Bursting near the static saltation threshold: A laboratory perspective

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Background

What is observed when wind speed increases gradually above a sand surface?

1 First nothing happens
2 Then we will observe rare bursting events (flurries) of saltation transport
3 As speed increases bursting become more frequent, but after each event saltation dies out
4 Eventually saltation (mass transport) becomes continuous

The bed friction speed for which saltation starts is the fluid threshold (u_{*c}).

5) If we artificially seed sand particles into the air stream at the upstream boundary then we can lower the friction speed below u_{*c} and still sustain transport. The lower friction speed is the impact threshold (u_{*i}),

Objectives

In the present study we first:

1) Consider some principal differences between Nature and the laboratory

Then we focus on:

1) The characteristics of the bursting events for increasing bed shear stress.

2) The variation of the average mass transport for increasing bed shear stress.

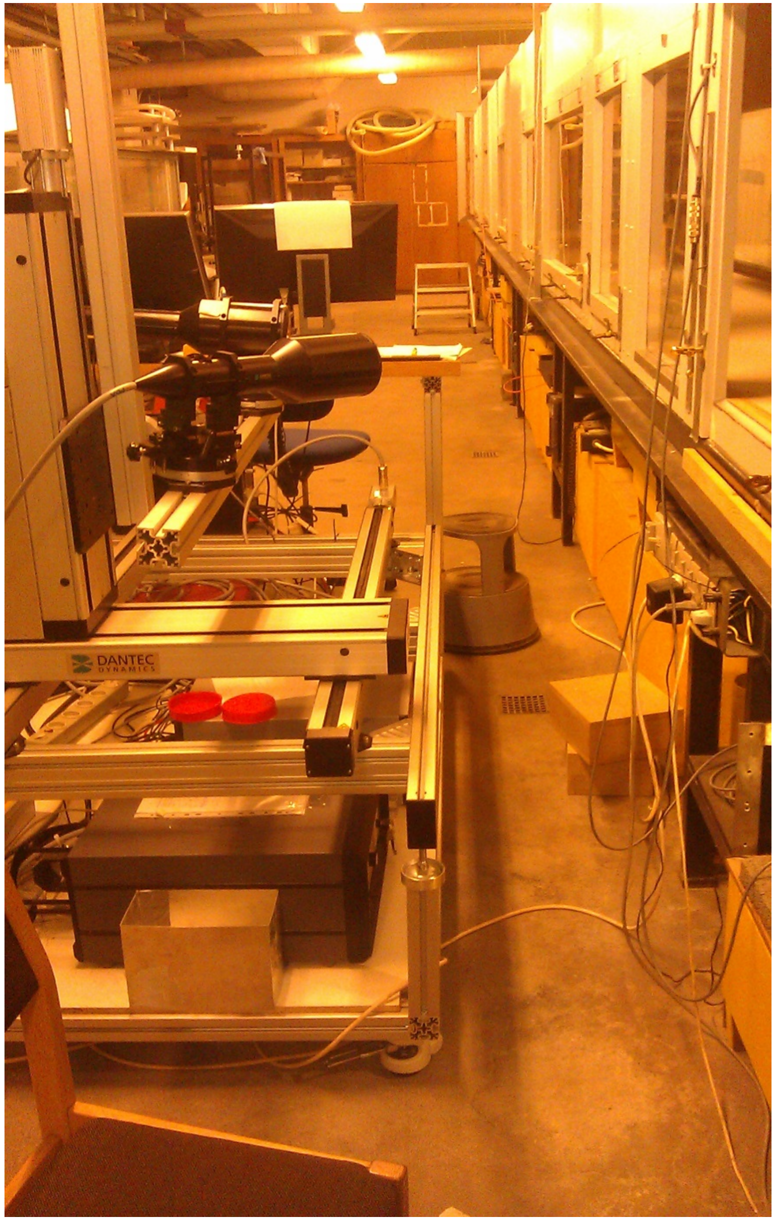
3) The influence from artificial seeding of sand particles into the flow!

