

Figure 1: Schematic representation of simulation domain with an example pseudo-realistic surface mounted. Normalization of lengths with H is applied in the figure.

SurfaceID	Re_τ	L_x/H	L_z/H	N_x	N_z	Δ_x^+	Δ_z^+	$\Delta_{y,k}^+$
0-199	500	2.4	0.8	480	160	2.5	2.5	≈ 1.74
200-399	500	3	1	576	192	2.6	2.6	≈ 1.74

Table 1: Simulation domain setup

1. Simulation setup

Turbulent channel with constant pressure gradient (CPG). $Re_\tau = u_\tau(H - k_{md})/\nu$, where $u_t au = \sqrt{\tau_w/\rho}$ and $\tau_w = -P_x(H - k_{md})$.

2. Roughness configuration

Identical Re_τ , varying k_9

2.1. PDF

Weibull:

$$f(k) = \lambda \beta^\lambda k^{(\lambda-1)} e^{-(\beta k)^\lambda},$$

Bimodal:

$$k(i) = \min\{\Phi_{0,1}(i), \Phi_{-\lambda,\lambda}(i)\},$$

Gaussian:

$$f(i) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{i-\mu}{\sigma}\right)^2}$$

2.2. PS

$\lambda_0 = 0.8H$ (1-199), $= 1H$ (200-399). $\lambda_1 = 0.04H$. PS normalized by $\lambda_{diff} = \lambda_0 - \lambda_1$. Roll-off length: $L_r/\lambda_{diff} = \Phi_{0.4,0.04}$. PS slope: $\theta_p = -|\Phi_{0.75,0.3}|$. Randomize along PS(20): $PS(i) - \Phi_{0,0.5 \star i}$.

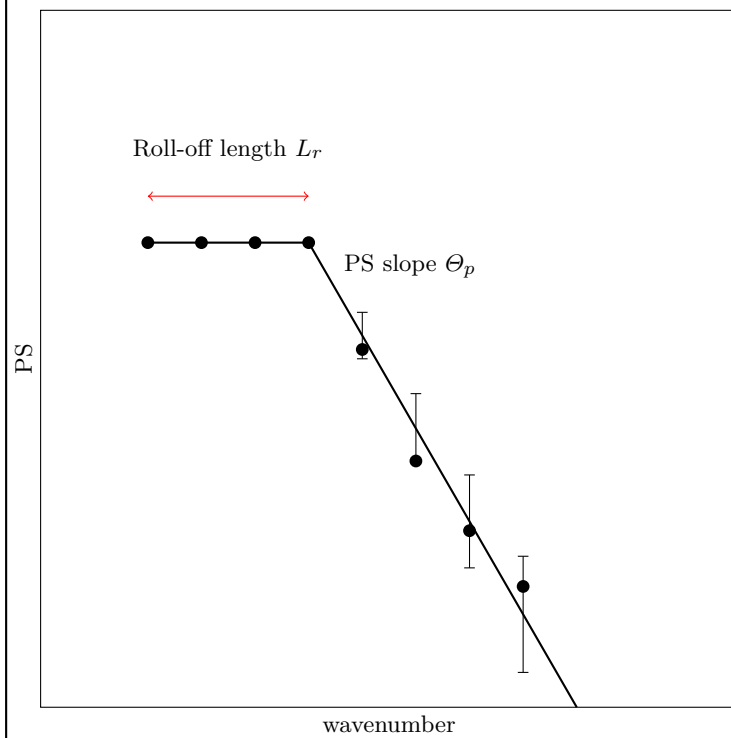
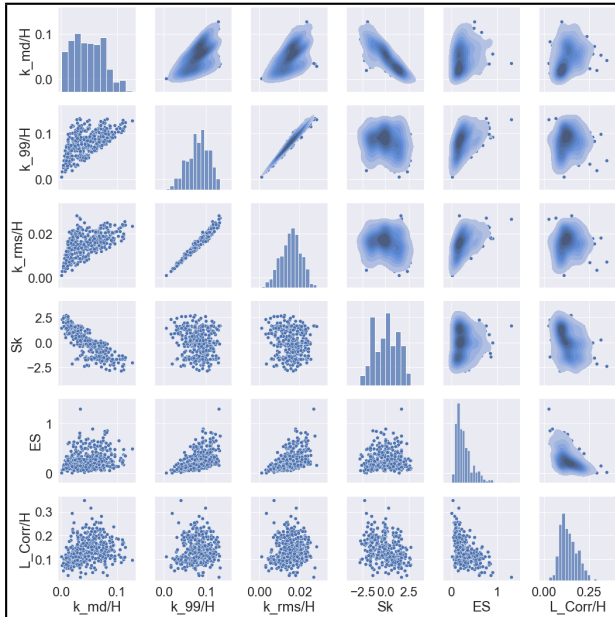


Figure 2: PS Sketch