Surface Fronts

Atmos 5210/6210

Synoptic–Dynamic Meteorology II

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What Is a Front?

- An elongated zone of strong temperature gradient (>10°C/1000 km) and relatively large static stability and cyclonic vorticity (Bluestein 1986)

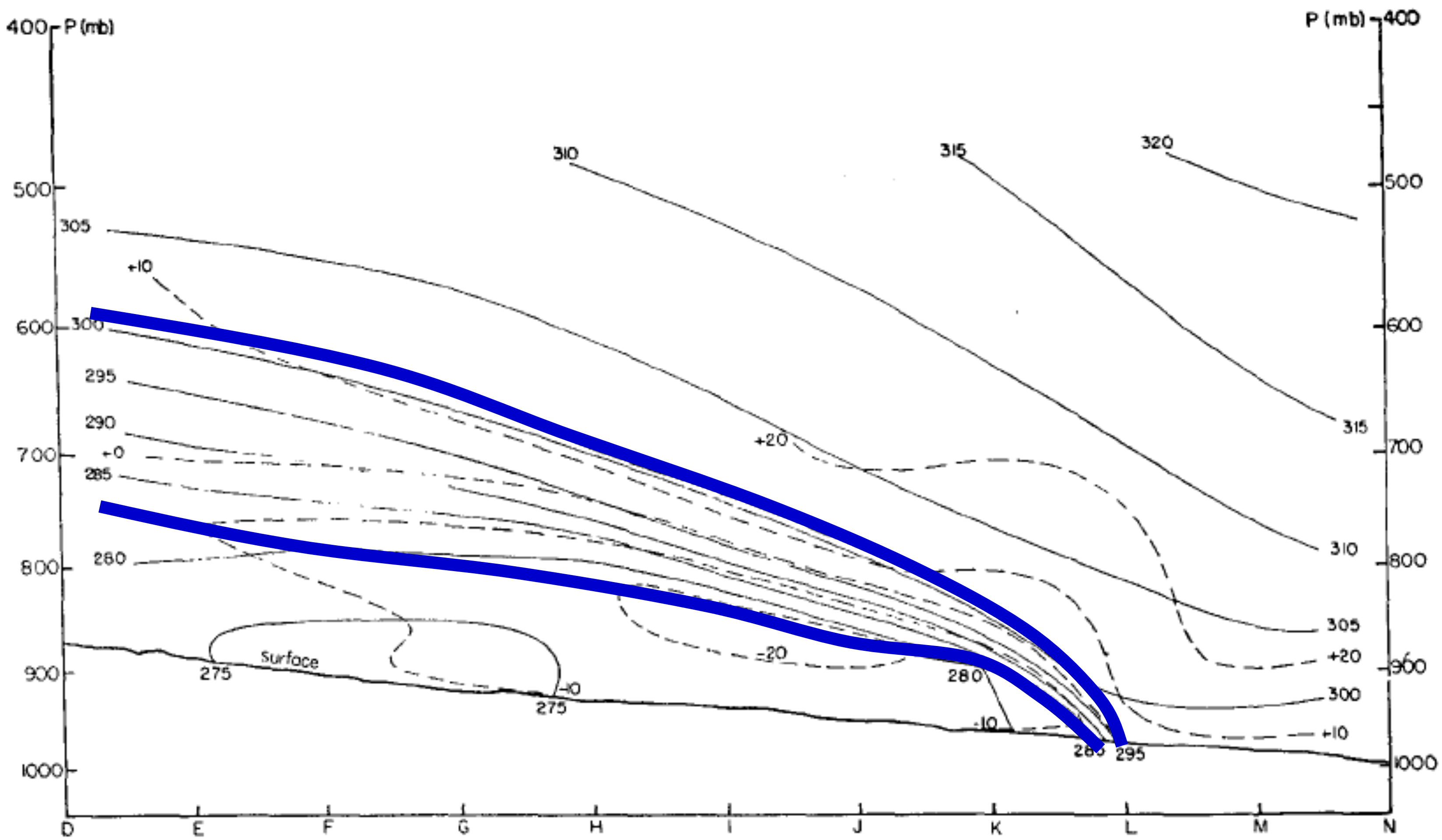
- Sloping zones of pronounced transition in the thermal and wind fields (Keyser 1986)

- In the broadest sense, it is a boundary between two airmasses (Bluestein 1993)

- The interface or transition zone between two airmasses of different density (Glossary of Meteorology 2000)

- I can't define front, but I know one when I see one (Steenburgh)

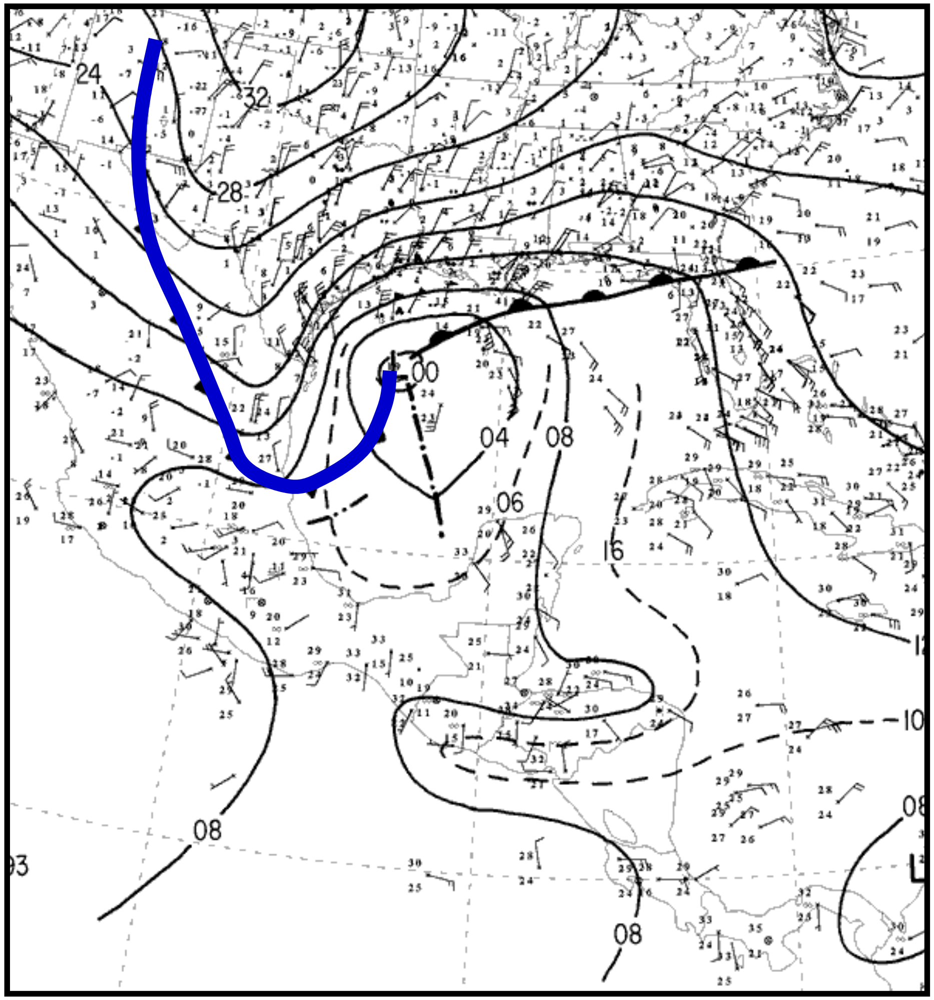
Types of Fronts

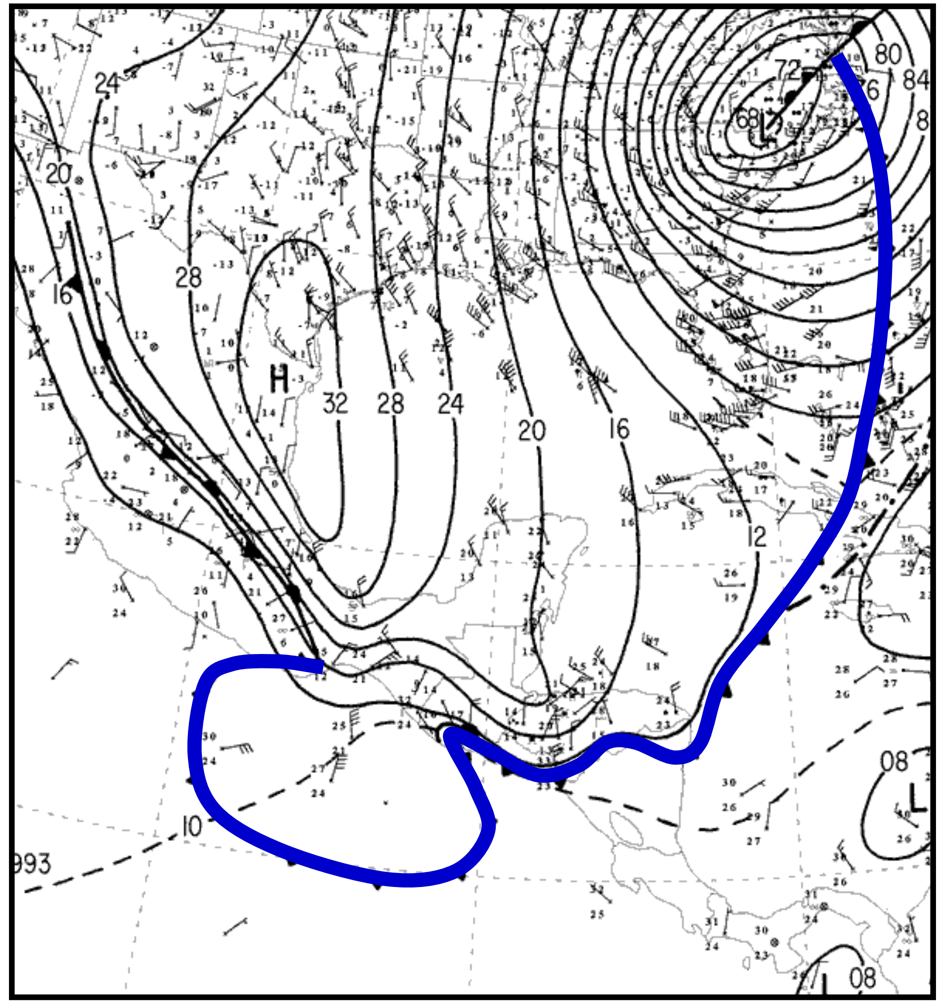


Surface front – A front with greatest intensity at the ground

Source: Sanders (1955)

Types of Fronts

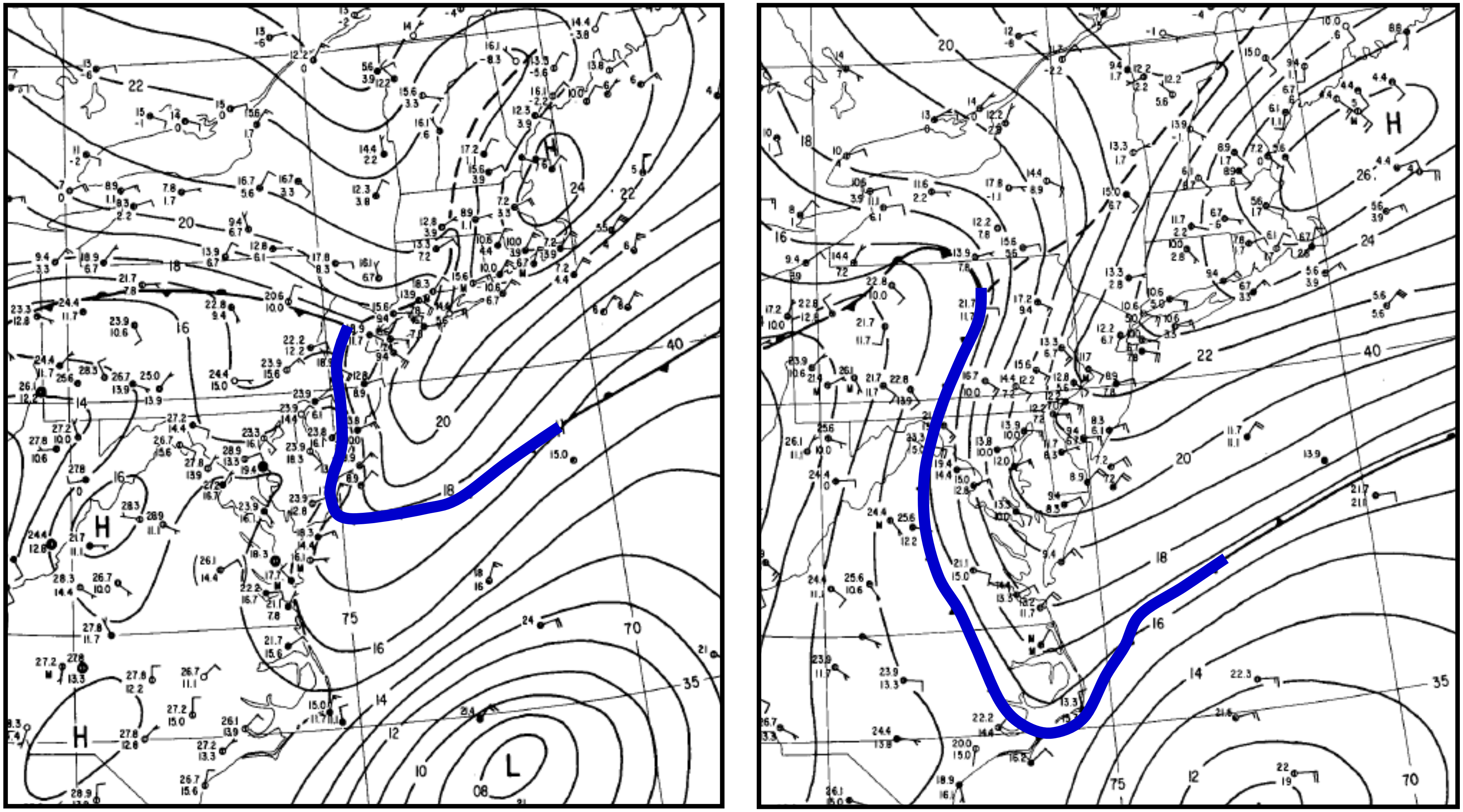




Cold front – A front with cold air advancing

Source: Schultz et al. (1997)

