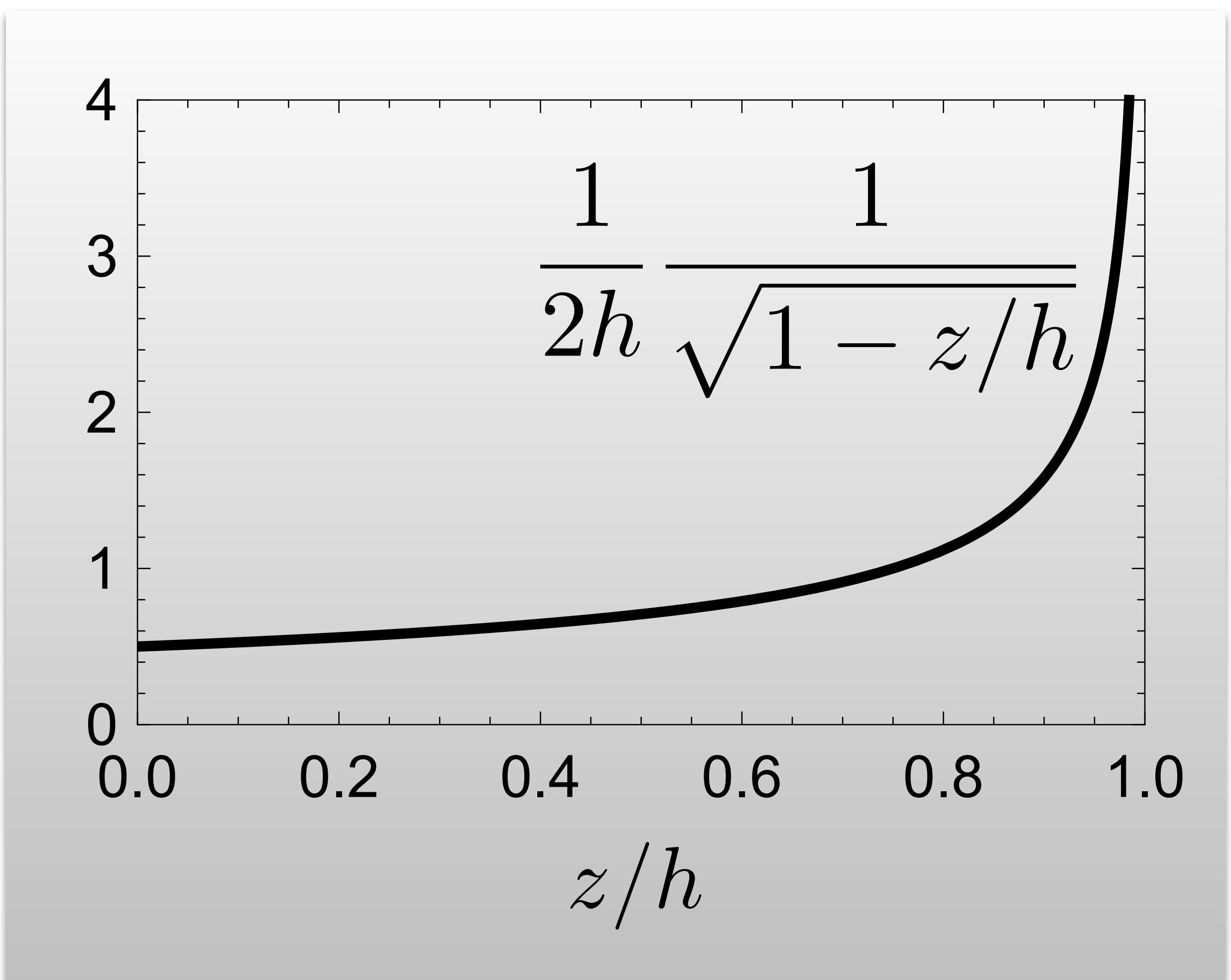
$$\frac{1}{2h}\frac{1}{\sqrt{1-z/h}}$$

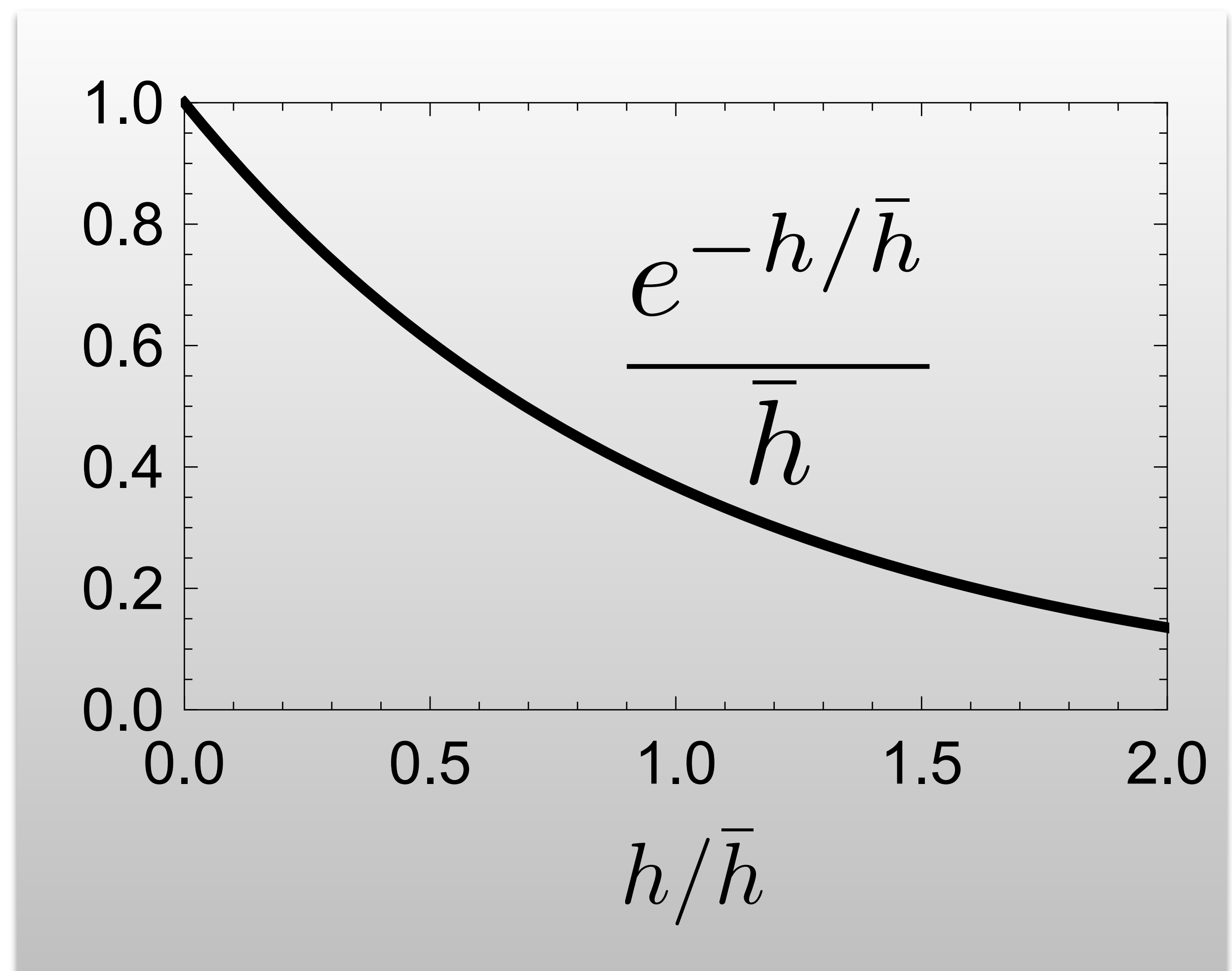
$$\frac{e^{-h/\bar{h}}}{\bar{h}}$$



particle distribution

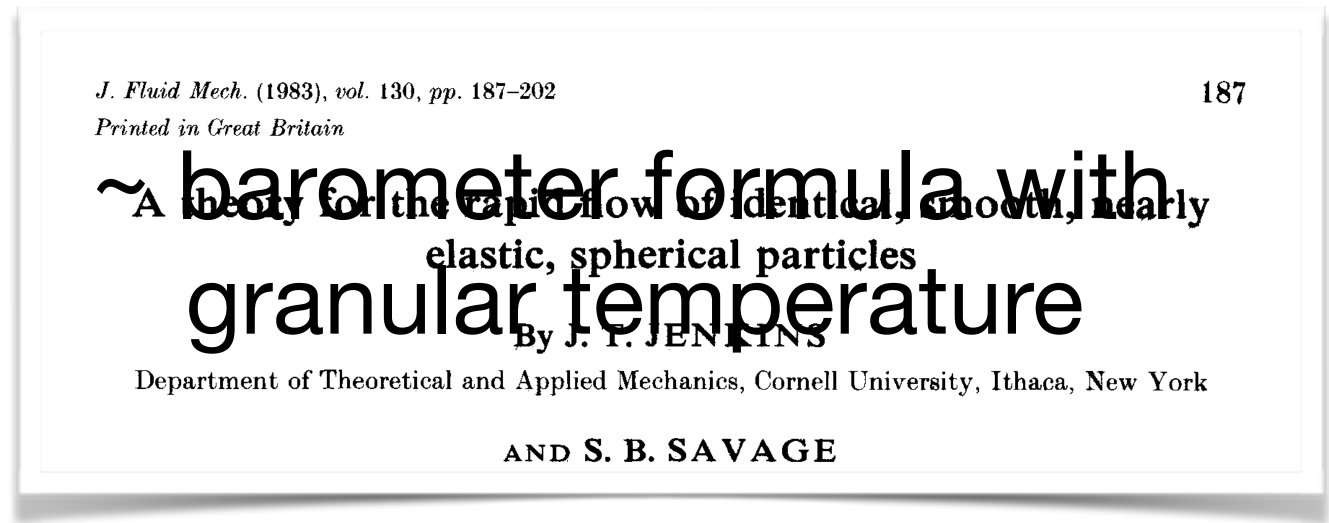
$$P_{\bar{h}}(z,h) = P(z|h)P_{\bar{h}}(h)$$





$$P_{\bar{h}}(h) \not\propto ?\, e^{-h/\bar{h}}$$

Reptation/Splash



~ barometer formula with granular temperature

J. Fluid Mech. (1983), *vol.* 130, *pp.* 187–202 187
Printed in Great Britain

A theory for the rapid flow of identical, smooth, nearly elastic, spherical particles