The most common simulation laboratory is a Wind Tunnel

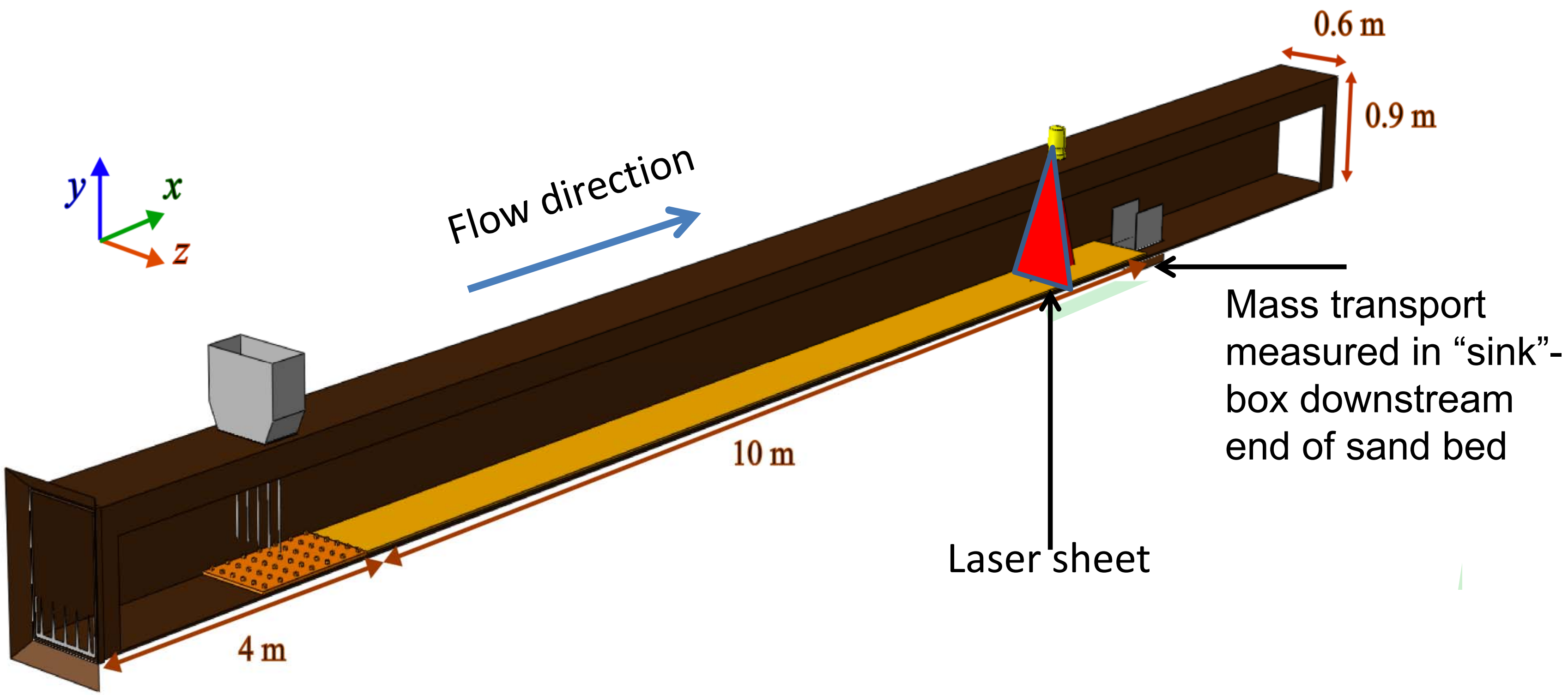
	Nature	Laboratory
Flow	Continuous spectrum. Large scale eddies limited by PBL-depth and topography. Buoyancy influence.	Eddy size/frequency limited by WT-dimensions; no buoyancy.
	3-D topography and solar insulation gives spatial and temporal variation of similar timescale as experiments.	Length and timescales small. Some similarity possible with correct h/z_0 scaling
Particles/ bed forms	Continuous scales from ripples to dunes. all transport modes: roll, slide, jump and suspension.	Small-scale bed forms. BL-height prevents development of large bed forms and suspension in vertical direction not possible.
	Shearstress not always a useful descriptor due to non-linearity of transport.	No influence from low frequency eddies. Shearstress is a useful descriptor.

Experimental set up

The 20 m long Aarhus wind tunnel: Outside (left) Inside (right)



