Spectral differences between smooth and rough wall zero pressure gradient boundary layers

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We know that….

- .. Surface roughness increases friction
- .. Changes or even removes the viscous sublayer
- .. Increases the turbulence level by a mechanism that must be different than for a smooth surface
- .. Mean velocity as well as all turbulent transport mechanisms are modified in a layer that is directly affected by this
- .. Townsend: the flow further out is unaware of the near wall processes (?)

But what if….

- .. The flow at the wall is continuously massaged at a scale that is very different from the smooth wall near wall scales?
- .. Will 2D roughness do this and introduce unique Strouhal frequencies in the spectrum?
- .. Will this be a local “at the wall” effect or be traceable across the layer?

Wall interaction

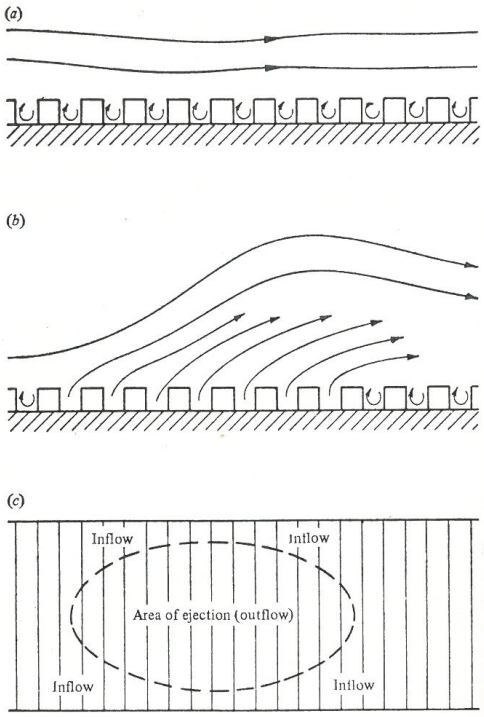


Fig. 5.4. Possible mechanism for 'd' type roughness behaviour. (a) Quiescent flow with stable vortices between the roughness elements. (b) Ejection of fluid induced by a transient region of adverse pressure gradient of extent comparable with the layer thickness. (c) Plan of the region of outflow.

Townsend, 1976

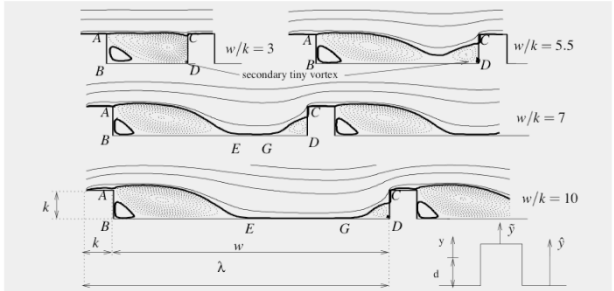


Figure 3.1: Mean streamlines, averaged with respect to time and z, for different w/k. The thick line corresponds to the zero streamfunction. The definitions of $k, w, \bar{y}, \hat{y}$ and λ are indicated

Leonardi PhD, 2002

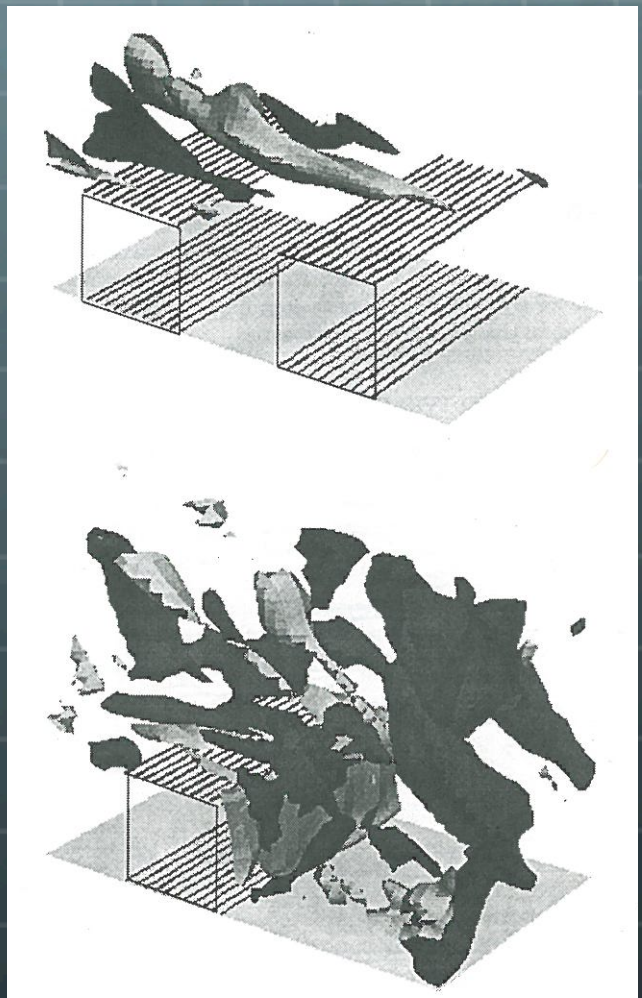
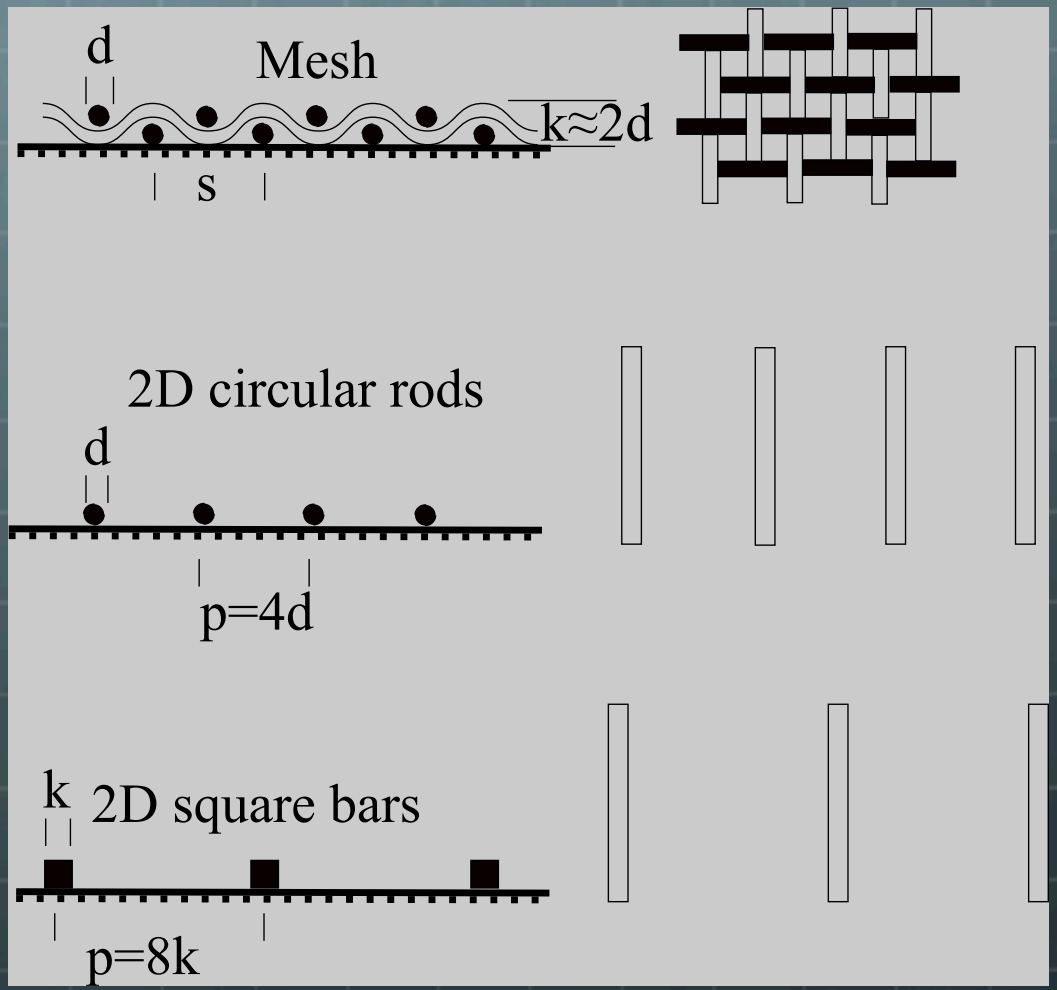


