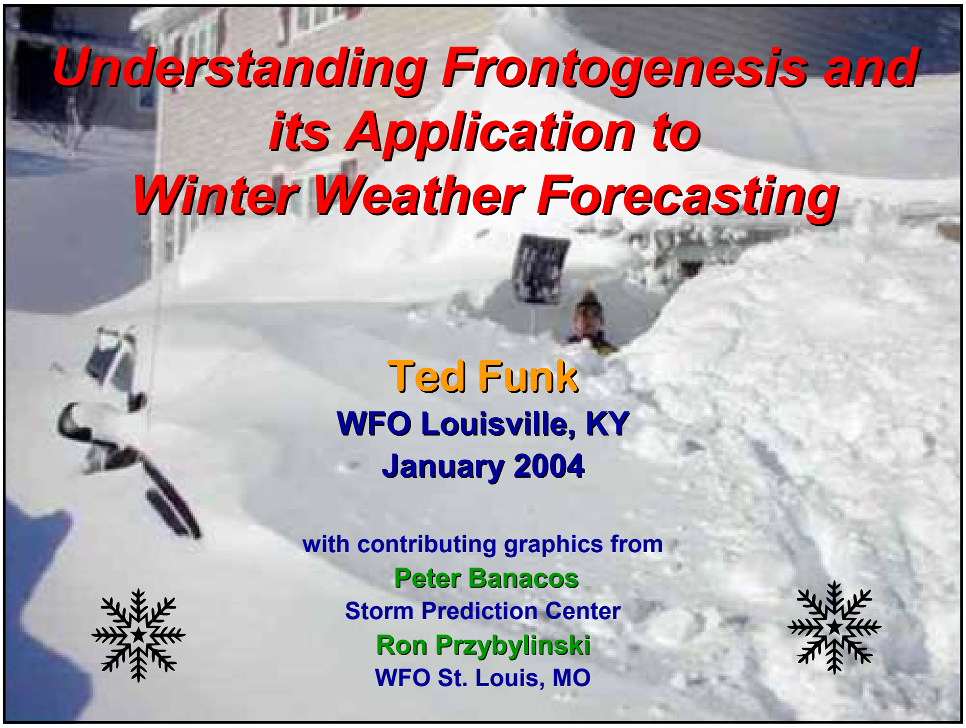

Understanding Frontogenesis and its Application to Winter Weather Forecasting

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General Outline

- Frontogenesis defined
- Components of frontogenesis
- What causes frontogenesis?:
  - Horizontal divergence/difluence
  - Horizontal deformation
  - Vorticity
  - Tilting effects
  - Diabatic heating
- Development of the frontogenetical circulation
- Use of frontogenesis in forecasting
- Common synoptic patterns: strong sfc low; weak or no sfc low
- Strong low case: Jan 6, 2002
- Weak low case: Oct 15, 2001
- Weak low case: Jan 7, 1999
- Role of deep-layered wind shear
- Deep-layered wind shear examples
- Non-banded, multiple banded, and warm season banded precipitation
- Spectrum of mesoscale instabilities; use of EPV and CSI
- Stability versus banding comparison
- Numerical model considerations: Feb 7, 2003
- Suggested snow band checklist

Frontogenesis Defined

Frontogenesis (in general terms) refers to the change in the magnitude and orientation of the temperature gradient at a level or in a layer (e.g., 850-700 mb) due to directional and speed changes in the wind field.

Frontogenesis (in specific terms) refers to an **increase** in the horizontal thermal gradient with time.

Frontolysis refers to a **decrease** in the horizontal thermal gradient with time.

QG frontogenesis (using geostrophic winds) allows for diagnosis of forcing and vertical motion on the synoptic-scale (e.g., extratropical cyclones/large troughs and ridges) which may or may not support mesoscale processes.

Petterssen's 2-D frontogenesis uses the total wind which can help diagnose features on the mesoscale (100-500 km) such as banded precipitation structure.

Frontogenesis Defined (cont.)

$$\boxed{F = \frac{D}{Dt}\left|\nabla_p \theta\right|}$$

(Petterssen 1936)

The 2-D scalar frontogenesis function (*F*) (i.e., F vector) quantifies the change in the horizontal (potential) temperature gradient following air parcel motion, where:

***F* > 0 is frontogenesis, *F* < 0 is frontolysis**

Conceptually, frontogenesis is the local change in the horizontal temperature gradient near an existing front, baroclinic zone, or feature as it moves.

Components of the Frontogenesis Function (F Vector)

(Keyser et al. 1988, 1992)

$$\mathbf{F} = F_n \mathbf{n} + F_s \mathbf{s}$$

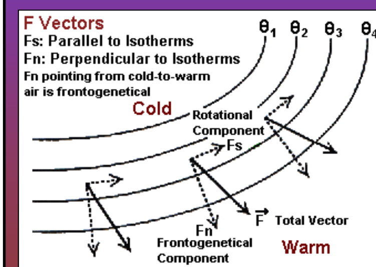
$$F_n = -\frac{D}{Dt}\left|\nabla_p \theta\right|$$

$$F_s = n \cdot \left(k \times \frac{D}{Dt}\nabla_p \theta\right)$$

The F vector is the full wind version of the quasi-geostrophic Q vector. It can be broken down into 2 components (natural coordinates): **Fn and Fs.**

Fn:

-Frontogenetical (dominant) component of F
-Directed perpendicular to temperature lines
-Refers to changes in magnitude of thermal gradient
-Corresponds to vertical motion on the frontal scale (mesoscale bands)



Fs:

-Rotational component of F
-Directed parallel to isotherms/thicknesses
-Refers to changes in direction (orientation) of thermal gradient with no magnitude change
-Corresponds to synoptic-scale vertical motion on the scale of the baroclinic wave itself

Fn and Fs Vectors

When F vectors point from cold-to-warm (warm-to-cold) air in the low-to-mid levels of the atmosphere, frontogenesis (frontolysis) is occurring.

Fn vectors can be very important (the dominant term), and force vertical motion on the mesoscale/frontal scale. Fn describes how the magnitude of the thermal gradient is changing, i.e., the gradient is becoming stronger (frontogenesis) via confluence or deformation or weaker (frontolysis) via difluence. Fn vectors are longest where the thermal gradient is changing the most, not necessarily where the tightest thermal gradient exists. Fn vectors are available in AWIPS.

Fs vectors describe temperature advection patterns, and force vertical motion on the synoptic scale. Fs describes how the orientation of the isotherms/thicknesses is changing with time due to horizontal changes in the wind. Fs vectors are most pronounced in areas where the wind is tending to rotate isotherms significantly, i.e., in areas of strong warm and cold advection. The longer the Fs vectors, the greater the temperature advection pattern and forcing for synoptic scale vertical motion.

What Causes Frontogenesis?

The geometry of the horizontal flow has a strong influence on frontogenesis in most situations.

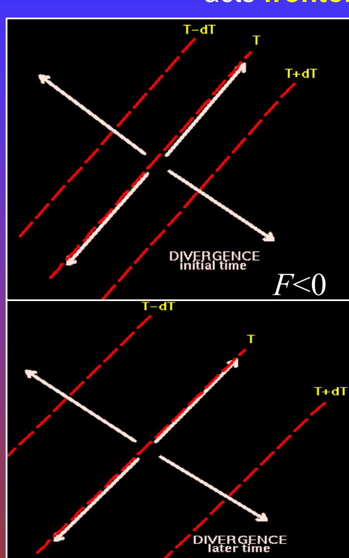
Two main processes (parameters) make significant separate contributions to the field of frontogenesis:

Divergence
Deformation

The focus here is exclusively on Petterssen's 2-D scalar frontogenesis (Fn)

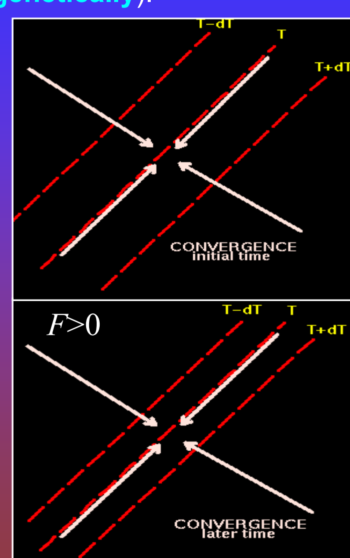
Horizontal Divergence/Difluence

Regardless of isotherm orientation, **divergence** (**convergence**) acts **frontolytically** (**frontogenetically**).

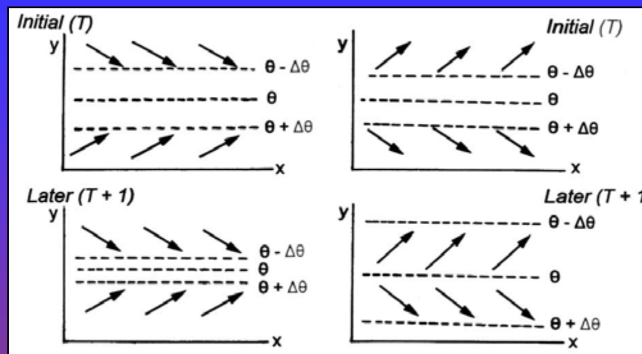


Frontogenesis (F>0; right) due to convergence oriented nearly perpendicular to a thermal gradient.

Frontolysis (F<0; left) due to divergence oriented nearly perpendicular to a thermal gradient.



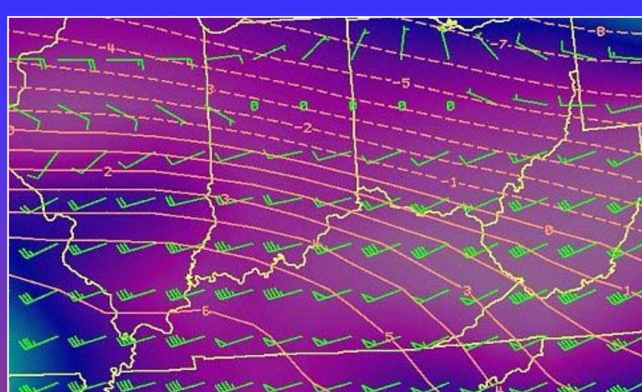
Horizontal Divergence/Difluence



Left 2 diagrams: **Confluent** wind field applied to the thermal gradient. At a later time (T+1), the wind acts to increase the thermal gradient, thus a ***frontogenetical*** situation.

Right 2 diagrams: **Difluent** wind field applied to the thermal gradient. At a later time (T+1), the wind acts to decrease the thermal gradient, thus a ***frontolytical*** situation.

Horizontal Divergence/Difluence



850-700 mb winds (kts) and temps, and 1000-500 mb RH image from AWIPS on Feb 15, 2003.

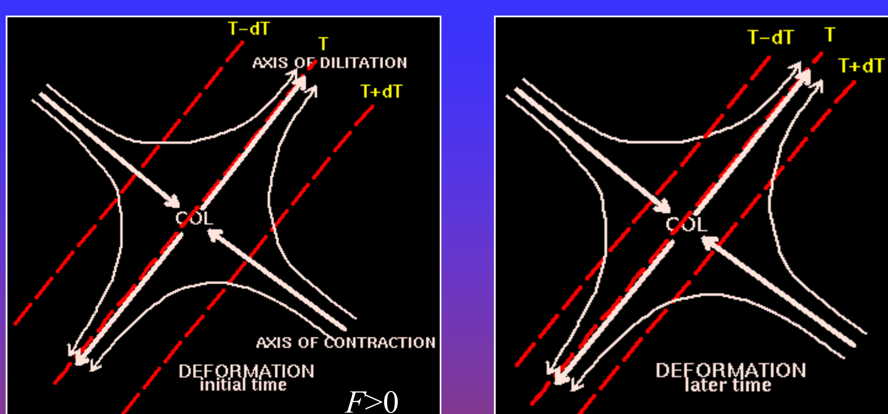
A rough qualitative assessment of 2-D frontogenesis can be made by viewing level or layer-average temperatures and isotherms. In the image above, frontogenesis in the 850-700 mb layer is implied over central and southern IN and OH, northern KY, and central IL where the winds indicate convergence superimposed on and directed nearly perpendicular to an existing tight thermal gradient. The frontogenesis can be quantified by viewing 2-D frontogenesis and Fn vectors in AWIPS (see next slide) . The convergence of the Fn vectors represents forcing for ascent.

