Fronts and Jets

Meteorology 411 – Iowa State University – Week 9

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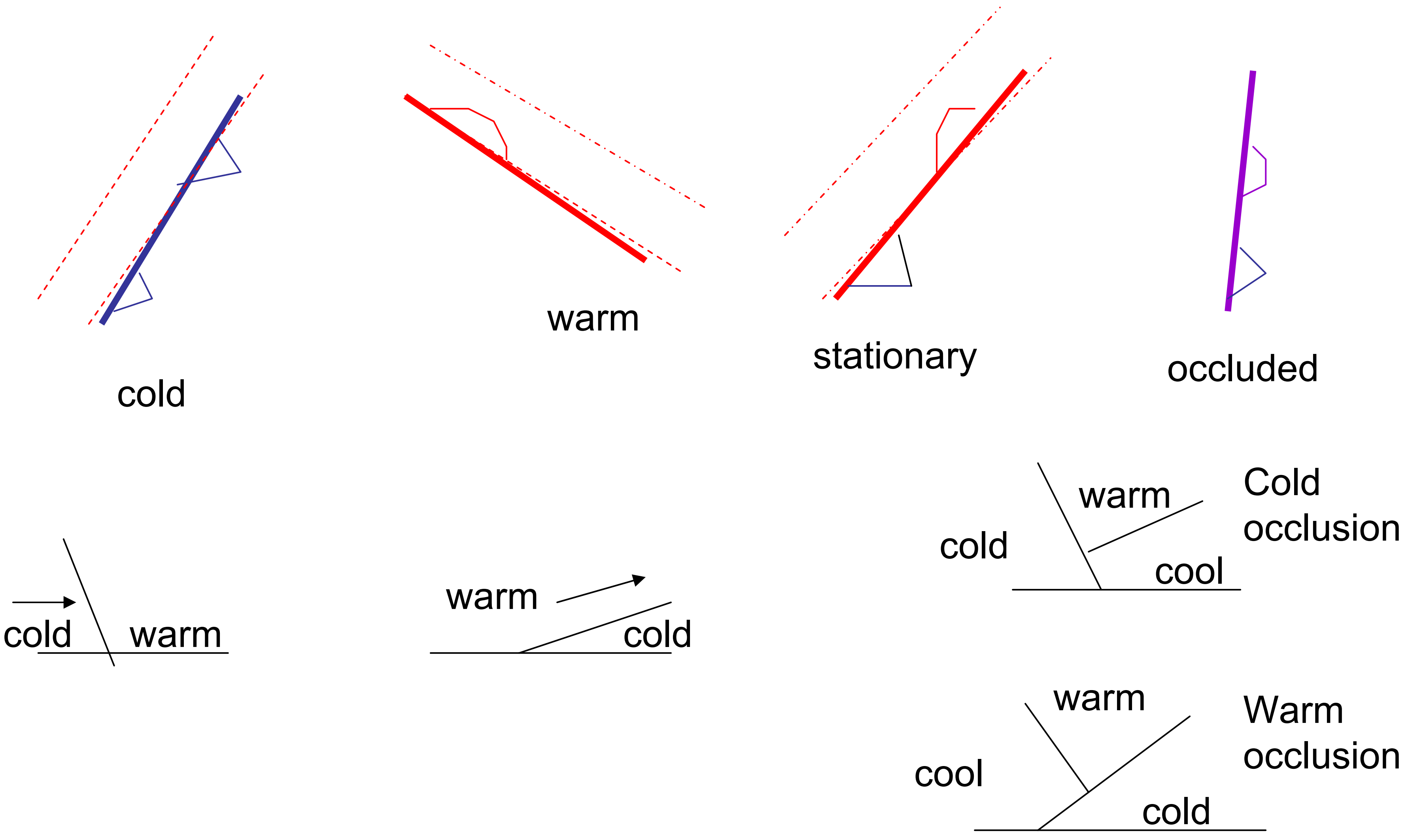
Review of frontal types

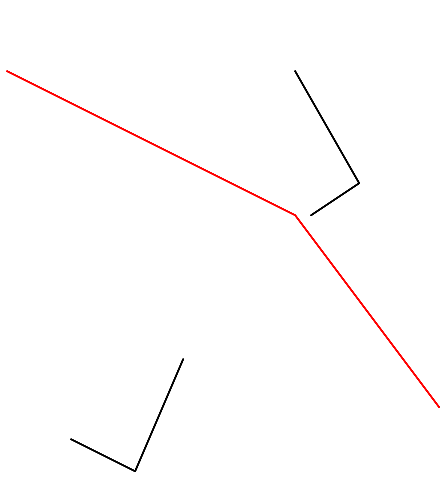


How is frontal type determined?

