Aeolian saltation dynamics
-
from experiment to model

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Outline of talk

Motivation:

  What variation is observed during steady/transient conditions

Wind tunnel experimental set-up

Characteristics and temporal evolution of:

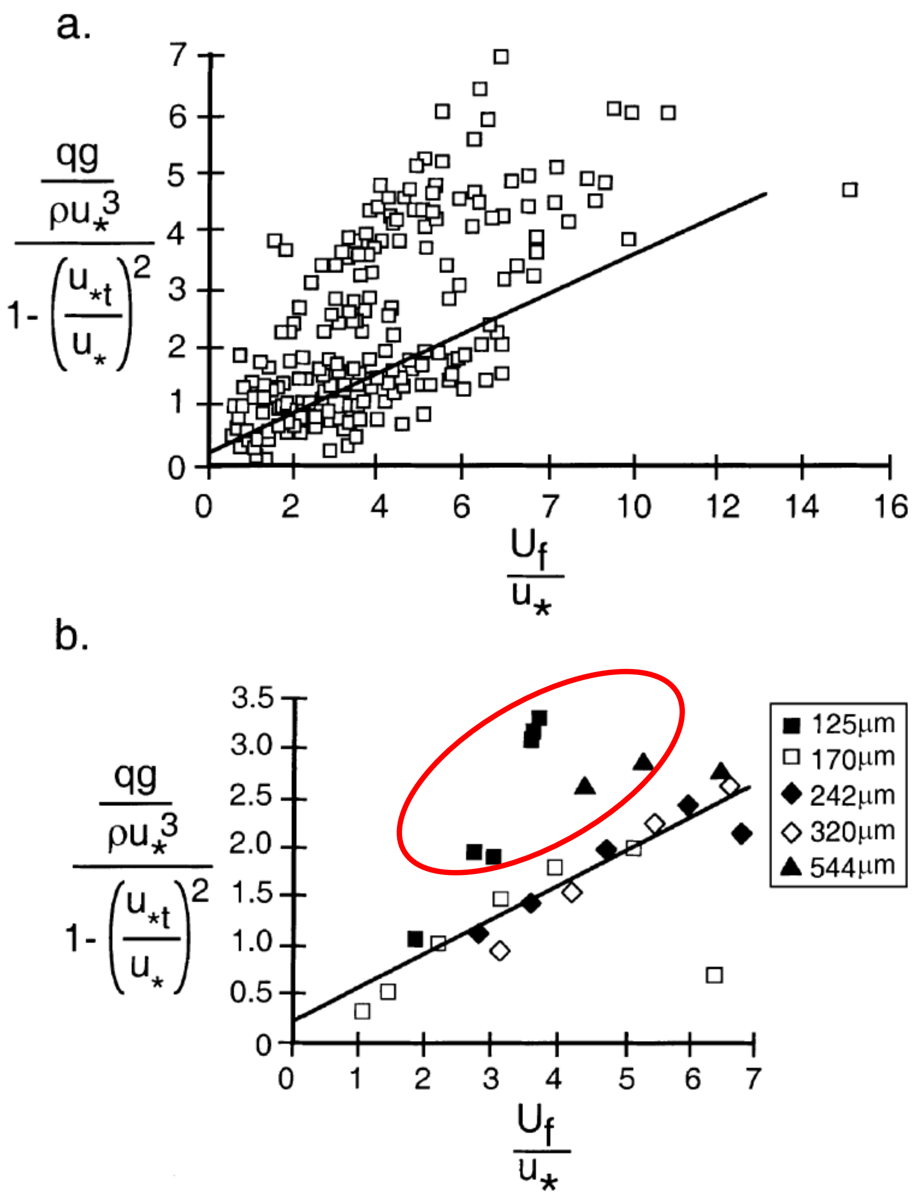
- Ripples
- Jump length
- Grain rate and speed

Analytical modelling of saltation

- Model
- Prediction results

Conclusions

Motivation – Steady state?



Normalized saturated mass transport

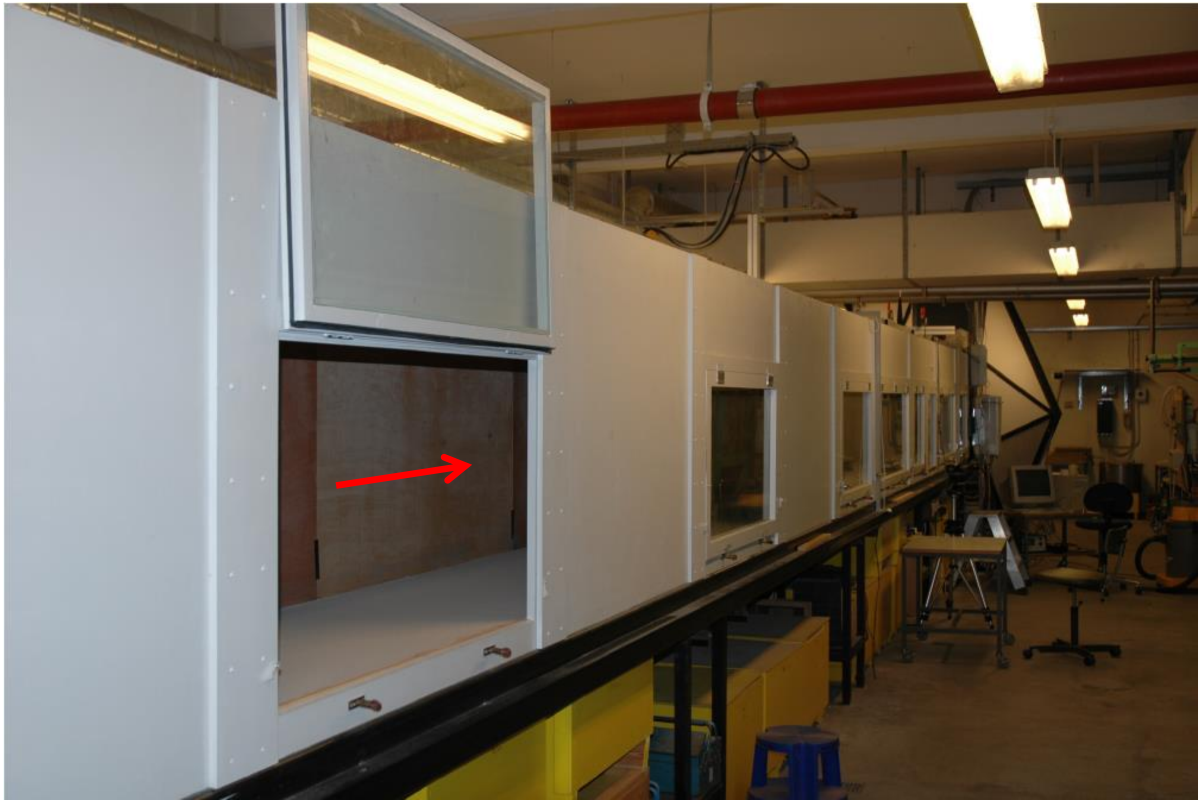
▽ Bagnold (1936)
▼ Belly (1964); Kadib (1964,1965)
◆ Chepil & Milne (1939)
◇ Greeley *et al.* (1984)
▲ Horikawa & Shen (1960)
△ Kawamura (1951)
× Nickling (1978)
+ Svasek & Terwindt (1974)
● White (1979)
○ Willetts *et al.* (1982), Jones & Willetts (1979)
■ Williams (1964)
□ Zingg (1953)

Owen (1964)

$$1.0\left(0.25+\frac{1}{3}\frac{u_f}{u_\star}\right)\left(1-\left(\frac{u_{\star t}}{u_\star}\right)^2\right)$$

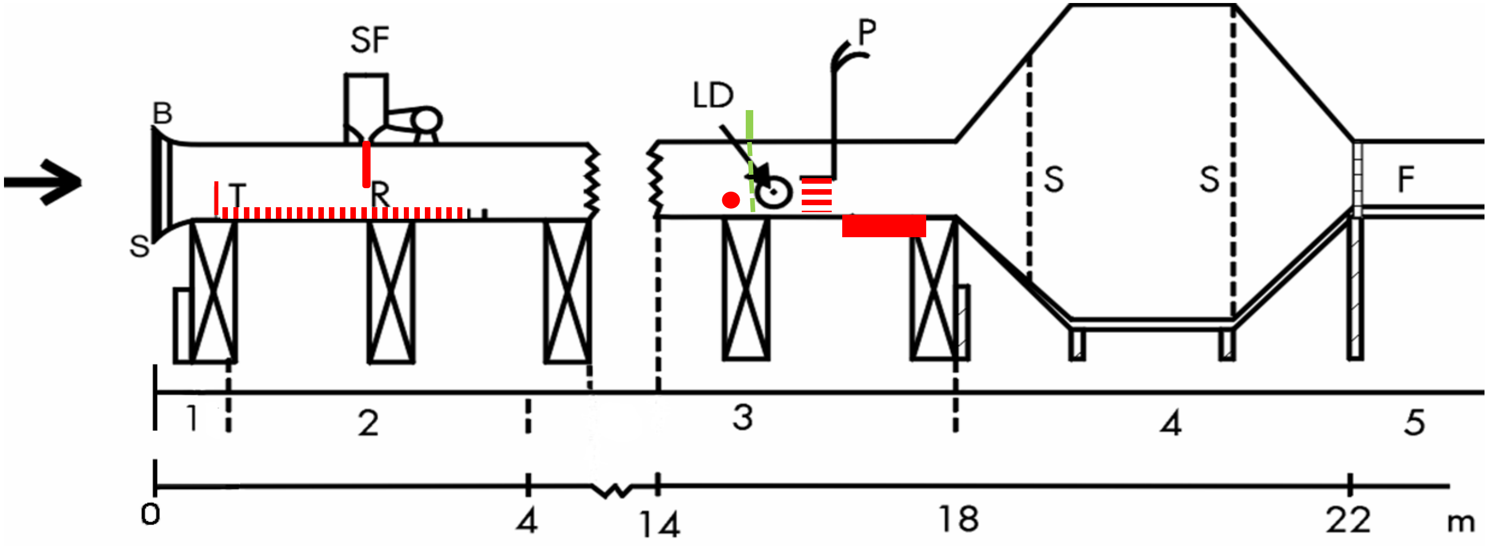
Shortly about our wind tunnel

Front to rear view

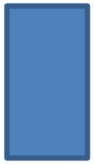


Turbulence spires (left) & Roughness array (right) ($u_* \sim 0.2$; $S^* < 0.02$

Overview of our wind tunnel set-up



Tunnel cross section
900 x 600 mm



- Long tunnel ⇒ Boundary layer design, grain feeding, wind flow/grain interaction ⇒ saturated steady state saltation

Study procedure:

- Short experiments observing processes on a flat bed?
- Long experiments over bed with ripples? If so how long time is needed to let the bed evolve?

