

Note: this homework builds on the 1<sup>st</sup> one. The geopotential field and all constants are the same.

$$\phi = \phi_o(p) + cf_o \left[ -y \left( 1 + \cos\left(\frac{\pi p}{p_o}\right) \right) + \frac{\sin k(x - ct)}{k} \right] \quad (1)$$

1. (20 pts) Use the quasigeostrophic vorticity equation (6.19 in Holton) to find an analytic expression for horizontal divergence ( $-\frac{\partial \omega}{\partial p}$ ). For simplicity, assume  $df/dy=0$ . Plot the divergence at 250 hPa, e.g. as dashed contours on top of the 250 hPa GPH field (solid contours). By hand, please mark regions of “DIV” and “CONV”. (**Fig 1**)
  
3. (20 pts) Differentiate  $-\frac{\partial \omega}{\partial p}$  from  $p_o$  to  $p$ . Set  $\omega(p_o)=0$ . Write the expression for  $\omega$  and calculate and plot  $\omega$  at 500 hPa (dashed lines). Again overlay the GPH (solid lines) so you can see the trof and ridge lines. Mark the figure by hand with “UP” and “DOWN”, indicating regions with rising/sinking motion. Interpret the vertical velocity pattern in terms of the QG vorticity equation. (**Fig 2** – use the title “500 hPa omega from QG vorticity”)
  
4. (10 pts) Use the thermodynamic energy equation (6.13b in Holton) to obtain an expression for  $\omega$ . Assume that  $J=0$  (no diabatic heating) and that  $\sigma$  is constant.
  
5. (20 pts) Compute and plot the vorticity advection by the thermal wind (right-hand side of eqn 6.36 in Holton), at 500 hPa (dashed). Again assume that  $df/dy=0$ , and overlay the GPH field at 500 mb (solid contours). Mark the regions of “PVA” and “NVA” by the thermal wind. (**Fig 3**)
  
6. (20 pts) Use the approximate omega equation (6.36 in Holton) to find an expression for  $\omega$ . Remember that the functional expression of  $\omega$  will look the same as the right hand side of 6.36, i.e. you can use the RHS to determine what  $\omega$  should look like, and then plug it into 6.36. Again assume that  $df/dy=0$ . Use  $\sigma=2.5 \cdot 10^{-6} \text{ m}^2\text{Pa}^{-2}\text{s}^{-2}$ . Plot  $\omega$  at 500 hPa (dashed lines), again superimposed with GPH contours (solid lines). Mark regions of “UP” and “DOWN” ward motion. Interpret these results in terms of the trof/ridge pattern, and the PVA/NVA (by the thermal wind) patterns plotted for question 5. Go back to your Figs in HW1, and see whether the classic omega interpretation applies, i.e. whether rising motion occurs in regions of PVA (by the geostrophic wind) at 250 hPa and/or warm-air advection at 750 hPa. (**Fig 4** – use the title “500 hPa omega from approx omega eqn”)
  
7. (10 pts) For what value of zonal wavelength  $L$  ( $L=2\pi/k$ ) is this expression for  $\omega$  in question 4 the same as the  $\omega$  obtained in question 3? Check whether for this value of  $L$ , the expression for  $\omega$  in question 6 is also the same.