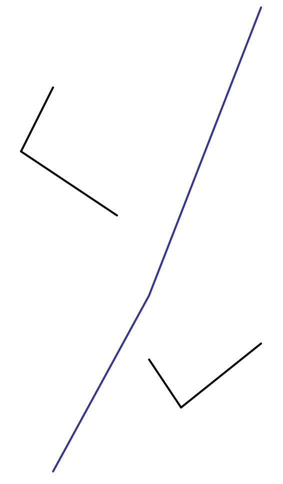
- By motion of cold air. It doesn’t matter what the warm air is doing, because it is lighter than the cold air and will be pushed away by the colder air.
- So, just because the warm air is flowing north, does not make a front a warm front. If the colder air on the other side of the front is not also moving away from the front, the warm air cannot move in.

What about winds in warm air?

- The motion of the warm air does NOT determine frontal type, but it DOES determine if a front is ACTIVE or INACTIVE.
- ACTIVE – warm air is blowing toward front
- INACTIVE – warm air is not blowing toward front
- Active fronts will have more clouds/precip since the warm air will overrun the cold air and be lifted upward



Active warm front



Inactive cold front

Also, remember that the front is drawn at the warm side of the temperature gradient – NOT in the middle of gradient, and NOT on cold side

Frontogenesis

- A useful diagnostic/tool for forecasting is frontogenesis – which is the rate of change of frontal strength
- Think about what variables you could use to measure frontal strength?
- Answer: temp gradient, moisture gradient, wind convergence, etc.
- Classic definition uses Potential Temperature Gradient (ideas why?)

Frontogenesis (cont)

- Potential Temperature avoids artificial gradients that might exist in temperature due to elevation changes
- So, we need an equation like:
- $d/dt\ |\nabla\theta| = \ldots\ldots$

We can get this by taking the thermodynamic equation, and it becomes a huge equation….

Frontogenesis Equation

$$\frac{d}{dt}|\nabla\theta| = 1/\nabla\theta \, \{-[(\partial\theta/\partial x)^2 \partial u/\partial x + (\partial\theta/\partial y)^2 \partial v/\partial y] - [\partial\theta/\partial x \, \partial\theta/\partial y(\partial v/\partial x + \partial u/\partial y)] - [\partial\theta/\partial x \, \partial\theta/\partial p \, \partial\omega/\partial x + \partial\theta/\partial y \, \partial\theta/\partial p \, \partial\omega/\partial y] + [\partial\theta/\partial x \, \partial/\partial x(d\theta/dt) + \partial\theta/\partial y \, \partial/\partial y(d\theta/dt)]$$

Red term (C) = confluence within a field of stretching deformation

Green Term (S) = horizontally sheared deformation in a field of shearing deformation

Purple Term (T) = tilting (differential warming due to cross-front vertical velocity gradient)

Black Term (DB) = gradients of diabatic heating

Simplified form

- Usually, we only need to know $d/dt(-\partial\theta/\partial y)$

which can be called the "frontal strength"

- If we assume a natural coordinate system with the x axis along the front and the y axis pointing into the cold air, we get..
- $d/dt(-\partial\theta/\partial y)=(\partial u/\partial y')(\partial\theta/\partial x') + (\partial v/\partial y')(\partial\theta/\partial y') +)=(\partial\omega/\partial y')(\partial\theta/\partial p) - \partial/\partial y'(d\theta/dt)$

Interpretation

Shear deformation

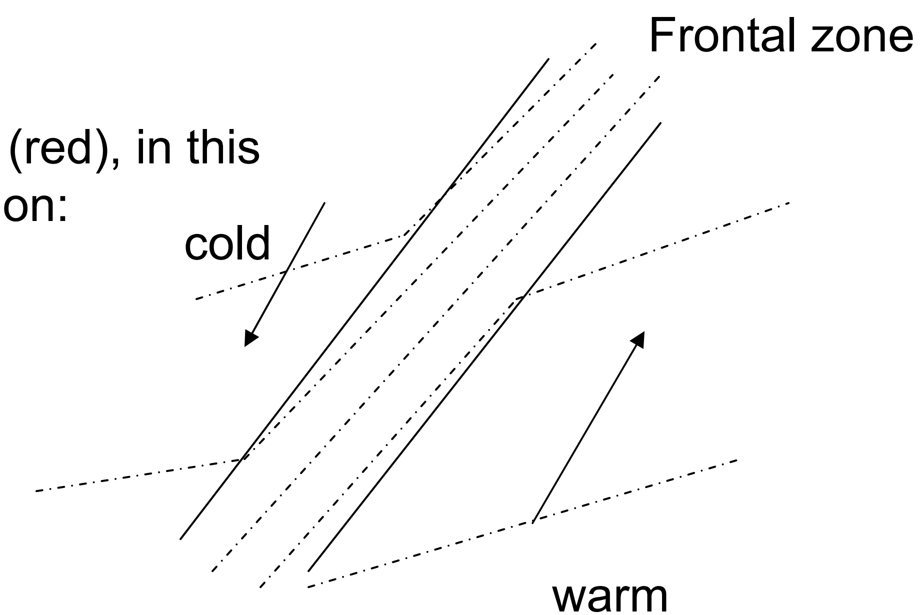
- $d/dt(-\partial\theta/\partial y) = (\partial u/\partial y')(\partial\theta/\partial x') + (\partial v/\partial y')(\partial\theta/\partial y') + (\partial\omega/\partial y')(\partial\theta/\partial p) - \partial/\partial y'(d\theta/dt)$

