Atmospheric Sciences 5220
Exercise 5: Boundary Layer Evolution

Problems:

1. WH problem 9.22
   Note that in WH 9.22(b), "divergence" means horizontal divergence:

   $$\mathrm{div} = \partial u/\partial x + \partial v/\partial y = -\partial w/\partial z.$$

   One can integrate this equation from the surface, where $w = 0$, to the top of the boundary layer, at $z = z_i$ to obtain $w_i \equiv w(z_i)$.

2. WH problem 9.25

3. Sketch profiles of potential temperature and wind speed in the boundary layer during fair weather over land in the summer at the following times of day:
   (a) Mid-afternoon
   (b) Shortly after sunset
   (c) Shortly before sunrise

4. (a) List and describe two similarities and two differences between closed-cell and open-cell convection in marine boundary layers.
   (b) Which of these two cloud regimes would you expect to have the greatest impact on the surface radiation budget? Explain why.

5. The plots on the next page show how the boundary layer height (h), vertically averaged potential temperature (θ), sensible heat flux at the top of the boundary layer (due to entrainment: $F_h \equiv (\overline{w'\theta'})_h$), and surface sensible heat flux ($F_s \equiv (\overline{w'\theta'})_s$) evolve in a cloud-free well-mixed boundary layer over an ocean surface with a fixed potential temperature of $\theta_s = 290$ K and a steady surface wind speed, $V = 5$ m/s. This boundary layer undergoes entrainment into the FA (free atmosphere) which has potential temperature $\theta_{FA} = 292$ K. The "entrainment" flux, F_h, was obtained from the surface flux, F_s, using the flux-ratio method: $F_h = -AF_s = -0.2F_s$.

   (a) What is the formula that relates the entrainment flux, F_h, to the entrainment velocity, w_e and the jump in potential temperture across the boundary layer top, $\Delta\theta = \theta_{FA} - \theta$?

   (b) How can you deduce the entrainment velocity, w_e, from the time series of boundary layer height, $h(t)$?

   (c) Why does w_e decrease with time?

w_e parameterized, w_LS = 0, th_FA = 292