By J. T. JENKINS
Department of Theoretical and Applied Mechanics, Cornell University, Ithaca, New York
AND S. B. SAVAGE

granular temperature

1. molecular gas with (turbulent) thermostat

$$p = nk_BT \qquad -m\,g\,n(z) = \partial_z p = k_BT\partial_z n$$

$$n(z) \propto \exp(-mgz/k_BT)$$

2. splash: free granular gas released at z=0

$$P(E)\mathrm{d}E = P(v)mv\mathrm{d}v = P(h)\mathrm{d}h$$

$$P(h) \propto \exp(-mgh/k_BT)$$

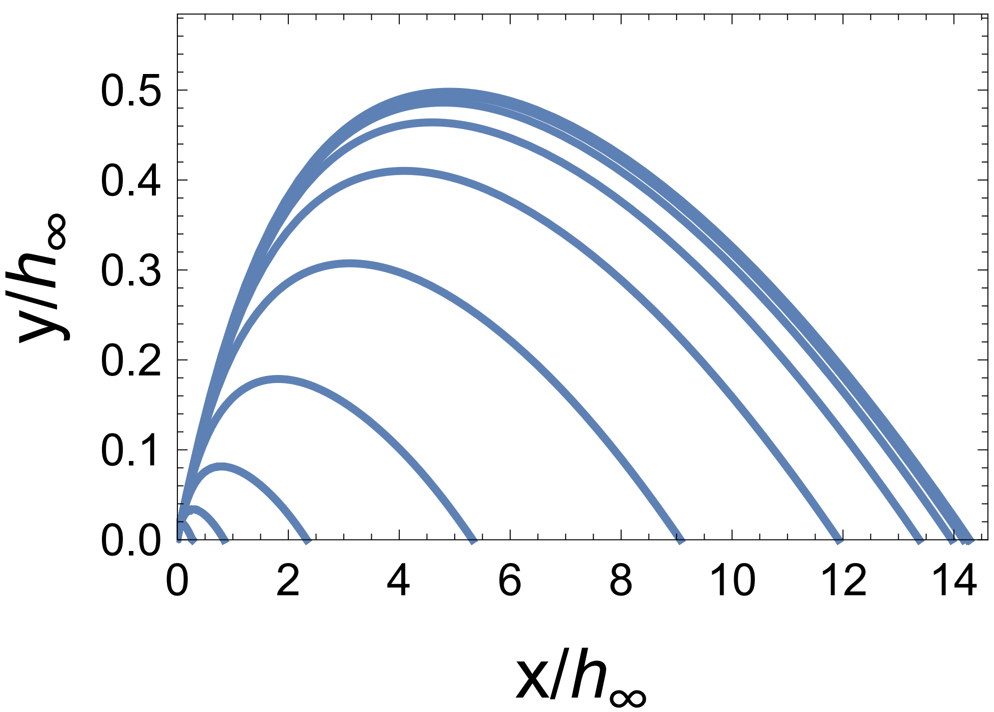
$$P_{\bar{h}}(h) \propto e^{-h/\bar{h}}$$ **Reptation/Splash**

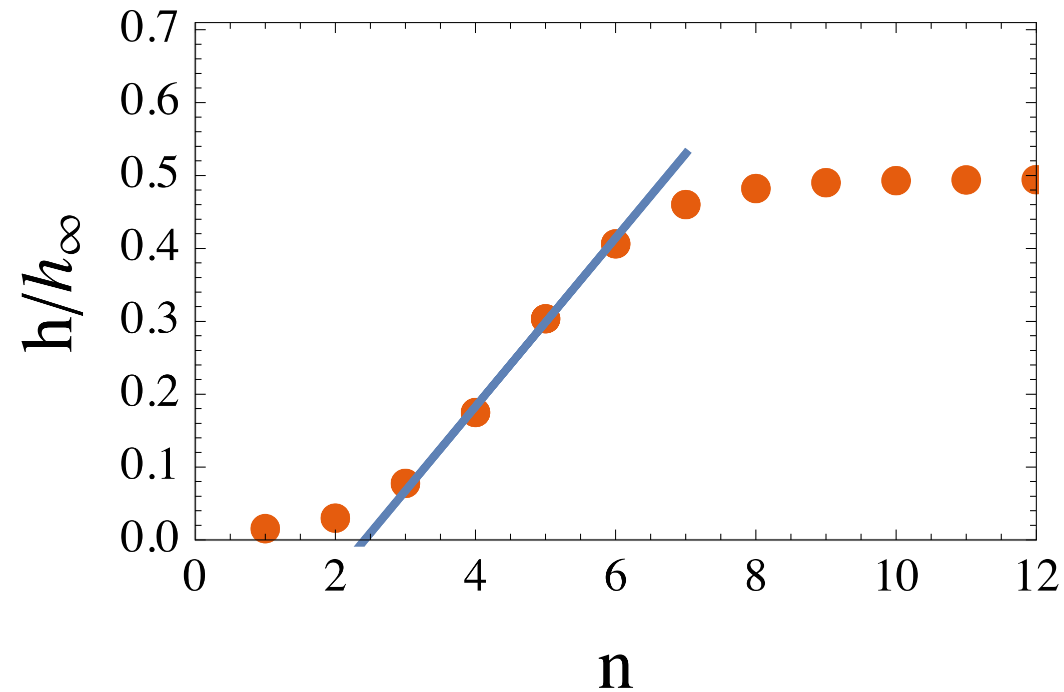
~ barometer formula with granular temperature

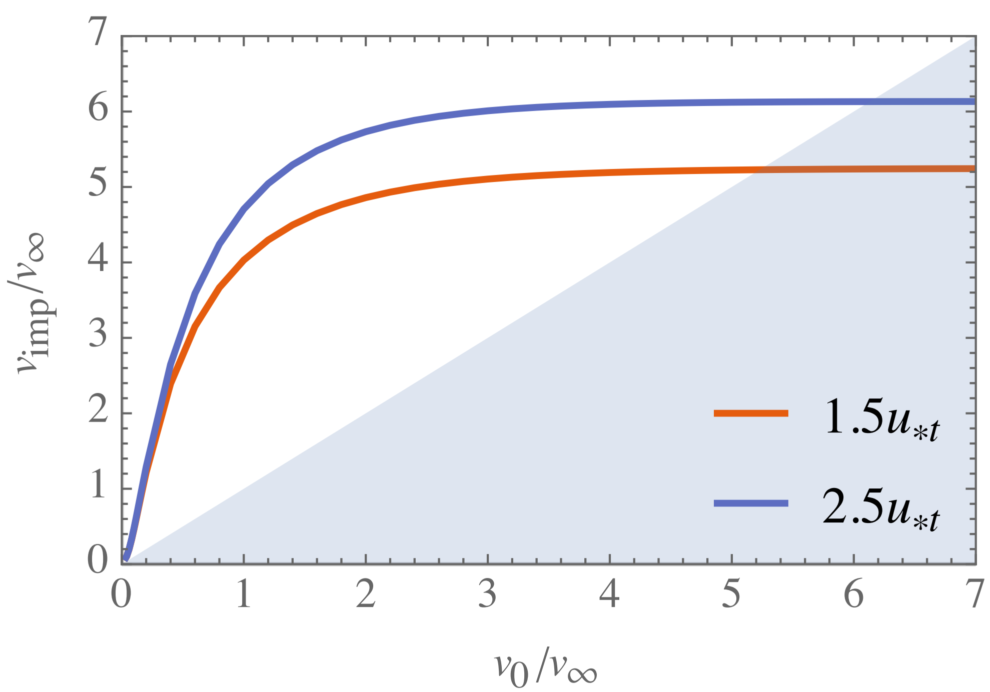
Saltation $$P_{\bar{h}}(h) \propto e^{-h/\bar{h}}$$

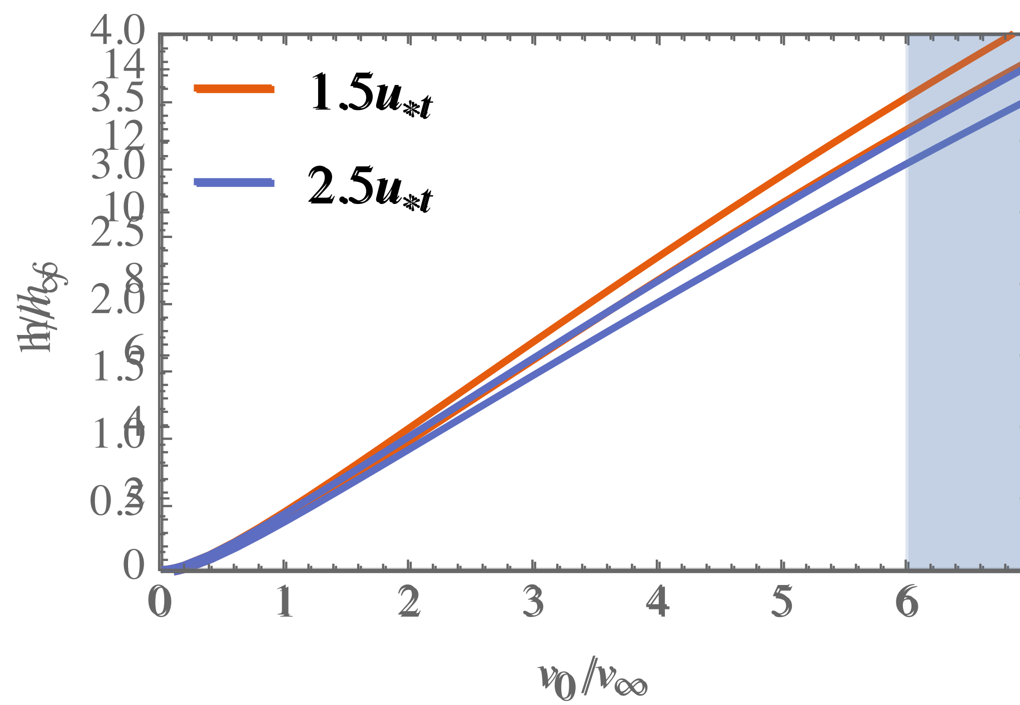
$$P(\#\ \text{hops} \gtrsim N) \propto e^{-N}\,; \quad h \propto N\,?$$

