Boundary Layer Meteorology
ATMOS 5220/6220

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Surface roughness and the logarithmic sublayer

Logarithmic wind profile

- friction velocity u_*
- roughness length z_0
- **how do they affect the wind profile?**

Aerodynamic bulk formula

- drag coefficient over land
- drag coefficient over water

Turbulence scales

- velocity scales (u^*, w^*)
- length scales (z, z_i, z_0, L)
- time scales (t_*, t_{*SL})

Surface Roughness and Logarithmic Sublayer

Surface momentum flux $$(\overline{u'w'})_s = u_*^2$$

Buoyancy flux $$(\overline{w'b'})_s = B_0$$

Obukhov length $$L = \frac{-u_*^3}{kB_0} = \frac{-u_*^3}{k(\overline{w'b'})_s}$$

u_*-Friction velocity
k-von Karman const.
z-height
z_0-roughness length

Typical values:
u_*=0.3 m/s

B_0=-3 x 10^{-4} m^2s^{-3} (nighttime) L=200m (-10W/m^2)

B_0=1.5 x 10^{-2} m^2s^{-3} (midday) L=-5m (500 W/m^2)

Neutral conditions

$$\overline{(u'w')}_s = u_*^2$$

$$u_*^2 = \overline{(u'w')}_s = K_m \frac{\partial \overline{U}}{\partial z}$$

u_*-Friction velocity
k-von Karman const.
z-height
z_0-roughness length

$$K_m = l^2 \left| \frac{\partial \overline{U}}{\partial z} \right| \qquad l = k \cdot z$$

$$u_*^2 = k^2 z^2 \left| \frac{\partial \overline{U}}{\partial z} \right|^2 \rightarrow \left| \frac{\partial \overline{U}}{\partial z} \right| = \frac{u_*}{k \cdot z}$$

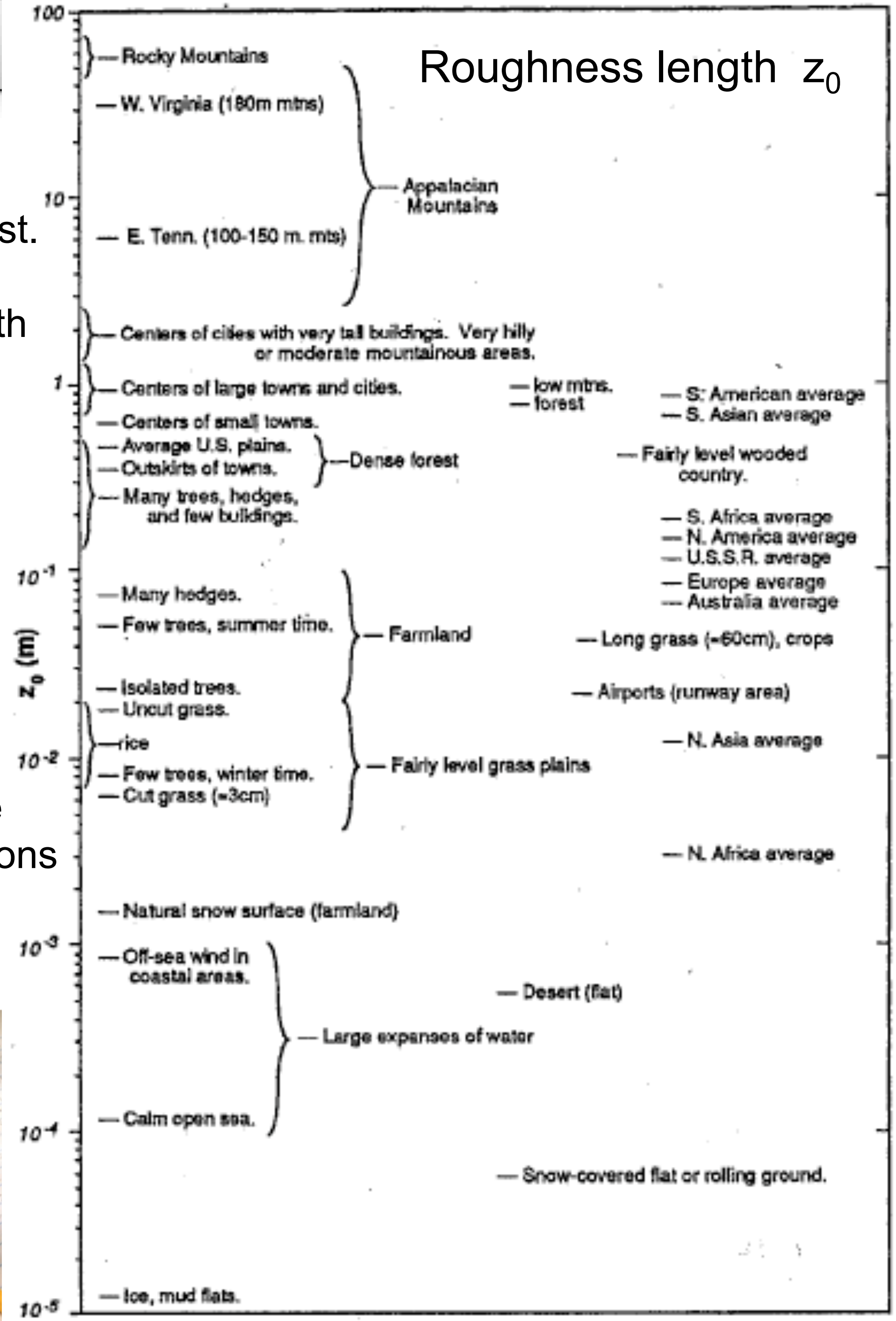
$$U(z) = \frac{u_*}{k} \log\left(\frac{z}{z_0}\right)$$