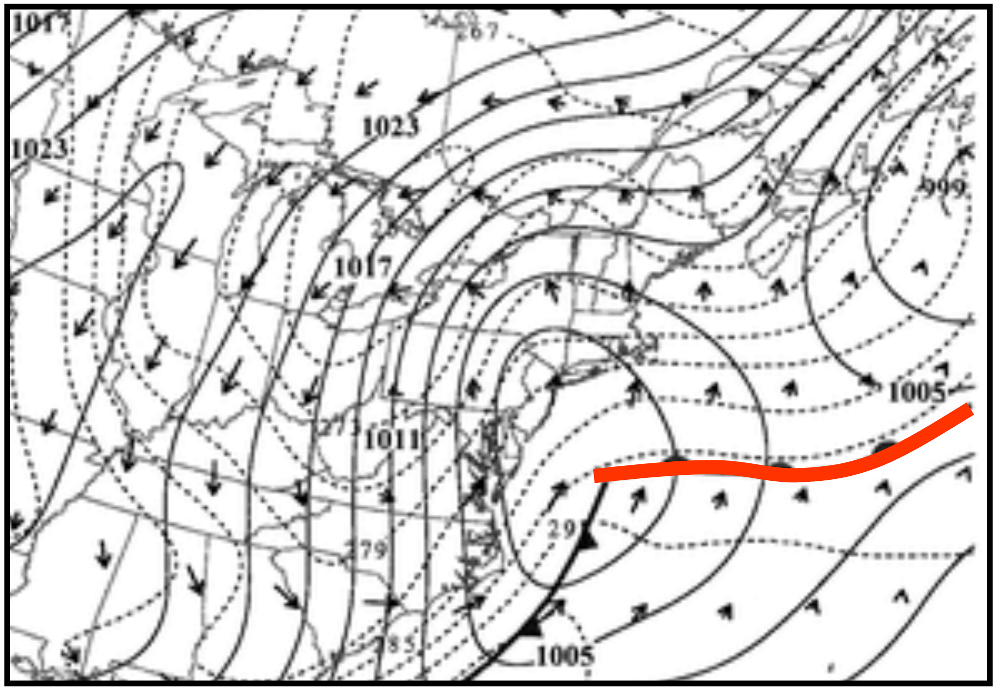
Types of Fronts

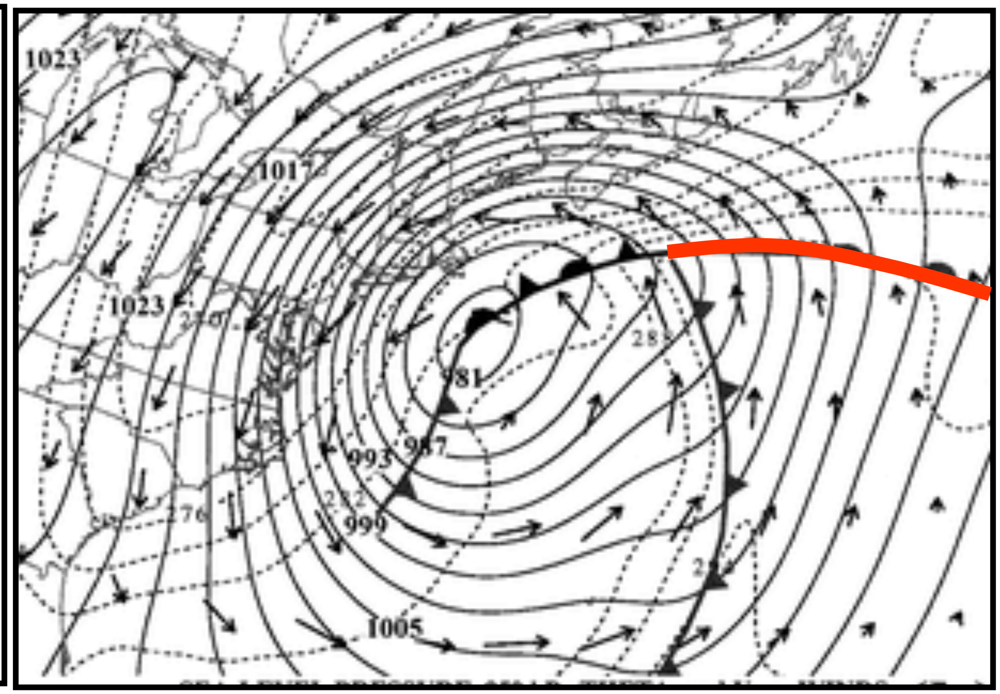


<u>Back-door cold front</u> – A cold front that moves westward, poleward, or westward and poleward

Source: Hakim (1992)

Types of Fronts

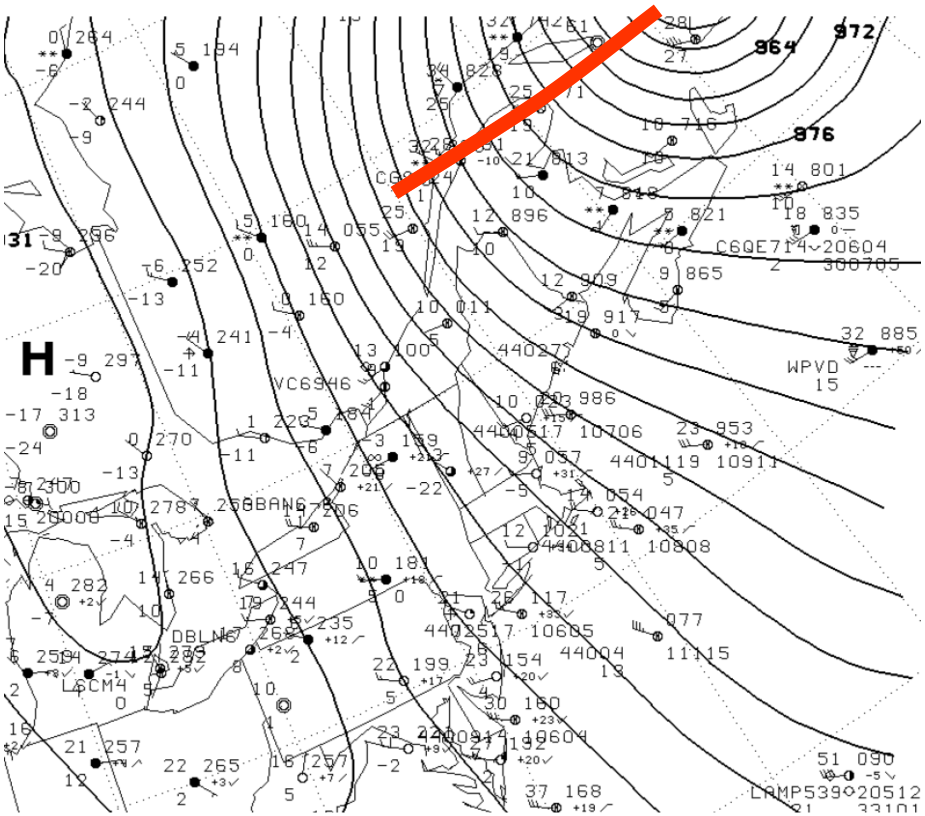




Warm front – A front with warm air advancing (or, alternatively, cold air retreating)

Source: Korner and Martin (2000)

Types of Fronts



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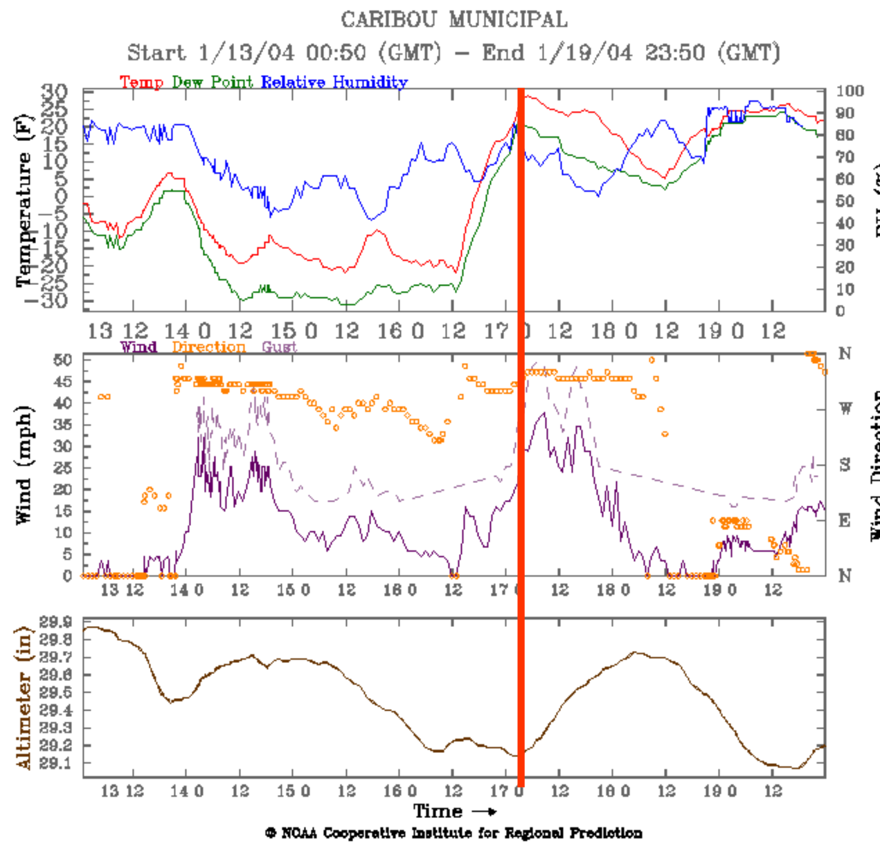
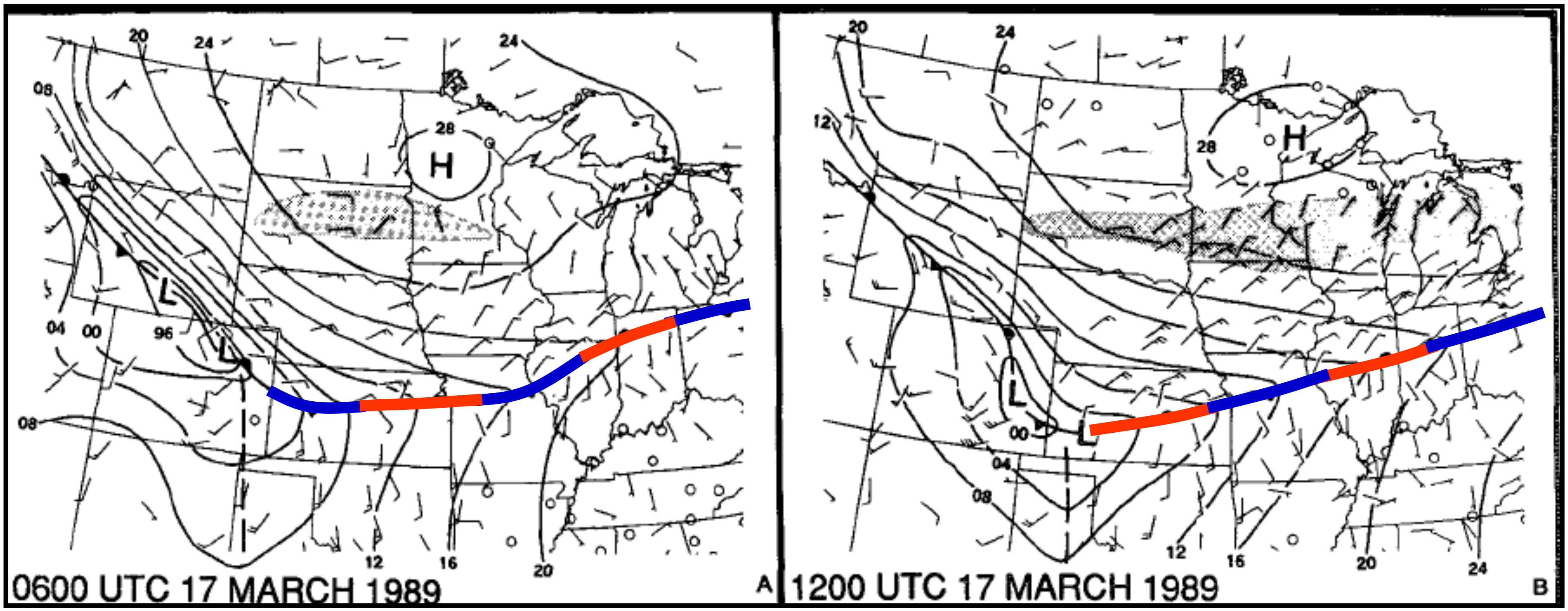


Caribou, ME

Back-door warm front – A warm front that is advancing equatorward, westward, or equatorward and westward

