Geophysical Fluid Dynamics

Lecture 18

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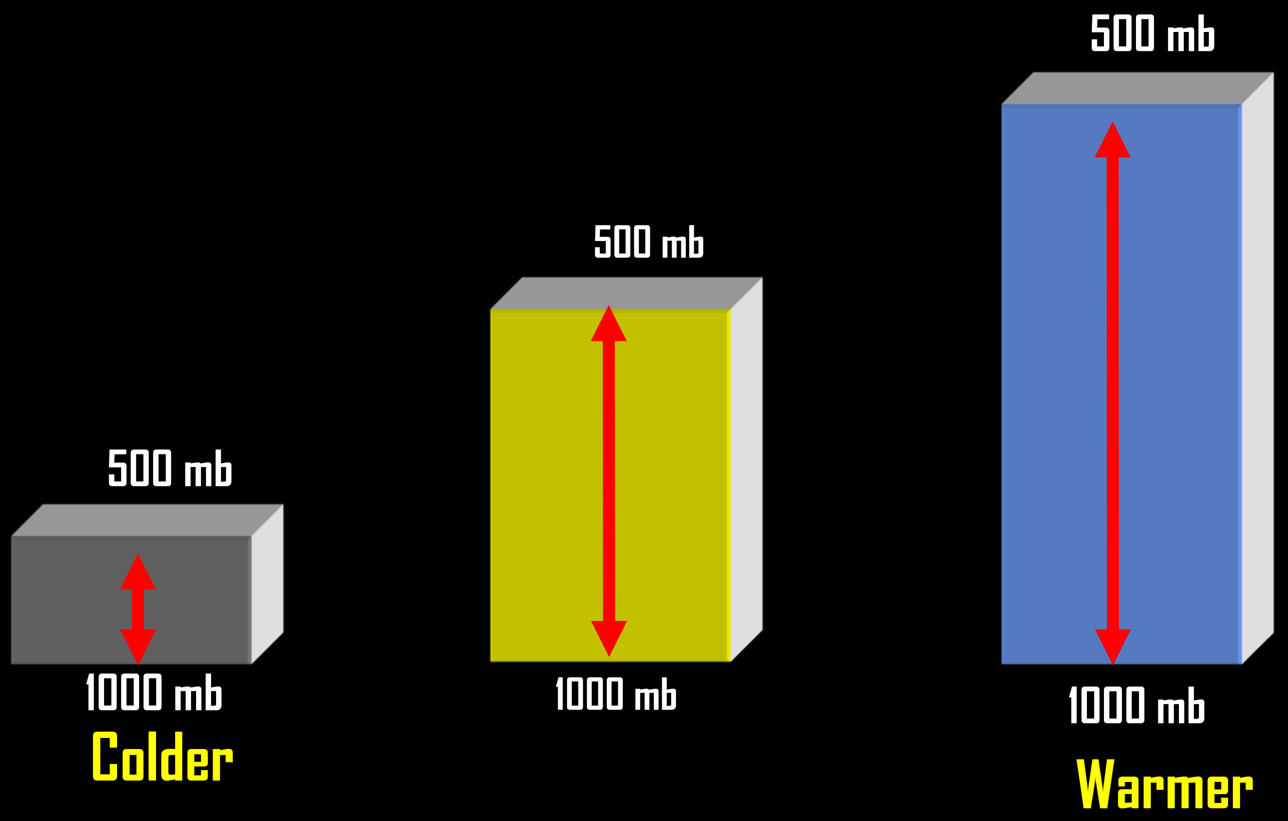
Thickness

Start with a column of air.



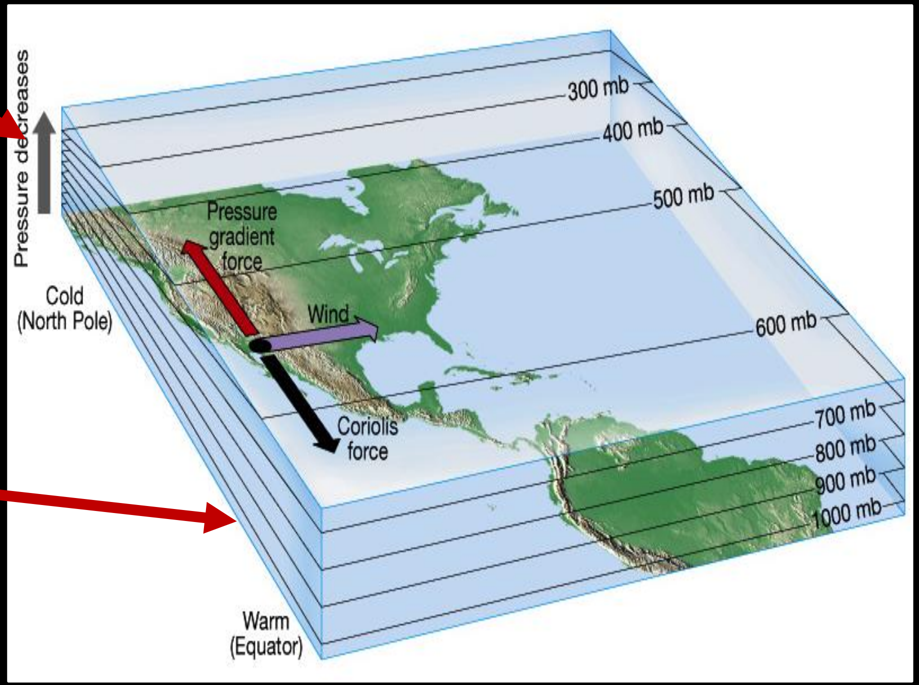
In fact, temperature is the ONLY factor in the atmosphere that determines the thickness of a layer.

At the poles, 700 mb is quite low to the ground

These layers are not very “thick”