Logarithmic wind profile valid for **neutral** conditions

$$\rho \cdot \overline{(u'w')}_s = \tau$$

surface stress

Roughness length z_0



Roughness length,

$z_0 = 0.1 h_c$

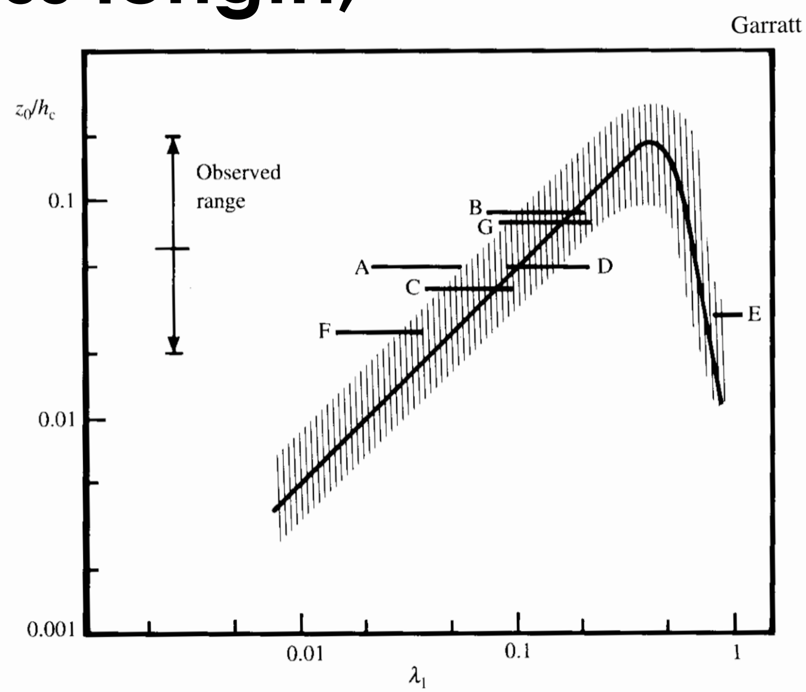
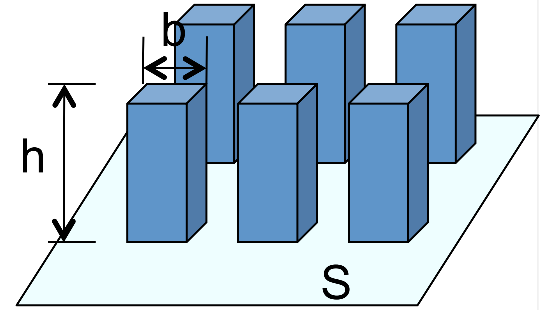
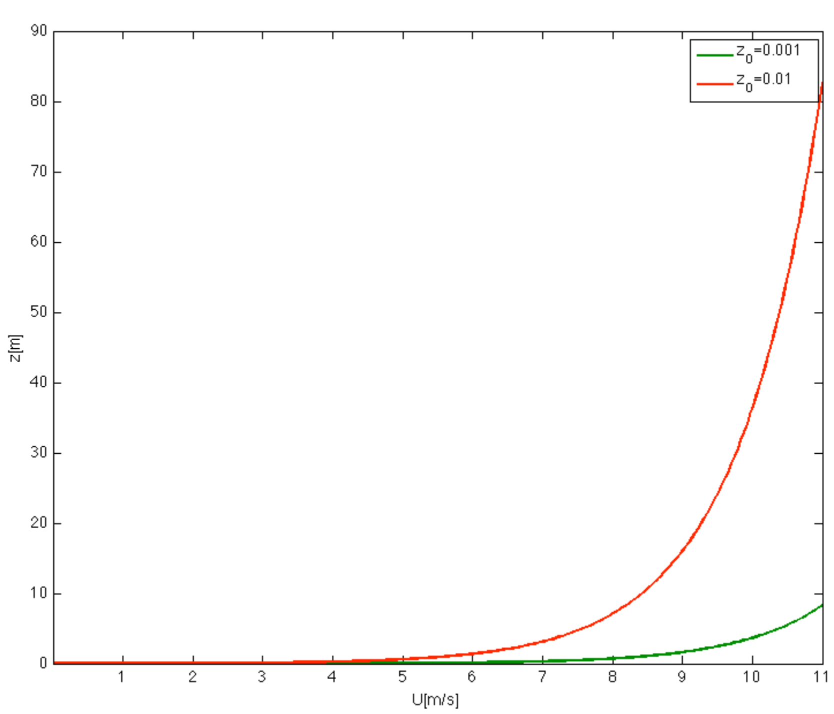