Figure 6: Contours of instantaneous ω_y. Top: $w/k = 1$, bottom: $w/k = 7$ Flow is right to left. Dark $\omega_y = -4$, light $\omega_y = 4$.

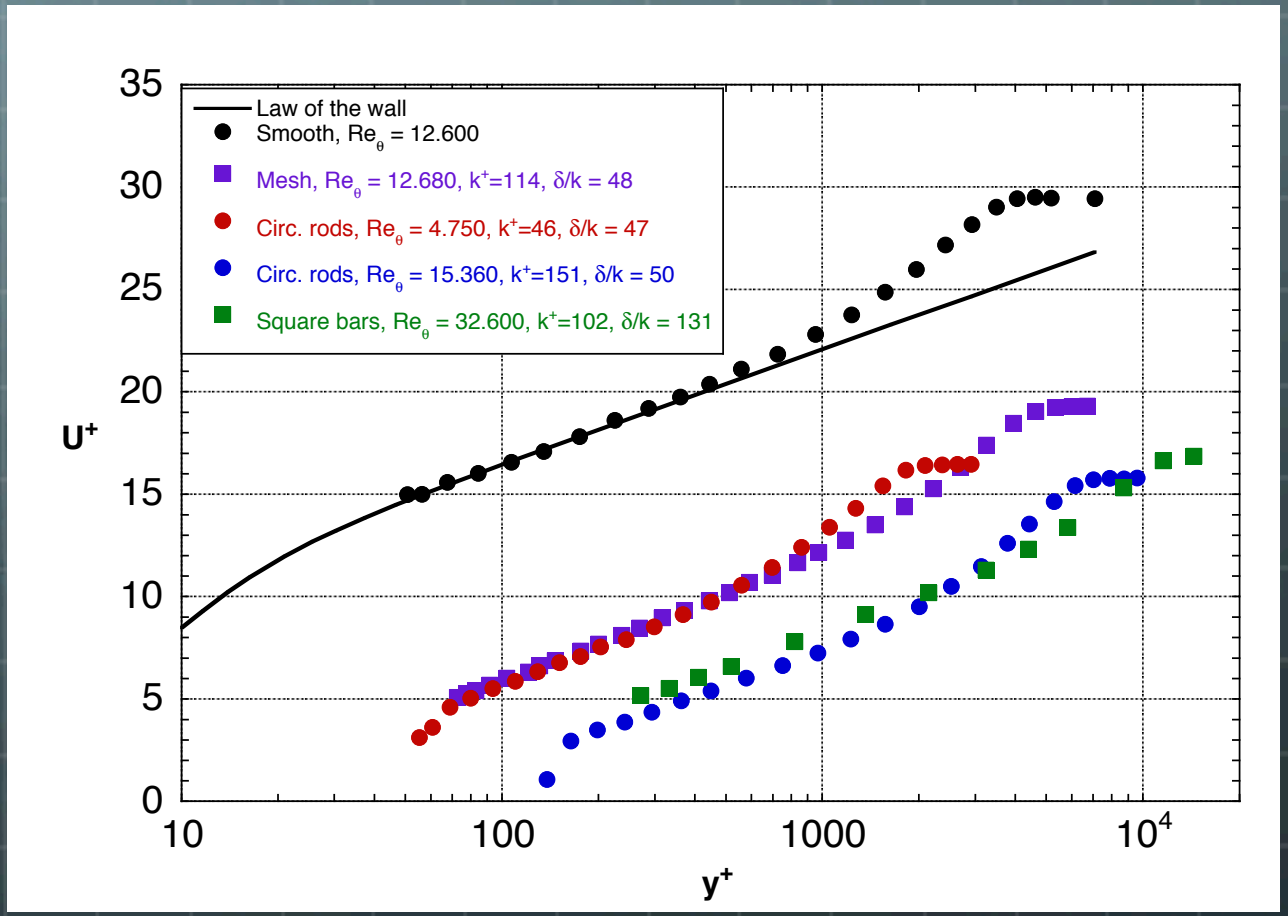
Orlandi et al., 2003

4 test surfaces

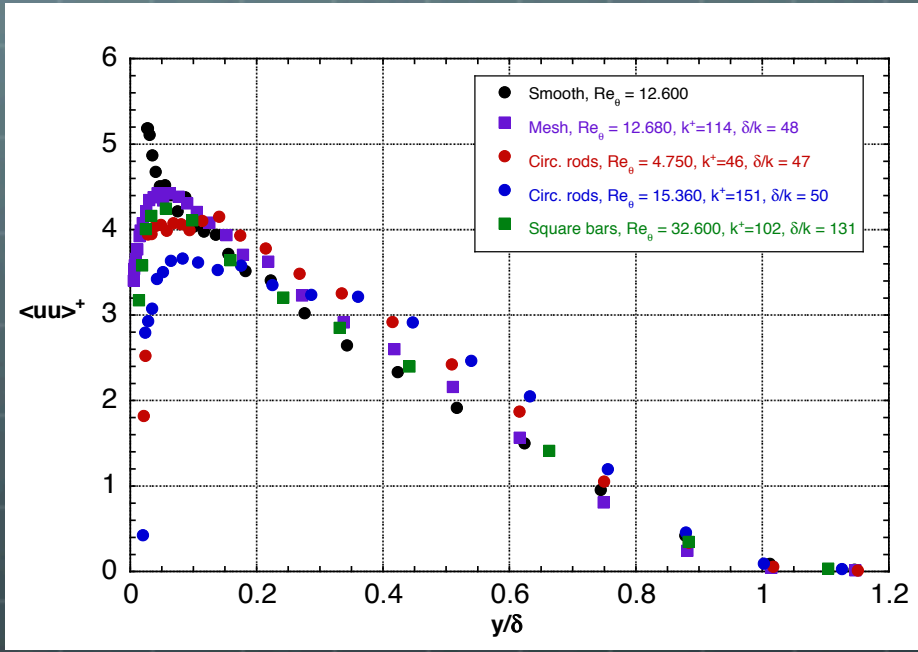


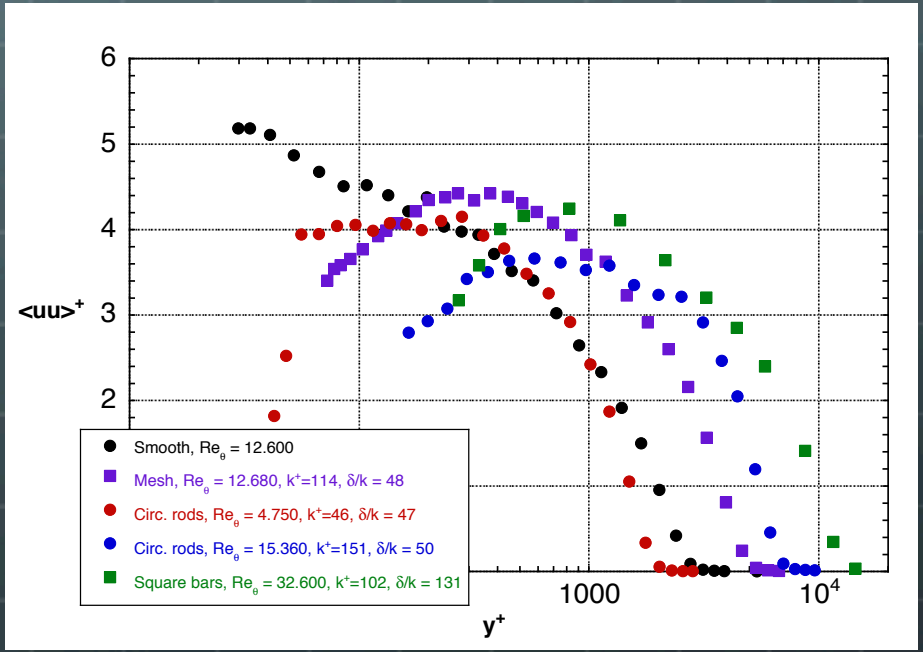
- Smooth polished aluminium
- Woven mesh, d=0.69mm, k=1.55mm s=3.18mm
- Spanwise circular rods, d=k=1.6mm, p=4d, two Re.
- Spanwise square rods, k=1.7mm, p=8k

