Bed protection and turbulence

Addition to chapter 3
Based on work of Hofland and Hoan

ct4310 Bed, Bank and Shoreline protection

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Problem

$$\Psi = \frac{u_*^{\,2}}{\Delta g D_{n50}} = \frac{\text{load } (= {}^1/_2 C_D r\, A u^2)}{\text{strength } (= (r - r_s)\, gV)}$$

$\Psi \geq \Psi_c$: damage / entrainment

- Influence of turbulence?

$$\Psi = \frac{u_*^{\,2}}{\Delta g D_{n50}}$$

← include turbulence

Very basic general equation

$$\Psi = \frac{(\bar{u} + u')^2 + A(\bar{a} + a')}{\Delta g D_n}$$

$$u' = ru \quad ???$$

$$r = \frac{\sigma(u)}{\langle \bar{u} \rangle}$$

Problem

Now, either:

- $u_{\text{new}} = K\,u$

or:

- $u_{\text{new}} = u\,(1+r)$

$$r = \frac{\sigma(u)}{\langle \bar{u} \rangle}$$

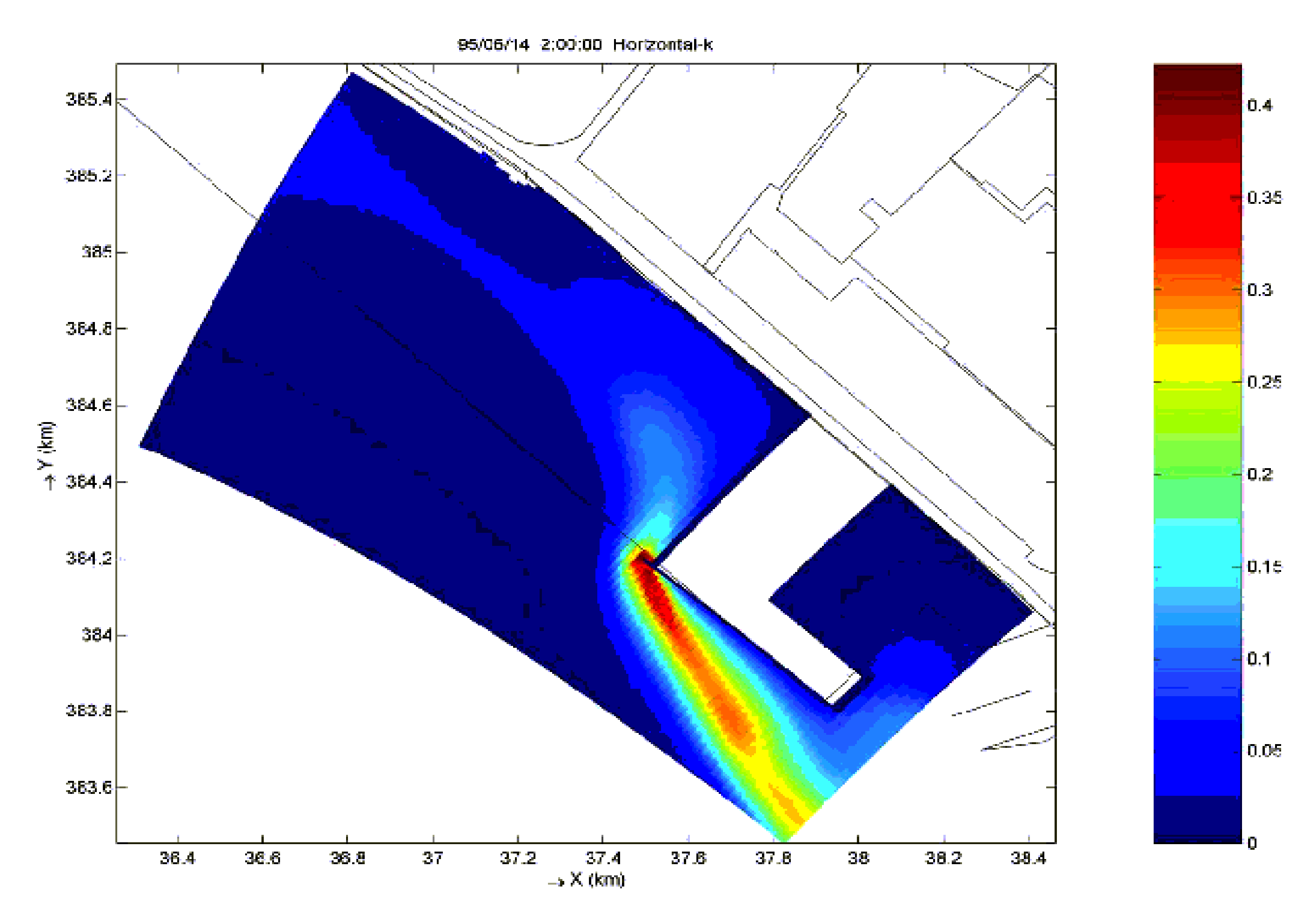
Problem

In the K-factors several influences can be present:

- different mean flow (vertical profile)
- different turbulence intensity
- different shape of prob. density function
- pressure gradients
- different stones
- etc.

This causes problems when new configurations are studied, for instance the Westerschelde Container Terminal

Problem - Westerschelde container terminal



(Bekker, 2003)

Aim

The exact influence of turbulence on stone stability is unknown, so the aim is to:

1) Investigate the influence of (non-equilibrium) turbulence on stone entrainment under stationary flows.

2) Find a way of introducing this into a design method

Approach

Precise measurements of:

– pressures on a (single) stone,

– the flow velocity around the stone, and

– the initial movement of the stone.

Problem

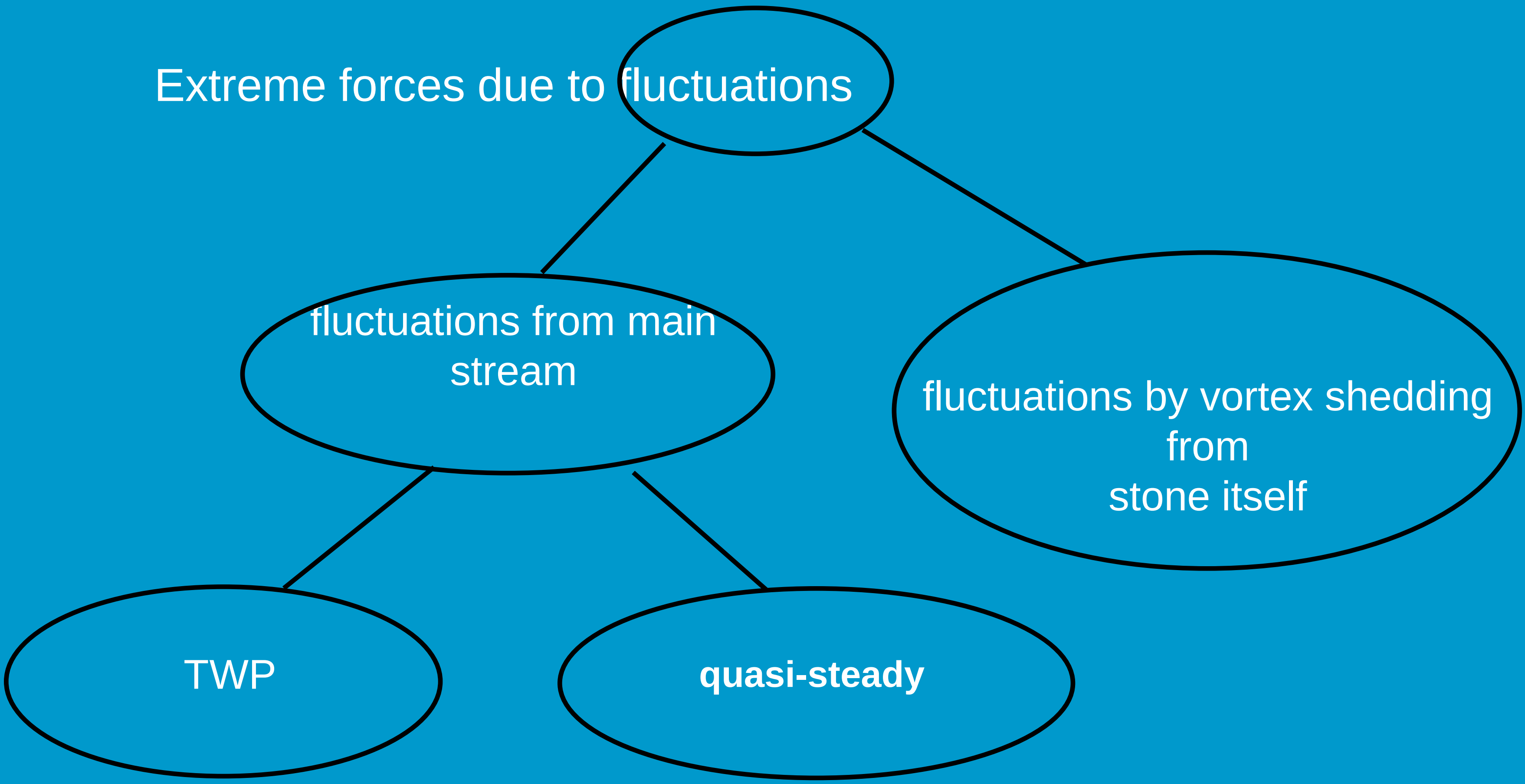
"The differences in protrusion of grains in a bed and, more in general the differences between the size and the shape in a natural material make an analytical approach of stone stability a dead end."

