1. Somewhere (in a galaxy far, far away) there is a planet whose atmosphere is just like that of the Earth in all respects but one—it contains no moisture. The planet’s troposphere is maintained by convection to be neutrally stable to vertical displacements (i.e., an air parcel displaced adiabatically upwards or downwards has the same density as its environment). Its stratosphere is in radiative equilibrium, at a uniform temperature $-80^\circ$C, and temperature is continuous across the tropopause. If the surface pressure is 1000hPa, and equatorial surface temperature is $32^\circ$C, what is the pressure at the equatorial tropopause?

2. Calculate the emission temperature for Mars. The observed mean surface temperature of Mars is about 240K. Comment. [Stefan-Boltzmann constant $\sigma = 5.67 \times 10^{-8}$Wm$^{-2}$K$^{-4}$; solar flux at the mean orbit of Mars = 593 Wm$^{-2}$; planetary albedo of Mars = 0.16; mean Mars surface pressure = 7hPa; the Martian atmosphere is mostly CO$_2$.]

3. Write down the expression for the angular momentum of a ring of air lying along a latitude circle, latitude $\varphi$, moving steadily toward the east with velocity $u$ relative to the earth. Consider what would happen if a force toward the pole were applied and the ring conserved its angular momentum. Calculate the relationship between a small displacement $\delta \varphi$ and the change in the speed of the ring $\delta u$, if the ring conserves angular momentum. How many kilometers northwards does the ring have to be displaced in order to change its relative velocity 10ms$^{-1}$? Comment on your result.

4. Consider the tropical Hadley circulation in northern winter, as shown schematically in fig.1. The circulation rises at 10$^\circ$S, moves northward across the equator in the upper troposphere, and sinks at 20$^\circ$N. Assuming that the circulation, outside the near-surface boundary layer, is zonally symmetric (independent of longitude) and inviscid (and thus conserves absolute angular momentum about the Earth’s rotation axis), and that it leaves the boundary layer at 10$^\circ$S with zonal velocity $u = 0$, calculate the zonal wind in the upper troposphere at (a) the equator, (b) at 10$^\circ$N, and (c) at 20$^\circ$N.
5. Define the geostrophic wind: describe the balance of forces it represents, and state the conditions under which it should be a good approximation to the actual wind.

Draw schematic diagrams analogous to Fig.6.14 of our notes, showing the geostrophic flow and corresponding balance of forces around centers of low and high pressure in a system in which the rotation vector, \( \Omega \), points in the same direction as gravity, \( g \).

Explain the connection to southern hemisphere meteorology.

6. The vertical average (with respect to log pressure) of atmospheric temperature below the 200hPa pressure surface is about 265K at the equator and 235K at the winter pole. Calculate the equator-to-winter-pole height difference on the 200hPa pressure surface, assuming surface pressure is 1000hPa everywhere. Assuming that this pressure surface slopes uniformly between 30° and 60° latitude and is flat elsewhere, use Eq.(6.58) of our notes to calculate the mean eastward geostrophic wind on the 200hPa surface at 45° latitude in the winter hemisphere.