In the tropics, 700mb is much higher above the ground

See how “thick” these layers are

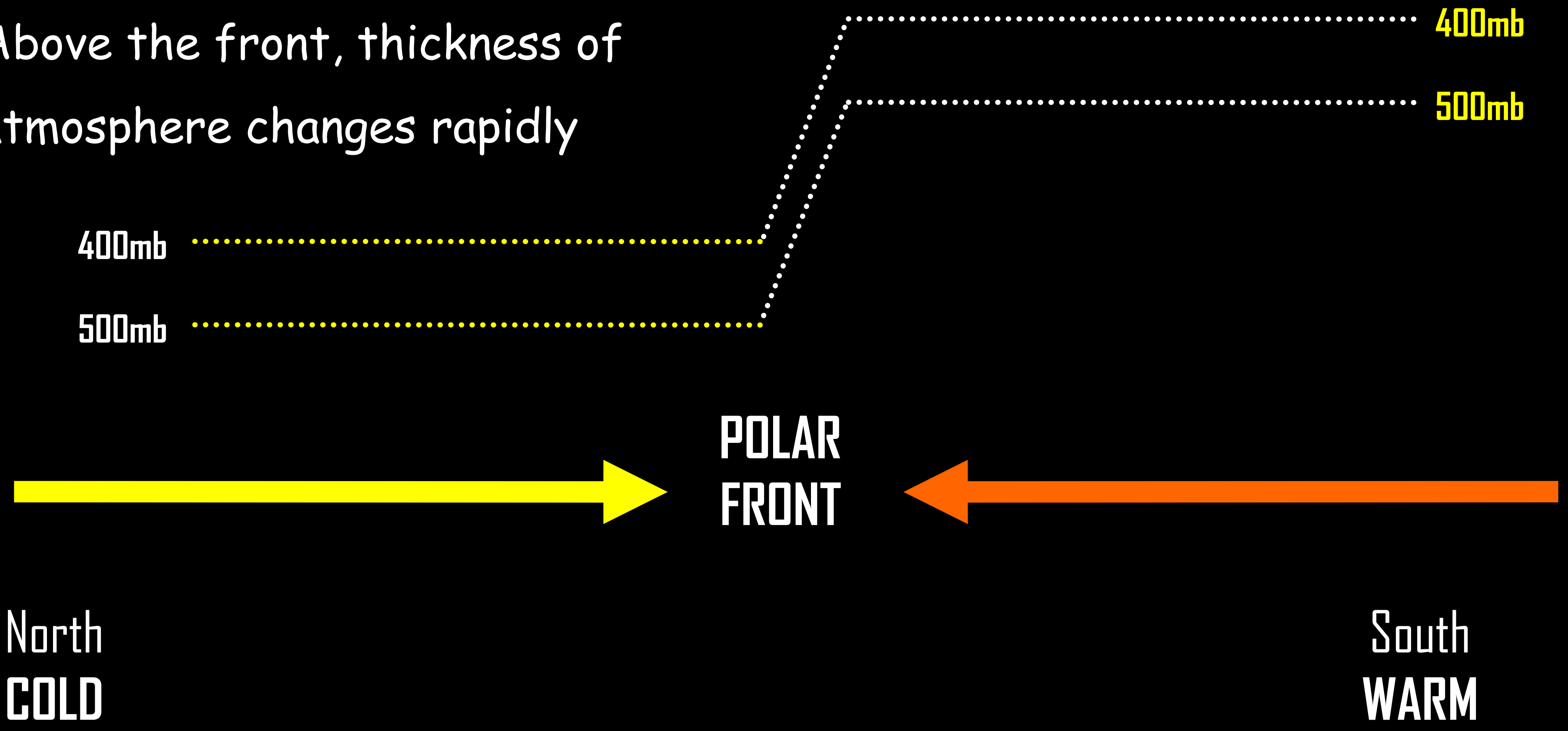


This is a cross section of the atmosphere

These winds meet at the polar front (a strong temperature gradient)

Now, think about what we just learned about how temperature controls the THICKNESS of the atmosphere

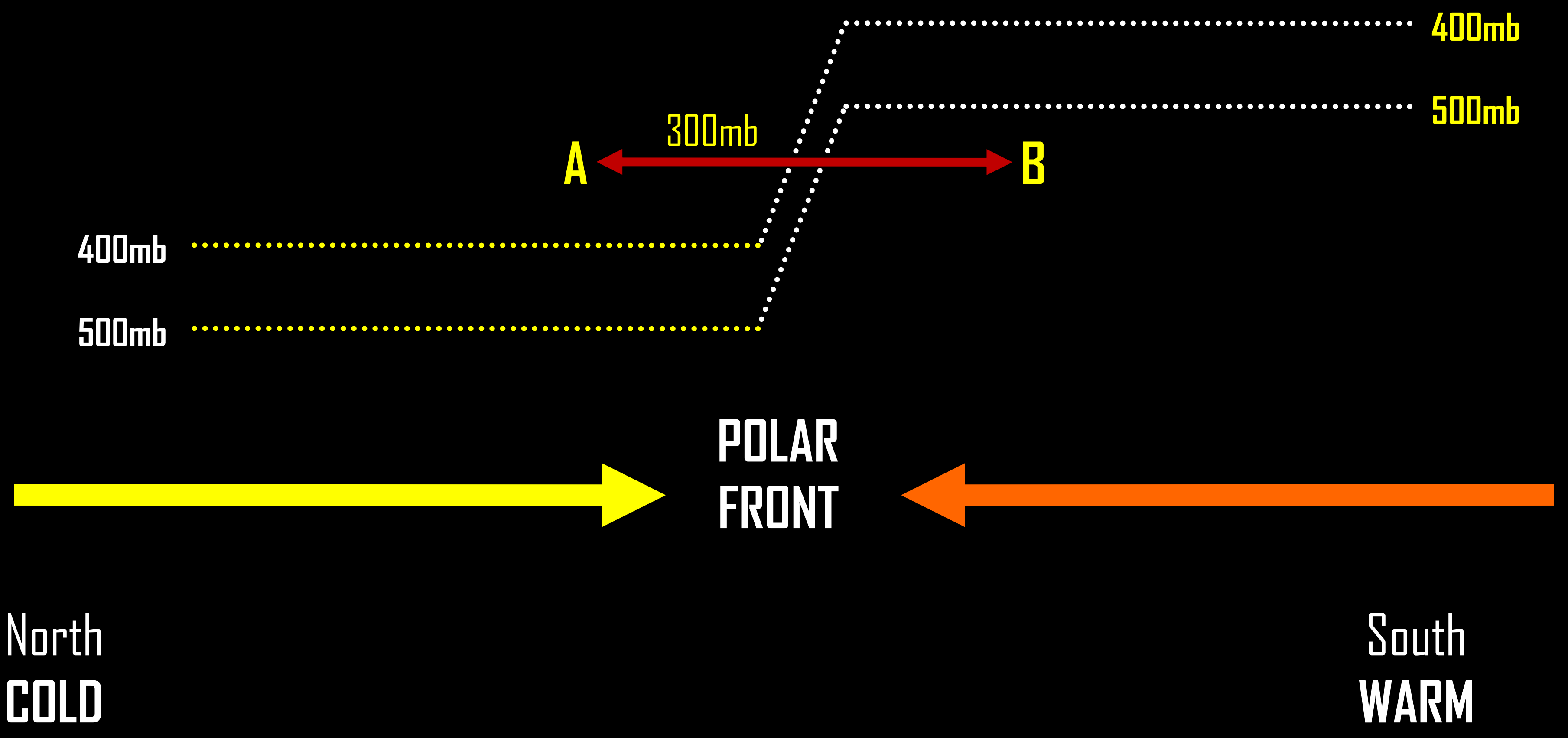
Above the front, thickness of atmosphere changes rapidly



Now, what about the PGF above the front?