(Schiereck, 2001)

Hydraulic forces on a stone

- Drag $(\rho\, A\, u^2)$
- Lift $(\rho\, V\, u\, \mathrm{d}u/\mathrm{d}z)$
- Added mass $(\rho\, \mathrm{d}u/\mathrm{d}t)$
- Pressure gradient $(\rho\, \mathrm{D}u/\mathrm{D}t)$

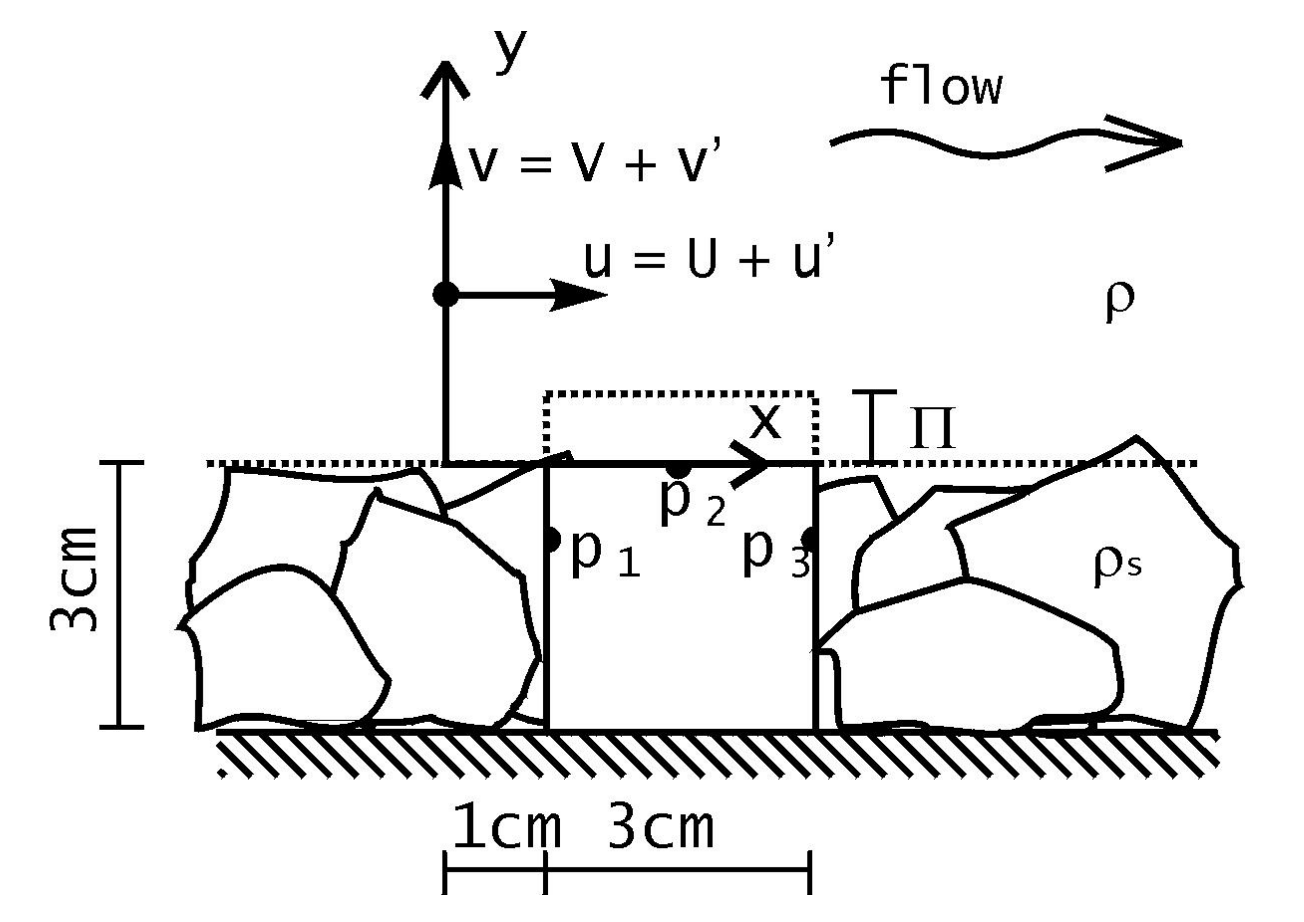
Hydraulic forces on a stone



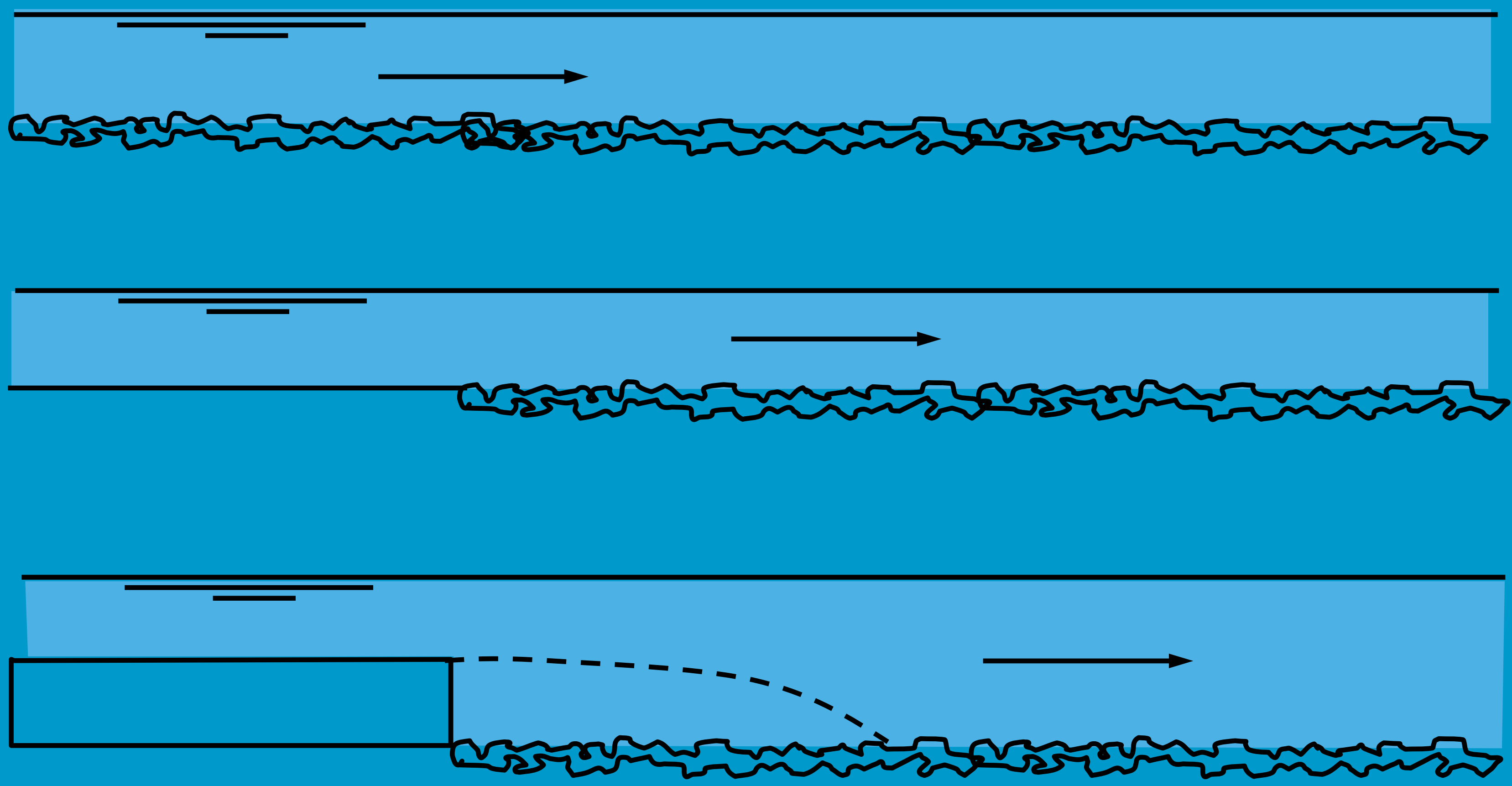
First measurements

$$D \approx p_1 - p_3$$

$$L \approx -p_2$$



Turbulence structure

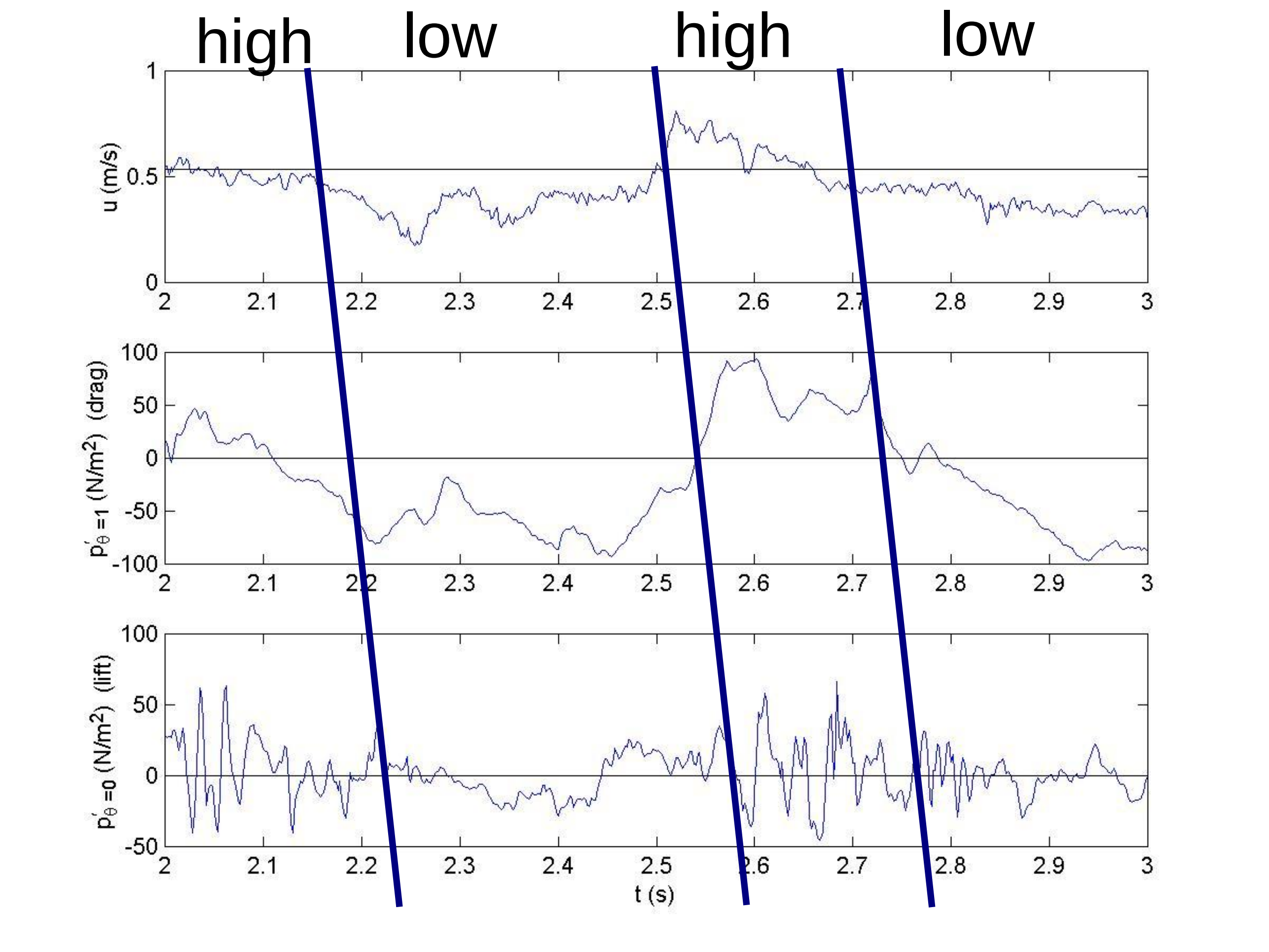


Vortex shedding ?