deterministic numeric solution

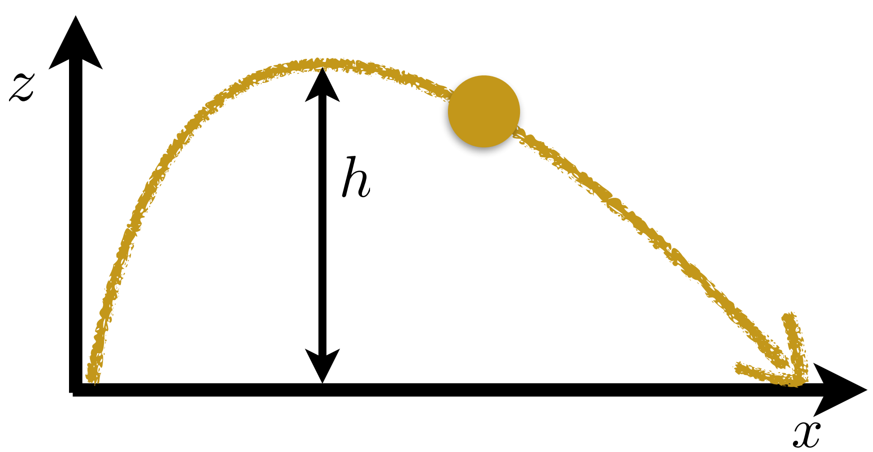


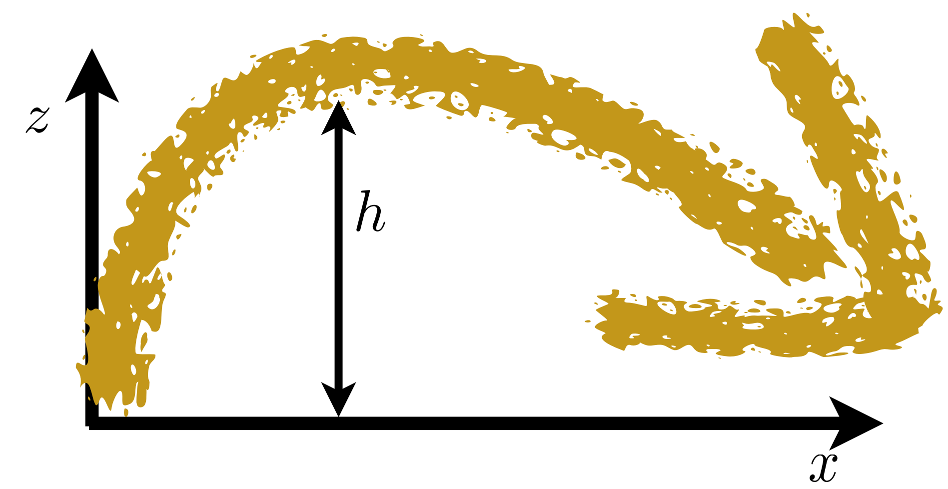






turbulent diffusion — how important is it?





$$\langle \Delta z^2 \rangle \simeq Dt$$

$$D \simeq u_* h$$

diffusion coefficient

$$t_\infty \approx \sqrt{2h/g}$$

time of flight

assume

$$P_{\bar{h}}(h) \propto e^{-h/\bar{h}}$$

for reptons & saltons

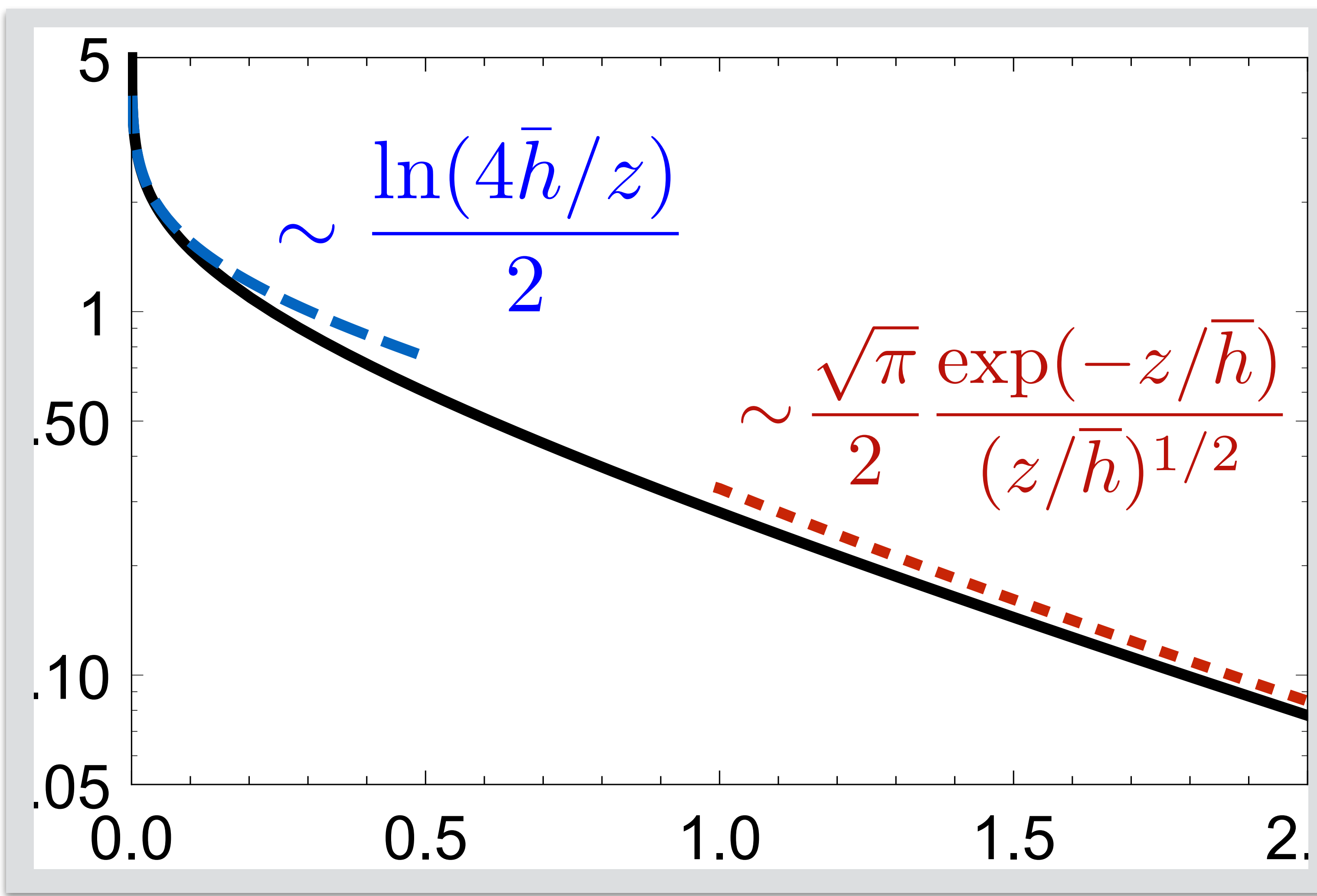
height-resolved observables

- **grain density** $\rho(z)$
- **horizontal flux** $j(z)$
- **vertical flux** $\phi(z)$
- **grain-borne stress** $\tau_{\mathrm{g}}(z)$
- **hop length distribution** $P(z, l)$
- **hop length distribution** $P(\ell) \propto -\partial_\ell \phi_\ell(0)$

particle distribution

$$\rho_{\bar{h}}(z) = \int \mathrm{d}h\, P_{\bar{h}}(z,h)$$

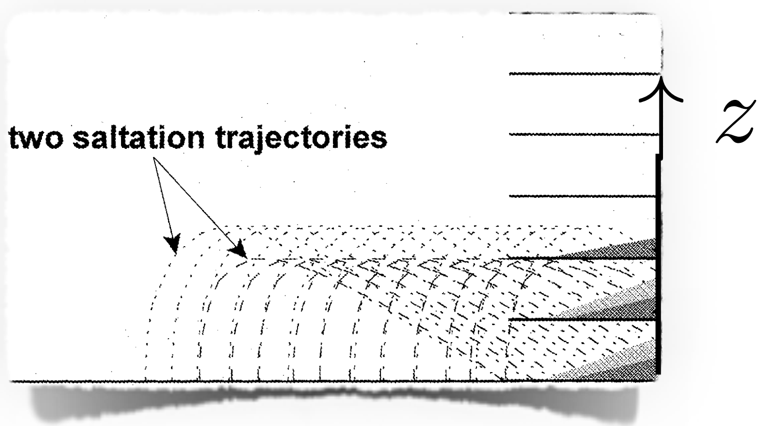
Prob for particle at z
for **any** trajectory



$z/\bar{h}$

wind, 2 spec

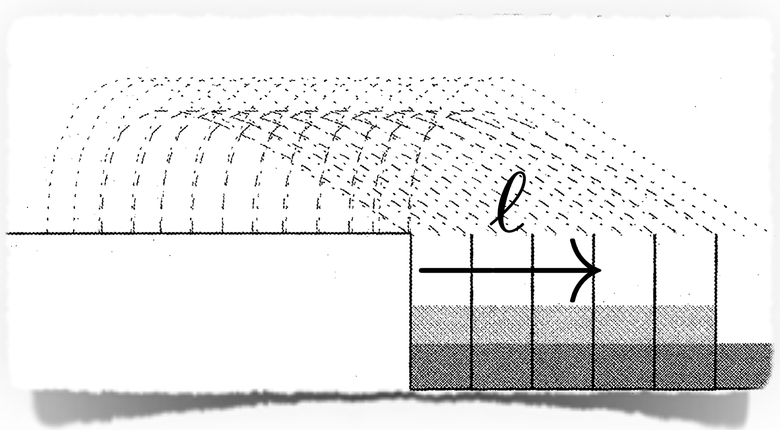
horizontal sand flux



$$j_{\bar{h}}(z) = \int \mathrm{d}h\, v_x(h)\, P_{\bar{h}}(z,h) = q\,\frac{e^{-z/\bar{h}}}{\bar{h}}$$

