Homework V

May 8, 2006. Due May 16th.

Question 1: orographic precipitation

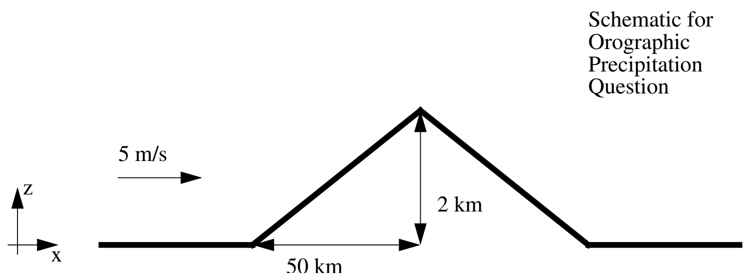

Figure 1:

After you work through this question you can do most of my research. Pay careful attention to units and to whether the answer seems 'reasonable'.

Situation: Assume a steady wind of 5 ms^{-1}, constant in height, and a surface temperature (i.e. $@z = 0$) of 10^oC. The halfwidth of the mountain is 50 km and its height is 2 km. Assume that the incoming air is completely saturated, and remains so as it rises up the windward flank of the mountain. Furthermore, assume pressure can be approximated by $p = p_{sfc}exp(-z/H)$, where H = 8 km and p_{sfc} is the surface pressure. Also assume that the lapse rate on the windward side is a constant -6.5Kkm^{-1} (which reasonable for saturated ascent).

(i) Using the expression for saturated specific humidity, show that the total vapor per unit area, W_{sat}, in an atmospheric column extending from the surface to the top of the atmosphere is approximated by:

$$W_{sat} \simeq \int_{p_{sfc}}^{\infty} -\frac{\epsilon e_{sat}}{gp} dp \tag{1}$$

where e_{sat} is the saturation vapor pressure. W_{sat} is also known, quite sensibly, as the maximum precipitable water.

(ii) Using the expression given in class, find good numbers for $e_{sat}|_{z=0}$ and for H_m in the following approximation to the Clausius-Clapeyron relationship (note you will have to find some sensible approximations):

$$e_{sat}(T) \simeq e_{sat}|_{z=0}\, exp\left[-\frac{z}{H_m}\right] \tag{2}$$

and further show that

$$W_{sat} \simeq \frac{\epsilon \; e_{sat}|_{z=0} \, H_m}{gH} exp\left[-\frac{z_{sfc}}{H_m}\right] \tag{3}$$

and hence note that the saturation vapor pressure at the surface is a proxy for total column water.

(iii) Using the above expression calculate the column integral of water vapor per unit area in m (N.B., make sure units are right!) at the windward foot of the mountain and also at the crest.

(iv) Hence estimate the average rainfall rate in mday^{-1} on the windward flank of the mountain for this situation.

(v) What do you think of this number and this calculation? What are the critical assumptions and what would make it more realistic? Why does it not always rain on the windward side of the Cascades, for example? Try to make a few quantitative estimates of how the approximations made here might affect the answer. Chapters 2 and 4 of Wallace and Hobbs may give you some ideas in answering this.

(vi) Briefly, what would the climate of Eastern Washington look like if the Cascades mountain range were not there? In Summer? In Winter?

Question 2: boundary layers

i) If θ' and q' represent fluctuations in potential temperature and in water vapor specific humidity, derive the following expressions for the vertical flux of heat Q and latent heat, LH, due to turbulent motions

$$Q = \rho c_p \overline{w'\theta'}, LH = \rho L \overline{w'q'} \tag{4}$$

Near the surface E is also the rate of evaporation divided by L. The quantity Q/LH is known as the Bowen ratio, and reflects the relative importance of sensible and latent heat fluxes in balancing the energy budget at the Earth's surface. It varies from ∞ in a desert to about 0.1 over the ocean.

ii) Work through section 9.3 in the textbook. Using the notation and parameter values in that section, find the depth averaged *velocity* in the layer between the surface ($z = 0$) and the approximate boundary layer height ($z = \pi/\gamma$). Hence find the angle between the average flow in the boundary layer and the flow in the free atmosphere above the boundary layer.

Note the answer to this part of the question should be compared with the answer from a previous homework which assumed a 15^o angle between the isobars and the 'typical' wind direction in the boundary layer.

Question 3 - random physics question - order of magnitude estimates

i) it has been said that every breath you take contains several molecules from the dying breath of Julius Caesar. Verify the basis for this statement.

ii) How many molecules from Socrate's cup of hemlock are likely to be contained in the next glass of water you drink?