Homework 4: Planetary Atmospheres: Some Basic Dynamics

1) [9 total] If we want to understand the dynamics of a planetary atmosphere we need to quantify atmospheric circulation, i.e. winds. One way to do this is to measure pressure gradients on a planetary surface just as we do with the network of meteorological stations on the Earth. It is proposed that a network of meteorological stations on the surface of Mars measure the large-scale winds from pressure gradients.

(a) Two barometers on Mars are separated along a line of longitude by 300 km in mid-latitudes and measure the surface pressure to an accuracy of ±1 Pa (standard error). What will be the uncertainty in the derived zonal wind speed? For the purpose of this calculation, you may assume geostrophic winds. Also assume that the errors of each barometer are random and uncorrelated. This means that you can propagate errors according to standard simple formulae (e.g., https://en.wikipedia.org/wiki/Propagation_of_uncertainty#Simplification)
(Estimate parameters such as temperature, pressure, and specific gas constant relevant to the surface of Mars.) [4 pts]

(b) The surface network will only provide near-surface winds, i.e. geostrophic winds above the boundary layer. To measure winds higher up, it is proposed that an instrument on an orbiter be used for temperature sounding, i.e. measuring temperature as a function of height. However, the instrument is only good enough to measure the vertical temperature profile with a vertical spatial resolution of 10 km. What is the required accuracy (in K) of the temperature measured with the remote sounder in order to characterize large-scale winds in the lower atmosphere to +/- 3 m/s? (Hint: consider how the hydrostatic equation would be used to derive pressure surfaces and apply calculus to get a ΔT). [5 pts]

2) [4 pts total] Two adjacent cloud bands on Jupiter differ in temperature by 5 K at the same altitude. The temperature change occurs over a 1000-km-wide band near 20°N. How strong a windshear over 1 km of altitude would be developed as a result of this horizontal temperature difference? Take the mean temperature as that at the cloud base. 140 K. You will need to look up other relevant parameters.

3) [3 pts] Hot Jupiter HD209458b has a 3.5-day orbital period, which we assume to be equal to its rotational period. There is contrast in temperature of $\Delta T \sim 300$ K operating over a meridional distance of 100,000 km at mid-latitudes due to day-night differences. Estimate the wind shear (i.e., increase in the square of the zonal wind) between pressure levels of 1 to 0.01 bar at mid-latitudes. If the zonal wind were negligible at 1 bar, what would the zonal wind be at 0.01 bar? Given your result, would you consider the wind speeds on HD209458b to be large, small or unremarkable compared to typical wind speeds on Solar System planets?
[Assume: Radius = $1.35R_J$, where R_J = Jupiter's radius = 69911 km; specific gas constant = 4160 J K^{-1} kg^{-1}. Hint: you can assume slow enough rotation to consider cyclostrophy].

4) [4 pts total] If a ball is thrown a horizontal distance of 100 m at 30° latitude in 4 seconds, what is its sideways deflection due to the rotation of the Earth?

5) [12 total] By considering the balance between the Coriolis force per unit mass, centrifugal acceleration, and pressure gradient force per unit mass, explain why it should be generally true on any planet that highs are regions of gentle winds but lows have strong winds. Start by drawing a diagram with balance of forces for a 'low' at radius r, and another diagram with balance of forces for a 'high' at radius r. Consider using a quadratic in the tangential speed v to justify the argument by thinking about which term or terms must be positive to be real, and a difference in the bounds for pressure gradients around 'low' or 'high' pressure systems. Also explain why the geostrophic wind for lows will necessarily be an overestimate. (Neglect friction).