$$v_x(\cancel{z},\cancel{l},h) \approx \sqrt{2gh}/4\epsilon$$

vertical sand flux

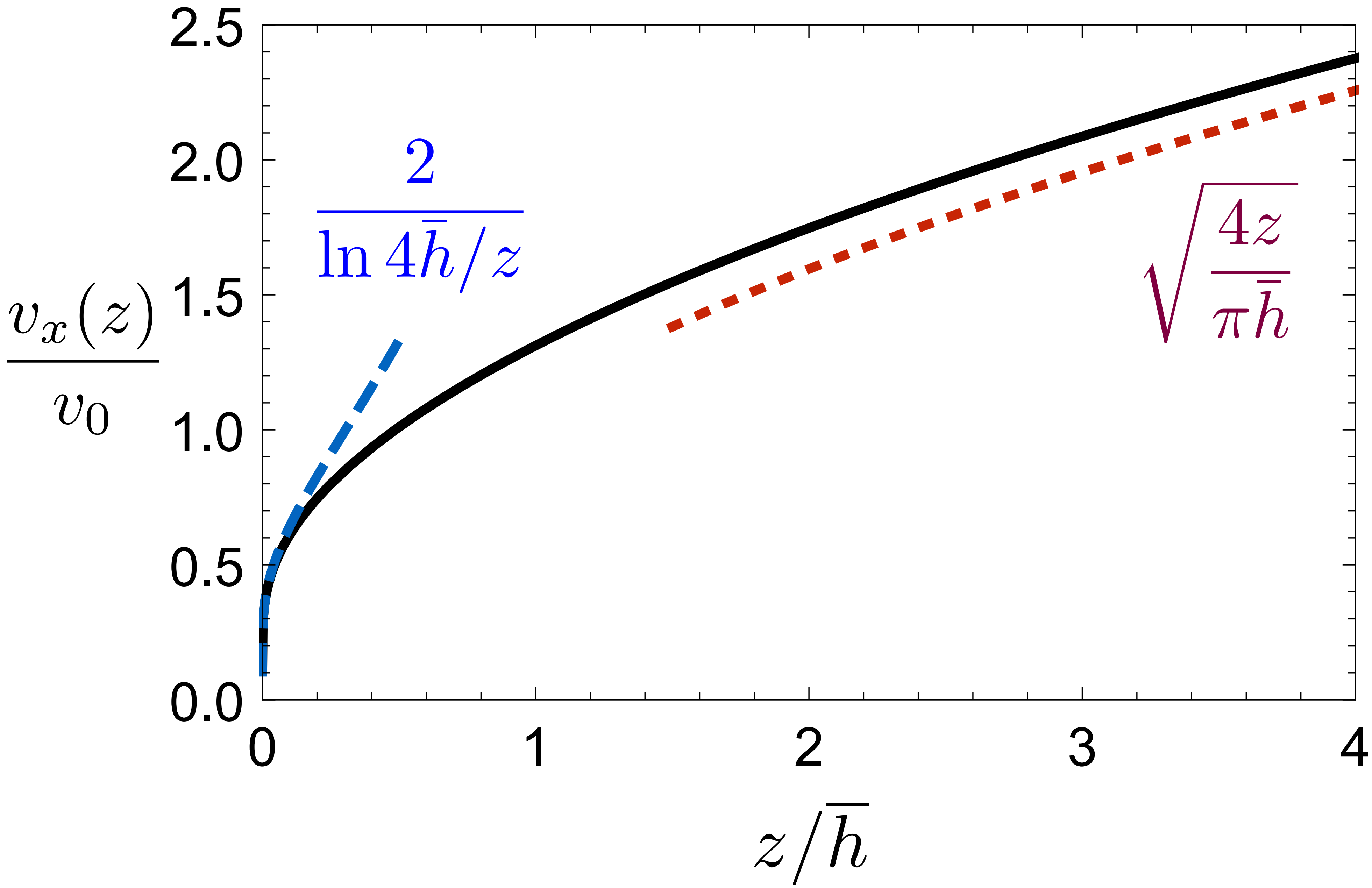


$$\phi_\ell(z) = \int_{l(h)>\ell} \mathrm{d}h\, v_z(z,h)\, P_{\bar{h}}(z,h)$$

$$v_z(z,h) = \sqrt{2g(h-z)} \qquad \phi_\ell(z=0) = q\,\frac{\mathrm{erfc}\sqrt{\ell\epsilon/\bar{h}}}{\bar{h}/\epsilon}$$

particle velocity

$$v_x(z) = j(z)/\rho(z)$$



grain-scale experiments

Rasmussen, Mikkelsen, Sedimentology (1998)

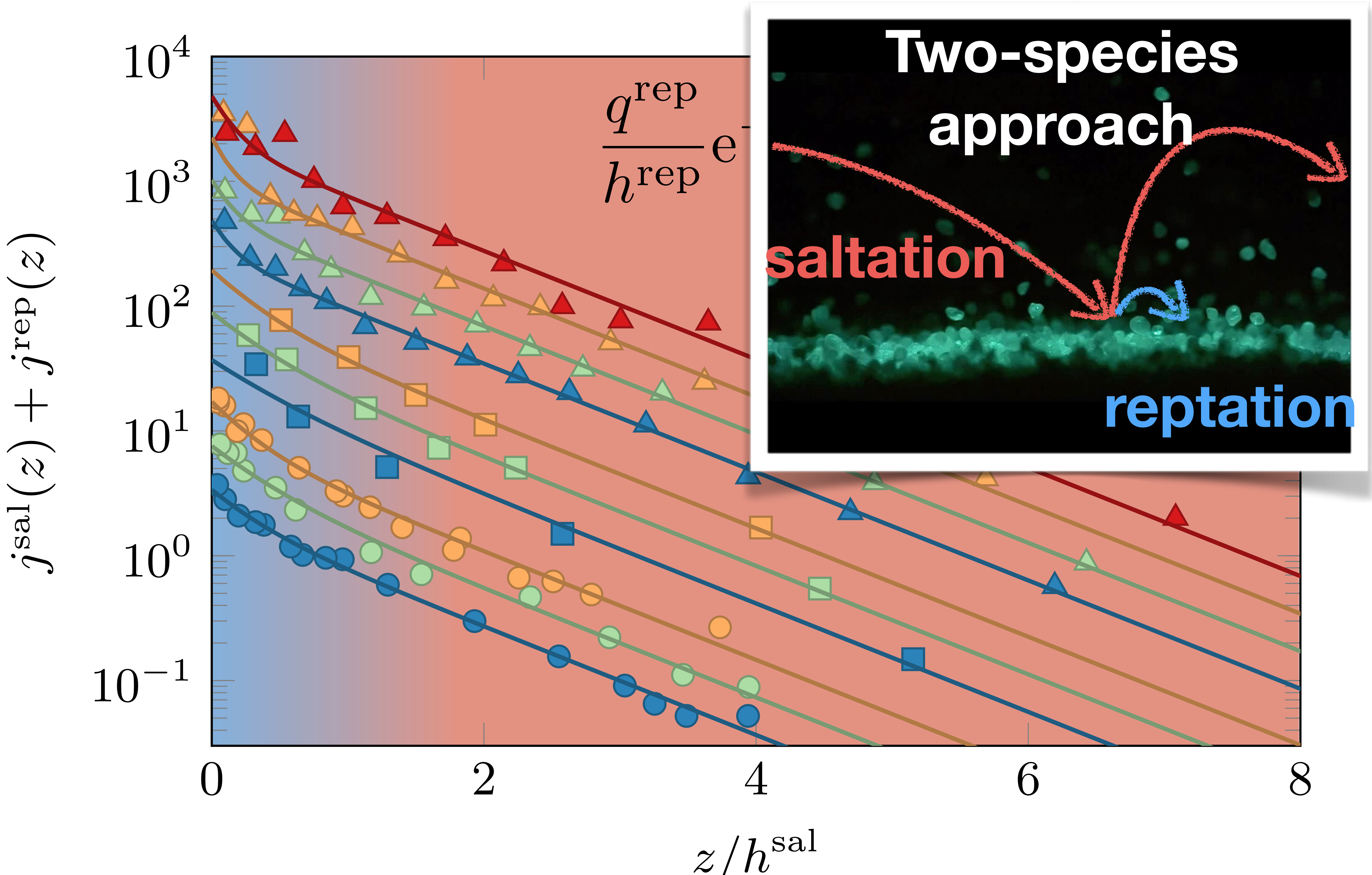
Namikas, Sedimentology (2003)

Rasmussen, Sørensen, J. Geophys. Res. (2008)

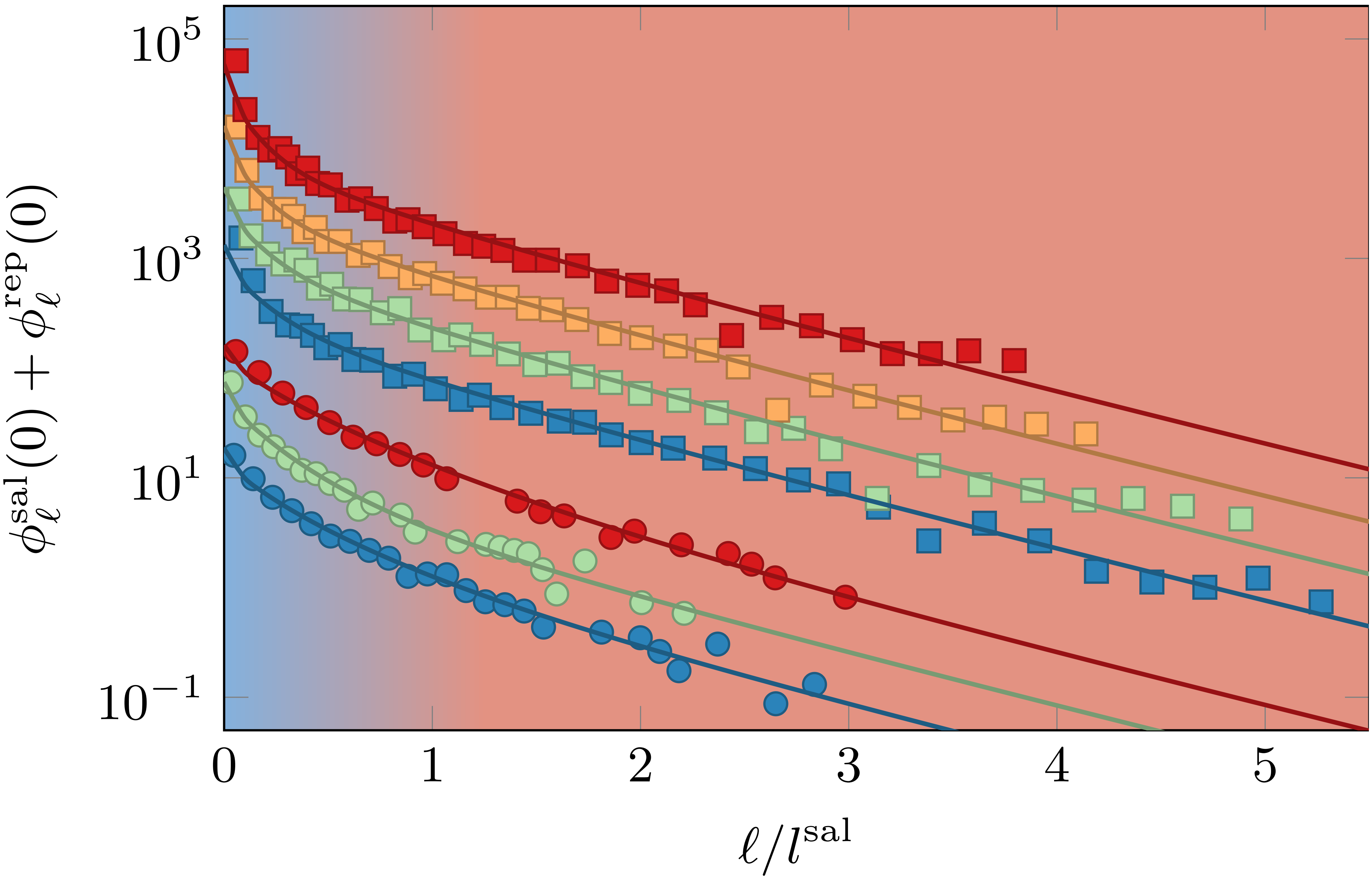
Ho, Valance, Dupont, Moctar, Aeolian Research (2014)

