ESCI 342 – Atmospheric Dynamics I
Lesson 9 – Thermal Wind

Suggested Reading: Martin, Section 4.3

THERMAL WIND

- The geostrophic wind in pressure coordinates is

$$\vec{V}_g = \hat{k}\times\frac{g_0}{f}\nabla_p Z \quad \textbf{(1)}$$

- The difference in geostrophic wind between two levels is

$$\vec{V}_{g2}-\vec{V}_{g1}=\frac{g_0}{f}\hat{k}\times\nabla_p Z_2-\frac{g_0}{f}\hat{k}\times\nabla_p Z_1=\frac{g_0}{f}\hat{k}\times\nabla_p\left(Z_2-Z_1\right)$$

  or

$$\vec{V}_{g2}-\vec{V}_{g1}=\frac{g_0}{f}\hat{k}\times\nabla_p Z_\Delta, \quad \textbf{(2)}$$

  where

$$Z_\Delta = Z_2 - Z_1 \quad \textbf{(3)}$$

  is the geopotential thickness between layers 2 and 1.
- This shows that the difference between the geostrophic wind at two layer is parallel to the contours of thickness.
- Substituting the hypsometric equation

$$Z_\Delta=\frac{R_d}{g_0}\ln\left(\frac{p_1}{p_2}\right)\overline{T} \quad \textbf{(4)}$$

  into (2) shows that the difference in geostrophic wind is parallel to the contours of layer average temperature,

$$\vec{V}_{g2}-\vec{V}_{g1}=\frac{R_d}{f}\ln\left(\frac{p_1}{p_2}\right)\hat{k}\times\nabla_p\overline{T}\,. \quad \textbf{(5)}$$

- Since the difference in wind is parallel to the layer-mean isotherms, it is commonly referred to as the *thermal wind*, and denoted as $\vec{V}_T$ so that we have two equivalent expressions for the thermal wind,

$$\vec{V}_T=\frac{g_0}{f}\hat{k}\times\nabla_p Z_\Delta \quad \textbf{(6)}$$

  or

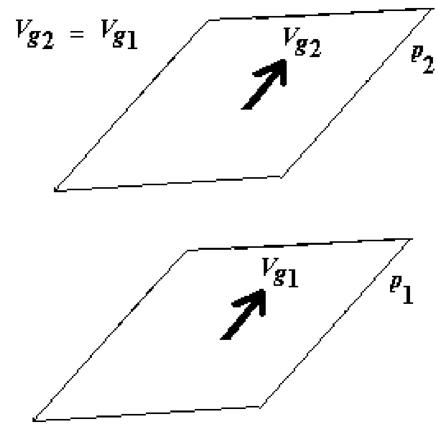
$$\vec{V}_T=\frac{R_d}{f}\ln\left(\frac{p_1}{p_2}\right)\hat{k}\times\nabla_p\overline{T}\,. \quad \textbf{(7)}$$

- Rules for the thermal wind
  - The thermal wind is parallel to the thickness lines with low thickness to the left.
  - The stronger the thickness gradient, the stronger the thermal wind.
- The rules for the thermal wind are analogous to those for the geostrophic wind, except that thickness is substituted for geopotential height.
- If you add the thermal wind to the geostrophic wind at the lower layer, you will get the geostrophic wind at the upper layer.
- Like the geostrophic wind, ***the thermal wind is a definition.***

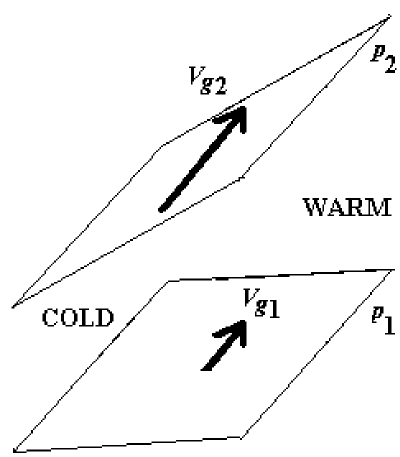
- o The actual difference between the wind at two levels will equal the thermal wind, only if the actual winds at the two levels are geostrophic. However, since the atmosphere is usually close to geostrophic balance, the thermal wind is a good approximation to the actual difference in wind between two levels.