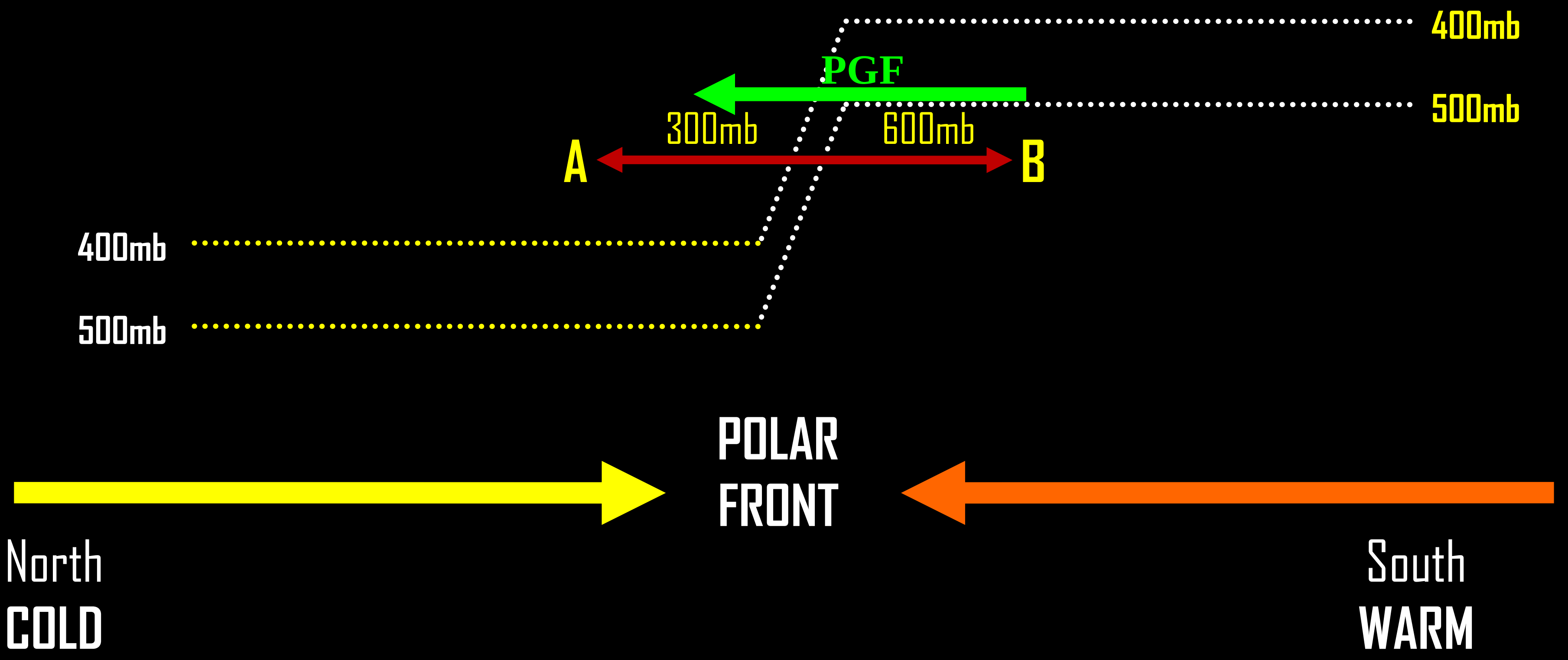
Let's draw a line between the cold side of the front and the warm side

What is the pressure at point A?



What is the pressure at point B?

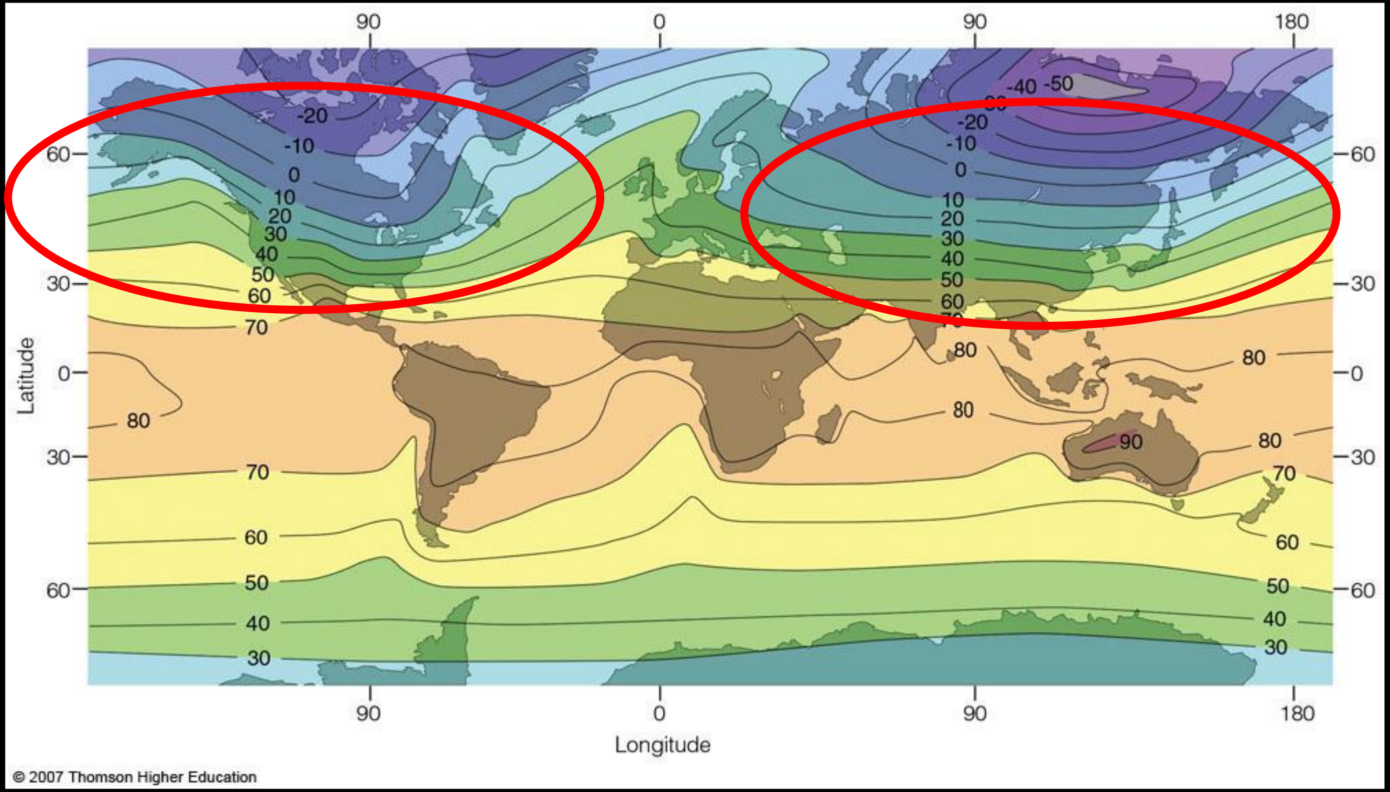
The pressure gradient force between point B & A is HUGE Therefore, all along the polar front, there will be a strong pressure gradient force aloft, pushing northward



Strong PGF is:

Aloft (above the surface)

Above the Polar Front (strong temperature gradient!)