Horizontal Divergence/Difluence

850-700 mb Petterssen's 2-D frontogenesis (contours), Fn vectors (blue arrows), and 1000-500 mb RH image (purple=highest RH) from AWIPS on Feb 15, 2003.

The contoured frontogenesis above quantifies the implied frontogenesis from observing winds and isotherms from the previous slide. Fn vectors are longest where frontogenesis is greatest. The length of a vector is valid at its origin point (not its arrowhead). The vectors point from cold-to-warm air, thus a frontogenetical situation is shown over the Ohio Valley.

Horizontal Deformation

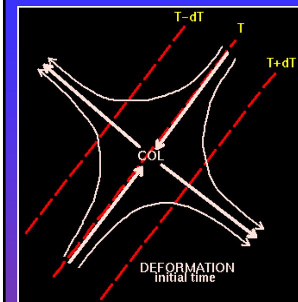


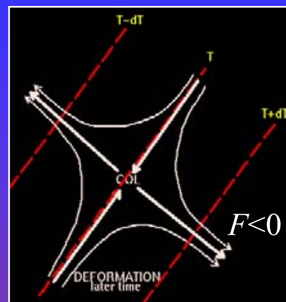
Flow fields involving deformation acting frontogenetically are prominent in the majority of banded precipitation cases.

Axis of dilatation: axis along which flow is being stretched (deformed) due to convergence in the flow; oriented parallel to the stretching due to the deformation field

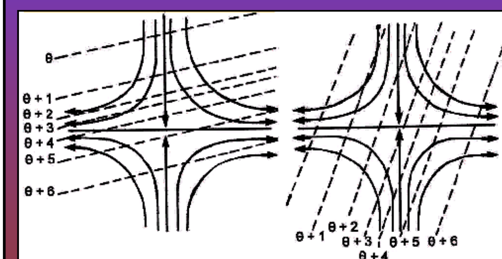
Axis of contraction: axis along which flow is being compacted within the deformation field; oriented perpendicular to the dilatation axis

Horizontal Deformation





Deformation of the wind can act frontogenetically or frontolytically. One needs to consider the orientation of the isotherms relative to the axis of dilatation. In the case at left, the axis is oriented perpendicular to isotherms, thus convergence and stretching along the axis actually results in frontolysis.



The key is the angle between isotherms and the axis of dilatation. If the angle is < 45º (far left), the wind field is acting *frontogenetically* (increase in thermal gradient). If the angle is > 45º (near left), the wind field is acting *frontolytically* (decrease in thermal gradient).

Streamline analysis is a good tool for detecting deformation zones. Normally, the axis of dilatation is associated with a frontogenetical situation.

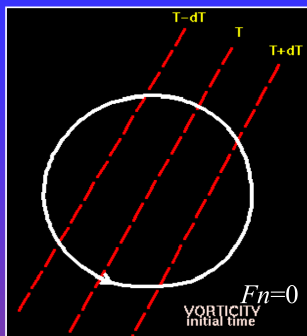
Other Contributing Factors to Frontogenesis

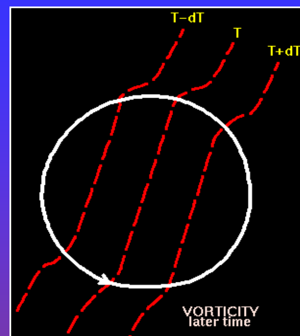
Deformation and divergence fields play the most prominent role in 2-D frontogenesis aloft.

However, other processes can contribute to frontogenesis, including:

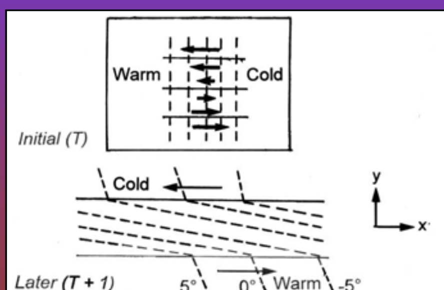
Vorticity
Tilting effects
Diabatic heating

Vorticity/Shear



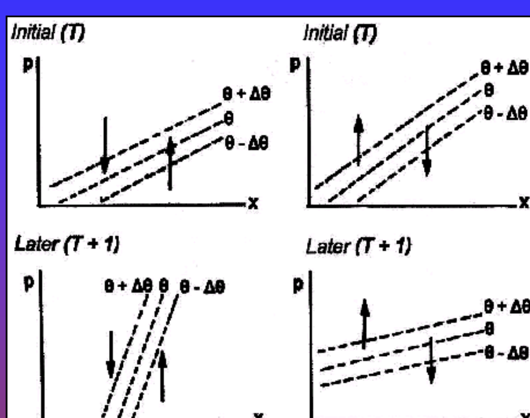


Pure vorticity acts to rotate isotherms, it cannot tighten or weaken the gradient.



If a sheared wind field (containing vorticity) is applied to an initially uniform thermal gradient (warm – left side; cold – right side), the wind field will act to rotate the thermal gradient at a later time.

Tilting Effects

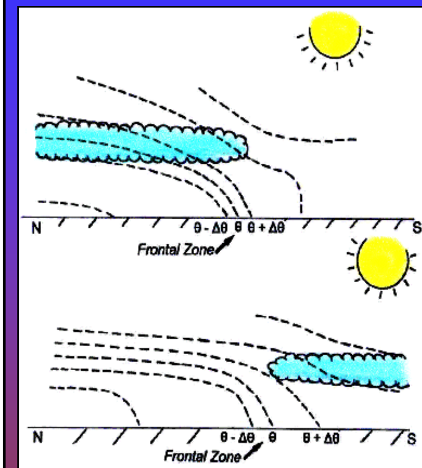


In these cases, the temperature gradient is in the vertical as opposed to the horizontal in the preceding examples. The temperature gradient is being tilting by the vertical motion field.

Above (left 2 images), differential vertical motion acts to increase the thermal gradient, i.e., *frontogenetically.*

Above (right 2 images), differential vertical motion acts to decrease the thermal gradient, i.e., *frontolytically.*

Diabatic Heating



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

Top (cold air on left; warm air on right): cloud cover is limiting radiational warming on colder left side, while cloud-free warm area on right heats up. Thus, thermal gradient strengthens (frontogenetical).

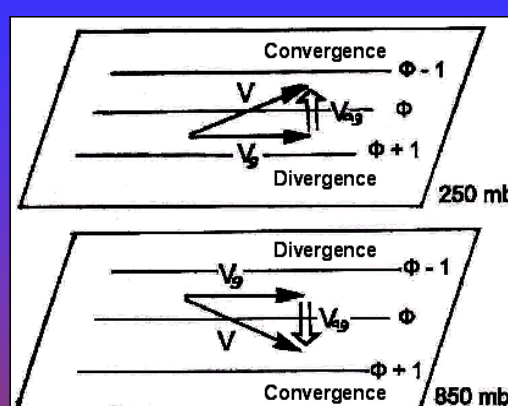
Bottom (cold air on left; warm air on right): the sun warms the cloud-free cold air while cloud cover limits radiational warming in the warm air mass. Thus, thermal gradient weakens (frontolytic).

Small-scale low-level frontogenesis due to diabatic heating can be important in unstable environments, where the resulting small-scale frontal lift causes convective development.

Development of the Frontogenetical Circulation

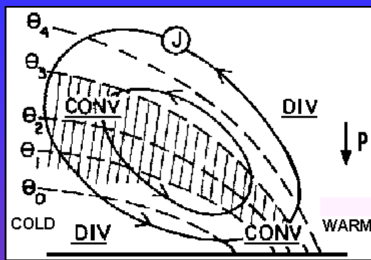
-When the temperature gradient strengthens, geostrophic and hydrostatic balance are disturbed.

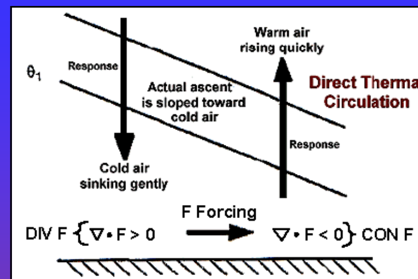
-Thus, QG theory states that the atmosphere responds to the disturbance (*frontogenetical forcing)* through ageostrophic vertical circulations which attempt to restore thermal wind balance *(the response).* This is accomplished as the geostrophic winds aloft and at low-levels respond to maintain balance.



-Winds aloft cut to the north (top image), while winds below cut to the south (bottom image) creating regions of divergence/convergence. Upward (downward) motions develop across the southern (northern) part of the plane, respectively. The upward motion field occurs on the southern edge of the axis of maximum frontogenesis, and slopes toward cold air with height.

Development of the Frontogenetical Circulation





F Forcing = Maximum frontogenetical area. F vectors are longest in this area. DIV/CON F is occurs on the flanks of the maximum frontogenesis, and is forcing for ascent.

-Frontogenesis produces a mesoscale direct thermal circulation that is sloped with height toward cold air.

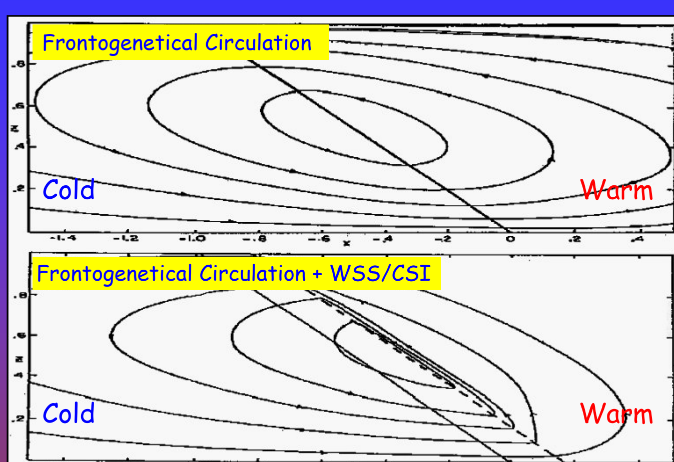
-Fn vectors are longest where frontogenesis is the greatest.

-Fn vector convergence (forcing for lift) occurs on southern/eastern periphery of maximum frontogenesis area (as shown above).

-A steeply sloped frontogenetical zone in low-to-mid levels can produce a definitive band of heavy precipitation (rain or snow).

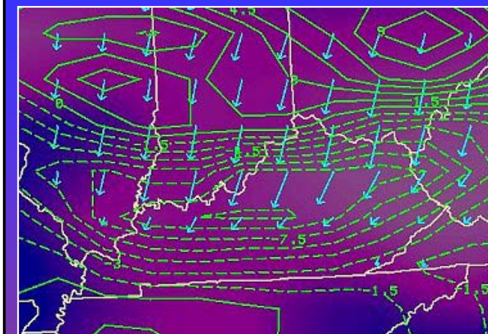
-The direct thermal circulation acts to weaken the temperature gradient (and restore balance) by producing lift and adiabatic cooling on the warm side, and weaker decent and adiabatic warming on the cold side of the maximum frontogenetical area. Thus, the vertical motion response to frontogenesis actually is frontolytic.

