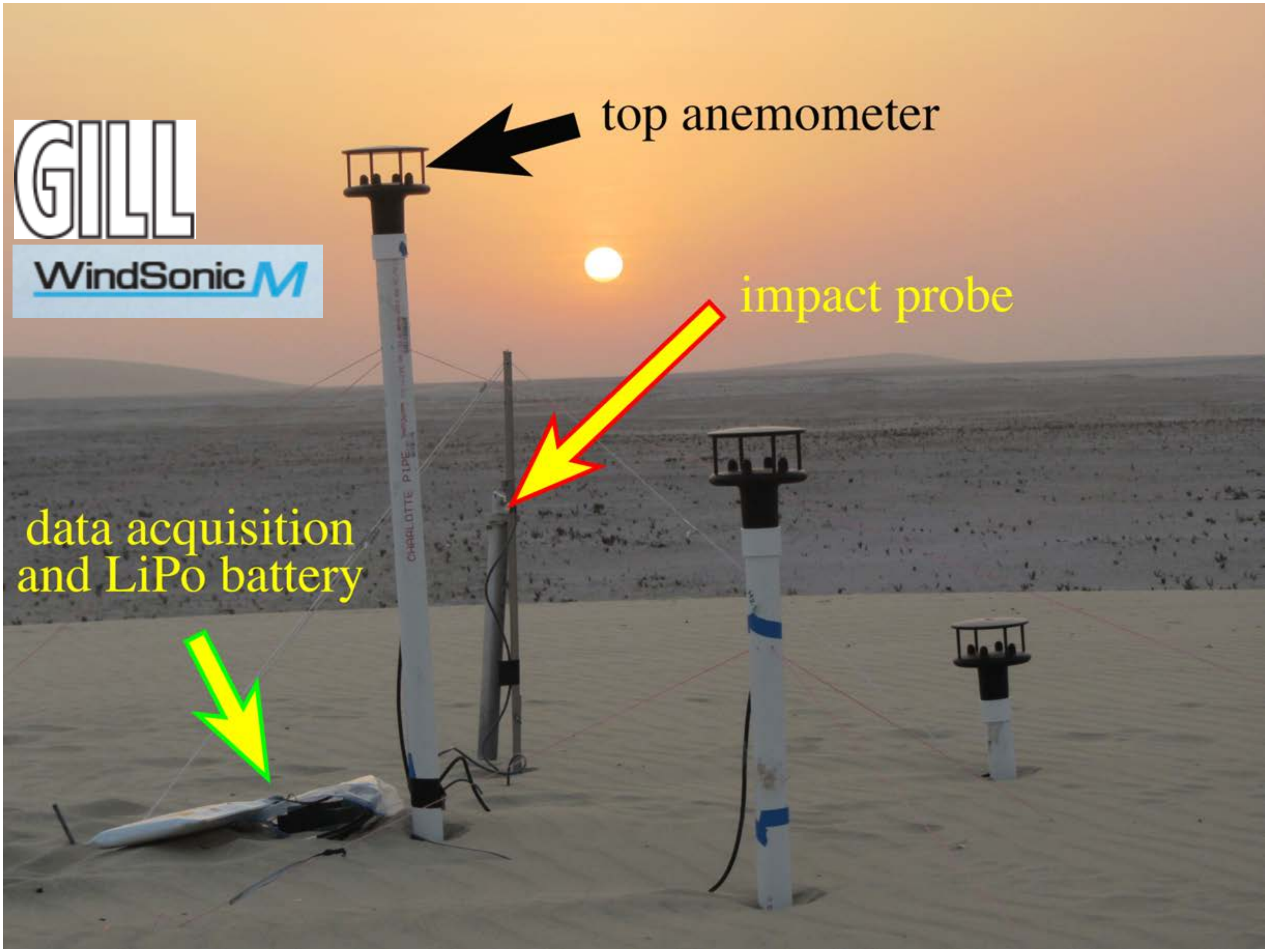
Anemometry on barchan sand dunes

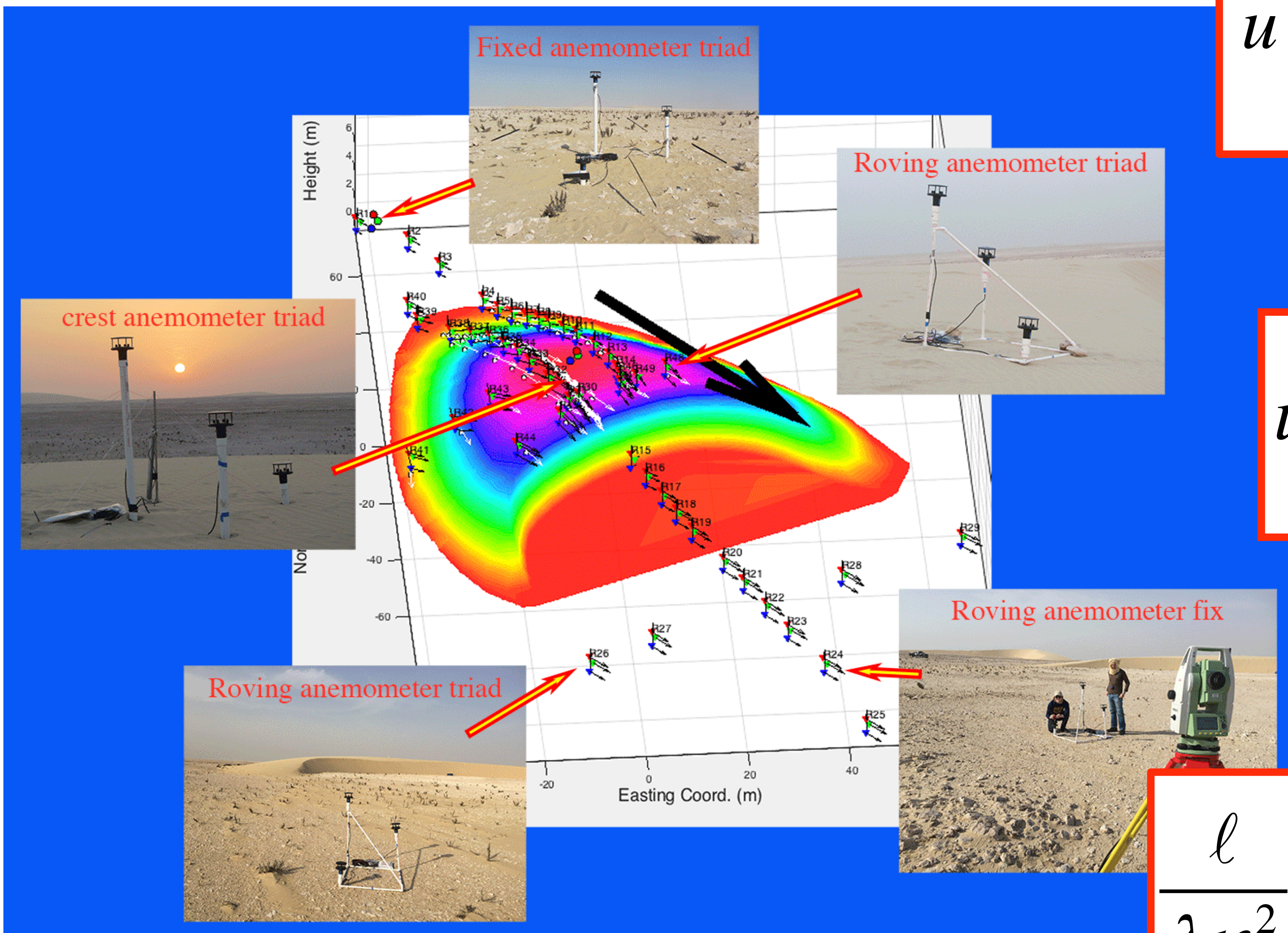
http://grainflowresearch.mae.cornell.edu