PGF pushes to the north (in the Northern Hemisphere)

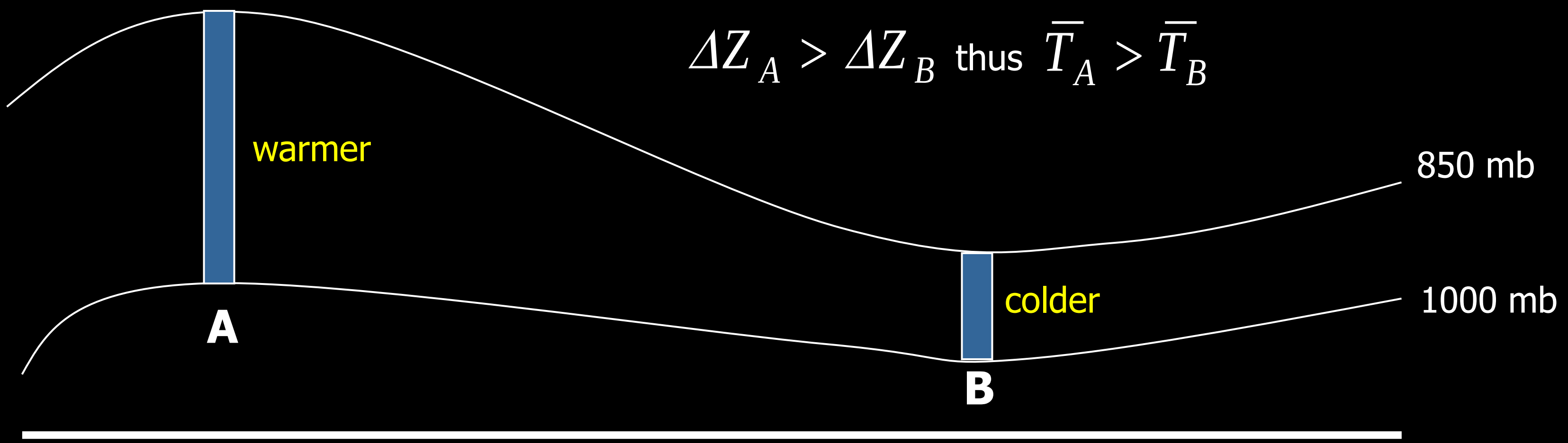
How does this cause the midlatitude jet stream?

Hyposmetric Equation and Thickness

$$\Delta Z \equiv Z_2 - Z_1 = \frac{R}{g}\int_{p_2}^{p_1} T \, d(ln\ p) \qquad \Phi_2 - \Phi_1 = R\bar{T} \ln \frac{p_1}{p_2}$$

The hypsometric equation relates the thickness, or vertical distance between two pressure levels. The thickness, ΔZ, is proportional to the mean temperature of the layer.

$\Delta Z_A > \Delta Z_B$ thus $\bar{T}_A > \bar{T}_B$



Thermal Wind Equation

We begin by writing the vector form of the geostrophic wind equation in isobaric coordinates for two levels:

$$\vec{V}_g(p_1) = \frac{1}{f}\hat{k} \times \nabla_p \Phi_1$$

$$\vec{V}_g(p_2) = \frac{1}{f}\hat{k} \times \nabla_p \Phi_2$$

Now we compute the difference in geostrophic wind between the two levels:

$$\vec{V}_T \equiv \vec{V}_g(p_2) - \vec{V}_g(p_1)$$

$$\vec{V}_T = \frac{1}{f}\hat{k} \times \nabla_p (\Phi_2 - \Phi_1)$$ thermal wind equation

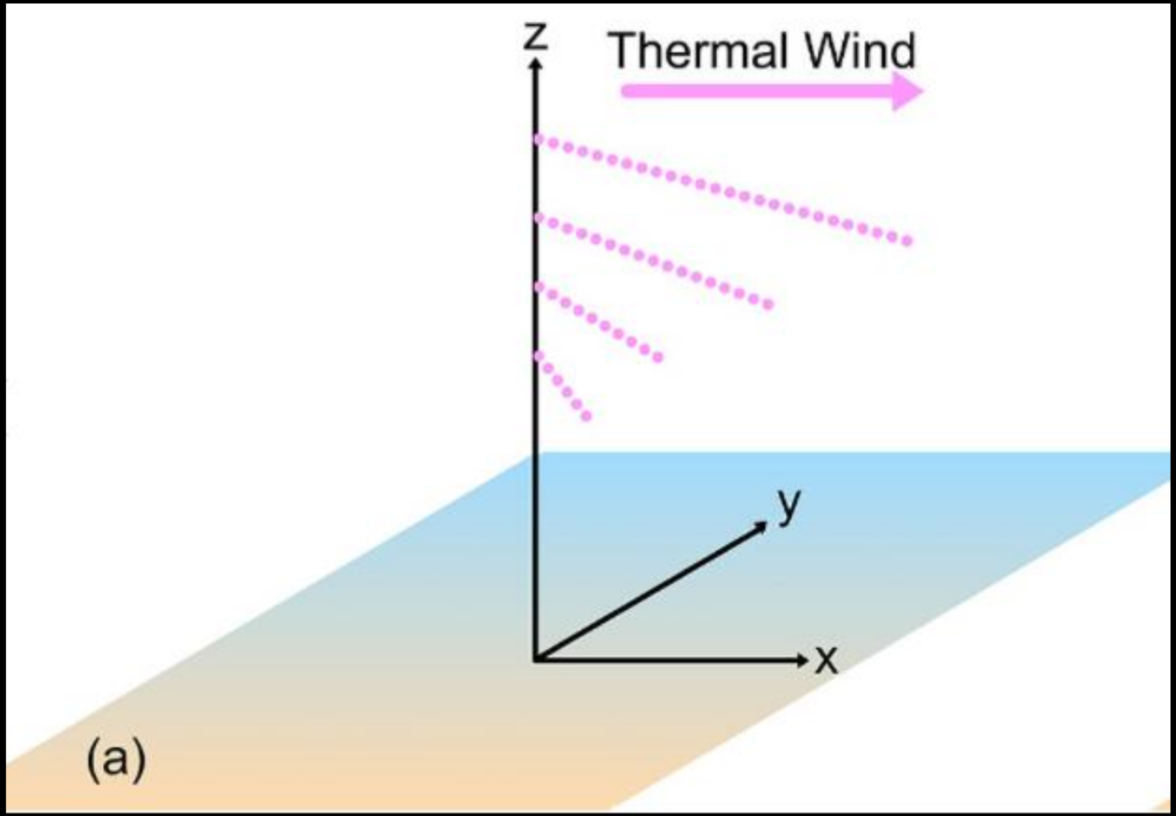
Substituting the hypsometric equation, one gets a form based on temperature,