Instruments in the working section

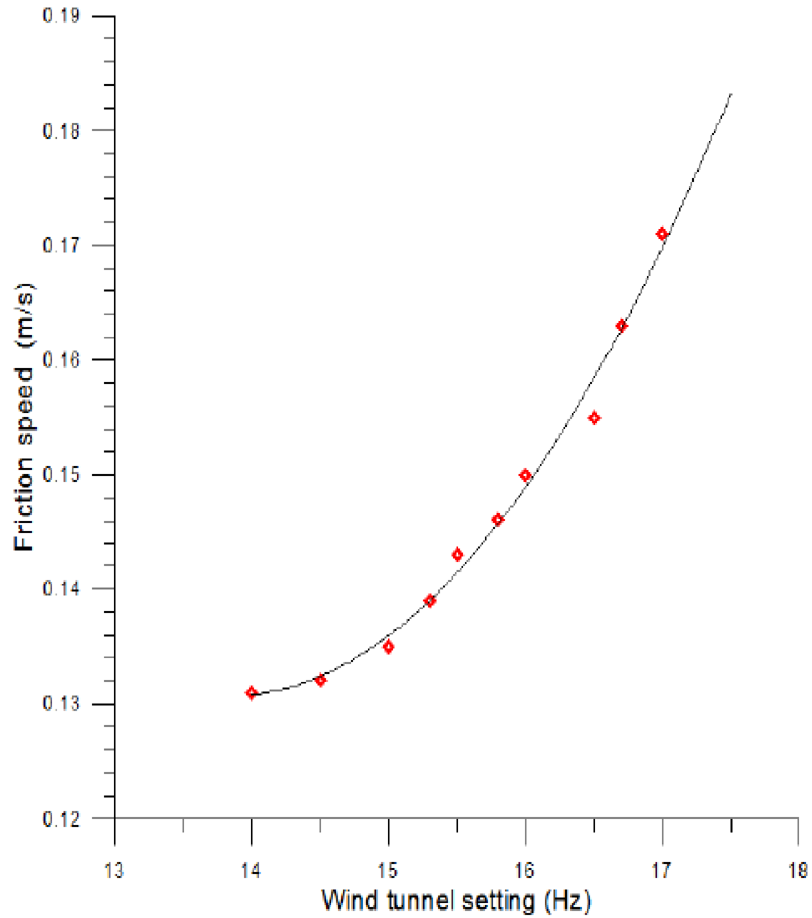


Measurement of shearstress

Before bursting experiments using vertical wind speed profiles were used to set up a correlation between shearstress and wind tunnel setting.

Wind speed is measured with Pitot-static tube and a precision manometer. With supplementary data on air pressure, humidity and temperature it is nicely first principle method.

Very precise (relative) friction speed values may be derived from equilibrium profile measurements.



Measurement of saltation

- Triple (almost) continuous 20-minute video recording of laser sheet at downstream end;
- Frame rate was 35 frames/s and resolution was 2 mega-pixels.
- Colour-frames extracted from the videos and converted to gray-scale [0,1] binary black and white images using a pixel threshold of 0.06. Some particles may be lost during this selection.
- Reflectance from bed also disturbs pixels near the bed so test area start above the bed.
- Pixel-sampling during conversion to jpg-format also influences counting.
- All in all these influences renders calculation of quantitative mass transport impossible from the images.
- Therefore average mass transport is measured from mass collected in the end box normalized with duration of run.

Numerical set-up of DEM-model

A three dimensional wind channel of dimensions $(700 \times 50 \times 7.5)\ D_{mean}{}^3$

Periodic boundary conditions in the direction of the average wind

The channel contains a poly-disperse 3D quiescent packing composed by 12 layers of hard spheres with Gaussian distributed diameters of $D_{mean} = 2 \times 10^{-4}$ m; size dispersion $\sigma_D = 0.15\ D_{mean}$ and density $\rho_s = 2650\ kg/m^3$.

The spheres are subjected to a gravitational field in the vertical (y-) direction and a logarithmic wind velocity profile u(y) imposed in horizontal direction.

The log-linear wind profile is based on von Karman's constant (κ=0.4) using a (fixed) aerodynamic roughness length of $D_{mean}/30$.