Mean velocities

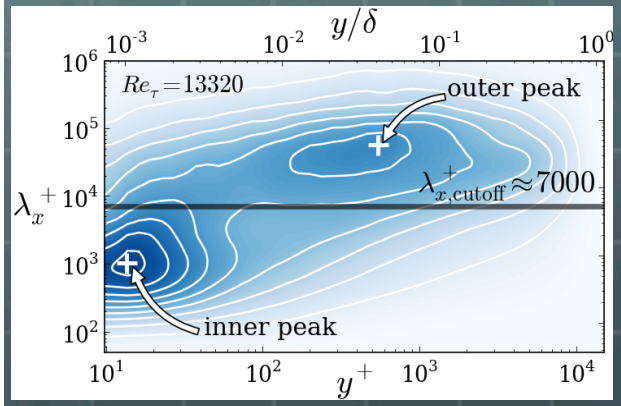


$\langle u^2 \rangle^+$ -stresses

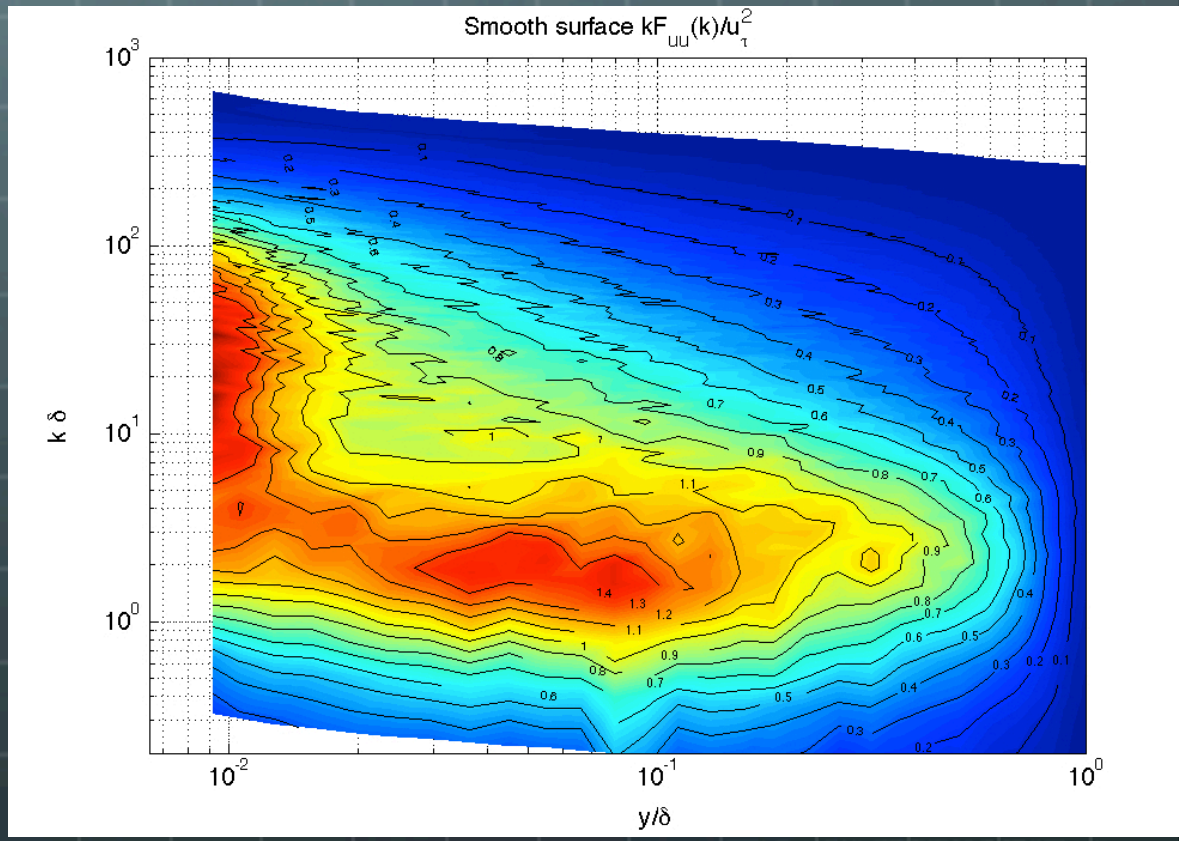




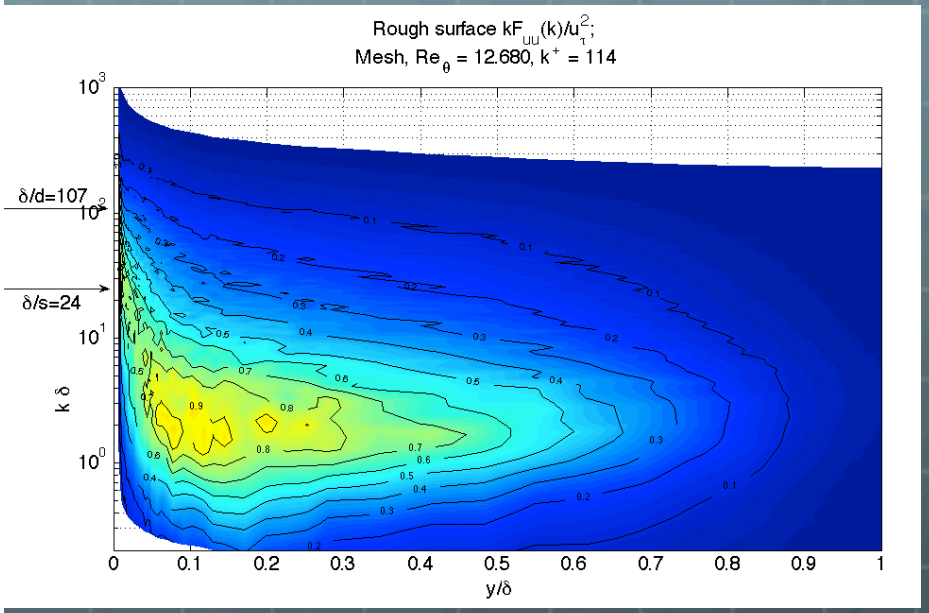
Smooth wall, Re_θ=13.400, δ^+=3000