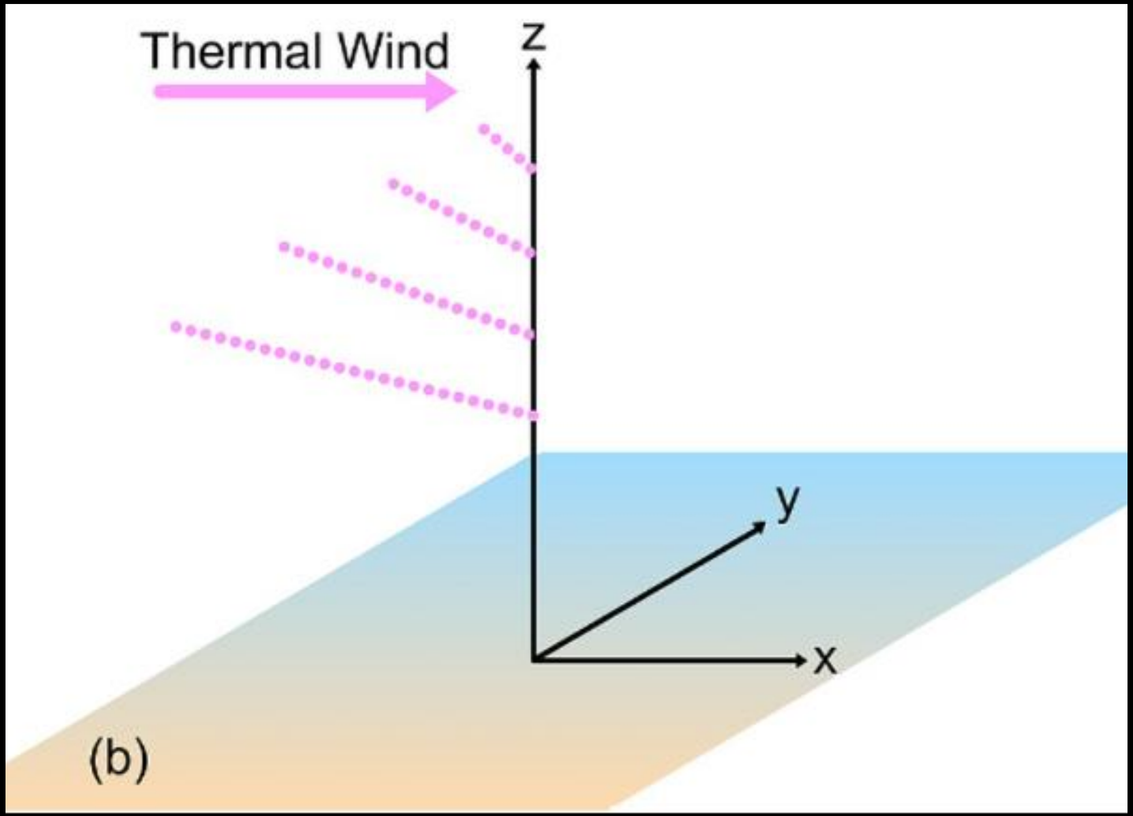
$$\Phi_2 - \Phi_1 = R\bar{T}\ln\frac{p_1}{p_2}$$

$$\vec{V}_T = \frac{1}{f}\hat{k}\times\nabla_p\left(\Phi_2 - \Phi_1\right)$$ thermal wind equation

$$\vec{V}_T = \frac{R}{f}\ln\left(\frac{p_1}{p_2}\right)\hat{k}\times\nabla_p\bar{T}$$

Note that thermal wind is at right angles to the horizontal temperature gradient, counter clockwise in the northern hemisphere. In the southern hemisphere, the change in sign of f flips the direction.





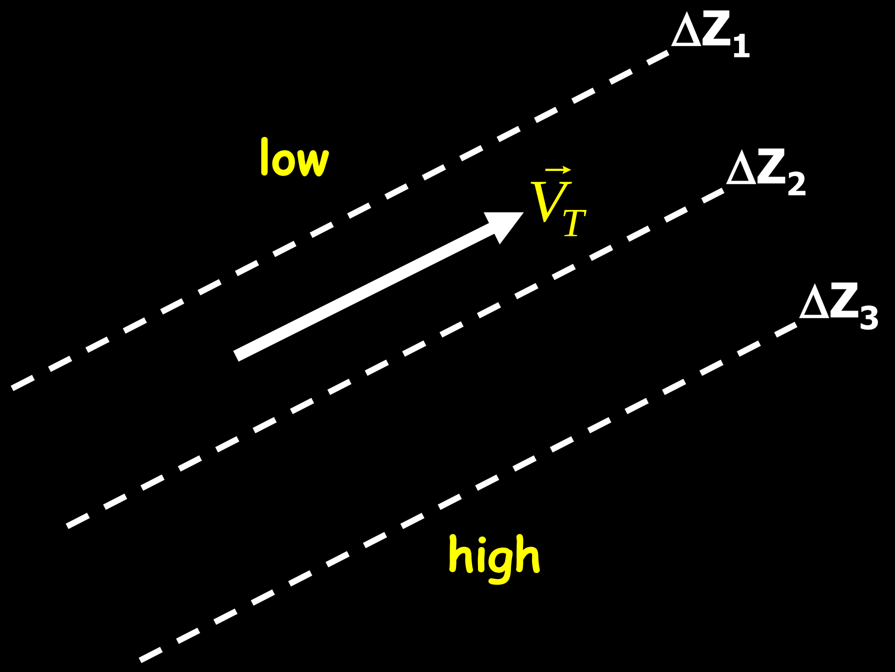
In (a), cold advection is occurring, so the thermal wind causes the *geostrophic* wind to rotate counterclockwise (for the northern hemisphere) with height.

In (b), warm advection is occurring, so the geostrophic wind rotates clockwise with height.

Thermal Wind

The thermal wind is the vertical shear of the geostrophic wind between two levels.