with *Renee Richer, Anthony Hay, Alexandre Valance, Ahmed Gueled, Patrick Chasle, Jin Xu, Jiannong Fang*

Wind and transport



Ultrasonic anemometers



turbulent core

$$u = \frac{u^*}{\kappa} \ln\left(\frac{z}{z_0}\right)$$

shear velocity

$$u^* = \sqrt{\frac{\tau}{\rho}}$$

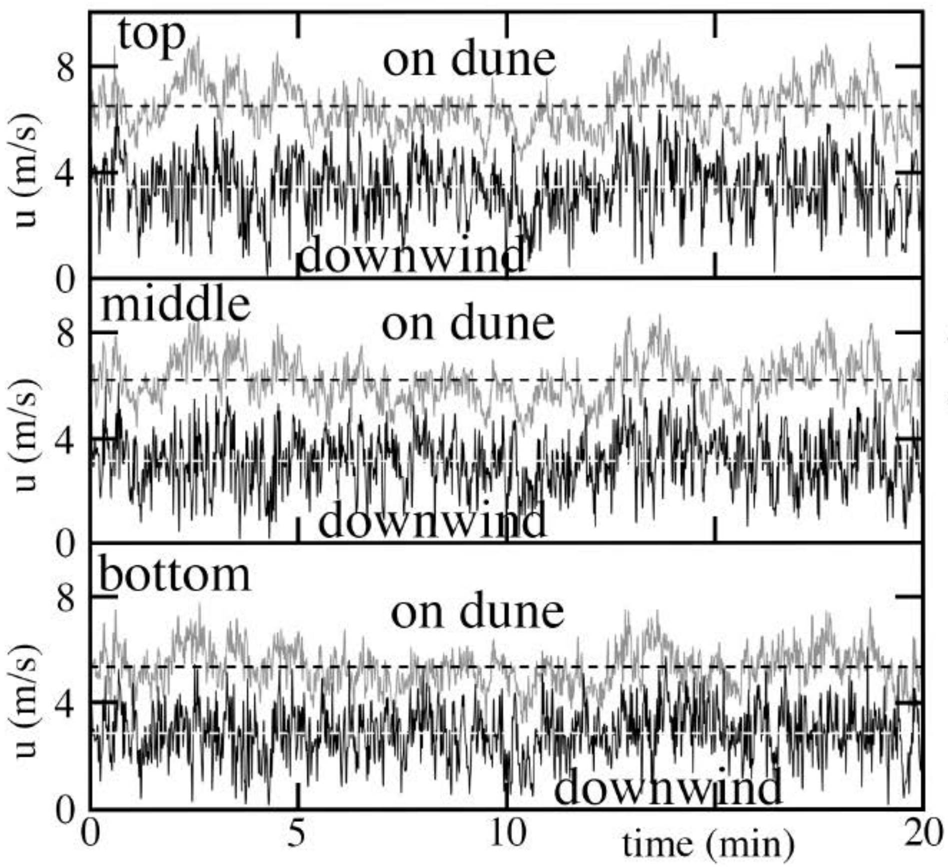
inertial inner layer thickness ℓ

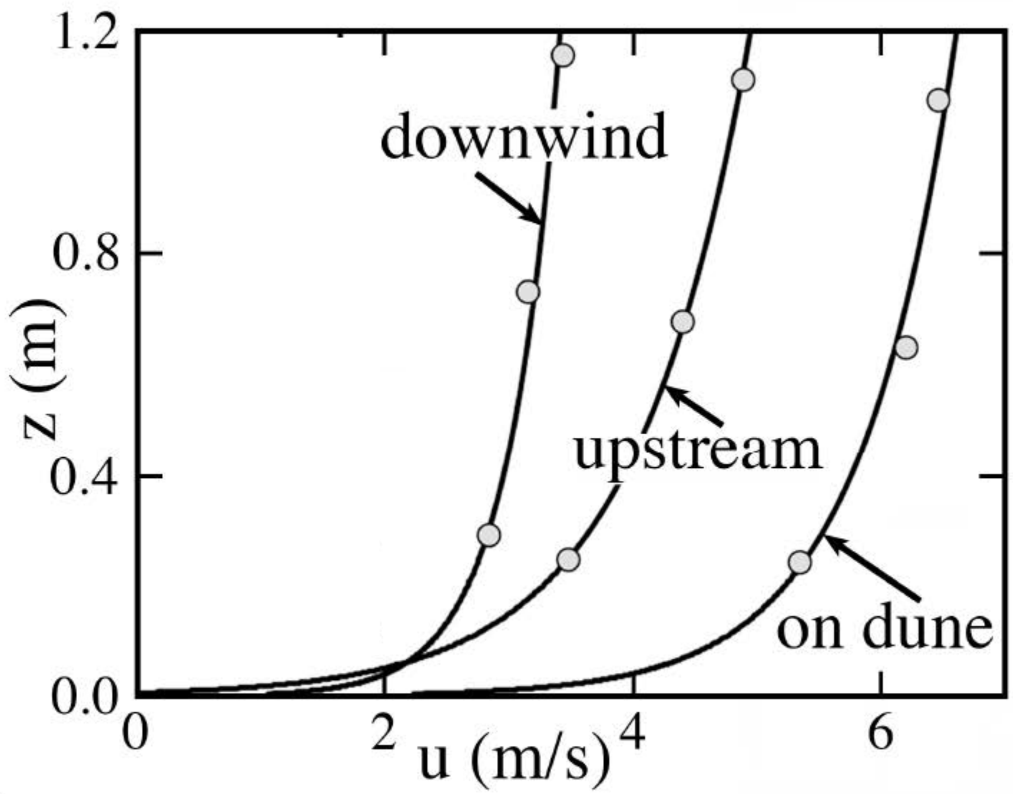
$$\frac{\ell}{\lambda \kappa^2} \ln^2\left(\frac{\ell}{z_0}\right) \sim o(1)$$

Claudin, Wiggs and Andreotti, Boundary-Layer Meteorol. (2013)