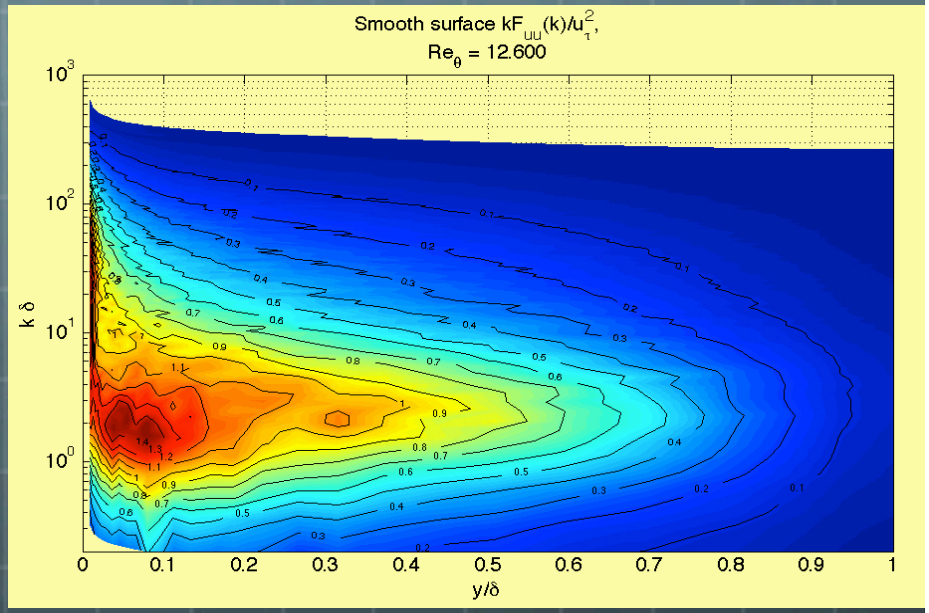


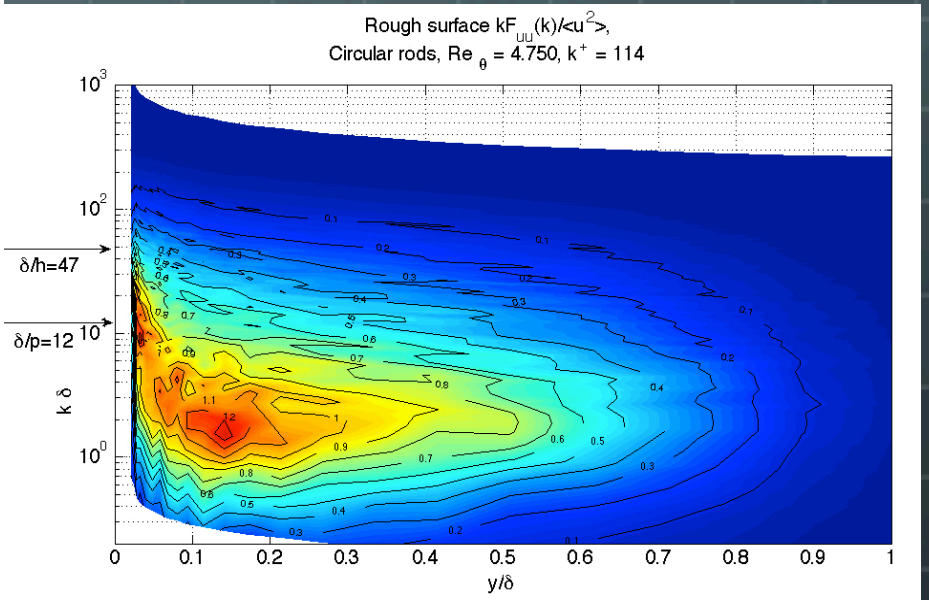
Kulandaivelu, 2012
δ^+=13400

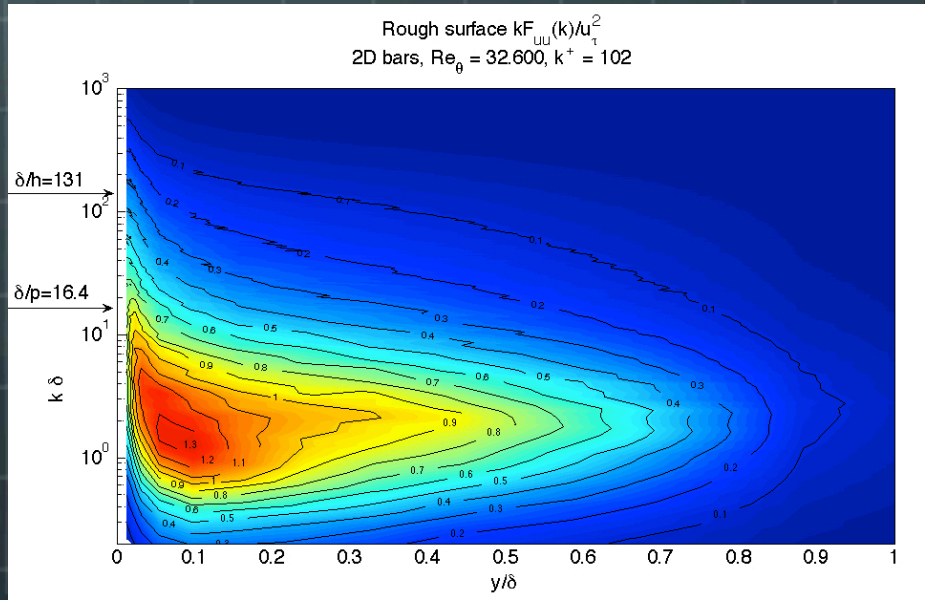


$\langle u^2 \rangle^+$ spectra, Outer layer

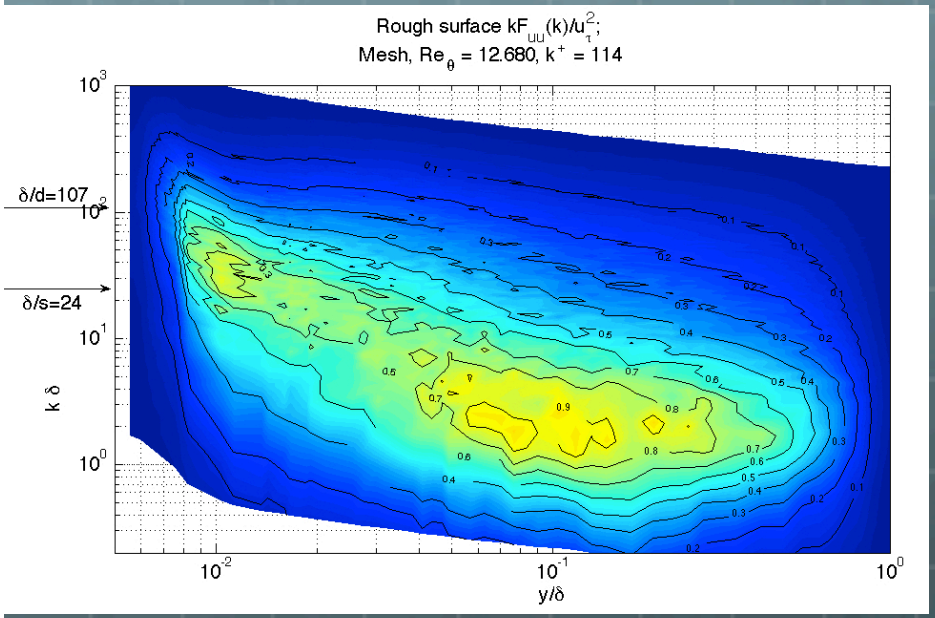


