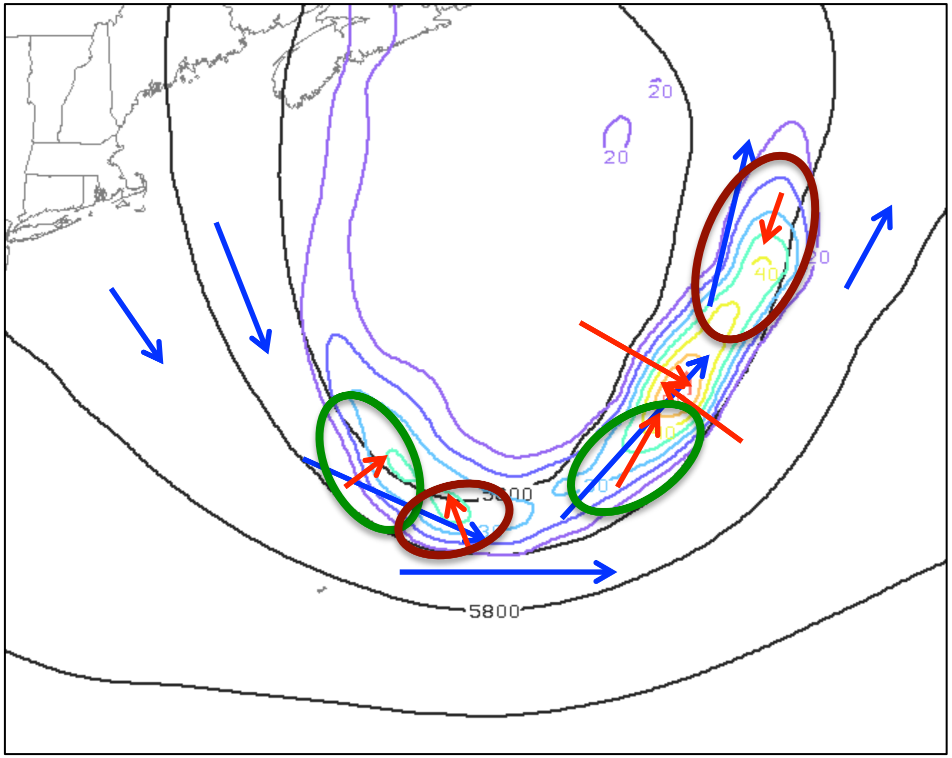

Figure 1: The 850 to 400 hPa thickness (m, black) and 850 to 400 hPa average absolute geostrophic vorticity (x10^{-5} s^{-1}, colors).

1. Use the Sutcliffe-Trenberth version of the QG-omega equation to identify regions of upward and downward vertical motion in Fig. 1.

Thermal wind vectors

Gradient of the 850 to 400 hPa average absolute geostrophic vorticity vectors

UVM

DVM

Sutcliffe-Trenberth version of the QG omega eq.

$$\sigma\left(\nabla^2 + \frac{f_o^2}{\sigma}\frac{\partial^2}{\partial p^2}\right)\omega \approx 2\left[f_o \frac{\partial \vec{V}_g}{\partial p} \bullet \nabla\left(\zeta_g + f\right)\right]$$

Sutcliffe-Trenberth version of the QG omega eq. tells us that if the thermal wind vector and gradient of the abs. geostrophic vorticity vectors are in the opposite (same) direction, then we have UVM (DVM) in that region