tilting

“confluence” or stretching deformation

Diabatic heating

Consider the shear term (red), in this typical cold frontal situation:



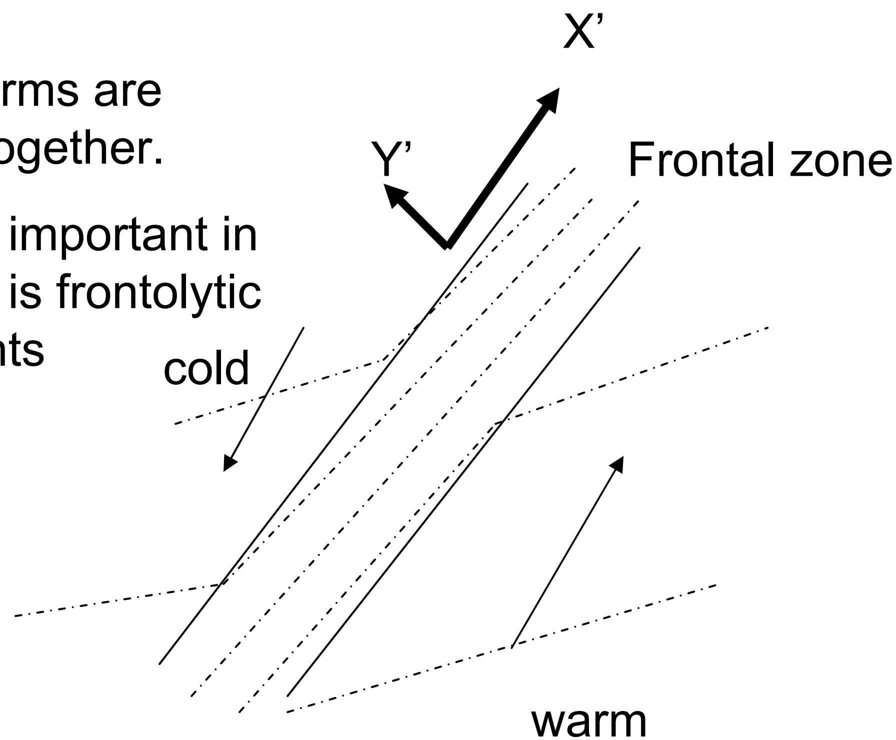
Interpretation

$(\partial u/\partial y')(\partial \theta/\partial x')$

Here, $\partial u/\partial y' < 0$, $\partial \theta/\partial x' < 0$ so the whole shear term is > 0 and this helps strengthen the front.

Think of it as the isotherms are getting pushed closer together.

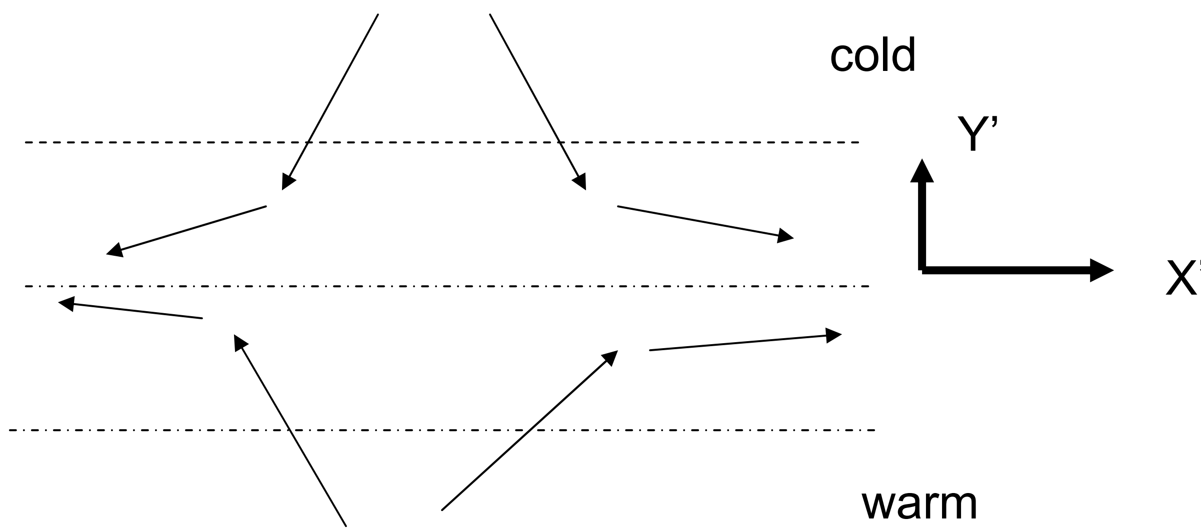
Shear term tends to be important in forming cold fronts, but is frontolytic and destroys warm fronts



