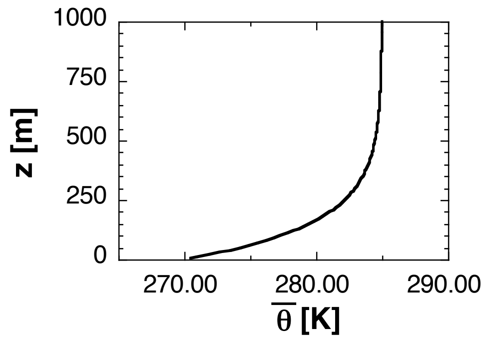
Problems 2 Due: 25 Sept, 2009

In the apple orchards of central Washington, some farmers have large fans (actually propellers) deployed in their fields to inhibit frost formation. Frost is typically a threat on clear nights with little or no wind, and the surface and air just above it cool due to radiation to space. The figure shows a profile of potential temperature $\bar{\theta}(z)$ for such a situation.



When turned on, the fans create turbulence, which affects the mixing coefficients K_m and K_h. Suppose the average eddy size (or mixing length) with the fans off is 10 cm, but with the fans on it is larger.

Challenge: How big should we make the propeller so that enough warm (high potential temperature) air is pulled downward by PBL turbulence to counterbalance the radiative cooling?

Further Assumptions:
(1) Radiative cooling is 1 K/hour at every level in the lowest 100 m.
(2) Vertical turbulent heat flux $\overline{w'\theta'} = 0$ at surface.
(3) Horizontal wind speed is 1 m/s at 100 m and 0 m/s at the surface.
(4) Mixing length is essentially the diameter of the spinning propeller.

(a) Why is this a *stable* PBL?

(b) What must be the magnitude of $\overline{w'\theta'}$ at 100 m so that the downward flux heats the lowest 100 m at the same rate that radiation cools this layer? [Hint: Consider the $\overline{D\theta}/\overline{D}t$ equations we discussed in class. Take the difference between heat flux in at the top minus heat flux out at the bottom, then divide it by the thickness of the layer.]

(c) Estimating dθ/dz from the figure, what must be the value of K_h ?

(d) Using the vertical shear of the wind speed in assumption (3), the mixing length hypothesis, and assumption (4), what is the diameter of the propeller?