Durand, Claudin, Andreotti, PNAS (2014)

horizontal sand flux

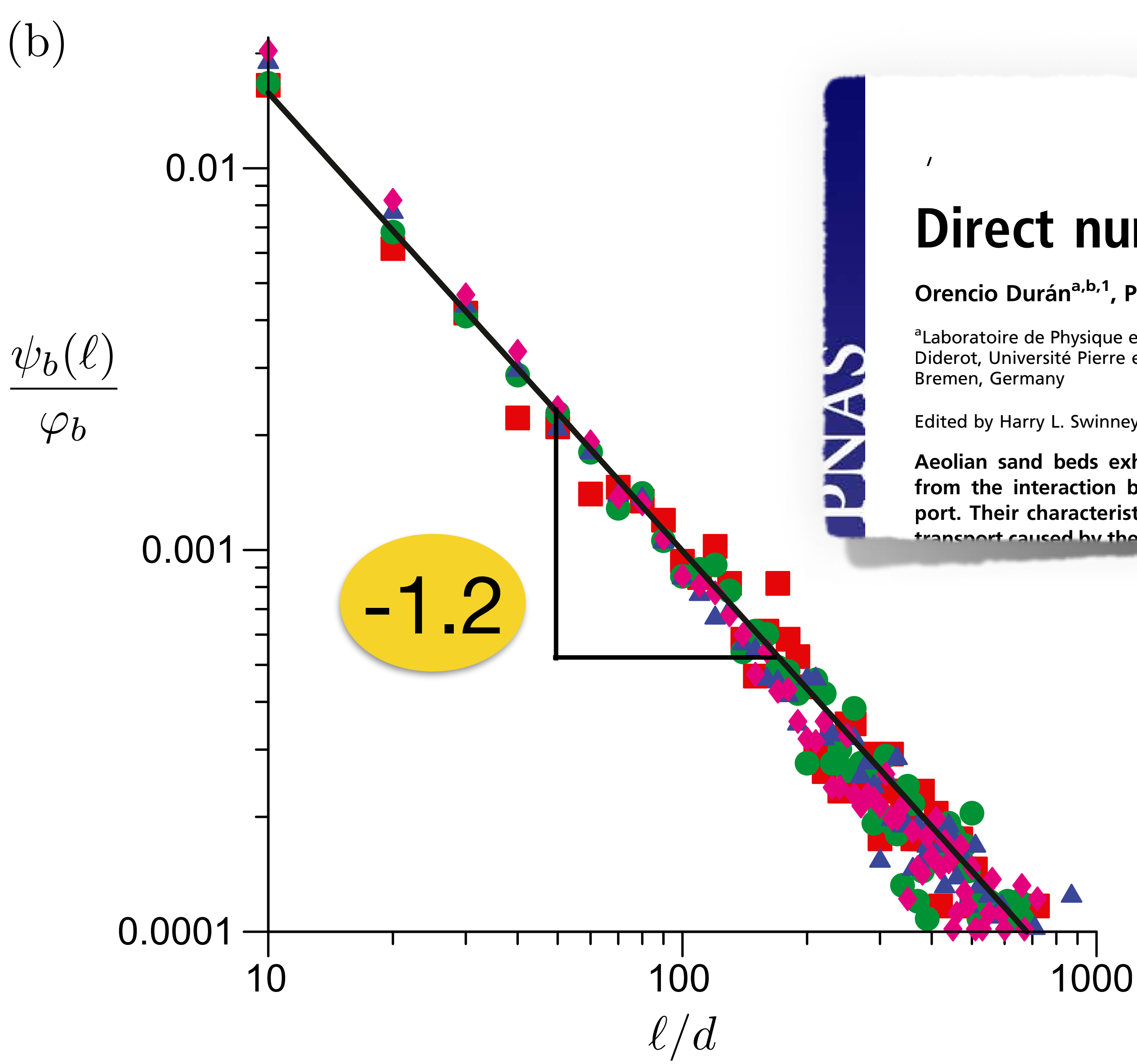


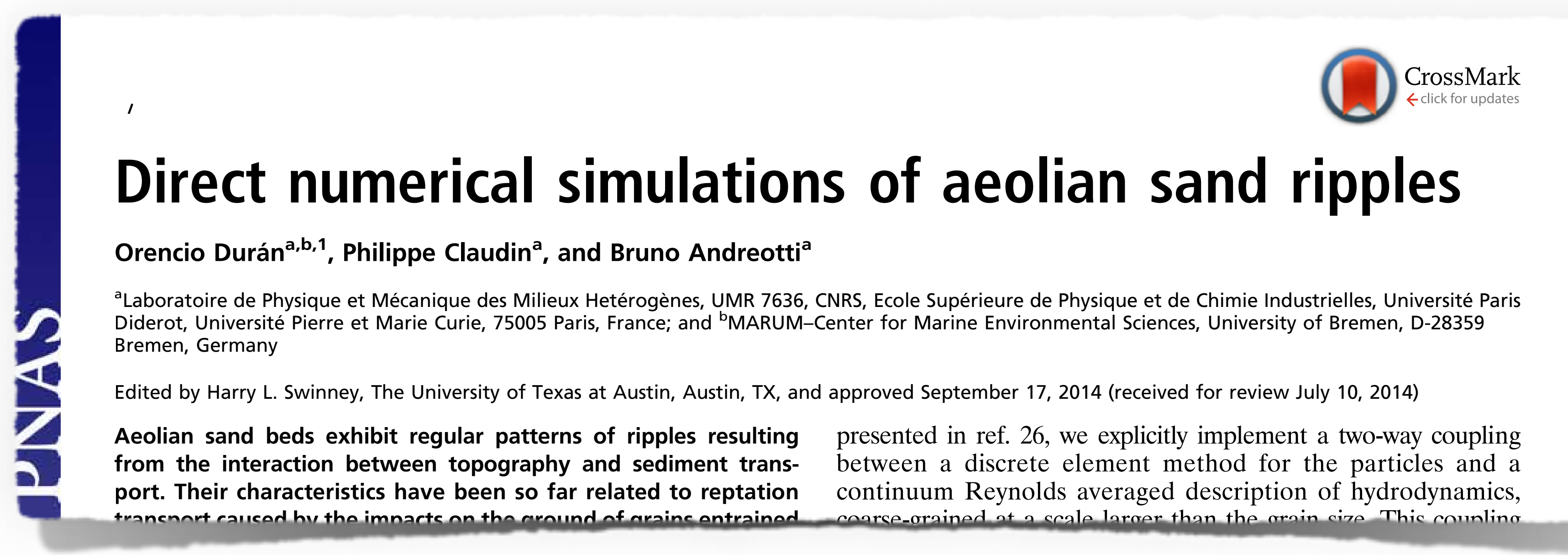
vertical sand flux



hop length distribution

$$P(l|z) \propto P[z, h(l)]\partial_l h(l) \propto \frac{e^{-\epsilon l/\bar{h}}}{l}$$





CrossMark
click for updates

Direct numerical simulations of aeolian sand ripples

Orencio Durán[a,b,1], Philippe Claudin[a], and Bruno Andreotti[a]

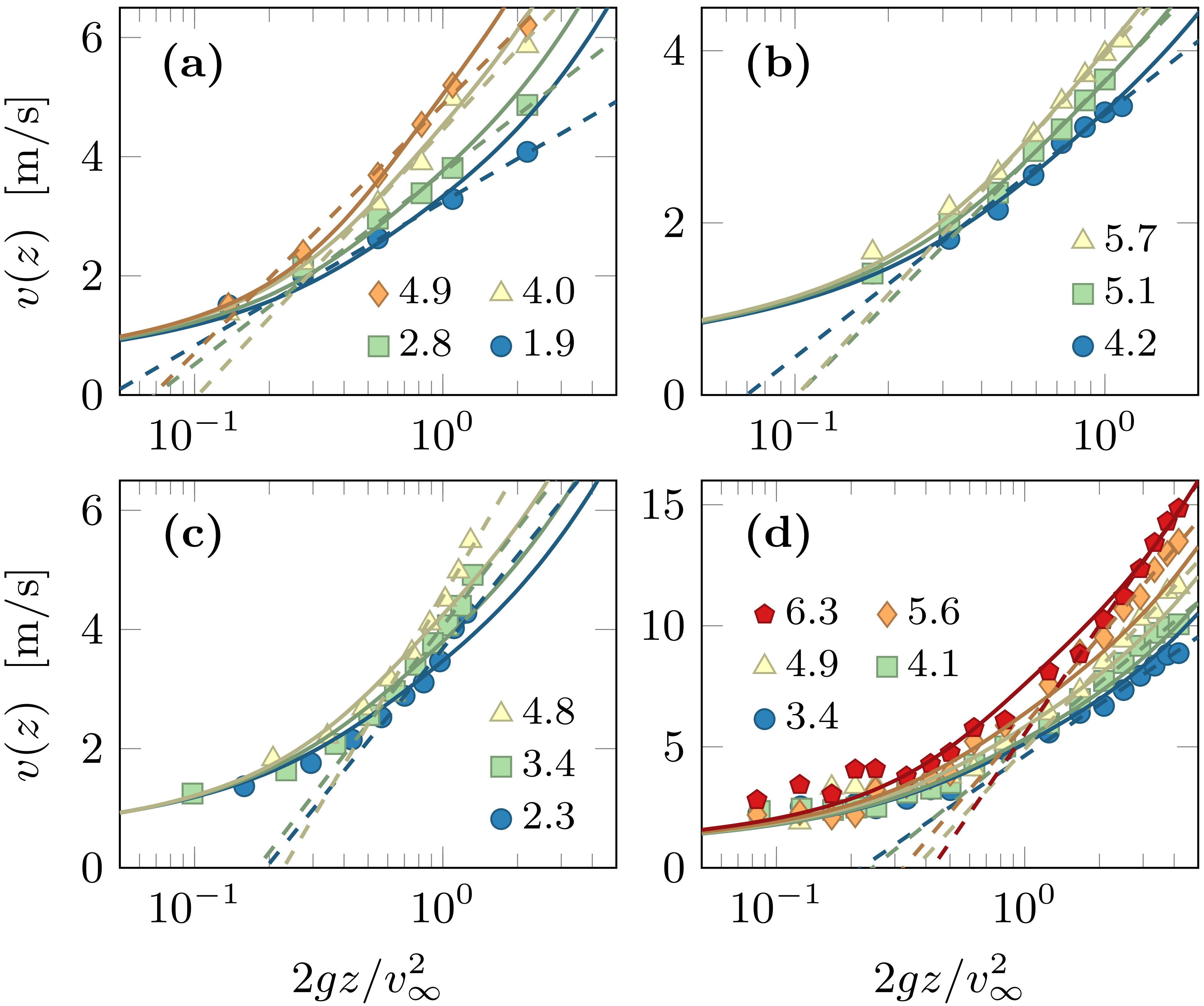
[a]Laboratoire de Physique et Mécanique des Milieux Hetérogènes, UMR 7636, CNRS, Ecole Supérieure de Physique et de Chimie Industrielles, Université Paris Diderot, Université Pierre et Marie Curie, 75005 Paris, France; and [b]MARUM–Center for Marine Environmental Sciences, University of Bremen, D-28359 Bremen, Germany