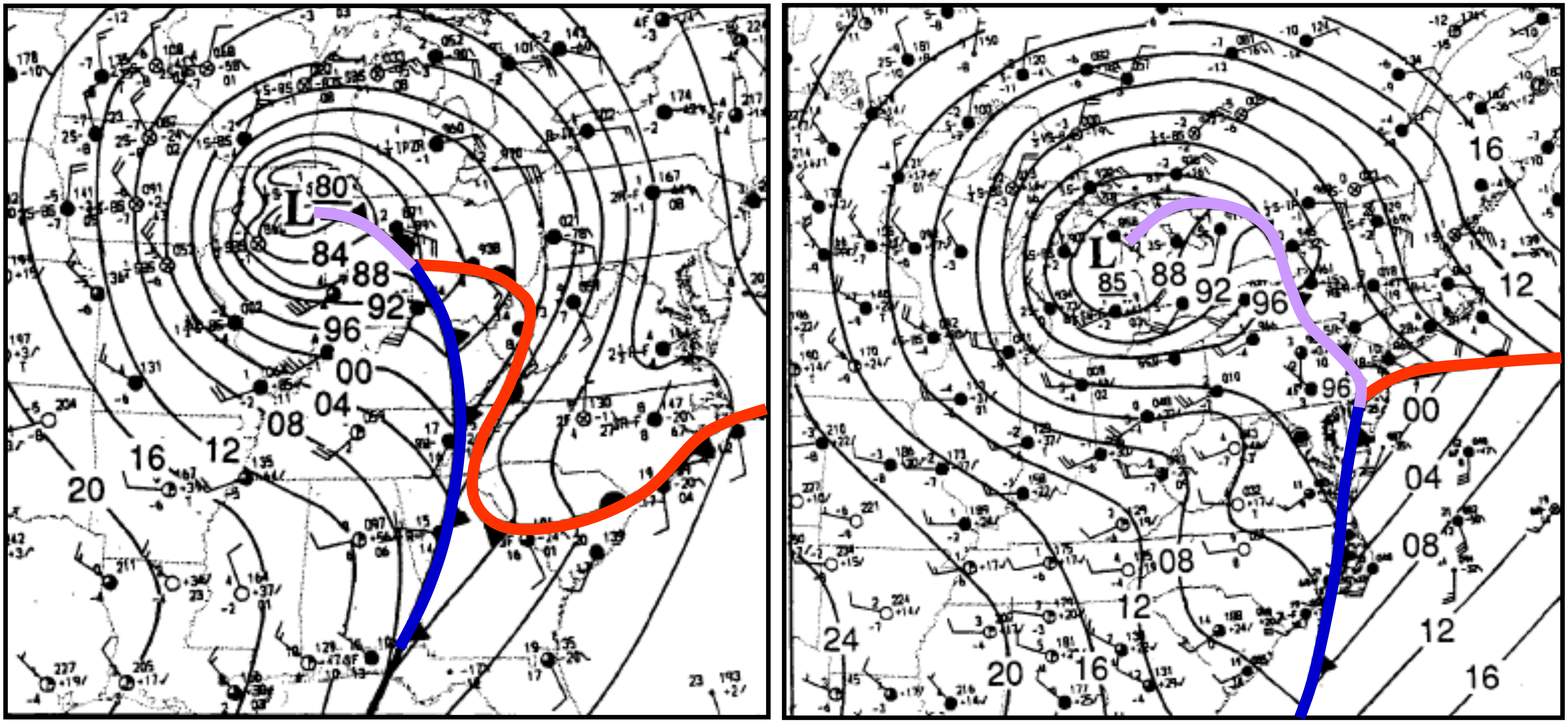
Types of Fronts



Stationary front – A quasistationary front. May become a warm or cold front if it begins to move

Source: Hakim and Uccelini (1992)

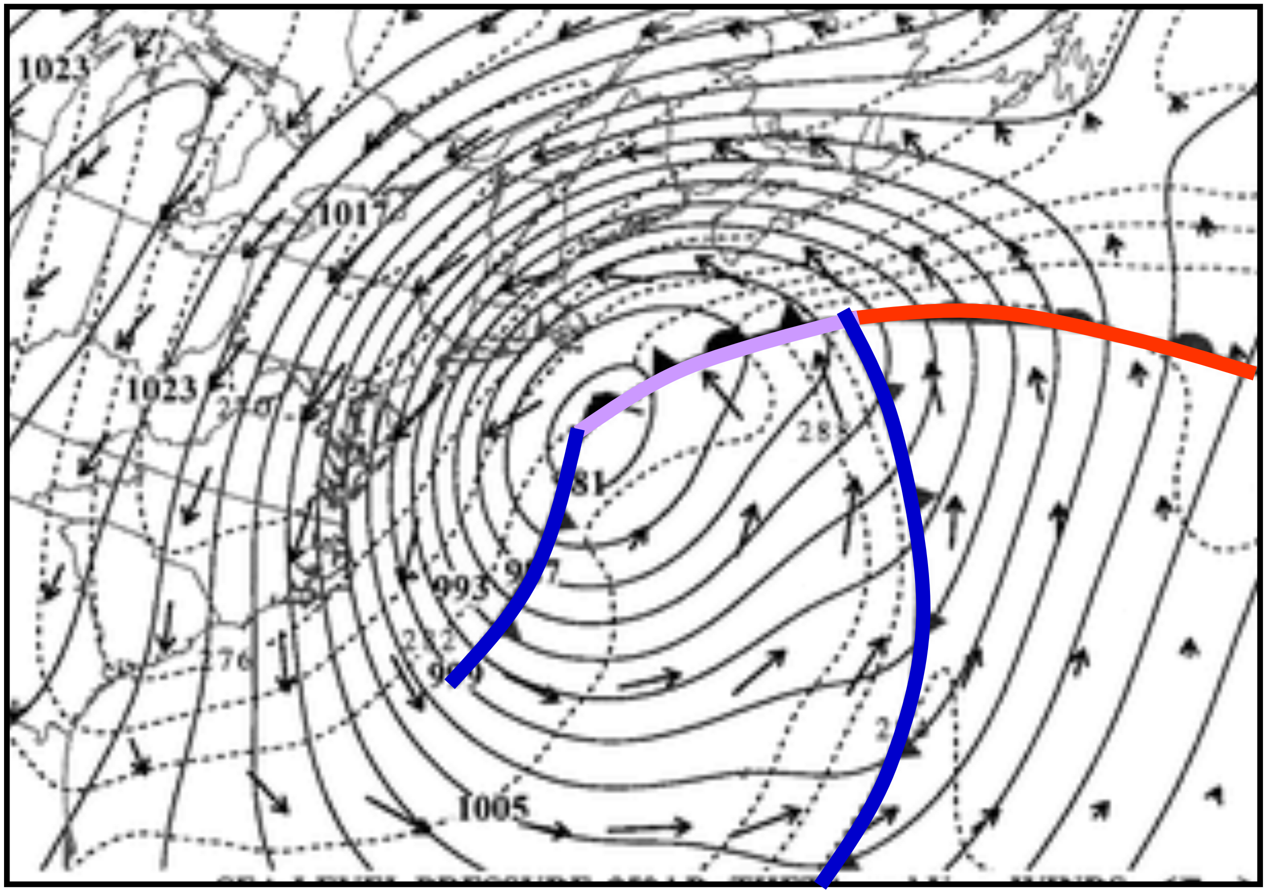
Types of Fronts



<u>Occluded front</u> – A tongue of warm air that extends from the low center to the peak of the warm sector

Source: Mass and Schultz (1993)

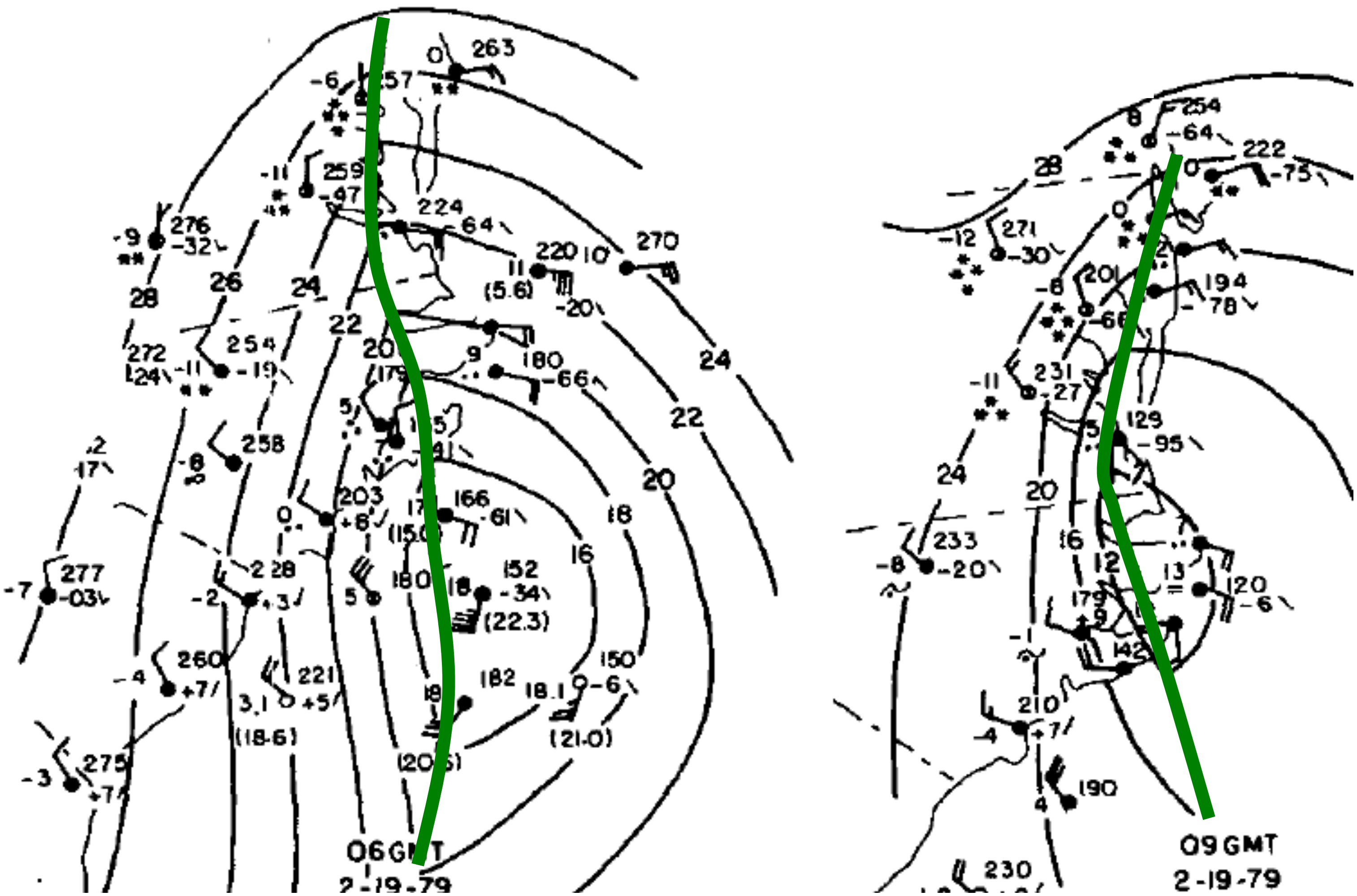
Types of Fronts



Bent-back front – A front that extends into the polar airstream behind the low center and may have the character of a cold front

Source: Korner and Martin (2000)

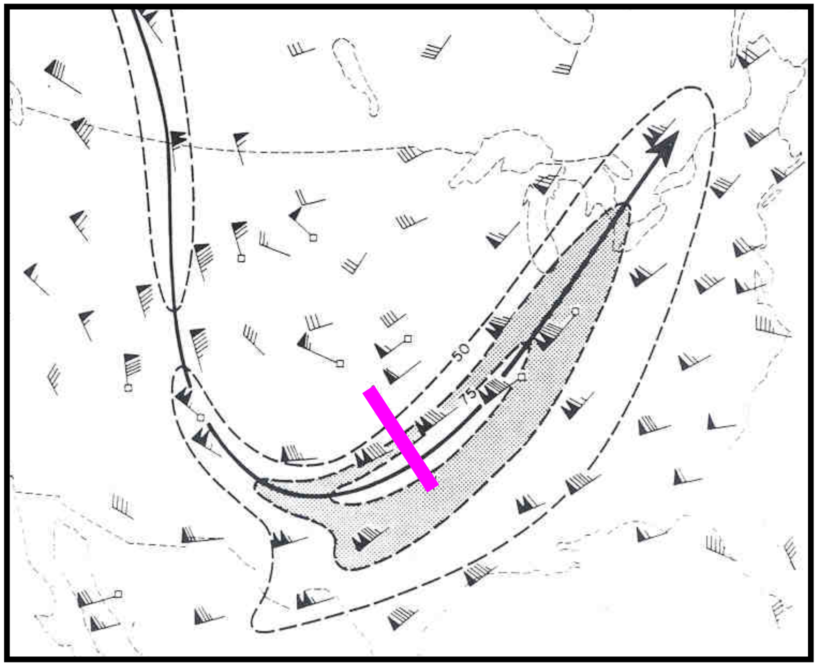
Types of Fronts

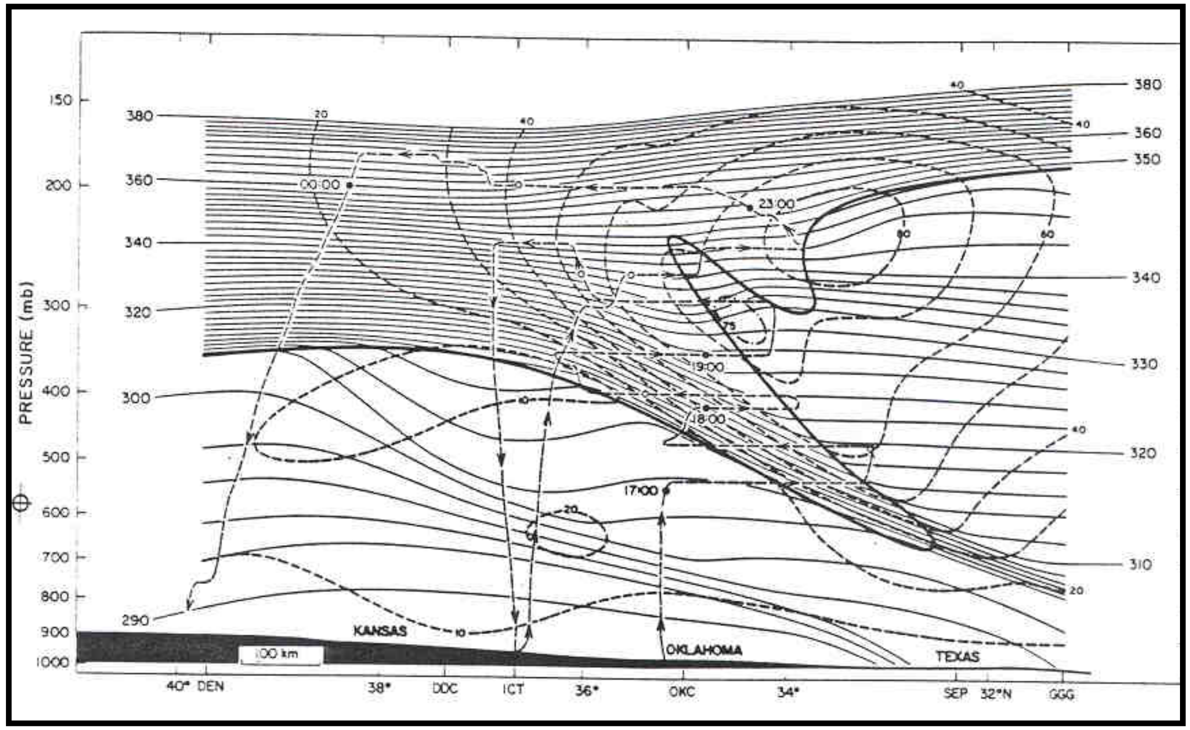


Coastal front – A shallow, mesoscale boundary separating warm marine air from cold continental air