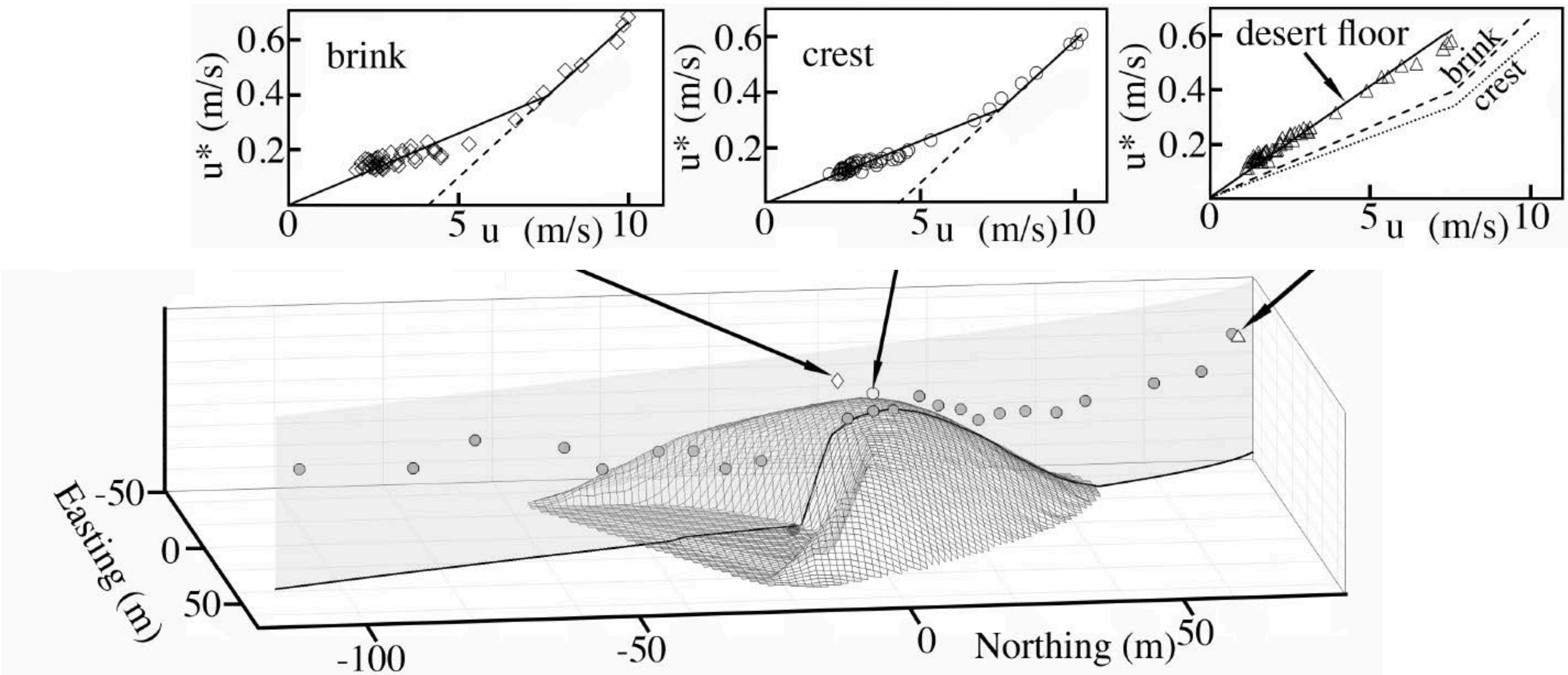
Log-law in the turbulent core

$$u = \frac{u^*}{\kappa} \ln\left(\frac{z}{z_0}\right)$$





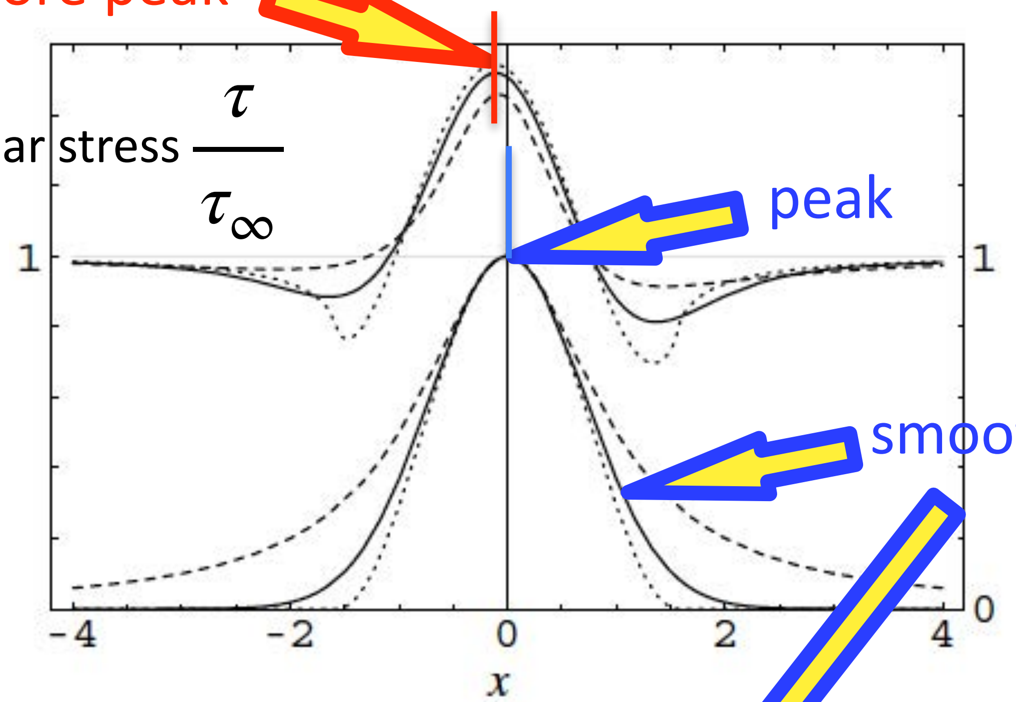
long-term records showing
the Bagnold transition to transport

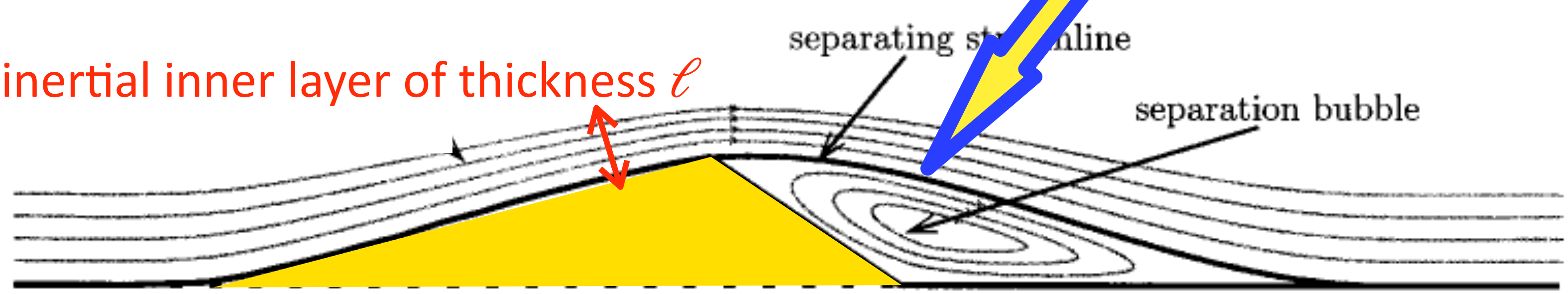


Surface shear stress

The conventional view of longitudinal shear stress profiles