PHYSICAL EXPLANATION OF THERMAL WIND

- The physical basis for the thermal wind can be explained as follows.
- First, remember that on a constant pressure surface the geostrophic wind is normal to the height gradient, and the speed is proportional to the slope of the pressure surface.
- Second, remember that the thickness between two pressure surfaces is proportional to the average temperature in the layer.
- If there is no thermal gradient in the layer, an upper level-pressure surface will be sloped the same as the lower-level pressure surface, and so the geostrophic wind on each surface will be identical.

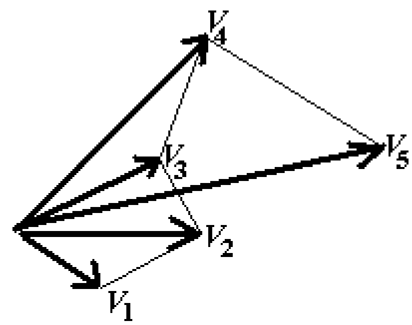


- If there is a thermal gradient in the layer, the upper-level surface will have a different slope than the lower-level surface, and therefore a different geostrophic wind.

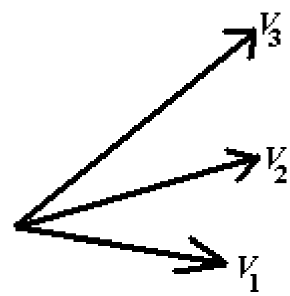


BACKING AND VEERING WINDS

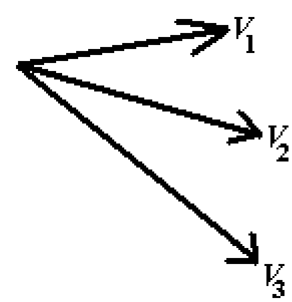
- A *hodograph* is a graph made by placing the tails of the wind vectors at different levels together, and then drawing a line that sequentially connects their heads in ascending order (see example below)



- *Backing winds* are winds whose vectors rotate counter-clockwise (either with time or with height).



- *Veering winds* are winds whose vectors rotate clockwise (either with time or with height).

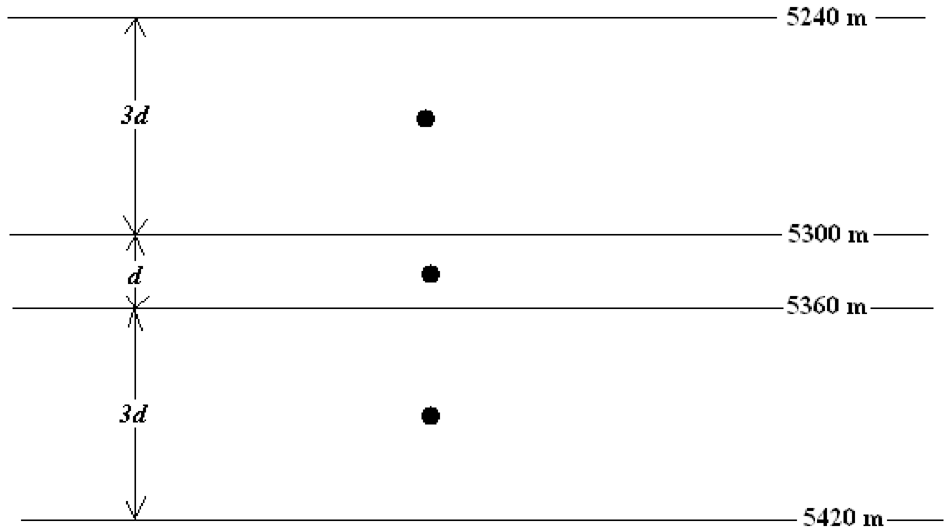


- The thermal wind leads to the following relations between the winds on a hodograph and temperature advection.
    - o Veering winds indicate warm-air advection
    - o Backing winds indicate cold-air advection

EXERCISES

1. The geostrophic wind is $\vec{V}_g = \hat{k} \times \frac{g_0}{f} \nabla_p Z$. Take the partial derivative of this with respect to p and show that $\frac{\partial \vec{V}_g}{\partial p} = -\frac{R_d}{f\,p} \hat{k} \times \nabla_p T$.

2. The diagram below shows contours of 1000 – 500 mb thickness.



a. Assume the 1000 mb geostrophic wind is SW at 5 m/s. At the three black dots draw wind barbs representing the geostrophic wind direction and speed at 500 mb. Use a latitude of 45 N, and d = 175 km.

b. Explain why the position of the jet stream seems linked to the position of the polar front.