Interpretation (cont)

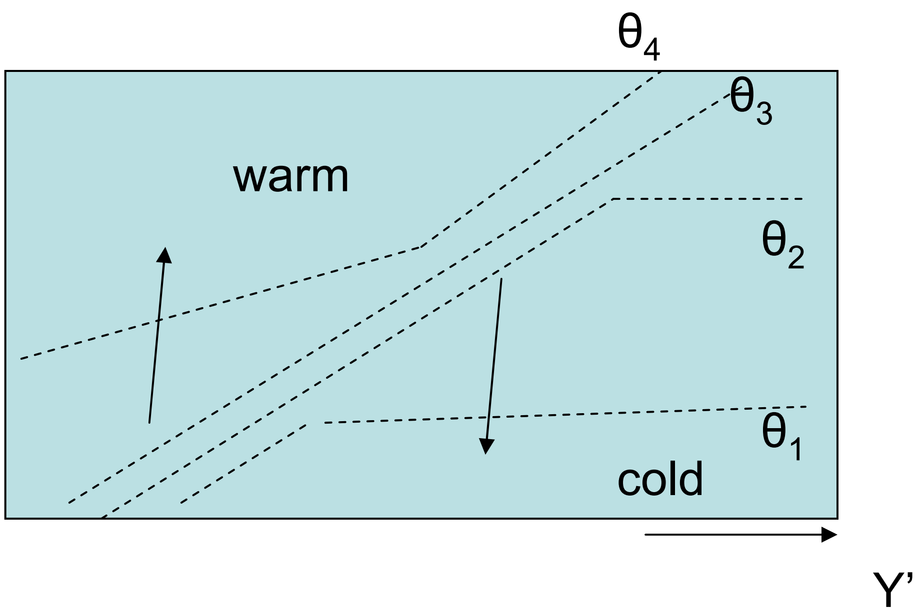
- Confluence term is usually helpful for both types of fronts, and especially important for warm fronts since the Shear term tries to destroy them

$\partial v/\partial y' < 0$ and $\partial \theta/\partial y' < 0$ below, so term is > 0



Interpretation (cont)

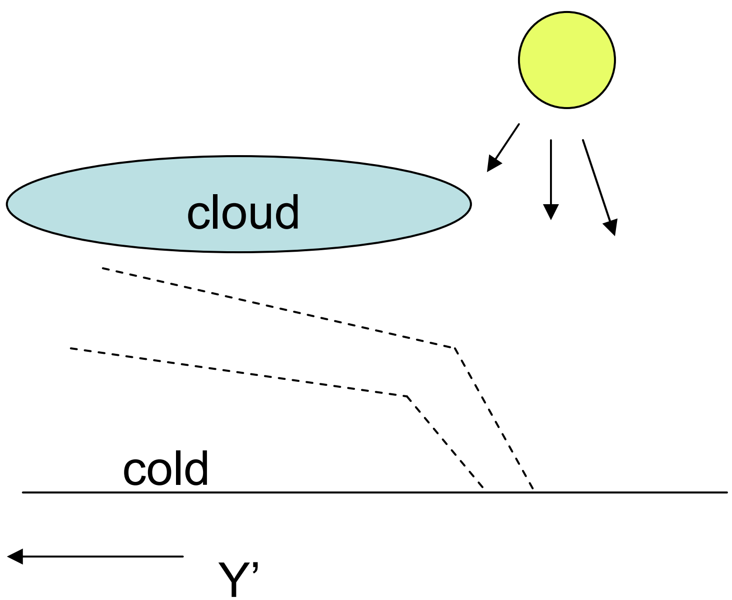
- Tilting term usually is frontolytic since warm air usually rises and cold air sinks



$\partial\omega/\partial y' > 0$ and $\partial\theta/\partial p<0$, so term is < 0

Interpretation(cont)

- Diabatic heating term is important if clouds/precip are on one side of front but not the other, or if we are near oceans, for example

