COMMENTS ON 'SCALING THE ATMOSPHERIC BOUNDARY LAYER'

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Holtslag and Nieuwstadt (1986) (hereafter called HN) review scaling regimes of the idealized atmospheric boundary layer (ABL). Since as the authors admit, their paper is addressed for 'someone not familiar with scaling of the ABL', it seems that it might be useful to supply some additional information. The paper is divided into two parts, one devoted to the stable and another to the unstable regime. Let us start with some comments on the stable ABL.

In the text and in Figures 1 and 2 of HN, the authors list so-called 'scaling parameters' in the ABL. For the stable regime these are:

\[ z, T, w' \theta' \]  \hspace{1cm} (1)

Following Monin and Obukhov (1953), it seems that it would be more educational to call these quantities as 'governing parameters', and use (or display in the figures) scales obtained from (1). All similarity functions in the surface layer are expressed not in terms of the 'governing parameters' but in terms of these scales (e.g., Businger, 1973). In the stable surface layer, the proper scales for velocity, temperature and height are \( u_* \), \( T_* \), and \( L \) (where \( L \) is customarily called the Monin–Obukhov length).

Local scales of the stable regime have the following form:

for velocity \[ U_* = \tau^{1/2}, \]

for temperature \[ t_* = -\frac{w' \theta'}{U_*}, \]  \hspace{1cm} (2)

for length \[ \Lambda = \frac{U_*^2}{\kappa \beta t_*} \]

where \( \kappa \) is the von Karman constant and \( \beta \) is a buoyancy parameter.

Extending the idea of the surface-layer similarity, Sorbjan (1986a, b, c) concluded that any nondimensional (in terms of the above scales) quantity should be a function of...
of dimensionless parameter $z/\Lambda$. For the temperature gradient, for example,

$$\Phi_\theta = \frac{\kappa \Lambda}{T_*} \frac{\partial \theta}{\partial z} = F(z/\Lambda),$$

(3)

where $\Lambda$ is the local Monin–Obukhov length.

When $z/\Lambda \to \infty$ (very stable limit), the turbulence should be independent of $z$, implying that all nondimensional quantities should be constant. In our example, for the function $\Phi_\theta$, we get,

$$\Phi_\theta = c,$$

(4)

where $c$ is constant. Sorbjan (1986a) suggests that $c = 4.7$.

In the stable ABL it is usually assumed that

$$\tau = \tau_0 (1 - z/h)^{\alpha_1},$$

$$\overline{w'\theta'} = \overline{w'\theta_0'} (1 - z/h)^{\alpha_2}.$$

(5)

Coefficients $\alpha_1$ and $\alpha_2$ strongly depend on meteorological conditions. The Minnesota data (Caughey et al., 1979) collected near sunset when the boundary layer is strongly evolving in time give $\alpha_1 = 2$ and $\alpha_2 = 3$ (Sorbjan, 1986a).

The authors mention that Nieuwstadt (1984), for horizontally homogenous and steady conditions, when the cooling rate of the ABL is constant, derived theoretically that $\alpha_1 = \frac{1}{2}$ and $\alpha_2 = 1$. This result was obtained with the assumption that $Ri = Ri_f = 0.2$, where $Ri_f$ is the flux Richardson number. The same assumption leads also to the following result:

$$\frac{L}{T_*} \frac{\partial \theta}{\partial z} = \frac{1}{\kappa} \frac{\text{Ri}}{Ri_f^2} \frac{1}{1 - z/h},$$

(6)

which gives a singularity at the top of the stable ABL. At the same time from (2)–(5) it can be derived that:

$$\frac{L}{T_*} \frac{\partial \theta}{\partial z} = \frac{c}{\kappa} (1 - z/h)^{2(\alpha_2 - \alpha_1)}.$$  

(7)

Formulas (6) and (7) are identical when $\alpha_2 - \alpha_1 = -\frac{1}{2}$ and $c = Ri/Ri_f^2$ (for $Ri = Ri_f = 0.2$, the value of $Ri/Ri_f^2$ is 5, close to the previously suggested value $c = 4.7$). However, to avoid a singularity,

$$\alpha_2 \geq \alpha_1.$$  

(8)

For Cabauw data it seems that $\alpha_2 = \alpha_1 \approx 1$ gives a better result, obeying (8) and fitting the data reasonably well in Figures 9 and 10 of Nieuwstadt (1984).

In HN the quantity $\delta$ is defined as ‘the maximum deviation of the height of the turbulent layer around its mean height $h$, as can be seen from acoustic sounder height-time charts’. This definition implies that $\delta$ is a constant value for a given stable condition. It needs to be clarified why the authors later assume that $\delta$ is a function of height: $\delta \sim \Lambda(z)$ and $\delta = h - z$. 