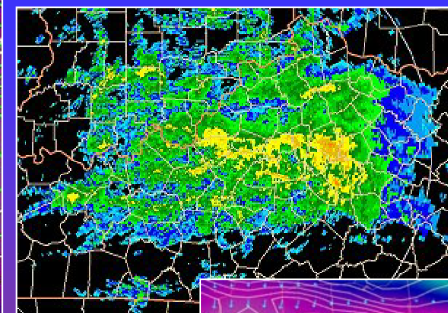
Development of the Frontogenetical Circulation

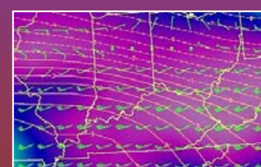


Top: Simplified, general frontogenetical circulation associated with a stable environment.
Bottom: In the presence of weak symmetric stability (WSS) or especially CSI (i.e., the co-existence of frontogenesis and small or negative values of EPV), the updrafts of the frontogenetical circulation become stronger and more concentrated than in a stable environment. Thus, one MUST assess stability when considering forcing and subsequent lift.

Development of the Frontogenetical Circulation



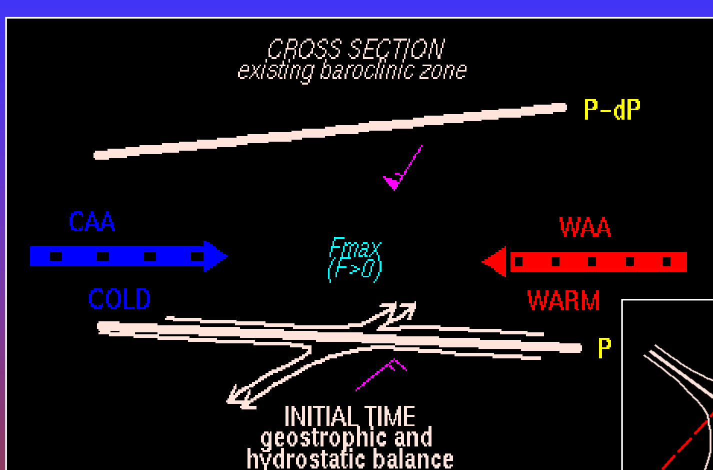




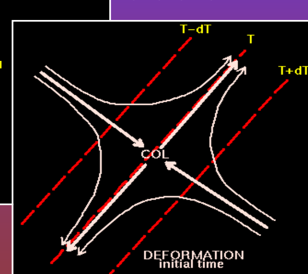
Above left: 850-700 mb Fn vectors (blue arrows) and Fn vector divergence (green lines; dashed lines = convergence), 1000-500 mb RH image from AWIPS at 06 utc Feb 15, 2003. **Above right:** KLVX radar 0.5 deg reflectivity image over central KY at 06 utc Feb 15. **At right:** 850-700 mb winds, temps, frontogenesis, and Fn vectors (shown earlier) from which above left image was derived.

A concentrated axis of Fn vector convergence represented forcing for strong ascent over central KY. Given air mass saturation (purple RH), banded heavy rainfall resulted, which matched up very well with frontogenetical forcing/circulation.

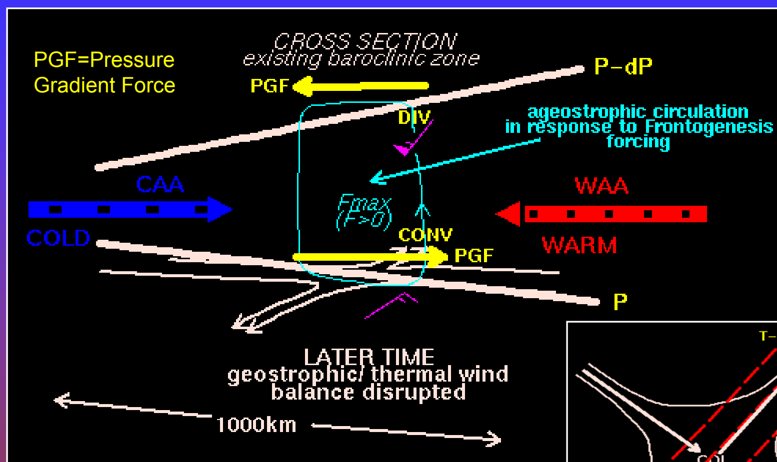
Development of the Frontogenetical Circulation (An Alternative Depiction)

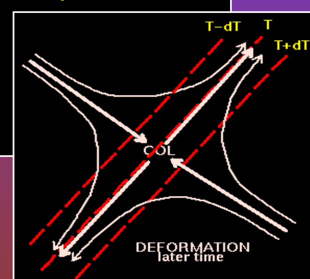


Flow field dominated by convergence and subsequent deformation along and near the axis of dilatation.



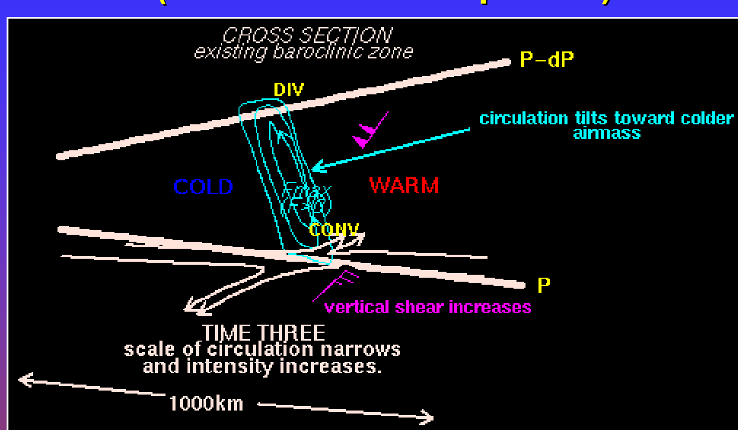
Development of the Frontogenetical Circulation (An Alternative Depiction)





In response to increasing temperature gradient, ageostrophic vertical circulation develops with convergence/ascent on warm side of maximum frontogenesis, and divergence aloft.

Development of the Frontogenetical Circulation (An Alternative Depiction)



The frontogenetical zone and thus responsive vertical circulation usually slopes with height toward cold air. Thus, ascent aloft can still occur above the area of low-level maximum frontogenesis or even Fn vector divergence. The steeper the slope, the better the potential for heavy precipitation. When evaluating frontogenetical forcing, it's the resulting ageostrophic circulation that is most important for precipitation forecasting.

Use of Frontogenesis in Forecasting

- Frontogenesis (usually in 850-500 mb layer) can occur with a variety of environments, including deep meridional flow, zonal flow, deep surface low systems, and non-surface low systems.

- Frontogenetical circulations within stable environments typically result in one primary band of heavy precipitation which is nearly parallel to the frontal zone. The potential for banding can be assessed easily using numerical models, even though model QPF fields likely will not reflect the banding potential.

- The strength of the circulation is affected by the ambient static stability.

- As stability decreases, the horizontal scale (width) of the band often decreases while the intensity of the band (reflectivity) increases.

- Greater instability results in classic CSI multiple bands of heavy precipitation.

Common Synoptic Patterns

Forecast premise for mesoscale precipitation banding:

- Requires a **strengthening baroclinic zone** in the presence of sufficient moisture for precipitation (AND the proper thermal stratification for snow).

- Deformation zones are the most common means of manifesting areas of frontogenesis within the 850-500mb layer.

- The presence of frontogenesis does **NOT** require a strong surface cyclone, only a low-mid tropospheric baroclinic zone.

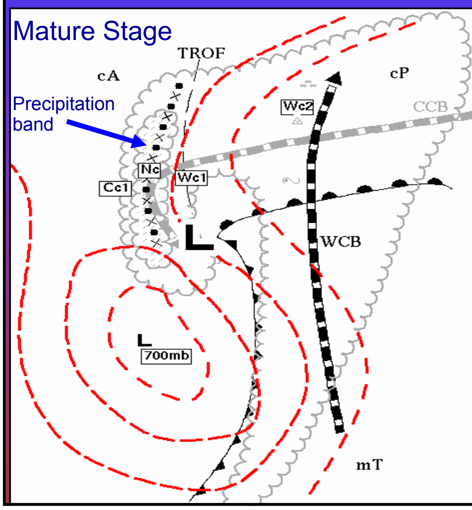
TWO CLASSES (TYPES) OF BANDS:

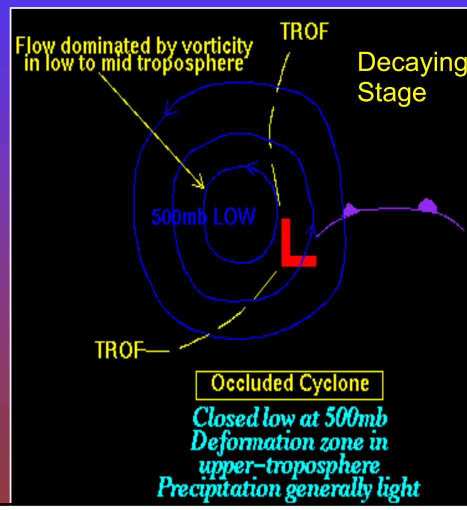
I. **Bands associated with significant surface lows**

II. **Bands associated with weak/no surface lows**

Type I: Significant Surface Low Pattern

Frontogenesis is common in the developing and mature stages of a low pressure system, but not in the dissipating stage when precipitation rates decrease. In mature systems, frontogenesis and potentially heavy “wrap around precipitation” can occur to the northwest of the surface cyclone.

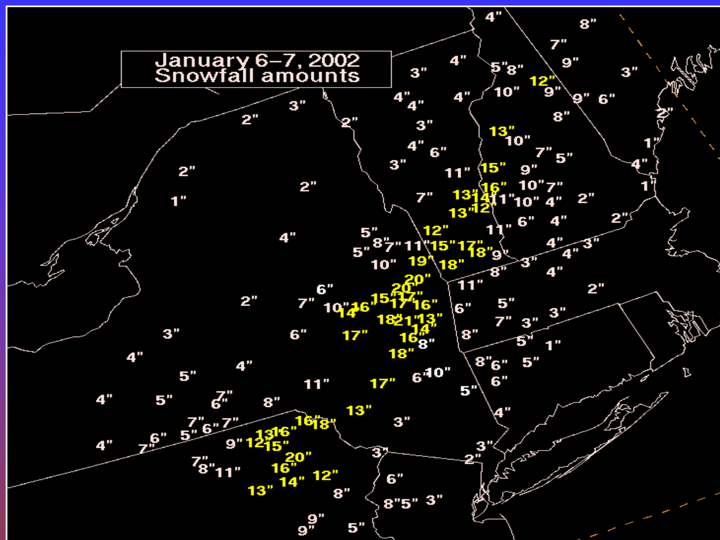




Type I Example: Jan 06, 2002

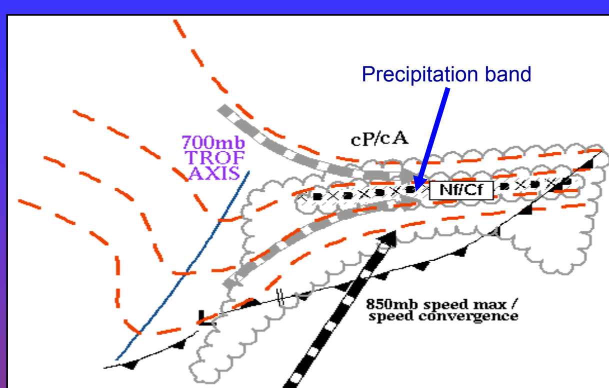
With a strong surface low, heavy banded precipitation often is to the north or northwest of the low near a deformation zone (comma head). Animated radar imagery in this event (not available) showed this snow band became very pronounced with time and shifted northeast across southeastern New York, southern Vermont, and New Hampshire.

Snowfall Accumulations



The deformation axis/frontogenetically-induced snow band produced a well-defined axis of very heavy snowfall accumulations in the storm.