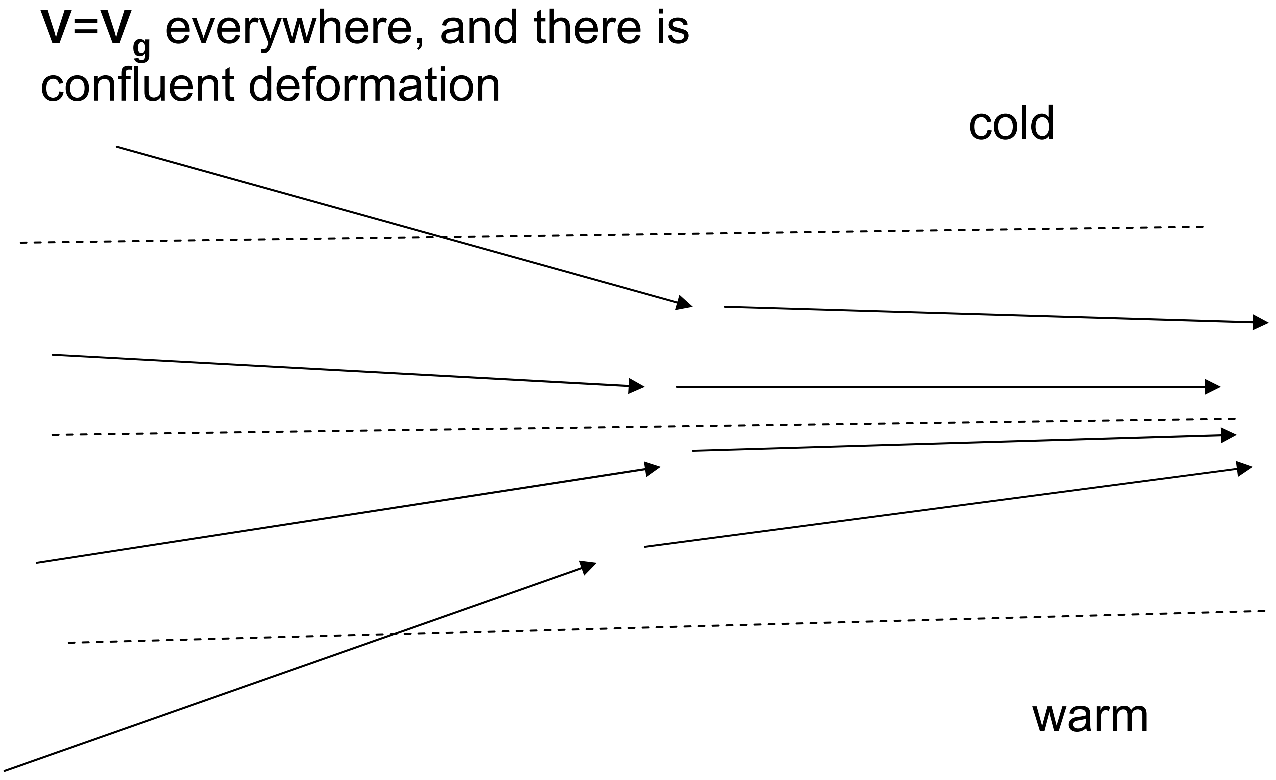


In this daytime case, the cold air side of front is cloudy, so $\partial/\partial y'(d\theta/dt) < 0$

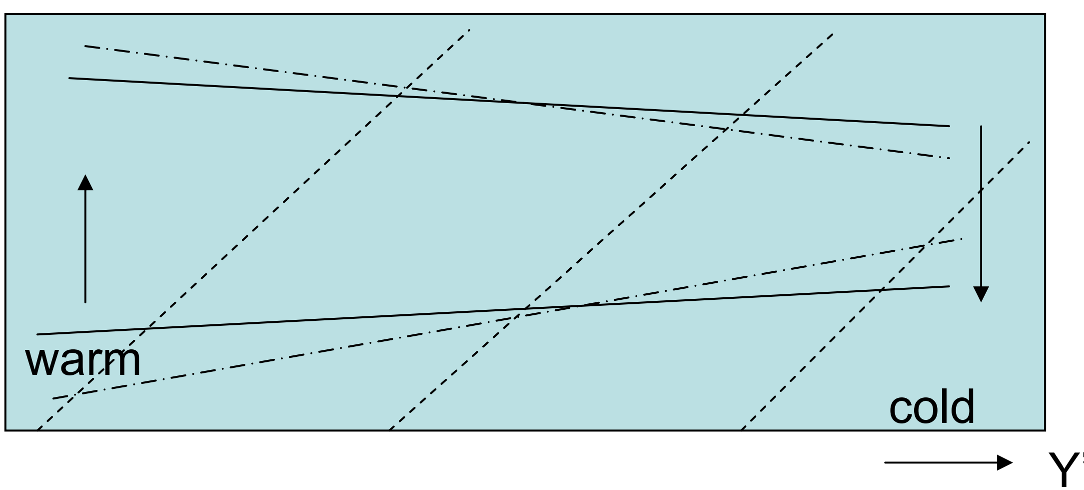
And the term itself has a negative in front, so the term would be positive → frontogenetic. The warm air heats up even warmer, so the front is strengthened. Similar thing happens off E. Coast of USA due to Gulf Stream when cold air moves offshore in winter

