12.812: Problem set 2

Due in class on October 17th, 2019

Need help?: Office hours Wednesday 11am-noon; Also email or drop by as needed.

Collaboration is allowed, but write up the solution on your own. Show all work. Give units for all numerical results. Put axis labels and units on any graphs.

1. **Contributions to the poleward energy flux in different climates**

   (a) Eddy sensible and latent heat fluxes contribute strongly to the poleward energy transport in midlatitudes. Write expressions for the poleward eddy sensible heat flux ($c_p\overline{v'T'}$) and the poleward eddy latent heat flux ($L\overline{v'q'}$) assuming that these fluxes are approximately diffusive along constant pressure surfaces. Then, by neglecting meridional variations in mean relative humidity, write an expression for the ratio of the latent to dry sensible heat fluxes in terms of the derivative of saturation specific humidity with respect to temperature ($\partial q_s/\partial T|p$).

   (b) Taking mean temperatures at 50 degrees latitude and 800 hPa as representative for midlatitude fluxes, make an estimate for this flux ratio in the present climate. To evaluate $\partial q_s/\partial T|p$ you may use simplified expressions for the saturation specific humidity $q_s \simeq \epsilon\, e_s/p$ and the saturation vapor pressure $e_s \simeq e_0 \exp(-L/R_v[1/T - 1/T_0])$ where $T_0 = 273.16K$, $e_0 = 610.78$Pa, $L = 2.5 \times 10^6$ J/kg, and $R_v = 461.5$ J/kg/K. Estimate how much the ratio would change in an ice-age climate (temperatures lower by 5K) and in a hothouse climate (temperatures higher by 10K).

2. **Simple estimate of the magnitude and latitude of peak poleward energy flux**

   Assume that the zonal and time mean planetary albedo and outgoing longwave radiation (OLR) are constant with respect to latitude, and that the zonal and time mean incident solar radiation is given by

$$[\overline{S}] = \frac{S_0}{4}(1 + S_2 P_2),$$

   where $P_2 = (3x^2 - 1)/2$, $x = \sin\phi$, and ϕ is latitude. Derive an expression for the mean poleward energy flux of the atmosphere-ocean system at equilibrium in terms of S_0, S_2, the albedo α, and the latitude ϕ.

   (a) At what latitude does the flux peak?

   (b) Further assuming S_2=-0.5 and picking a representative value for planetary albedo, what is the magnitude of the poleward energy flux at the latitude where it reaches its peak?

(c) How do these values of the peak flux and its latitude compare with observational estimates in each hemisphere? Comment on the implications of your comparison.

3. **Meridional versus zonal energy transport**

   In class, we considered the decomposition of the meridional energy transport in terms of (a) the types of circulation contributing to it (e.g., eddies versus mean) and (b) the division into components associated with temperature, geopotential height, latent heat, and kinetic energy (including the possibility of compensating fluxes). Now consider the same decompositions but for zonal energy transports. Describe the ways in which you would expect the relative importance of the contributions to be similar or different for the meridional and zonal energy transports. (Hint: Pay particular attention to the role of the mean flow and the contribution from the geopotential term.)