Sampling strategy

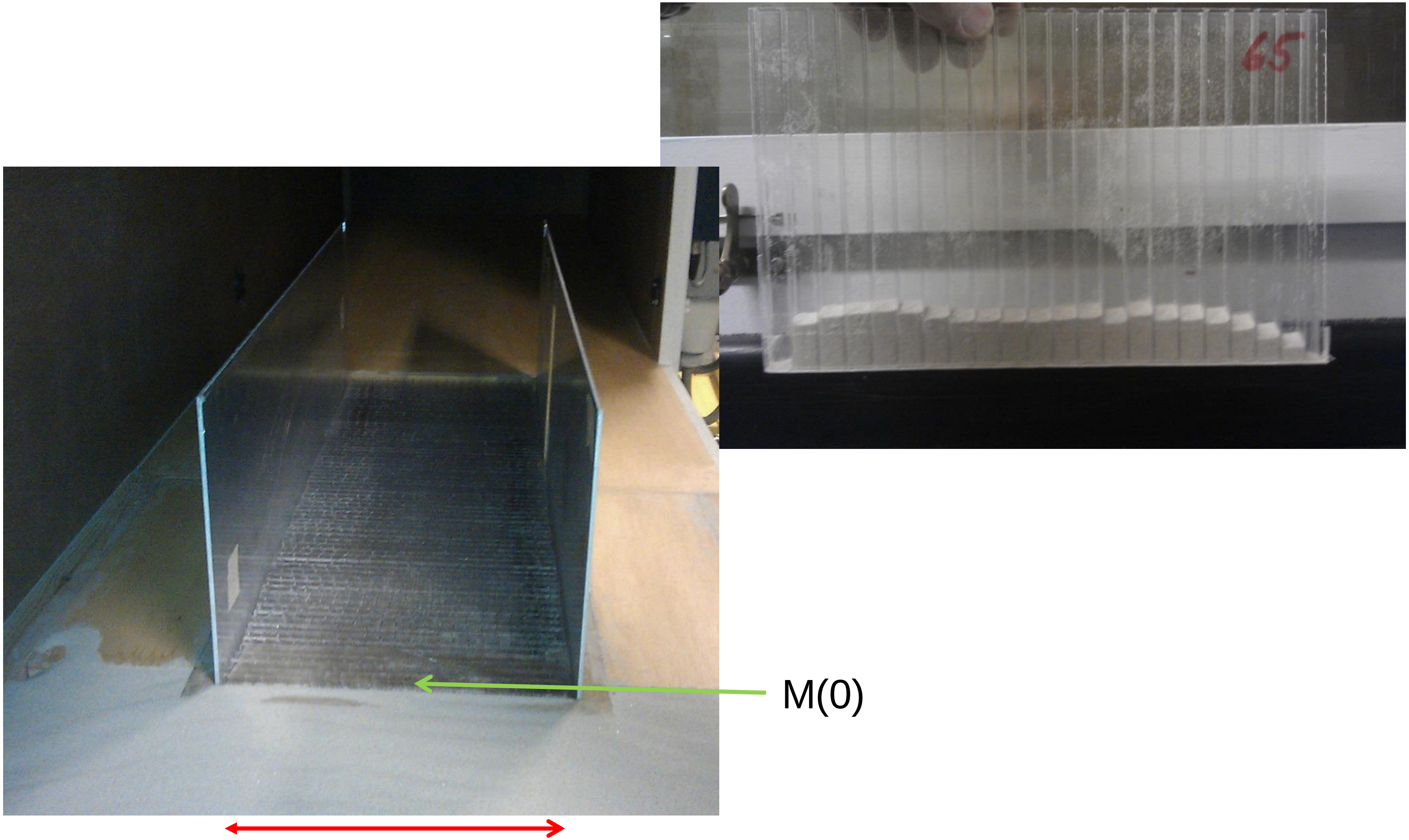
Acquire data in 3 runs following each other - starting with a flat bed:

1. Collect saltating grains in downstream trap for jump-length estimation;
2. Record ripple pattern - camera outside WT: 1 frame/30s;
3. Measure wind speed at 40 mm height with pitot tube
4. Measure grain speed between 3 mm and 60 mm with LDA
   a. Max of〈1000-5000 grains; 30-50 seconds〉approximately similar run lengths
5. End run: stop camera, empty trap, save files before next run

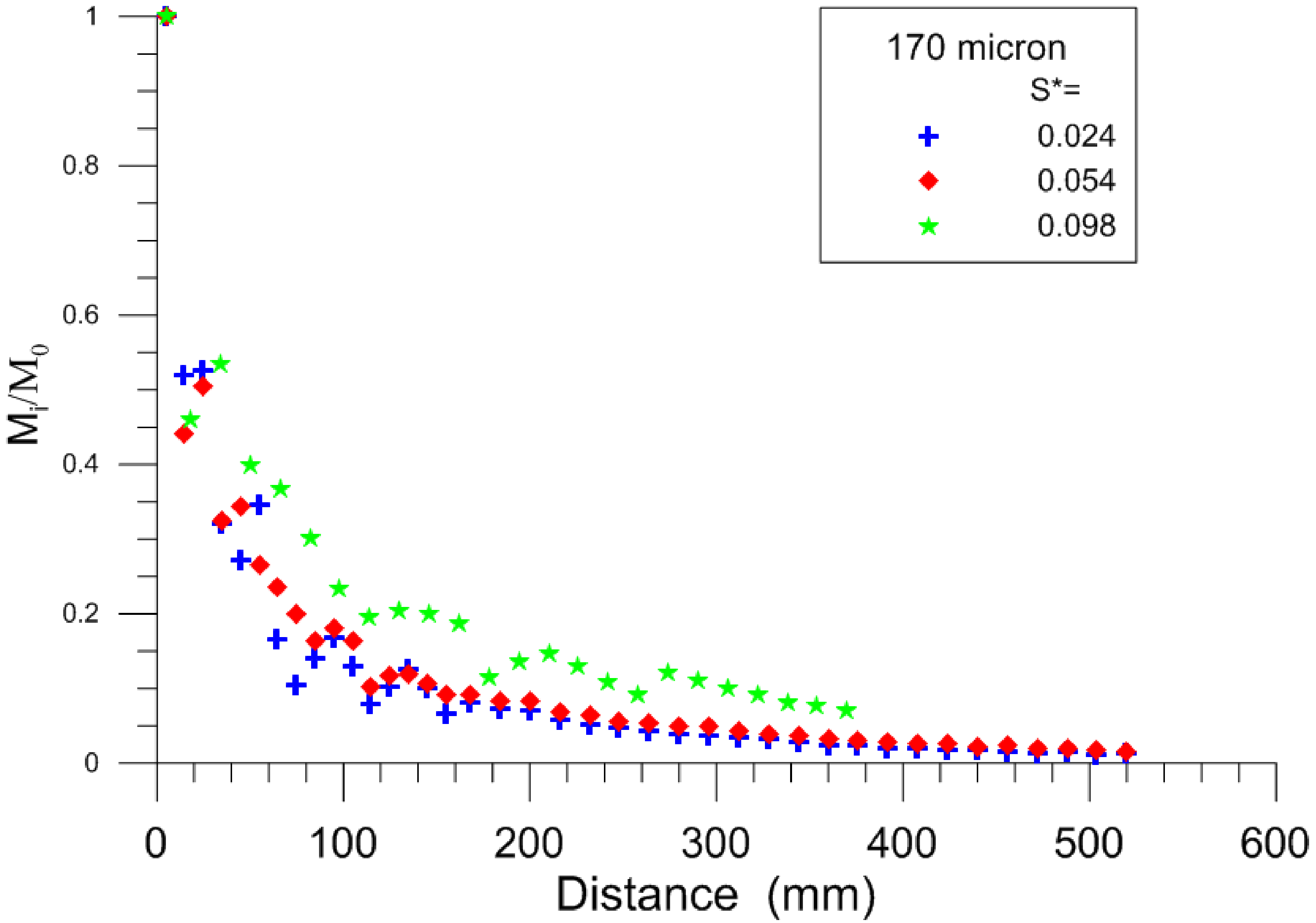
Not all parameters can be measured in each run. In some runs trap data were merged.

Show a poor-quality video S* = 0.05, with 170 micron quarts grains!