II. Frontal / Weak Surface Low Pattern



In these situations, look for:

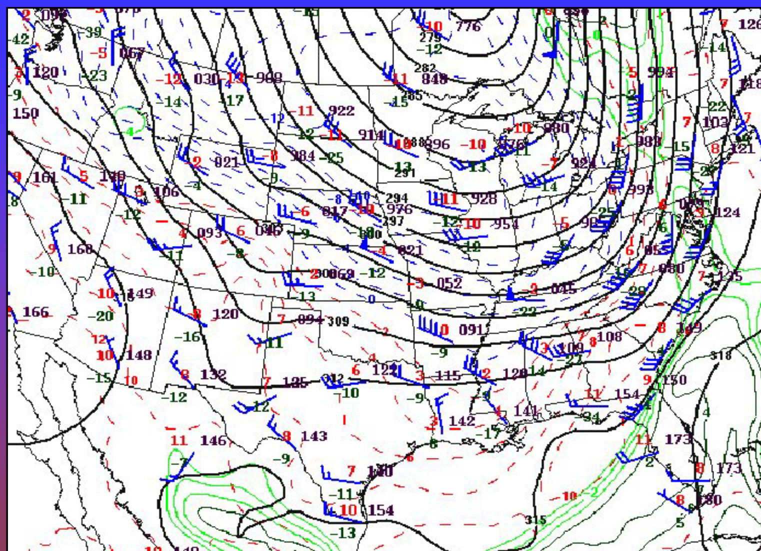
-Confluent flow around 700mb in advance of a positively tilted trough.

-Weak or non-existent surface wave cyclone along the surface front.

-Deformation and convergence creating frontogenetical forcing north of the front, resulting in a band of precipitation.

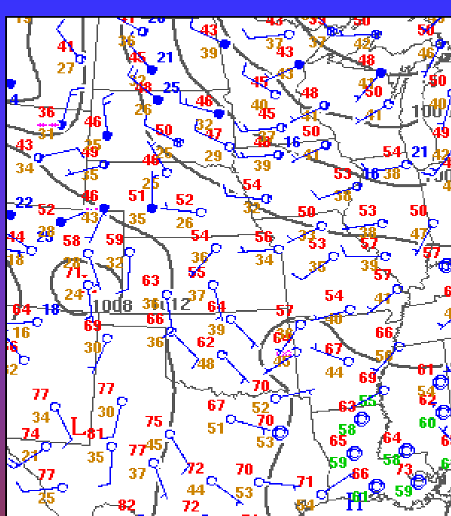
-Most common given sufficient low-mid-level baroclinicity and adequate moisture.

Type II Example: Oct 15, 2001

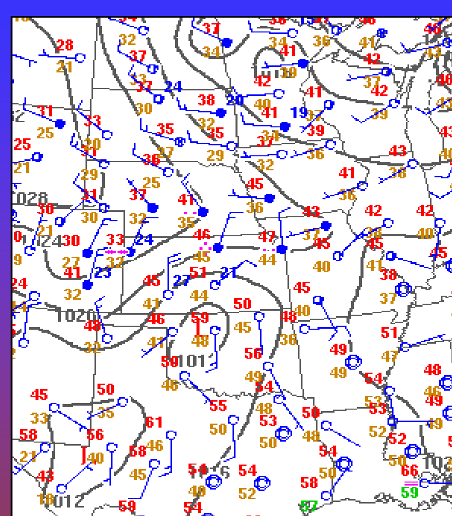


700 mb 00 utc 15 Oct: A weak trough was located over New Mexico and eastern Colorado, with confluent flow over eastern Kansas.

Type II Example: Oct 15, 2001

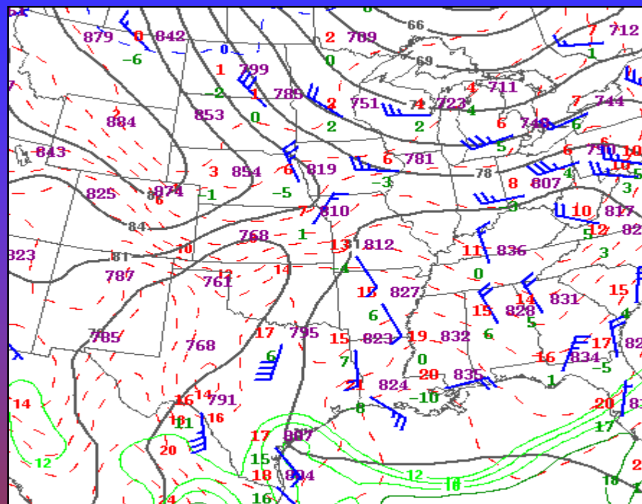


Sfc map 00 utc 15 Oct: A weak low was over Colorado, with warm air to the south and cooler air to the northeast.



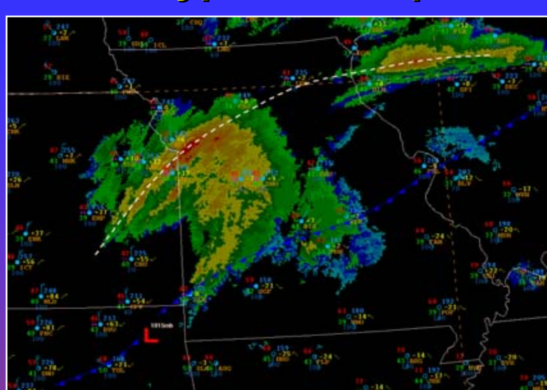
Sfc map 12 utc 15 Oct: A weak low moved or reformed over OK, with a weak front extending through eastern KS and MO.

Type II Example: Oct 15, 2001

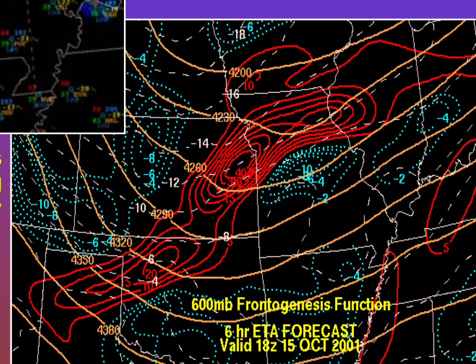


925 mb 12 utc 15 Oct: Above the surface, note that the wind fields suggested a tightening thermal gradient across eastern Kansas and western Missouri where convergence was resulting in a stretching deformation field.

Type II Example: Oct 15, 2001



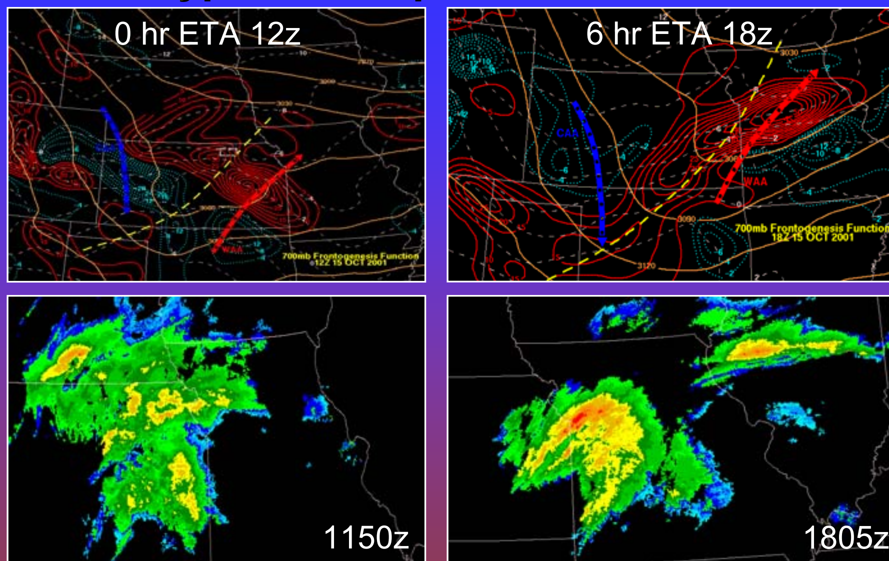
18 utc 15 Oct mosaic base reflectivity and surface observations (cold front shown in blue; dashed line denotes main precipitation band associated with deformation)



18 utc 15 Oct 600mb frontogenesis (solid red lines); significant forcing existed aloft despite the weak sfc low

A narrow band (1-2 counties wide) of moderate-to-heavy rainfall occurred from eastern KS to central IL. Kirksville, MO reported 0.25 inches per hour as the band passed through, with lower rates outside of the band.

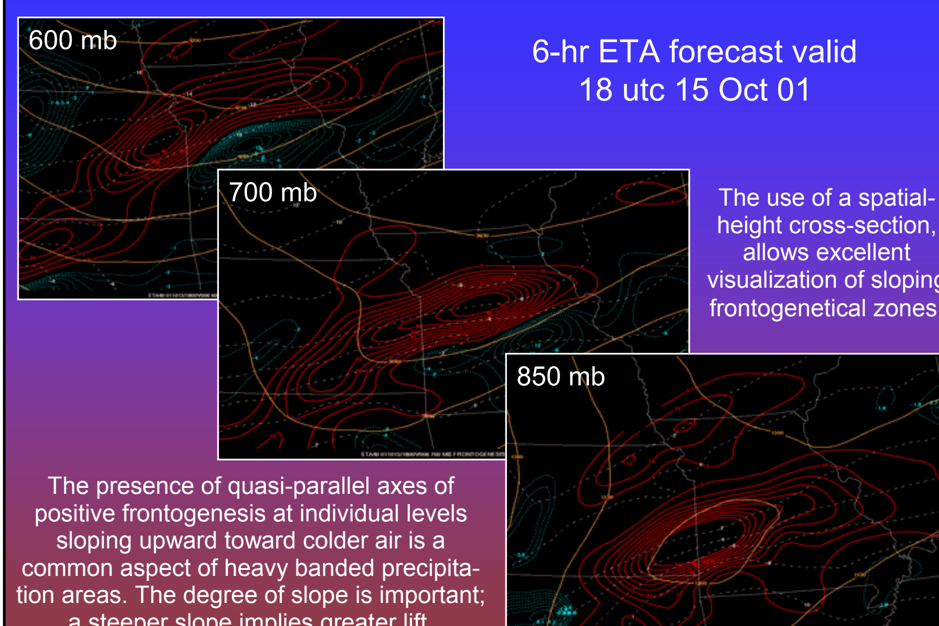
Type II Example: Oct 15, 2001



700 mb frontogenesis (top) and base reflectivity (bottom): Organization of precipitation into a banded structure increases as the frontogenesis orientation becomes aligned with the isotherm orientation at low-to-mid levels.

Sloped Continuity of Frontogenesis

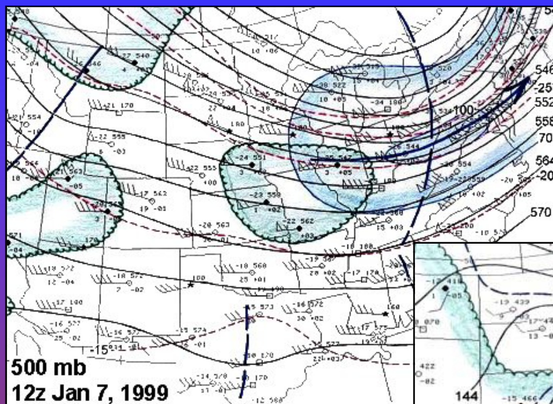
6-hr ETA forecast valid
18 utc 15 Oct 01



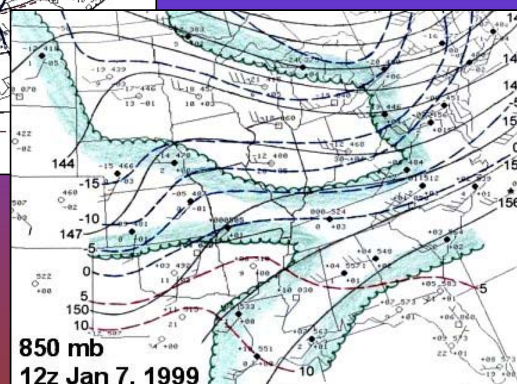
The use of a spatial-height cross-section, allows excellent visualization of sloping frontogenetical zones.