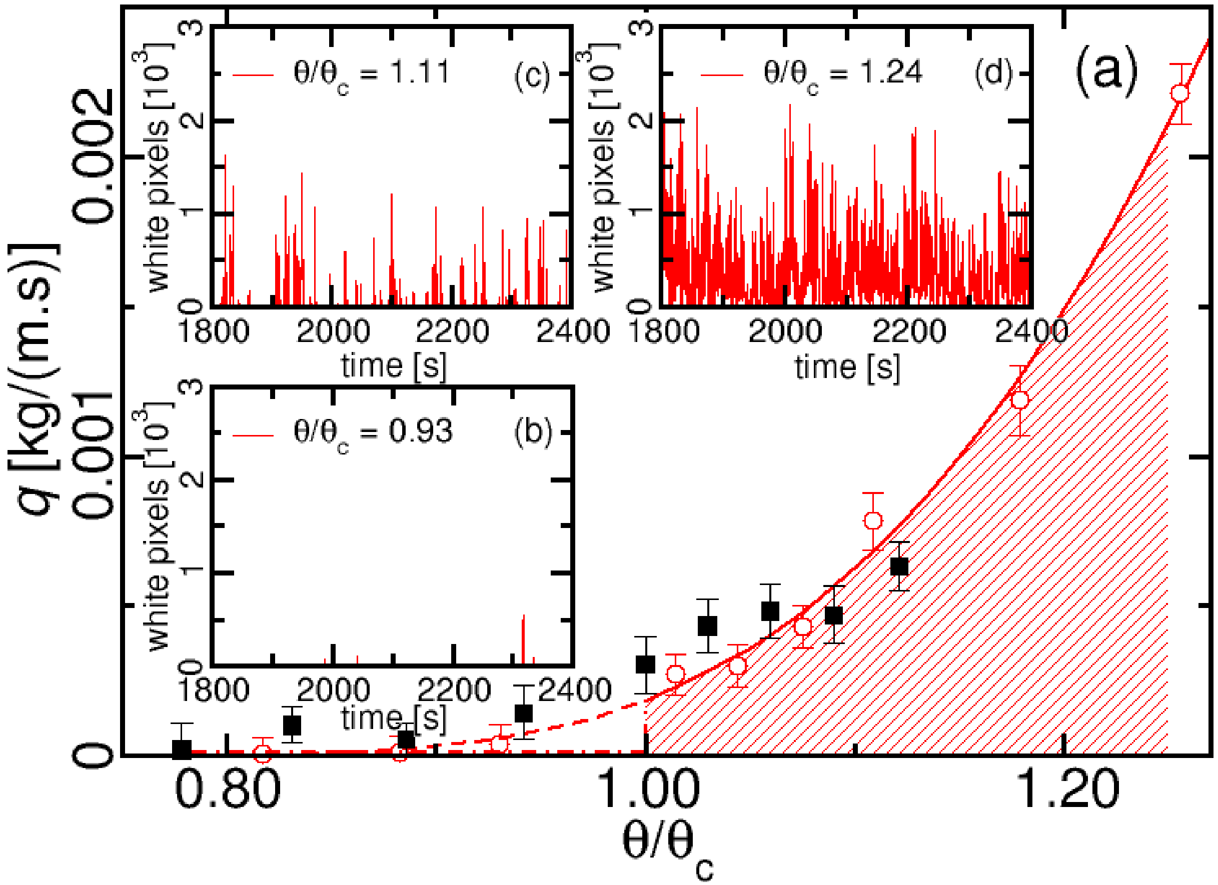
We express the wind velocity through the dimensionless Shields number,

$$\theta = \frac{u_*^2}{(\rho_s/\rho_a - 1) g D_{mean}}.$$

We use θ_c for the value corresponding to u_{*c} and θ_l for the value corresponding to u_{*l}