Estimation of Jumplengths



Trapdata

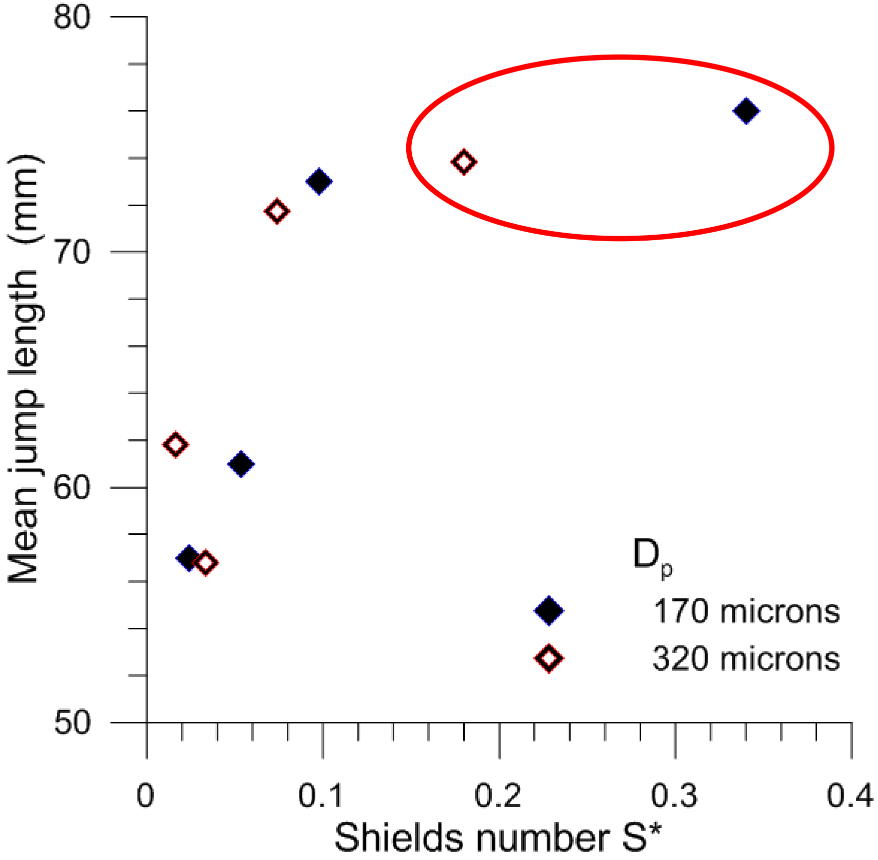

170 micron
S*=
✚ 0.024
◆ 0.054
★ 0.098
1
0.8
0.6
0.4
0.2
0
M_i/M_0
0
100
200
300
400
500
600
Distance (mm)

Mean jump lengths (MJL)

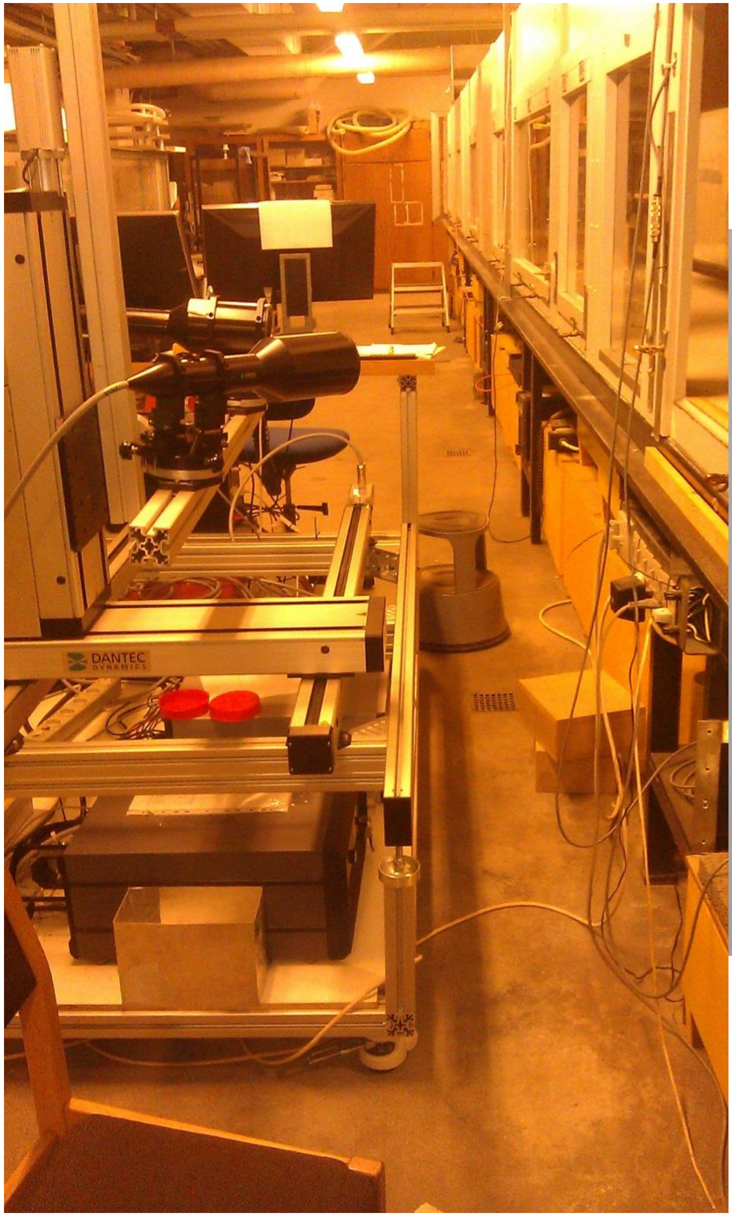
$$MJL = \sum_N x_i P(x_i) = -\frac{1}{M(0)} \sum_N x_i \left[M_i - M_{i+1} \right]$$

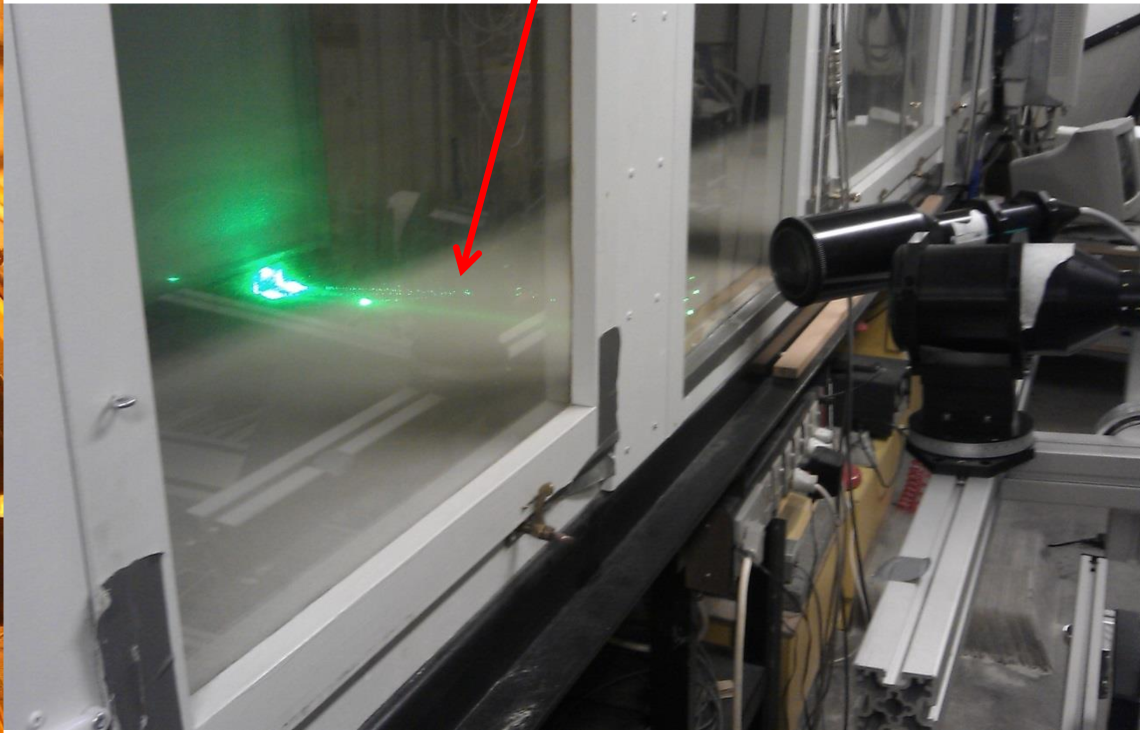
Grain size (micron)	Shields number	Mean jump length (mm)
170	0.024	57.0
	0.054	61.0
	0.098	73.0
320	0.016	61.8
	0.033	56.8
	0.074	71.7
	0.18	73.8*

