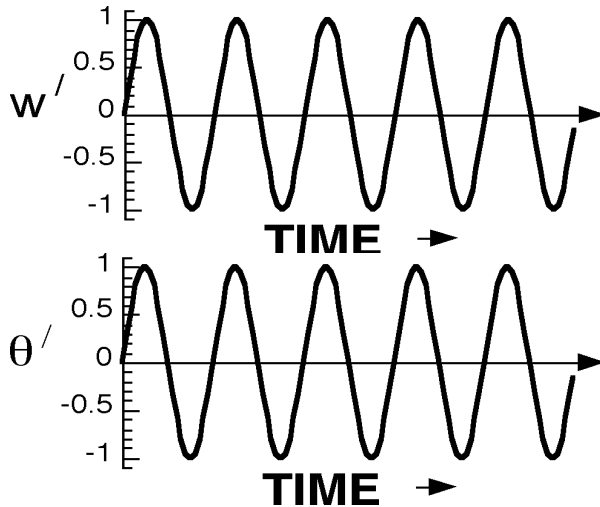


There are three questions, with point values as marked (100 pt. total).



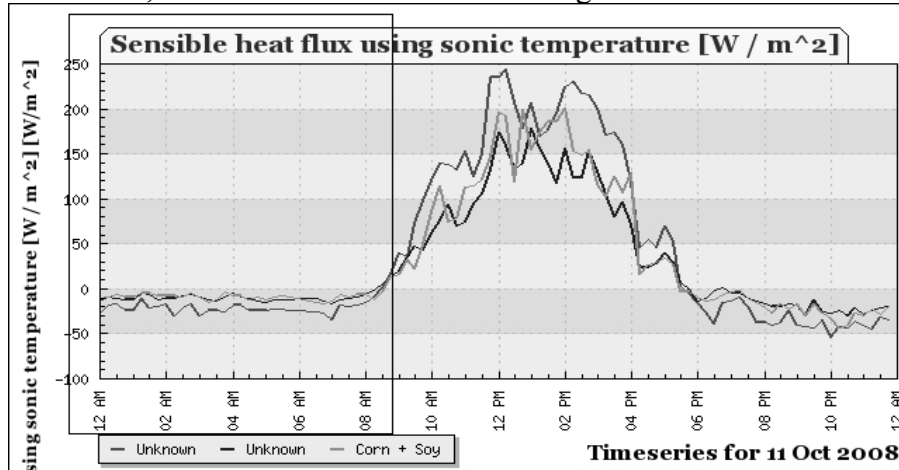
Time allowed: 50 minutes

1. A set of measurements gives the following data for the turbulent vertical motion field w' and the turbulent temperature field θ' :



- (a) [10 points] Will the vertical heat flux given by these measurements be producing positive or negative buoyant production of turbulent kinetic energy? Explain your answer.
- (b) [15 points] If the relationship between w' and θ' depicted above is typical for all levels in the planetary boundary layer, how is the center of mass of the PBL changing?
- (c) [10 points] More specifically, suppose the vertical turbulent heat flux at the surface is $(\overline{w'\theta'})_{sfc} = 0.2 \left[\frac{m}{s} \text{ } ^\circ\text{C} \right]$ and that the PBL is 1 km deep. If the PBL is a *well-mixed layer* so that θ is constant with height and its change with time is also constant with height, what is the value of $\overline{w'\theta'}$ at 800 meters? Explain your answer.

2. During the night, the boundary layer over land is often stable ($d\theta/dz > 0$). Consider the measurements of sensible heat flux ($\overline{w'\theta'}$) at the surface shown below, focusing on the nighttime period 12 am – 6 am, when the flux of heat is into the ground.

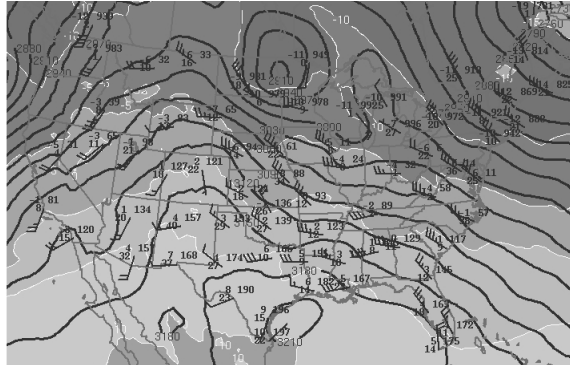


(a) [10 pt] Using a representative value of the observed sensible heat flux during 12 am – 6am, if the eddy diffusivity is $5 \text{ m}^2/\text{s}$, what is the static stability, $d\theta/dz$?

(b) [10 pt] Suppose the mixing length for eddies in this situation is 50 m. What is the vertical shear of the horizontal wind?

(c) [10 pt] Using your representative value of the observed sensible heat flux during 12 am – 6am, if the depth of the boundary layer is 500 m, what is the rate at which this heat flux into the surface is cooling the boundary layer (averaged over the depth of the layer)?

3. Consider the cut-off low appearing in the 700 hPa height field below, in the area of Minnesota and North Dakota. The same pattern appears at 850 hPa and 500 hPa, so we can analyze the flow as barotropic. The vorticity of the cut-off low is $1.1 \times 10^{-4} \text{ s}^{-1}$. For this location, you can assume $f = 1.1 \times 10^{-4} \text{ s}^{-1}$, the depth of the troposphere is 10 km and the boundary layer is approximated by an Ekman layer.



(a) [10 pt] The vorticity of this cut-off low decays at a rate that would reduce it by a factor of $e^{-1} = 0.37$ in 10 days. What is value of the eddy diffusivity?

(b) [10 pt] What is the initial vertical wind speed at the top of the Ekman layer?

(c) [15 pt] Sketch the direction of the surface winds in the vicinity of this low center.

Some random equations

$$\gamma = (f/2K_m)^{1/2}$$

$$u_*^2 = |w'u'|_s \quad d = \pi(2K_m/f)^{1/2}$$

$$\bar{u} = (u_*/k_K) \ln(z/z_o)$$

$$w = \zeta_g |K_m/2f|^{1/2} \frac{f}{|f|}$$

$$\tau_e = H|2/fK_m|^{1/2}$$

$$\frac{D}{Dt} \bar{\theta} = -\bar{w} \frac{\partial \theta_o}{\partial z} - \left\{ \frac{\partial}{\partial x} (\overline{u'\theta'}) + \frac{\partial}{\partial y} (\overline{v'\theta'}) + \frac{\partial}{\partial z} (\overline{w'\theta'}) \right\}$$

$$(\overline{w'\theta'}) = -K_h \frac{d\bar{\theta}}{dz}$$

$$d = \pi(2H\zeta_g/f)^{1/2} \quad BPL = \overline{w'\theta'}(g/\theta_o)$$

$$(\overline{w'u'}) = -K_m \frac{d\bar{u}}{dz}$$

$$K_m = \overline{(\xi')^2} \left| \frac{\partial \vec{V}}{\partial z} \right|$$