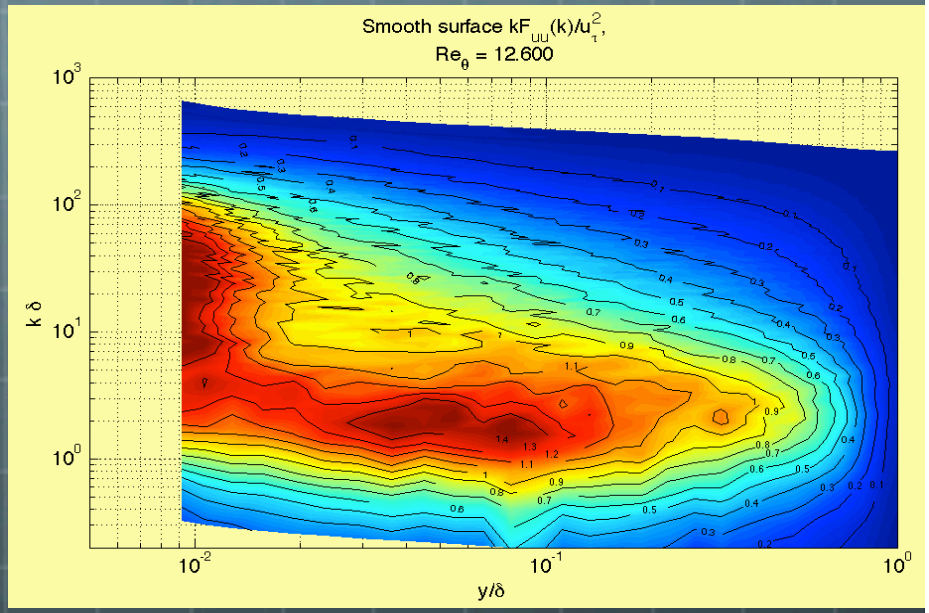


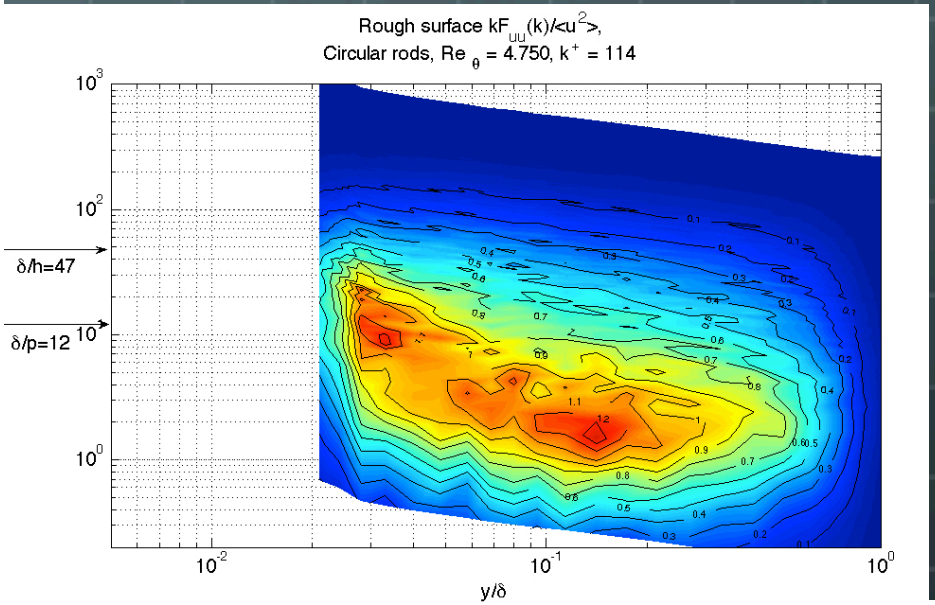


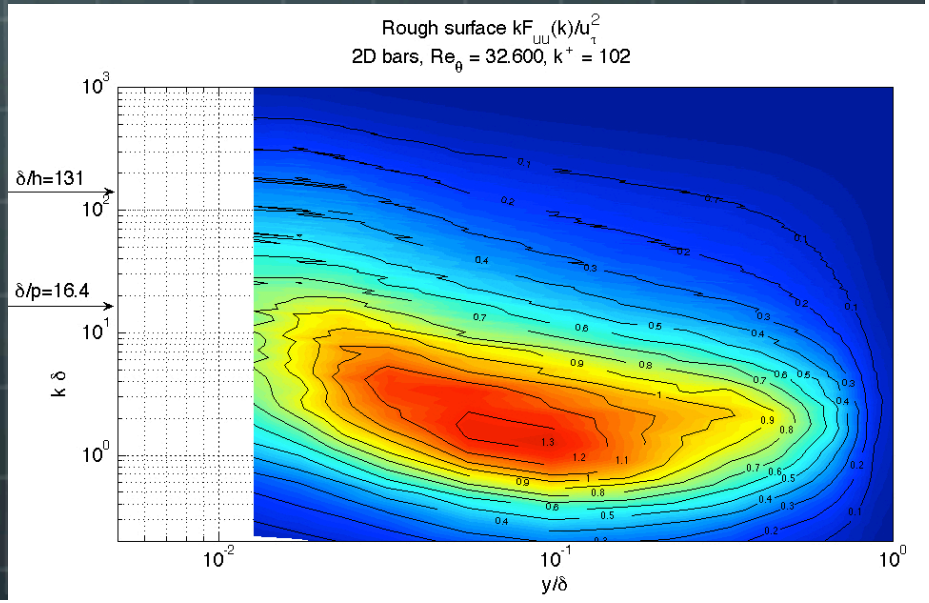


$\langle u^2 \rangle^+$ spectra, Inner layer

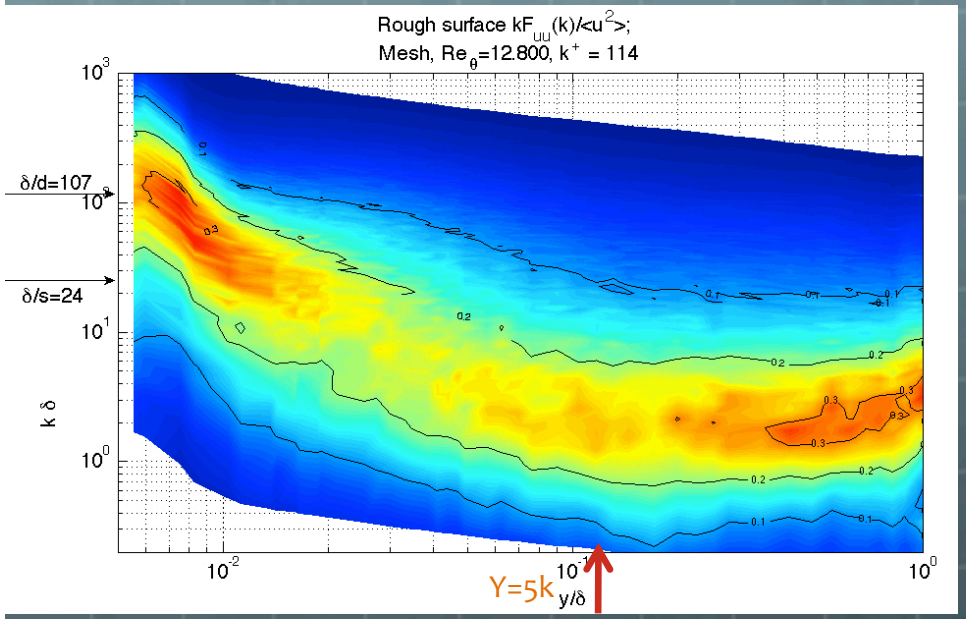