Jackson & Hunt (1975)
max shear stress before peak





Kroy, Sauermann and Herrmann, PRE 66 & PRL 88 (2002)

Jackson & Hunt (1975) theory

Kroy, Sauermann and Herrmann, PRL 88 (2002)

Excursion in shear stress

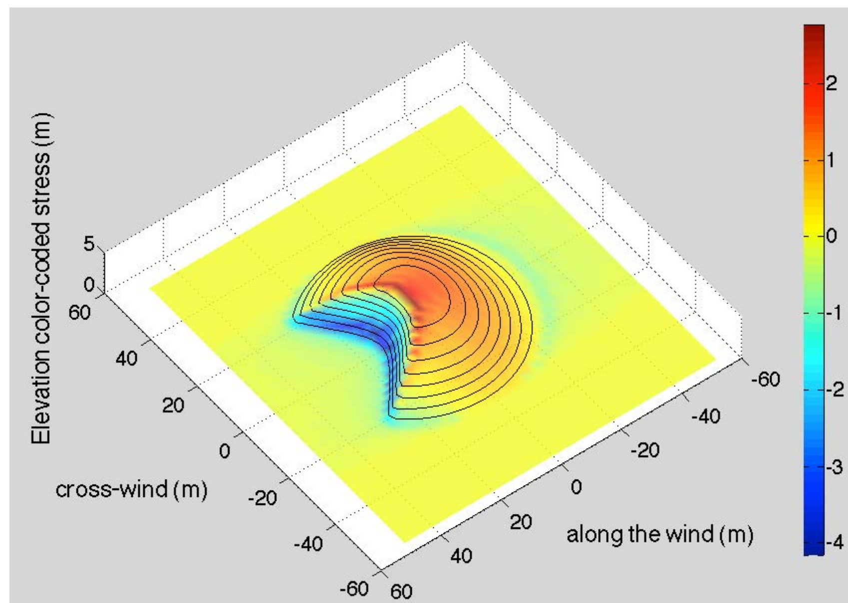
$$\frac{\hat{\tau}}{\rho u^{*2}} = B\ h'(x) + A\int_{-\infty}^{+\infty} h'(x-\xi)\frac{\mathrm{d}\xi}{\pi\xi}$$

