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METR 4433 – Mesoscale Meteorology
Spring 2017

Problem Set #4
Deep Convective Storms – Part I

Distributed Tuesday, 28 March 2017
Due Thursday, 13 April 2017

INSTRUCTIONS: Please answer each of the questions shown below. Pay close attention to neatness and describe your work at each step of the solution process.

1. Buoyancy Term. The vertical equation of motion in an inviscid, Boussinesq atmosphere is given by

$$\frac{Dw}{Dt} = -\frac{1}{\rho}\frac{\partial p}{\partial z} - g\ .$$

Let the dependent thermodynamic variables be given by

$$p(x,y,z,t) = \bar{p}(z) + p'(x,y,z,t)$$
$$\rho(x,y,z,t) = \rho_o + \rho'(x,y,z,t)$$

where the first terms on the RHS denote the basic state, which is in hydrostatic balance, with a subscript "o" indicating a constant value. Show that the momentum equation can be written

$$\frac{Dw}{Dt} = -\frac{1}{\rho_o}\frac{\partial p'}{\partial z} + g\left(\frac{\theta'}{\bar{\theta}} - \frac{P'}{\bar{\rho} c_s^2} + 0.61 q_v'\right)$$

where q_v is the water vapor mixing ratio, the prime indicates a perturbation from a basic state which is a function only of height, and $c_s^2 = \gamma \bar{P} / \rho_o$ is the square of the speed of sound. HINT: Linearize the pressure gradient force as you did in Problem Set #1 but use the virtual temperature to account for moisture effects.

2. Thermodynamics – Adverse Pressure Gradients in Cloud Updrafts. Consider a hypothetical air parcel that is moving vertically in an atmosphere with a constant potential temperature of 300 K. If the parcel is 4 K warmer than the environment at the ground and rises dry adiabatically, starting from a state of rest, a) Find the vertical velocity of the parcel at an altitude of 4 km; b) What must be the magnitude and direction of the vertical perturbation pressure gradient force per unit mass (units of m s^{-2}) if the parcel attains an upward vertical velocity of 30 m s^{-1} at an altitude of 4 km? c) How long did it take for the parcel to reach an altitude of 4 km?

3. Buoyancy. For the parcel in problem 2, neglecting the term involving the sound speed, determine the liquid water mixing ratio (in g/kg) that would be required to make this parcel neutrally buoyant.

4. CAPE. (a). For the parcel in problem 2, determine the maximum updraft speed at an altitude of 6 km, assuming only contributions from thermal buoyancy. (b). How does the maximum updraft speed change if the perturbation water vapor mixing ratio is 4 g kg^{-1} (neglecting the perturbation pressure gradient force and liquid water loading). (c). Re-do part (b), adding liquid water drag with a liquid water mixing ratio of 2 g kg^{-1} and comment on the results.

5. Surface Cold Pools. A gust front initiated by a decaying thunderstorm is propagating into a calm environment. Compute the surface pressure rise across the front if the ambient surface pressure is 1000 mb, the depth of the density current is 1500 m, the ambient surface temperature is 34C, and the surface temperature within the cold pool is 28C.