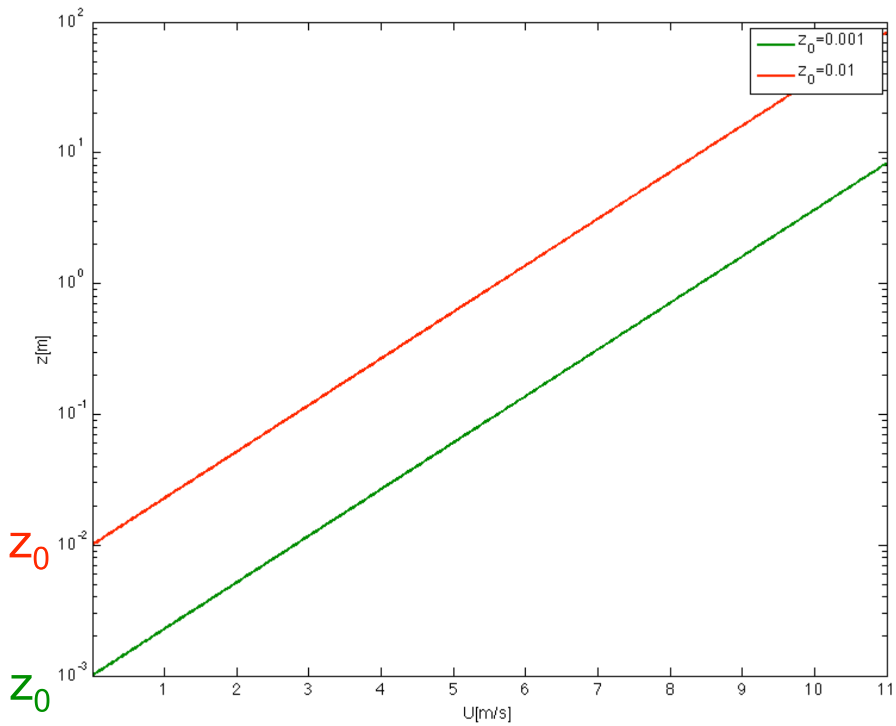
Fig. 4.1 Variation of z_0/h_c with element density, based on the results of Kutzbach (1961), Lettau (1969) and Wooding *et al.* (1973), represented by the shaded area and solid curve. Some specific atmospheric data are also shown as follows: A and B, trees; C and D, wheat; E, pine forest; F, parallel flow in a vineyard; G, normal flow in a vineyard. Analogous wind-tunnel data are described in Seginer (1974). From Garratt (1977b).