The presence of quasi-parallel axes of positive frontogenesis at individual levels sloping upward toward colder air is a common aspect of heavy banded precipitation areas. The degree of slope is important; a steeper slope implies greater lift.

Type II Example: Jan 7, 1999

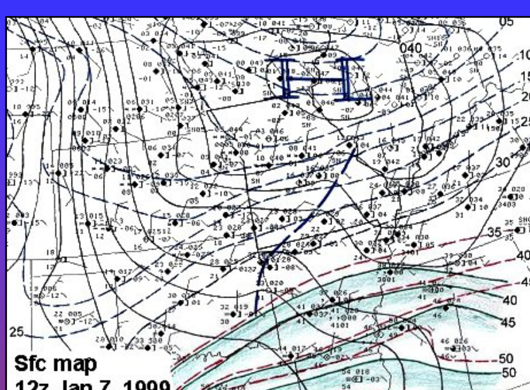


At 500 mb, the mean long-wave trough extended from the eastern Great Lakes through TN, with a 500 mb jet streak (100 kts) from southern PA through IN. Moisture was noted over MO near the broad *right entrance region* of the 500 mb jet.

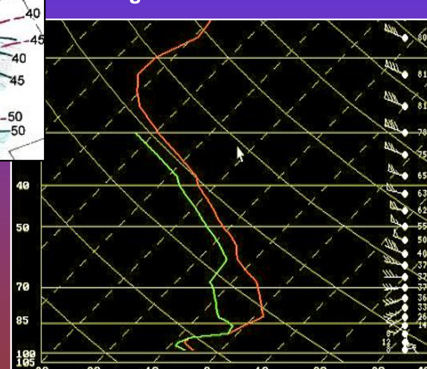


At 850 mb, warm advection was noted across the central and southern Plains. Weak warm advection to neutral advection prevailed over MO and IL. A large area of low-level moisture extended from CO through southern IL to the East Coast.

Type II Example: Jan 7, 1999

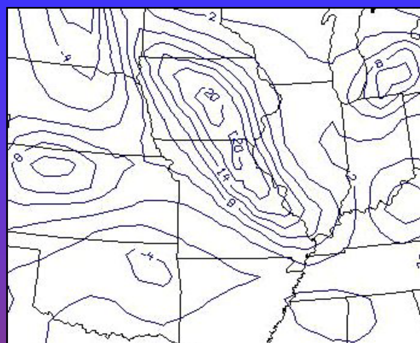


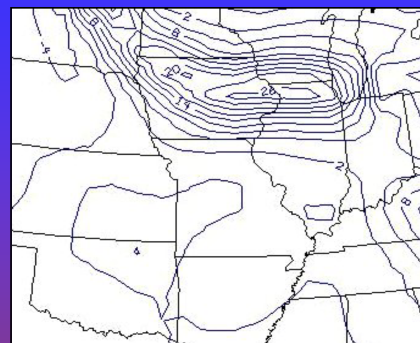
At the surface, cold high pressure was along the IA-IL border at 12 utc Jan 7 with a light northeast flow (weak cold conveyer belt) over MO. There was no discernible surface low, just an inverted surface trough over MO. This was a reflection of divergence and frontogenetical forcing aloft.



SGF sounding (12 utc Jan 7) showed a cold boundary layer with a warmer frontal zone above 950 mb. Sounding exhibited good speed shear, and was conditionally unstable above 690 mb, suggesting organized banded precip was possible. The elevated warmer, dry layer would cool and moisten due to seeder-feeder processes from moisture above.

Type II Example: Jan 7, 1999



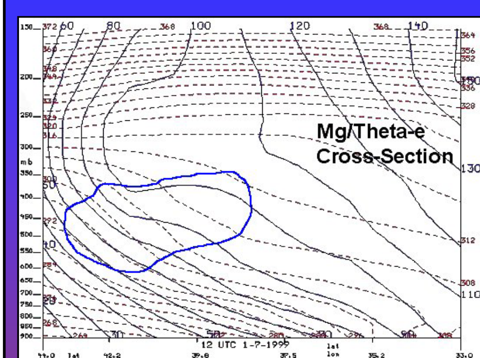


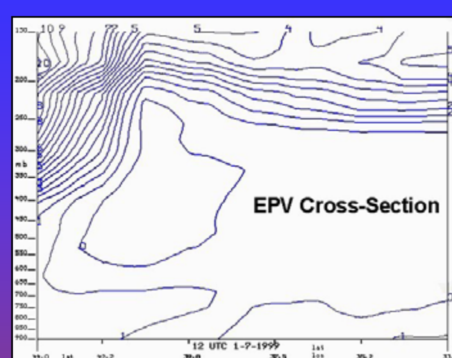
2-D Petterssen's Frontogenesis at 700 mb (left) and 500 mb (right) at 1200 utc Jan 7

At 700 mb, frontogenesis extended from southern Minnesota to western Kentucky. The region of implied lift (i.e., convergence of Fn vectors) stretched from southwest Iowa to south-central/southeast Missouri. At this time, snow was occurring over northwest and central Missouri, nearly coincident with frontogenetical forcing aloft.

At 500 mb, frontogenesis extended from eastern South Dakota to southern Lake Michigan. Implied mid-level lift extended along the southern part of this axis across southern Iowa/northern Missouri into central Illinois.

Type II Example: Jan 7, 1999

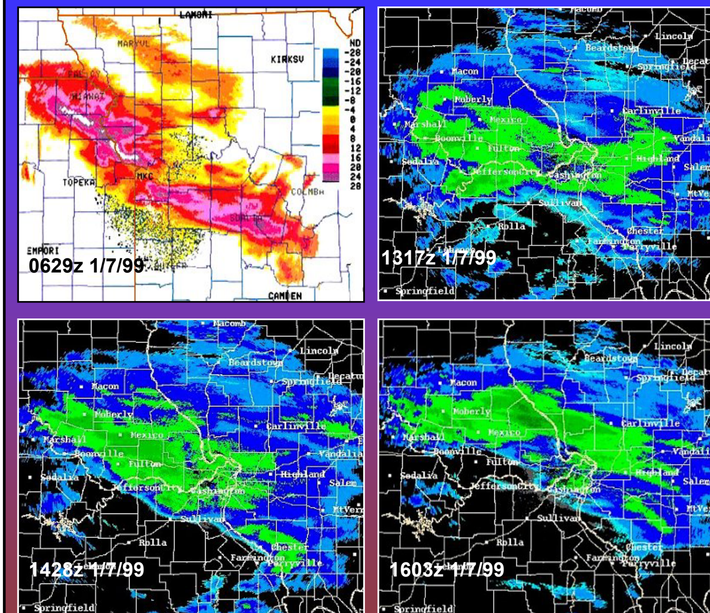




Spatial-height cross-sections at 1200 utc Jan 7 extending from 75 nm southeast of MSP, MN (left side of images) to 100 nm west of JAN, MS (right side)

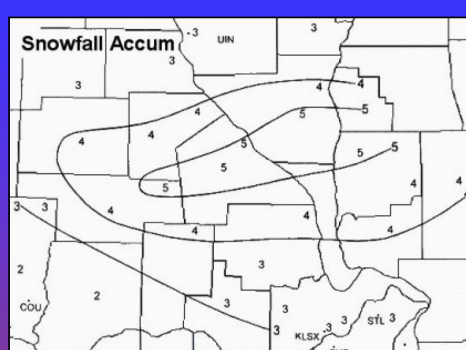
Above left, 2e surfaces are parallel to or more steeply sloped than the absolute geostrophic momentum (Mg) surfaces aloft within the blue line (mid to upper Mississippi Valley). This area suggests the presence of CSI which could result in multiple banding of precipitation given existing frontogenetical forcing. EPV (above right) is 0 or negative, i.e., CSI is present, in nearly the same area as shown by Mg and 2e. The use of spatial-height cross-sections is imperative to assess CSI, EPV, and sloped frontogenesis, and their affect on precipitation.

Type II Example: Jan 7, 1999



This sequence of 0.5 deg reflectivity images shows evolution of banded snowfall in this case (upper left image in radar clear air mode). For most of the event, a primary mesoscale band was evident with a sharp reflectivity gradient on the southern edge, suggesting focused frontogenetical forcing was dominant. However, there was evidence of smaller scale sub-bands and multiple bands (e.g., 1317z) suggesting the presence of low EPV values/release of CSI.

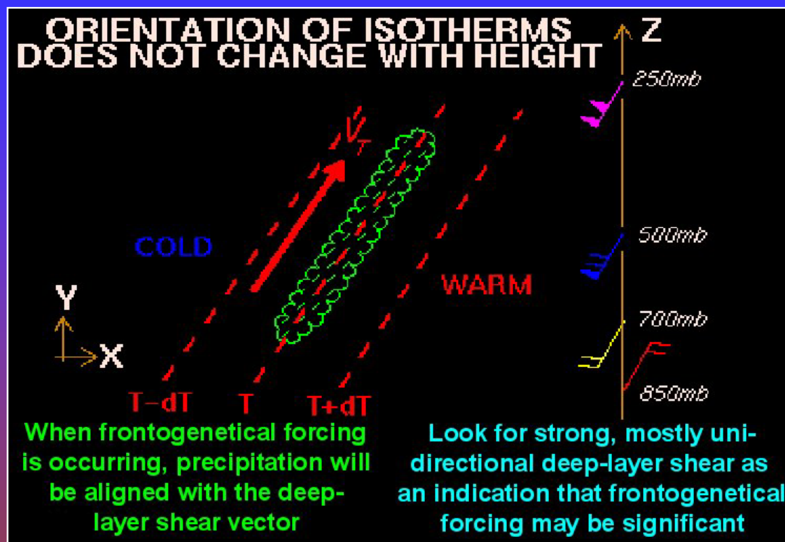
Type II Example: Jan 7, 1999



The primary snow band resulted in a narrow axis of 5 inch amounts over eastern MO and west-central IL, north of St. Louis. The band moved slowly northward with time, thus the south-to-north gradient in amounts was not as tight as suggested by the tight reflectivity gradient in radar.

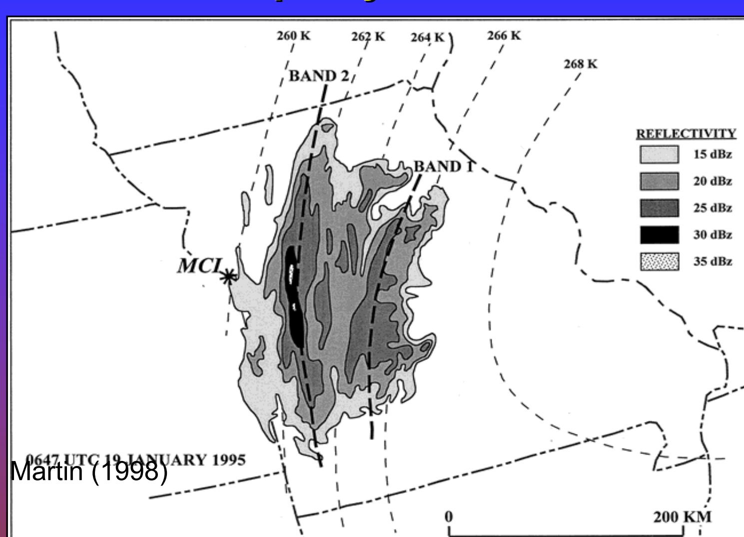
Bottom Line: *Even within a weak system with only a weak or no surface low, frontogenetical forcing and elevated CSI can still exist resulting in banded precipitation and significant precipitation rates.*

Role of Deep-Layered Wind Shear



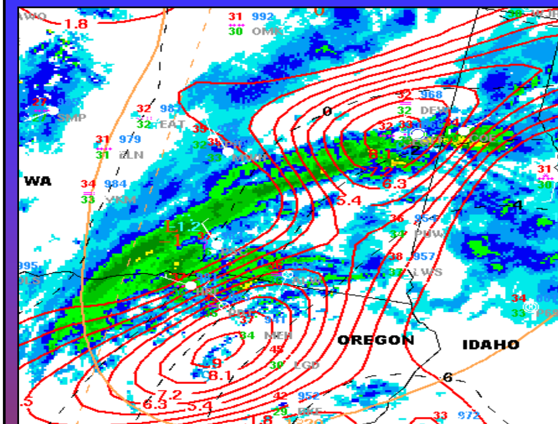
Frontogenetically-forced precipitation banding is most common given a strong vertical wind shear (especially speed shear) and a straight-line hodograph aloft.

