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METR 3113 – Atmospheric Dynamics I
Fall 2016

Problem Set #6

Distributed Friday, 28 October 2016
Due Friday, 11 November 2016

INSTRUCTIONS: For each of the problems below, apply all 6 steps in the problem-solving handout. Pay close attention to neatness, and describe your work at each step of the solution process.

1. Total Derivative. A person who recently piloted a balloon around the world (fortunately without crashing!) reported during the early moments of his flight that the air temperature aboard the balloon was falling by 5 C per hour. As the balloon passed overhead, very near the ground, scientists noted from their local mesonet that the north-south temperature gradient was -10 C/100 km. Assuming the temperature at the scientists' location was not changing with time, estimate the speed (m/s) and direction of the balloon to the extent the information given allows.

2. Total Derivative. An observer notes that the temperature at Oklahoma City is falling by 2 C per hour. A strong north-south temperature gradient exists across the state with temperatures increasing toward the south at 5 C/100 km. A howling north wind of 20 m/s is bringing more cold air into Oklahoma. Under the prevailing clear sky conditions, at what rate (in degrees per hour) is the air being heated by the sun?

3. **Vertical Equation of Motion.** The radial pressure gradient force per unit mass at the ground beneath an intense cylindrical wall cloud is 1.3 m/s^2, i.e., the pressure increases away from the center of the wall cloud. **(a).** How long (in minutes) will it take an air parcel, starting from rest a distance of 2 km away from the wall cloud along the storm's inflow tail, to reach the center of the wall cloud? Assume that the parcel moves only horizontally. **(b).** How fast will the parcel be traveling when it reaches the center of the wall cloud?

4. Taylor Series. Assume that the temperature at Norman, Oklahoma is 70F. If the temperature between Norman and Oklahoma City, 40 km to the north, varies exponentially as $T(y) = T_o e^{-0.00001y}$, where T_o is the temperature at Norman (deg C) and y is distance in *meters*,

> **a.** Determine the accuracy of using a Taylor series expansion to estimate the temperature at Oklahoma City using the first one, two, and three terms in the expansion. Compare the estimate with the exact value and comment on the results. Do the estimates change smoothly as you add more terms?
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> **b**. Repeat this same calculation, though for an Oklahoma Mesonet station located only 2 km north of Norman. Again, comment on the results.

5. Mass Continuity Equation. Suppose the surface zonal wind varies as $u(x) = -10^{-3}x$ and the meridional surface wind varies as $v(y) = -3.5 \times 10^{-3} y$, where x and y are specified in inches. **(a).** Is this flow field divergent or convergent? **(b).** Find the vertical velocity 5000 meters above the flat ground if it is zero at the ground. **(c).** Would you say that the flow field is that associated with a cold front or a thunderstorm outflow boundary? Explain your reasoning.

6. Scale Analysis. Referring to Lecture #27, repeat the scale analysis for the horizontal and vertical equations of motion, this time for a thunderstorm instead of a synoptic-scale weather system, using the following characteristic scales. Neglect friction.

L ~ 10 km is the length scale;
H ~ 10 km is the depth scale
U ~ 10 m/s is the horizontal velocity scale
W ~ 1 m/s is the vertical velocity scale
L/U ~ 1000 s is the time scale;
Δp ~10 hPa is the horizontal pressure fluctuation scale
Δp ~100 hPa is the vertical pressure fluctuation scale
ρ ~1 kg m^{-3} is the density scale
F ~ 10-4 is the Coriolis parameter

7. Thermodynamics. An air parcel that has a temperature of 20 C at 1000 hPa is lifted dry adiabatically. What is the density when it reaches 500 hPa?

8. Thermodynamics. Suppose an air parcel starts from rest at 800 hPa and rises vertically to 500 hPa while maintaining a constant 1 C temperature excess over the environment. Assuming that the mean temperature of the 800-500 hPa layer is 260 K, compute the energy released due to the work of the buoyancy force. Assuming that all energy released is realized as kinetic energy of the parcel, what will be the vertical velocity of the parcel at an altitude of 500 hPa?