Source: Bosart (1981)

Types of Fronts

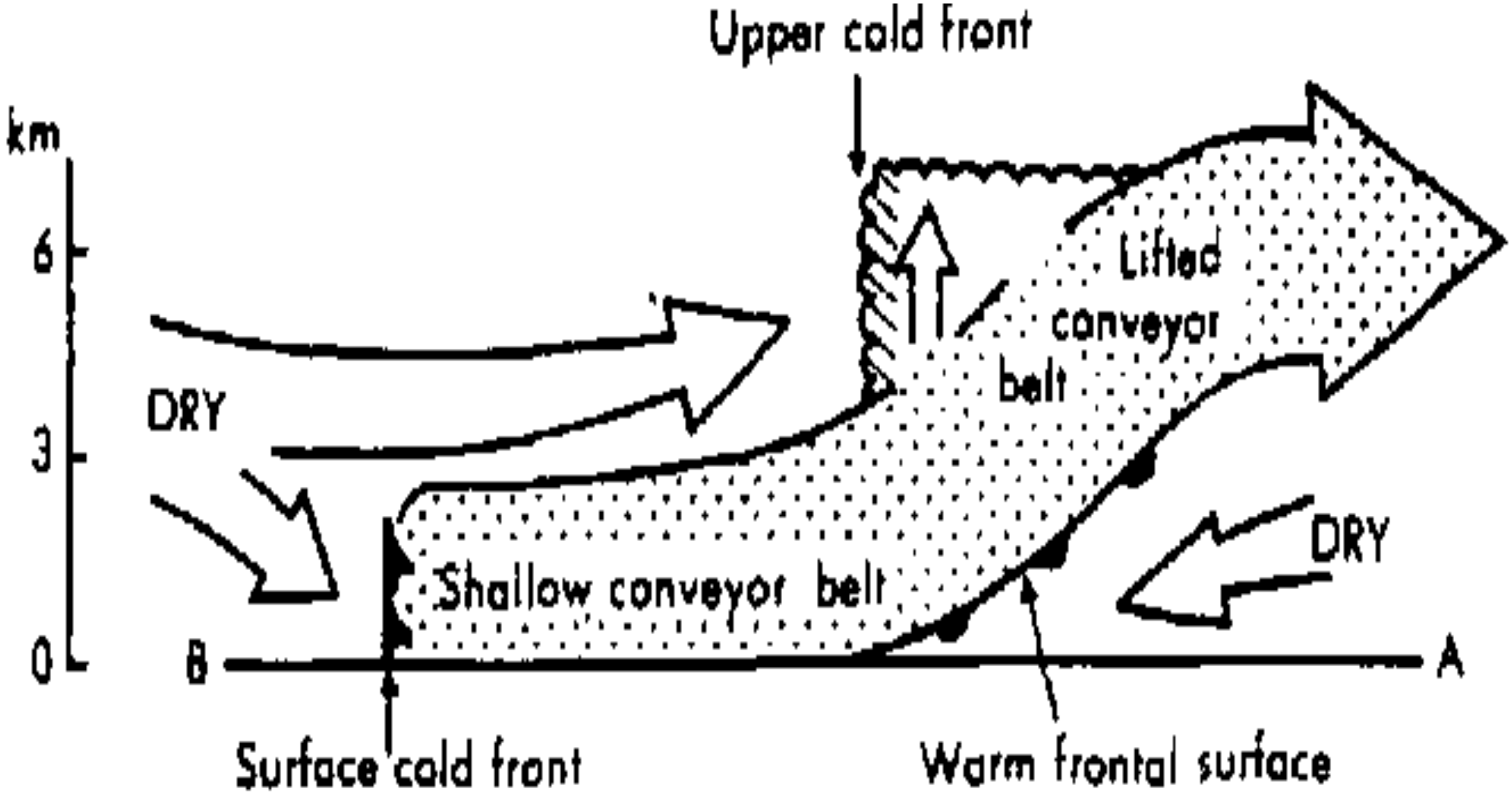




<u>Upper-level front</u> – A zone of strong horizontal temperature gradient in the upper and middle troposphere that does not necessarily extend to the ground

Source: Shapiro (1983)

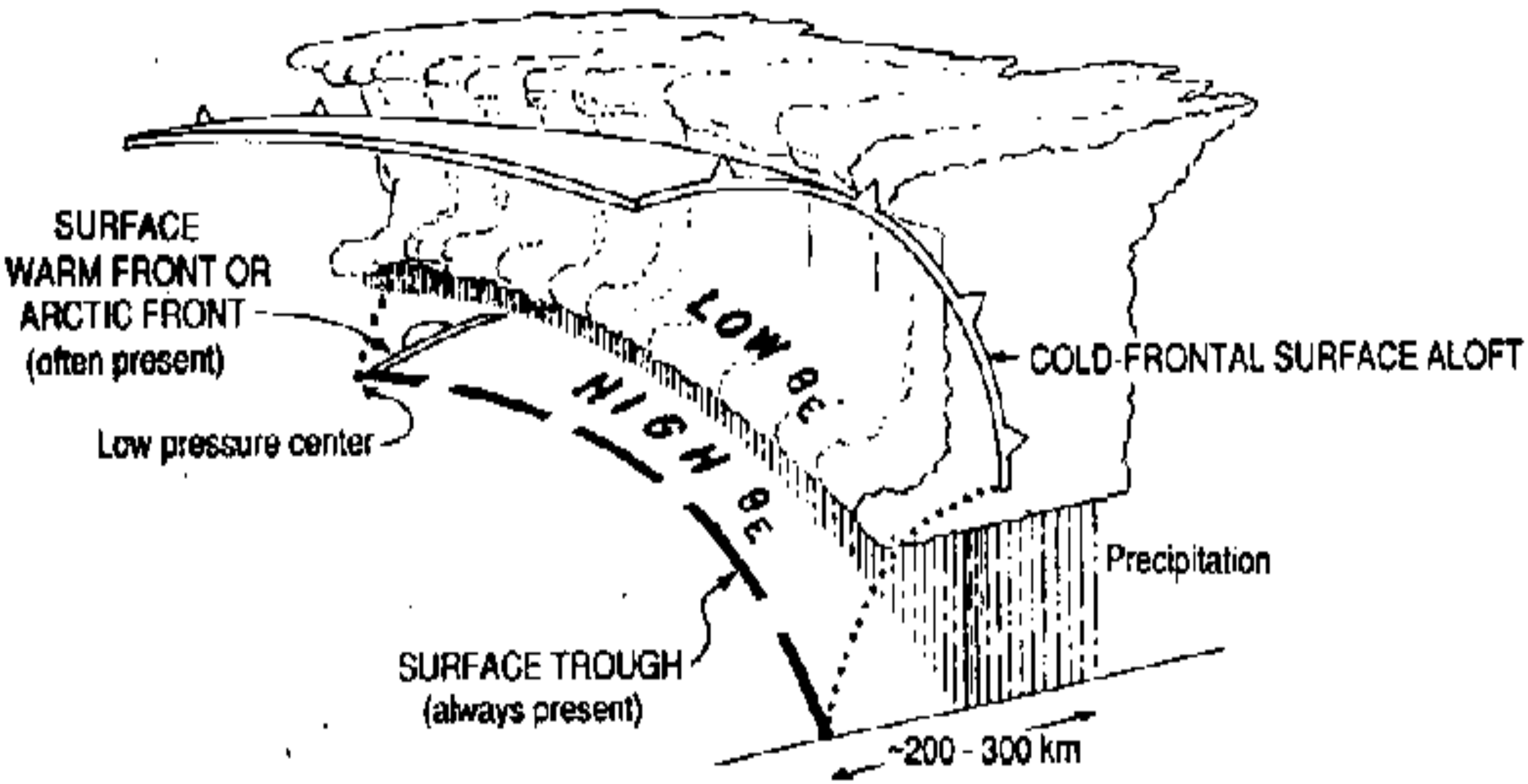
Types of Fronts



Split front – A cold front that has been “overrun” by low-θe air aloft (i.e., Browning and Monk’s upper cold front)

Source: Browning and Monk (1982)

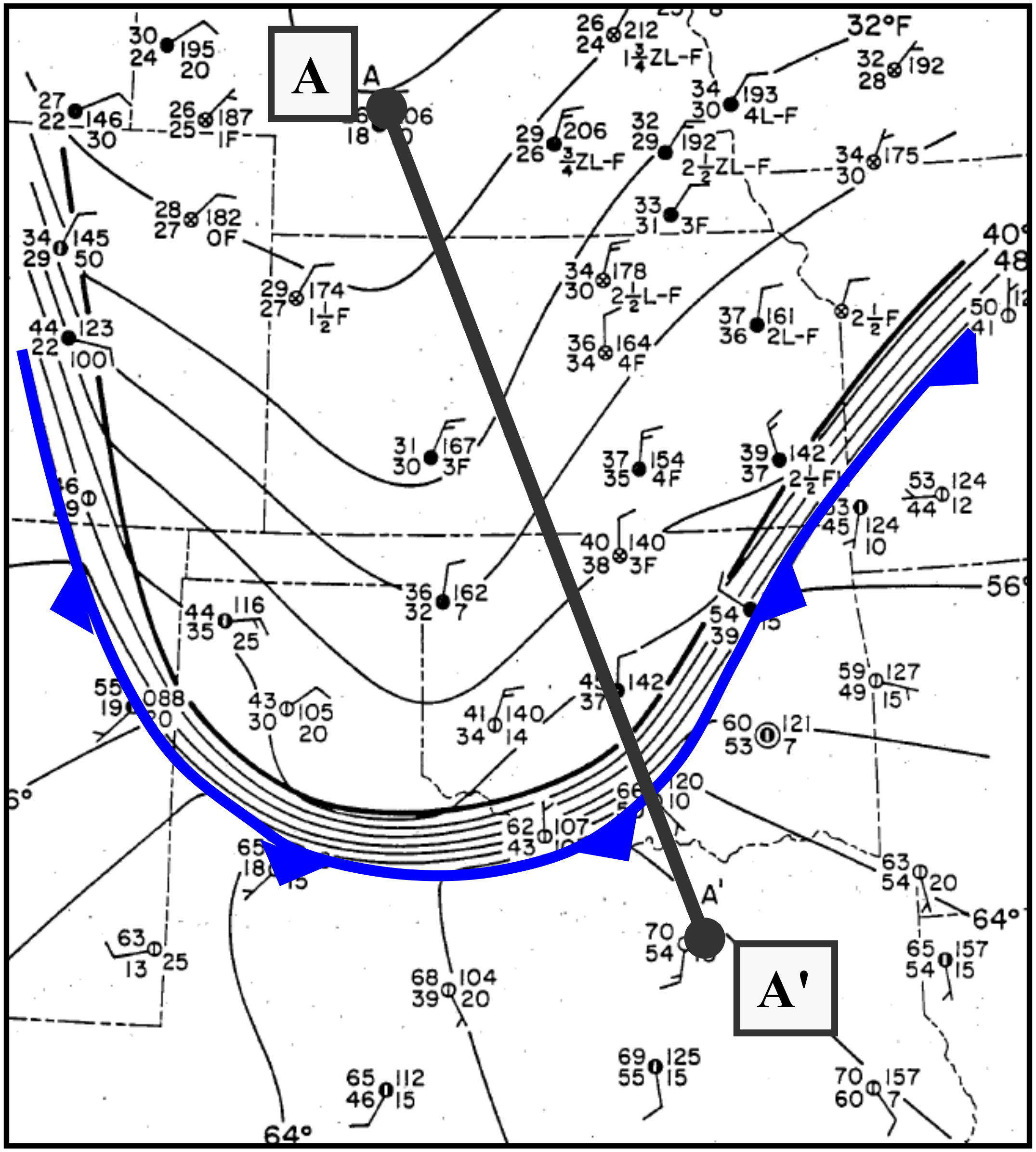
Types of Fronts



<u>Cold front aloft</u> – A cold front that is located aloft and ahead of a surface pressure trough

Source: Hobbs et al. (1990)

