Fundamental Meteo Concepts

Atmos 5110 Synoptic–Dynamic Meteorology I

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Suggested reading: Lackmann (2011), sections 1.3–1.4

Holton and Hakim (2013), sections 3.1–3.2

These are essential meteorological concepts for success in this and other atmospheric sciences classes. To do well in this class, you must understand these concepts mathematically and physically.

Geostrophic wind

Horizontal momentum equation is given by

$$\frac{D\vec{V}}{Dt} = -\frac{1}{\rho}\nabla p - f\hat{k}\times\vec{V} + Friction$$

Acceleration PGF Coriolis Friction

Assuming acceleration and friction are zero gives a balance between the PGF and Coriolis with the geostrophic wind given by

$$\vec{V}_g = \frac{1}{\rho f}\hat{k}\times\nabla p$$

In component form

$$u_g = -\frac{1}{\rho f}\frac{\partial p}{\partial y} \qquad v_g = \frac{1}{\rho f}\frac{\partial p}{\partial x}$$

The geostrophic wind is oriented parallel to the isobars with lower pressure on the left in the Northern Hemisphere

The magnitude of the geostrophic wind is:

- Proportional to the pressure gradient
- Inversely proportional to f (i.e., latitude)

$$|\vec{V}_g| \propto \left|\frac{1}{f}\right|, |\nabla p|$$

Therefore:

- The larger the pressure gradient, the larger the geostrophic wind
- The lower the latitude, the stronger the geostrophic wind for a given pressure gradient
- The higher the latitude, the weaker the geostrophic wind for a given pressure gradient

Geostrophic flow: A flow in which the actual wind and the geostrophic wind are equivalent

Geostrophic approximation: Assumes the total wind can be approximated by the geostrophic wind

Geostrophic wind in pressure coordinates

- Meteorologists typically use pressure rather than height as a vertical coordinate.
- The pressure gradient on a height surface is proportional to the geopotential (and geopotential height) gradient on a pressure surface.

$$-\frac{1}{\rho}\left(\frac{\partial p}{\partial y}\right)_z = -\left(\frac{\partial \Phi}{\partial y}\right)_p \propto -\left(\frac{\partial Z}{\partial y}\right)_p, where\ Z = geopotential\ height$$

- The geostrophic wind in pressure coordinates is given by

$$\vec{V}_g = \hat{k} \times \frac{1}{f}\nabla\Phi$$

$$\Rightarrow |\vec{V}_g| = \frac{g_0}{f}|\nabla_p Z|$$

The geostrophic wind is oriented parallel to the isohypses with lower heights on the left in the Northern Hemisphere

The magnitude of the geostrophic wind is:

- Proportional to the height gradient
- Inversely proportional to *f* (i.e., latitude)

$$|\vec{V}_g| \propto \left|\frac{1}{f}\right|, |\nabla_p Z|$$

<u>Class activity</u>

Using the IDV Supernational bundle, diagnose the 925-mb geostrophic temperature advection of over (a) Seattle, WA, (b) Salt Lake City, UT, and (c) Albany, NY. To do this, you will need to change the geopotential height level from 500 to 925 mb.