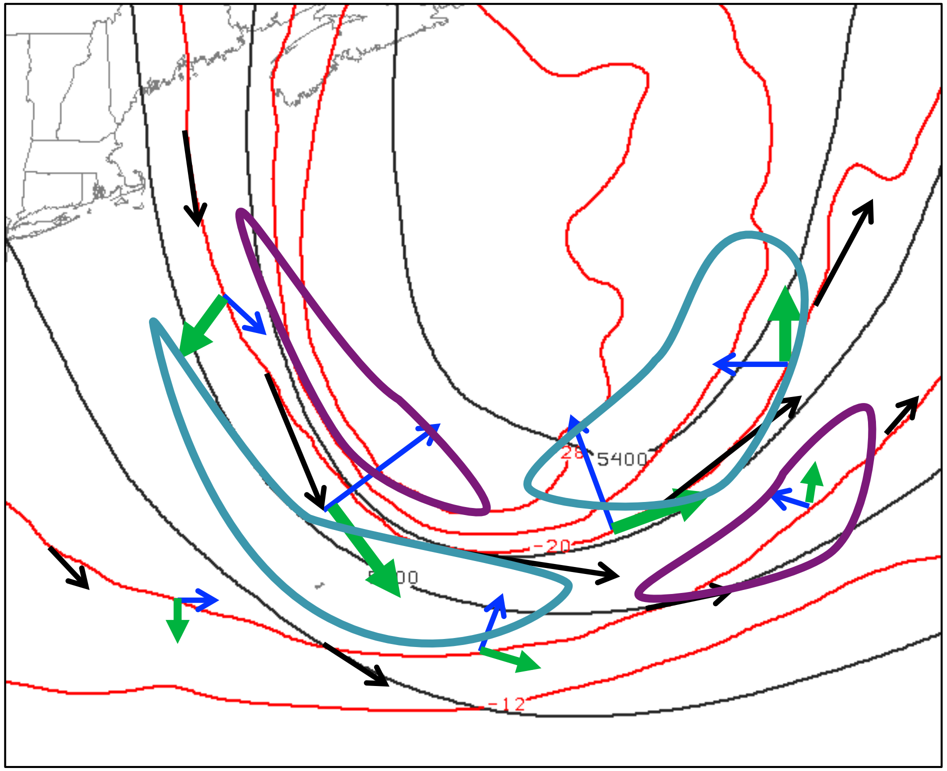

Figure 2: The 500 hPa geopotential height (m, black) and temperature (˚C, red).

2. Draw several Q-vectors in Fig. 2 and identify regions of upward and downward motion.

Geostrophic wind vector

$\frac{\partial \vec{V}_g}{\partial s}$ Vector (where the s-dir is along the isotherms with cold air to the left)

Q-vectors, where Q is defined as:

$$\vec{Q} = -\frac{R}{P}\left|\frac{\partial T}{\partial n}\right|\left[k \times \frac{\partial \vec{V}_g}{\partial s}\right]$$

The Q-vector version of the QG omega equations tells us that twice the convergence of the Q vector describes regions of vertical motion, with:

- convergence of Q associated with UVM (regions marked by →)
- divergence of Q associated with DVM (regions marked by →)

$$\sigma\left(\nabla^2 + \frac{f_o^2}{\sigma}\frac{\partial^2}{\partial p^2}\right)\omega = -2\nabla \bullet \vec{Q}$$

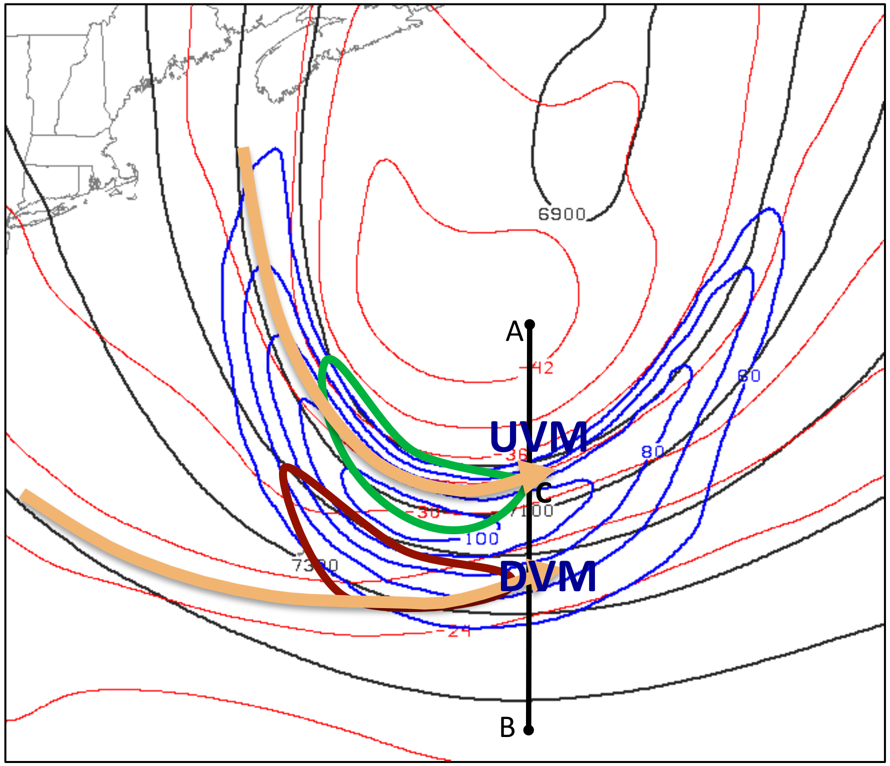

Figure 3: 400 hPa geopotential height (m, black), temperature (˚C, red) and geostrophic wind speed (m s^{-1}, blue). A cross section along the line A-B is shown in Fig. 4.