Results

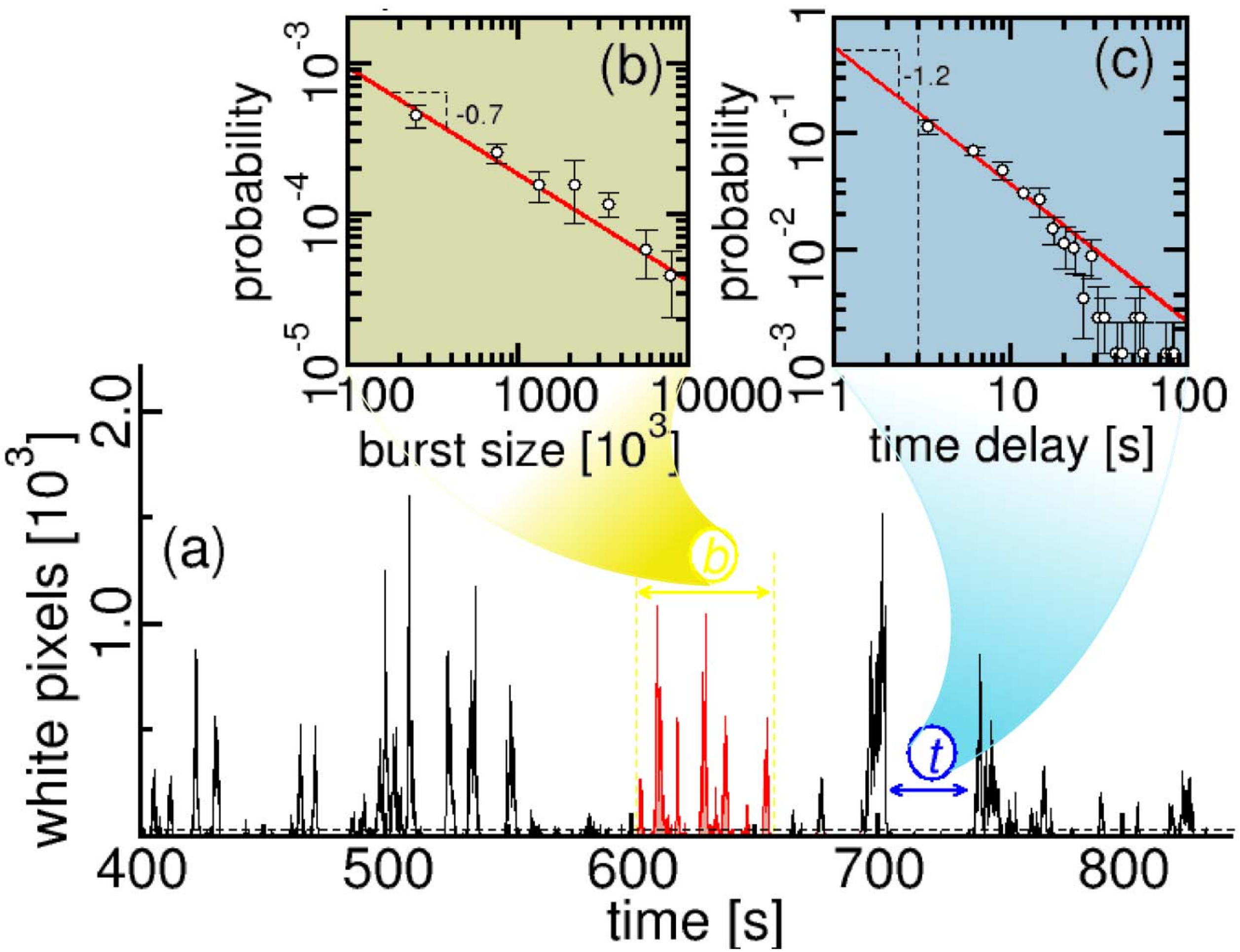
Mass transport



a) The transport rate obtained from the sand collected in the experiments (o) compared with results from the numerical simulations (□) $\langle \varepsilon \rangle = 0.05\ \mathrm{kg\,m^3\,s^{-1}}$

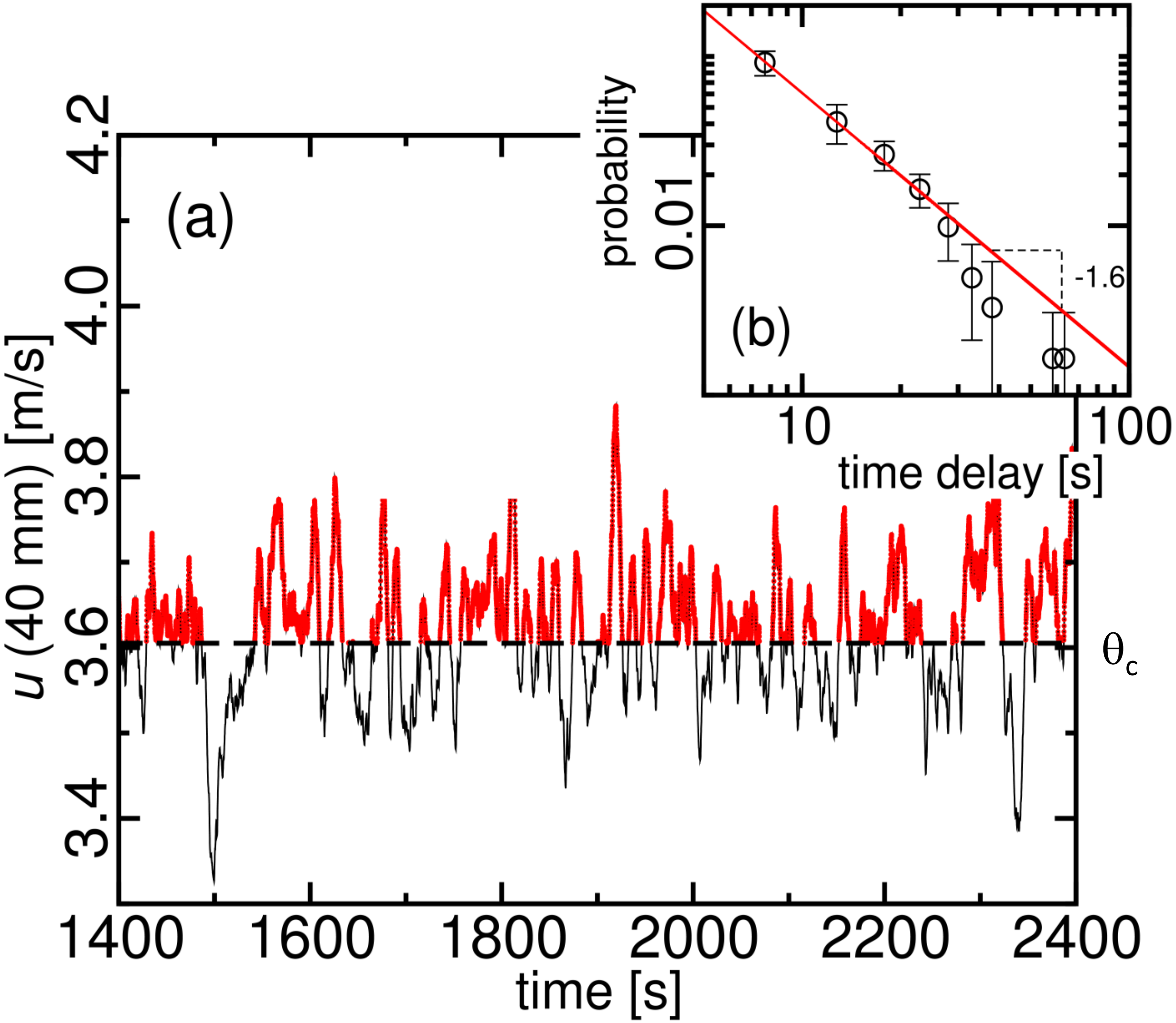
b) Figures (b), (c) and (d) show the time series obtained from the video analysis.

