AOS 610 GFD I Fall 2018 Prof. Hitchman Name \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Problem Set #2 Due Thursday November 1, 2018

1. (1 pt) *Orbits* An orbit may be defined as occurring when $\vec{g}\_{eff}= \vec{∇} \left(Φ\_{g}+ Φ\_{c}\right)= 0$, where the gravitational and centripetal potential functions are $Φ\_{g}$ = G M/r and $Φ\_{c}= Ω^{2}r^{2}/2$. Solve for the distances r from the center of the earth for an object going around a) once per day and b) once every 28 days.

2. (1.5 pts) *Circulation and vorticity*

a) What is the circulation about a circle of radius 500 km for a cyclonic vortex in the Northern Hemisphere, where the tangential wind speed increases outward at 10 m/s per 100 km?

b) What is the mean relative vorticity in the circle?

c) Evaluate the mean vorticity of the earth itself near the north pole, using the same method for a circle of radius 500 km centered at the north pole, assuming that the earth is in solid body rotation and the angular frequency is $Ω$ = 7.292 x 10-5 s-1.

3. (1.5 pt) *Thickness*

a) Estimate the 1000-500 hPa thickness for an atmosphere with constant lapse rate 6.5 K/km and surface temperature $T\_{o}$ = 273 K.

b) Examine a 1000-500 hPa thickness chart from a weather analysis or numerical forecast, such as a “surface” chart from the NCEP NAM model, at <http://www.aos.wisc.edu/weather/Models>. What is the mean and the range of thickness across the contiguous 48 states? From this, estimate a typical thickness anomaly.

4. (2 pts) *Geostrophic wind and thermal wind*

a) Estimate the geostrophic wind at 4 km over Tateno Japan in Fig. 2 of the article about Ooishi and compare with the radiosonde observations in Fig. 9 (1$°$ latitude = 111 km).

b) Surface winds are calm in Madison, but temperatures in the lower troposphere are observed to increase eastward at 1 K per 100 km. Estimate the wind speed and direction over Madison at 5 km altitude if the surface temperature is 290 K and the lapse rate is adiabatic.

5. (1 pt) *Curvature versus Coriolis*

 Consider the horizontal momentum equations on a sphere with no vertical motion. Calculate the curvature and Coriolis terms for a missile fired from Madison a) toward the west at 1000 m/s. After the missile has gone 100 km, estimate how much and in which direction it is deflected from its original path. b) What if it is fired toward the east?

7. (1 pt) *Tracer continuity equation*

 Ozone mixing ratio is observed to be 50 ppbv in Madison and the wind is from the northeast at 20 knots. Stations along the shore of Lake Michigan, 125 km to the east, report ozone observations of 100 ppbv. A photochemical sink of 2 x 10-4 ppbv s-1 applies throughout Wisconsin. Assuming that ozone only varies in longitude, forecast the ozone mixing ratio 6 hours from now in Madison. (1 m/s $≈$1.94 knots)

8. (2 pts) *Ideal gas law*

a) Linearize the ideal gas law to show that

$$\frac{p^{'}}{\overbar{p}}≈ \frac{ρ^{'}}{\overbar{ρ}}+ \frac{T^{'}}{\overbar{T}}$$

b) The Boussinesq approximation includes the assumption that | $\frac{p^{'}}{\overbar{p}}|\ll |\frac{T^{'}}{\overbar{T}}|$, so that $ \frac{ρ^{'}}{\overbar{ρ}}≈- \frac{T^{'}}{\overbar{T}}$.

By inspecting surface analyses at <http://www.aos.wisc.edu/weather/Models>, choose typical values for synoptic scale variations and evaluate the validity of this assumption for the synoptic scale.