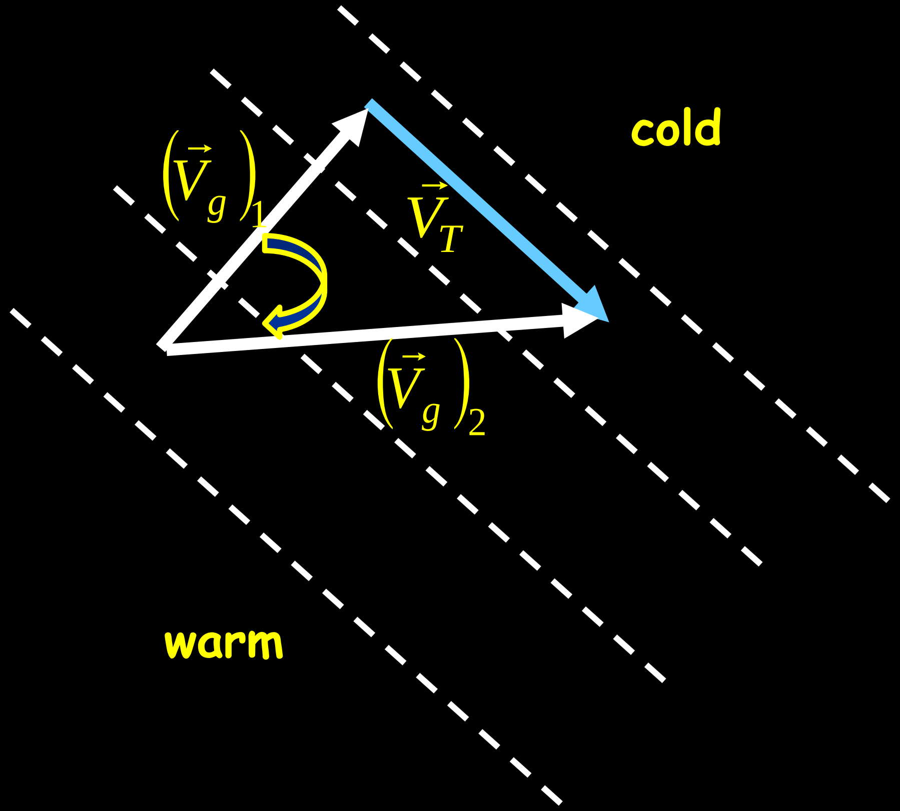
The thermal wind is a vector that is oriented parallel to the thickness isolines with lower values to the left (in the N. Hemisphere).



Its magnitude is proportional to the thickness gradient.

Geostrophic Wind Shear and Thermal Advection

Case 1: Geostrophic wind veers (i.e., turns clockwise) with height.



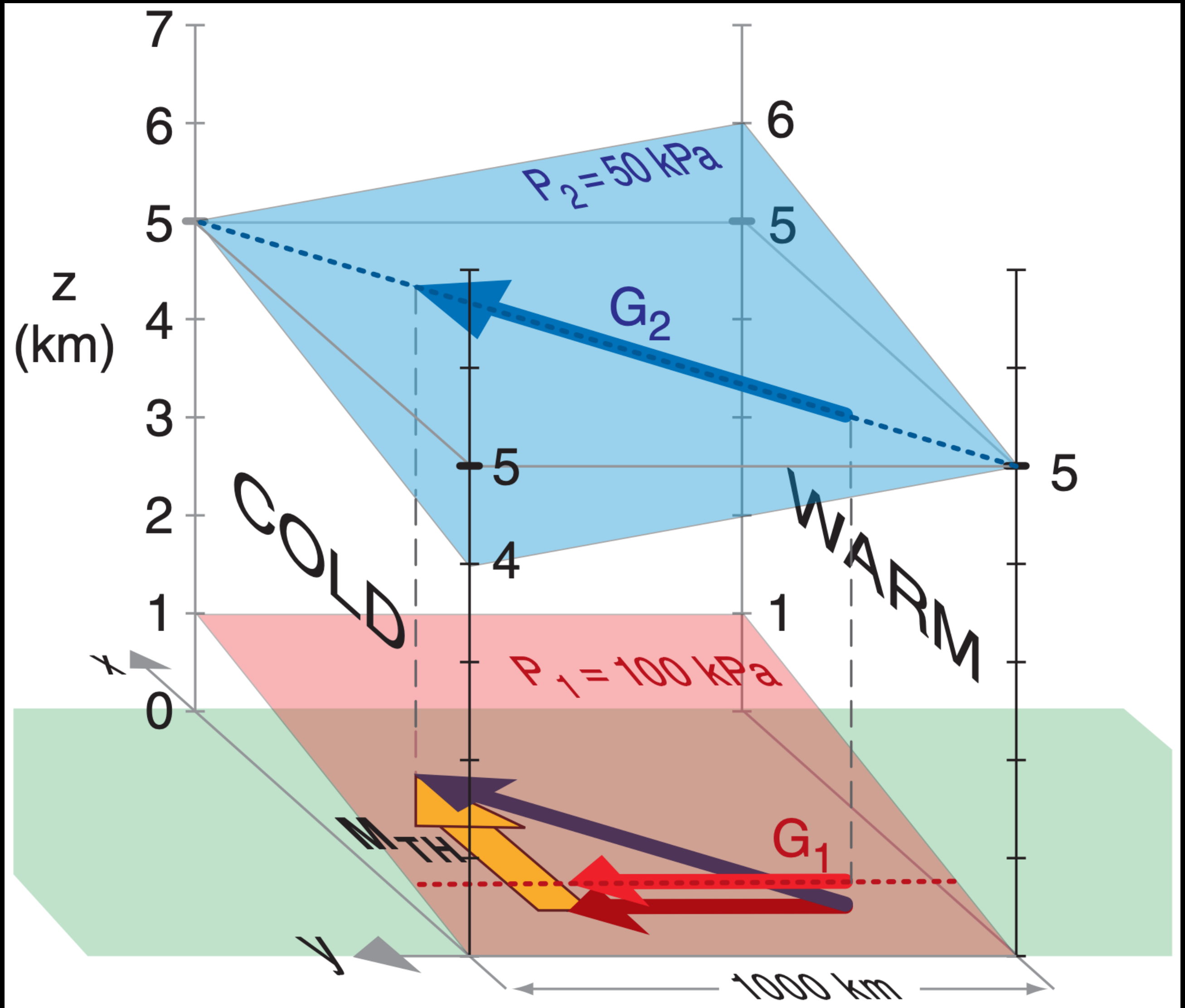
Lower level wind is from SW.

Upper level wind is from W.

