Frontogenetic Precipitation Bands and CSI Primer

Winter Weather Workshop
National Weather Service Wakefield, VA
December 3, 2008

Excerpts from Nicosia and Grumm (1998), Przybylinski (2000), Schumacher (2002), Banacos (2003), and Funk (2008)

Outline

- Define Frontogenesis and Frontolysis
- Examine Factors Contributing to Frontogenesis/Frontolysis
- Dynamic Response to Frontogenesis
- Frontogenetical Circulations and the Development of Mesoscale Precipitation Bands
- Diagnosing CSI, CI, and EPV
- Case Study: The Development of CSI Precipitation Bands in Southeast Virginia on 10/27/2008

Frontogenesis and Frontolysis Defined

- **Frontogenesis** refers to the change in the magnitude and orientation of the temperature gradient at a level or layer due to the directional and speed changes in the wind field.

- Frontogenesis <u>increases</u> the horizontal thermal gradient with time.

- **Frontolysis** – similar process as described above, except that frontolysis <u>decreases</u> the horizontal thermal gradient with time.

Factors Contributing to Frontogenesis/Frontolysis

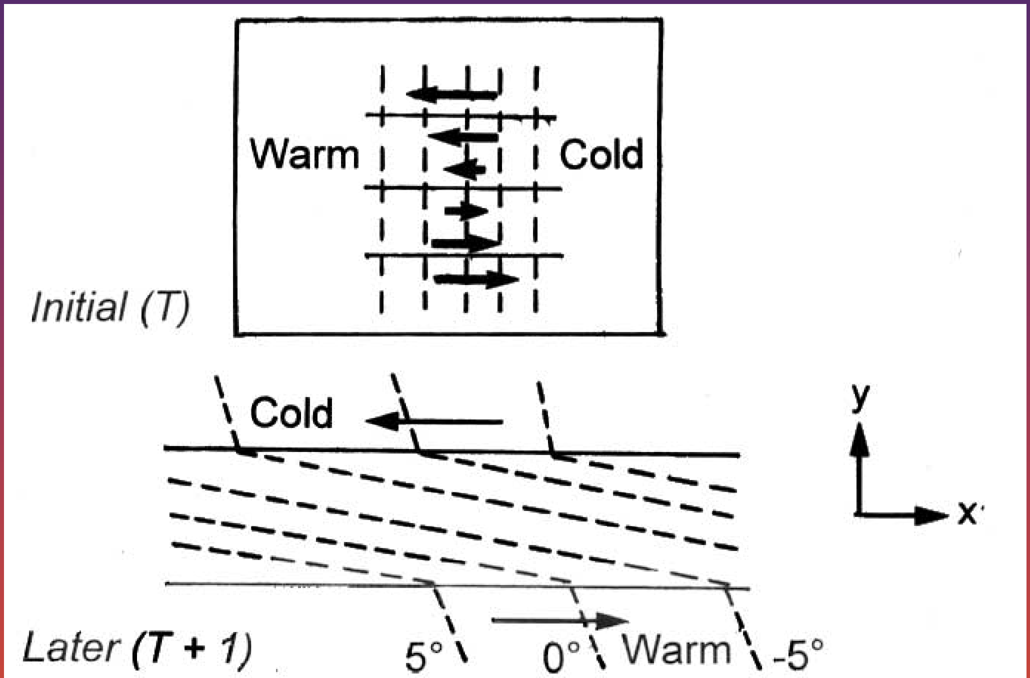
There are three factors which can effect the horizontal thermal gradient resulting in frontogenesis or frontolysis.

- Deformation (Primary synoptic scale contributor)
  - Shear
  - Confluence (stretching)/Difluence (spreading)
- Tilting (differential vertical motion)
- Diabatic Heating

Deformation from Shear

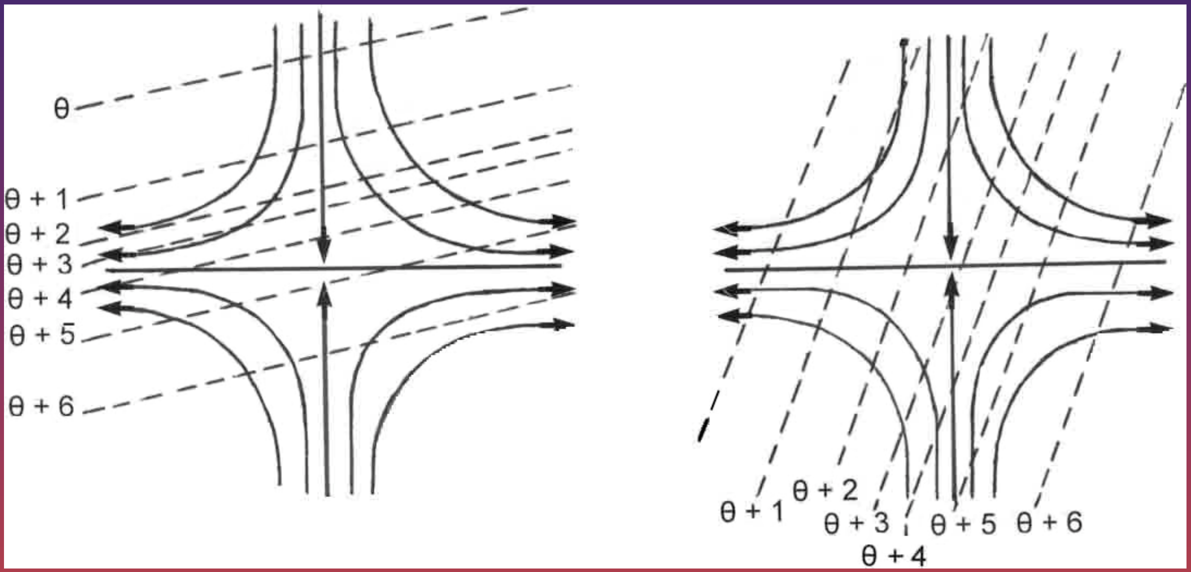
Initially, the sheared wind field applied to a uniform thermal gradient (warm left side, cold right side).

At time T+1, the sheared wind field acts to rotate, and in the process tighten the thermal gradient.



Common Example of Frontogenesis from Shearing Deformation: In the vicinity of a cold front south of a surface low pressure area.

Deformation from Confluence/Difluence



Confluent Deformation (Left): The angle between the deformation axis ('axis of dilatation') is less than 45º. The wind field is acting ***frontogenetically*** by stretching the isotherms and thus increasing the thermal gradient.

Difluent Deformation (Right): The angle is greater than 45º. The wind field is acting ***frontolytically*** by spreading the isotherms and thus decreasing the thermal gradient.

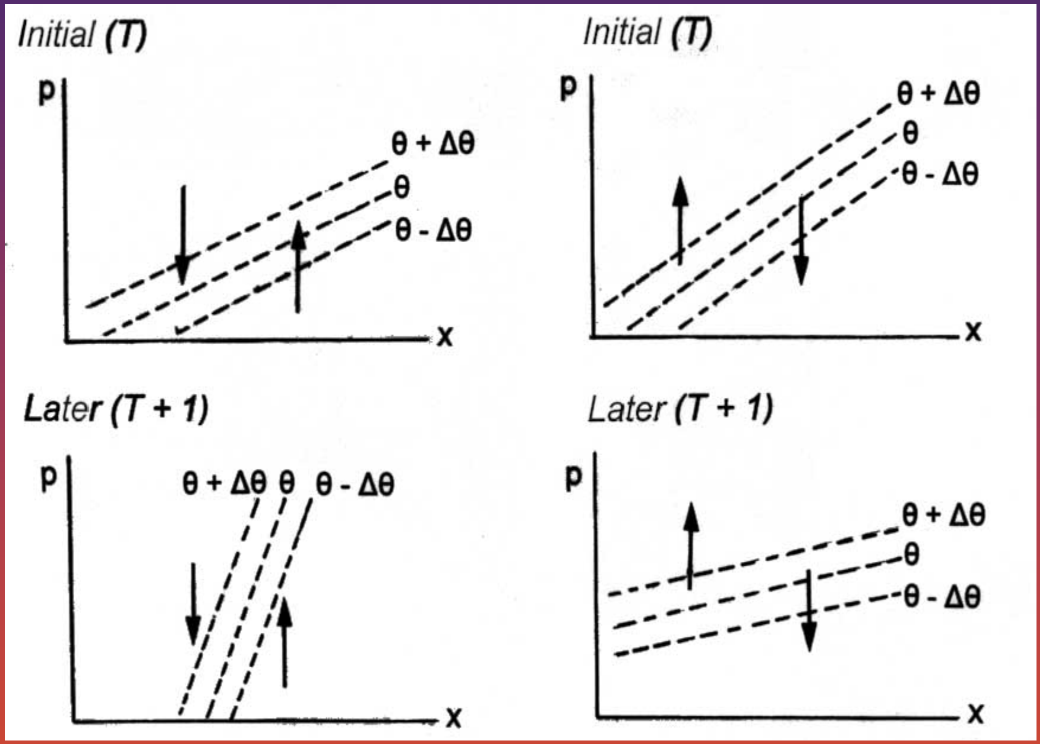
Examples of Frontogenesis from Confluent Deformation: Entrance Regions of mid and upper level jet streaks (500-300 mb). Also, just west of a mid level (700-500 mb) closed low, NW of the surface low.

Tilting (differential vertical motion)

The temperature gradient is being tilting by the vertical motion field.

Left: Differential vertical motion acting to <u>increase</u> the thermal gradient. *(frontogenetic)*

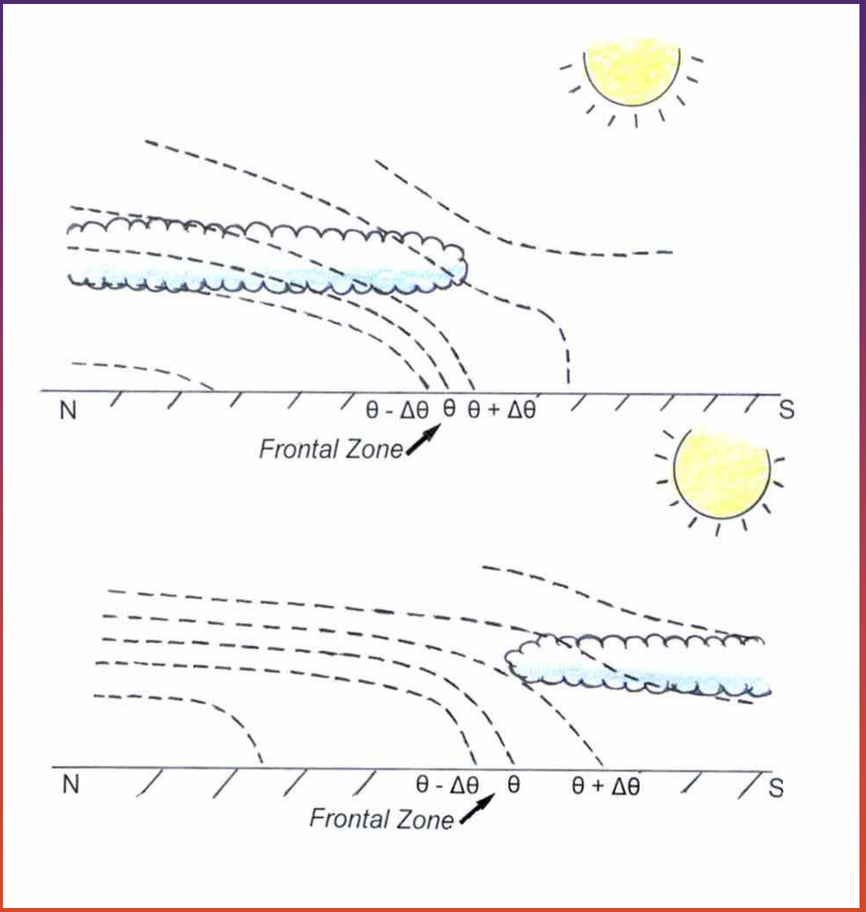
Right: Differential vertical motion is acting to decrease the thermal gradient. *(frontolytic)*



Examples of Frontogenesis from Tilting: Indirect thermal circulation in exit region of an upper-level jet. <u>*Frontogenetic response*</u> to <u>*frontolytical forcing*</u> (*geostrophic frontolysis*)

Diabatic Heating

Diabatic Heating can act *frontogenetically* (top) or *frontolytically* (bottom).