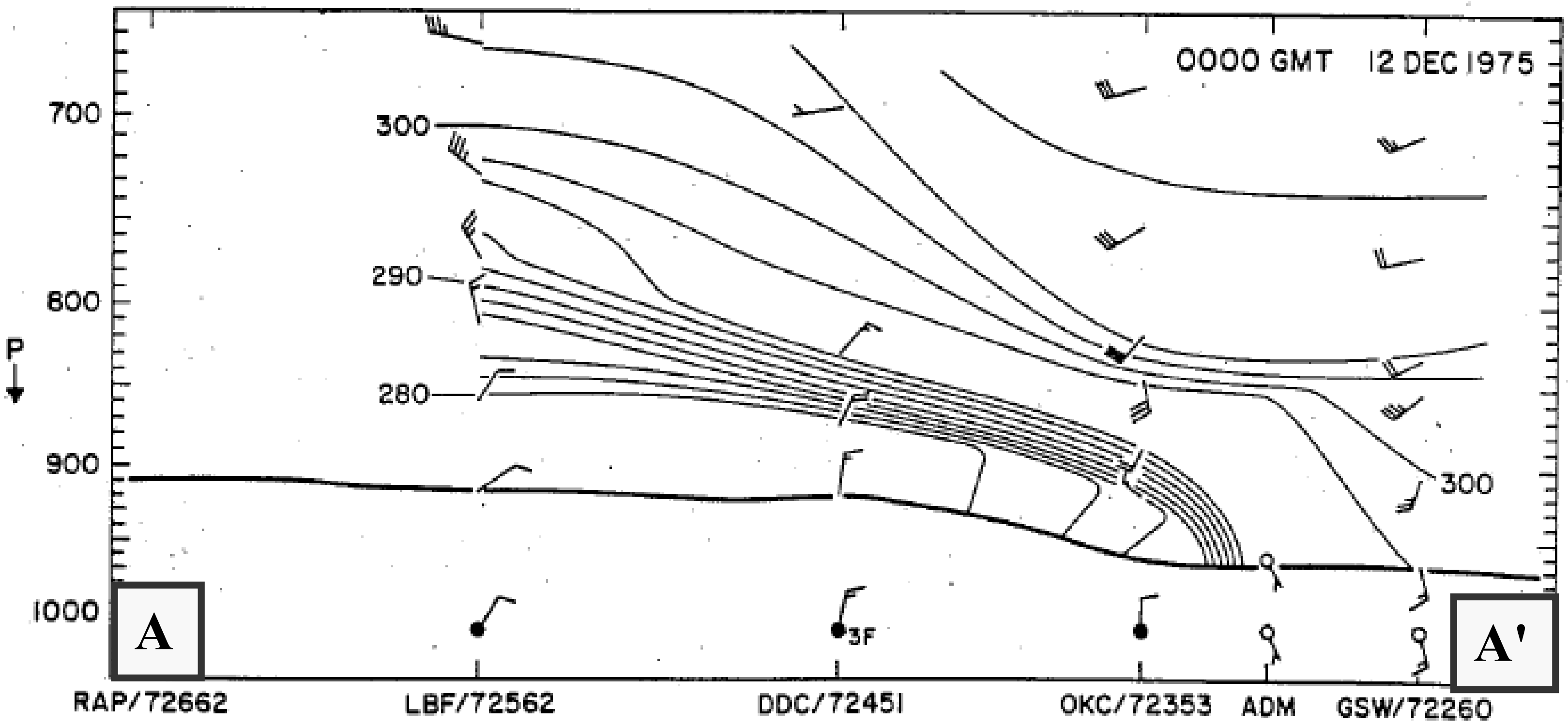
Characteristics of Surface Cold Fronts



Source: Shapiro (1983)

- Frontal zone is located on cold side of wind shift
- Wind veers as one moves across front toward cold air
- Identified with triangles pointing toward the warm air
- Strip of high vorticity @ wind shift (not shown)

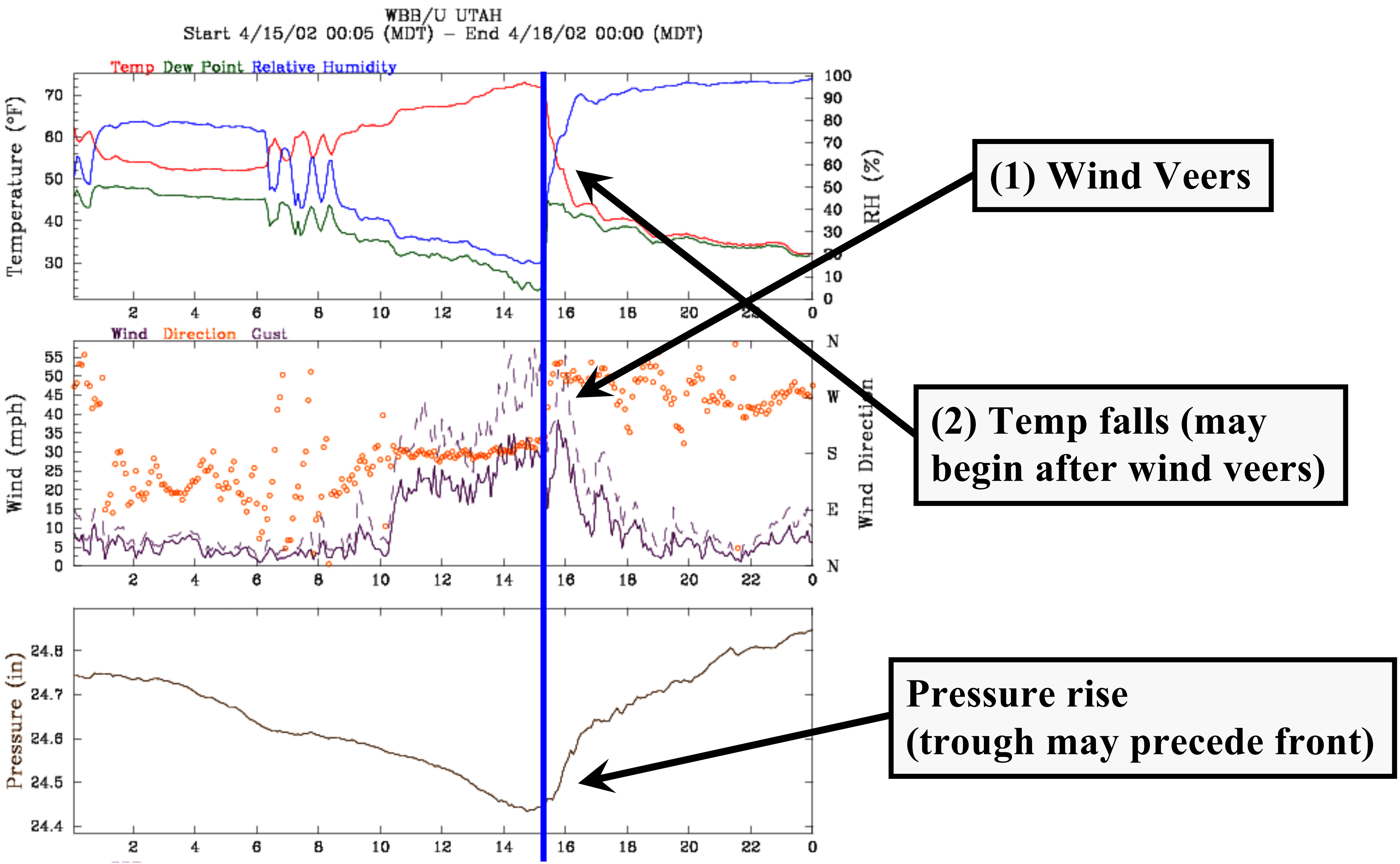
Vertical Structure



- Temperature gradient most intense @ ground and weakens with height
- Frontal zone marked by strong static stability and vertical wind shear
- Front steepest near the ground

Source: Shapiro (1983)

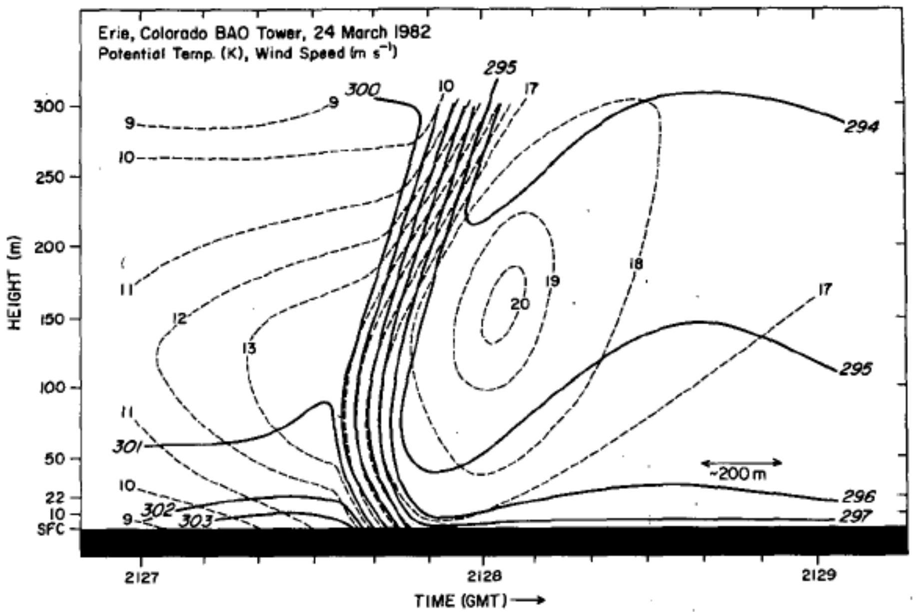
Example Cold-Front Passage

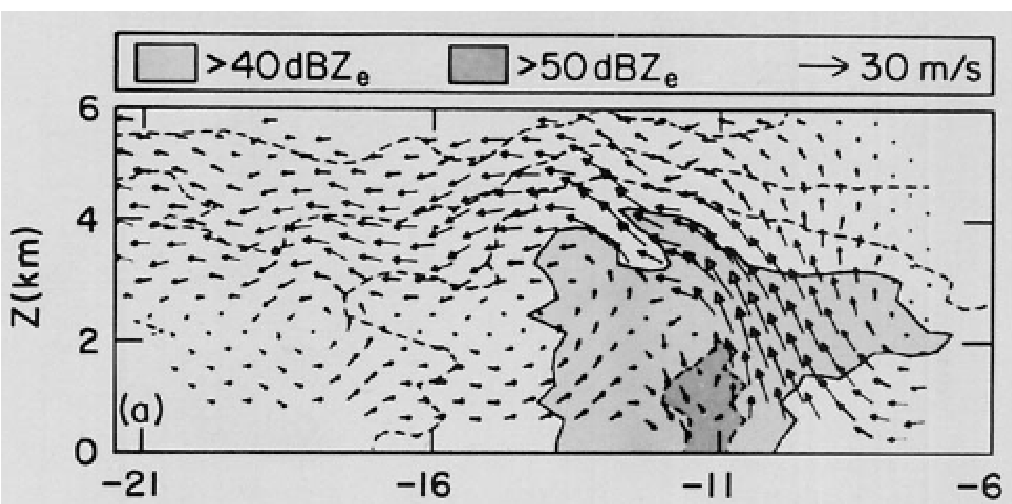


Cold Front Movement

- Speed of cold front not necessarily determined by the difference between pre and post-frontal winds normal to the front
- Speed better correlated with wind speed normal to the front in the cold air
- Numerical models generally quite good at cold-frontal speed today so don’t rely on old rules of thumb!
- Situations where the front propagates (i.e., moves faster than expected from advection) exist – beware!

The Frontal Nose

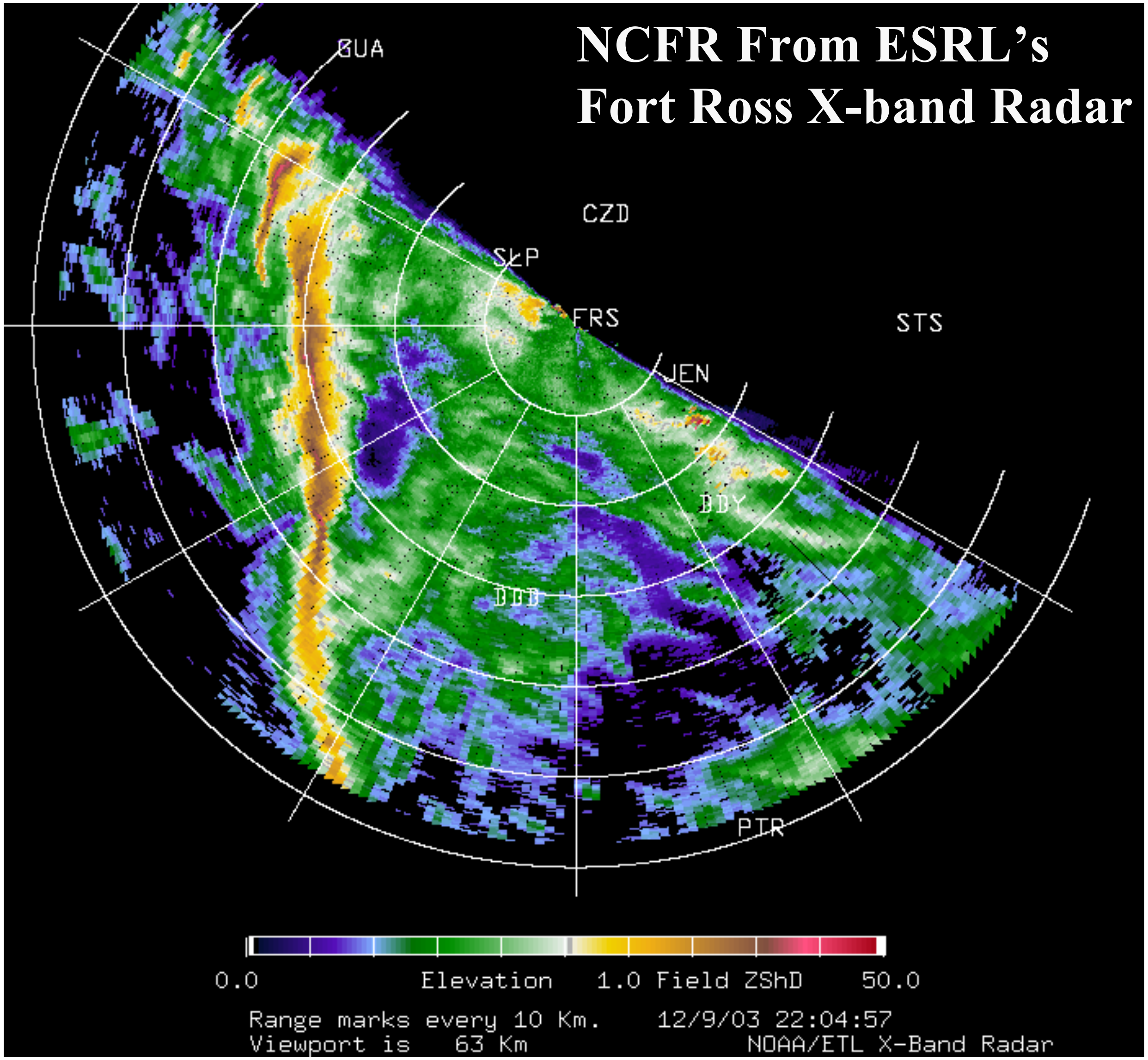




- Front may slope forward at lowest levels
- Narrow plume of intense ascent (> 10 m/s) may be found at leading edge
  - Sometimes produces rope cloud or narrow cold-frontal rainband