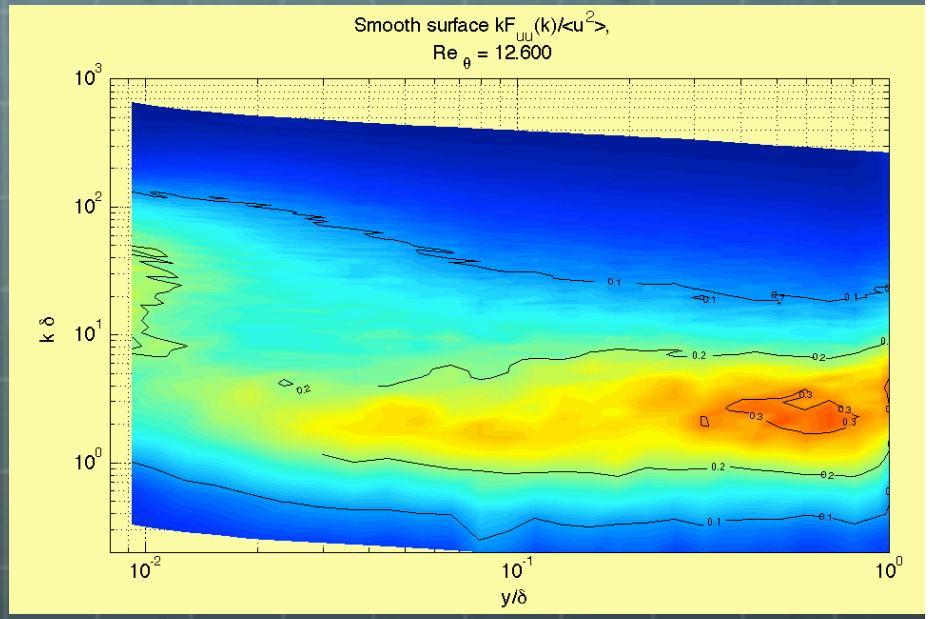


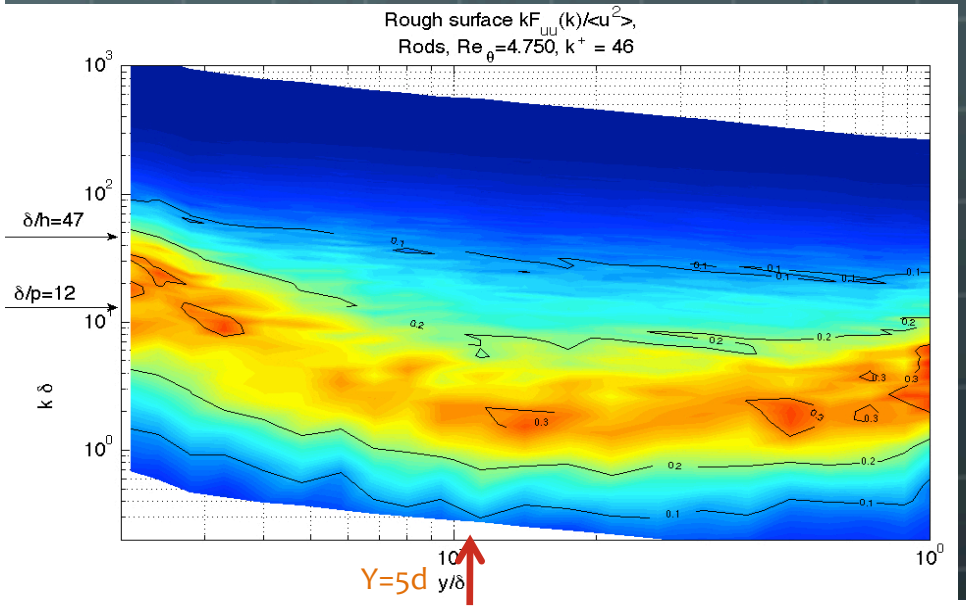


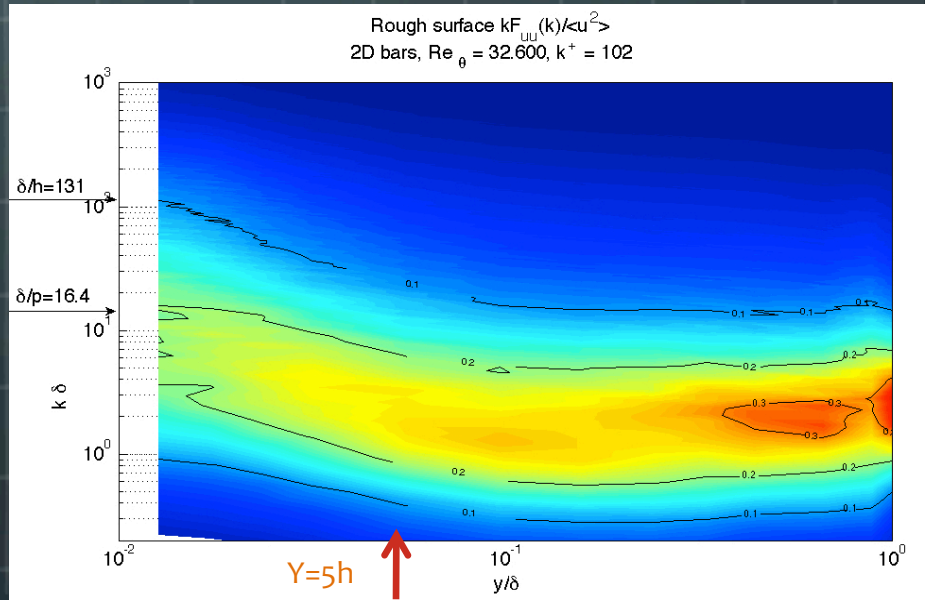


Spectra normalized with $\langle u^2 \rangle$ show information independent of u_τ

