12.003 Physics of Atmospheres and Oceans

Problem Set 4: Horizontal structure of the atmosphere and the Hadley Circulation

Due date: Friday 19th October, 2007

1. Read again Chapter 3 and 5 of our notes.

2. 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^o and 60^o latitude and is flat elsewhere, use the geostrophic wind relationship (zonal component) in pressure coordinates,

$$u = -\frac{g}{f}\frac{\partial z}{\partial y} \ .$$

   to calculate the mean eastward geostrophic wind on the 200hPa surface at 45^o latitude in the winter hemisphere. Here $f = 2\Omega \sin(lat)$ is the Coriolis parameter, g is the acceleration due to gravity, z is the height of a pressure surface and $dy = a \times d(lat)$ where a is the radius of the earth is a northward pointing coordinate.

3. Write down the expression for the angular momentum of a ring of air lying along a latitude circle, latitude φ, 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 δu, 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°S, moves northward across the equator in the upper troposphere, and sinks at 20°N. Assuming that the circulation, outside the near-surface boundary layer, is zonally symmetric (independent of x) and inviscid (and thus conserves absolute angular momentum about the Earth's rotation axis), and that it leaves the boundary layer at 10°S with zonal velocity $u = 0$, calculate the zonal wind in the upper troposphere at (a) the equator, (b) at 10°N, and (c) at 20°N.

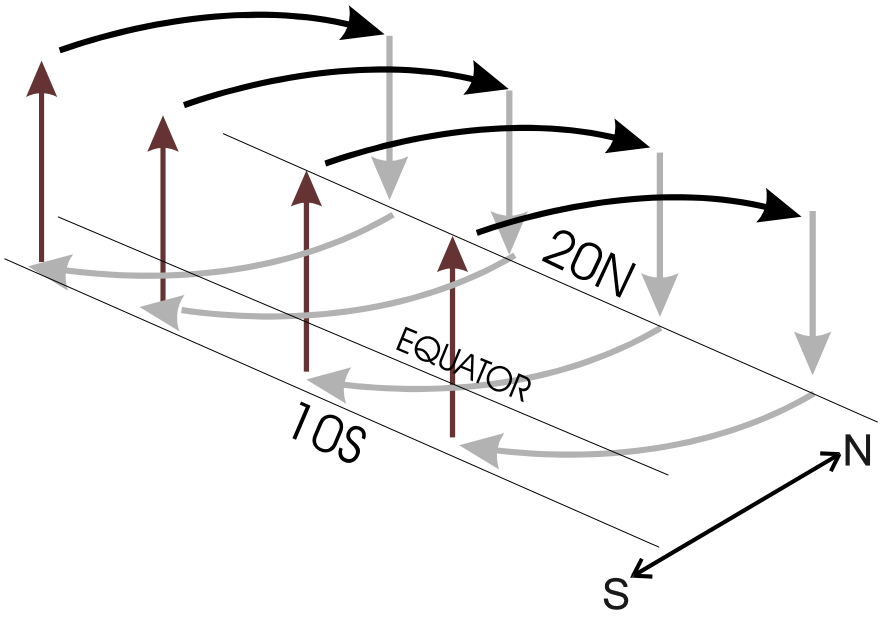

Fig.1