How a front can form:

- Assume 700 mb pattern like:



- 1) $\partial v/\partial y' < 0$ and $\partial \theta/\partial y' < 0$ so C in frontogenesis equation is positive
- 2) Cold advection happening in north, warm advection down below, so as temp. gradient increases, so must thickness gradient. To get lower thickness, surface pressures rise and heights fall aloft



- 3) since thickness changes, height surfaces do too, meaning ug changes. Near the sfc, $u_g < u < 0$, so $u_{ag} > 0$

  aloft, opposite, so $u_{ag} < 0$

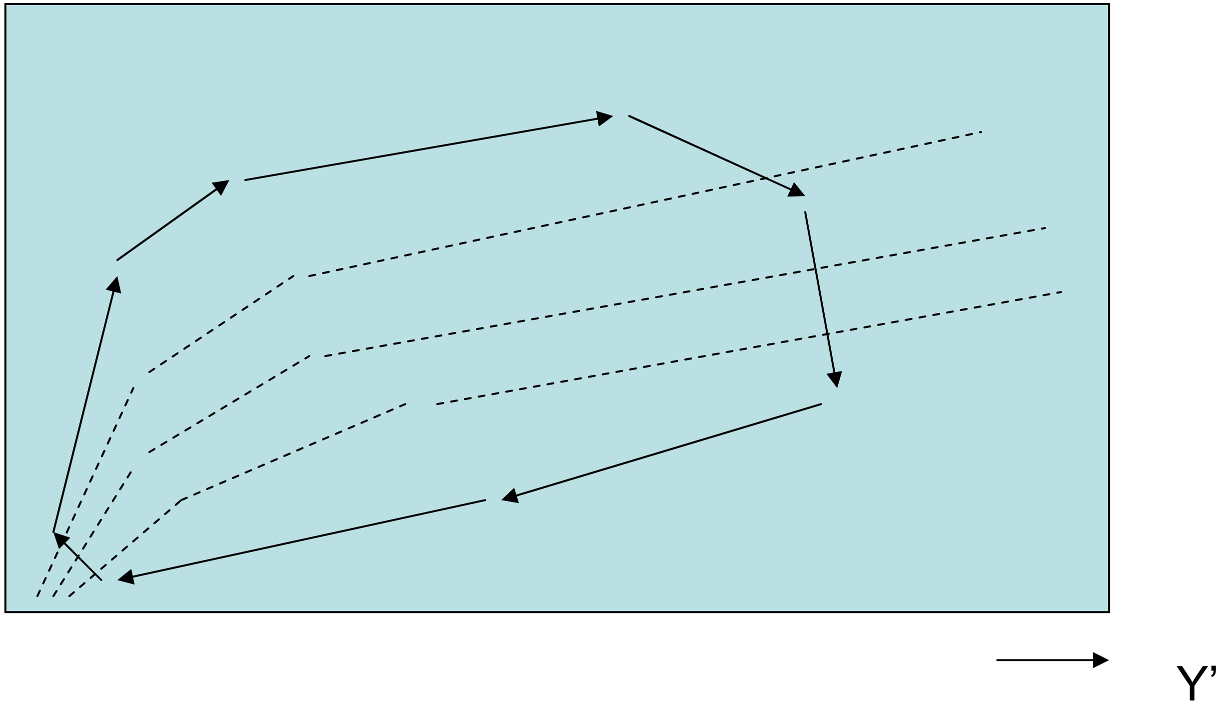
  Coriolis force acts on uag to produce v_{ag} which causes motion from warm to cold aloft, and cold to warm below

4) In addition, momentum advection of u is also occurring. Aloft, the winds bring in lower u values, so $u<u_g$ and $u_{ag}<0$, which produces similar v_{ag} as in step (3)

- 5) the $\mathbf{V}_{ag}$ circulations result in low-level convergence at left of box and upper-level divergence there. Reverse is true on right side of box. Vertical motion results
- 6) Coriolis force acting on V_{ag} leads to du/dt which is > 0 aloft and < 0 below. Since thickness changes are making $du_g/dt > 0$ aloft and $du_g/dt < 0$ below, this means the ageostrophic motions are helping to maintain geostrophic balance.