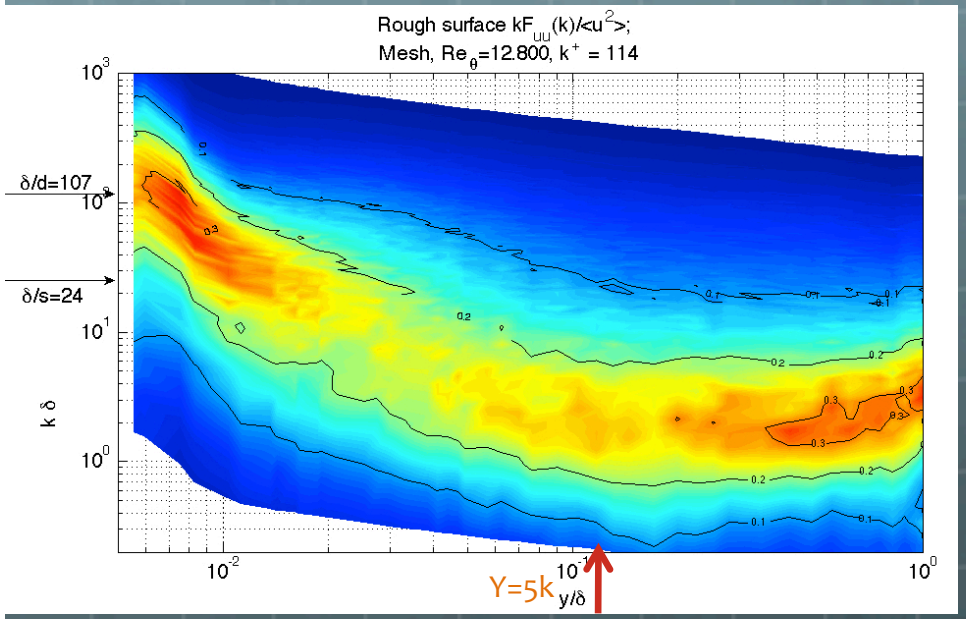


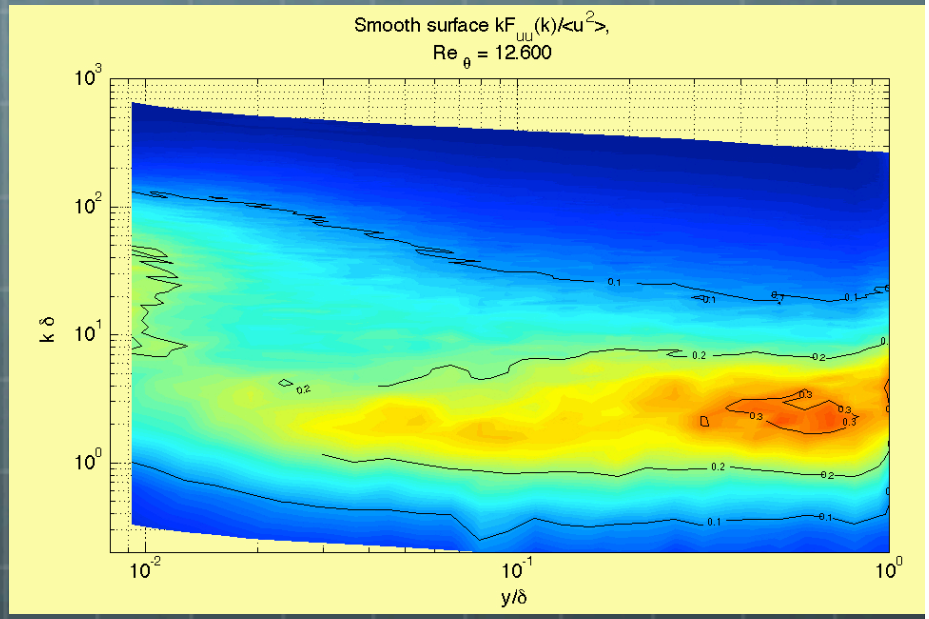


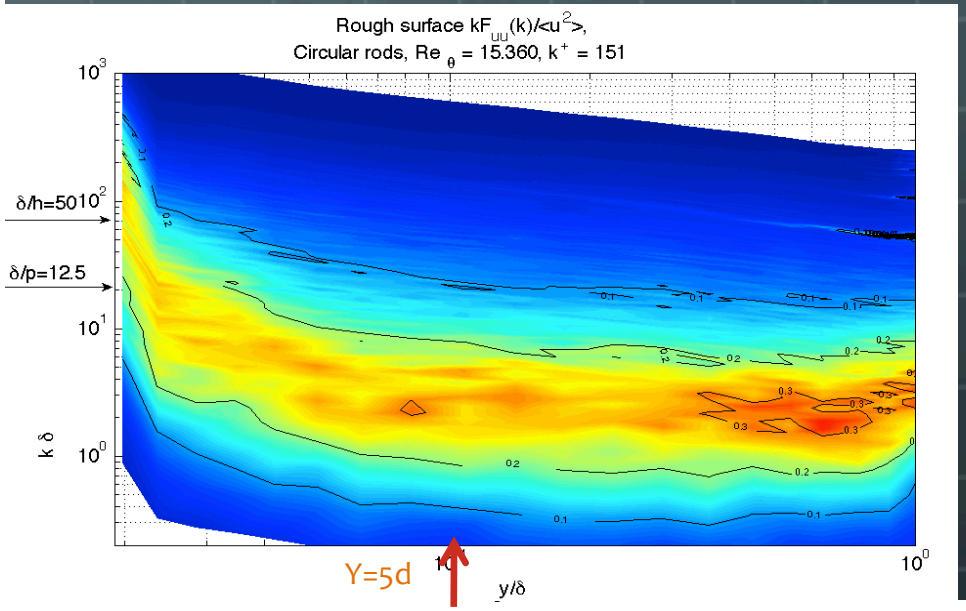


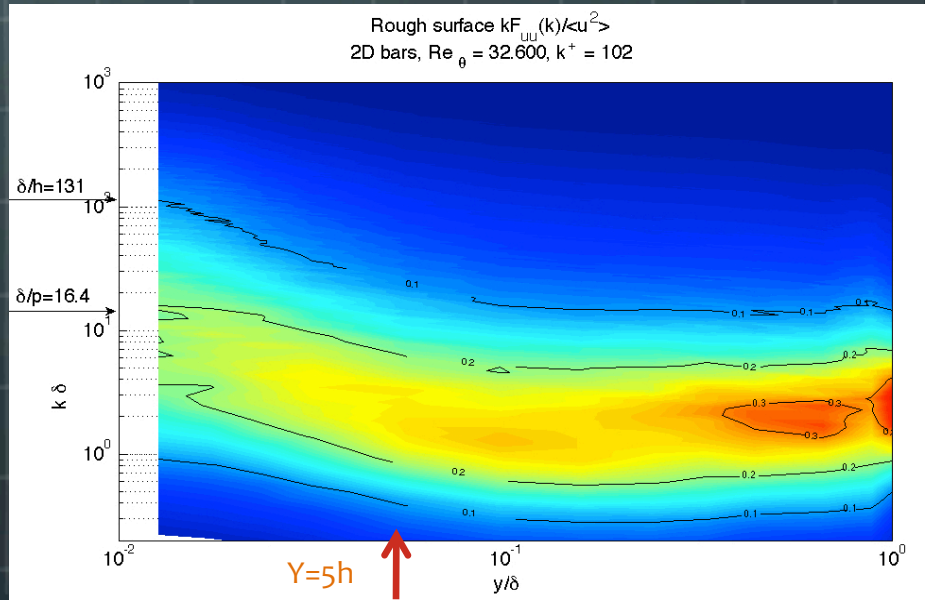


High Re data only…

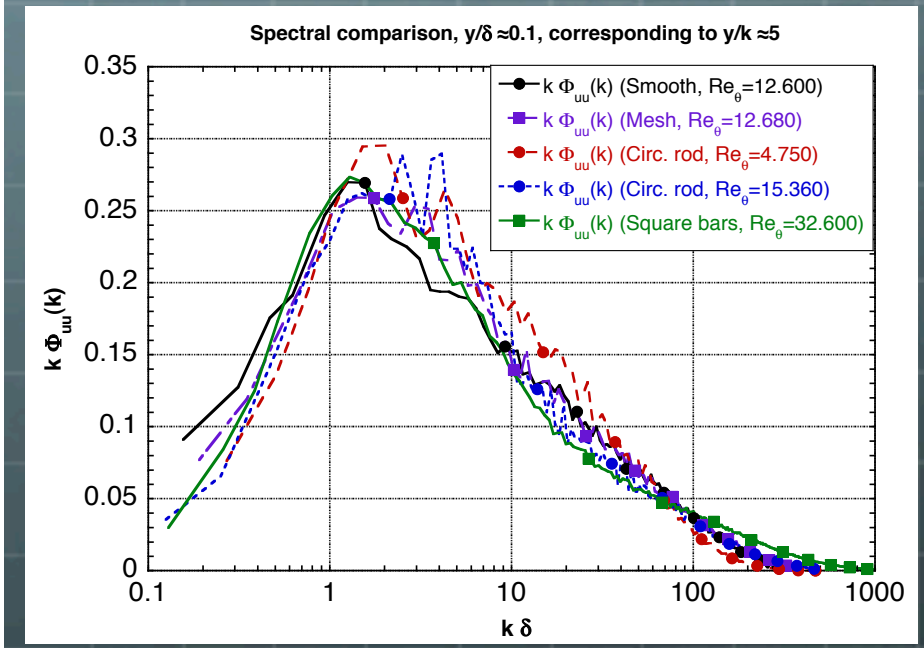


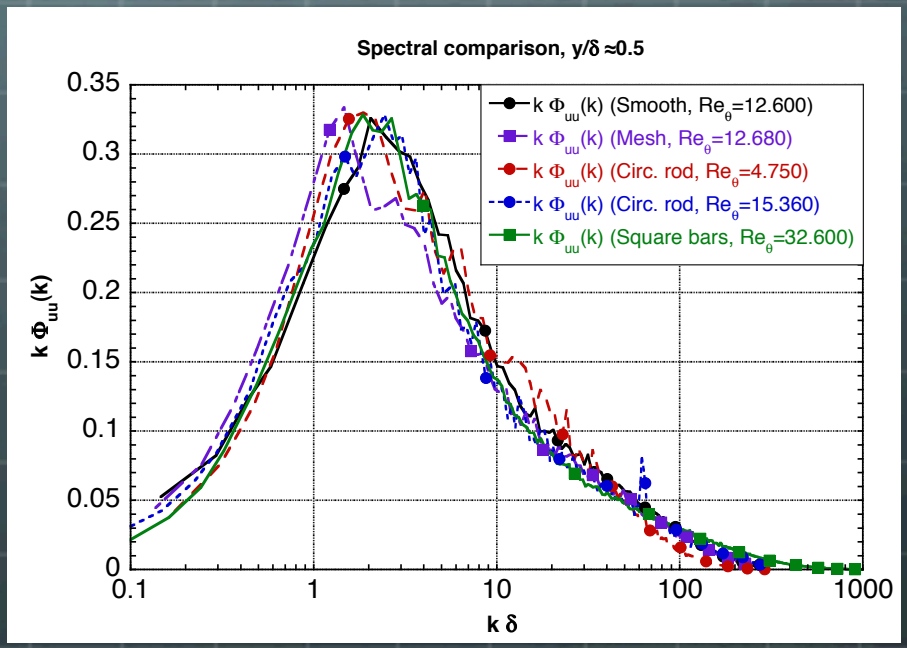






Spectra near y/k=5 and in the outer layer (y/δ≈0.5)





y/δ≈0.1
(y/k≈5)

y/δ≈0.5

Some conclusions…

- Surface roughness removes small scale dominance near the wall
- No dominant frequency observed in the roughness layer for any of the surfaces studied, but the wave number range is more narrow than on a smooth wall
- Spectral energy distribution very similar for all surfaces for $y > 5k$ despite significant differences in stress profiles