Fourier transform

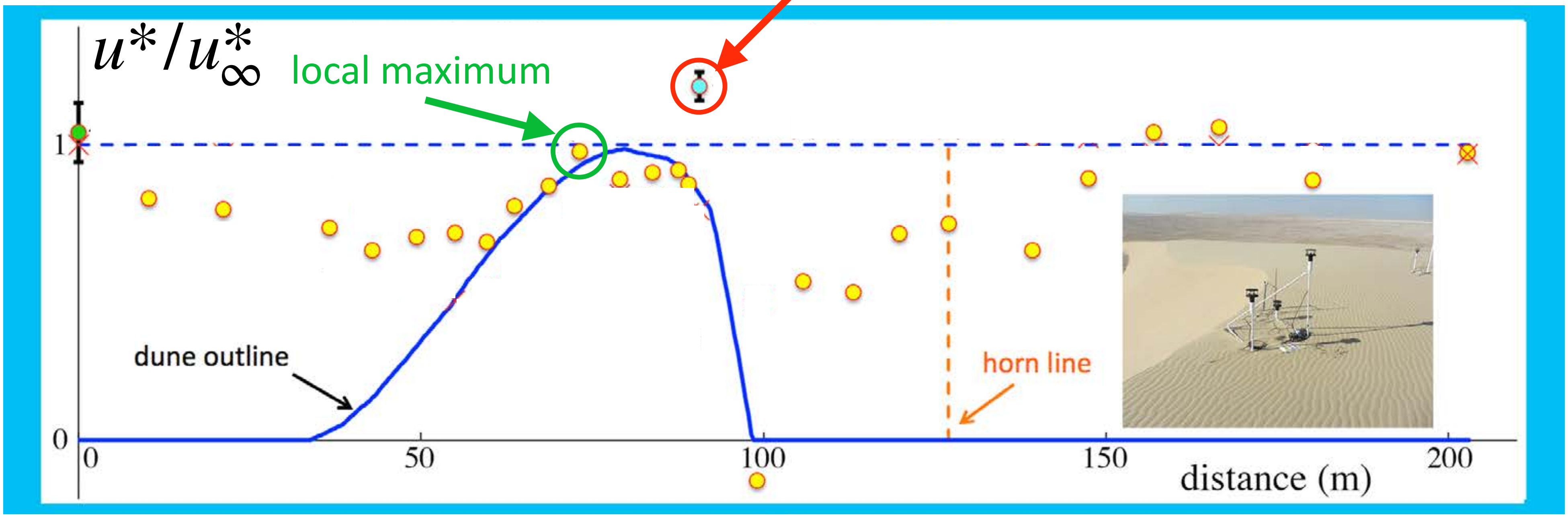
$$\frac{\bar{\hat{\tau}}}{\rho u^{*2}} = \frac{Ak_x^2 + iBk_x\left|k_x\right|}{\sqrt{k_x^2 + k_y^2}}\bar{h}$$