Top example: Cloud cover is limiting radiational warming in the colder air, while cloud-free area on the warm side heats up. (*Thermal gradient strengthens)*

Bottom example: The sun is warming the colder air, while cloud cover limits warming on the warm side. *(Thermal gradient weakens)*

Example of Frontogenesis from Diabatic Heating: Stratus clouds forming on north side of cold front.

Dynamic Response to Frontogenesis

- An increase in the temperature gradient disrupts the thermal wind balance, since the horizontal temperature gradient becomes too large for the associated vertical wind shear.

- To restore thermal wind balance, the atmosphere produces a thermally-direct ageostrophic circulation traverse to the baroclinic zone.

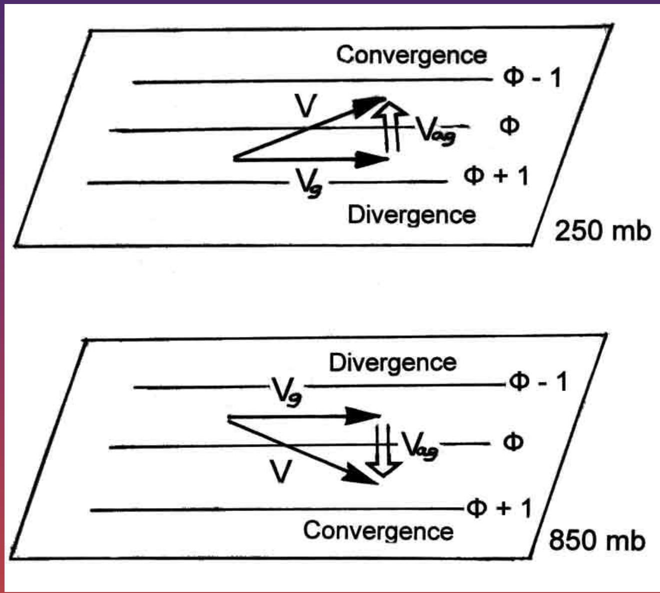
- As a consequence of the ageostrophic circulation, *upward vertical motion increases on the warm side of the low-mid level (1000-500 mb) frontogenetic zone.*

- This thermodynamically-direct ageostrophic circulation attempts to weaken the horizontal baroclinicity, while at the same time increase the vertical wind shear, in an attempt to bring the atmosphere back in thermal wind balance.

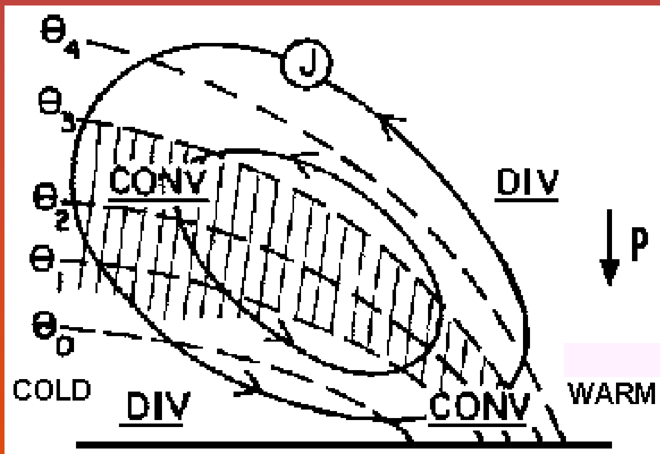
Dynamic Response to Frontogenesis

Aloft: Ageostrophic flow is directed toward lower geopotential heights.

At Low Levels: Ageostrophic flow is directed toward higher geopotential heights.



This sets up a *thermally-direct ageostrophic circulation*, where upward (downward) motions develop across the southern (northern) part of the plane respectively.

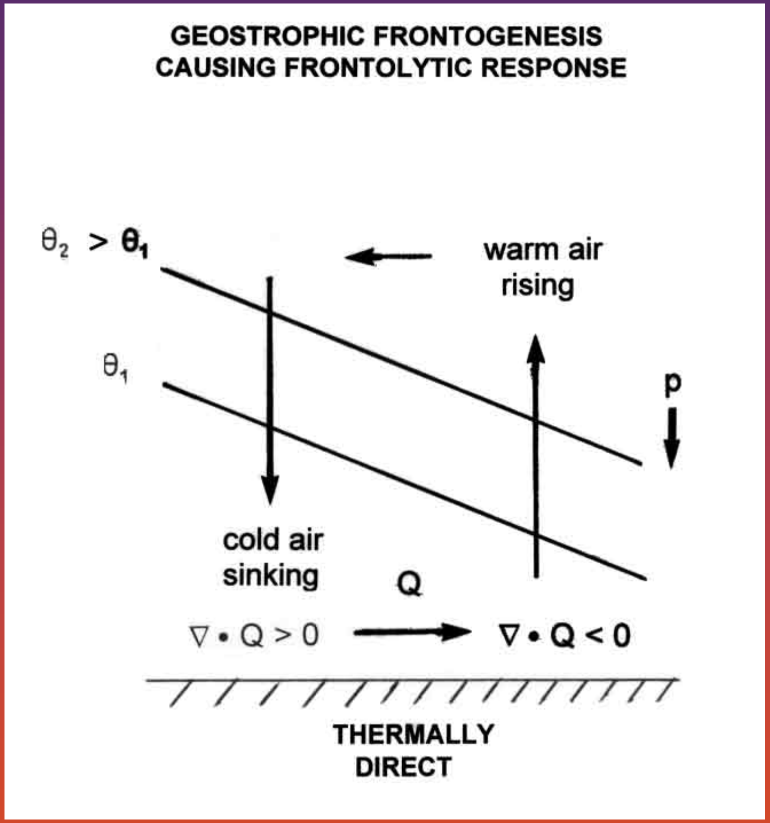


Dynamic Response to Frontogenesis

The development of a direct thermal circulation acts to *weaken the temperature gradient and frontal zone.*

• Synoptic forcing leading to geostrophic frontogenesis causes a frontolytic response, as air on the warm side rises (cools), and air on the cool side sinks (warms).

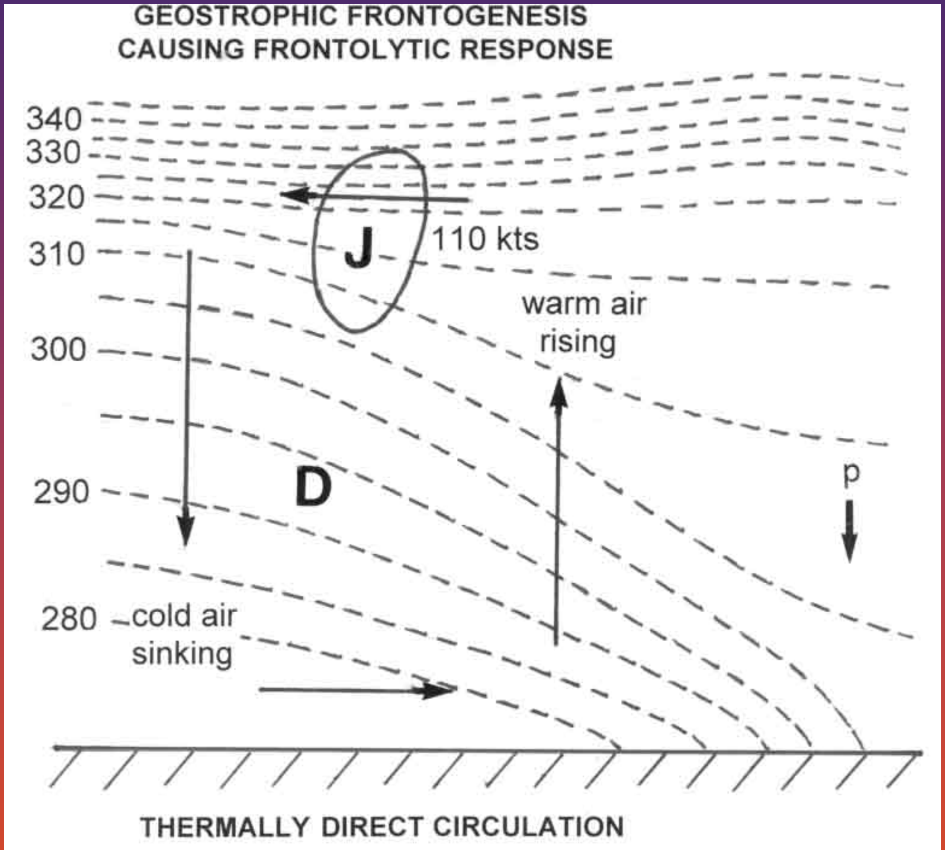
• The opposite occurs with geostrophic frontolysis, which causes a frontogenetic response, as air on the warm side sinks (warms), and air on the cool side rises (cools).



Note: QG frontogenesis is limited to forcing on the synoptic scale (e.g. through deformation).

Dynamic Response to Frontogenesis

Thermally Direct Circulations typically develop in the *'entrance region'* or RRQ of an upper-level jet streak (250 – 300 mb).