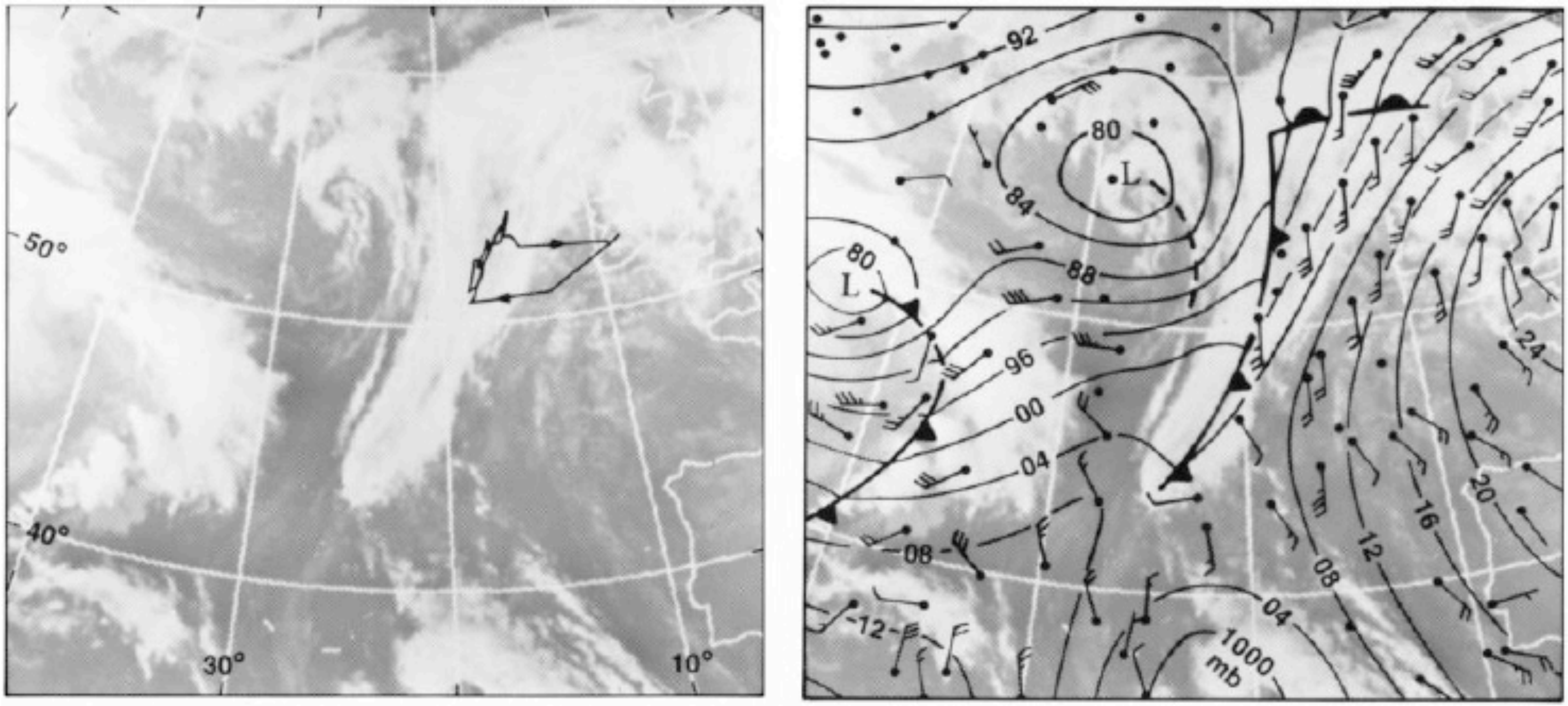
Source: Carbone (1982), Shapiro (1984)

Narrow Cold-Frontal Rainband (NCFR)



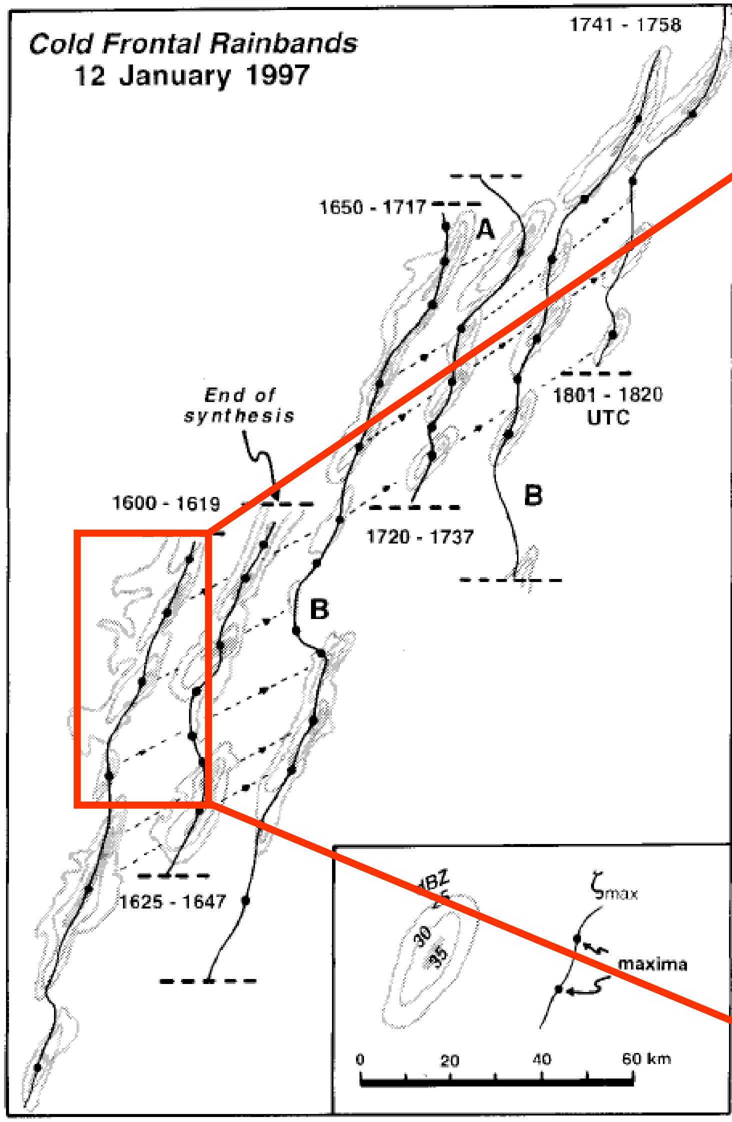
Source: ESRL

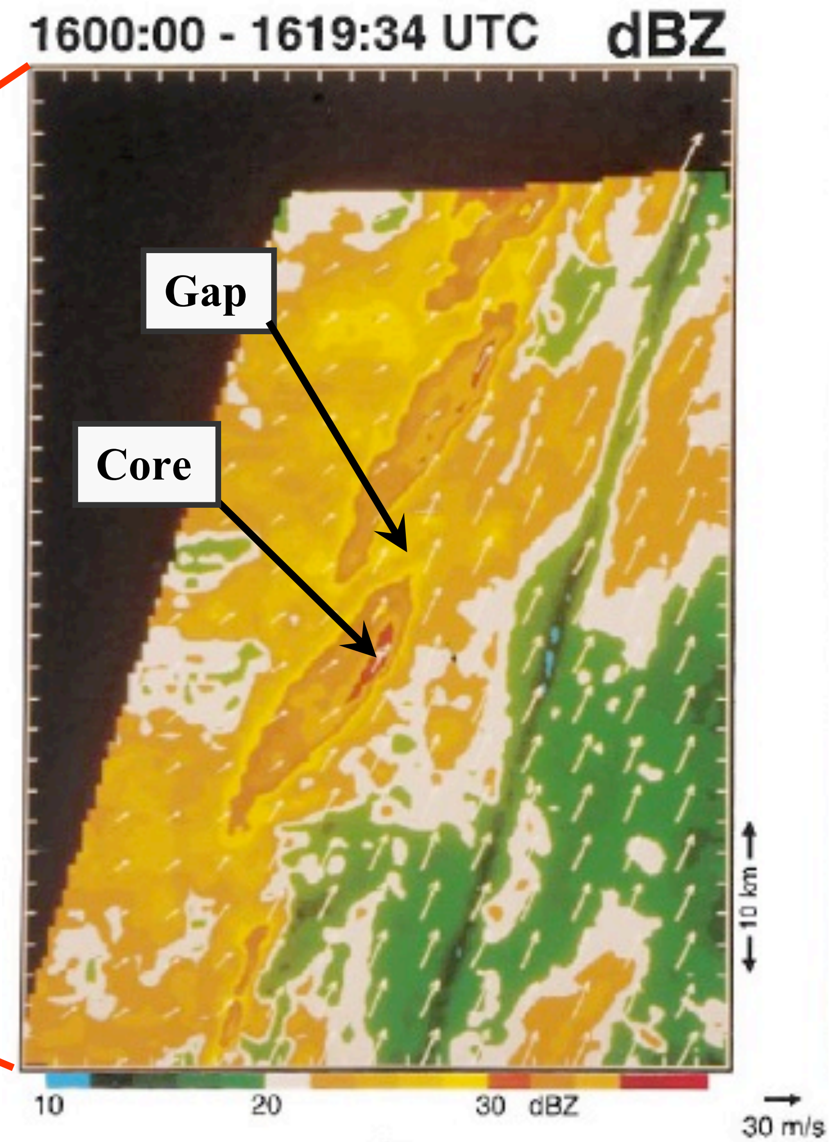
Cold-Front Example



Source: Wakimoto and Bosart (2000)

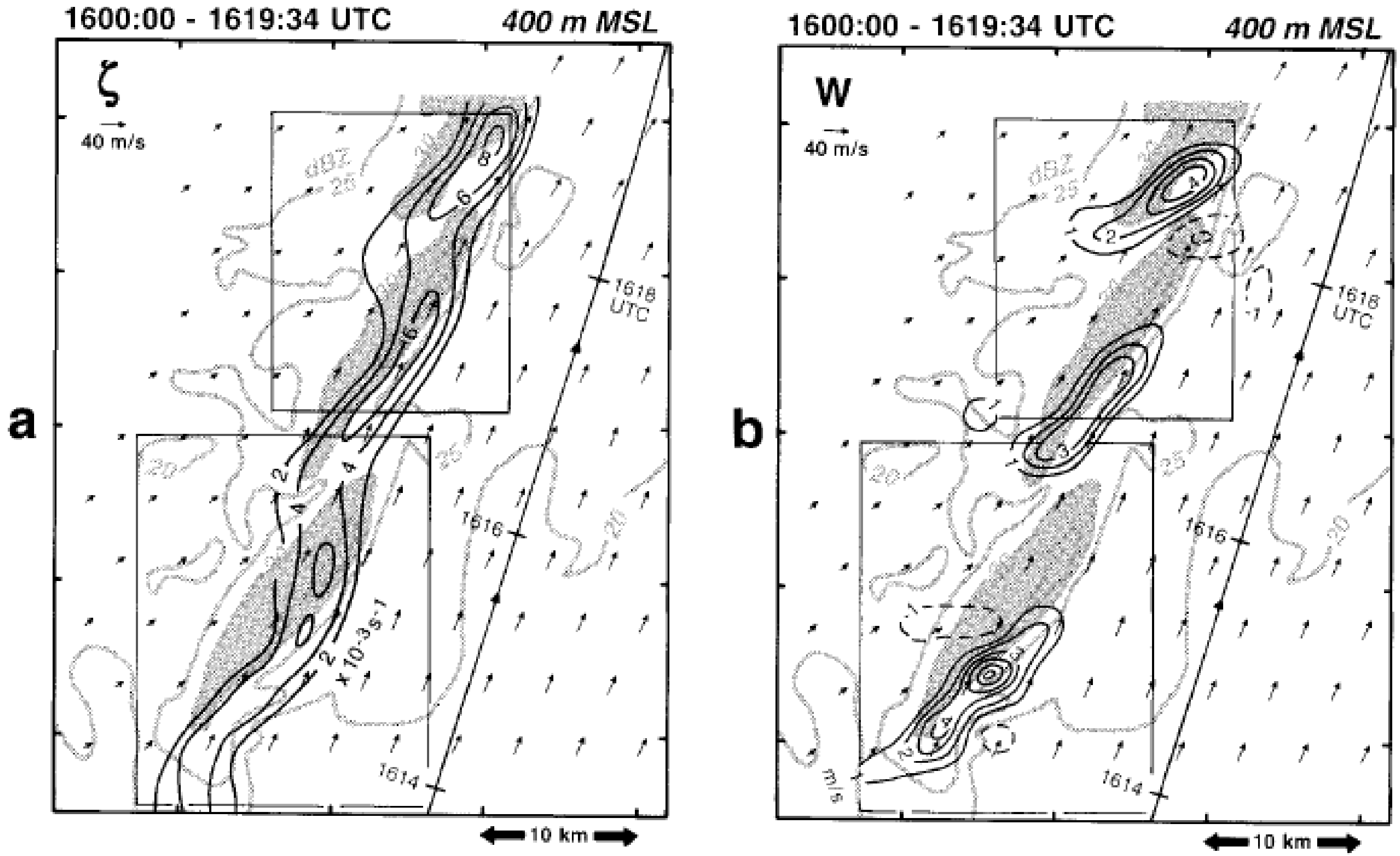
Core and Gap Structure





Source: Wakimoto and Bosart (2000)