Since colder air must lie to the left of the thermal wind, the layer average wind blows from warm to cold, which implies warm advection.

$$(\vec{V}_g)_1 + \vec{V}_T = (\vec{V}_g)_2$$

$$\vec{V}_T = (\vec{V}_g)_2 - (\vec{V}_g)_1$$



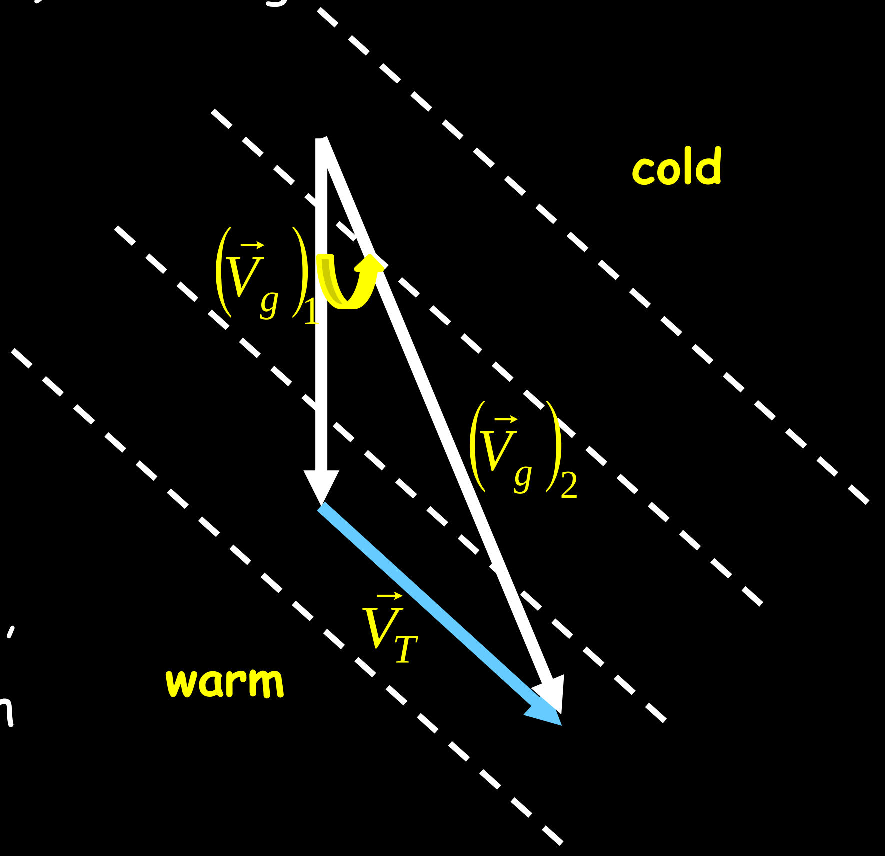
7
6
5
4
3
2
1
0
z
(km)
6
5
5
4
5
1
$P_2 = 50$ kPa
G_2
COLD
WARM
$P_1 = 100$ kPa
G_1
M_{TH}
x
y
1000 km

Geostrophic Wind Shear and Thermal Advection

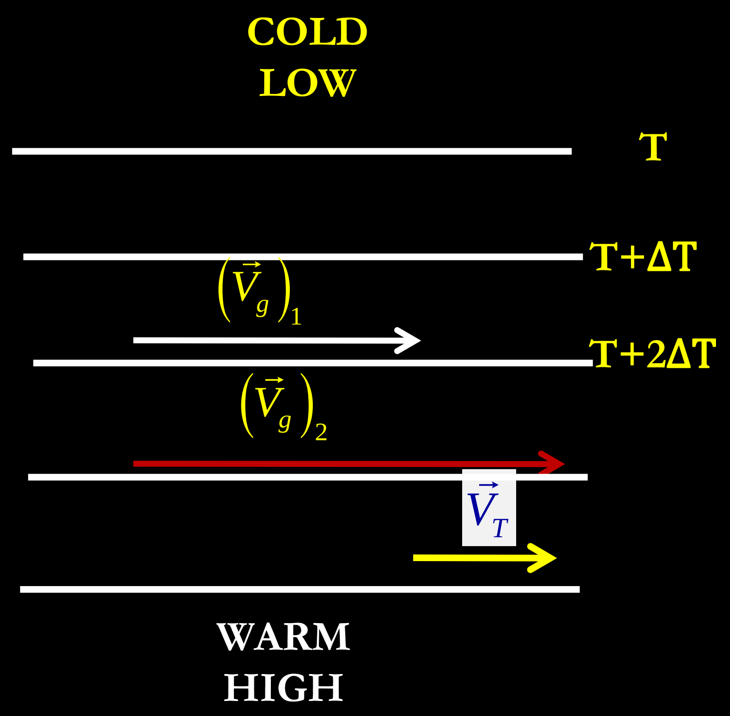
Case 2: Geostrophic wind backs (i.e., turns counterclockwise) with height.

Lower level wind is from N.

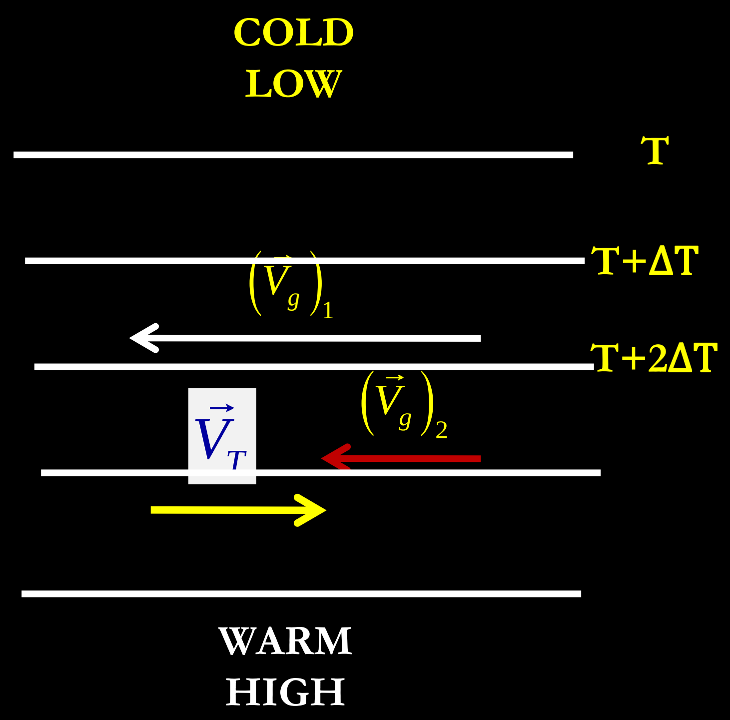
Upper level wind is from NW.



Since colder air must lie to the left of the thermal wind, the layer average wind blows from cold to warm, which implies cold advection.