Dune surface elevation $h(x, y)$

A and *B* are functions of $\frac{\lambda_x}{z_0} = \frac{2\pi}{k_x z_0}$

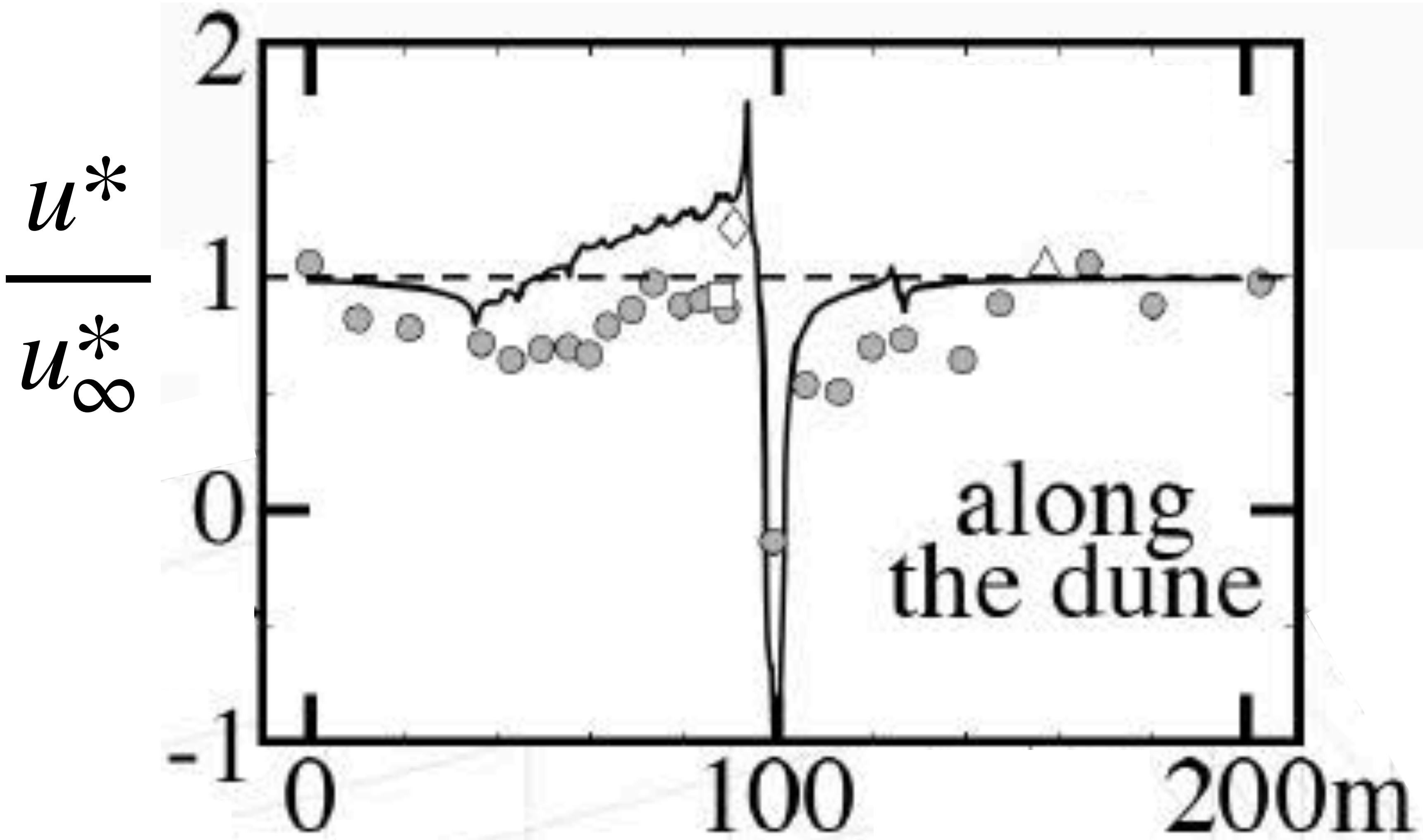


Anomalous peak of shear velocity at the brink

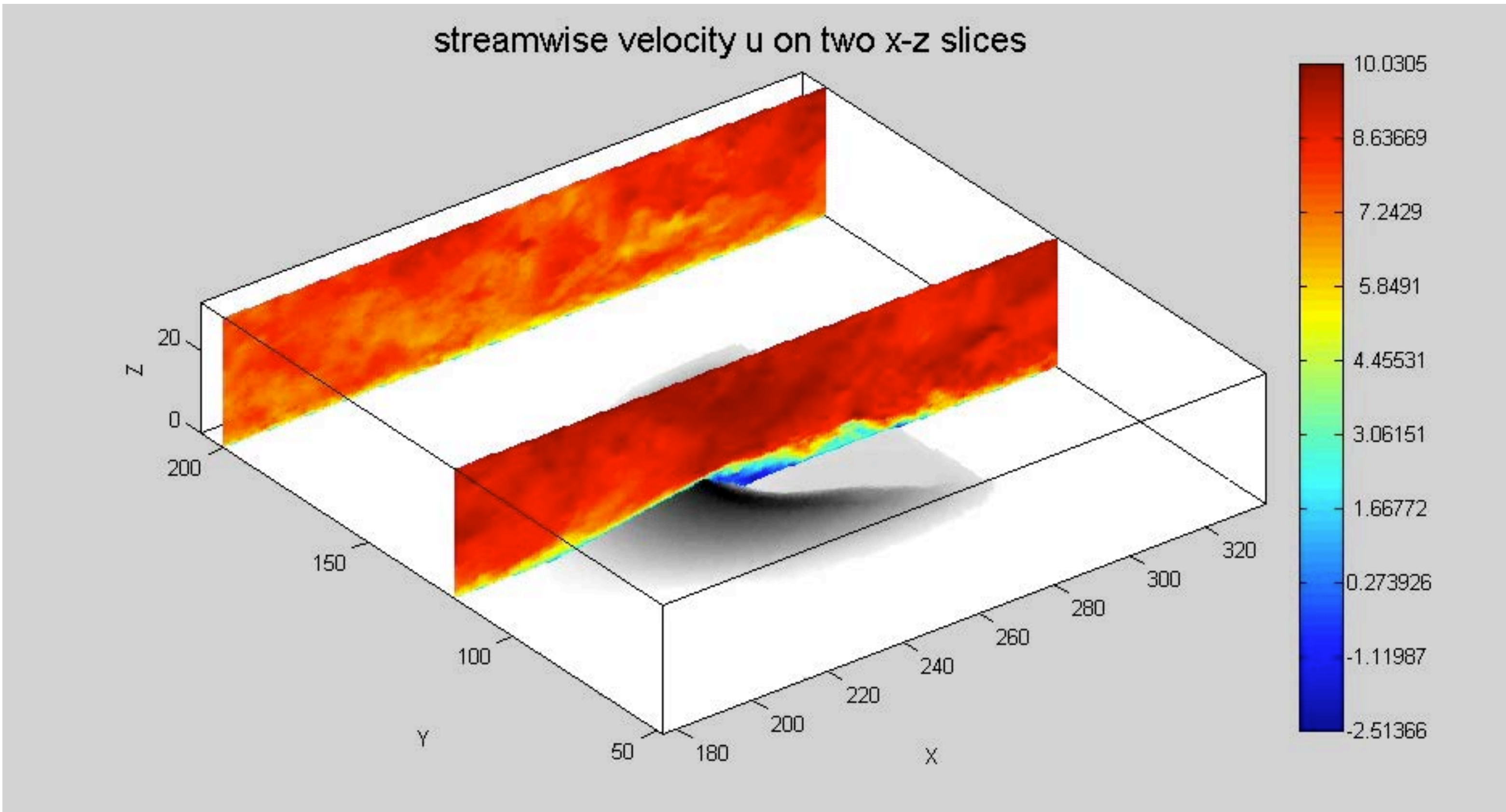


shear velocity $\boxed{u^* = \sqrt{\frac{\tau}{\rho}}}$

Jackson & Hunt captures u^* evolution qualitatively



Large-eddy simulations (LES)