Mix of runs so no temporal evolution can be detected



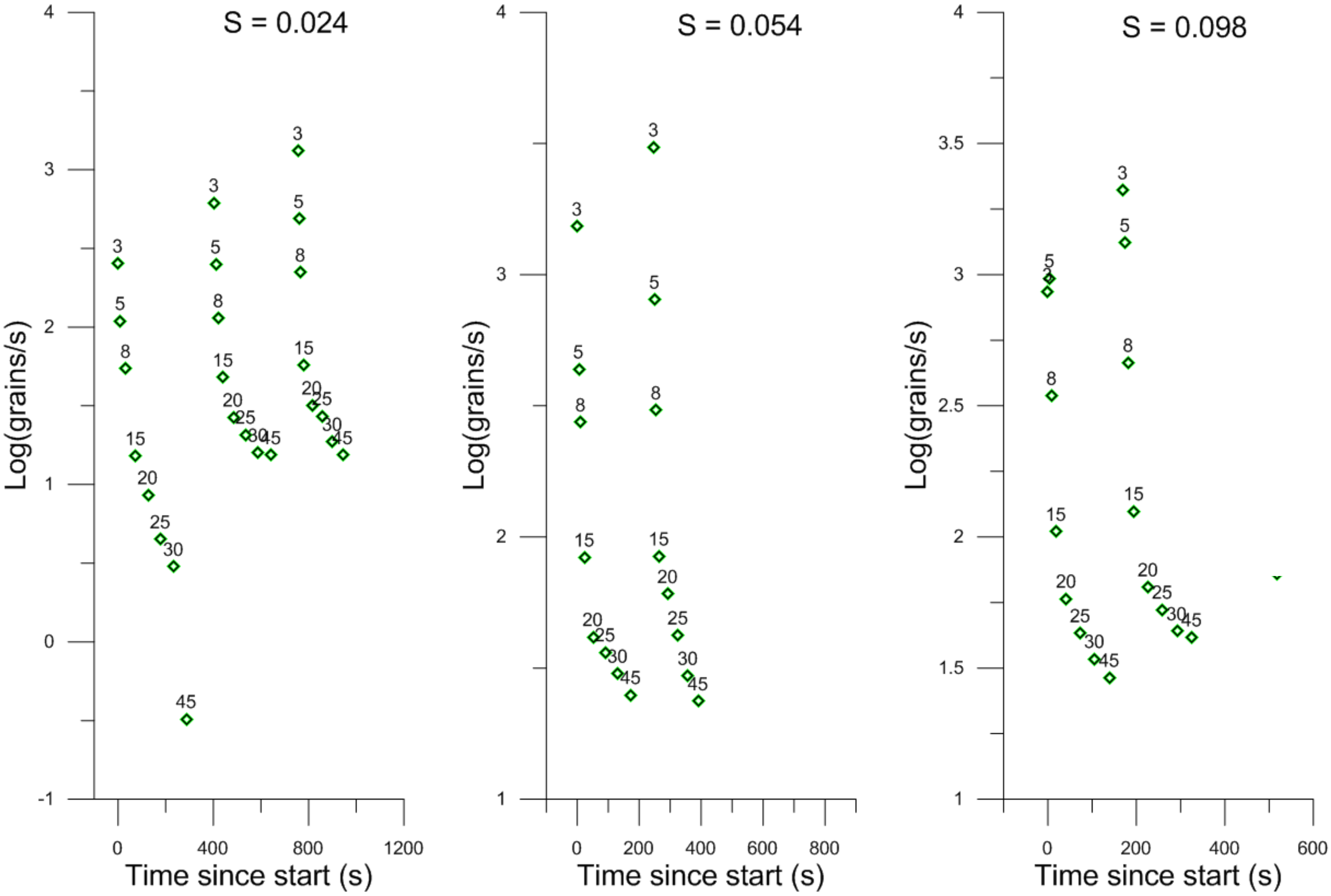
Grain rate and speed



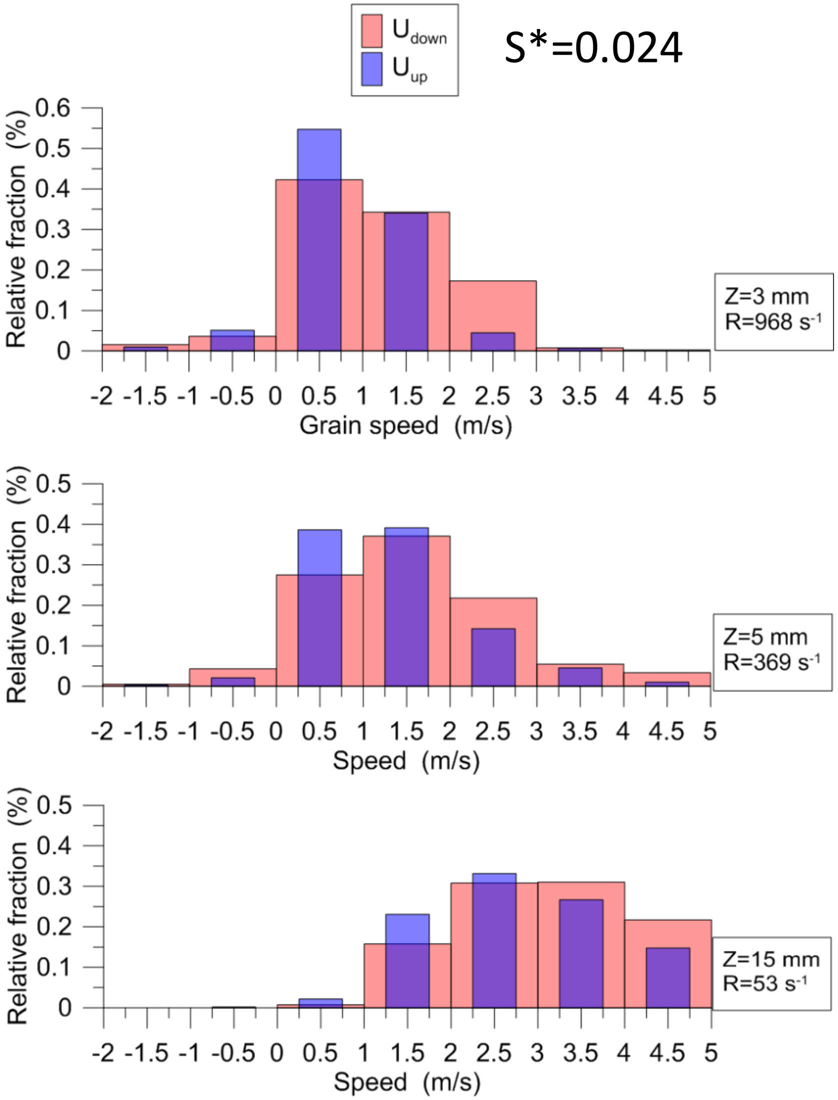


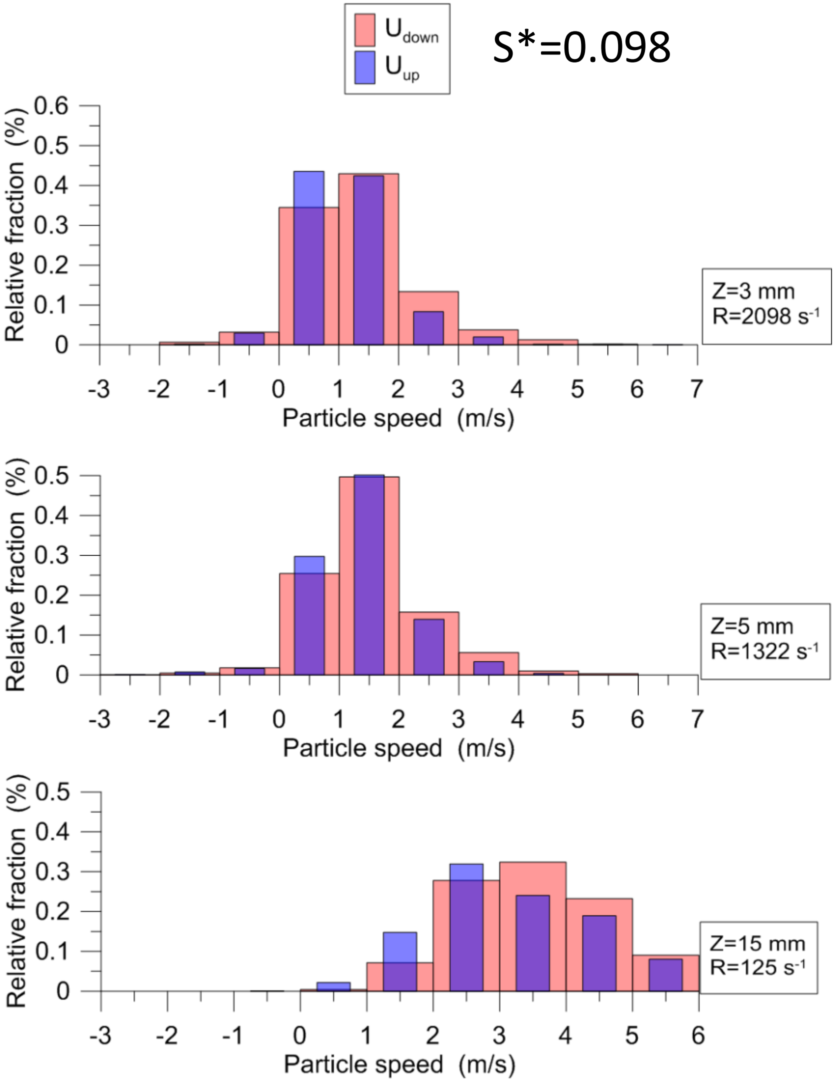
Cross section: 0.134 x 1.729 mm^2

Grain rate versus Run

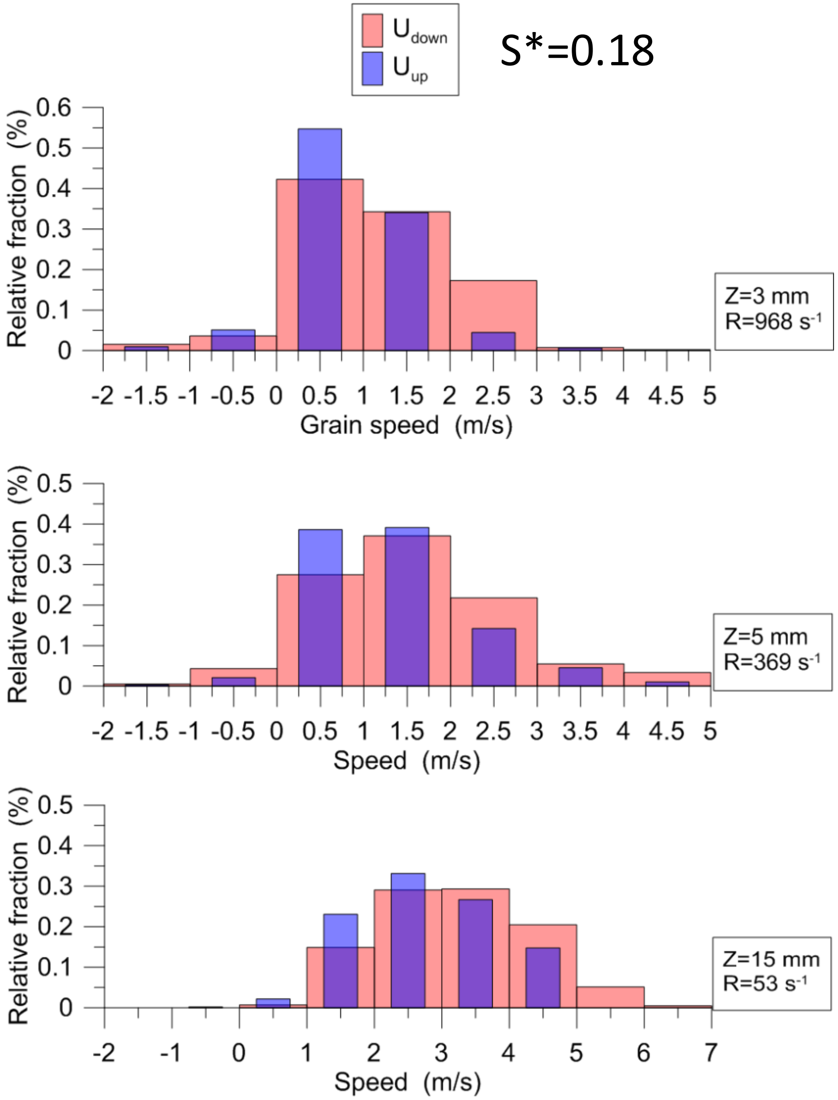


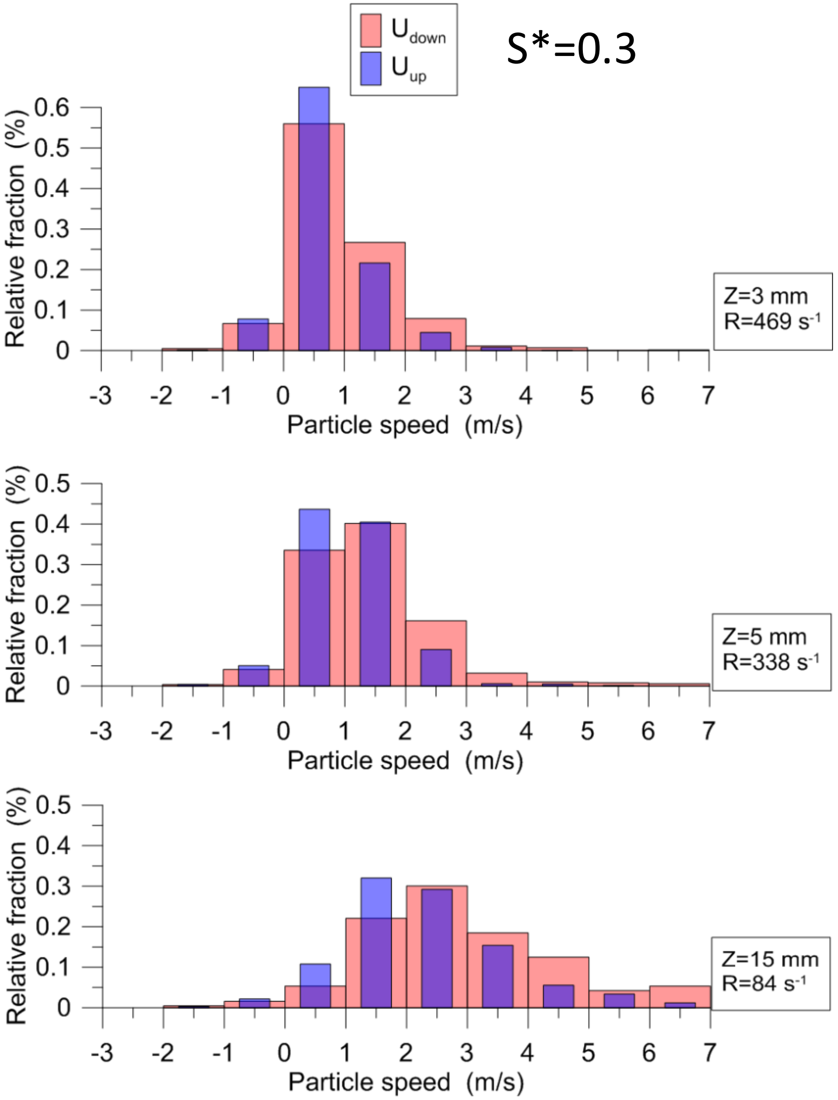
Grain velocities - 170 micron


S*=0.024


S*=0.098

Grain velocities - 170 and 320 micron