<u>Gradient wind</u>

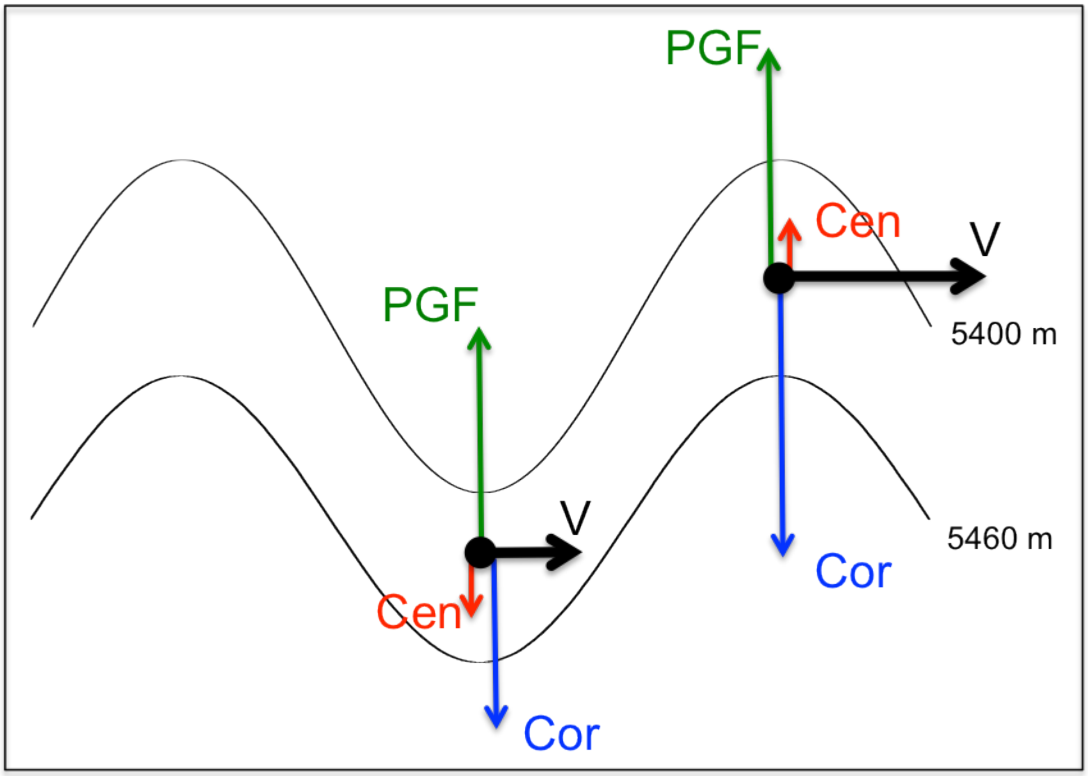
Considers the effect of curvature with a balance between the PGF, Coriolis, and centrifugal accelerations

$$V_{gr} = \frac{fR}{2} \pm (\frac{f^2R^2}{4} - R\frac{\partial \Phi}{\partial n})^{1/2}$$

R=Radius of curvature; *n* positive to the left of the flow (natural coordinates)

In gradient wind balance, the flow is parallel to the isobars and

- $V_{gr} < V_g$ in the trough (subgeostrophic)
- $V_{gr} > V_g$ in the ridge (supergeostrophic)

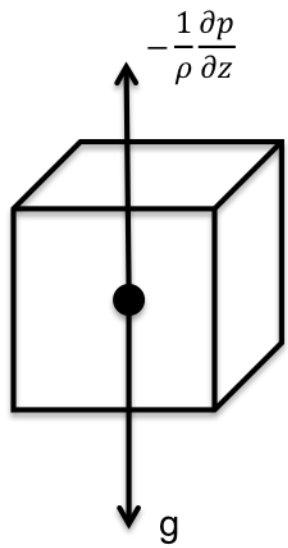


<u>Class activity</u>

Using the 5110>geowind-vs-totalwind bundle in IDV, identify a ridge and a trough and diagnose the total and geostrophic wind in the ridge and trough axes. Are the differences consistent with gradient wind balances?

Hydrostatic balance

A balance between gravity and the vertical component of the pressure-gradient force



Hydrostatic approximation

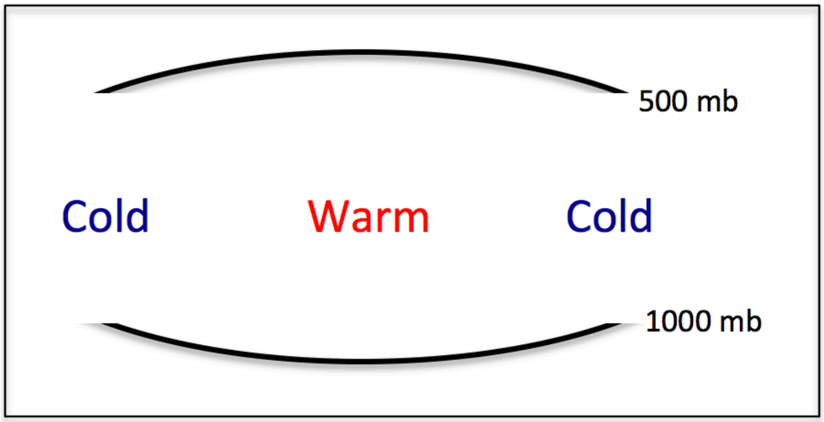
$$\frac{\partial p}{\partial z} = -\rho g$$

Applicable to the synoptic scale, but not necessarily the mesoscale or smaller scales. Learn it, know it, love it.

