Atm Sci 547 Due Thursday, 26 April 2018

Homework Set 3

1. (Adapted from Arya, p. 180) The following measurements of mean wind and potential temperature were taken around noon during the 1968 Kansas field program:

z (m)	2	4	8	16	32
u (m s^{-1})	5.81	6.70	7.49	8.14	8.66
θ (K)	307.20	306.65	306.28	305.88	305.62

We wish to calculate the surface fluxes of heat and moisture using the Monin-Obuhkov relations $\phi_h = \phi_m^2 = \{1 - 16z/L\}^{-1/2}$ for an unstable surface layer. To proceed:

(a) Calculate the gradients of u and θ by differencing between successive heights. In the surface layer, the profiles tend to vary roughly logarithmically with height, so it is better to difference using ln(z) as the height coordinate. Note that $du/dz = z^{-1}\, du/d(\ln z)$ and similarly for θ. Numbering the levels 1 (2 m) to 5 (32 m), the estimated gradient of u between levels 1 and 2 would be

$$\left(\frac{\Delta u}{\Delta z}\right)_{21} = \frac{1}{z_m}\left(\frac{\Delta u}{\Delta \ln z}\right)_{21} = \frac{1}{z_m}\left(\frac{u_2 - u_1}{\ln z_2 - \ln z_1}\right)$$

at a height z_m such that $\ln z_m = (\ln z_1 + \ln z_2)/2 = (\ln 2 + \ln 4)/2$, i. e. at $z_m = 2.82$ m. This works out to a gradient $(\Delta u/\Delta z)_{12} = 0.45\ s^{-1}$. Neglecting virtual effects on buoyancy, use your calculated gradients to find Ri vs. z.

(b) From this data, estimate the Obukhov length L (note that Ri = z/L in an unstable surface layer).

(c) Using the data from the lowest two heights and your L from (b) , calculate the friction velocity, the sensible heat flux, and the surface roughness length z_0. Does the implied roughness length seem appropriate for a field of wheat stubble? Take the air density = 1.2 kg m^{-3} and $C_p = 10^3$ J kg^{-1} K^{-1}. Can we also estimate the thermal roughness length z_T from the given data?

2. By simultaneously solving Charnock's formula (Eq. 5.8 of notes) and Eqs 5.9-10 for the neutral drag coefficient over the ocean, calculate and plot how C_{DN} varies with 10 m wind speed u_{10} over the range $4 < u_{10} < 20$ m s^{-1}. Also plot the approximation for C_{DN} given in Eq. 5.11; they should agree pretty well.

3. An oceanographic research ship is stationed 100 km off the California coast. At a height z_R = 10 m above sea level, it measures a wind speed of 10 m s^{-1}, an air temperature of 286.9 K (i.e. 287 K if adiabatically displaced to the sea surface), a water vapor mixing ratio of 7.4 g kg^{-1}, and an air density of 1.2 kg m^{-3}. The ocean surface temperature is 284 K and the saturation mixing ratio for salt water at the sea surface is 7.9 g kg^{-1}. We wish to find the surface fluxes. We proceed iteratively, starting by assuming a neutral boundary layer ($\zeta_R = z_R/L = 0$), inferring the fluxes and L, then updating:

(a) Using the bulk aerodynamic approach, with $C_{DN} = (0.75 + 0.067u_{10})\text{x}10^{-3}$, find the neutral surface stress and friction velocity.

(b) Using neutral bulk formulas with $C_{qN} = C_{HN} = 1.3\text{x}10^{-3}$, calculate the surface latent heat flux, sensible heat flux, virtual heat flux, buoyancy flux, and Obukhov length L. Use L to make a new guess at ζ_R; it won't be perfect, but it is good enough for this purpose.

(c) Using this ζ_R in Garratt Fig. 3.7 (shown on page 6 of the Lecture 6 notes; use the $z/z_0 = 10^5$ curve), estimate by what percentage C_D is decreased from C_{DN}.