Vorticity and Vertical Velocity

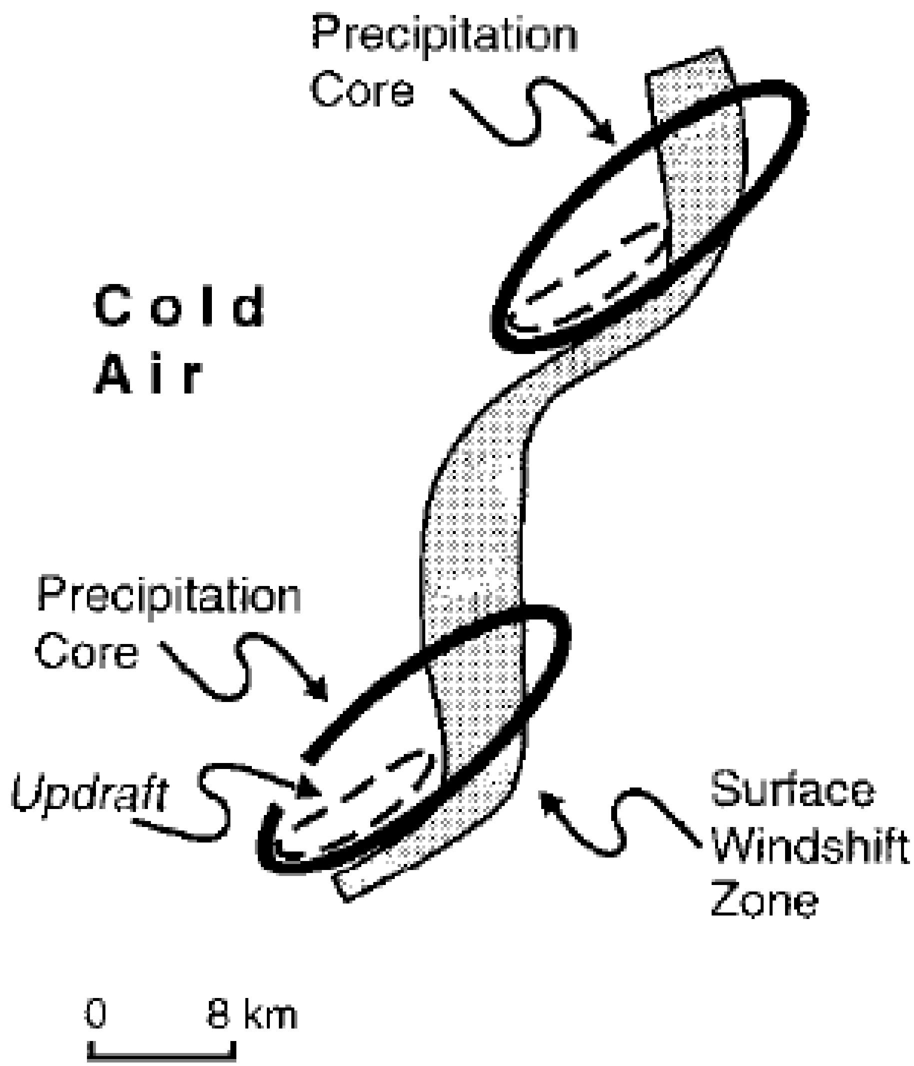


Frontal vorticity strip

Core updrafts approach 5 m/s
Reflectivity maxima downstream of cores

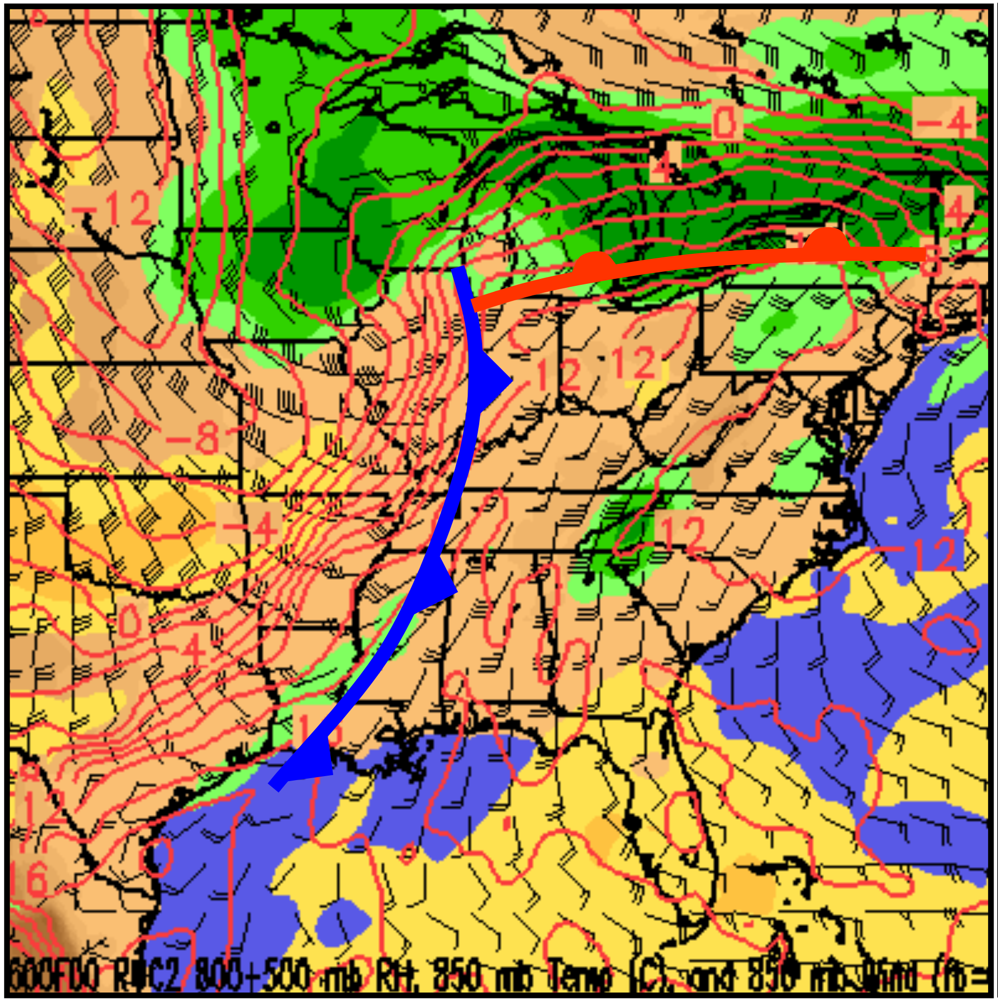
Source: Wakimoto and Bosart (2000)

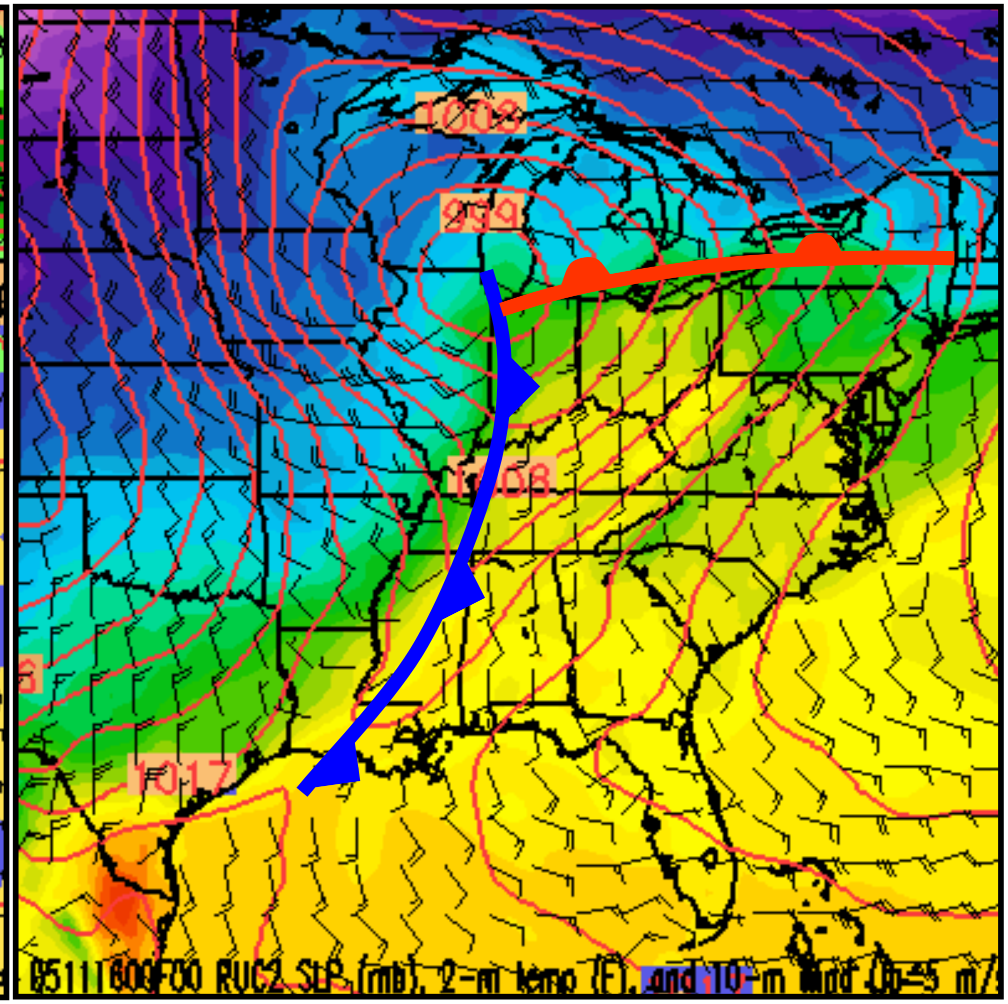
Conceptual Model



Source: Wakimoto and Bosart (2000)

Characteristics of Warm Fronts

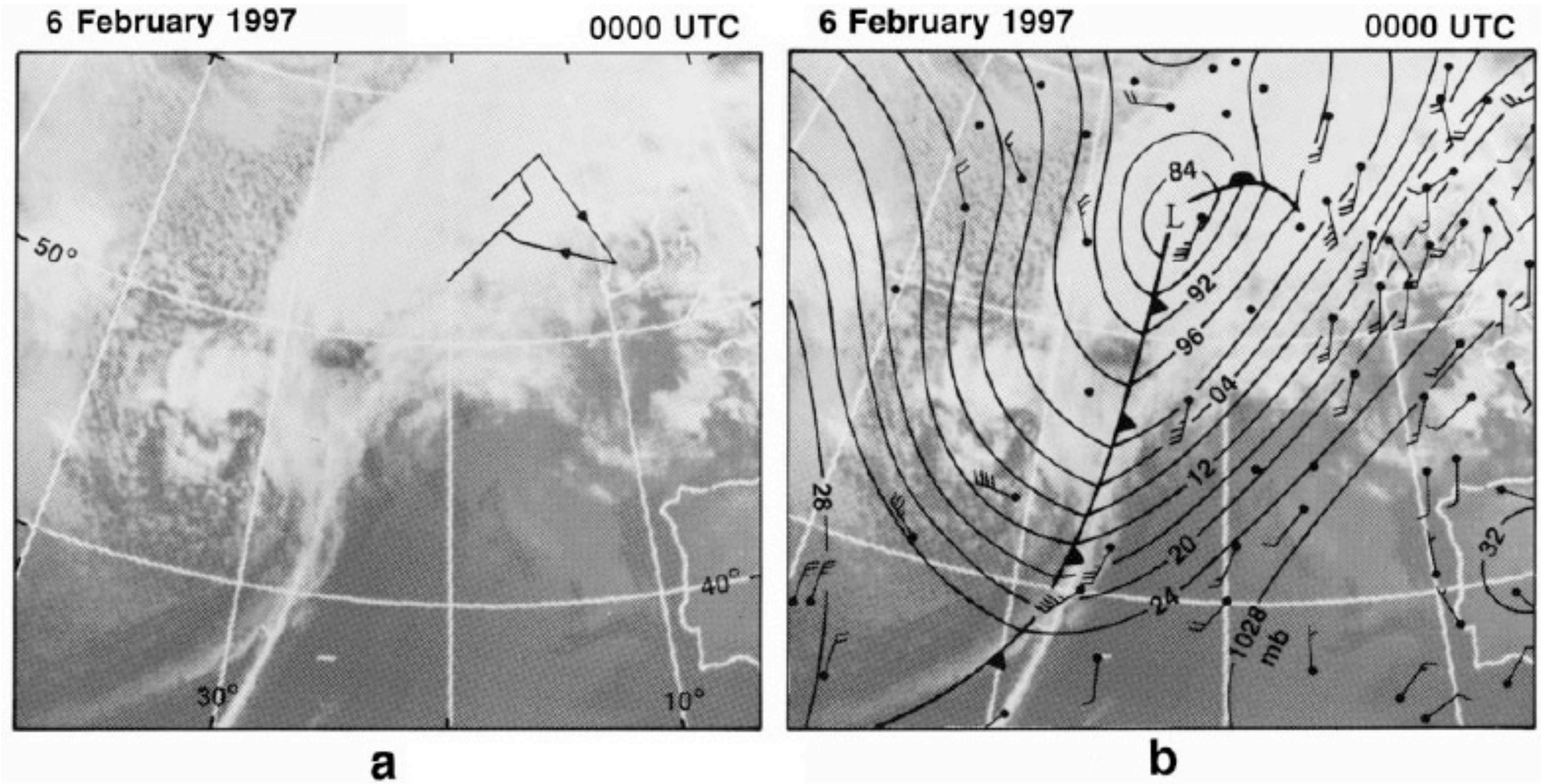




- Frontal zone is on cold side of warm front
- Wind veers across front as one moves toward the warm air

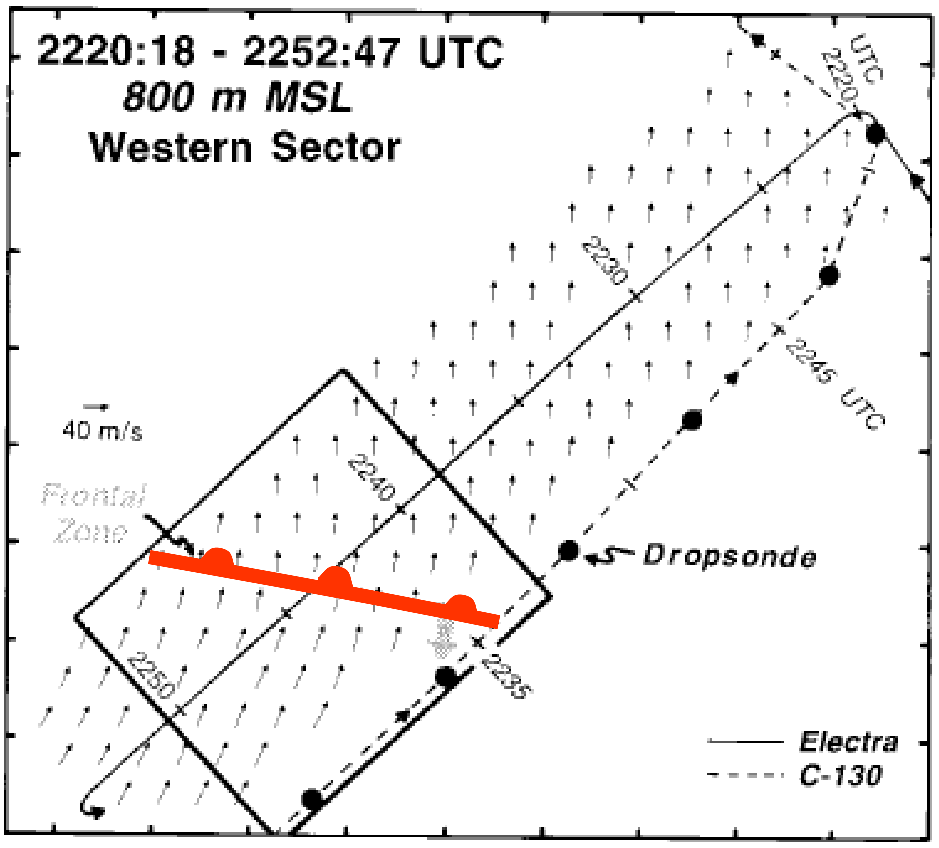
- Strip of high vorticity at wind shift (not shown)
- Identified with semicircles pointing toward cold air