Hypsometric equation

Assuming hydrostatic balance, provides a relationship between the mean temperature and the "thickness" of a layer (i.e., the distance between two p levels)

$$\Delta Z = Z_u - Z_l = \frac{R\overline{T_v}}{g} \ln\left(\frac{p_l}{p_u}\right)$$
$$\Longrightarrow \Delta Z \propto T_v$$

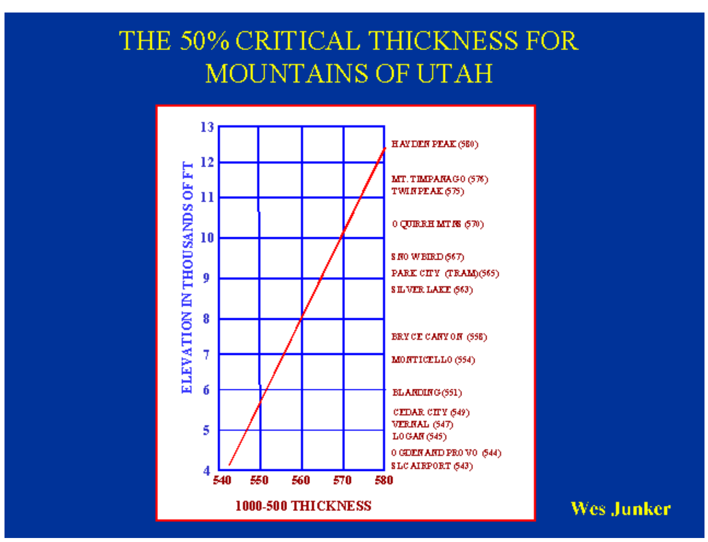


<u>Critical thickness</u>

Back in the day, temperature and precipitation type forecasts were often made using the 1000–500 mb thickness.

The critical thickness is the thickness at which there is a 50/50 chance of snow or frozen precipitation occurring.

- The lower the thickness, the greater the chance of snow or frozen precipitation
- The higher the thickness, the smaller the chance
- Near sea level in the northeast U.S., the critical 1000–500-mb thickness is ~540 dm
- At Denver it is ~548 dm



Problem: Critical thickness does not fully account for the influence of varied lapse rates, shallow cold pools, etc.

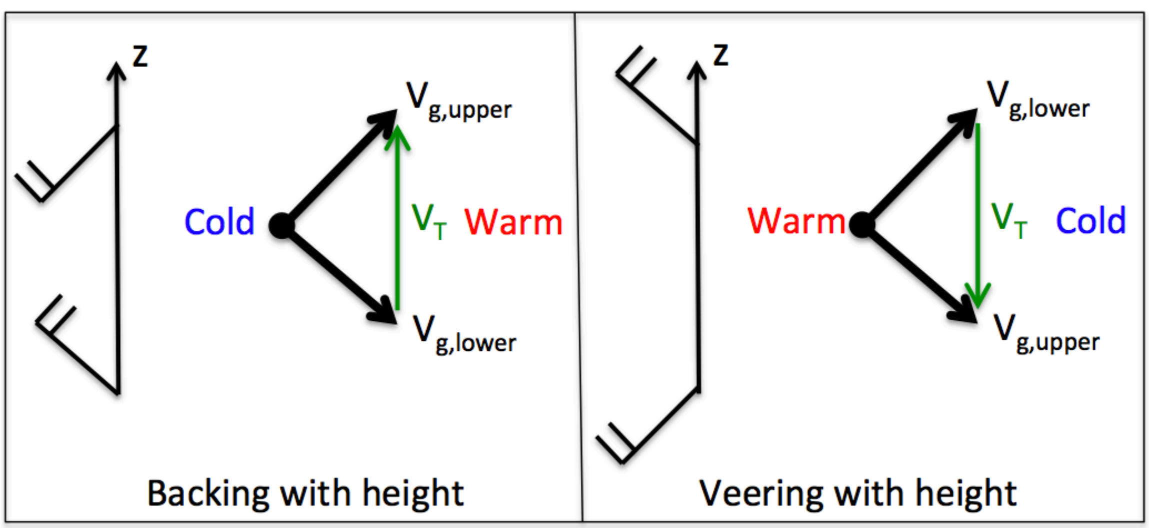
Result: Best to use model soundings (especially BUFR soundings) when forecasting temperature and precipitation type