Edited by Harry L. Swinney, The University of Texas at Austin, Austin, TX, and approved September 17, 2014 (received for review July 10, 2014)

Aeolian sand beds exhibit regular patterns of ripples resulting from the interaction between topography and sediment transport. Their characteristics have been so far related to reptation

presented in ref. 26, we explicitly implement a two-way coupling between a discrete element method for the particles and a continuum Reynolds averaged description of hydrodynamics,

particle velocity

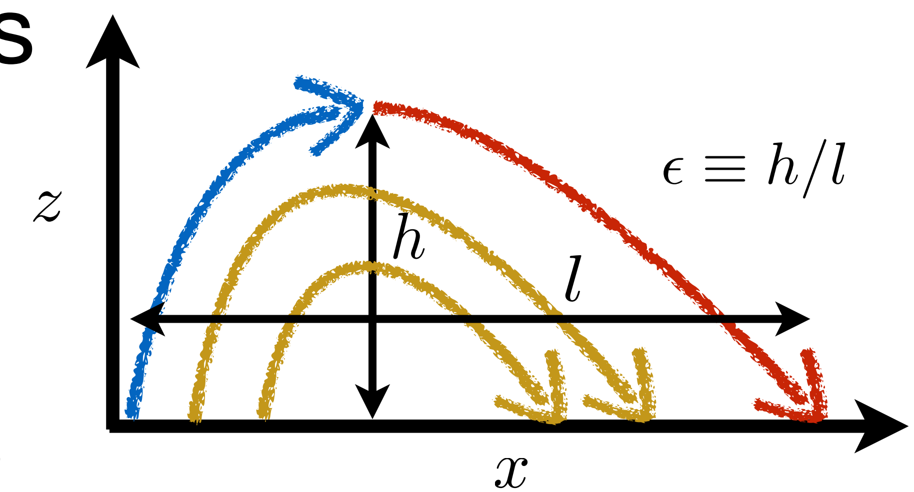


Summary

▸ **analytical mesoscale model of aeolian transport**

- based on grain scale physics
- ensemble of trajectories
- & two-species
- height-resolved observables
- applications to turbulent closure

  & data analysis & various mesoscale phenomena



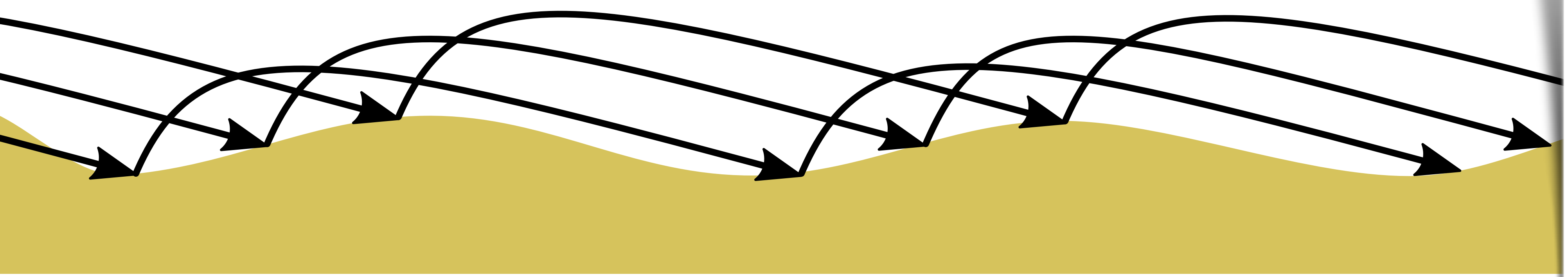
Analytical Mesoscale Modeling of Aeolian Megaripples

