SIO 217B Atmospheric and Climate Sciences II

Exercise #17

1. a) Write down an equation for calculating horizontal advection of relative vorticity from zonal and meridional wind components in spherical coordinates.

   b) An examination of the ζ_{500} pattern in Exercise #15 indicates that it has structure on the scale of a few hundred km. For wind speeds on the order of 50 m s^{-1}, this corresponds to an advection time scale of only a couple hours, which is incommensurate with the half-day time scale over which we have calculated local tendencies (e.g., Exercises #6 and #14). For this reason, I have used spherical harmonics to remove structure at scales smaller than 5 degrees of latitude and longitude. Download files containing *smoothed* ζ_{500}, *smoothed* u_{500}, and *smoothed* v_{500} for 1993 March 14 00Z and divide ζ_{500} by 10 to convert to units of 10^{-5} s^{-1}. Calculate horizontal advection of relative vorticity in units of 10^{-5} s^{-1} day^{-1}. Plot contours of relative vorticity overlaid by wind vectors in the domain 20-50°N, 270-310°E using intervals of 5 (actually 5×10^{-5} s^{-1}). Add contours of horizontal relative vorticity advection using intervals of 10 (actually 10×10^{-5} s^{-1} day^{-1}).

2. a) Write down an equation for calculating horizontal advection of planetary vorticity from zonal and meridional wind components in spherical coordinates.

   b) Calculate horizontal advection of planetary vorticity in units of 10^{-5} s^{-1} day^{-1}. Plot contours of planetary vorticity overlaid by wind vectors in the domain 20-50°N, 270-310°E using intervals of 1 (actually 1×10^{-5} s^{-1}). Add contours of horizontal planetary vorticity advection using intervals of 2 (actually 2×10^{-5} s^{-1} day^{-1}). Note that planetary vorticity advection is much smaller than relative vorticity advection for waves of this spatial scale.

   c) Briefly explain what governs the location of regions of cyclonic and anticyclonic advection of planetary vorticity.

3. a) Download the files containing *smoothed* ζ_{500} for 1993 March 13 18Z and March 14 06Z and divide by 10 to convert to units of 10^{-5} s^{-1}. Calculate the average local rate of relative vorticity change (Eulerian frame of reference) between these two times (as in Exercises #6 and #14). Plot the results in the domain 20-50°N, 270-310°E using intervals of 10 (actually 10×10^{-5} s^{-1} day^{-1}). Add wind vectors and contours of relative vorticity for 1993 March 14 00Z using intervals of 5 (actually 5×10^{-5} s^{-1}).

   b) Briefly explain the spatial relationship between wind direction, locations of strong cyclonic/anticyclonic relative vorticity, and locations of maxima in the local rate of change of relative vorticity.

4. One of the terms in the horizontal vorticity equation is $-f\,\nabla\cdot\boldsymbol{V}$. Download the file containing *smoothed* $\nabla\cdot\boldsymbol{V}_{500}$ for 1993 March 14 00Z and divide by 10 to convert to units of 10^{-5} s^{-1}. Plot wind vectors and $\nabla\cdot\boldsymbol{V}_{500}$ in the domain 20-50°N, 270-310°E using intervals of 10 (actually

10×10^{-5} s^{-1}). Calculate $-f\,\nabla\cdot\boldsymbol{V}_{500}$ in units of 10^{-5} s^{-1} day^{-1}. Add contours of $-f\,\nabla\cdot\boldsymbol{V}_{500}$ to the plot using intervals of 10 (actually 10×10^{-5} s^{-1} day^{-1}).

5. Another term in the horizontal vorticity equation is $-\zeta\,\nabla\cdot\boldsymbol{V}$. Calculate $-\zeta_{500}\nabla\cdot\boldsymbol{V}_{500}$ in units of 10^{-5} s^{-1} day^{-1} (be mindful of the units of ζ_{500} and $\nabla\cdot\boldsymbol{V}_{500}$ when you multiply them) and plot the results in the domain 20-50°N, 270-310°E using intervals of 10 (actually 10×10^{-5} s^{-1} day^{-1}). Add wind vectors and contours of relative vorticity for 1993 March 14 00Z using intervals of 5 (actually 5×10^{-5} s^{-1}). Think about why regions of cyclonic and anticyclonic $-\zeta_{500}\,\nabla\cdot\boldsymbol{V}_{500}$ occur where they do.

6. a) Write down an equation for calculating the rate of change of absolute vorticity experienced by air parcels as they move around in the Lagrangian frame of reference, assuming that vertical advection of vorticity is zero (e.g., $D_h\eta_{500}/Dt$).

   b) Apply this equation to the data obtained above for 1993 March 14 00Z, and plot the results in the domain 20-50°N, 270-310°E using intervals of 10 (actually 10×10^{-5} s^{-1} day^{-1}). Calculate $-\eta_{500}\nabla\cdot\boldsymbol{V}_{500}$ and add to the plot using intervals of 10 (actually 10×10^{-5} s^{-1} day^{-1}). Regions of cyclonic and anticyclonic $D\eta_{500}/Dt$ and $-\eta_{500}\nabla\cdot\boldsymbol{V}_{500}$ do not exactly coincide (as would be expected from the horizontal vorticity equation) due to finite difference approximations and the exclusion of the vertical advection, tilting, and solenoidal terms.