1. Prove that the "shearing over the surface wind" term shows that surface high pressure systems (represented by the dot in the center of the isobars below) propagate in the direction of the vertical shear. Use the idealized scenario below to show your work:

\[
\begin{align*}
\frac{\text{d} \mathbf{V}}{\text{d}t} - \left( \frac{\text{d} \mathbf{V}}{\text{d}t} \right)_0 &= \mathbf{V}_s \cdot \nabla \mathbf{V}_s + \left[ \frac{\text{d} \mathbf{V}_s}{\text{d}t} \right] \\
\text{Shearing over the surface wind} &= \left( \mathbf{u}_s \frac{\partial v}{\partial x} + \mathbf{v}_s \frac{\partial u}{\partial y} \right) + \left( \mathbf{u}_s \frac{\partial v}{\partial x} + \mathbf{v}_s \frac{\partial u}{\partial y} \right) + \nabla (\mathbf{u}_s \mathbf{v}_s)
\end{align*}
\]

Thickness from 1000-500 hPa

2. In Sutcliffe's derivation of what we now know as the "Sutcliffe Development Theorem" we took the Laplacian of a set of term that involved both the column average geostrophic wind and the thermal wind. The following is an example of one of the terms in Sutcliffe's derivation:

\[
\nabla^2 (\mathbf{u}_s \mathbf{v}_s) = \frac{\partial}{\partial x} \left[ \frac{\partial (\mathbf{u}_s \mathbf{v}_s)}{\partial x} \right] = \mathbf{u}_s \frac{\partial^2 \mathbf{v}_s}{\partial x^2} + 2 \frac{\partial \mathbf{u}_s}{\partial x} \frac{\partial \mathbf{v}_s}{\partial x} + \mathbf{v}_s \frac{\partial^2 \mathbf{u}_s}{\partial x^2}
\]

Sutcliffe, however, neglected the collective group of terms that involved the product of derivatives — these terms are called the deformation terms.

a. Identify the deformation term in the above expression.

b. Describe the characteristics of a flow that would lead to the deformation term being greater than 0.

c. Draw an example of the flow that you described in (b).

Deformation term: \(2 \frac{\partial \mathbf{u}_s}{\partial x} \frac{\partial \mathbf{v}_s}{\partial x}\)

One example to make this term positive: \(\frac{\partial \mathbf{u}_s}{\partial x} > 0\) and \(\frac{\partial \mathbf{v}_s}{\partial x} > 0\)

Collected avg \(u_s\) increases in x-dir and y component of the thermal wind increases in x-dir. Since the thermal wind is related to column avg T \(\rightarrow\) we need the column avg temp. gradient to increase in the x-dir.

Description: Increasing cold air advection in a jet advection region by the column avg wind.