ON THE ROUGHNESS SUBLAYER OVER IDEALIZED URBAN ROUGH SURFACES IN ISOTHERMAL CONDITIONS

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Handout (1.5 MB)

Turbulent flows over a rough surface exhibit a constant Reynolds-stress region in the proximity of the bottom solid boundary. This region is known as the inertial sublayer (ISL) that is commonly described by the logarithmic law of the wall (log-law)

$$\frac{u|_z}{u_*} = \frac{1}{\kappa} \ln\left(\frac{z-d}{z_0}\right) \qquad (1)$$

where u_* is the friction velocity, k (= 0.41) the von Kármán constant, z the wall-normal distance, d the displacement height, and z_0 the roughness length scale. The log-law is well received by the community to parameterize the flows in the lower atmospheric boundary layer (ABL). While the size of roughness elements is not negligible compared with the boundary layer thickness, there exists another layer of enhanced mixing in-between the ISL and the bottom surface that is characterized by the influence of individual (inhomogeneous) roughness elements. This layer is called the roughness sublayer (RSL) in which the velocity is more uniform, deviating from the conventional log-law. Under this circumstance, parameterizing the flows in the lower ABL by Equation (1) must be applied with caution.

In view of the limitation of applying log-law to the RSL, this study is conceived to examine the RSL flows and turbulence in response to various surface-roughness configurations of different aerodynamic resistance. Idealized urban-roughness elements, in the form of identical ribs placed in cross flows, are used to model simplified urban morphology in our wind tunnel in isothermal conditions. The aerodynamic resistance of the rough surfaces is adjusted by the rib-separation-to-height ratio (pitch, k/h). Hot-wire anemometry (HWA) is used in data sampling. A new analytical solution to the mean velocity profile over rough surfaces, including both RSL and ISL influence, is arrived as follows

$$\frac{u|_z}{u_*} = \frac{1}{\kappa}\left\{\ln\left(\frac{z-d}{z_0}\right) - \left[\gamma + \ln\left(\mu\frac{z-d}{z_*}\right) + \sum_{n=1}^{\infty}\frac{(-1)^n \times \left(\mu\frac{z-d}{z_*}\right)^n}{n \times n!}\right]\right\} \qquad (2)$$

where z_* is the RSL thickness, γ (= 0.5772156649) the Euler constant, and μ an empirical constants based on the surface roughness. Figure 1 shows that the new analytical solution (root-mean-square (RMS) error = 0.0756 to 0.226) agrees well with wind-tunnel-measured wind speed than does log-law (RMS error = 0.102 to 0.959). Equation (2) is then used together with the classic *K*-theory, anti-gradient model to describe the vertical momentum flux, depicting the different mixing length scales and transport processes in the RSL and ISL. More detailed results will be reported in the symposium.

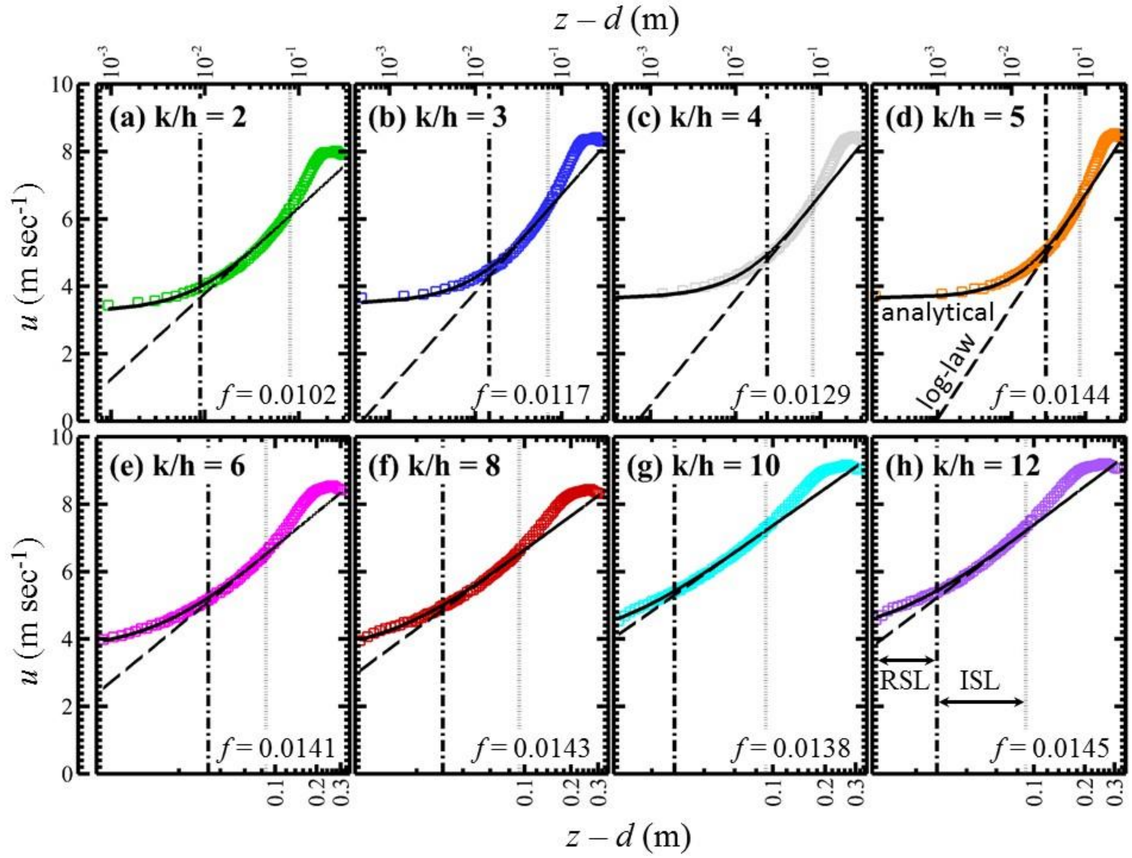

Figure 1. Velocity profiles of wind tunnel measurement (symbols) over rough surfaces of different friction factor *f* by adjusting the pitch (*k*/*h*). Also shown are the conventional log-law (dashed lines), the analytical solution proposed in this paper (solid lines; Equation (2)), and the RSL/ISL.