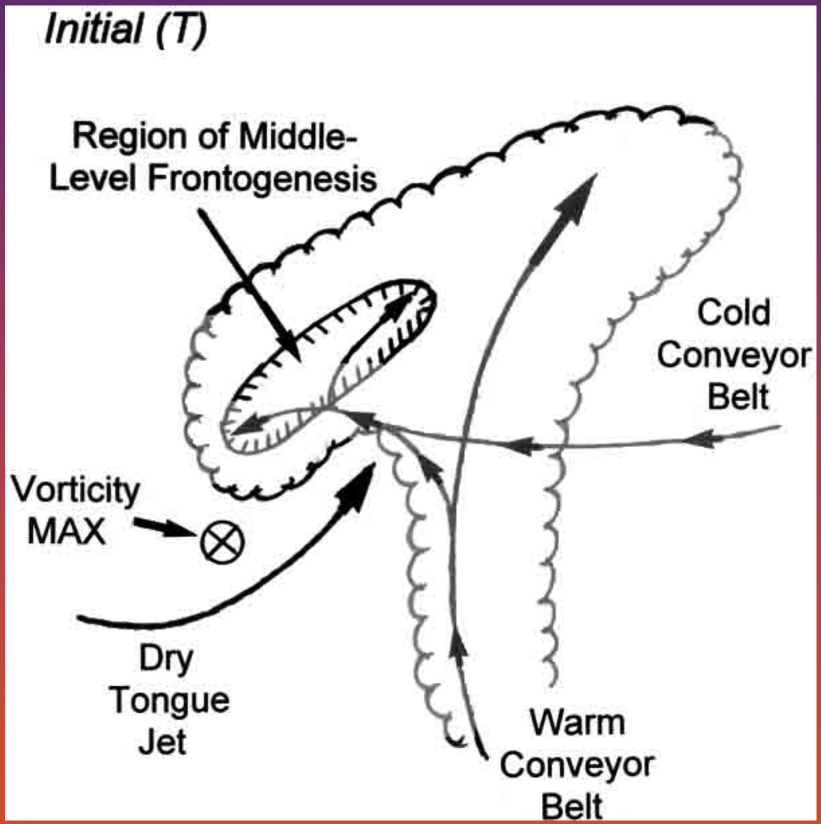


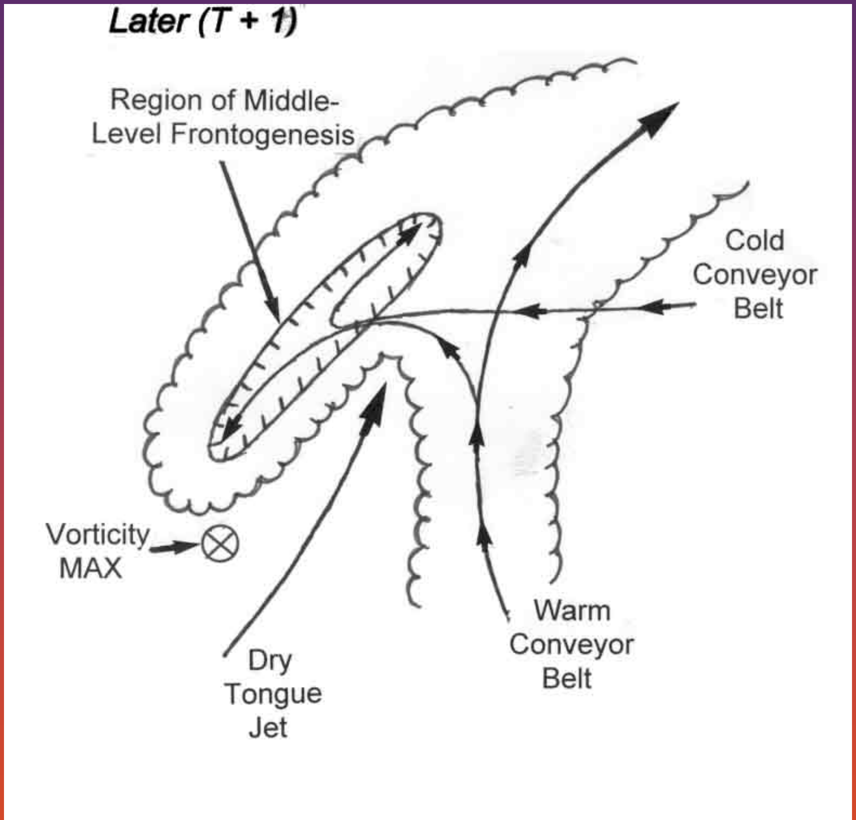
The result of the forcing, or response, is *frontolytic.* Air on the warm side rises and cools, while air on the cool side sinks and warms (thereby weakening the temperature gradient).

Since ULJ streaks inherently occur in a baroclinic environment which implies thermal wind shear, it follows that geostrophic frontogenesis and frontolysis are associated with jet streaks.

Dynamic Response to Frontogenesis

Evolution of Mid-Level Frontogenesis





Deepening low pressure (closed low through at least the mid levels) leads to more intense low-mid level frontogenesis, thereby increasing the likelihood that frontogenetic precipitation bands will development.

Types of Frontogenesis

- **Q-G Frontogenesis** refers to the frontogenesis resulting from the deformation of the geostrophic wind. *Forcing is synoptic-scale driven.*

- **Petterson Frontogenesis** refers to the 2-dimensional horizontal frontogenesis resulting from the thermally direct ageostrophic circulation, typically applied to low or low-mid levels (e.g. 1000-850 & 850-700 mb). *Forcing is mesoscale-driven.*

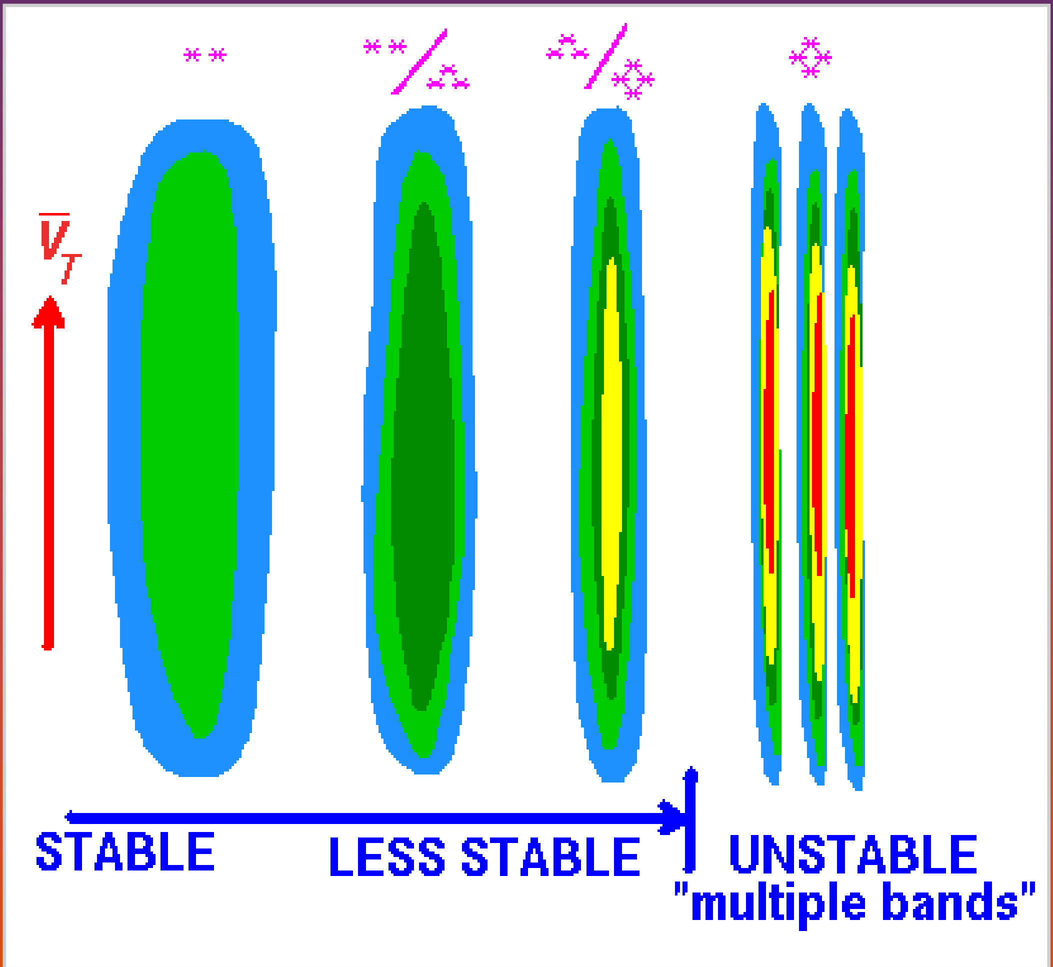
- **Key Point:** while the ageostrophic circulation is established to restore thermal wind balance (through a frontolytic response, or *decrease* in the geostrophic frontogenesis), the by-product of this circulation is an *increase* in low-mid level Petterson Frontogenesis!

Frontogenetical Circulations and the Development of Mesoscale Precipitation Bands

- Frontogenetical circulations typically result in one band of precipitation which is parallel to the frontal zone.
- The strength of the circulation can be affected by the ambient static stability.
- Numerous studies have shown that a weakly stable environment in the presence of frontogenesis lead to one band of heavy precipitation.
- *However*, the same studies have also shown that a greater instability resulted in multiple (narrow) convective bands of precipitation (also parallel to the frontal zone).

Frontogenetical Circulations and the Development of Mesoscale Precipitation Bands

From Funk (NWS LMK), 2008



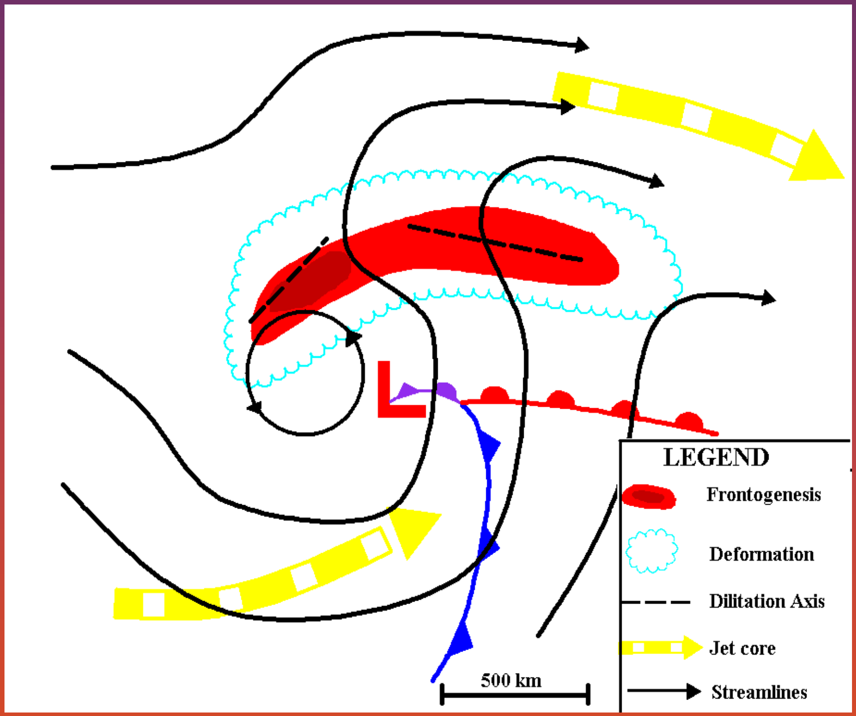
Atmospheric stability affects vertical motion response to Frontogenesis.