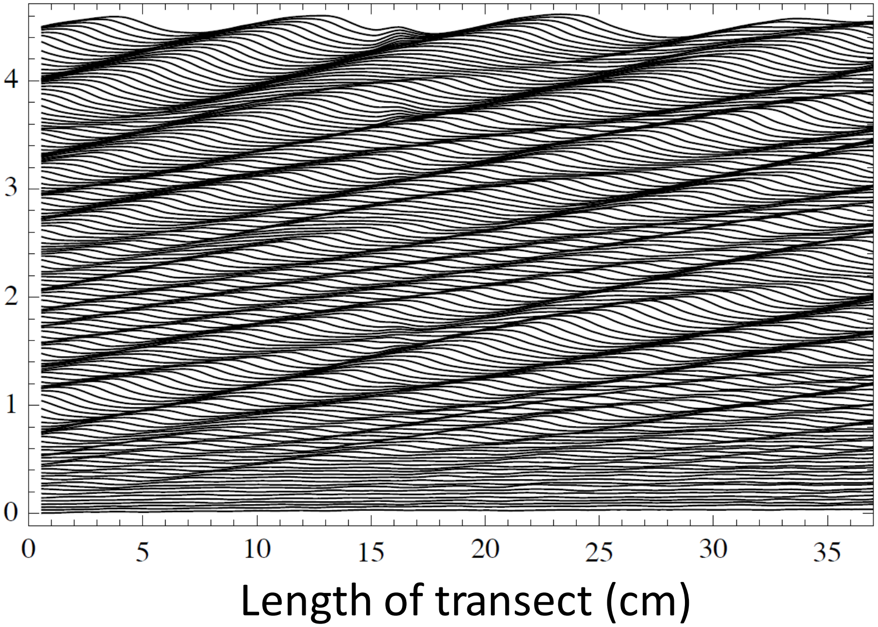

S*=0.18


S*=0.3

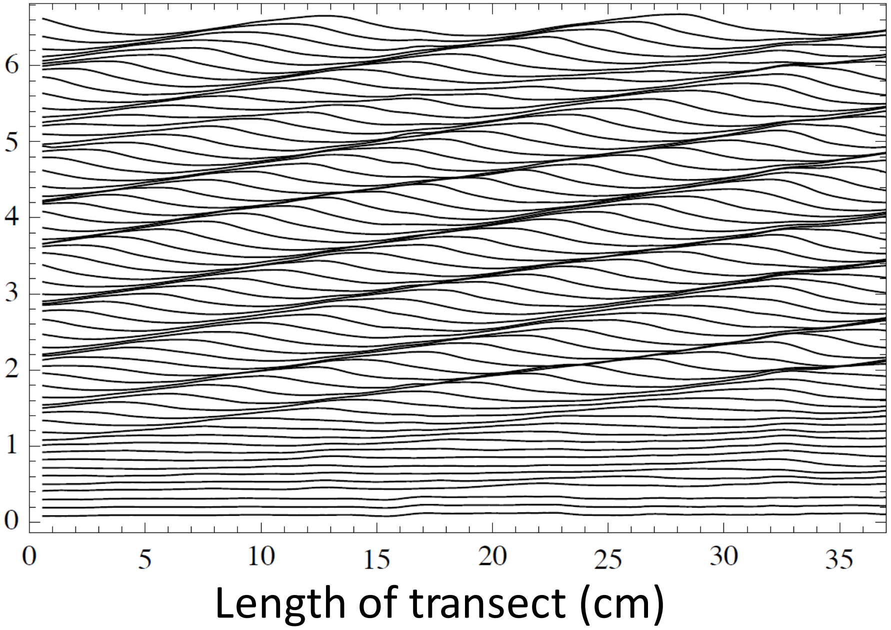
Bed characteristics 170 micron

Digitized images of the bed illuminated by a 40 cm laser line along the centre-line of the tunnel at 1 frame/30 seconds

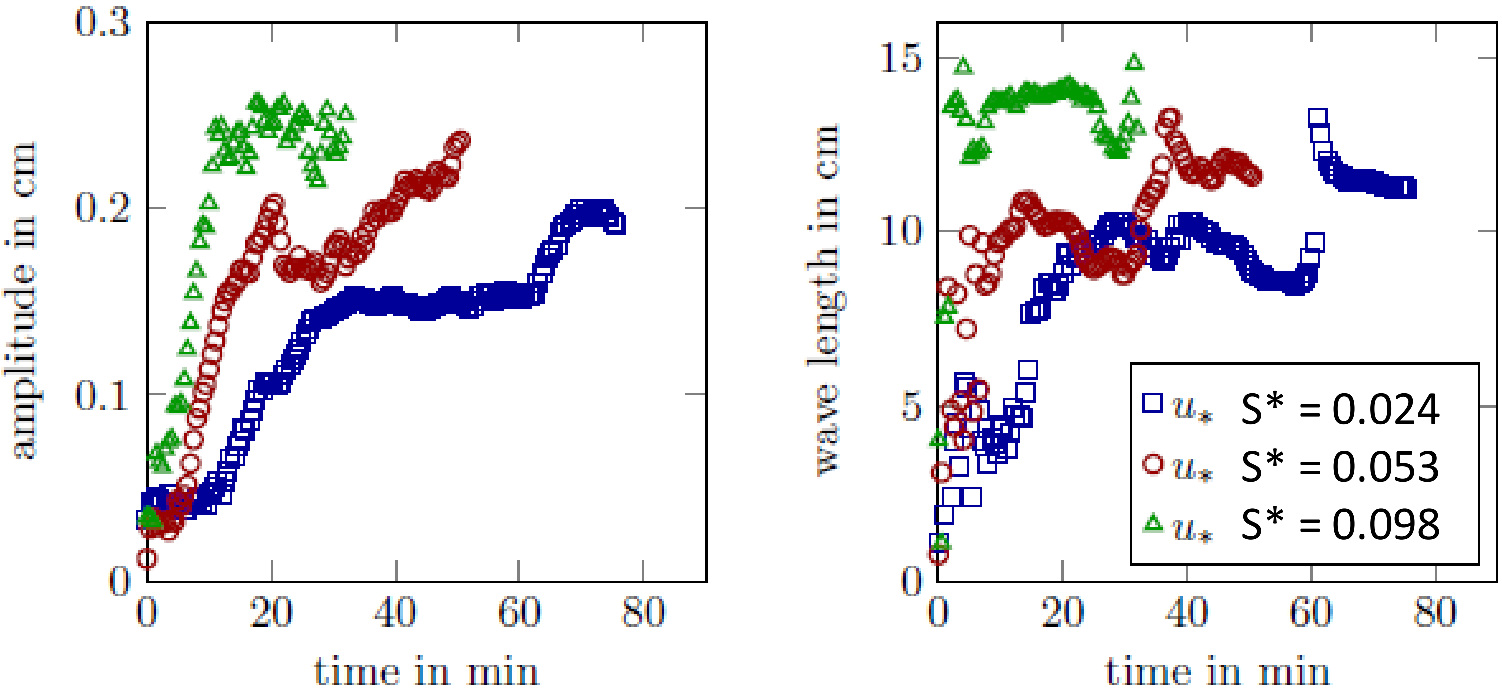
S*=0.024



S*=0.053



Ripples



Have we reached steady state or will the amplitude/wavelength continue to increase?

