PROBLEM SET ON ATMOSPHERIC AND OCEANIC CIRCULATIONS

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1. Dynamics of an off-equatorial Hadley cell

The latitude of the ascending branch of the Hadley cell varies depending on season. Consider the cross-equatorial Hadley cell during December-January-February (DJF): Air ascends at 10°S, moves northward across the equator, and descends at 20°N.

(1) Assuming that the upper-tropospheric zonal wind u is zero at 10°S and that angular momentum is perfectly conserved, calculate the upper-tropospheric zonal wind at (i) the equator, (ii) 10°N, and (iii) 20°N. In each case give a qualitative explanation in terms of distance to the rotation axis for the changes in magnitude and/or sign of the wind.

(2) Compare your answers with the mean zonal winds in the upper troposphere (e.g. at a pressure of 500mb) during DJF. Is angular momentum conserved in the upper branch of the Hadley cell? If not, discuss possible reasons why. You can plot various atmospheric quantities, including zonal wind, using the NOAA Earth System Research Laboratory's web interface: `https://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage.pl`

2. Water cycle in a changing climate

Understanding future changes in the Earth's water cycle is an important but challenging question for climate scientists. As discussed in class, the water cycle is commonly quantified as the precipitation minus evaporation ($P-E$). In the 'wet' tropics and extratropics $P-E>0$, and in the 'dry' subtropics $P-E<0$. Make predictions (if possible quantitative predictions!) for how the following changes in temperature and winds will impact the water cycle in wet and dry regions:

(1) *Temperature change:* How will $P-E$ change if global temperature increases by 1K? Hint: Consider what this temperature increase implies for atmospheric moisture content using the Clausius-Clapeyron relationship (you may assume that relative humidity is constant).

(2) *Wind change:* How will $P-E$ change as a function of latitude if all winds: (a) decrease in speed by 5%, and (b) shift poleward by 1°?

3. Ekman transport in the ocean

The zonal wind stress of the Equatorial trade winds at 5°N (see Figure 1) is of the order $-0.1\,\mathrm{Nm}^{-2}$. Assuming an Ekman depth of 50m, calculate the northward meridional Ekman velocity v_e. Then, assuming a width of $8,000$km, how much water flows northward in the

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Ekman layer? Express your answer in "Sverdrups" where $1Sv = 10^9$kg/s and compare it with the mass transport of the Hadley cell.

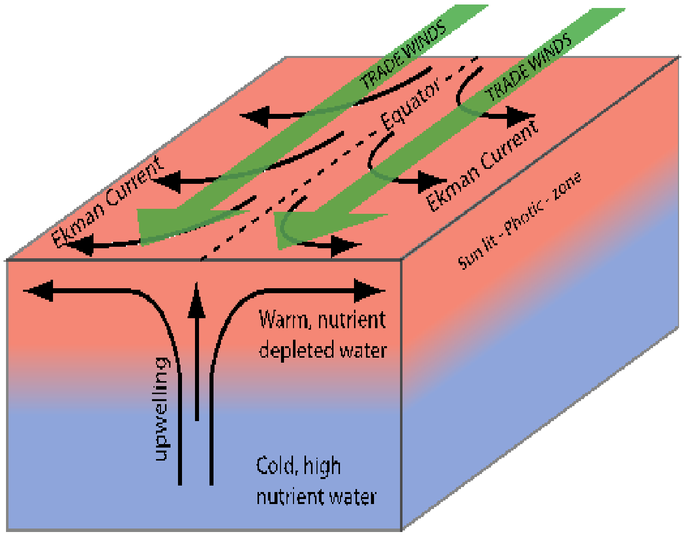

FIGURE 1. A schematic of the upper layer circulation of the ocean at low latitudes.