<u>Thermal wind</u>

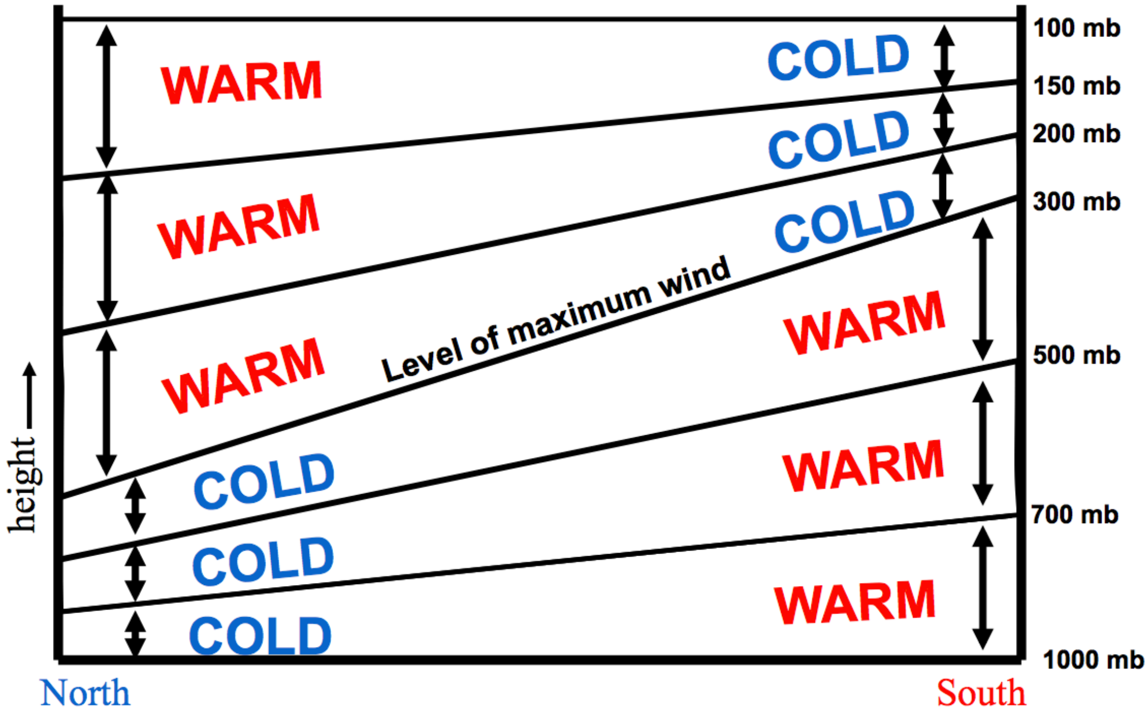
The thermal wind is not an actual wind, but the name given to the vertical shear of the geostrophic wind

$$\vec{V}_T = \vec{V}_{g,upper} - \vec{V}_{g,lower} = \frac{g}{f}\hat{k} \times \nabla Thickness = \frac{g}{f}\hat{k} \times \nabla\overline{T_v}$$