3. Apply *your favorite* version of the QG-omega equation to identify the circulations in the jet entrance/exit regions in Fig. 3.


Max in cyclonic vorticity (from shear and curvature)


Max in anticyclonic vorticity (mainly from shear)

Sutcliffe-Trenberth version of the QG omega eq.

$$\sigma\left(\nabla^2 + \frac{f_o^2}{\sigma}\frac{\partial^2}{\partial p^2}\right)\omega \approx 2\left[f_o \frac{\partial \vec{V}_g}{\partial p} \bullet \nabla\left(\zeta_g + f\right)\right]$$

Sutcliffe-Trenberth version of the QG omega eq. tells us that if the thermal wind vector and gradient of the abs. geostrophic vorticity vectors are in the opposite (same) direction, then we have UVM (DVM) in that region.

In this figure → Thermal Wind is parallel to the isotherms. In the exit region, where we have cyclonic (anticyclonic) vorticity advection by the thermal wind → UVM (DVM)

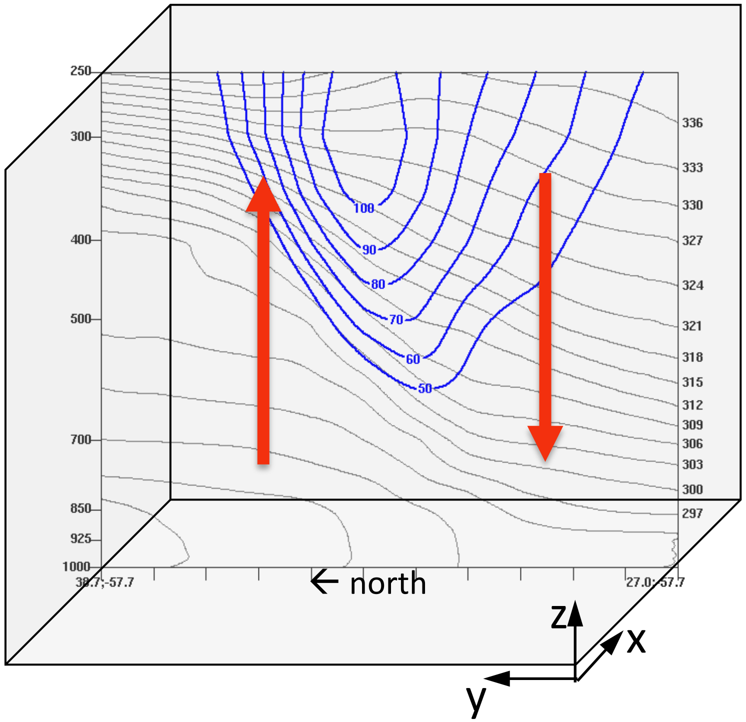

Figure 4: A cross section along the line A-B in Fig. 3, showing potential temperature (K, gray) and geostrophic wind speed (m s^{-1}, blue). The dashed line represents the exact location of the line in Fig. 3.

4. Using your analysis of the jet exit region circulation in (3), label regions of expected upward/downward vertical motion in the cross section and determine the sign of the thermal circulation.

→ Warm air sinking and cold air rising is what we saw from our results from question 3.

→ This type of circulation is thermally indirect.

The vorticity eq tilting term:

$$\frac{d\left(\varsigma + f\right)}{dt} \approx -\left(\frac{\partial w}{\partial x}\frac{\partial v}{\partial z} - \frac{\partial w}{\partial y}\frac{\partial u}{\partial z}\right)$$

$$\frac{d\left(\varsigma + f\right)}{dt} \approx -\left((0) - (+)(+)\right) \rightarrow -(-) = (+)$$

The vorticity will increase with time as a result of the tilting in the jet exit region