u

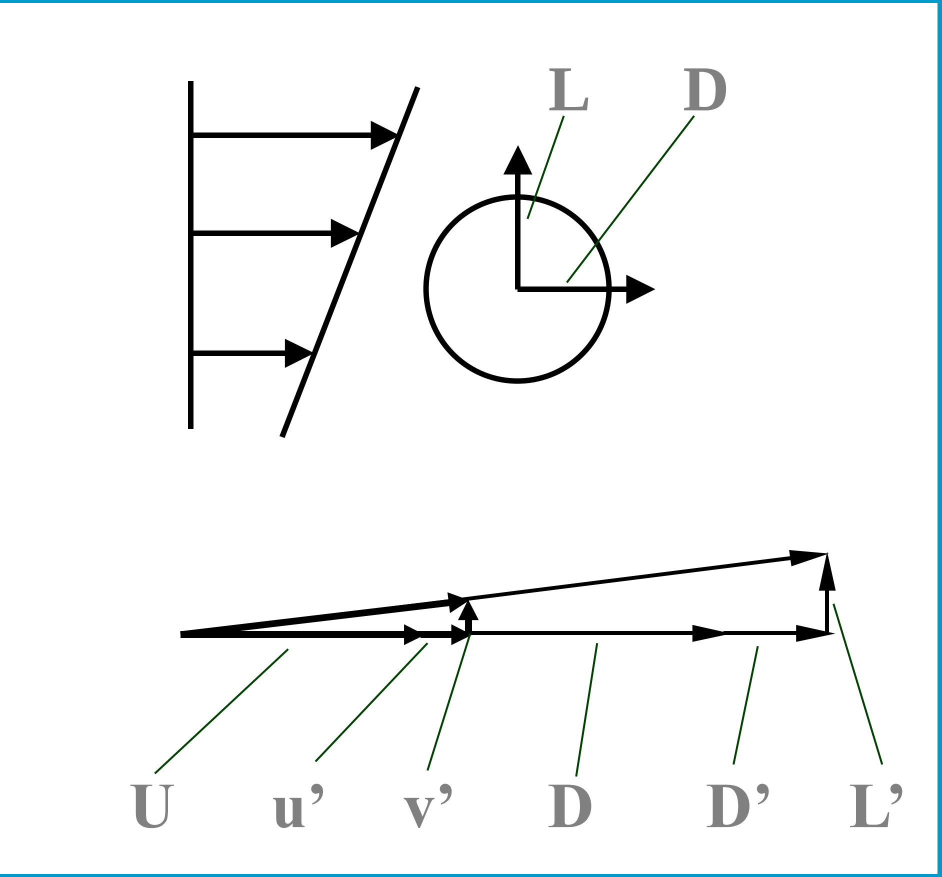
Drag

Lift

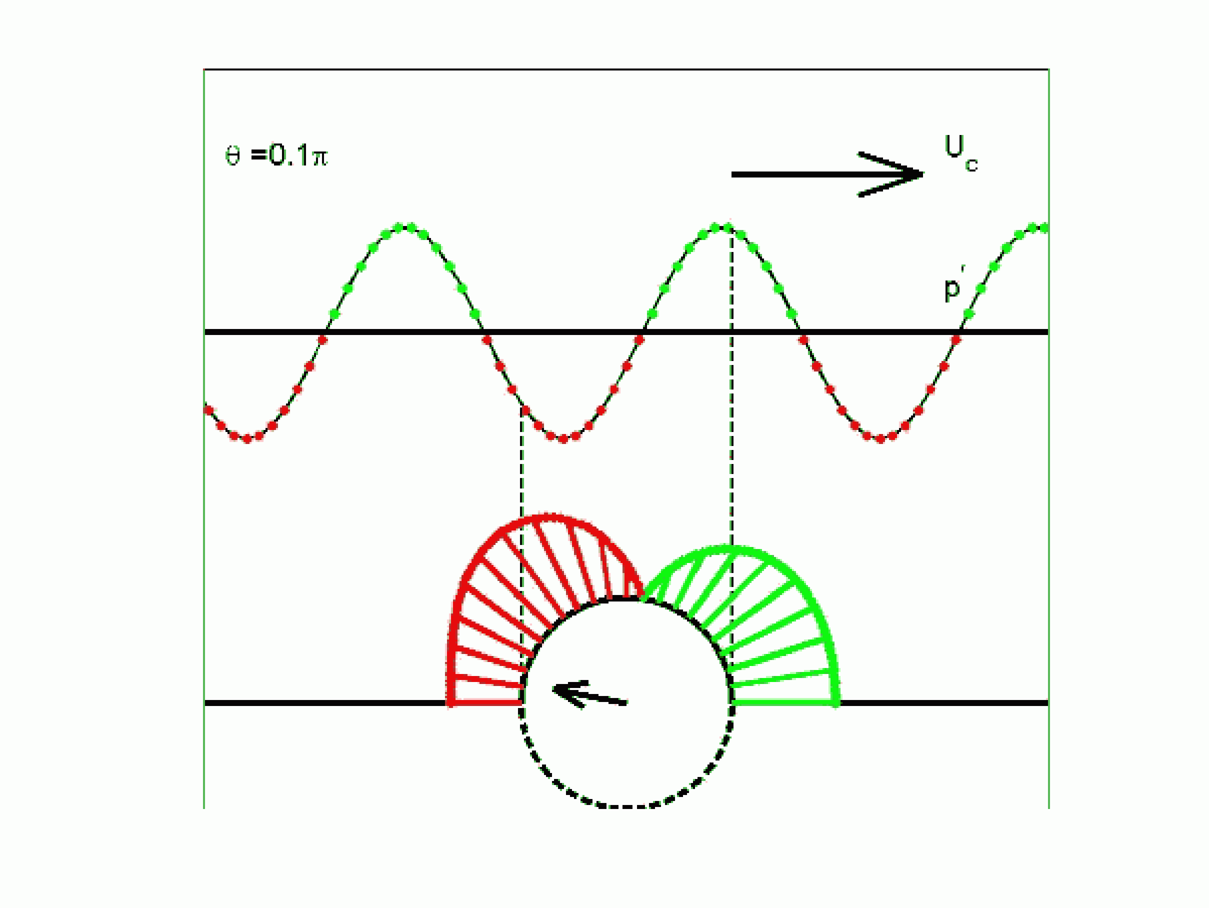


Quasi-steady forces

- *Drag*: $F_D' \propto Uu'$
- *Lift*: $F_L' \propto aUu' + bUv'$



Turbulent Wall Pressures

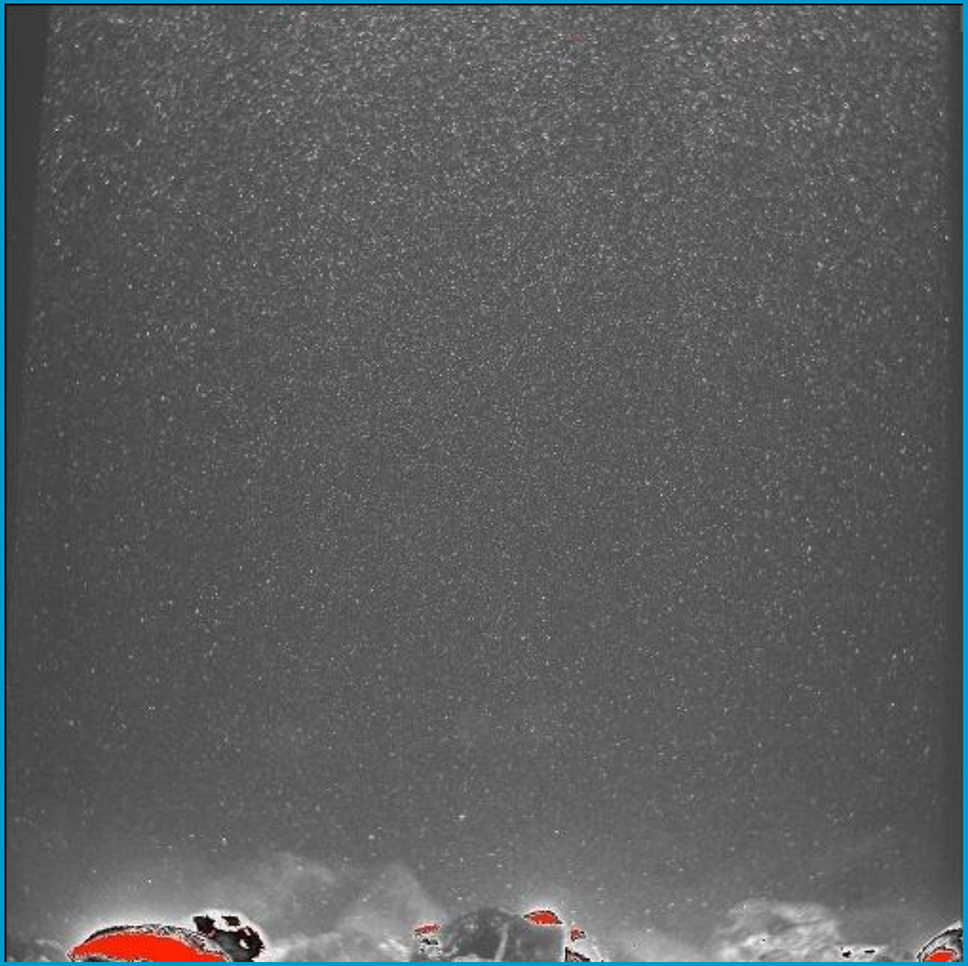


Aim PIV

- Visualize spatial structures in the flow
  - Origin of movement