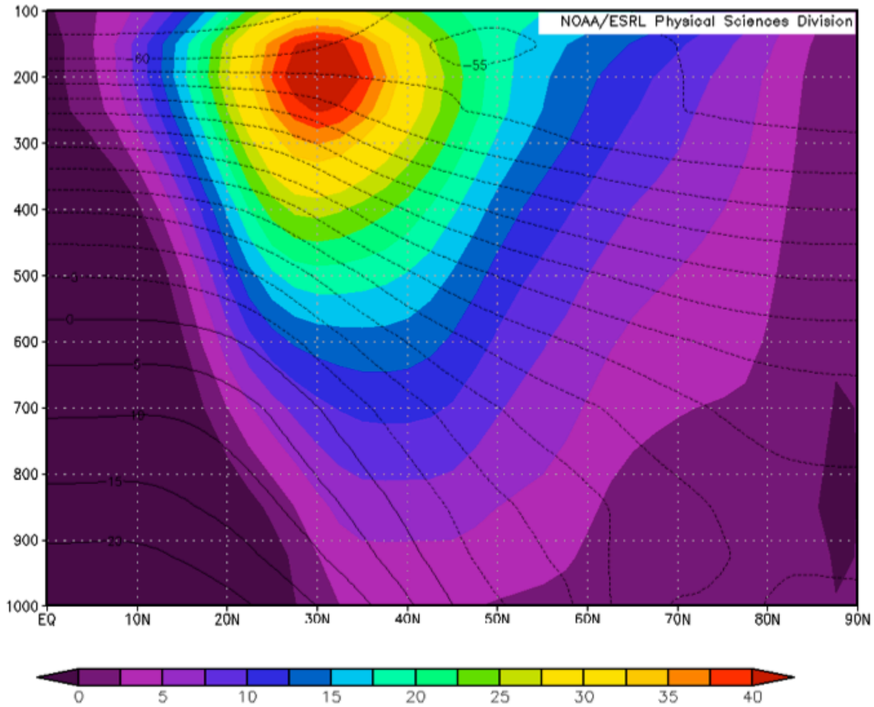
- The magnitude of the thermal wind (i.e., the shear of the geostrophic wind) is proportional to the strength of the thickness/temperature gradient
  - ⟹ A large temperature gradient yields a lot of shear
- The thermal wind vector (i.e., the geostrophic wind shear vector) is oriented parallel to the thickness/temperature contours with lower values on the left
- Cold advection is associated with backing (counterclockwise turning) winds with height and warm advection with veering (clockwise turning) winds with height

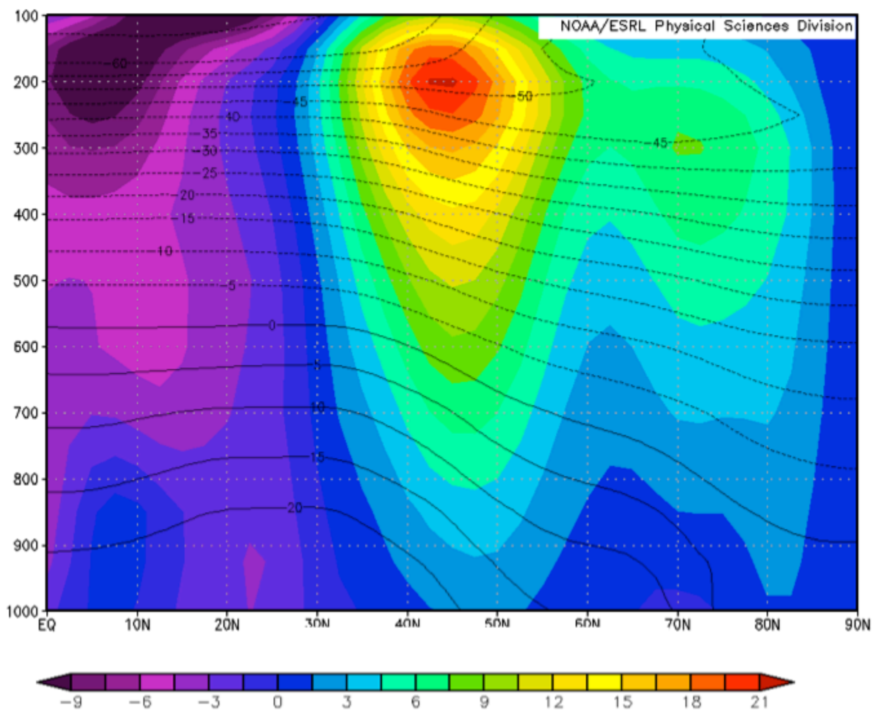


The integrated influence of horizontal temperature contrasts on thickness, height gradients, wind shear, and wind speed is shown by Figure 1.5 of Lackmann (2011):