As stability decreases, horizontal width of precip band decreases while band intensity increases. Multiple bands occur in an unstable regime.

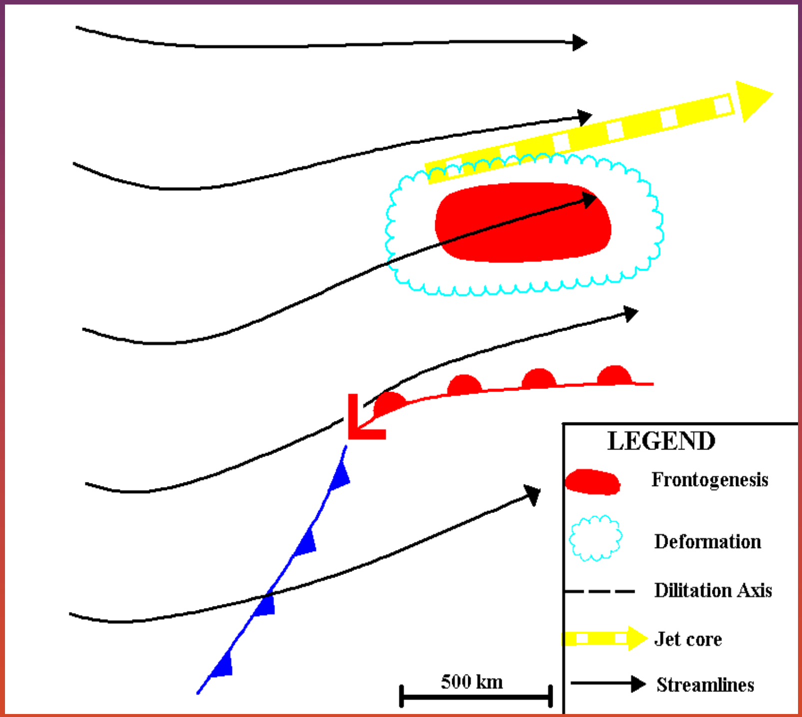
One MUST assess stability together with frontogenesis to determine expected vertical motion response and precip evolution.

Frontogenetical Circulations and the Development of Mesoscale Precipitation Bands

From Novak and Waldstreicher (NWS ERH), along with Bosart and Keyser (SUNY Albany), 2002



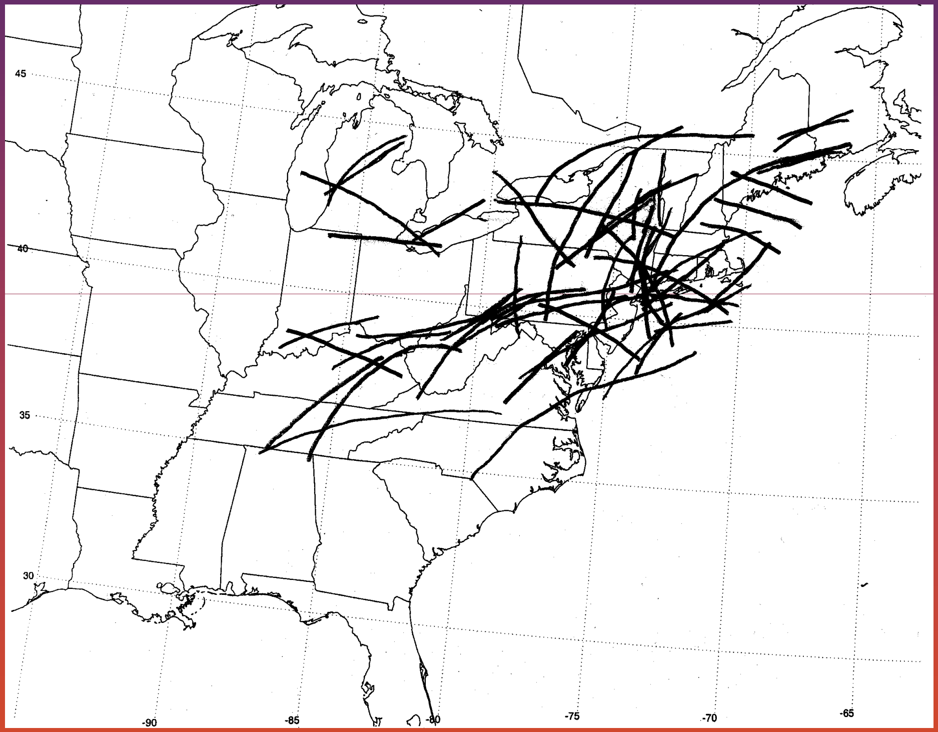
Banded Example

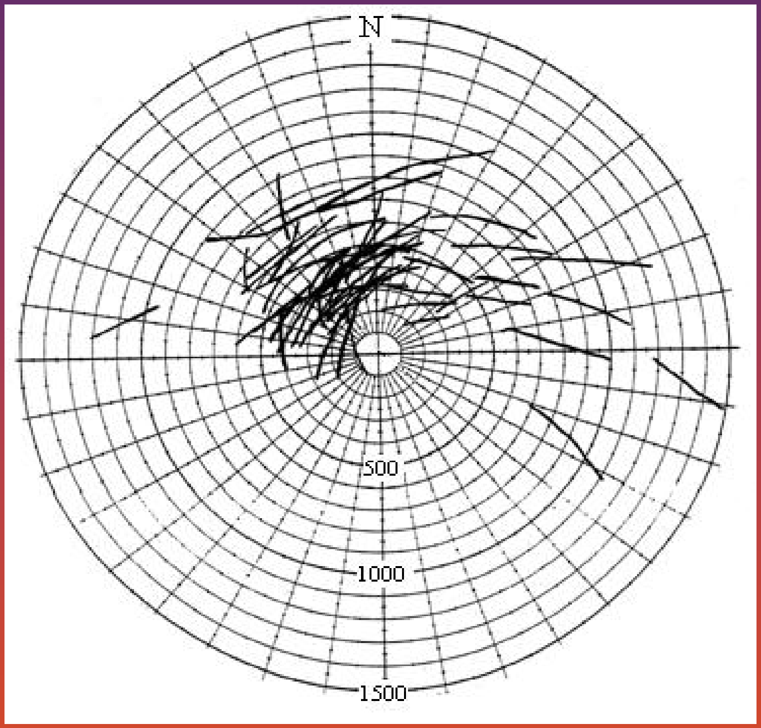


Non-banded Example

Frontogenetic Band Distribution

From Novak and Waldstreicher (NWS ERH), along with Bosart and Keyser (SUNY Albany), 2002

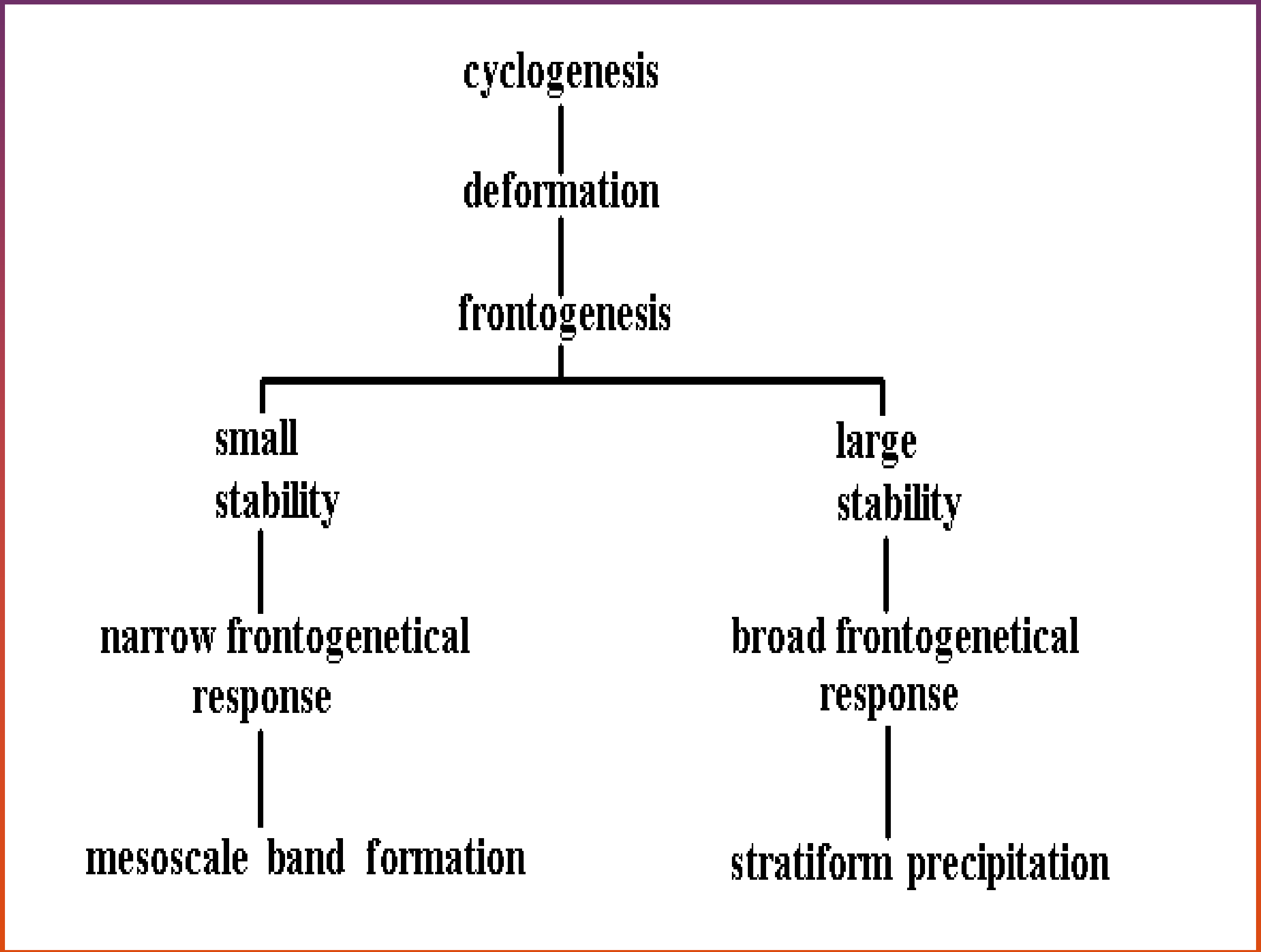




Novak et. al. identified 48 events, 80% of which were banded cases in the NW quadrant of the surface low pressure system, in the vicinity of maximum 700-500 mb frontogenesis.