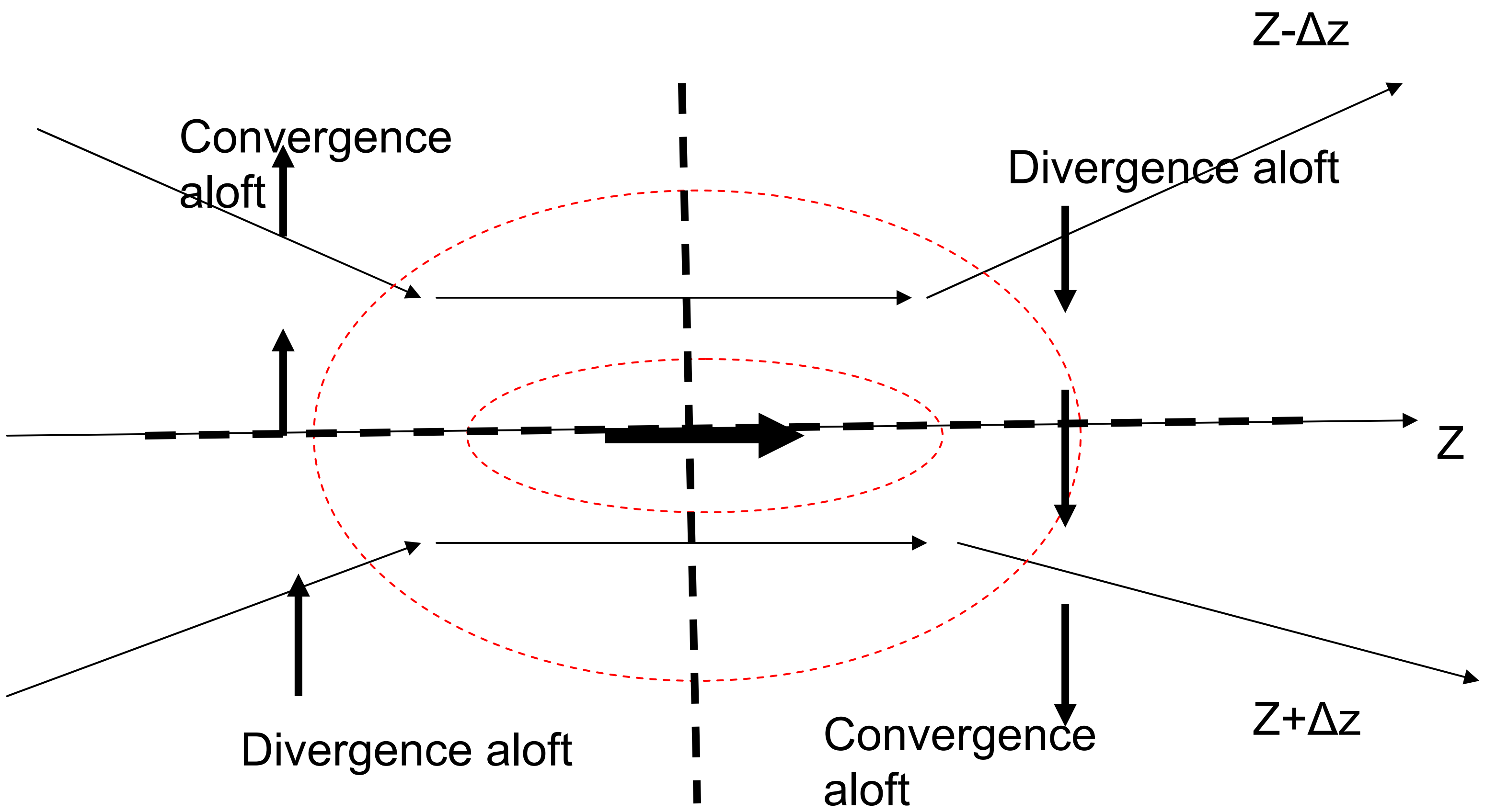
  So our $\partial\theta/\partial y'$ changes are complemented by du_g/dp changes maintaining thermal wind balance

- 7) the circulation that has formed will tilt the frontal zone into a more horizontal position.



Jet Streaks

- Thermal wind arguments tell us the wind should change the fastest in the vertical above regions of strong horizontal temperature gradients. Thus, we expect to find strong winds (jets, jet streaks) in the general vicinity of fronts.
- Jet streaks are localized areas of higher wind speed, and they induce circulations with upward and downward motion



In a linear jet streak, we expect the LEFT FRONT and RIGHT REAR quadrants, also known as LEFT ENTRANCE and RIGHT EXIT regions, to have upward motion due to divergence aloft, while the other two quadrants, LEFT REAR and RIGHT FRONT, have downward motion

Ways to explain this…

- There are 2 explanations for this
- First is to recall that the lateral shear will be greatest near the jet core, implying strongest positive vorticity just north of core, and strongest negative just south. Thus, one can picture a vort max just north of the core and a vort min south of it. Then, the usual PVA and NVA arguments explain the upward or downward motion