Bursting



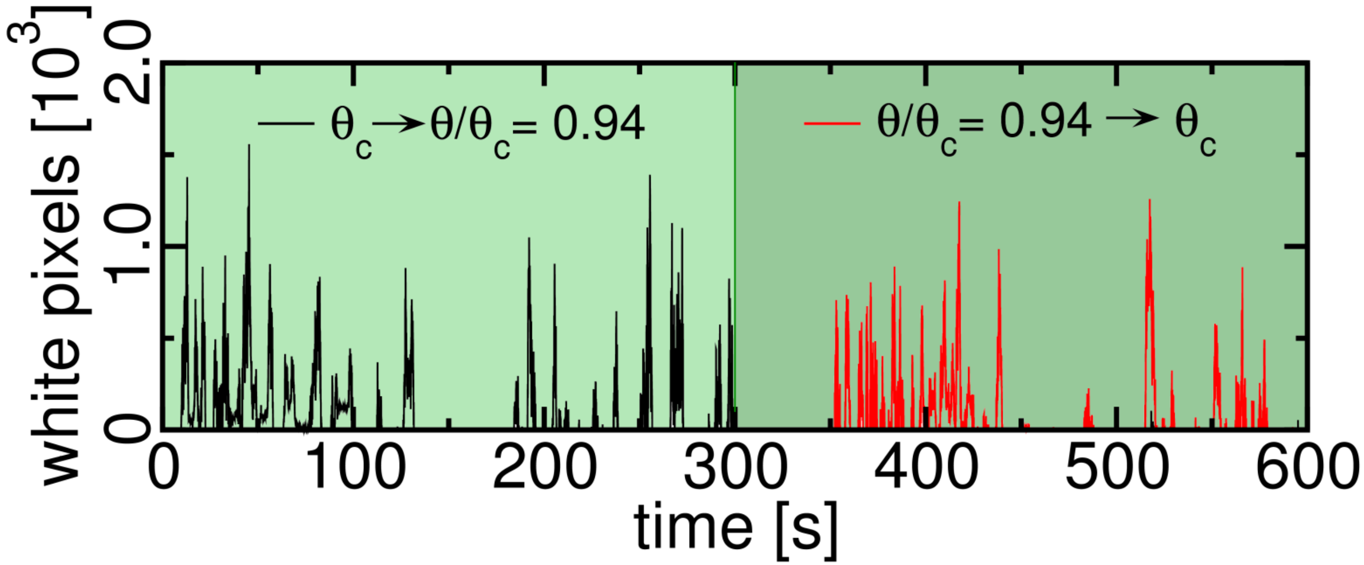
a) The time series of intermittent saltation at θ_c.
b) The burst size is obtained from the integration of the events within the yellow dashed lines in (a). The burst size distribution is fitted by a power law with an exponent -0.7;
c) The time delays between the sand bursts illustrated by the blue arrow also follow a power law distribution with exponent -1.2.