Boundary influences, e.g. crosswise variation in saltation flux, will create instabilities which will propagate downstream.

Conclusions

1) The average jump-length is a weak function of wind speed;
2) Saltation dynamics changes when ripples form on a flat bed;
3) The variation of grain velocity below approx. 50 D_p is moderate;
4) The velocity of grains that jump higher clearly increase with wind speed;
5) We observe that ripple wave length and amplitude saturates and then probably vary due to the formation of new ridges;

A simple saltation model: trajectories

$$\ddot{x} = H(v)(U(y) - \dot{x})$$

$$\ddot{y} + g + H(v)\dot{y} = 0$$

$(x(0), y(0)) = (0, 0)$ $(\dot{x}(0), \dot{y}(0)) = (v_1^0, v_2^0)$ is random

$H(v) = D(v)/(mv)$

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$t_* = m/\delta$ is the response time of a grain to changes in the wind speed

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$t_* = m/\delta$ is the response time of a grain to changes in the wind speed

$$\begin{aligned} x(t) &= \int_0^t \left(1 - e^{-(t-s)/t_*}\right) U(y(s))ds + t_* v_1^0 \left(1 - e^{-t/t_*}\right) \\ y(t) &= t_*(v_f + v_2^0)(1 - e^{-t/t_*}) - v_f t \qquad v_f = g t_* \end{aligned}$$

A simple saltation model: lift-off velocity

$(\dot{x}(0), \dot{y}(0)) = (v_1^0, v_2^0)$ is random

Probability density of v_2^0:

$$\pi \lambda_s e^{-\lambda_s x} + (1-\pi)\lambda_r e^{-\lambda_r x}, \qquad 0 < \pi < 1$$

Saltators: $E(v_1^0 \,|\, v_2^0) = \kappa v_2^0 \qquad \kappa = \cot(\alpha), \quad \alpha = 30$

Reptators: $\overline{v_1^0} = 0$

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Model fitted by least squares to data for grains of size 310 μ:

Horizontal and vertical velocity components of grains going up and grains going down at 9 heights: 0.3, 0.5, 0.8, 1.5, 2.0, 2.5, 3.0, 4.5, 6 cm

4 shear velocities: 31, 44, 66 and 103 cm/s

A simple saltation model: parameter estimates

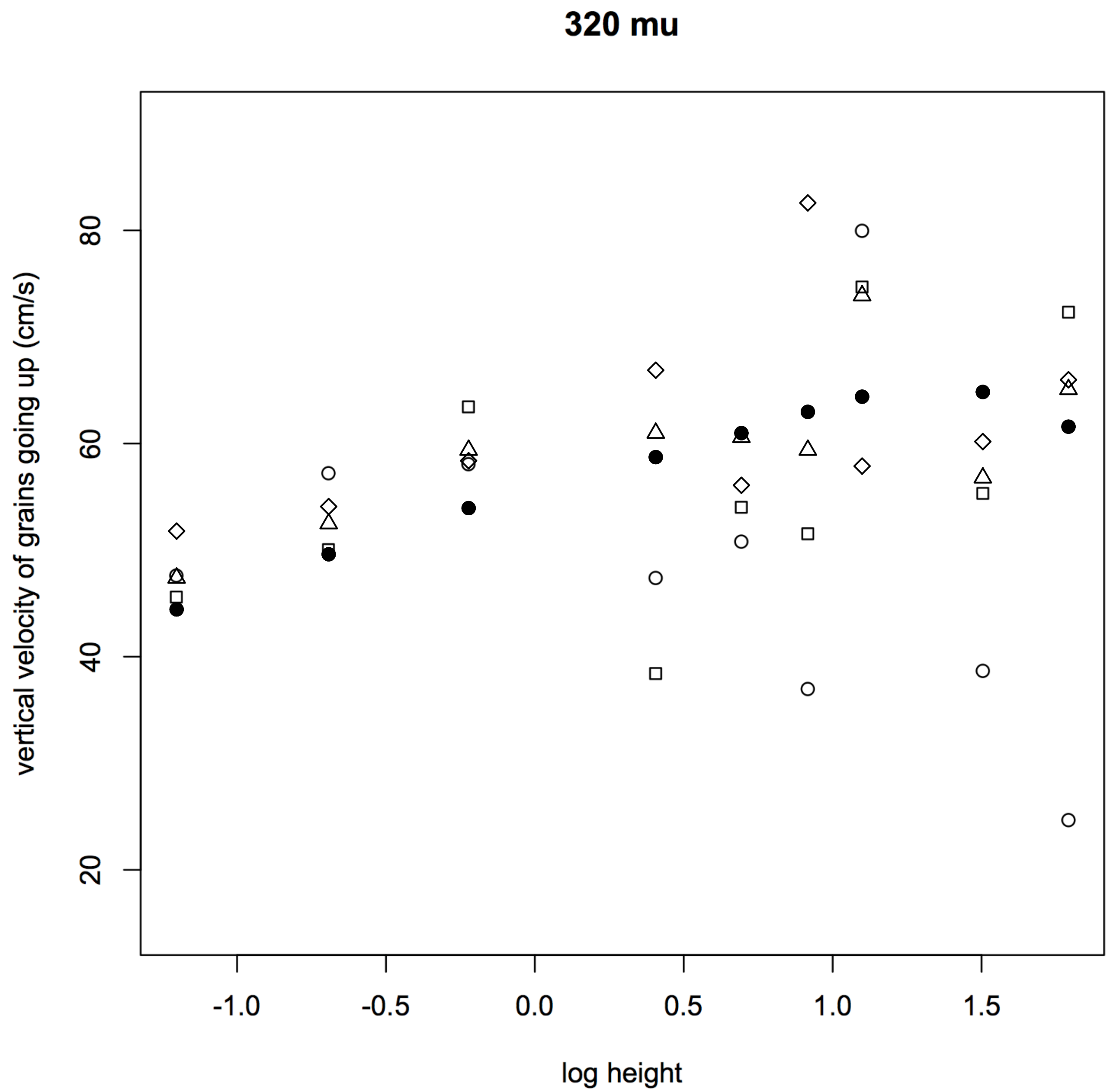
$\pi = 0.33$

Mean number of grains ejected by an impinging saltator: $\bar{n} = \frac{1-\pi}{\pi} = 2.02$