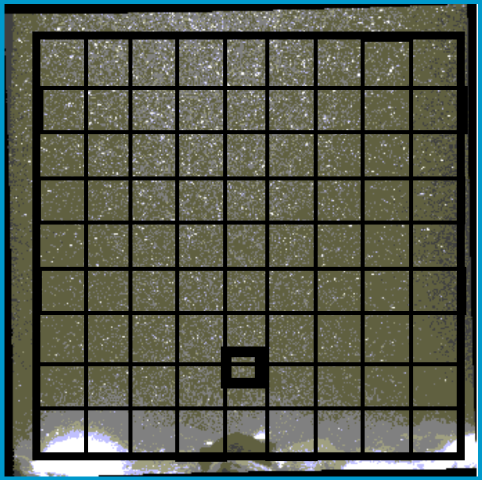
- Multiple simultaneous measurements

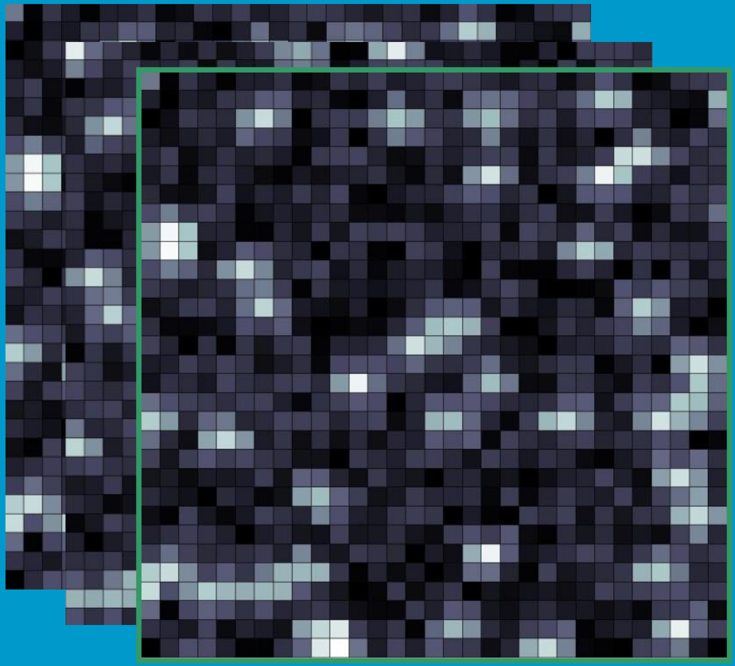
Particle Image Velocimetry

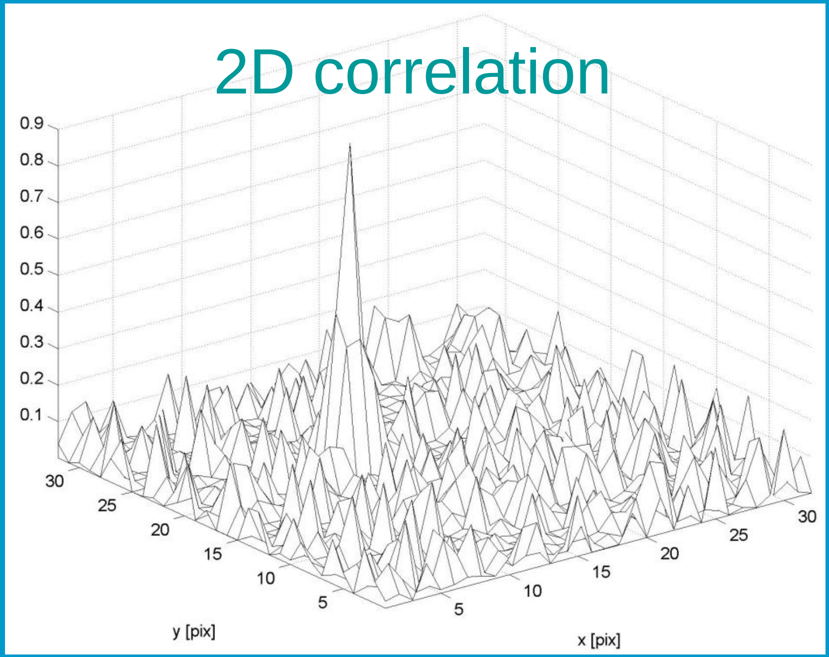


2e frame

PIV



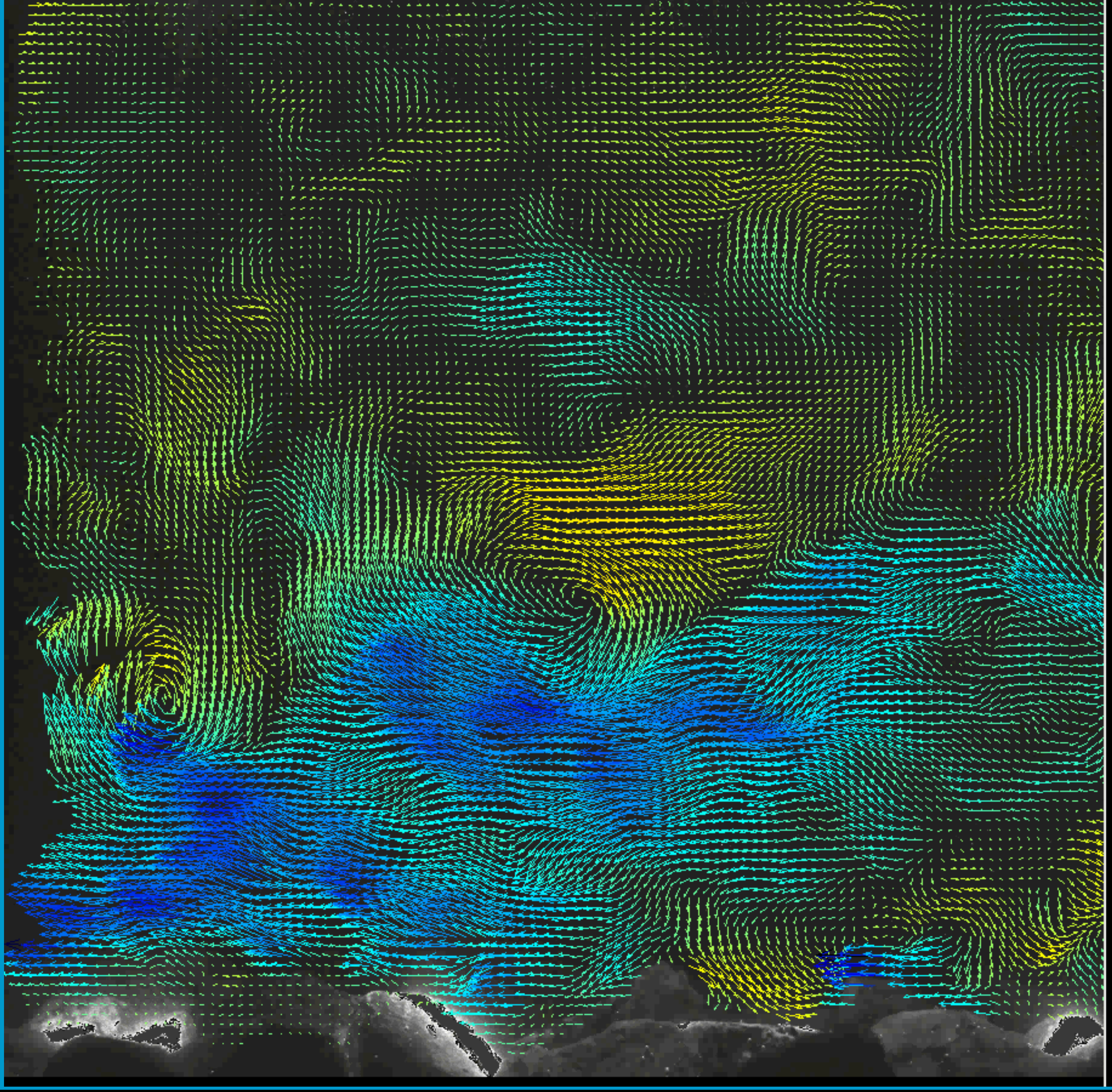




2D correlation
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
30
25
20
15
10
5
y [pix]
5
10
15
20
25
30
x [pix]