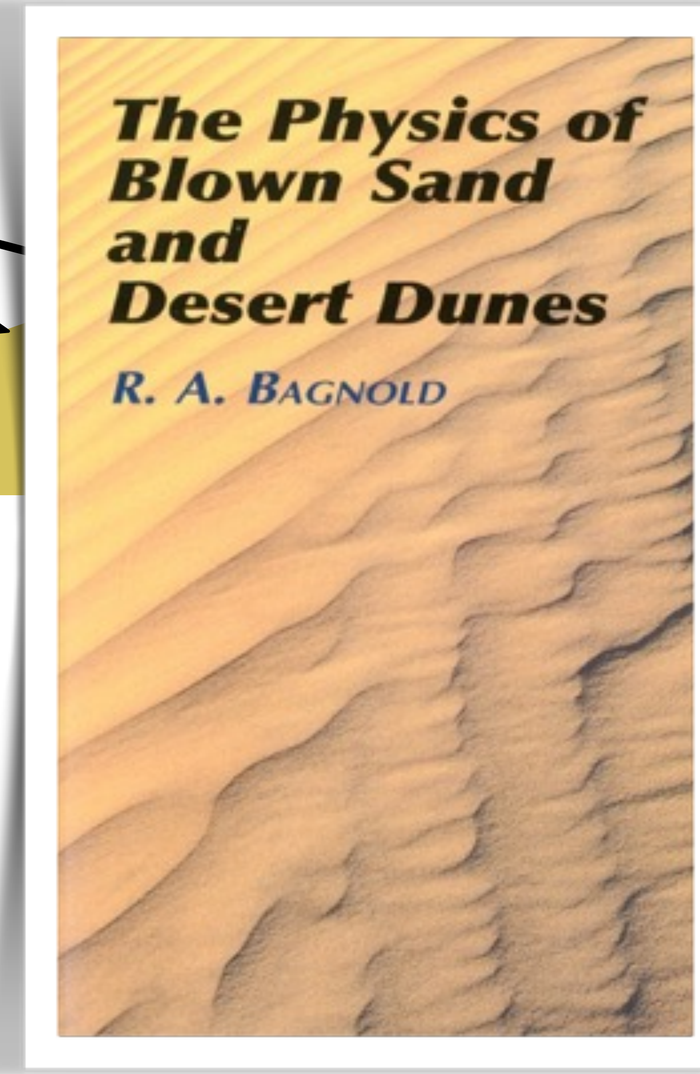
Marc Lämmel, Anne Meiwald, Klaus Kroy

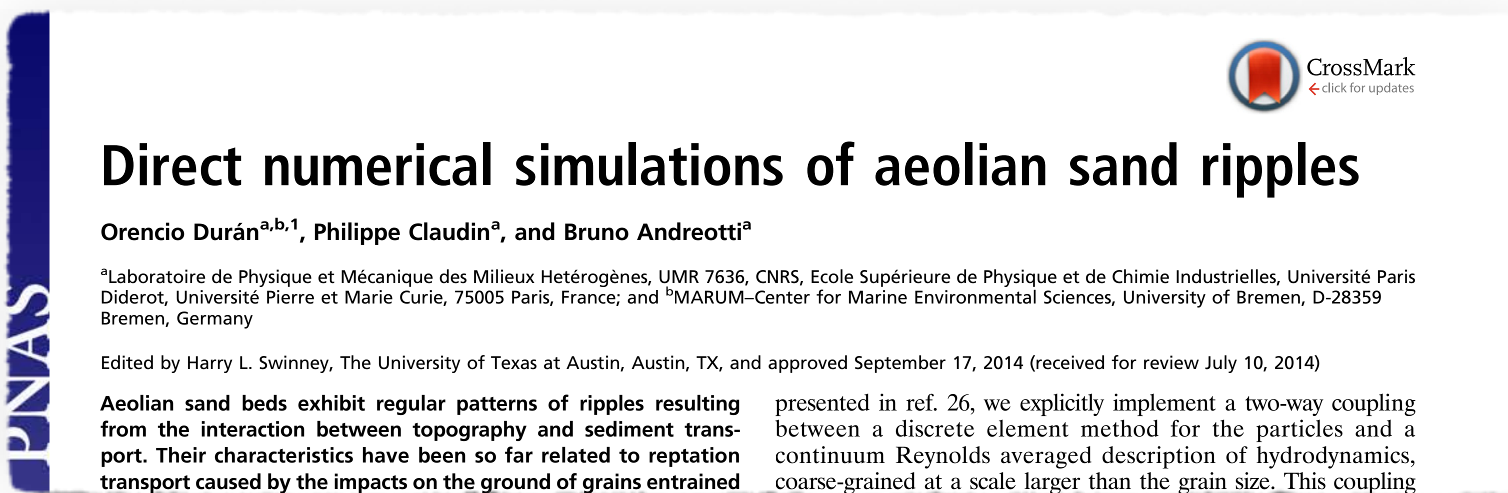
UNIVERSITÄT LEIPZIG

GeoFlo16 — Dresden

normal ripples







Direct numerical simulations of aeolian sand ripples

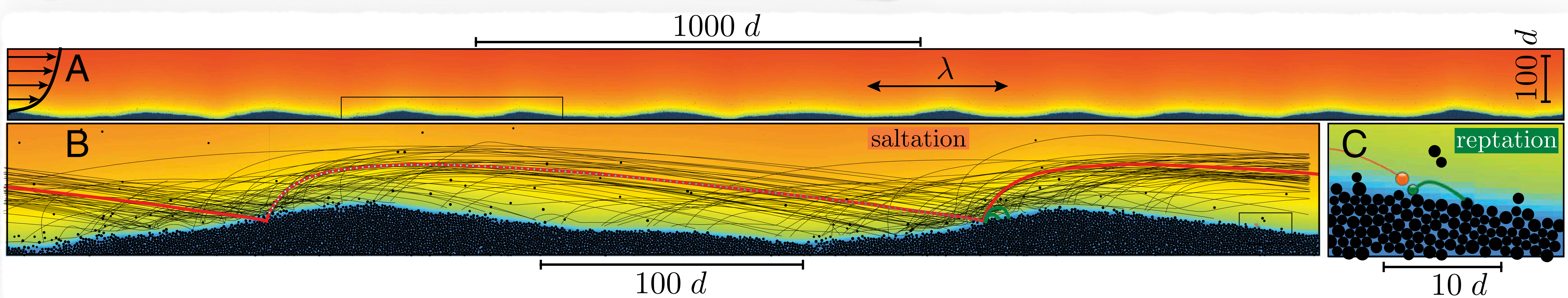
Orencio Durán[a,b,1], Philippe Claudin[a], and Bruno Andreotti[a]

[a]Laboratoire de Physique et Mécanique des Milieux Hetérogènes, UMR 7636, CNRS, Ecole Supérieure de Physique et de Chimie Industrielles, Université Paris Diderot, Université Pierre et Marie Curie, 75005 Paris, France; and [b]MARUM–Center for Marine Environmental Sciences, University of Bremen, D-28359 Bremen, Germany

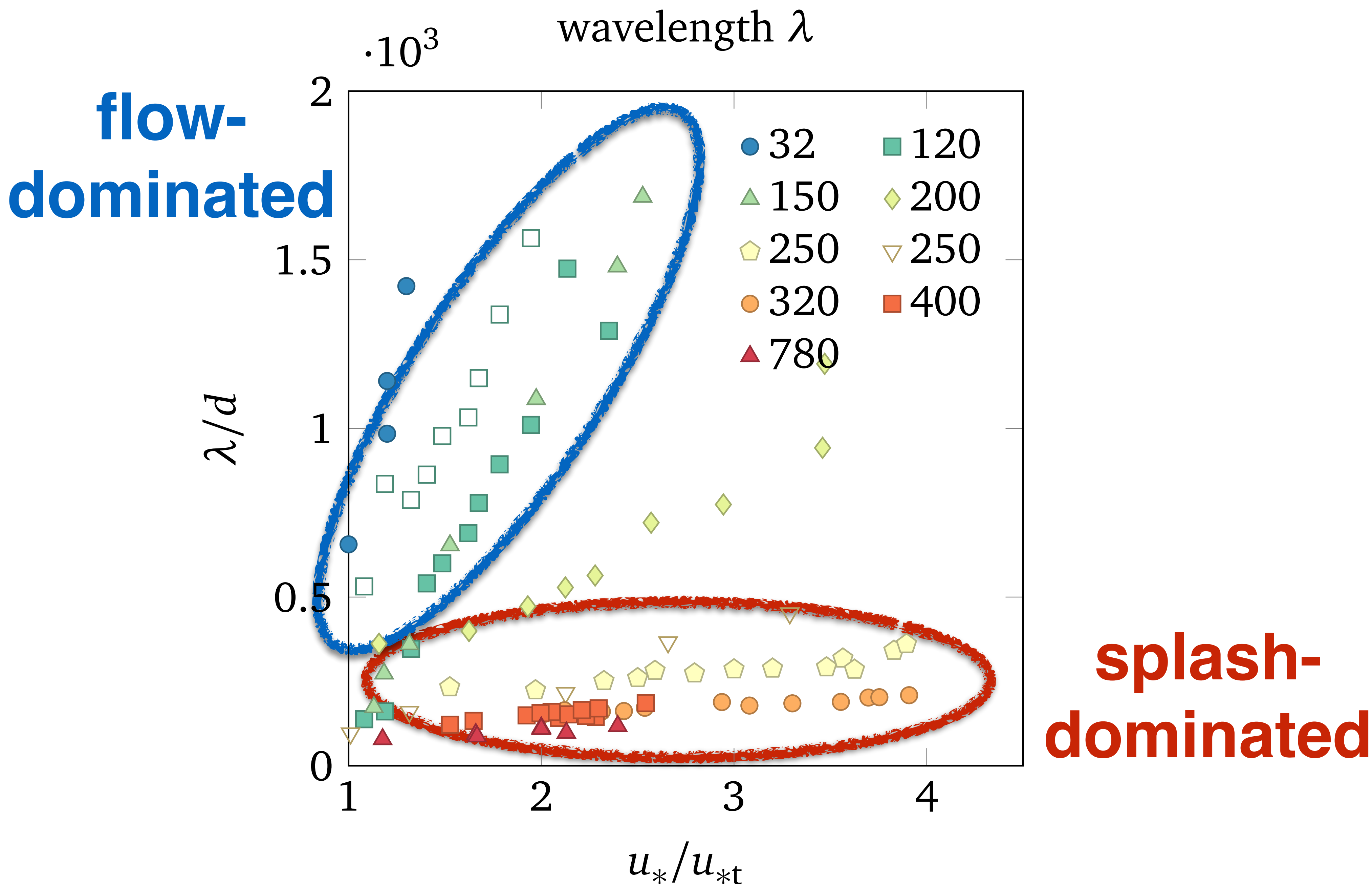
Edited by Harry L. Swinney, The University of Texas at Austin, Austin, TX, and approved September 17, 2014 (received for review July 10, 2014)

Aeolian sand beds exhibit regular patterns of ripples resulting from the interaction between topography and sediment transport. Their characteristics have been so far related to reptation transport caused by the impacts on the ground of grains entrained

presented in ref. 26, we explicitly implement a two-way coupling between a discrete element method for the particles and a continuum Reynolds averaged description of hydrodynamics, coarse-grained at a scale larger than the grain size. This coupling



normal ripples



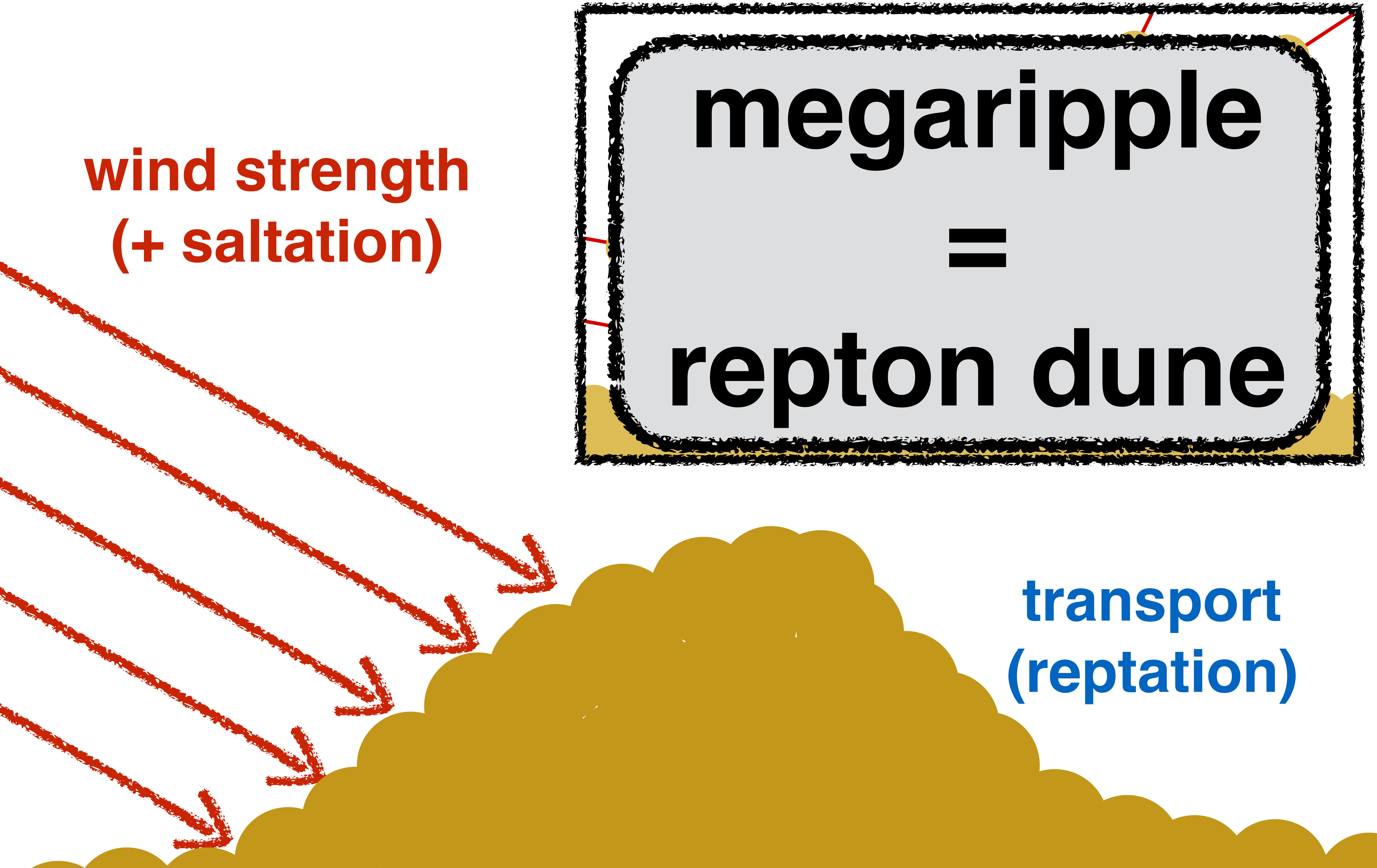
Andreotti et al., PRL 96, 028001 (2006): field 180μm, wind tunnel 120μm