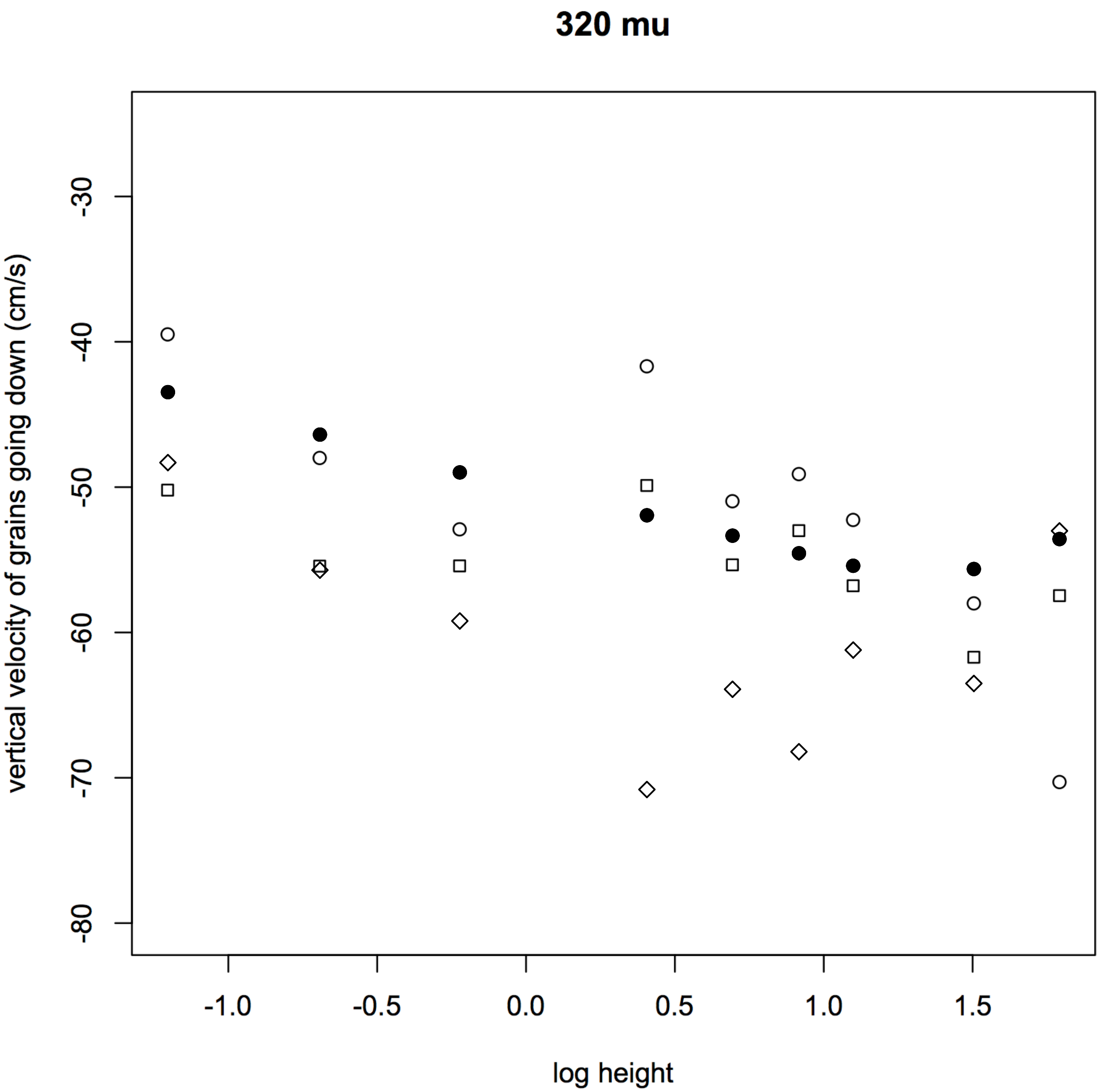
$1/\lambda_s = 31$ cm/s

$1/\lambda_r = 7$ cm/s

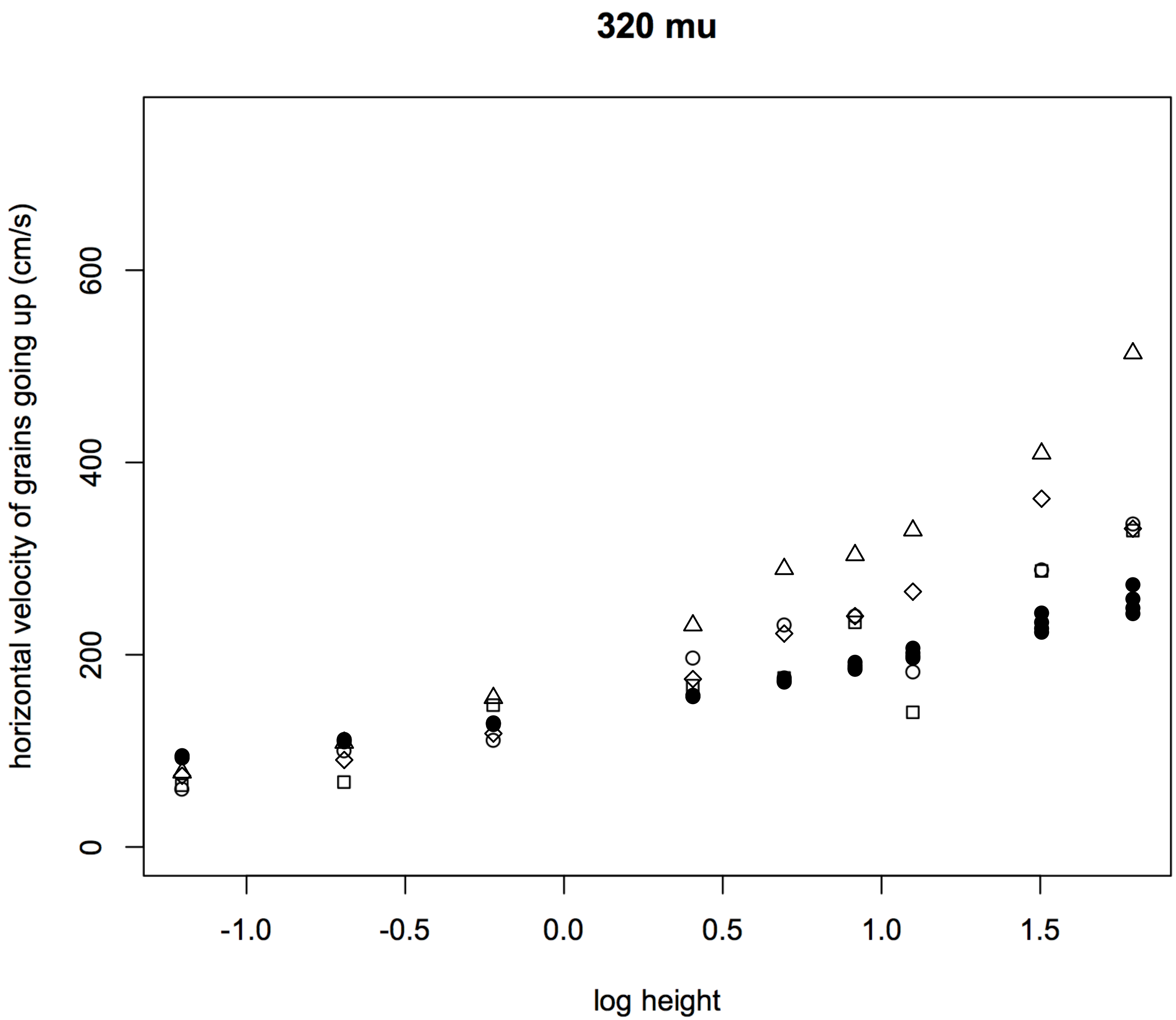
Vertical velocity component of grains going up



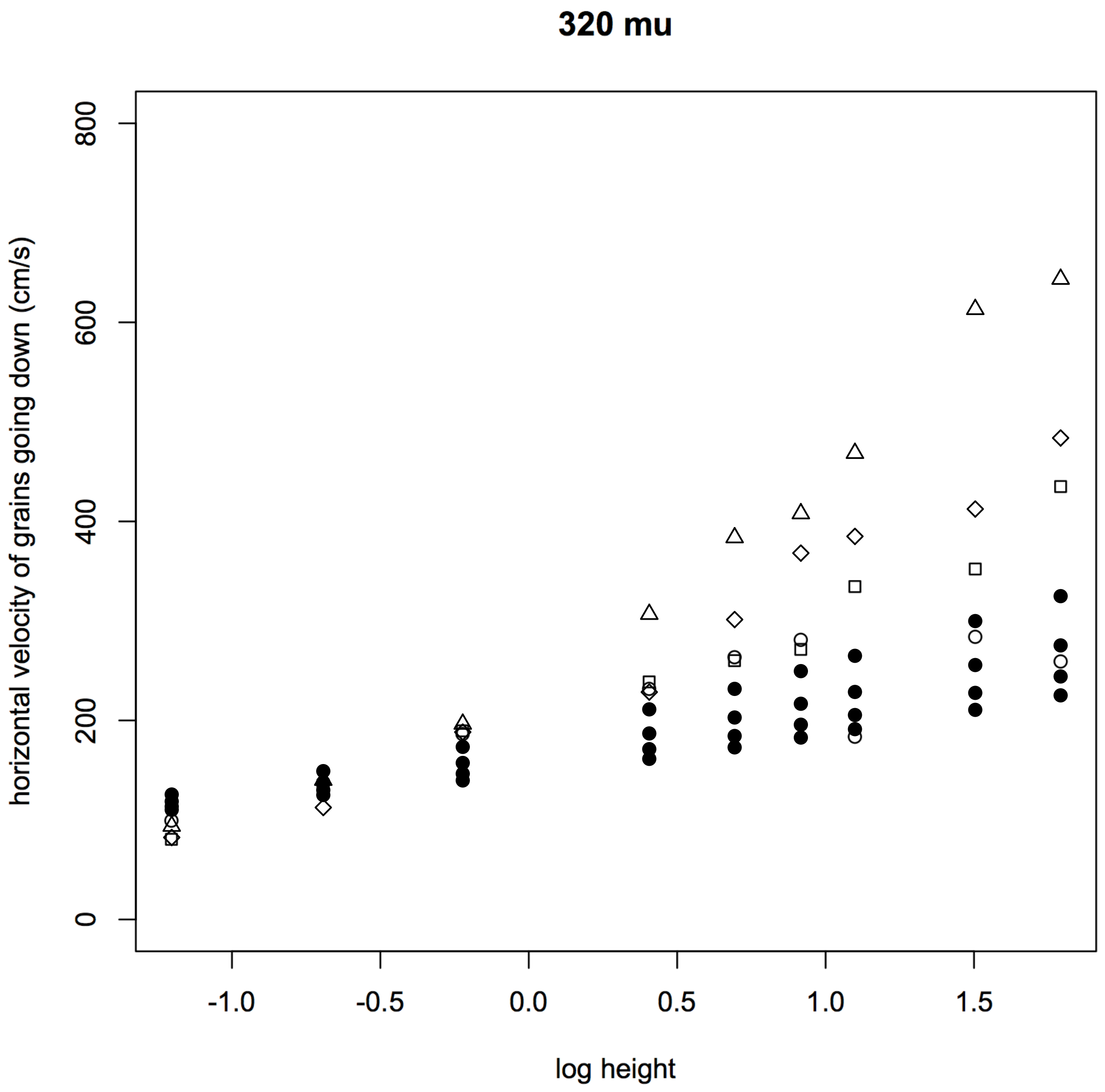
Vertical velocity component of grains going down



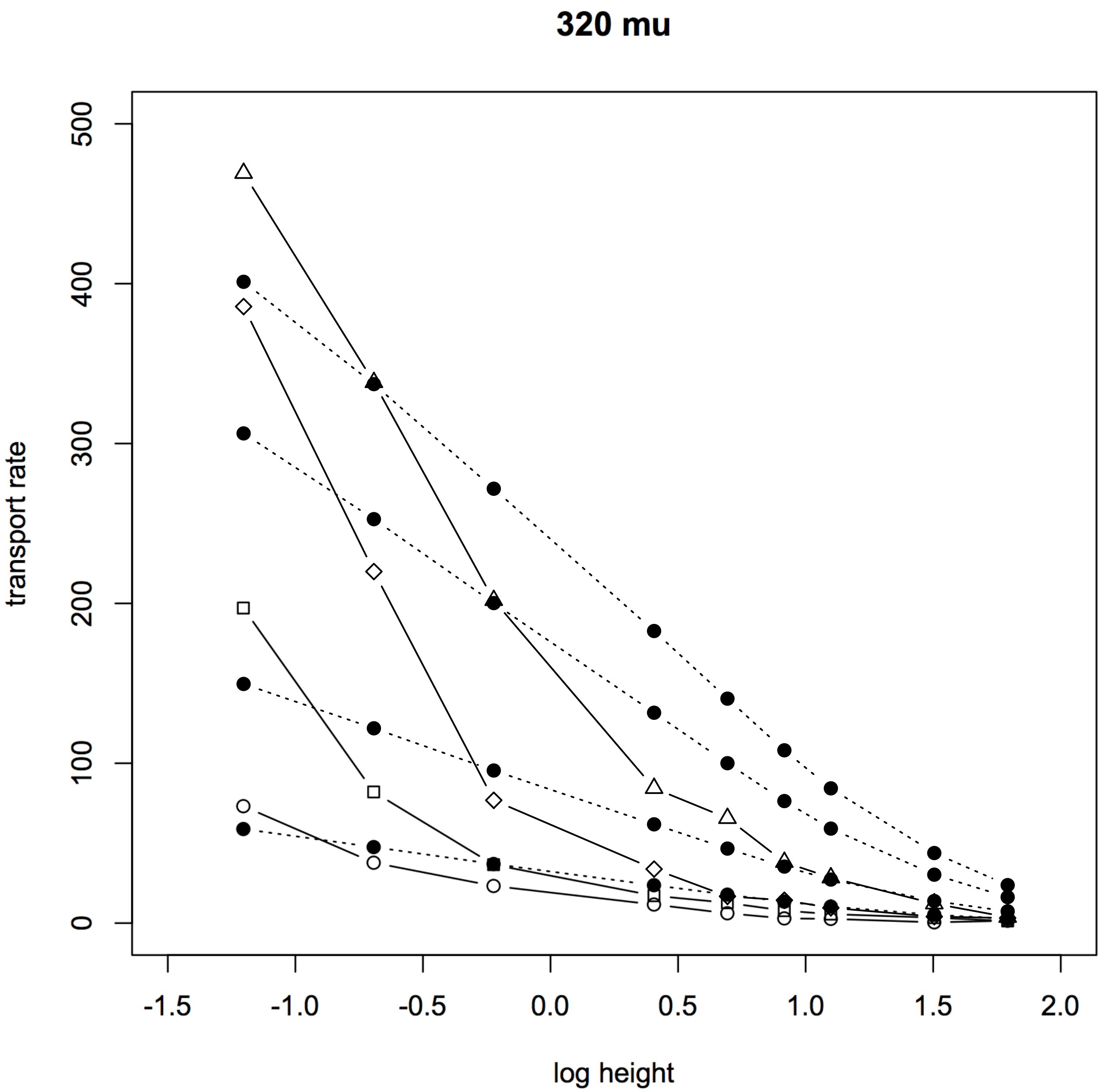
Horizontal velocity component of grains going up