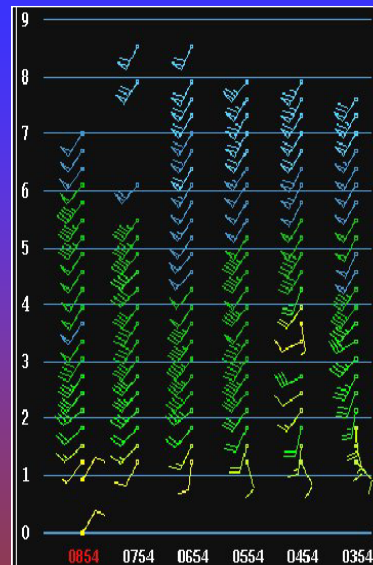
Role of Deep-Layered Wind Shear



In this case, deep-layer speed shear was significant. Note that the heavy precipitation bands were oriented parallel to the isentropes/isotherms. Given multiple bands, it is likely these are associated with the release of CSI in addition to frontogenesis.

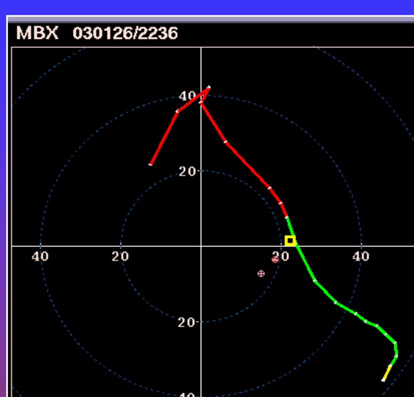
Deep-Layer Shear Example: 12/29/02



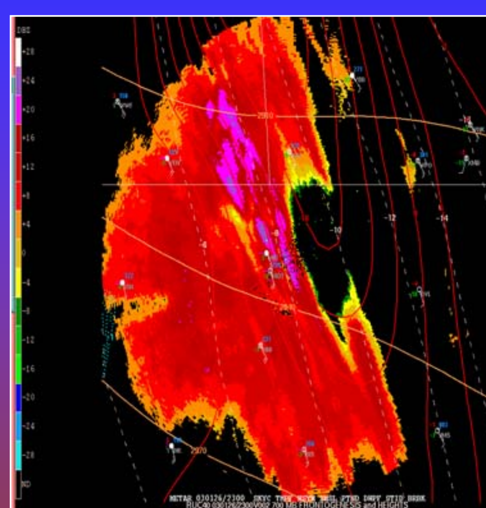


RUC 2-hr frontogenesis forecast at 850 mb (red lines; 700 mb frontogenesis was to northwest of 850 mb area). Note definitive band of precipitation. This occurred in an environment with significant vertical speed shear (image at right) and a quasi-straight-line hodograph (not shown).

Deep-Layer Shear Example: 01/26/03

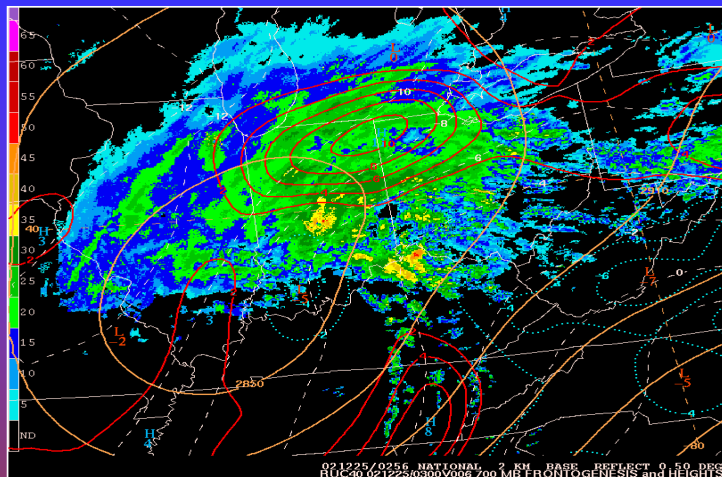


This example shows banded precipitation along the southern/western edge of 700 mb frontogenesis. The banding was associated with vertical wind shear and a straight-line hodograph aloft. Heavy precipitation did not occur due to limited moisture and fast movement.



Radar reflectivity image (clear air mode) in North Dakota and RUC-forecasted 700 mb frontogenesis (thin red lines).

Non-Banded Precipitation Example: 12/25/02

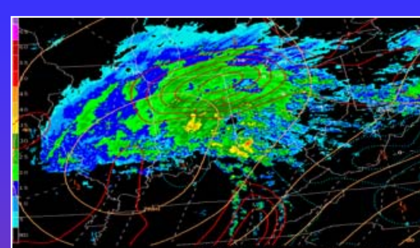


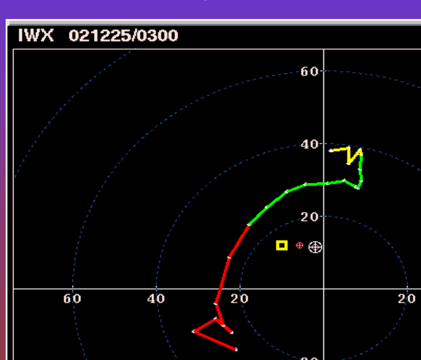
RUC 700 mb heights (orange) and frontogenesis (red) over the Ohio Valley.

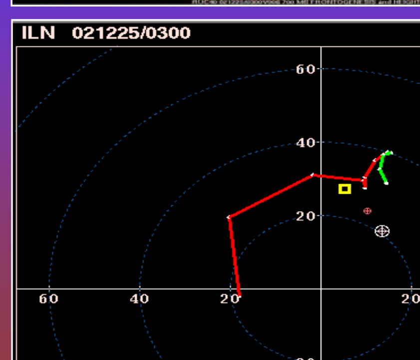
Note that the heaviest precipitation is along the southern gradient of the maximum 700 mb frontogenesis, although definitive banding was not present. The nature of the vertical wind profile and hodograph (next slide) apparently played a role in this.

Non-Banded Precipitation Example: 12/25/02

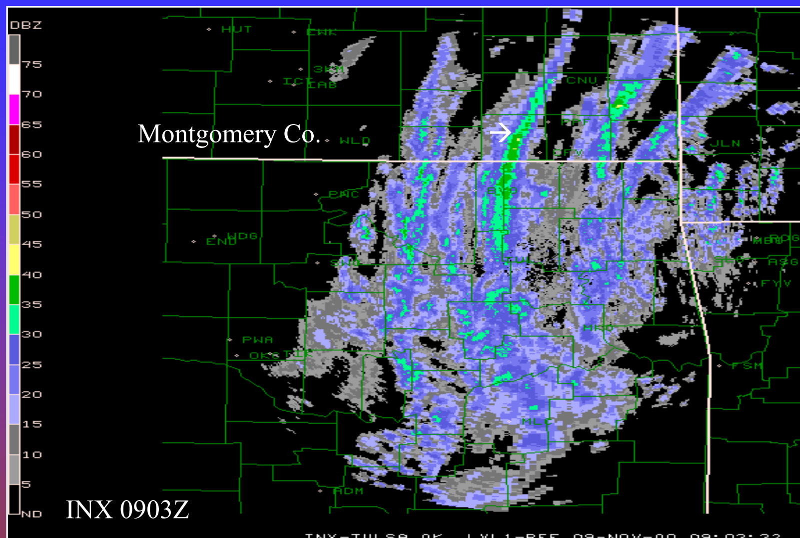
In this case, note the strong curvature in the shear vector with height (hodograph). This may preclude coherent banding, even in the presence of frontogenesis. Nevertheless, the presence of significant frontogenetical forcing and moisture still could well lead to an area of heavy precipitation.





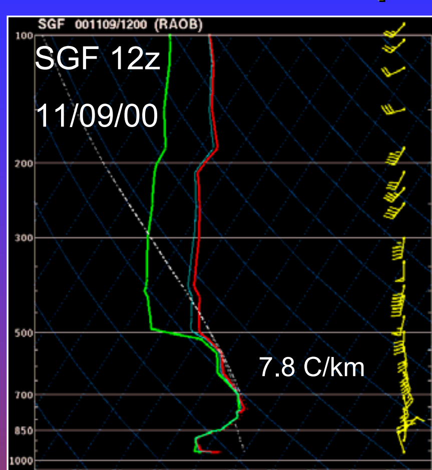


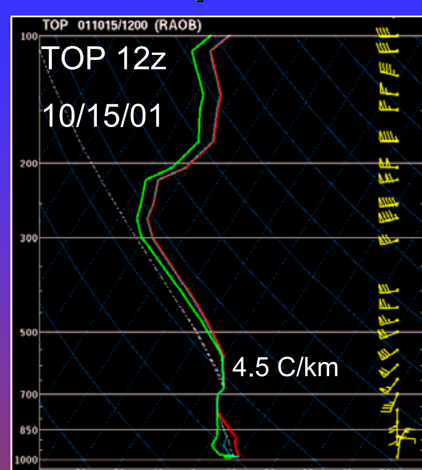
Multiple Banded Precipitation Example: 11/09/00



In this case, multiple narrow bands of precipitation occurred, due to lower stability (i.e., the release of elevated CSI) combined with frontogenetical forcing.

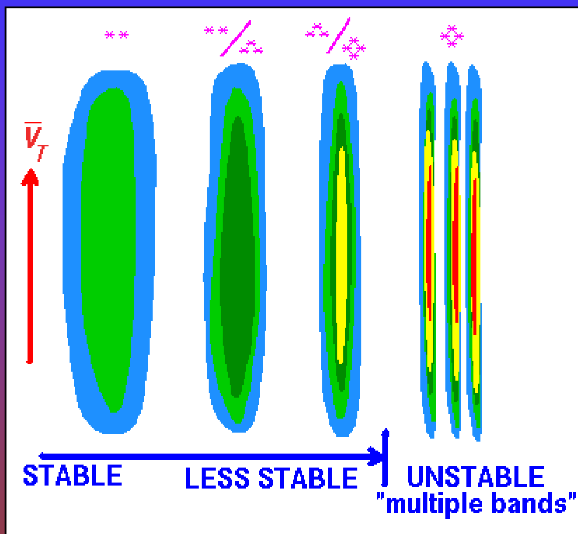
700-500mb Lapse Rate Comparison





Note the steep lapse rates from 700-500 mb at SGF (corresponding to radar image on previous slide). Near neutral or unstable lapse rates (with respect to a moist adiabat) implies multiple narrow and intense bands (maybe 5-10 km or so in width). This resulted in 2-3"/hr snowfall rates on Nov 9, 2000. The TOP lapse rate was not as steep from 700-500 mb, and was associated with a more general single band of precipitation (see earlier slides).