Wind flow



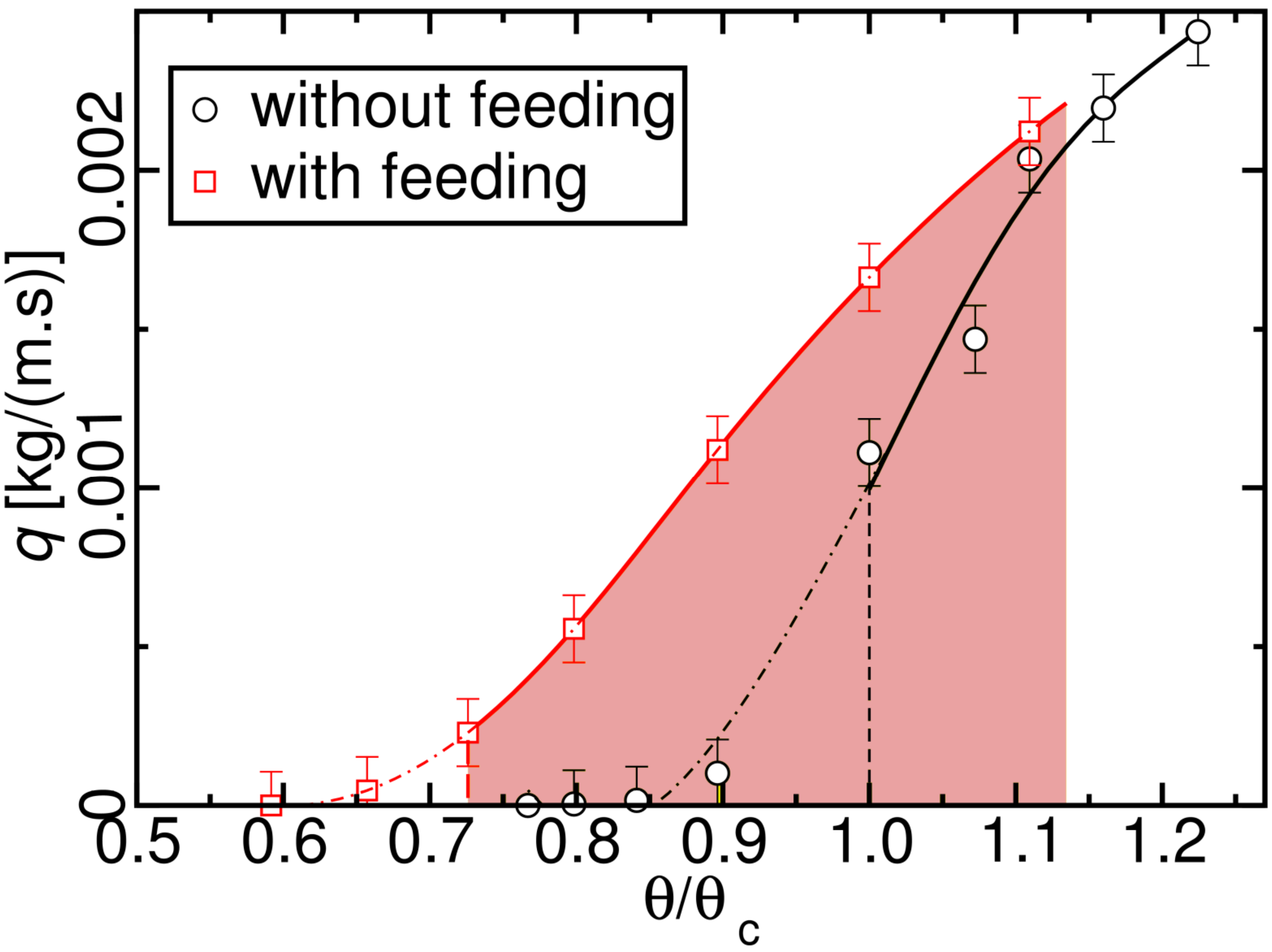
a) The wind fluctuations measured at 40 mm above the sand bed at θ_c.
b) The probability distribution of the time delays between the wind fluctuations in red is fitted by a power law with exponent -1.6.

Sensitivity



In black, the bursting activity at θ_c stops when θ decreases to θ = 0.94. In red, bursts start a few seconds after the Shields number increases to the fluid threshold Shields number θ_c

Feeding



The short experiments with feeding (red squares) and without feeding (black circles) show a hysteresis zone (red area) between θ/θ_c = 1.12 and the dynamic threshold at θ/θ_i = 0.73.