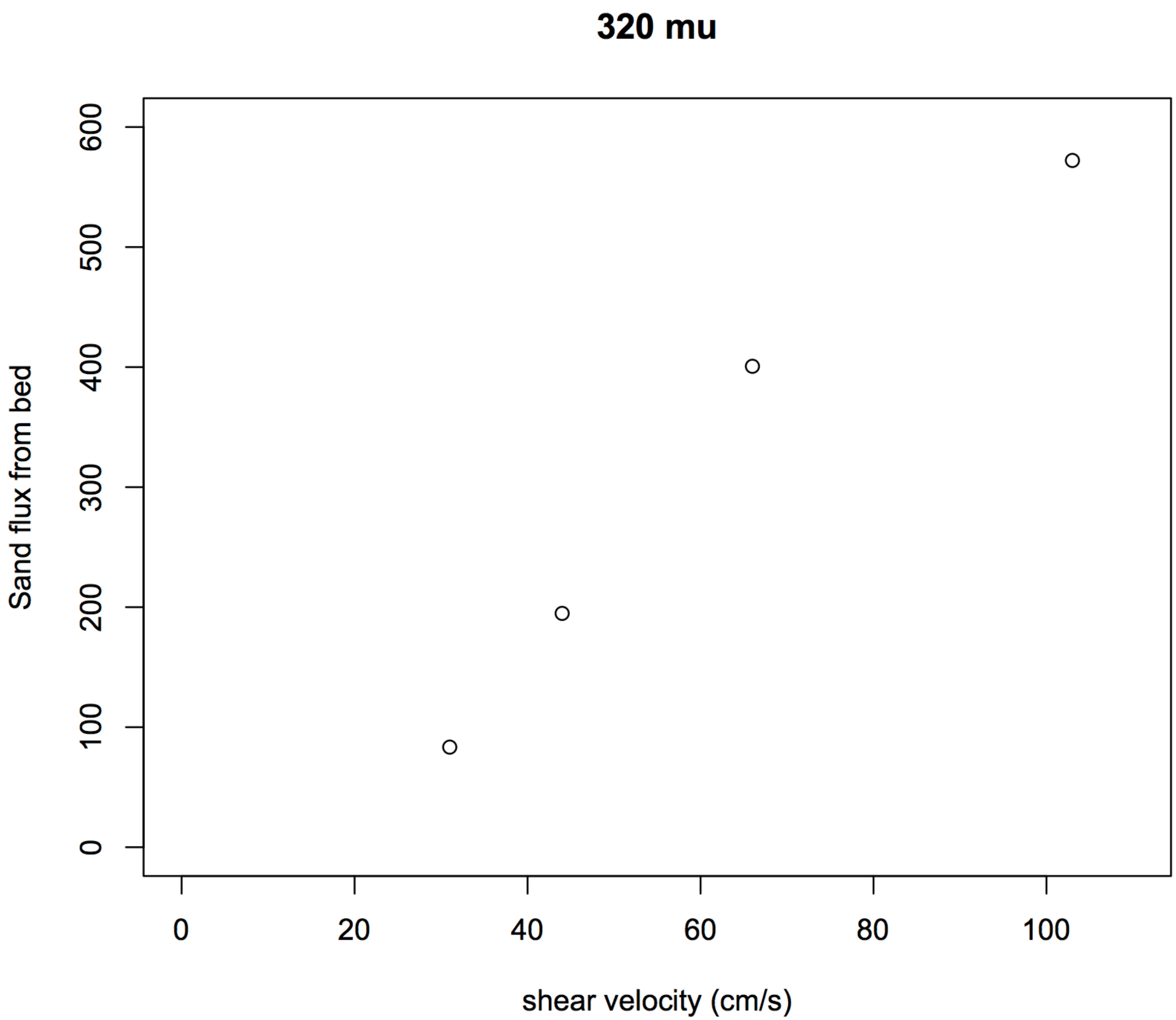
lorizontal velocity component of grains going down



Transport rate profile



Flux from bed to air



Grain borne shear stress

Owen (1964)

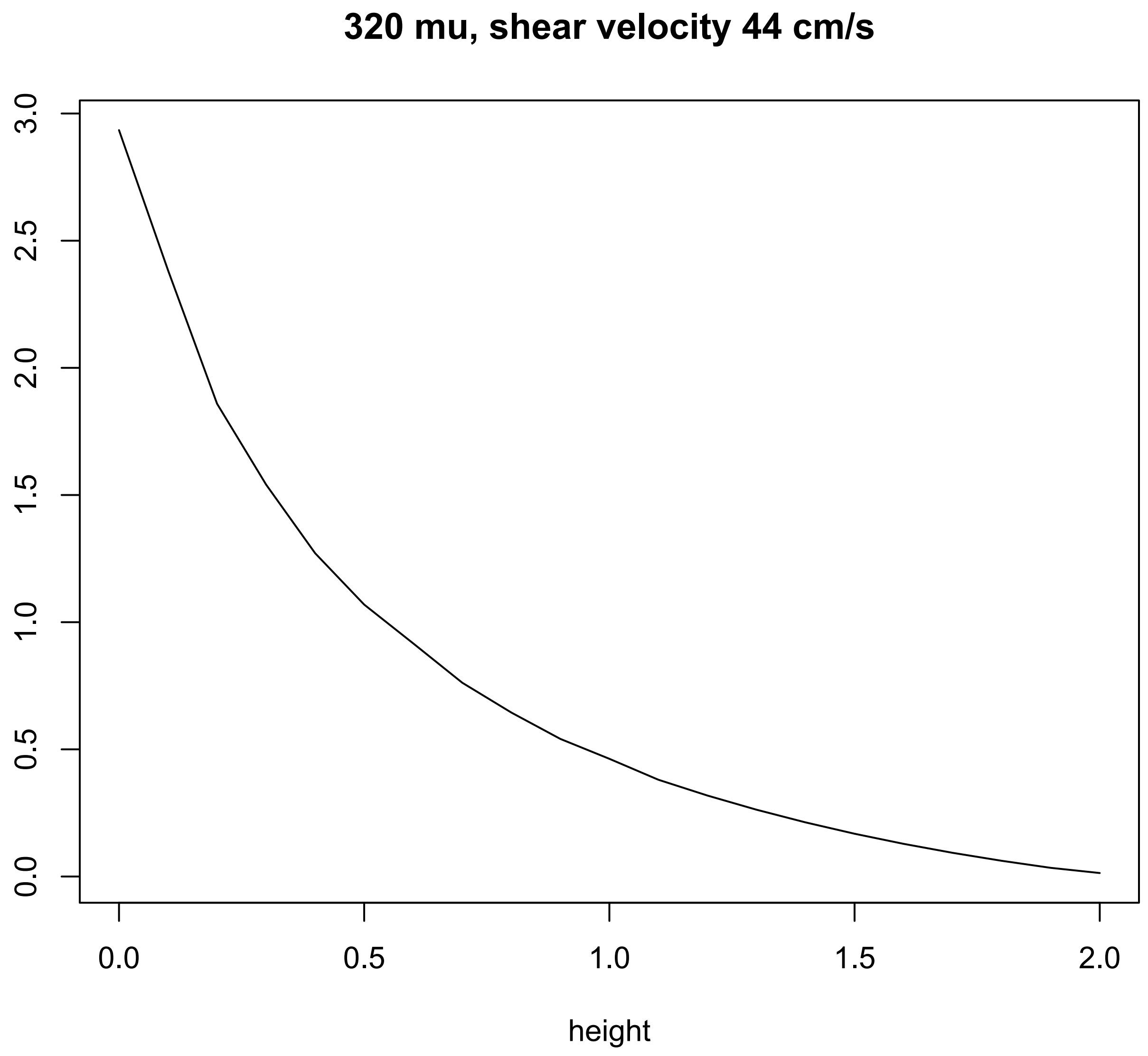
$$\begin{aligned} \rho U_*^2 &= \text{AIR BORNE SHEAR STRESS + GRAIN BORNE SHEAR STRESS} \\ &= T_a(y) + T_g(y) \end{aligned}$$

U_* shear velocity in the grain free wind, ρ density of air

Grain borne shear stress at height y: $T_g(y) = \Phi v(y)$

$v(y)$ = the average increase of the horizontal velocity component of a saltating grain while it is above the level y

Grain borne shear stress profile



Shear velocity at the bed