COLD
LOW
T
T+ΔT
$\left(\vec{V}_g\right)_1$
T+2ΔT
$\left(\vec{V}_g\right)_2$
$\vec{V}_T$
WARM
HIGH



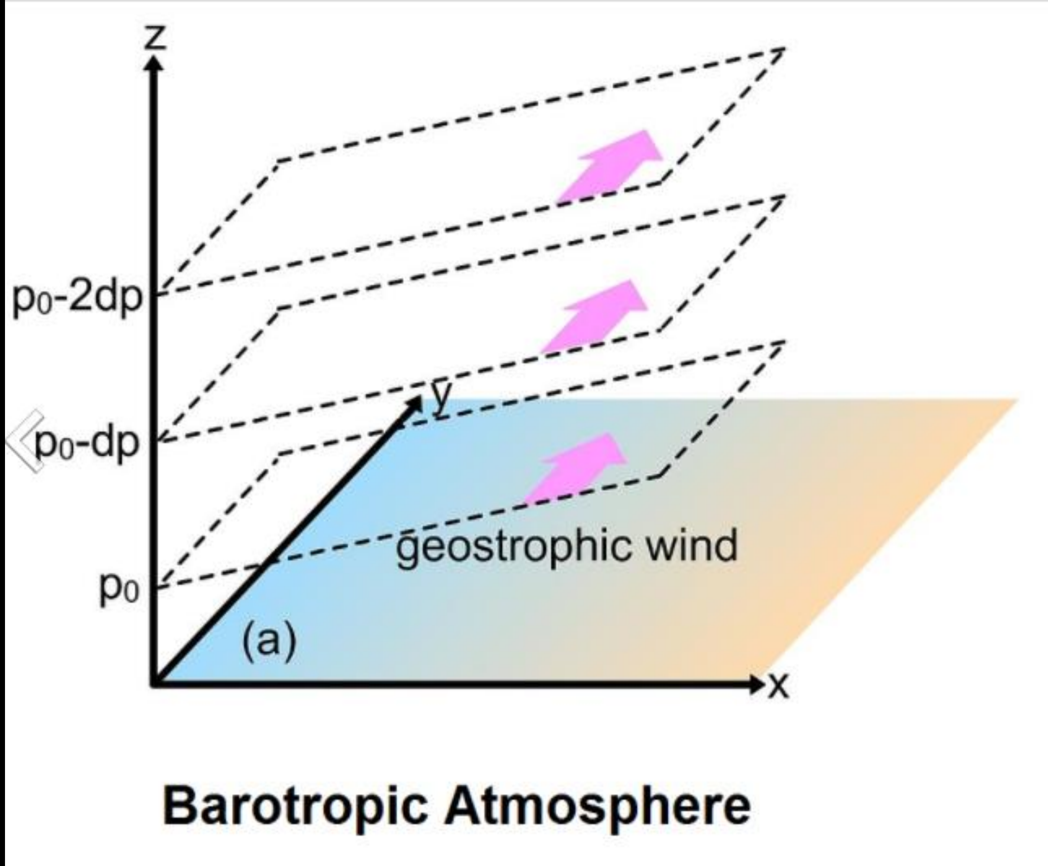
COLD
LOW
T
T+ΔT
$\left(\vec{V}_g\right)_1$
T+2ΔT
$\vec{V}_T$
$\left(\vec{V}_g\right)_2$
WARM
HIGH

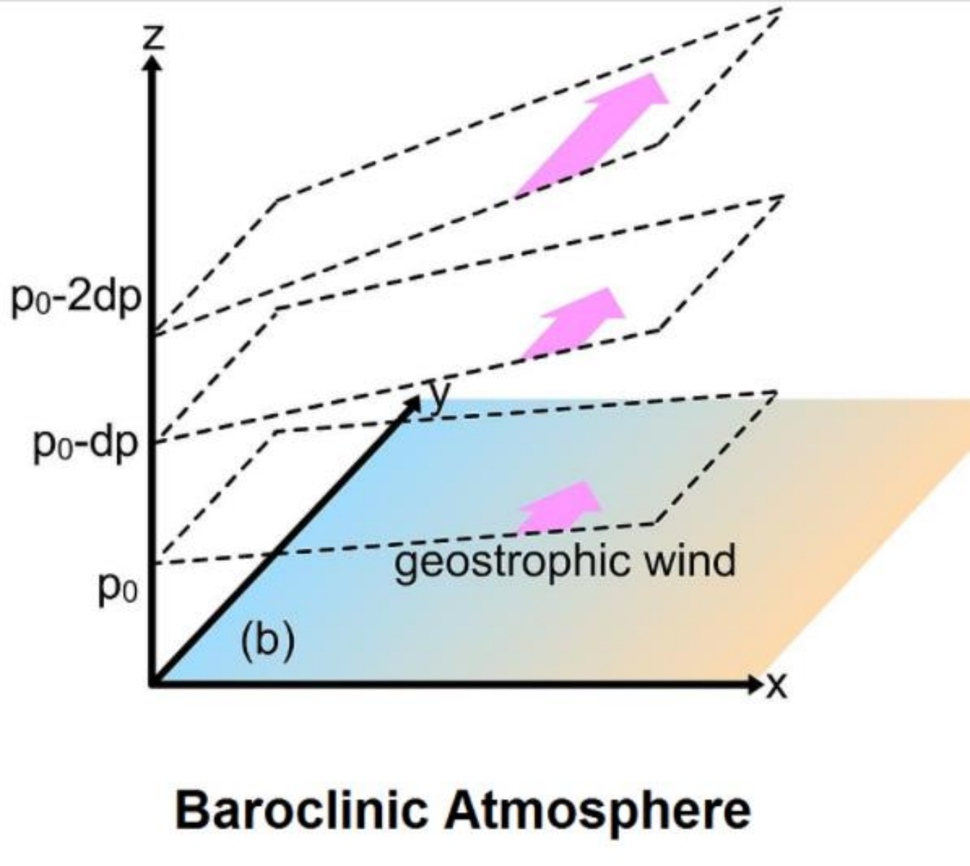
Baroclinic vs. Barotropic

Barotropic	Baroclinic
$\rho=\rho(p)$ only **Implications:** 1) isobaric and isothermal surfaces coincide 2) no vertical wind shear (thermal wind = 0) 3) no tilt of pressure systems with height	$\rho=\rho(p,T)$ **Implications:** 1) isobaric and isothermal surfaces intersect 2) vertical wind shear (thermal wind ≠ 0) 3) pressure systems tilt with height

Seasons: Atmosphere is most baroclinic in winter.
Atmosphere is least baroclinic in summer.

Geographic: Atmosphere is most baroclinic in midlatitudes
Atmosphere is least baroclinic in the Tropics


z
p_0-2dp
p_0-dp
p_0
y
geostrophic wind
(a)
x
Barotropic Atmosphere


z
p_0-2dp
p_0-dp
p_0
y
geostrophic wind
(b)
x
Baroclinic Atmosphere