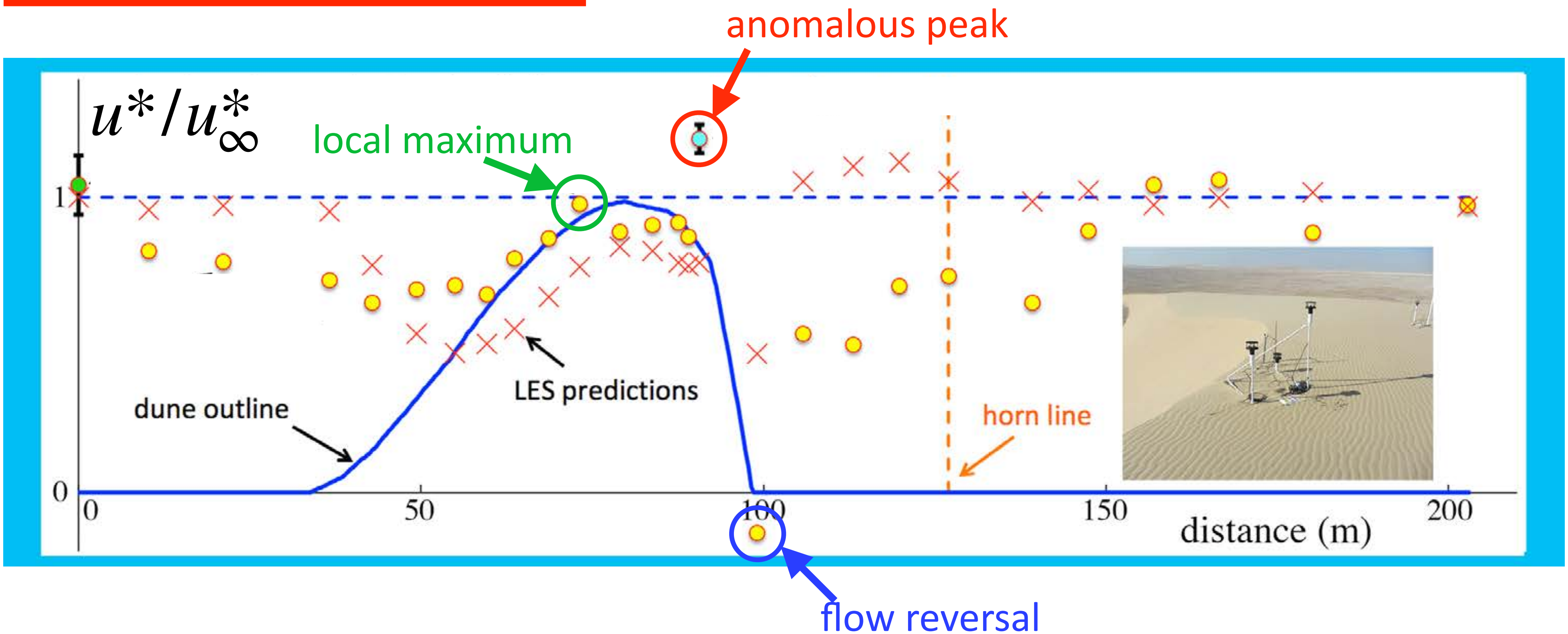


ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Jiannong Fang and Fernando Porte-Agel

LES predictions

LES capture the general trend in u^*/u^*_∞ , but …

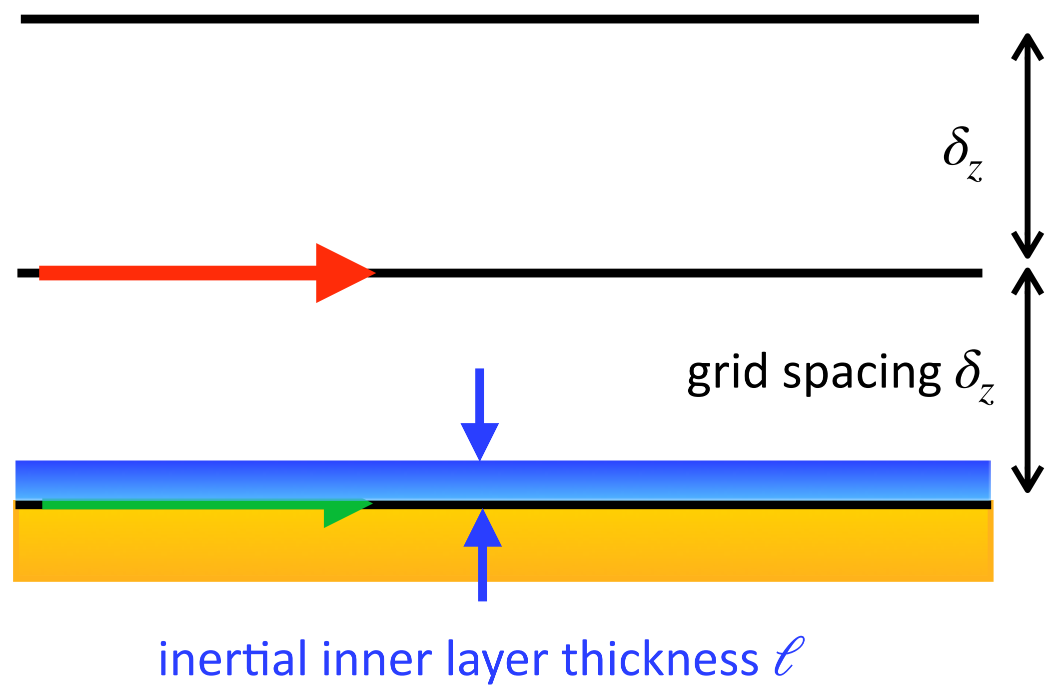


- they do not have a local maximum ahead of the crest, as predicted by Jackson & Hunt;
- they have no anomalous u^* at the brink;
- they return to upstream u^*_∞ ahead of the line joining the dune horns;
- they do not have a significant flow reversal behind the avalanche face.

LES surface boundary condition

at first grid point, $u(z = \delta_z) = \frac{u^*}{\kappa} \ln\left(\frac{\delta_z}{z_0}\right)$