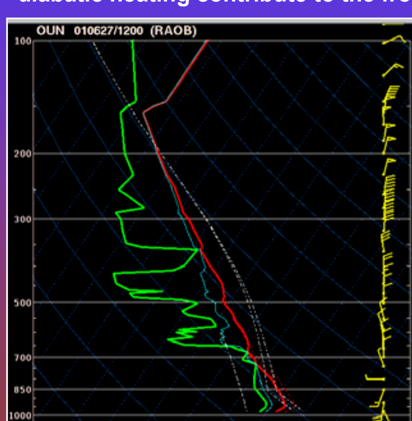
Modulation of Band Intensity by Instability for a Constant Value of Frontogenesis

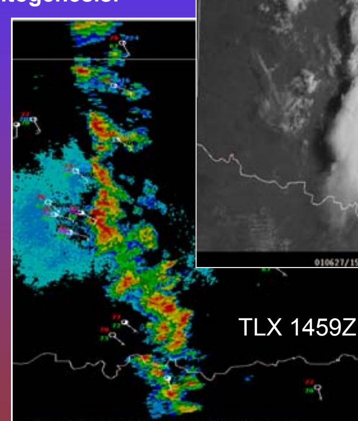


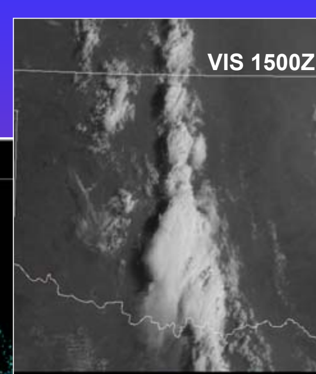
As gravitational or symmetric stability decreases, the horizontal scale (width) of a precipitation band decreases while the intensity (reflectivity) of the band increases. Multiple bands become established in an unstable regime. Thus, it is very important to look for CSI and convectively unstable areas aloft besides just frontogenesis.

Warm Season Banded Precip Example: 6/27/01

While most important during the cool season when baroclinicity is greatest, low-level and surface frontogenesis also can be important in the convective season. The forcing produced by the frontogenesis may be enough to initiate deep convection given adequate instability. Convergence, deformation, and diabatic heating contribute to the frontogenesis.

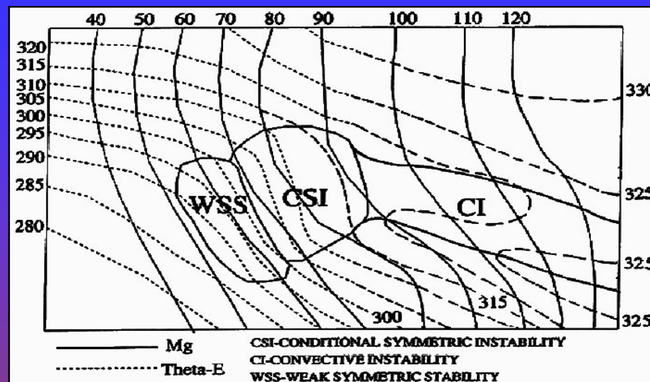






Spectrum of Mesoscale Instabilities; EPV

From Moore and Lambert (1993)



Many heavy precipitation events display different types of mesoscale instabilities including:

- **Convective Instability: CI; 2_e decreasing with height**

- **Conditional Symmetric Instability: CSI; lines of 2_e are more vertical than lines of constant absolute geostrophic momentum or M_g**

- **Weak Symmetric Stability: WSS; lines of 2_e are nearly parallel to lines of constant absolute geostrophic momentum or M_g, but still can result in banded heavy precipitation in the presence of sufficient frontogenetical forcing**

Spectrum of Mesoscale Instabilities; EPV

- **Equivalent Potential Vorticity (EPV)** is a parameter that can be used to diagnose areas of CSI simply and effectively.

- Look for areas of negative or small positive EPV.

- Consider the terms of the EPV equation (Moore and Lambert 1993):

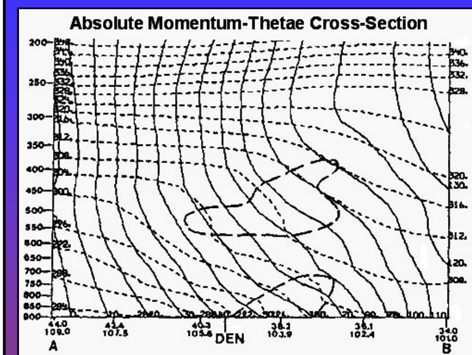
$$EPV = g\left[\left(\frac{\partial M_g}{\partial p}\frac{\partial \theta_e}{\partial x}\right) - \left(\frac{\partial M_g}{\partial x}\frac{\partial \theta_e}{\partial p}\right)\right]$$

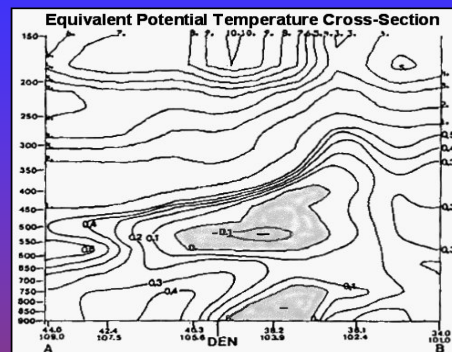
- The closer EPV is to zero, the more responsive the atmosphere will be to a given amount of forcing.

- EPV will be smallest (near zero or negative) given a strong south-to-north horizontal 2e gradient, significant vertical wind speed shear, near entrance regions of jet streaks, and where 2e decreases with height (although convective instability also will be present).

- If EPV < 0 , then CSI is present. Overlaying geostrophic momentum (Mg) with 2e on a spatial-height cross-section is an effective way to determine if CSI or convective (gravitational) instability exists.

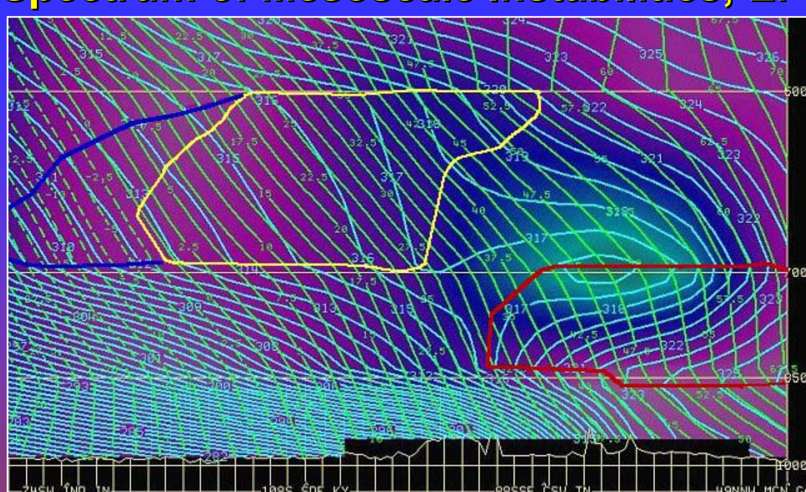
Spectrum of Mesoscale Instabilities; EPV





Example from Moore and Lambert (1993) showing elevated CSI (within dashed area) where the dashed 2e lines are more vertical than the solid Mg lines (left). In this same area, EPV values are around or below zero (shaded areas on right diagram).

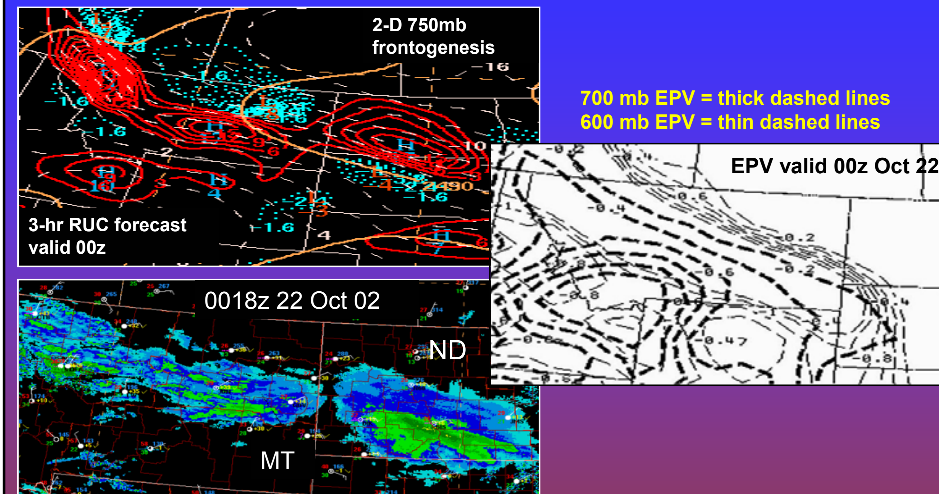
Spectrum of Mesoscale Instabilities; EPV



Spatial-height cross-section from central GA (left) through central KY to west-central IN on Feb 15, 2003. Shown are 2e (blue lines), Mg (green lines), and RH image (purple=high RH).

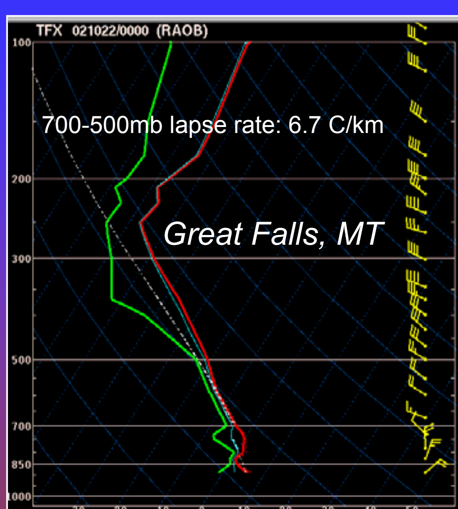
The cross-section shows a very stable boundary layer (tight 2e packing and increasing with height). Aloft, an area of convective instability (2e decreasing with height) is outlined in red. An area of CSI (given saturation) is within the yellow area (2e sloped steeper than Mg). Finally, an area of weak symmetric stability is outlined in dark blue where 2e is sloped about the same as Mg.

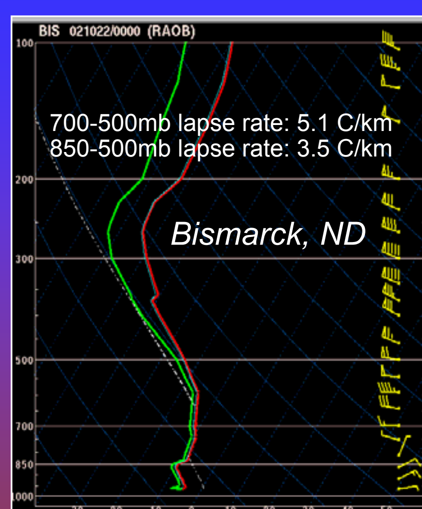
Stability vs. Banding Comparison



750 mb frontogenesis is noted over Montana and North Dakota. Meanwhile, negative EPVs existed over the southern half of Montana (on southward), with more stable EPVs over North Dakota. Note the difference in banding structure at 0018 utc: frontogenesis produced banding, but multiple banding existed near the area of negative EPVs, with a single band in the more stable environment over North Dakota.

Stability vs. Banding Comparison





The Great Falls sounding at 00 utc Oct 22 showed steeper mid-level lapse rates than at Bismarck. This compares favorably with the negative EPVs and the multiple banded precipitation on the previous slide. The more stable air near Bismarck was associated with a single band within the frontogenetical regime.