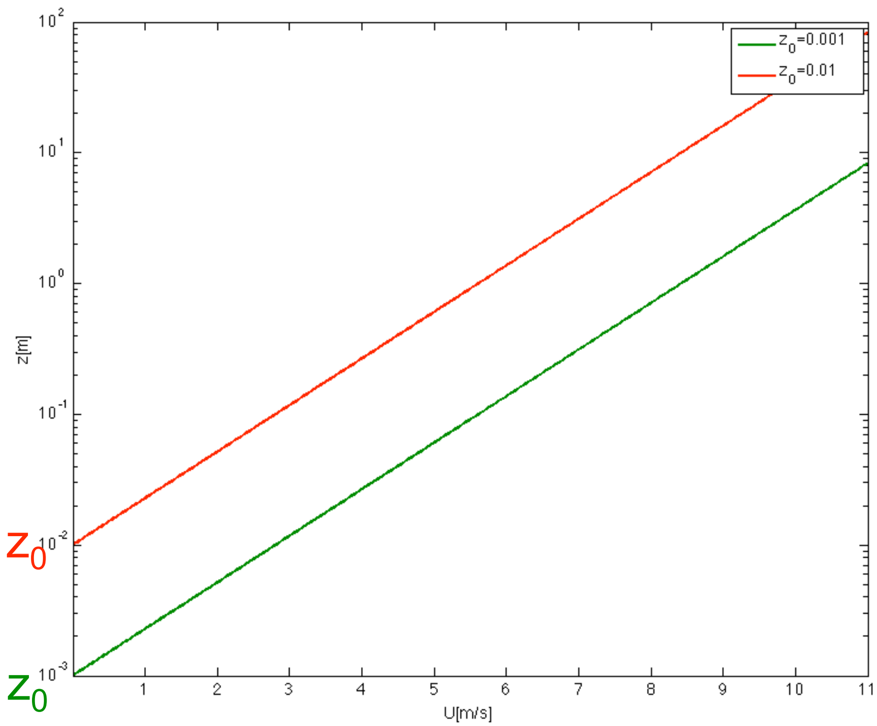
$$\lambda = \frac{n \cdot b \cdot h}{S}$$

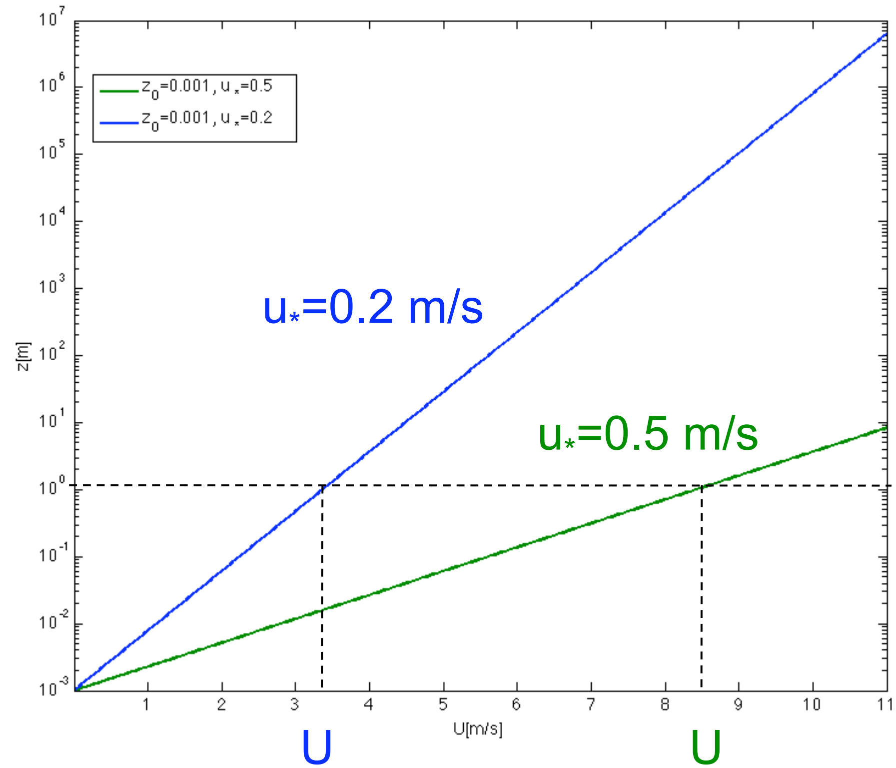
Logarithmic wind profiles, u_*=0.5 m/s:





Logarithmic wind profiles, u_*=0.5 and 0.2 m/s:





Logarithmic wind profiles,

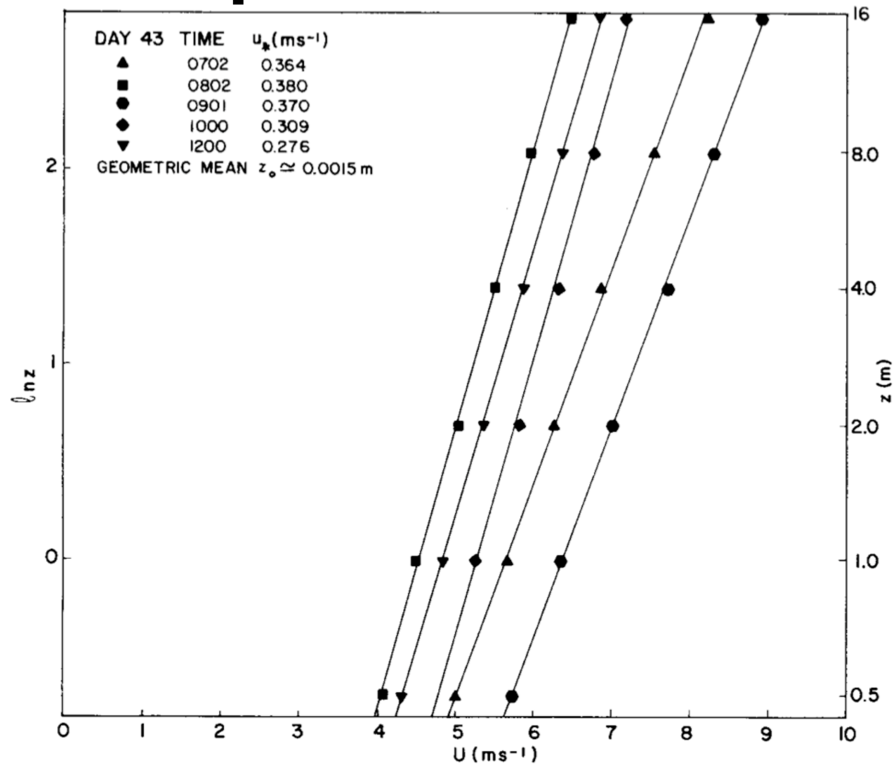


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Fig. 10.4 Comparison of the observed wind profiles in the neutral surface layer of day 43 of the Wangara Experiment with the log law [Eq. (10.6)] (solid lines). [Data from Clarke *et al.* (1971).]

Task 1

Giving the following wind speeds measured at various heights in a neutral boundary layer, find:

-friction velocity u_*

-the aerodynamic roughness length (z_0)

-shear stress at the ground τ

-wind speed at 6m

z(m)	U(m/s)
1000	10
500	9.5
300	9.0
100	8.0
50	7.4
20	6.5
10	5.8
4	5.0
1	3.7

Task 2

Giving the following wind speeds measured at various heights in a neutral boundary layer, find:

-friction velocity u_*

-the aerodynamic roughness length (z_0)

-shear stress at the ground τ

-wind speed at 6m

z(m)	U(m/s)
1000	10
500	9.5
300	9.0
100	8.0
50	7.4
20	6.5
10	5.8
4	5.0
1	3.7

Task 3

Giving the following wind speeds measured at various heights in a neutral boundary layer, find:

-the aerodynamic roughness length (z_0)

-friction velocity u_*

-shear stress at the ground τ

-wind speed at 6m

z(m)	U(m/s)
1000	10
500	9.5
300	9.0
100	8.0
50	7.4
20	6.5
10	5.8
4	5.0
1	3.7

Task 4

Giving the following wind speeds measured at various heights in a neutral boundary layer, find:

- -the aerodynamic roughness length (z_0)
- -friction velocity u_*
- -shear stress at the ground τ
- -wind speed at 6m

z(m)	U(m/s)
1000	10
500	9.5
300	9.0
100	8.0
50	7.4
20	6.5
10	5.8
4	5.0
1	3.7

Displacement height (d)

$$U(z) = \frac{u_*}{k} \log\left(\frac{z-d}{z_0}\right)$$

d=0.7h_c

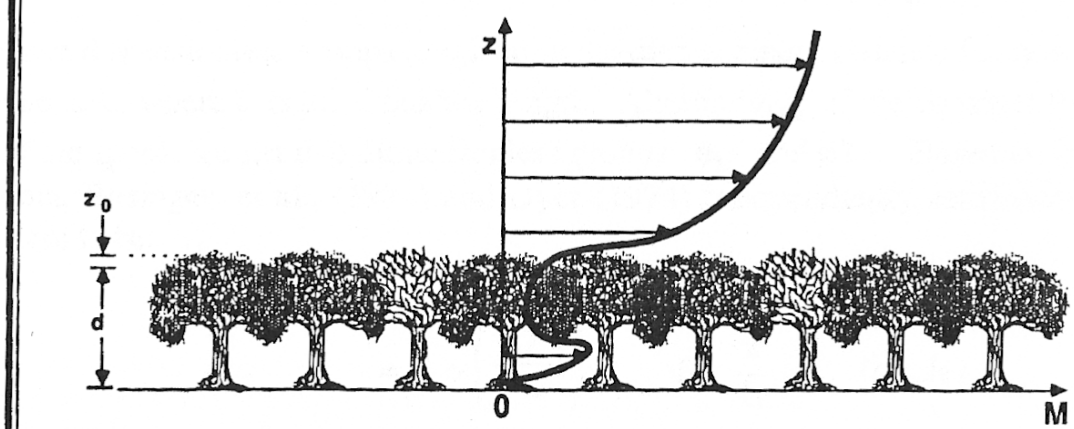

Fig. 9.7 Flow over forest canopy showing wind speed, M, as a function of height, z. The thick canopy layer acts like a surface displaced a distance, d, above the true surface. z_0 = roughness length.

Aerodynamic bulk formula ($\tau = \rho$) $C_D \cdot U^2$

$$\rho \cdot (\overline{u'w'})_s = \tau$$

surface stress

$$(\overline{u'w'})_s = u_*^2$$

$$U(z) = \frac{u_*}{k} \log\left(\frac{z}{z_0}\right)$$

↓

$$u_* = \frac{k \cdot U(z)}{\log\left(\frac{z}{z_0}\right)}$$

$$(\overline{u'w'})_s = \frac{k^2 \cdot [U(z)]^2}{\left[\log\left(\frac{z}{z_0}\right)\right]^2}$$

$$\tau = \rho \cdot (\overline{u'w'})_s = \rho \frac{k^2}{\left[\log\left(\frac{z}{z_0}\right)\right]^2} \cdot [U(z)]^2$$

drag coefficient C_D

$$\tau = \rho \cdot C_D \cdot U^2$$

Drag Coefficient (C_D)

$$\tau = \rho \cdot C_D \cdot U^2$$ surface stress

$$(\overline{u'w'})_s = \frac{\tau}{\rho}$$

In practice the drag coefficient is given usually with respect to the wind speed at z=10m and for neutral conditions (C_{DN10})

Typical values of the drag coefficient over the land are significantly larger than over the water

$C_{D\ land} \approx 7\times10^{-3}$

$C_{D\ water} \approx 1\times10^{-3}$