It can also be seen in the NCEP/NCAR zonal mean temperature (°C) and wind (m s^{-1}, note scale change) climatology (1981–2010) for the northern hemisphere in January (top) and July (bottom)





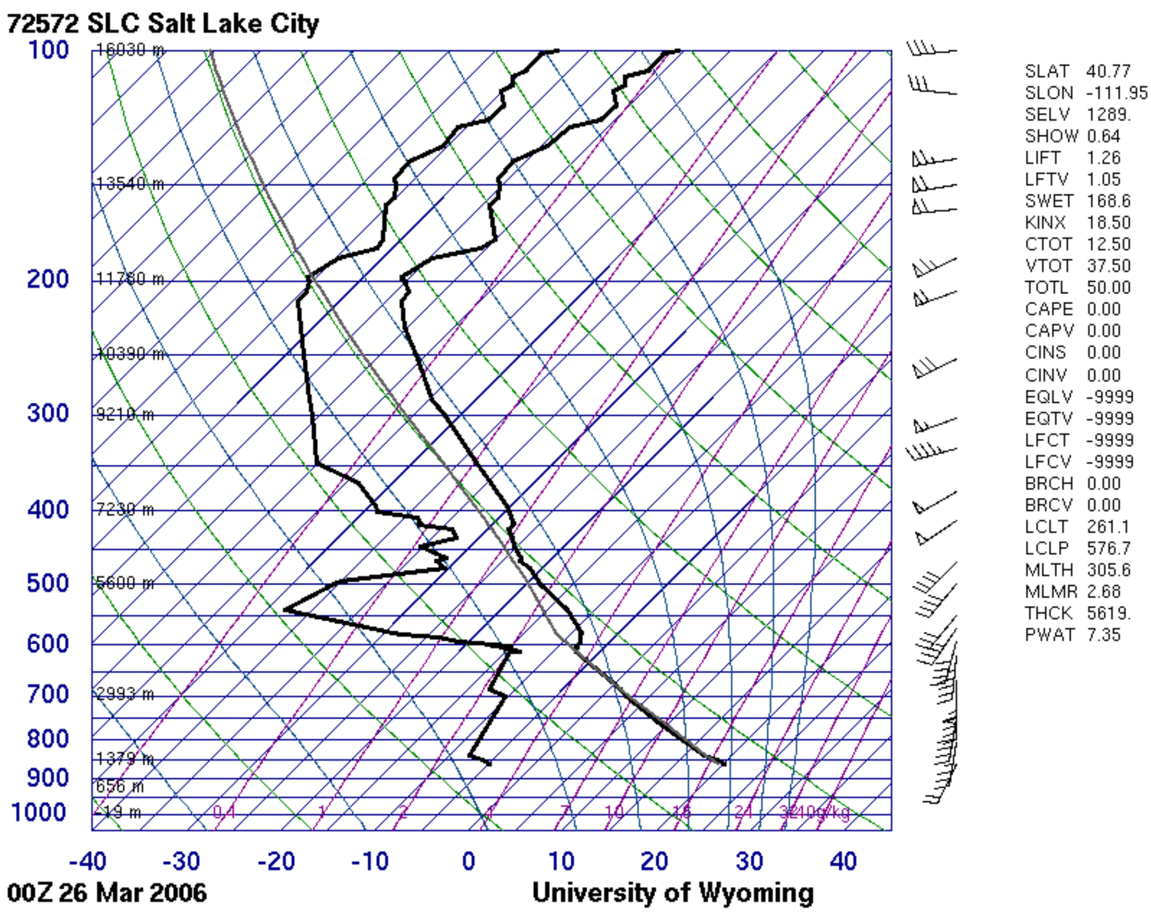
Class activity

Answer the question, "have you seen the thermal wind today?"