Numerical Model Considerations

February 7, 2003

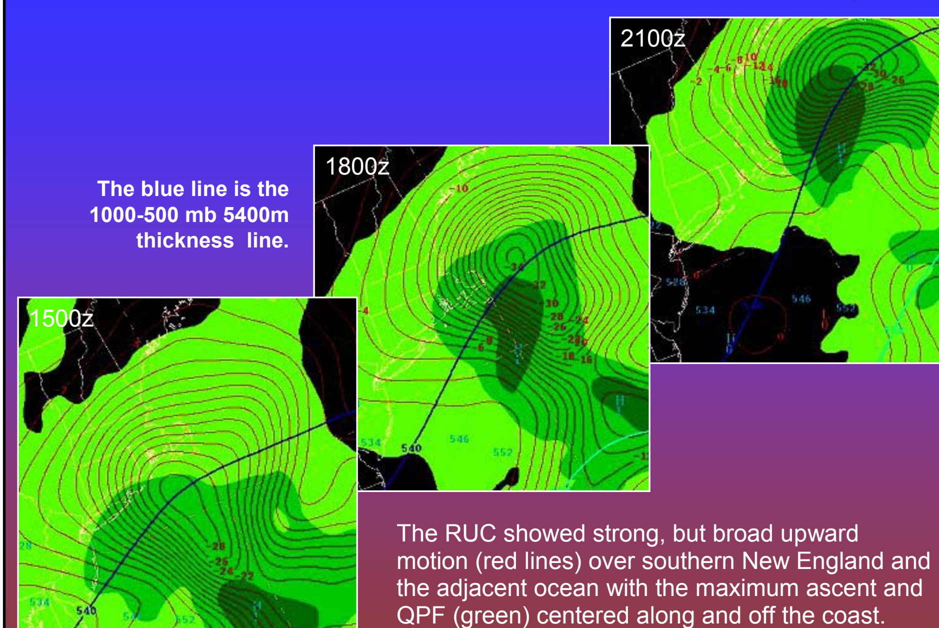
Heavy snow band across southern New England.

Model-forecasted warm advection, 700mb omega, and QPF fields indicated one thing (heaviest precipitation along/off coast), but frontogenesis and radar showed something different (well-defined, prolonged heavy snow band inland).

In other words, the models may not tell you what you need to know, even for a “well-handled” system:
“What you see isn’t always what you get”

Feb 7, 2003: RUC-Forecasted QPF/Omega

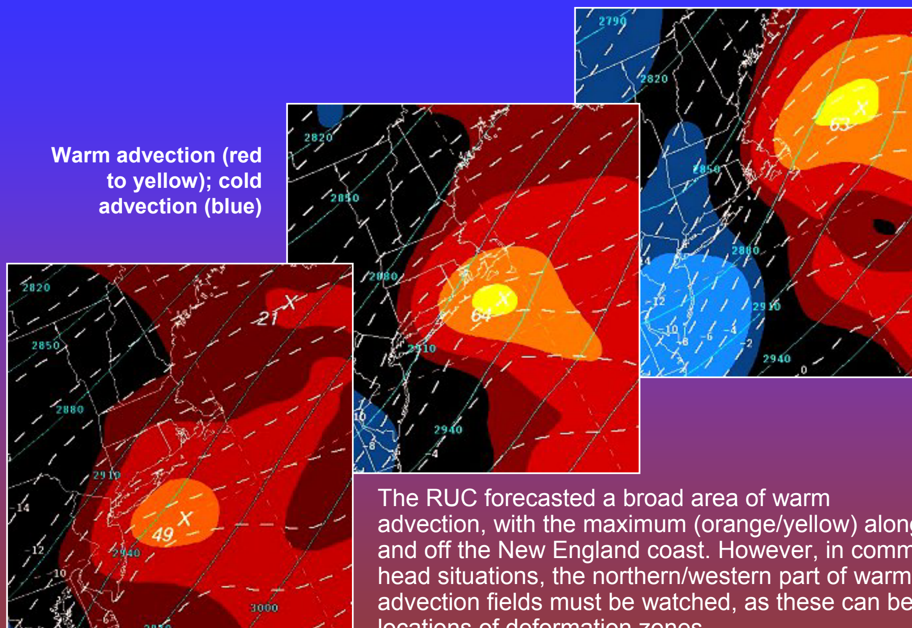
The blue line is the 1000-500 mb 5400m thickness line.



The RUC showed strong, but broad upward motion (red lines) over southern New England and the adjacent ocean with the maximum ascent and QPF (green) centered along and off the coast.

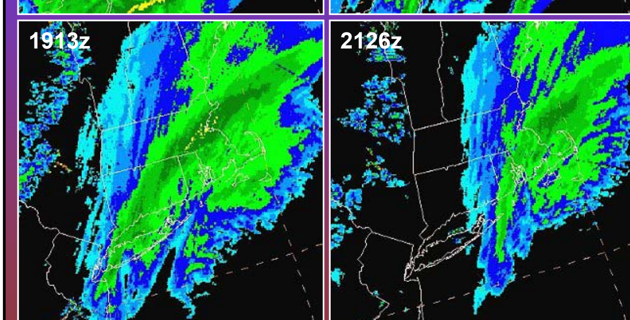
Feb 7, 2003: RUC-Forecasted Warm Advection

Warm advection (red to yellow); cold advection (blue)



The RUC forecasted a broad area of warm advection, with the maximum (orange/yellow) along and off the New England coast. However, in comma head situations, the northern/western part of warm advection fields must be watched, as these can be locations of deformation zones.

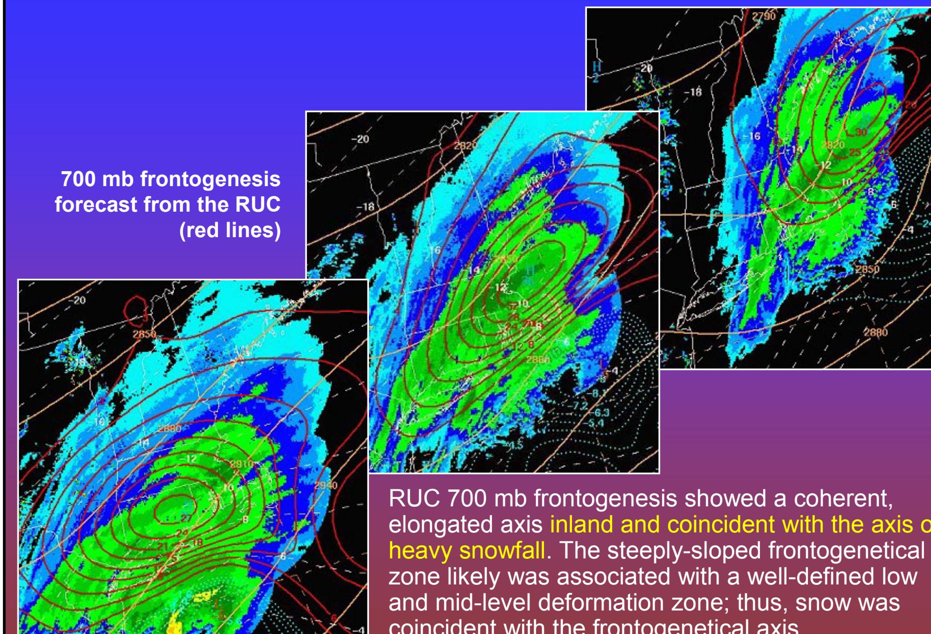
Feb 7, 2003: Mosaic Radar 1317-2126 utc



Radar data every 2 hours showed a large area of precip, similar to what the RUC suggested. However, a long-lasting definitive heavy snow band developed inland over CT and eastern MA on the northern edge of the RUC's omega, WAA, and QPF fields. What did frontogenesis show? See next slide.

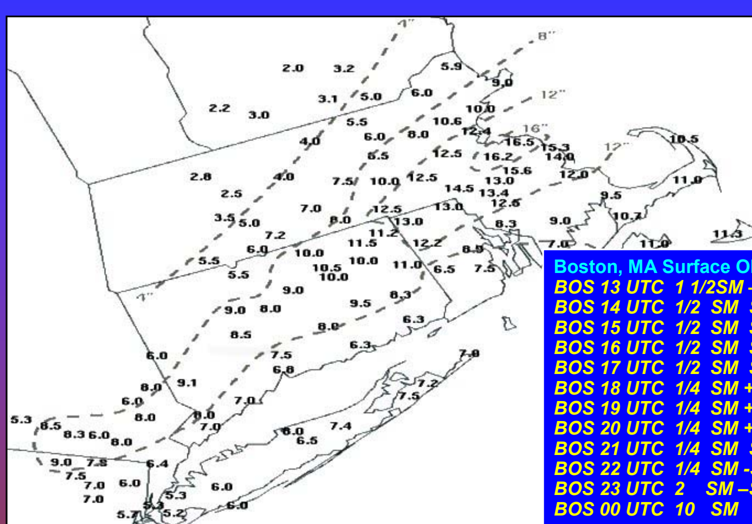
Feb 7, 2003: Radar & 700 mb Frontogenesis

700 mb frontogenesis forecast from the RUC (red lines)



RUC 700 mb frontogenesis showed a coherent, elongated axis inland and coincident with the axis of heavy snowfall. The steeply-sloped frontogenetical zone likely was associated with a well-defined low and mid-level deformation zone; thus, snow was coincident with the frontogenetical axis.

Feb 7, 2003: Snowfall Accumulations



A definitive band of heavy snow with amounts of 8-16 inches fell across CT and eastern MA.

Boston, MA Surface Observations:

BOS 13 UTC 1 1/2SM –SN
BOS 14 UTC 1/2 SM SN
BOS 15 UTC 1/2 SM SN SNINCR 1/ 2
BOS 16 UTC 1/2 SM SN SNINCR 1/ 3
BOS 17 UTC 1/2 SM SN SNINCR 2/ 4
BOS 18 UTC 1/4 SM +SN SNINCR 2/ 6
BOS 19 UTC 1/4 SM +SN SNINCR 2/ 8
BOS 20 UTC 1/4 SM +SN SNINCR 2/10
BOS 21 UTC 1/4 SM SN SNINCR 1/10
BOS 22 UTC 1/4 SM -SN
BOS 23 UTC 2 SM –SN
BOS 00 UTC 10 SM

Conclusion:* *Model data usually possess inadequate resolution to correctly predict and refine vertical motion and QPF fields in winter storms. However, through assessment of frontogenesis, deformation, stability (EPV/CSI), and other fields, forecaster situational awareness will increase leading to a better forecast.

Suggested Snow Band Checklist

Presence of 1"/hr snowfall rates:

- ❑ *Near saturation in low-mid levels (1000-500 RH>85%)*
- ❑ *Favorable thermodynamic profile for snow: cloud top temperatures < -10 C; no melting layers aloft*
- ❑ *Sloped region of low-mid-level 2-D frontogenesis/ deformation axis in 850-500mb range*
- ❑ *Relative minimum in wind speed (< 20kt) within 850-700 mb region (col point aloft) and/or uniform deep-layer shear profile with absence of substantial hodograph curvature*

Suggested Snow Band Checklist

Higher snowfall rates (1-3"/hr):

- ❑ *Same parameters as for 1"/hr snowfall rates AND:*
- ❑ *Saturation and strong ascent through the primary dendritic growth layer (-12 to -16 C), i.e., high precipitation efficiency*
- ❑ *Isothermal layer just colder than 0 C above surface: suggests higher atmospheric moisture content and enhances aggregation*
- ❑ *Presence of ambient or just upstream negative EPV, steep mid-level lapse rates (along moist adiabats), and elevated potential or slantwise instability: enhance convective snow potential and band multiplicity/intensity*

SUMMARY

- Frontogenesis is very useful for assessing the potential for mesoscale banded precipitation zones.
- Does not require a strong cyclone, only a baroclinic zone, often enhanced through horizontal convergence or deformation associated with a col point aloft
- Col point aloft is a cue that frontogenesis may be occurring due to deformation
- Precipitation banding is affected by wind structure and stability; deep-layer vertical shear, a straight hodograph, and small stability enhance banding
- Frontogenesis in a stable atmosphere normally results in one main band; given CSI or CI, multiple bands with high precipitation rates can result
- Banding is not always represented by the models