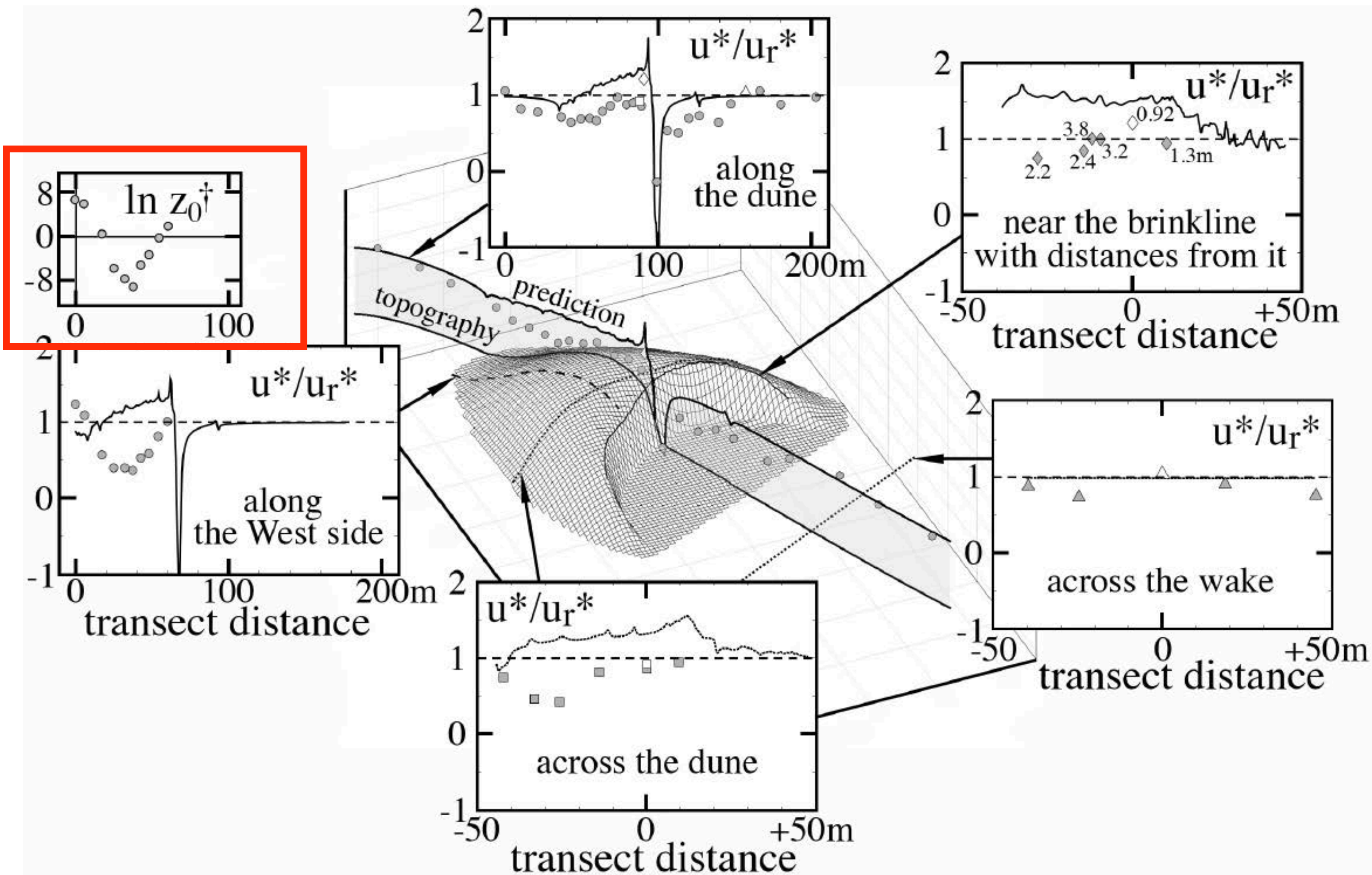
surface shear stress $\tau_0 = \rho u^{*2}$



issues
- $\ln z_0$ varies on dune
- inner layer not resolved

could one use the Jackson & Hunt BC instead?

$\ln z_0$ can be $\ll \ln(d/30)$

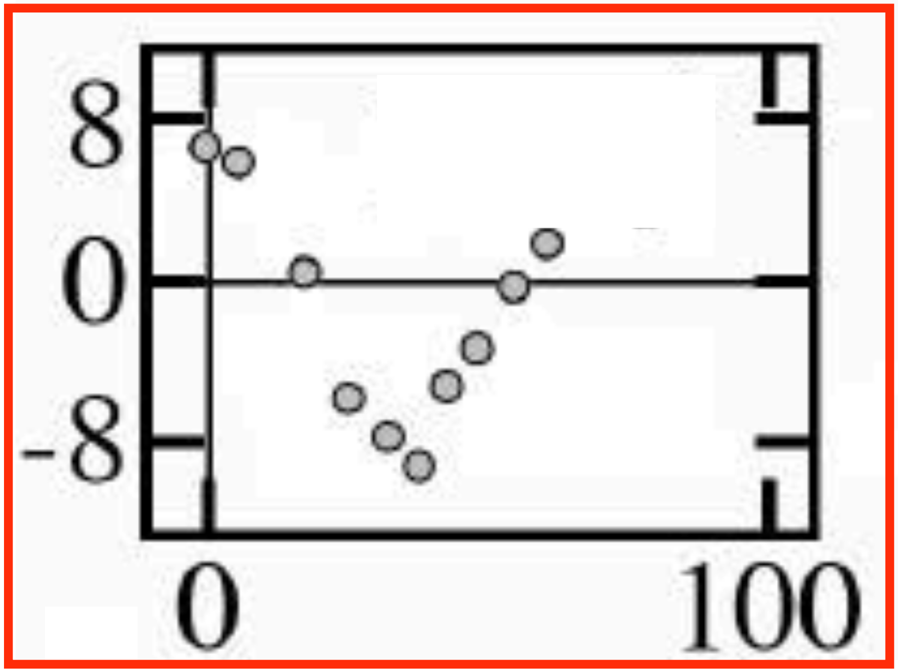


$$\ln z_0 \text{ can be } \ll \ln(d/30)$$

Nikuradse (1931) measurements in a roughened pipe suggest that $d/30$ is the minimum value of z_0

BUT

$$\ln\left(\frac{z_0}{d/30}\right)$$



distance along transect (m)

Conclusions

u^* (and $\ln z_0$) evolve on topography

Jackson & Hunt captures trends qualitatively

there is an anomalous peak of u^* at the brink

Bagnold's focal point predicts transport transitions in u^* and $\ln z_0$

LES boundary conditions need repair