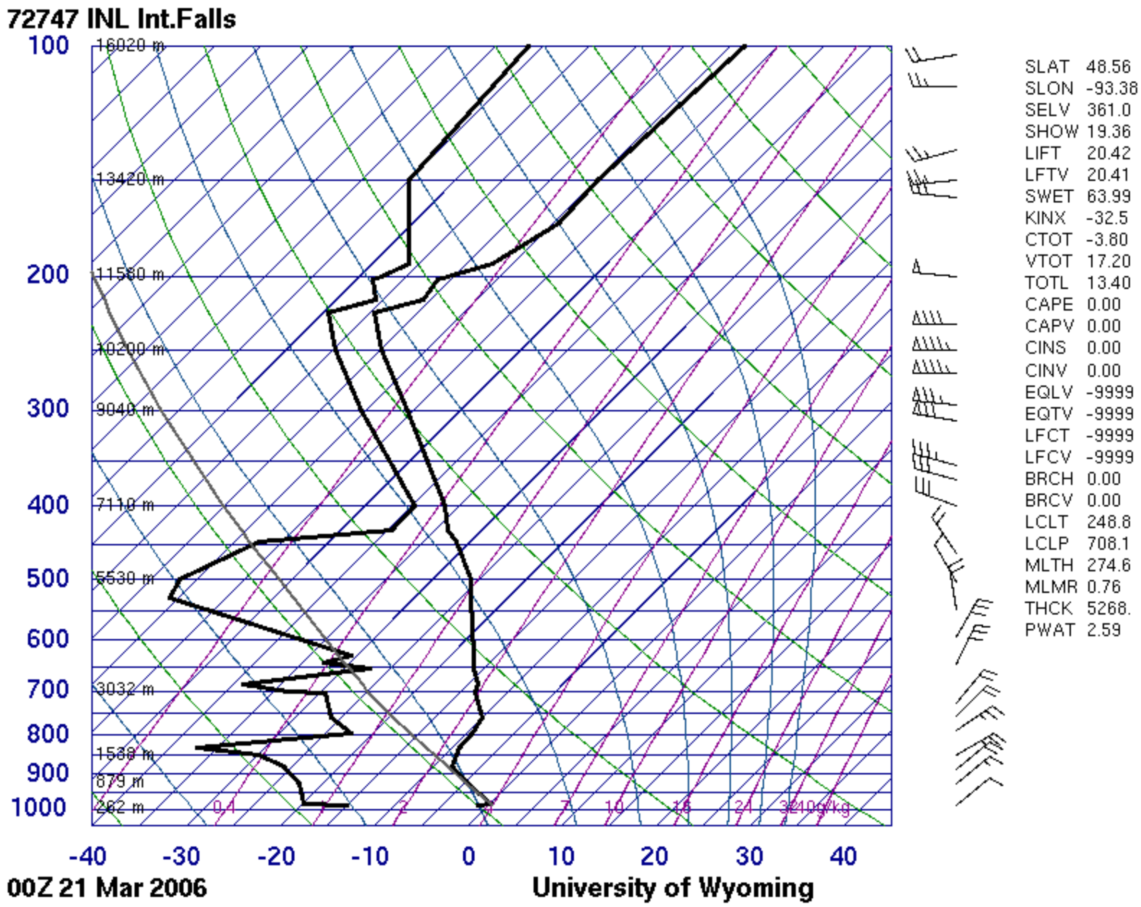
Using IDV and soundings available on the web, examine the relationship between the temperature gradient and wind speed in the atmosphere, including how to diagnose temperature advection based solely on soundings.

Review (using Classquestion)

Q1: The sounding below features ______ temperature advection in the 650 to 450 mb layer?



Q2: The sounding below features ______ temperature advection in the 750 to 400 mb layer?



Q3-Q4: See Classquestion