Output

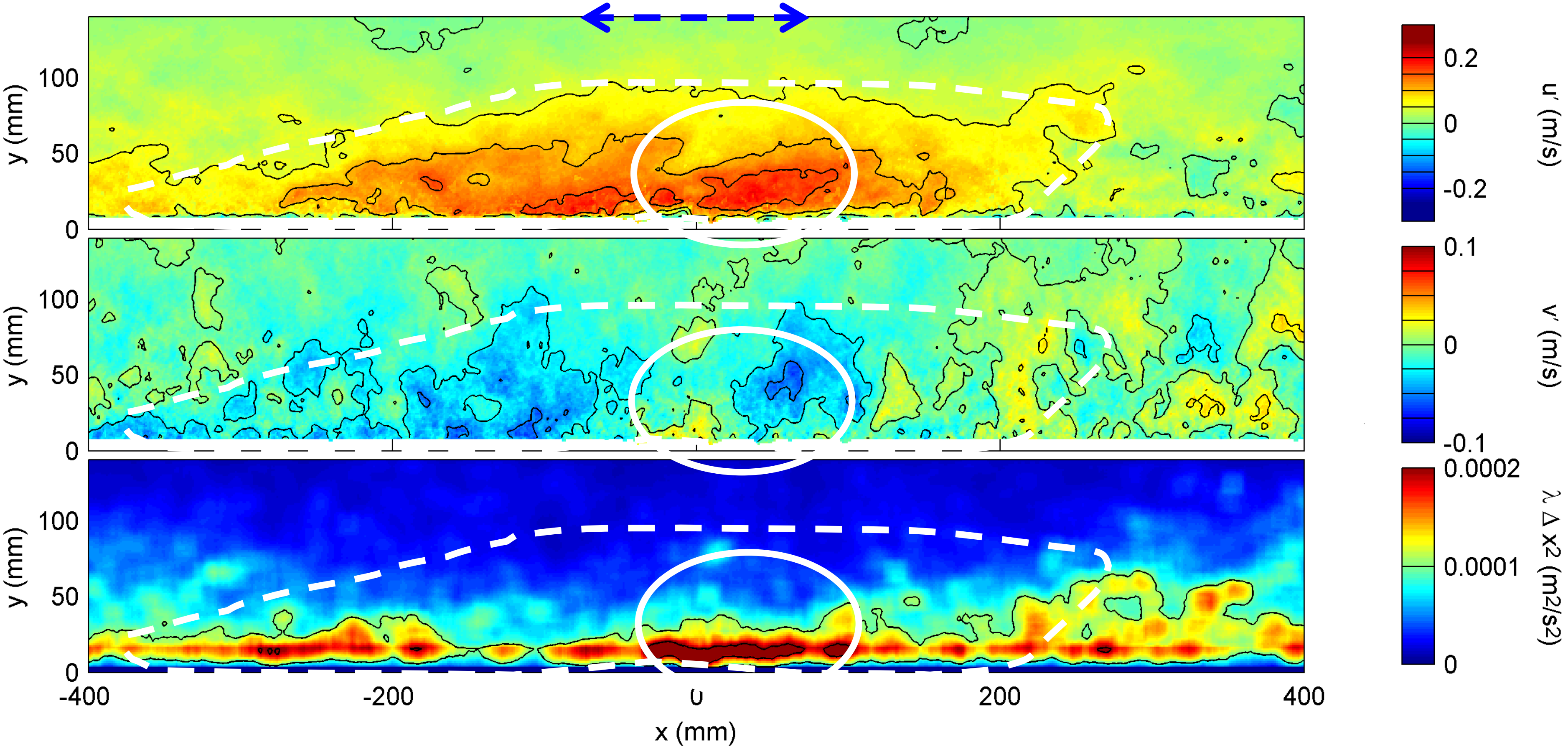
PIV-software



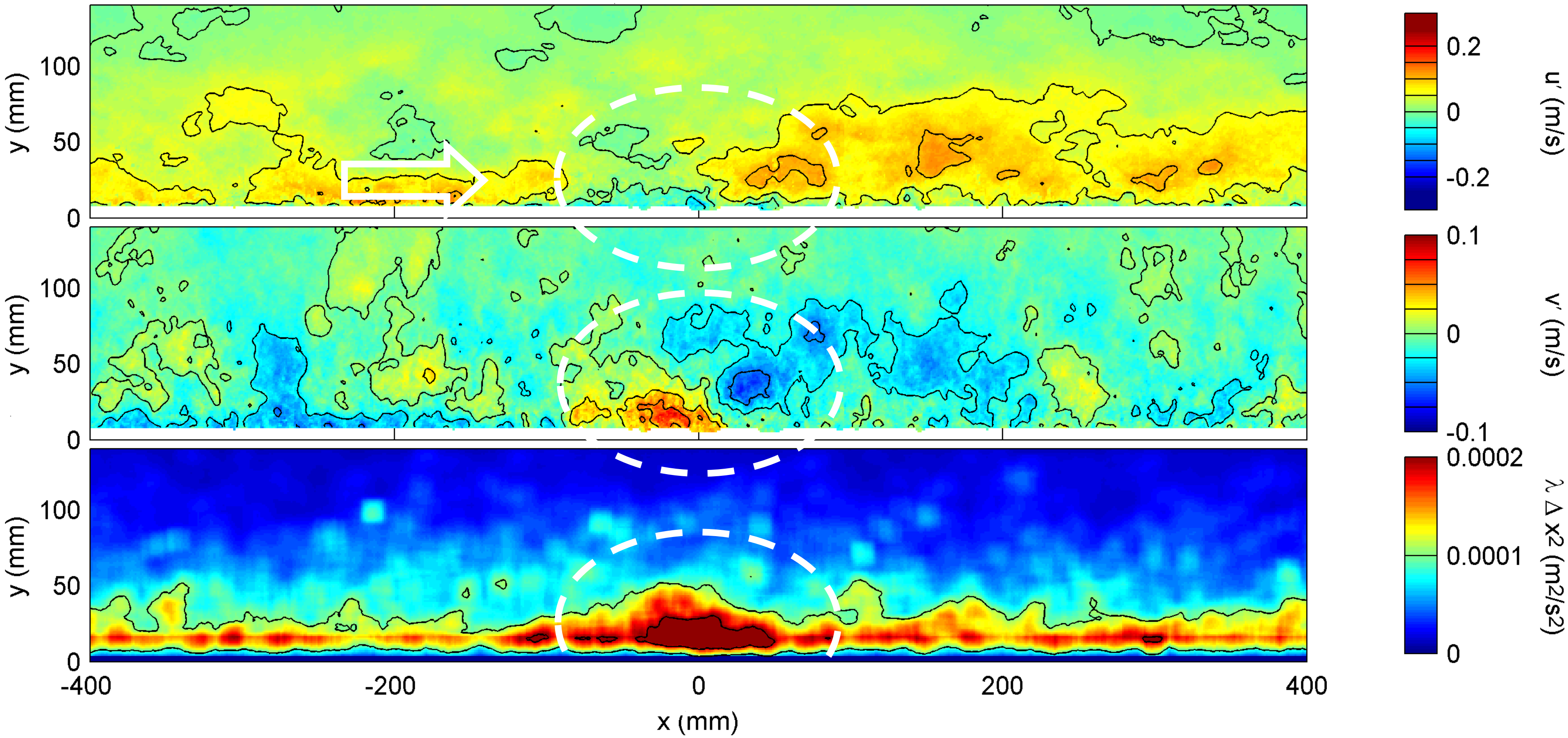
3 2 1

t x

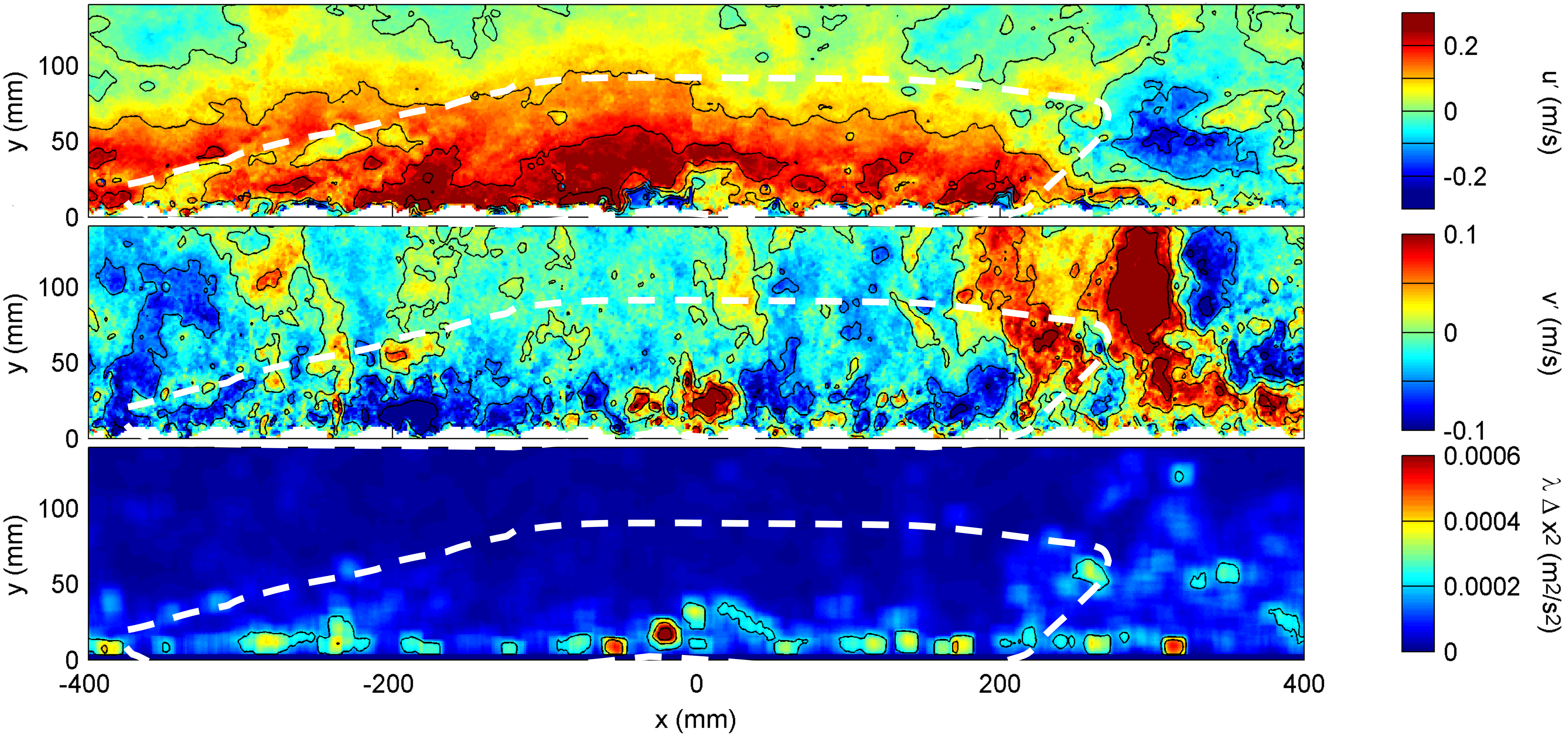
Sweep - conditional average