Assessing the Potential for the Development of Mesoscale Precipitation Bands

From Novak and Waldstreicher (NWS ERH), along with Bosart and Keyser (SUNY Albany), 2002



Dynamic Consequences of Intense Frontogenesis

(Introduce EPV, CSI, CI)

- When the vertical wind shear and associated horizontal temperature gradient are large (i.e. strong horizontal frontogenesis), the change in momentum with respect to height (decreasing pressure) will be greater, with the momentum surfaces attaining a more shallow slope in the x-p plane.
- When this happens, there is a better chance that theta-e will slope more steeply than the momentum surfaces, which is a necessary condition for Conditional Symmetric Instability (CSI).
- By definition, the greater the vertical wind shear, the more reduced the Equivalent Potential Vorticity (EPV) becomes.

Dynamic Consequences of Intense Frontogenesis

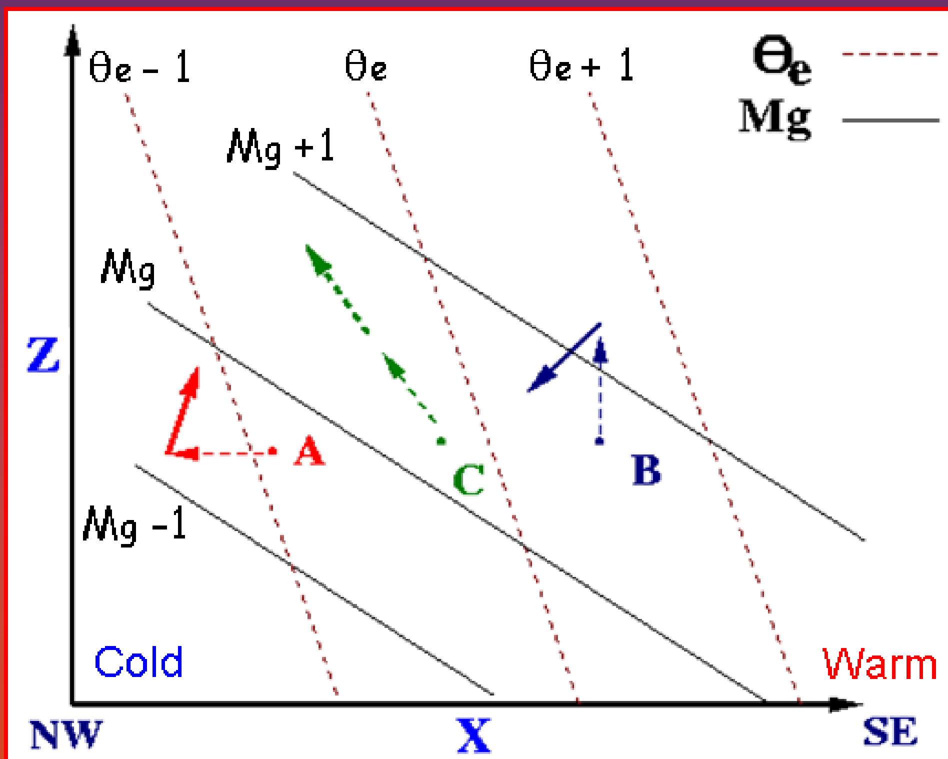
(Introduce EPV, CSI, CI)

- The closer EPV is to zero, the more responsive the atmosphere will be to a given amount of forcing.
- When EPV becomes negative, CSI (potential for slantwise convection), and/or CI (potential for upright convection) is present.

Diagnosing CSI

From Funk (NWS LMK), 2008

Construct a spatial-height cross-section of θe and Mg normal to 850-300 mb thickness or temp lines



Better chance for CSI:

-Lines of θe are more vertical (steeper) and increase slightly with height

-Lines of Mg are more horizontal implying good speed shear with height

-Lines of θe are steeper than Mg

Parcel A is inertially stable when displaced horizontally

Parcel B is gravitationally stable when displaced vertically

Parcel C is unstable (will accelerate) when displaced slantwise up:

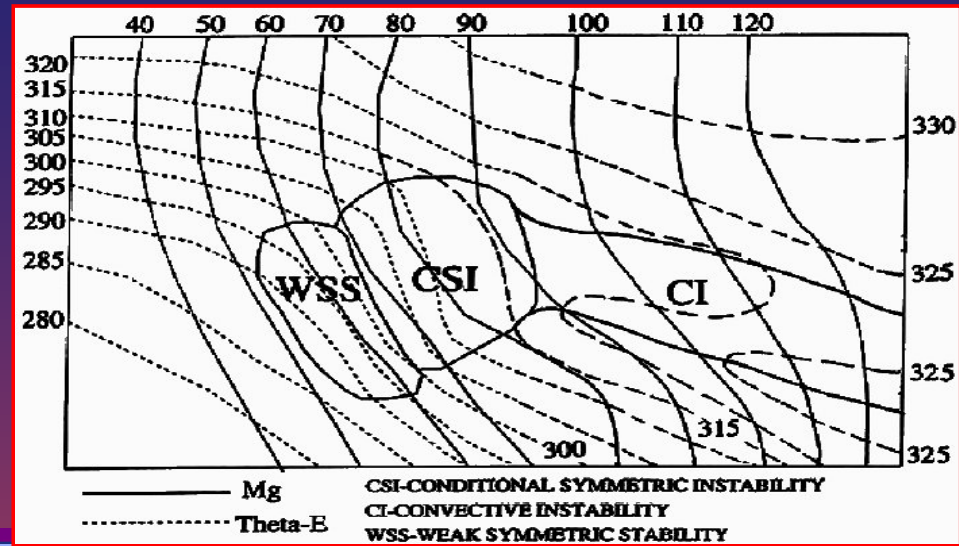
θe (parcel) > θe (environ) and Mg (parcel) < Mg (environ)

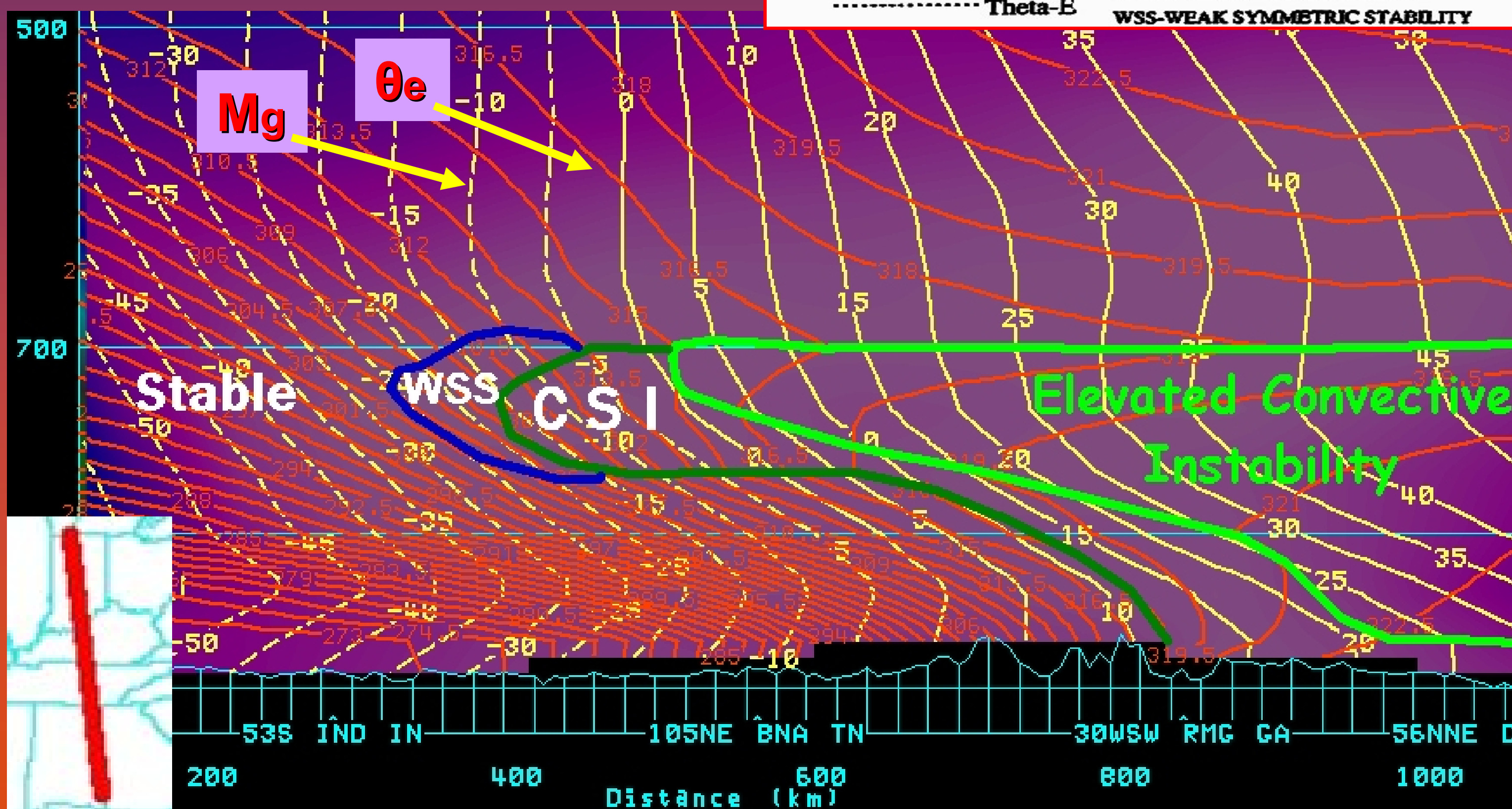
Diagnosing CSI

Convective Instability (CI): θe decreasing with height; elevated upright convection possible.

Conditional Symmetric Instability (CSI): θe lines more vertical than momentum lines (Mg).

