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METR 3113 – Atmospheric Dynamics I
Fall 2016

Problem Set #7

Distributed Monday, 21 November 2016
Due Monday, 5 December 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 and Geostrophic Wind. Suppose an aircraft is flying a heading of 60 degrees (i.e., 60 degrees to the east of north, or pointing ENE) at an air speed of 200 m/s, and further assume it moves relative to the ground (ground speed and track) due east (90 degrees) at 225 m/s. (a) If the plane is flying at constant pressure, what is the rate of change in altitude (in meters per kilometer of horizontal distance traveled) if the pressure field is steady, the winds are geostrophic, and the Coriolis parameter is constant and equal to $10^{-4}\ s^{-1}$? This is a very important problem because altimeters in airplanes measure pressure altitude, and flying at constant pressure can actually lead to unexpected changes in geometric altitude. HINT: The environmental wind speed, which is geostrophic in this case, is blowing such that the airplane must point its nose to the ENE in order to track perfectly eastward. (b) Under what general conditions do you believe the change in altitude would be much larger, i.e., huge and dangerous?

2. Ageostrophic Wind. Suppose the actual wind is directed 30 degrees to the right of the geostrophic wind. If the geostrophic wind speed is 20 m/s, what is the time rate of change of the wind speed, assuming a constant Coriolis parameter of $10^{-4}\ s^{-1}$?

3. Cyclostrophic Balance/Natural Coordinates. Suppose a tornado rotates with constant angular velocity ω. (a) Show that the surface pressure at the center of the tornado may be written

$$p = p_o\, e^{\left(-\frac{\omega^2 r_o^2}{2RT}\right)}$$

where p_o is the surface pressure a distance r_o from the center, T is the temperature, which is assumed to be constant, and R is the gas constant. (b) If the temperature is 288K and the pressure and wind speed at a distance 100 m from the center are 1000 hPa and 100 m/s, respectively, what is the central pressure? Does this seem reasonable? Why or why not?

4. Mass Continuity Equation. The following wind data were received from 50 km to the east, north, west, and south of an observing station, respectively: 90 degrees and 10 m/s, 120 degrees and 4 m/s, 90 degrees and 8 m/s, and 60 degrees and 4 m/s.
(a) Compute the approximate horizontal divergence at the station. (b) Estimate the vertical velocity 3 km above ground assuming incompressible flow and w = 0 at ground.

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5. Mass Continuity Equation. Suppose the wind speeds in problem 4 are each in error by plus or minus 10%. (a) What would be the percentage error in the computed horizontal divergence in the WORST CASE? (b) For this worst case situation, what would be the vertical velocity at 3 km above ground, assuming incompressible flow? How does this value compare with the answer you obtained in problem 3? Does this surprise you? Why or why not?

6. Thermal Wind. Suppose the mean temperature in the layer between 750 and 500 hPa decreases toward the east by 3 degrees C per 100 km. If the 750 hPa geostrophic wind is from the southeast at 20 m/s, what are the geostrophic wind speed and direction at 500 hPa? Assume a constant Coriolis parameter of 10^{-4} s^{-1}.