Bagnold (1941): 250μm

Walker, MA thesis (1981): 200, 250,320,400,780μm

Seppälä and Lindé, Geografiska Annaler. A (1978): 150μm

megaripple morphology



megaripple morphology

megaripple
=
repton dune

WIND RIPPLES[1]

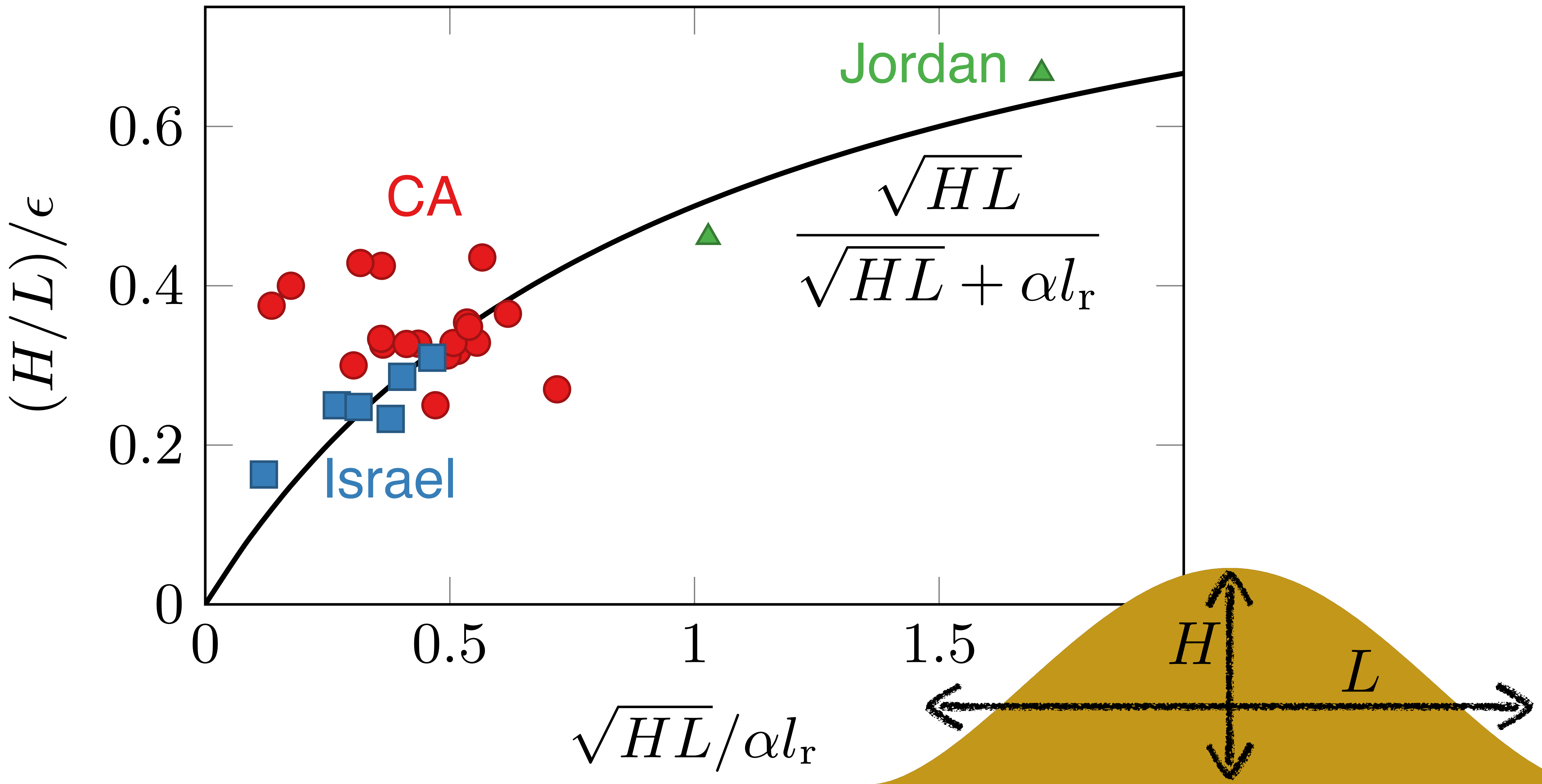
ROBERT P. SHARP
California Institute of Technology[2]

ABSTRACT

Two types of wind ripples are distinguished; sand ripples composed of m
median diameter roughly between 0.30 and 0.35 mm., and granule ripples co
proaching granule size 2–4 mm. The planimetric patterns and facing directio

aspect ratio

reptation length: $l_\mathrm{r} \propto u_* \sqrt{d_2/g}$



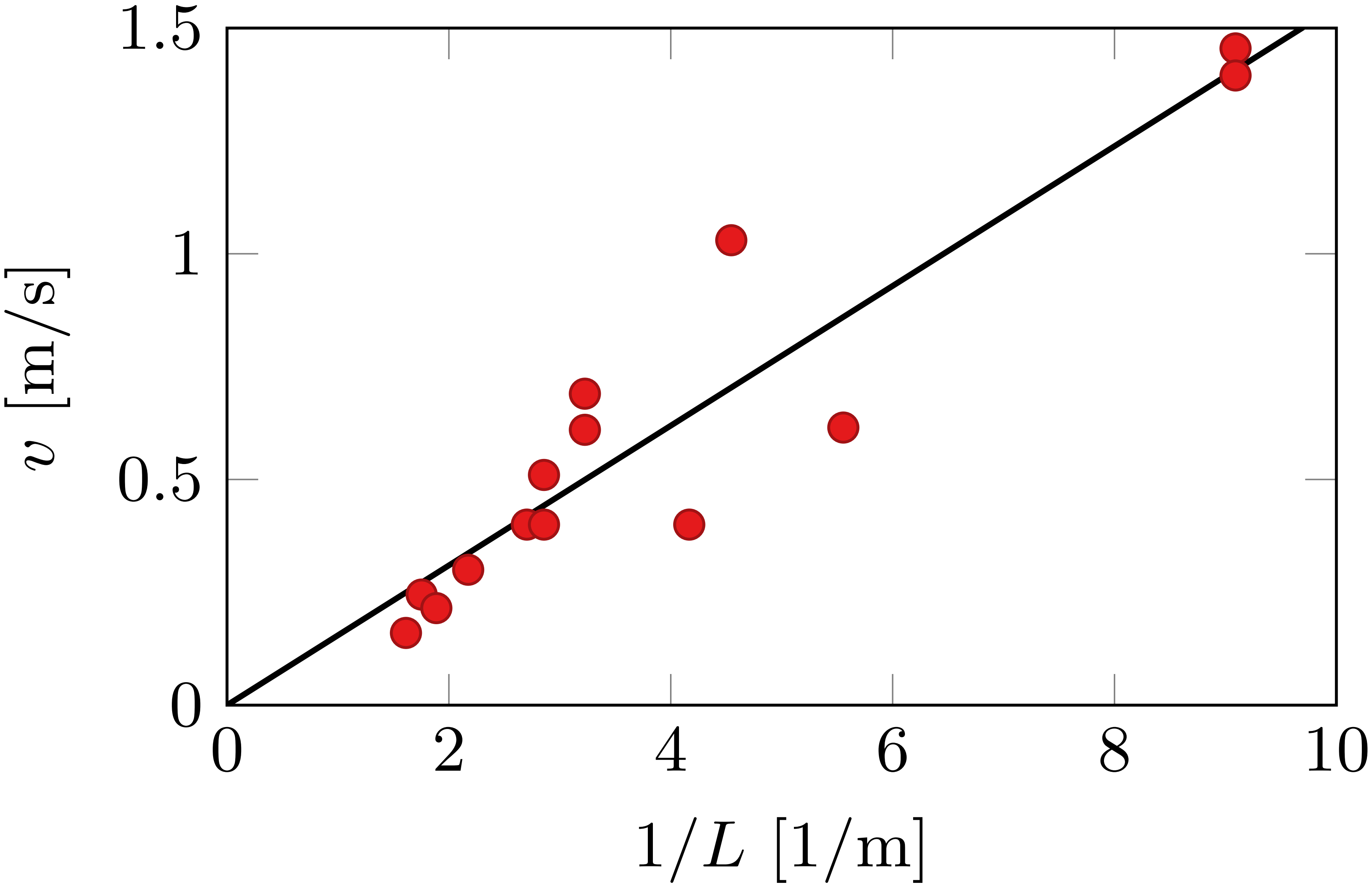
migration speed

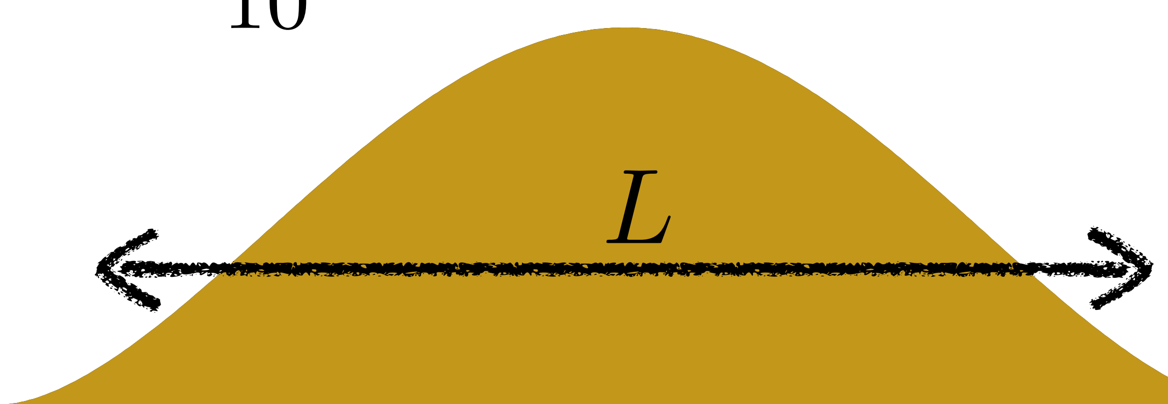
$$v = -\frac{\partial_t h}{\partial_x h} \propto \frac{\partial_x q}{\partial_x h} \propto 1/L$$

$$\partial_x q \sim q'(\tau)\partial_x \tau$$

$$\tau \propto H/L$$

$$\text{“}\partial_x \sim 1/L\text{”}$$





Lorenz and Valdez, Geomorphology 133 (2011)

Summary

- **analytical mesoscale model of aeolian ripples**
  - ripples vs megaripples
  - two-species ~ two particle sizes
  - megaripples = repton dunes
  - disintegration of wave structures
  - velocity scaling with length (not separation)
  - aspect ratio vs mass as predicted for dunes

thank you!