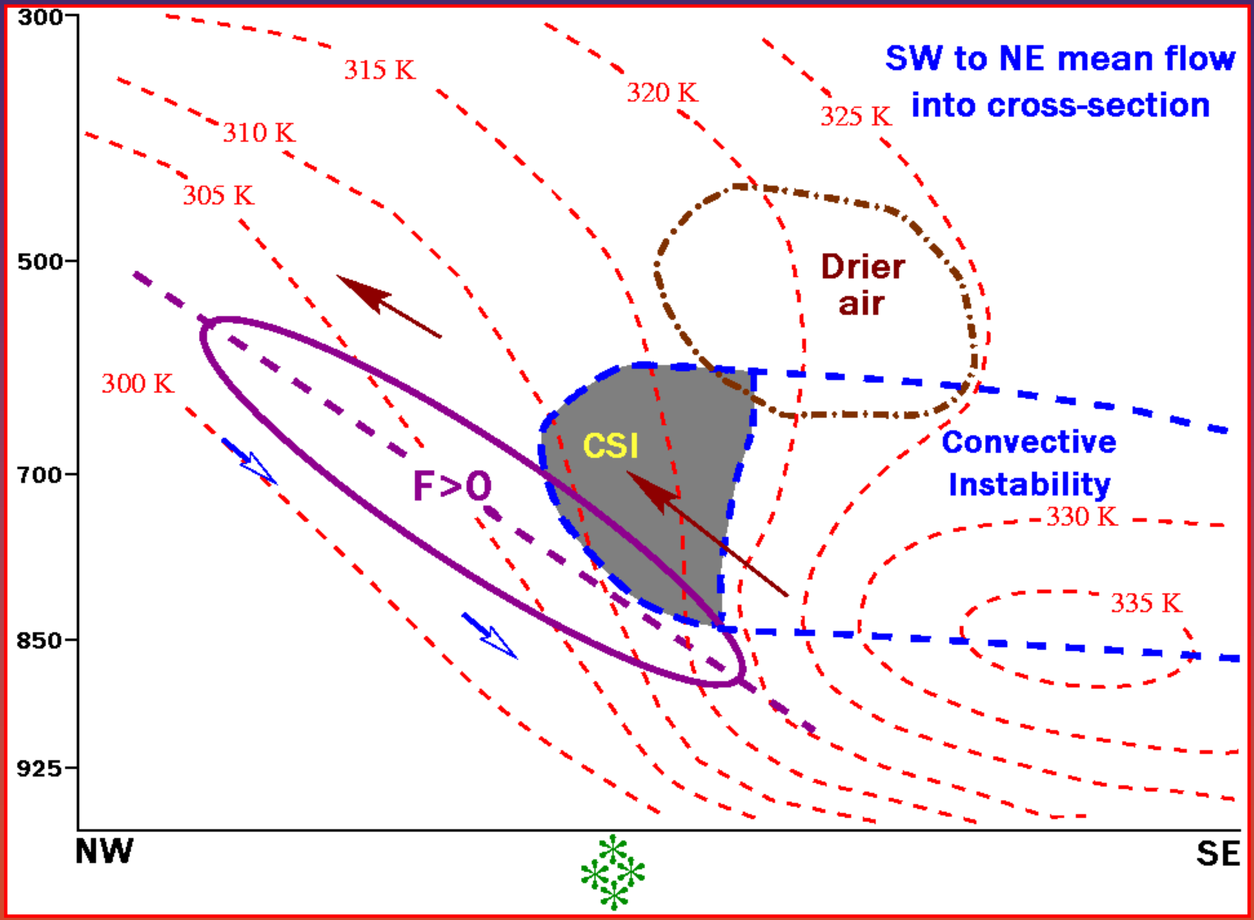
Weak Symmetric Stability (WSS): θe lines about parallel to Mg lines; can still get banded heavy precip given sufficient frontogenesis.





Spectrum of mesoscale instability: CI → CSI → WSS → Stable

Diagnosing CSI

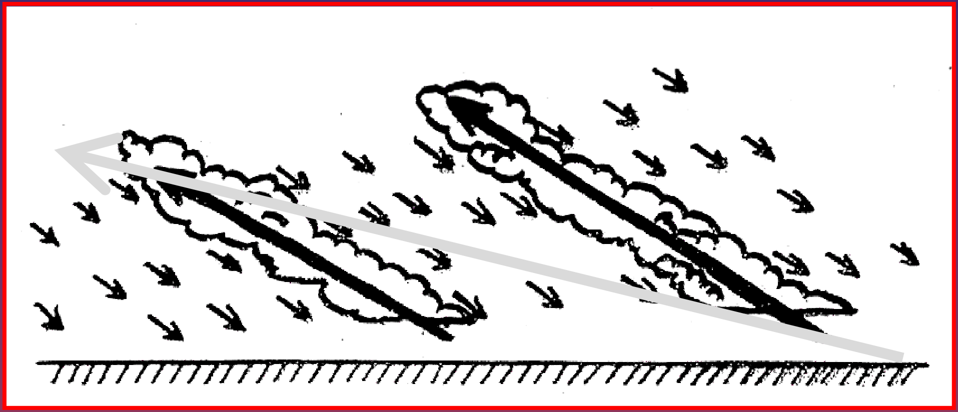


On plan view, look for ridge axis of Total Totals poking northward into area of concern (may be hint of elevated weaker stability or elevated instability).

On cross-section, look for area of CSI or CI upwind of and/or above area of frontogenetical forcing

Banded, heavier precipitation occurs under a slanted, strengthening moist frontogenetical zone coincident with or downstream of elevated CSI and/or CI

Diagnosing CSI



Moist slantwise convection results from release of CSI. Slanted updrafts are narrow and intense (black lines), while downdrafts are diffuse and weak. Circulation is superimposed on broader-scale ascent (blue line).

CSI is favored in regions of:

- High mean RH and large-scale ascent
- Usually north of warm fronts
- Saturated moist-adiabatic lapse rates aloft
- Vertical speed shear aloft (baroclinic environment)
- Weak absolute vorticity (within/near ridges downstream from troughs)
- Weak convective stability (θe increases slightly with height or is nearly vertical)
- Entrance region of anticyclonically-curved jet streaks; may occur within a exit region
- Nose of dry slot aloft (this may be where CI is present)
- CSI can produce elevated CI, as vertical circulation associated with CSI can overturn θe surfaces with time creating convectively unstable zones aloft

Diagnosing EPV

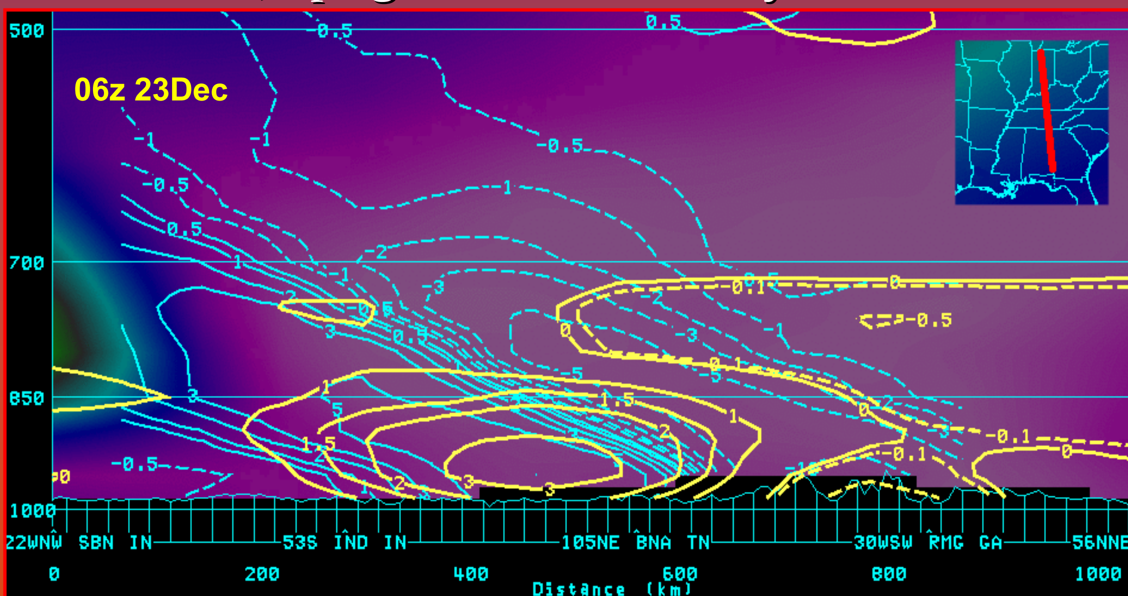
► EPV can be used to assess stability, and is viewable on plan views & spatial cross sections.

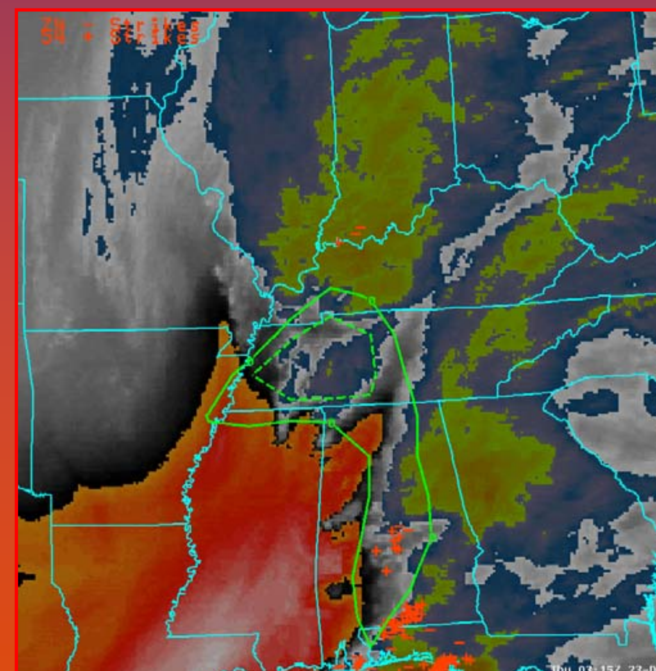
► Areas of EPV around or < 0 is where CSI and/or CI are present.

► EPV is lower when strong vertical speed shear and south-north θe gradient exist.

► EPV often is around or < 0 within ridge axes, south of jet streaks, and in the nose of upper dry slots.

► Given CI, upright convection may form which overwhelms CSI-induced motions.