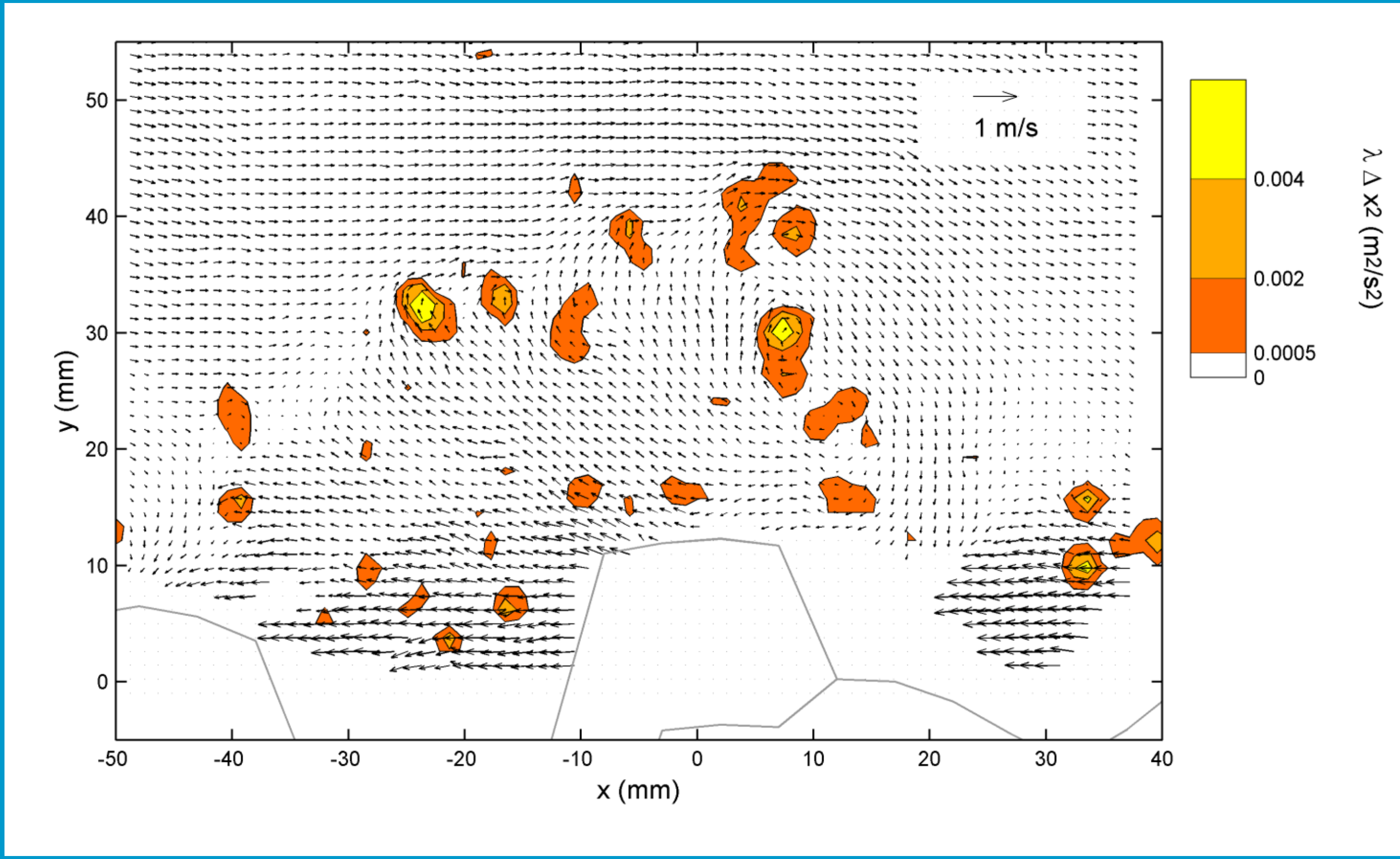
TWP - conditional average



Instantaneous - sweep



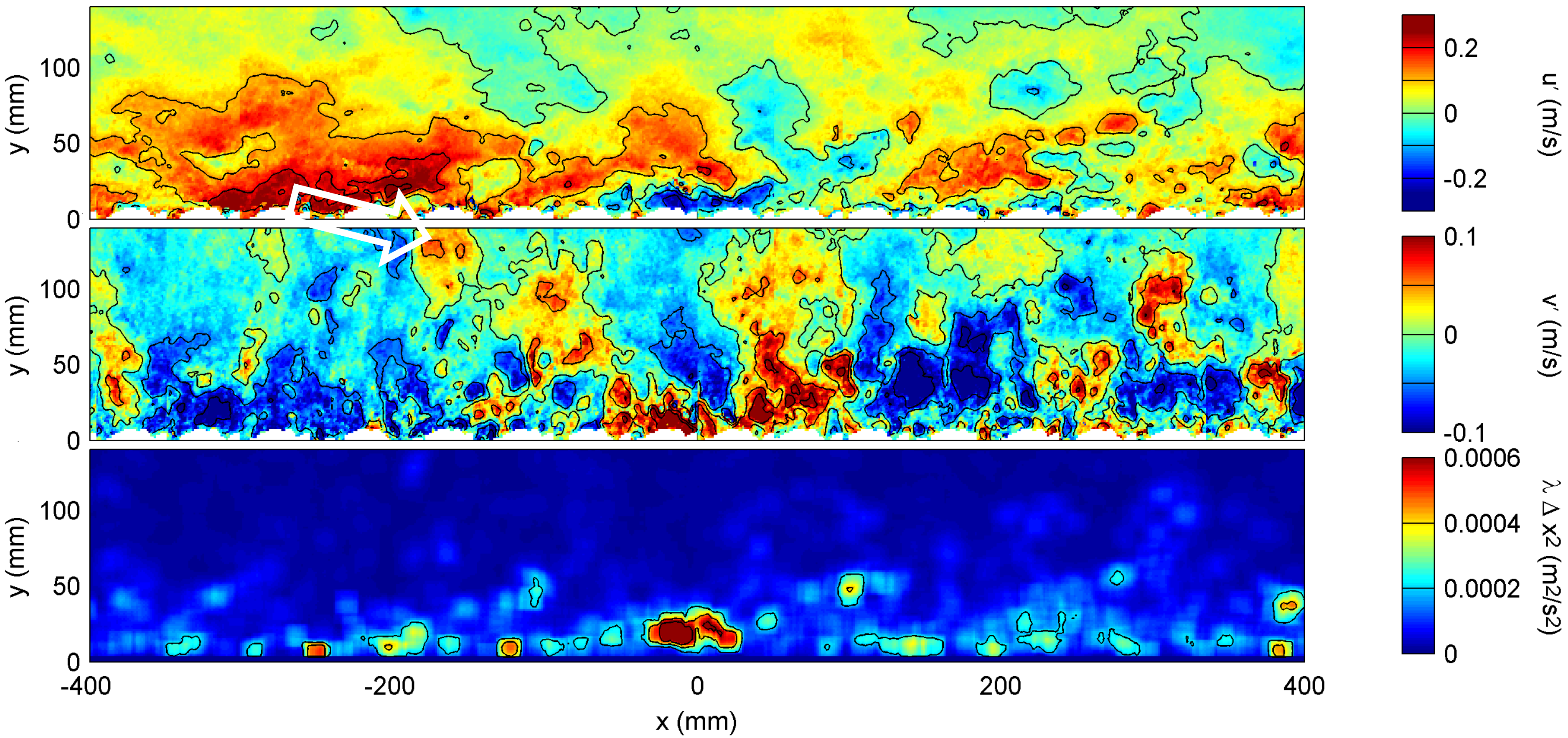
Instantaneous - sweep - detail



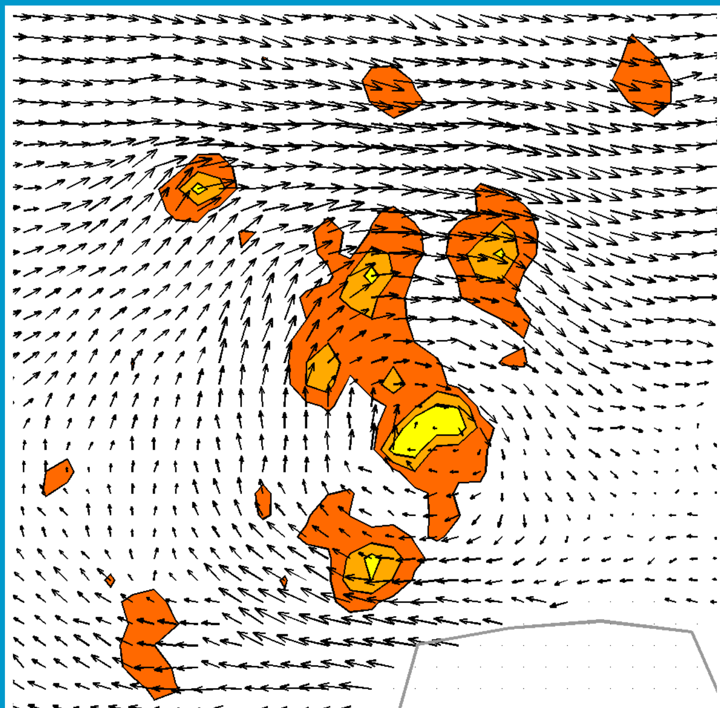
vectors:

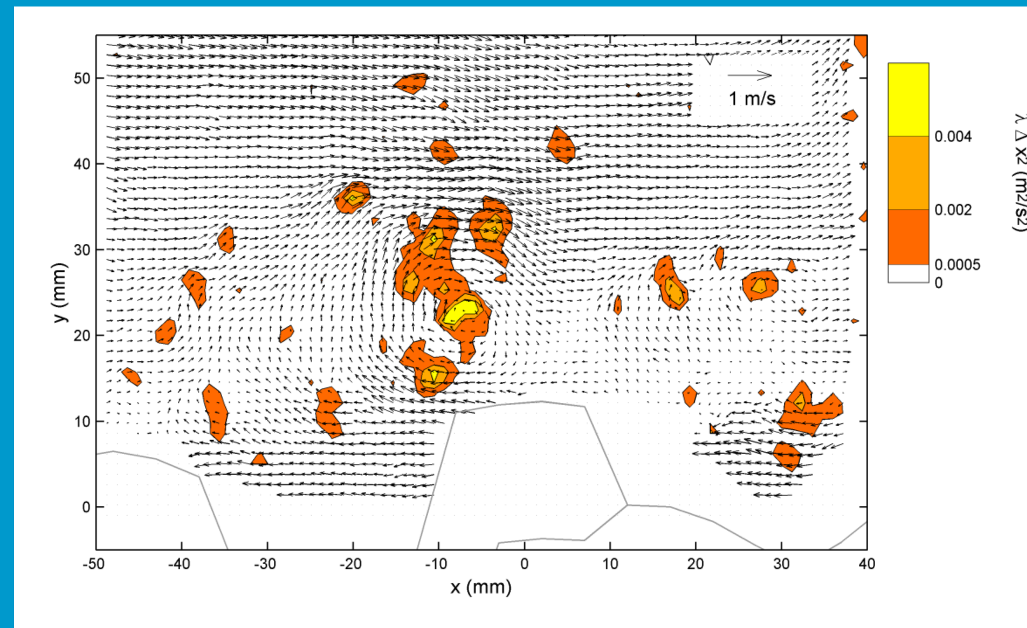
u*-1.0*U

Instantaneous - Turbulent Wall Pressures



Instantaneous - Turbulent Wall Pressures - detail



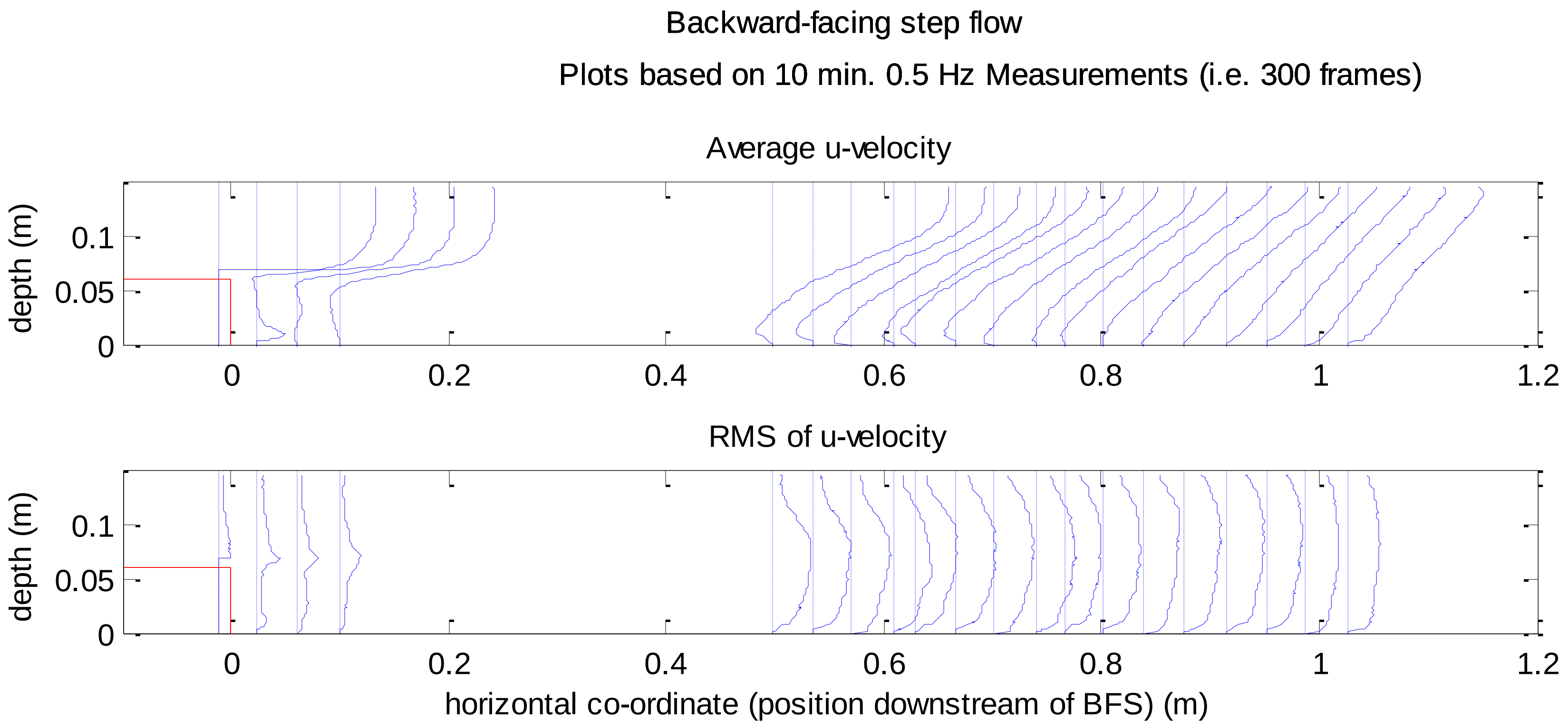


vectors:

u*-0.65*U

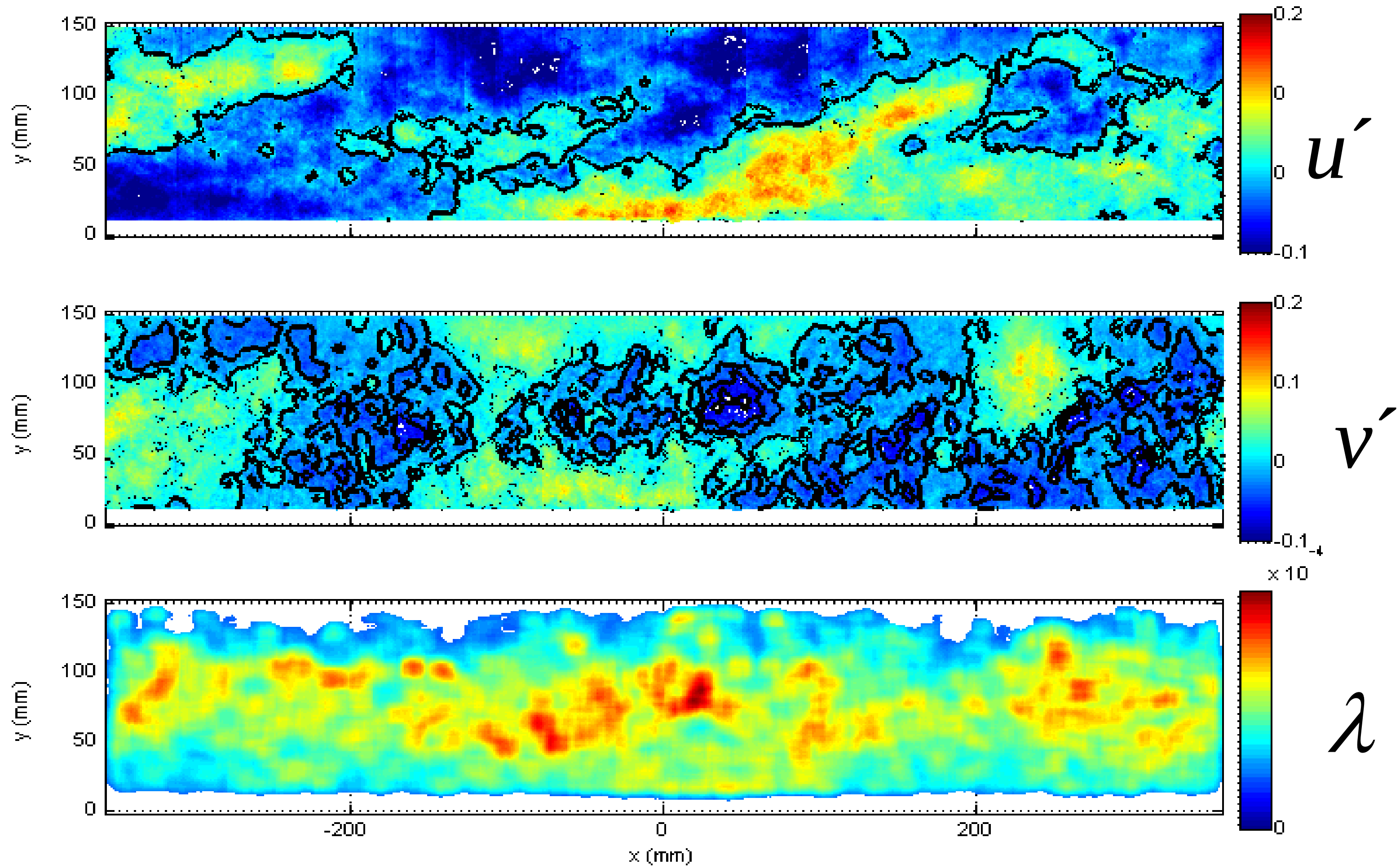
Backward-facing step

(De Ruijter, 2004)



Backward-facing step

(De Ruijter, 2004)



Conclusions

- Turbulence is an important factor
- Turbulent structures from the main stream reach the bed and cause pressure fluctuations

New formulas for the stability parameter

$$\Psi_{wl} = \frac{\left\langle \left(\bar{u} + \alpha\sqrt{k}\right)^2 \right\rangle_{hm}}{\Delta g d}$$

$$hm = 5d + 0.2h$$

$$\Psi_{Lm} = \frac{\max\left[\left\langle \bar{u} + \alpha\sqrt{k} \right\rangle_{Lm} \frac{L_m}{2}\right]^2}{\Delta g d}$$

$$Lm = \kappa z \sqrt{1 - \frac{z}{h}}$$

(Bakmetev mixing length)

$$\Psi_{u-\sigma[u]} = \frac{\left\langle \left[u + \alpha\sigma(u)\right]^2 \sqrt{1 - \frac{z}{h}} \right\rangle_h}{\Delta g d}$$

$$\Psi_S = \frac{u_{*c}^2}{\Delta g d}$$

$$k = \frac{1}{2}\left(\overline{u'^2} + \overline{v'^2} + \overline{w'^2}\right)$$

Non uniform flow

Stability criterion

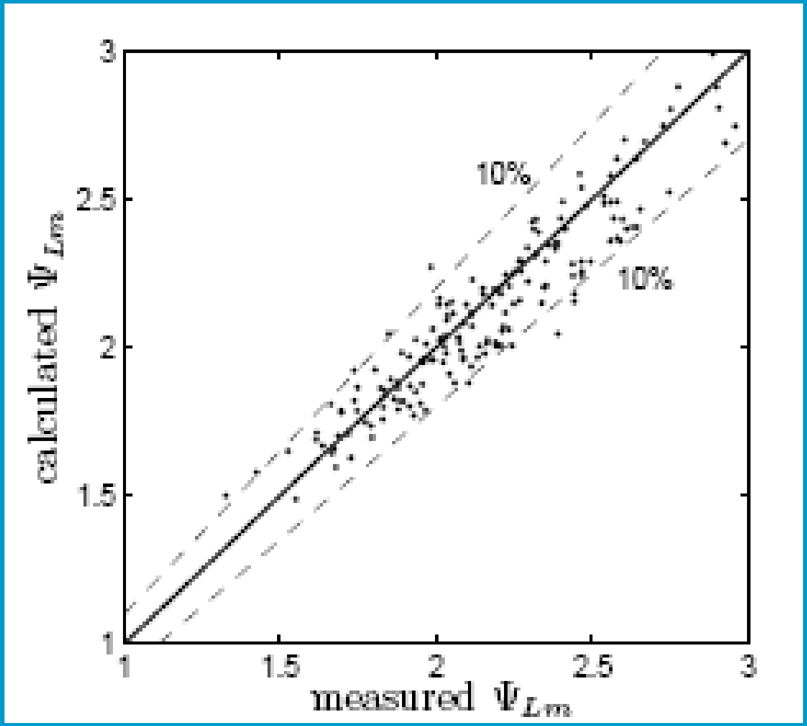
- In textbook Schiereck: $$d_{n50} = \frac{\left(K_v \langle \bar{u} \rangle_h\right)^2}{K_s \Delta \Psi_{s,c} C^2} \qquad (3.17)$$

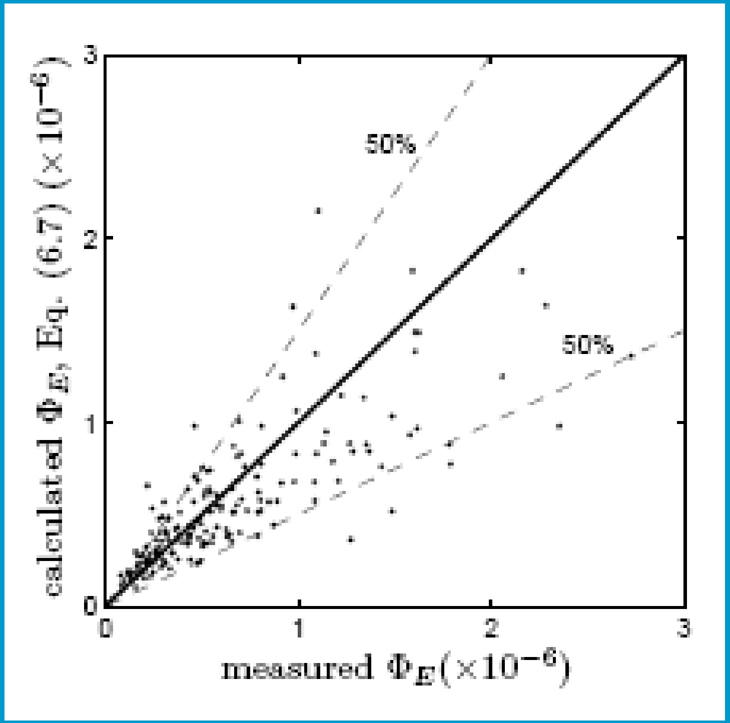
- Using the Hoan formula: $$d_{n50} = \frac{\left\langle \left[u + \alpha\sigma(u)\right]^2 \sqrt{1 - \frac{z}{h}} \right\rangle_h}{\Delta g \Psi_{Hoan,c} C^2}$$

- Using the Hofland formula: $$d_{n50} = \frac{\max\left[\left\langle \bar{u} + \alpha\sqrt{k} \right\rangle_{Lm} \frac{Lm}{z}\right]^2}{\Delta g \Psi_{Lm,c} C^2}$$

$\Psi_{Hoan} = 2.9 \qquad \Psi_{Lm} = 0.5 \qquad \alpha = 3$

Measured and computed Ψ_{Lm} and Φ_E





Comparison of Shields and Hoan

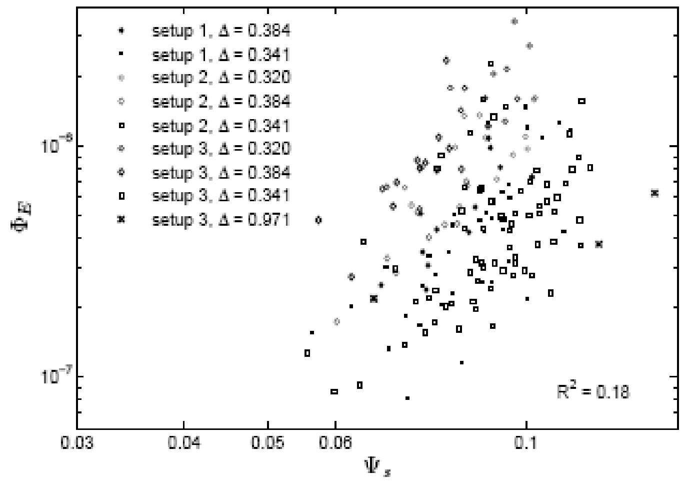


Figure 5.5: Measured Ψ_s versus measured Φ_E.

Shields

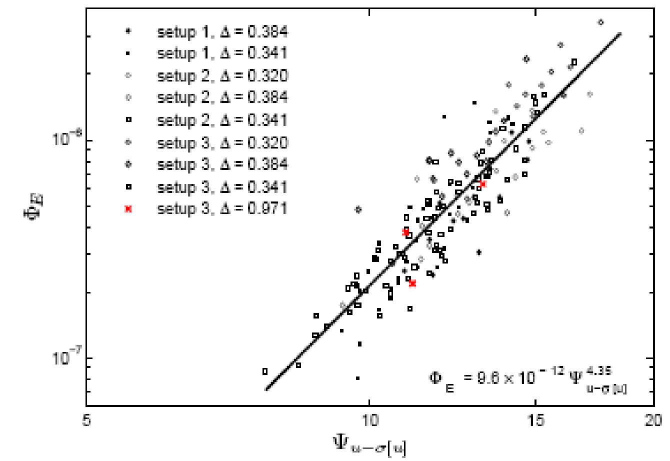


Figure 5.4: Measured $\Psi_{u-\sigma[u]}$ versus measured Φ_E.

Hoan