ATM 419/563 – The log wind profile as used in WRF

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The logarithmic wind profile gives the wind speed at height z as

$$V(z) = \frac{u*}{\kappa}\left[\ln\left(\frac{z-d}{z_0}\right) - \psi\right],$$

where V is the Reynolds-averaged wind speed, u^* is the "friction velocity", z_0 is the roughness length, d is the zero-plane displacement, ψ is a function of stability, and κ is von Karman's constant (≈ 0.4). The friction velocity u^* was previously formulated as a shear stress and one way to look at it

$$u^* = \kappa\frac{dV}{d\ln z},$$

It was from this definition of u^* that the log wind profile was derived.

The roughness length z_0 is often taken as a height between 1/10 and 1/30 of the average height of "roughness elements" on the surface. Its values range from 0.0002 m over surfaces like calm seas, smooth deserts and snow-covered flat plains, to 0.03 m for grass prairies or airports, 0.1 m for open rough areas (short crops and single bushes), 0.25 m for tall crops, 0.5 m for orchards, and ≥ 1 m for villages and forests. In practice, it represents the height at which the wind speed is zero; i.e., $V(z_0) = 0$. The zero-plane displacement raises the log wind profile above the surface by distance d. It is usually specified as about two-thirds of the average height of the obstacles, and typical values range from zero over water, ice, snow, sand and soil, to $<$ 0.07 m for short grasses, $<$ 0.66 m for tall grasses, $<$ 3 m and $<$ 4 m for crops and orchards, $<$ 20 m for deciduous forest and $<$ 30 m for conifer forest. This displacement is typically ignored in WRF, which means we're applying the log wind profile to very well-exposed locations (and presuming the anemometers are well-exposed as well).

The WRF model predicts wind speed (V_a) at the first scalar level, which is height Z_a above the ground (and about 27 m by default). Then, the log wind profile is presumed to be valid between Z_a and the surface (or, technically, to height $z = z_0$), and is used to compute the friction velocity u^*:

$$u^* = \kappa\frac{V_a}{\left[\ln\frac{Z_a}{z_0} - \psi\right]}.$$

In neutral conditions, $\psi = 0$, and thus u^* varies only with the resolved-scale wind at the first scalar level, but is much smaller than V_a itself. Typical values of u^* range from 0 in calm flow, 0.5 m/s with moderate winds and 1 m/s during strong wind conditions.

Finally, the wind at the WMO-standard anemometer height of 10 m above ground level (V_{10}) is then obtained, again by assuming a logarithmic wind profile between the lowest sigma level and the 10 m height:

$$V_{10} = V_a\frac{\ln\frac{10}{z_0} - \psi_{10}}{\ln\frac{Z_a}{z_0} - \psi}.$$

Again, in neutral conditions, $\psi = \psi_{10} = 0$. When applied between two different heights, the friction velocity is not explicitly involved.

If your wind observations are not measured at the 10 m height, then it should be obvious that a further correction is necessary. Say your anemometer height is 6.1 m, as in the SDGE mesonet. The above equation can be reconfigured as

$$V_{6.1} = V_{10} \frac{\ln \frac{6.1}{z_0} - \psi_{6.1}}{\ln \frac{10}{z_0} - \psi_{10}}.$$

Thus, the height correction will (again) depend on stability and surface roughness. For neutral conditions and a roughness length of about 0.25 m, characteristic of shrublands in some land surface models, the correction factor is about 13%.