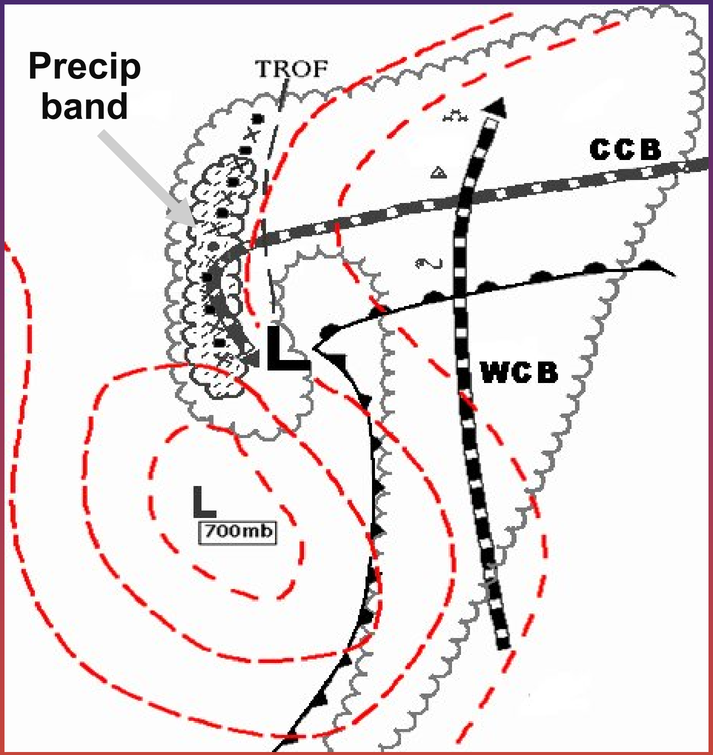


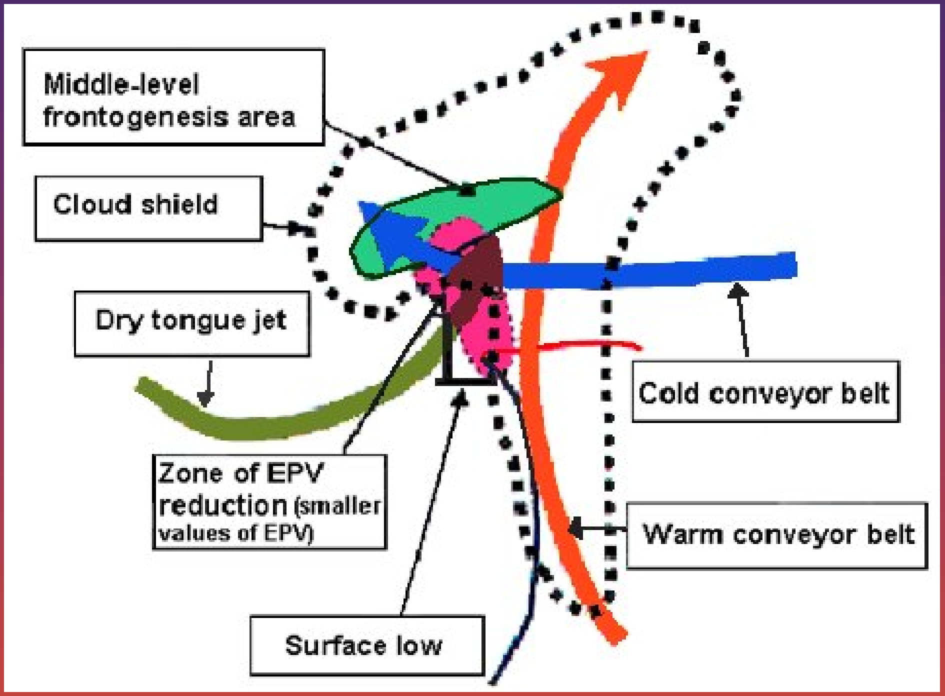


***** For more info on atmospheric stability and its effect on vertical motion, review Winter AWOC IC5, Lesson 3 *****

Synoptic Patterns

Favoring Intense Frontogenesis and Banded Precipitation





- Heavy banded precip occurs during developing/mature stages of a low: 1) ahead of low associated with LLJ; 2) to N or NW of low near a deformation zone (comma head).

- Component of warm conveyer belt often wraps around into comma head overtop cold conveyer belt (TROWAL).

- Banded precip is typically on the warm side of the max mid-level frontogenetical zone, with reduced or negative EPV within or just upstream of area toward nose of mid-level dry slot (reduced or negative theta-e lapse rates).

When will CI Dominate over CSI ?

- As Theta-e decreases with height, EPV then becomes more negative.

- Therefore, negative EPV values will be largest when 1) the vertical wind shear and associated horizontal temperature gradient are large ***and*** when 2) theta-e decreases with height or decreasing pressure.

$\Rightarrow$ When both of these processes are occurring, ***upright convection will dominate over slantwise convection*** given sufficient lift and saturation.

Summary of Slantwise vs. Upright Convection

- ***Slantwise convection (CSI)*** will dominate when the horizontal baroclinicity (vertical wind shear) is strong (leading to negative EPV) ***yet*** when theta-e is either constant or slightly increasing with height (i.e. when the column is saturated through mid levels).

- ***Upright convection (CI)*** will dominate when the horizontal baroclinicity (vertical wind shear) is strong, *and* when theta-e decreases with height (i.e. when dry advection occurs at mid levels, leading to a "more negative" EPV).

- In general, mesoscale convective precipitation bands will take <u>much longer</u> to develop under slantwise convection compared to upright convection.

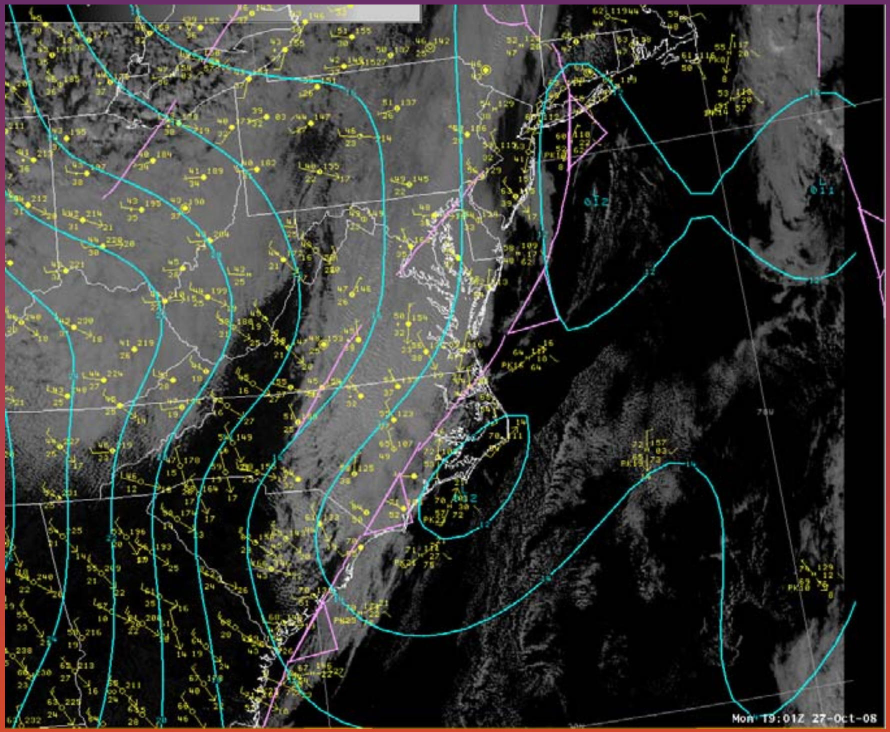
Mesoscale Precipitation Bands

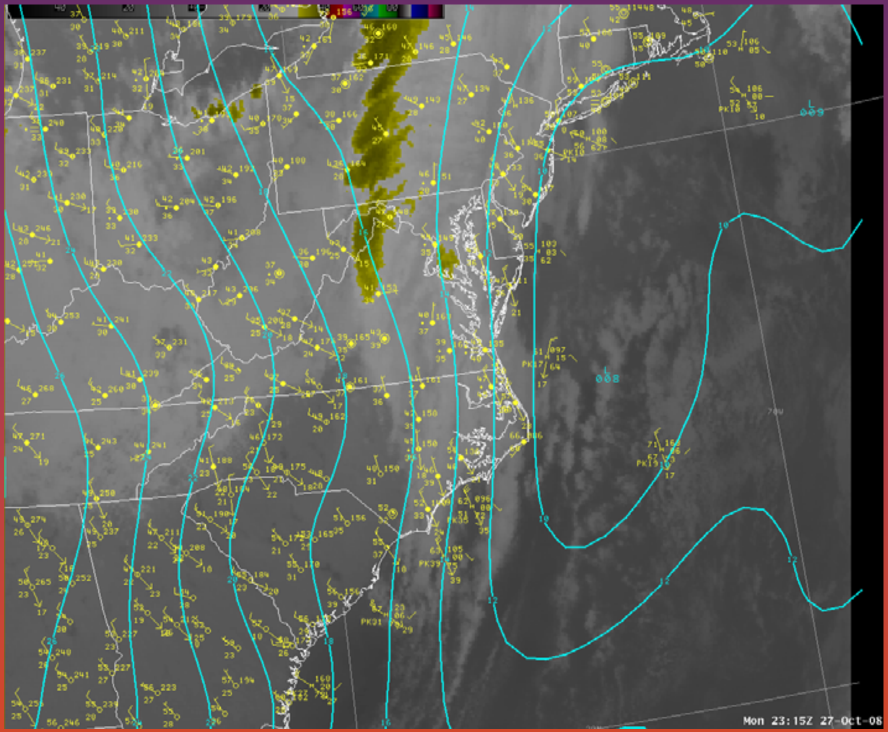
Case Study:

The Development of CSI Precipitation Bands in Southeast Virginia on 10/27/2008

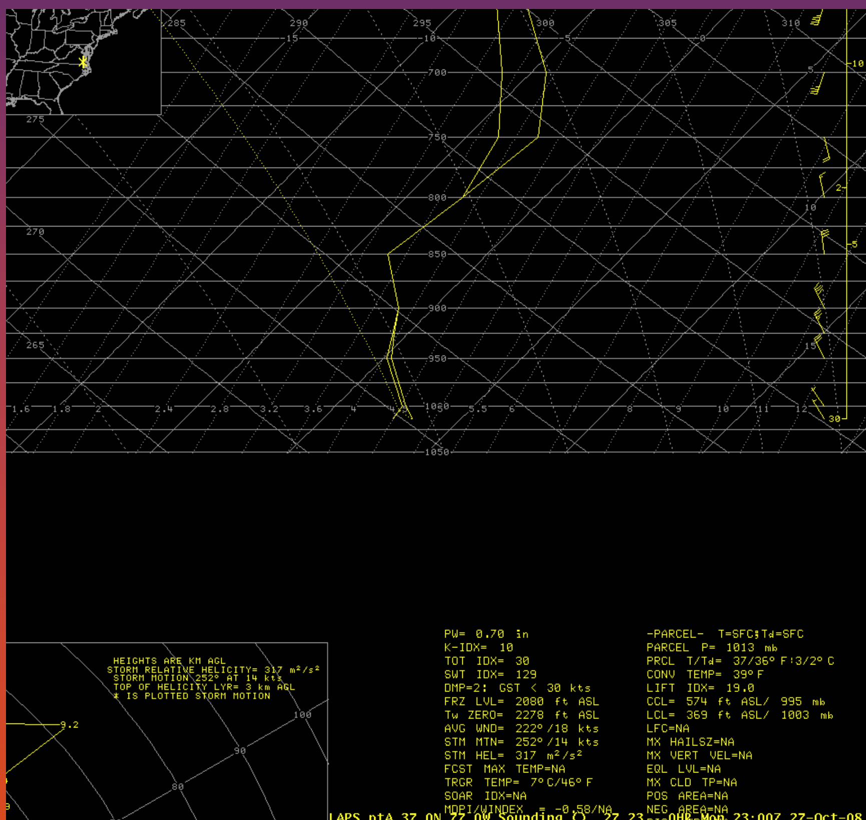
Visible Satellite (19Z Oct 27)

IR Satellite (23Z Oct 27)