Turbulence ingredients of the numerical model

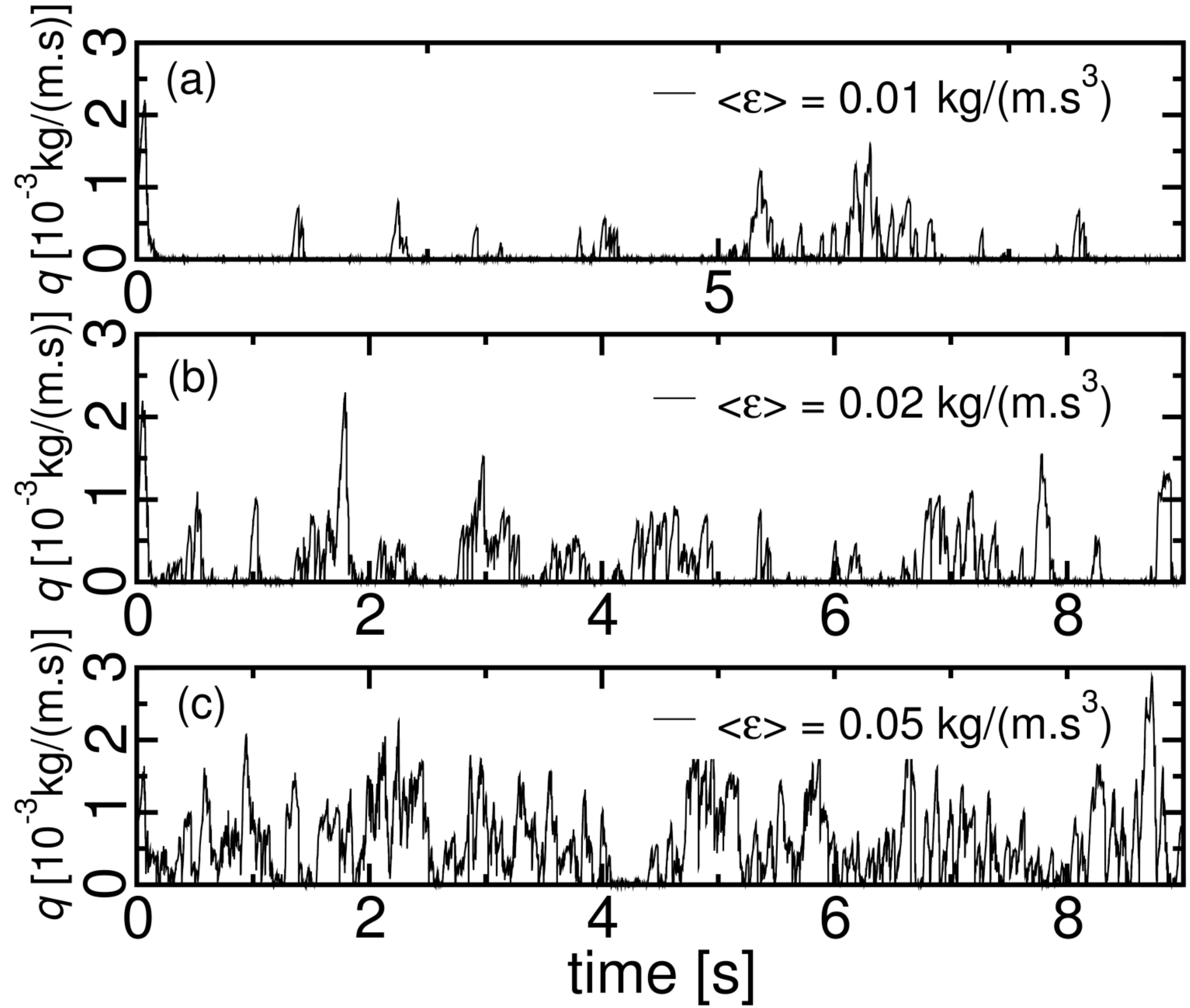
Reynolds* formulated a system of stochastic differential equations for the logarithm of the dissipation rate

$$\chi = log(\varepsilon / \langle \varepsilon \rangle)$$

with ε as the mean dissipation rate that reproduces the Gaussian distribution of the velocities u_s and the highly non-Gaussian distribution for the acceleration as of the particles in fully developed turbulence.

* A. M. Reynolds, Phys. Rev. Lett. 91, 2003.

Simulation of saltation transport at different intensities



Conclusions

The turbulent gusts create intermittent saltation through bursting, which can be simulated numerically in a DEM simulation.

Without feeding intermittent saltation occurs at Shields numbers between $1 < \theta/\theta_c < 1.25$.

For $\theta/\theta_c > 1.25$ saltation is non-intermittent and the saturated flux is continuous.

Both wind measurements and video analysis displayed scaling laws and connect the burst initiation with the wind fluctuation above the fluid threshold.

Aeolian sand bursts evolve downstream into streamers, which are so far, poorly understood.

Future studies in the field should focus on these interesting coherent 3D-structures.