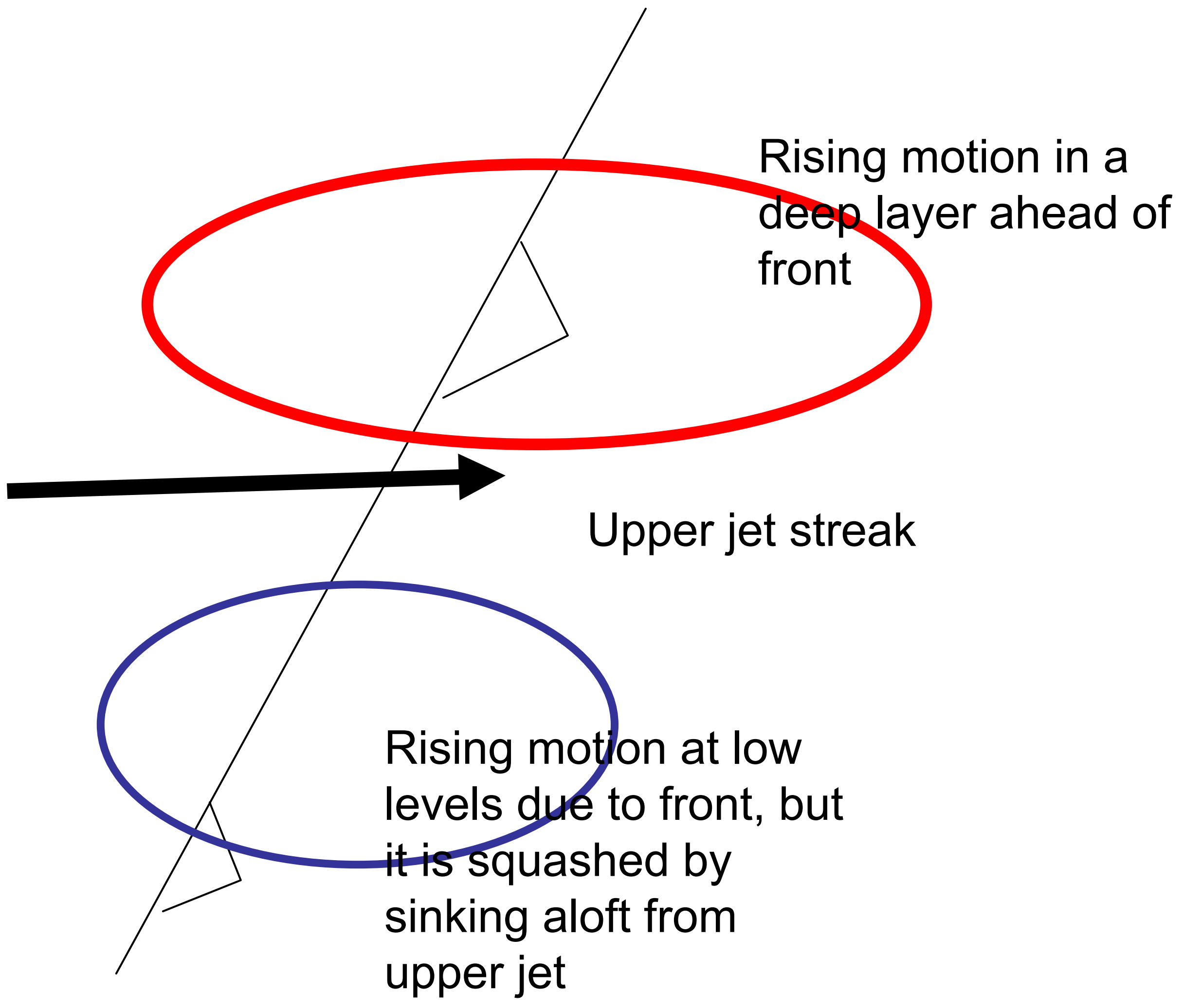
Ways to explain this…

- The other explanation is to note that the wind blows through features like trofs and jet streaks. Thus air approaching the jet core must speed up. To do this, it has to "blow downhill" or cross toward lower heights, so it picks up speed. Outside the jet streak, the flow is undisturbed. Thus, air ends up converging left of the jet streak in the entrance region, and diverging to its right.

Likewise, when air leaves the jet streak, it must slow down. To do this, it has to “blow uphill” or head toward higher heights. This leads to divergence aloft left of the jet streak in the exit region, and convergence to the right.

Jet Coupling

- We have been talking about jet streaks aloft. Keep in mind that fronts induce circulations at low levels. These two different circulations can oppose each other or work in tandem. Often, one portion of a surface front will be under the sinking portion of the upper-level jet and not experience much precipitation while another area is under the rising portion and gets deep clouds and precipitation


Rising motion in a deep layer ahead of front
Upper jet streak
Rising motion at low levels due to front, but it is squashed by sinking aloft from upper jet