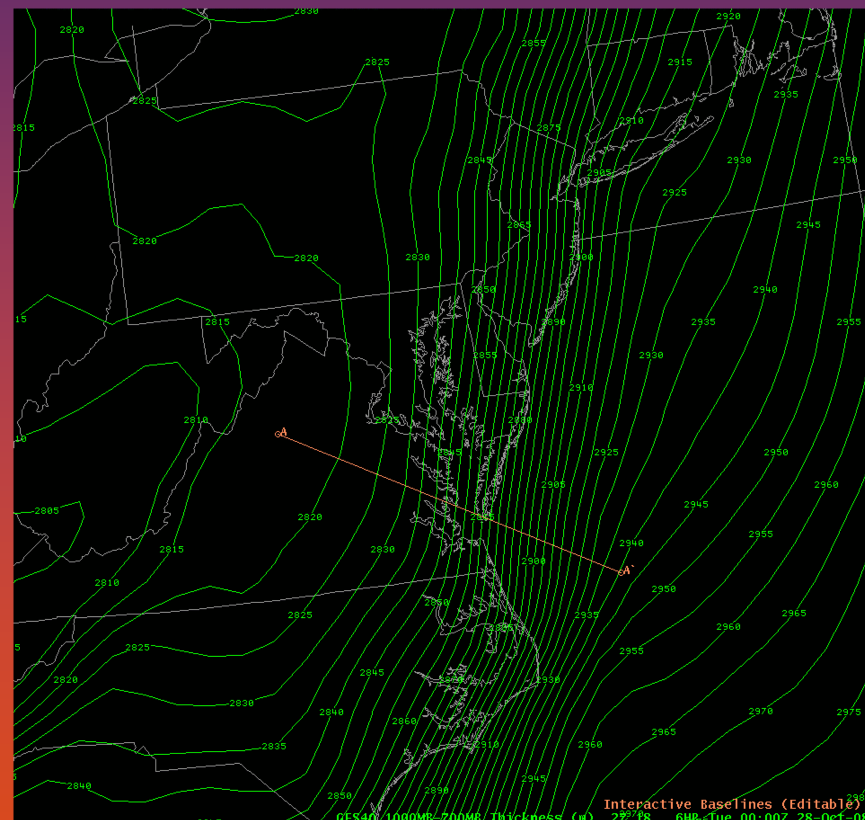




AKQ LAPS Sounding (23Z Oct 27)



1000-700mb Thickness (GFS Initialization 18Z Oct 27)

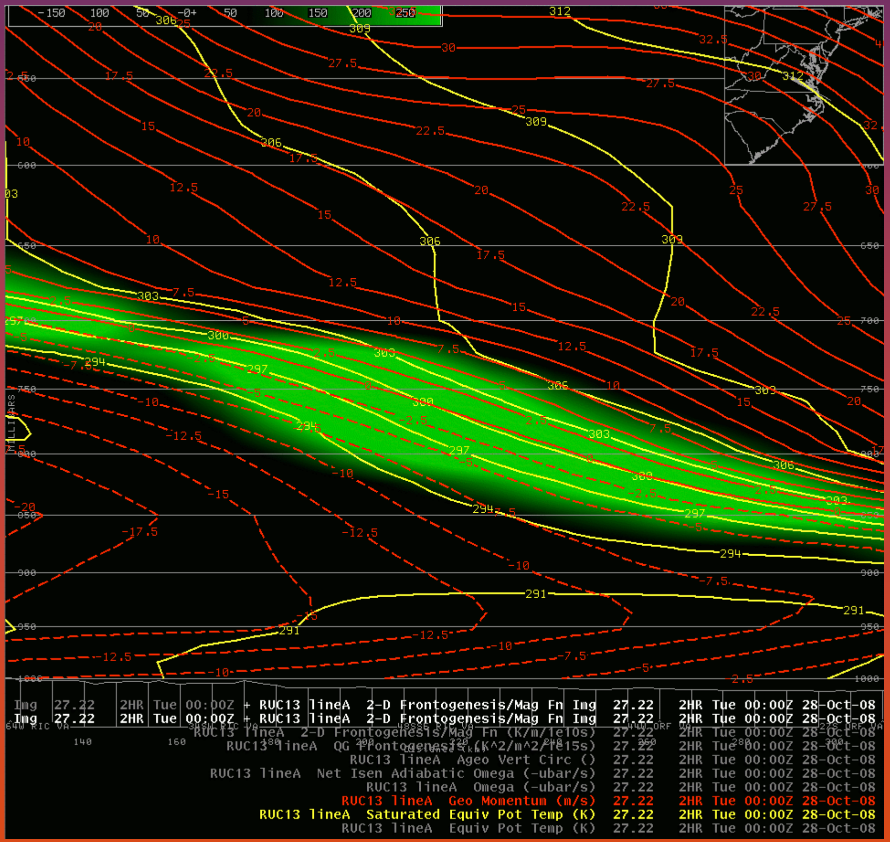


RUC Cross Section, 00Z Oct 28

Saturated Theta-e (solid yellow)

2-D Frontogenesis (shaded green)

Geostrophic Momentum (dashed red)



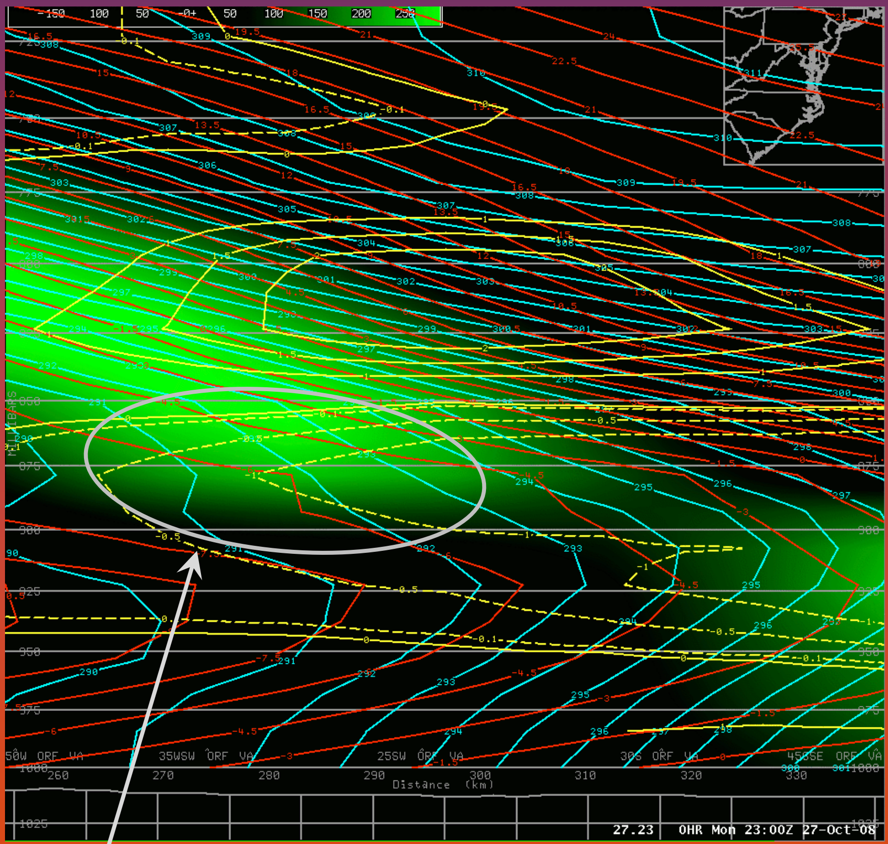
RUC Cross Section, 23Z Oct 28

Theta-e (solid light blue)

Relative Humidity (shaded green)

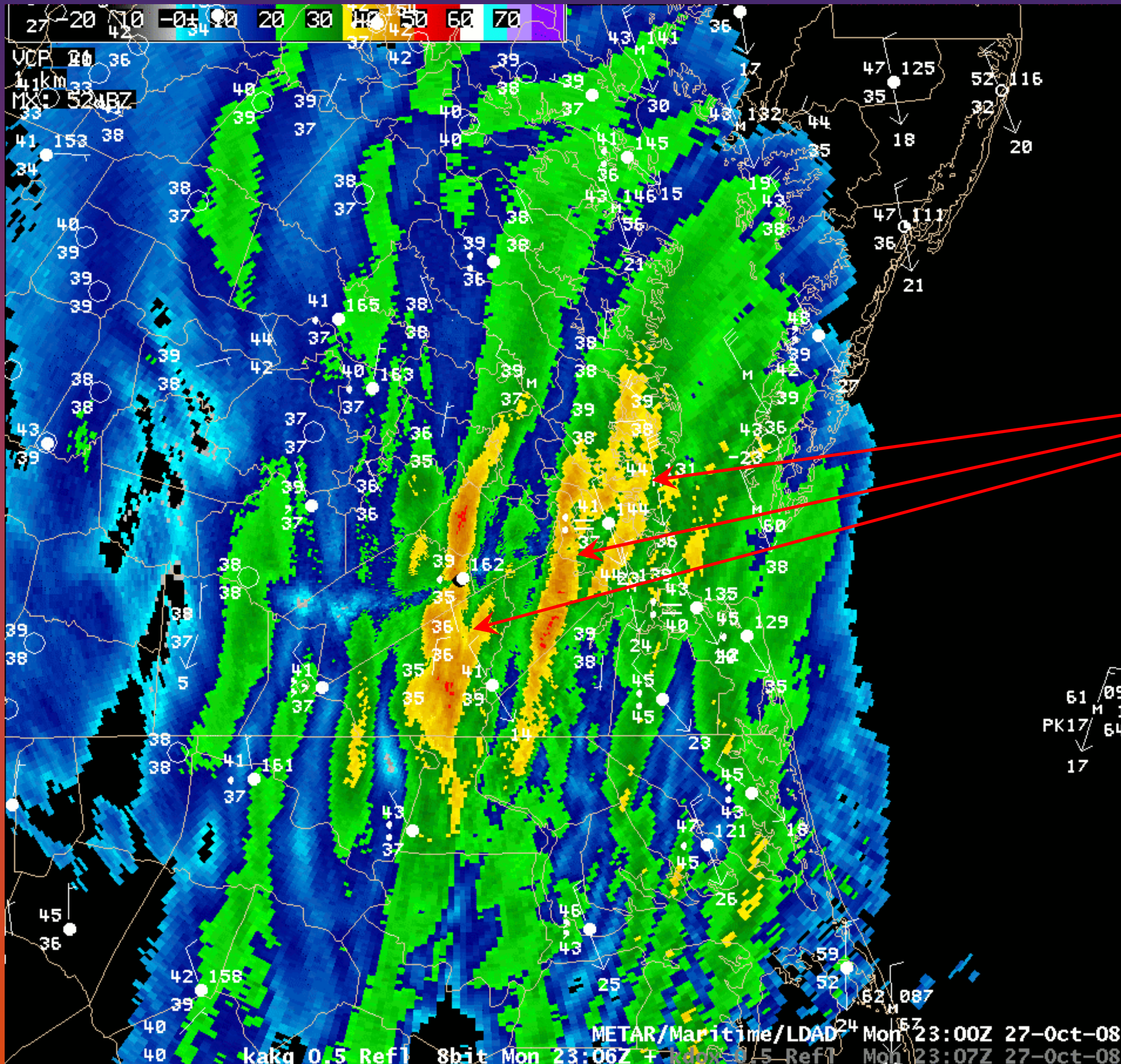
Geostrophic Momentum (solid red)

EPV (yellow; negative values dashed)



Presence of CSI (Potential for Slantwise Convection)

Banded Precipitation (23Z Oct 27)



CSI Bands

Column-cooling due to evaporation and melting processes within heavier convective bands allowed for a rain-snow mix, or in some areas, a brief changeover to all snow.

The End