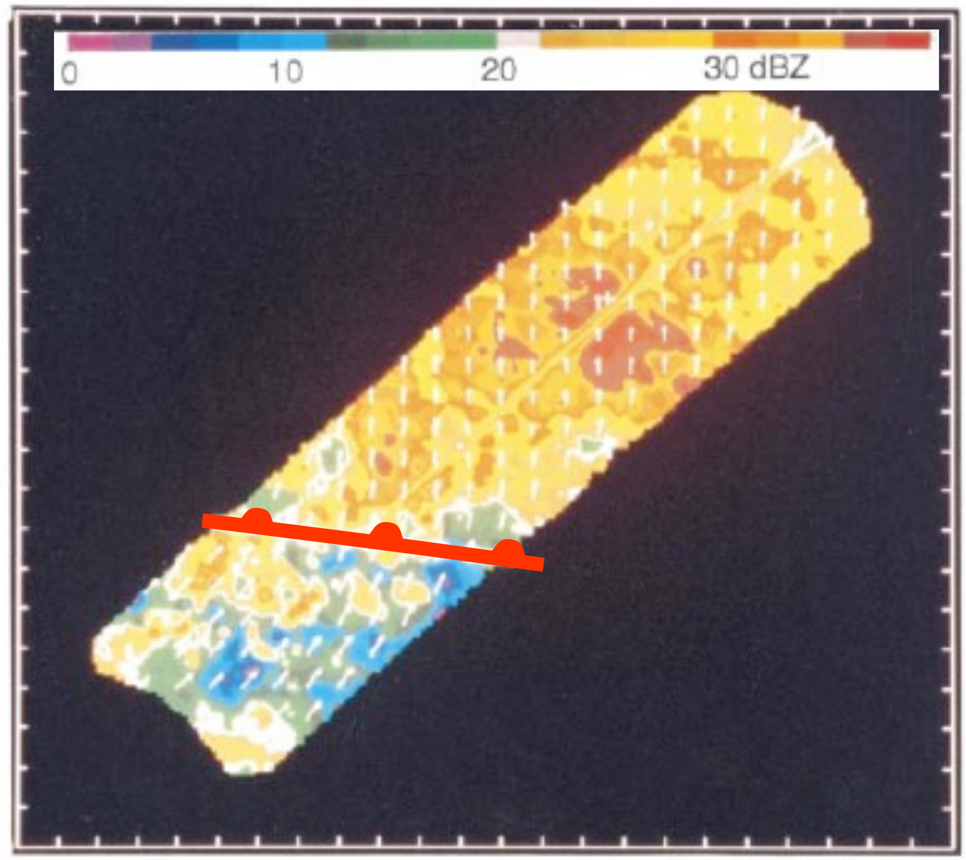
Warm Front Example



Source: Wakimoto and Bosart (2001)

Mesoscale Structure

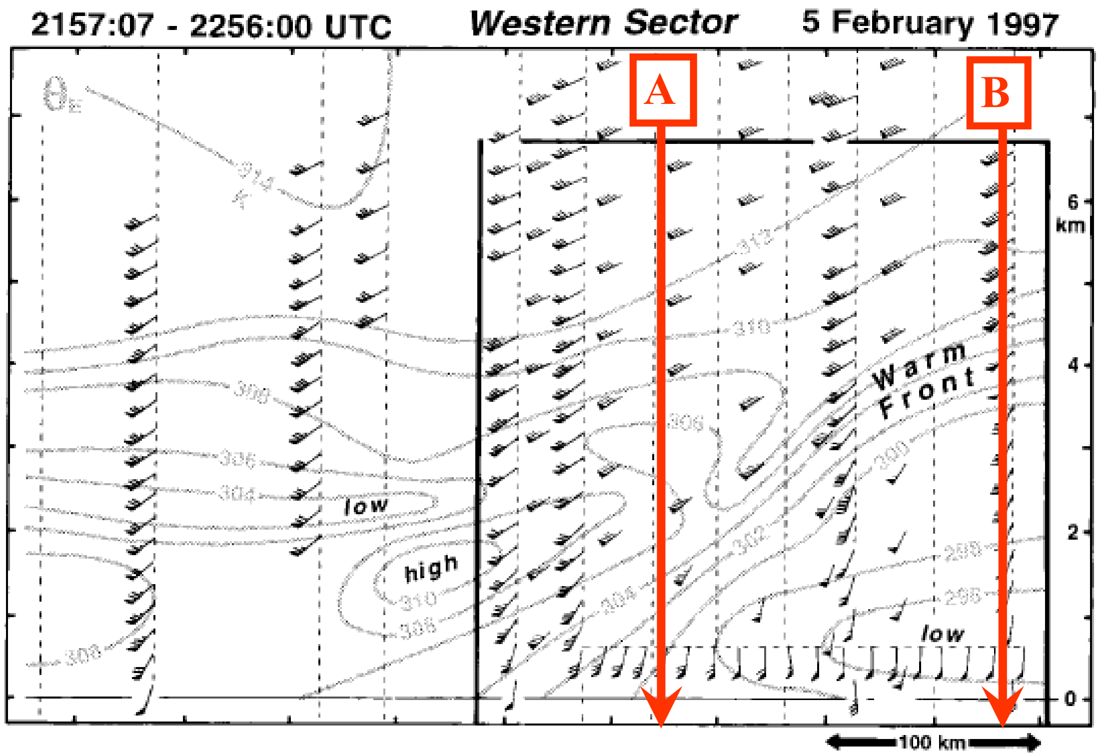


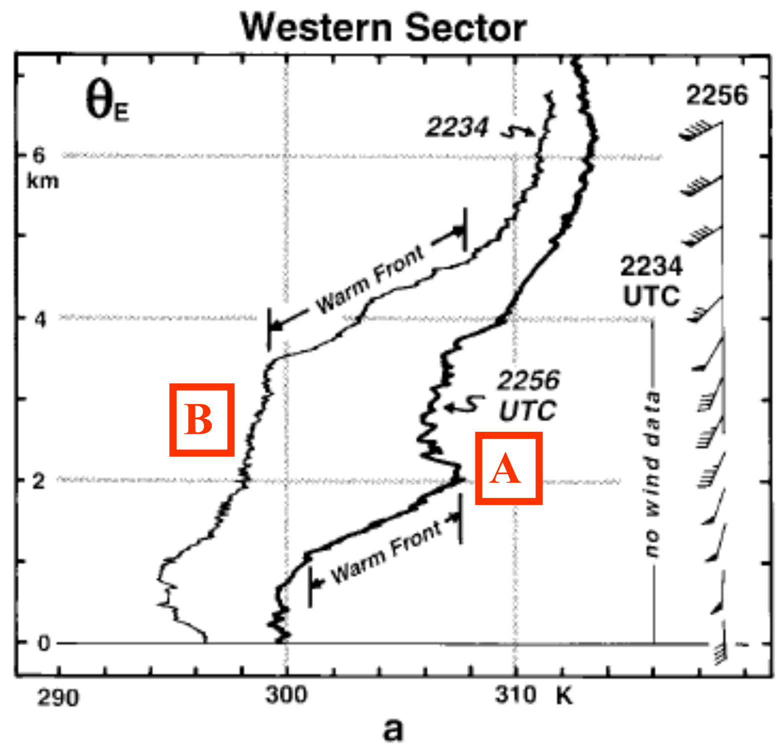


- Weak wind shift across front at low levels (800 m AGL)
- Precipitation (infered from dBZ) strongest ahead (poleward) of warm front

Source: Wakimoto and Bosart (2001)

Vertical Structure

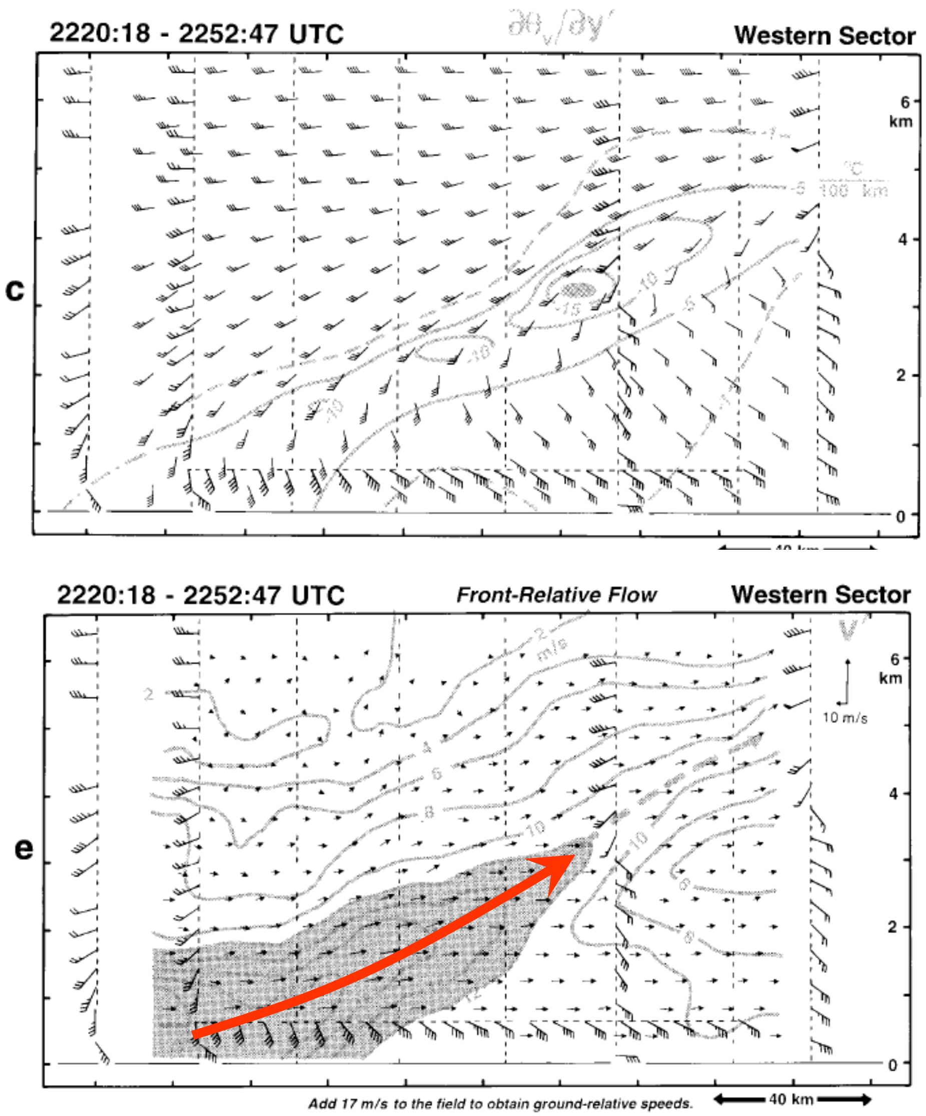




- Sloping region of enhanced horizontal and vertical θ_e gradient
- Veering winds with height
- No distinct frontal discontinuity at surface (front best defined aloft)

Source: Wakimoto and Bosart (2001)

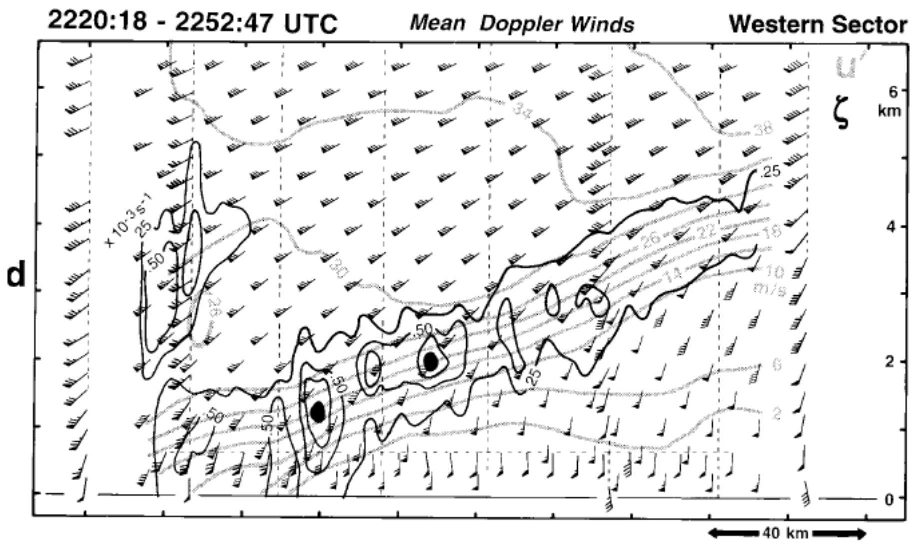
Vertical Structure



- Front-relative winds show strong veering with height
- Cross-front θ_v gradient delineates frontal zone
  - Weak near surface
- Strong sloping region of front-relative cross-frontal flow
  - Warm sector air ascending underlying cold air

Source: Wakimoto and Bosart (2001)

Vertical Structure



- Strip of high vertical vorticity with localized maxima in frontal zone
- Highest vorticity also found aloft, not at the surface

Source: Wakimoto and Bosart (2001)

Basic Frontal Dynamics

- Frontogenesis: Process of increasing the magnitude of the horizontal temperature gradient (i.e., creating a front)

- Frontolysis: Process of decreasing the magnitude of the horizontal temperature gradient (i.e., destroying a front)

Frontogenesis Mathematically

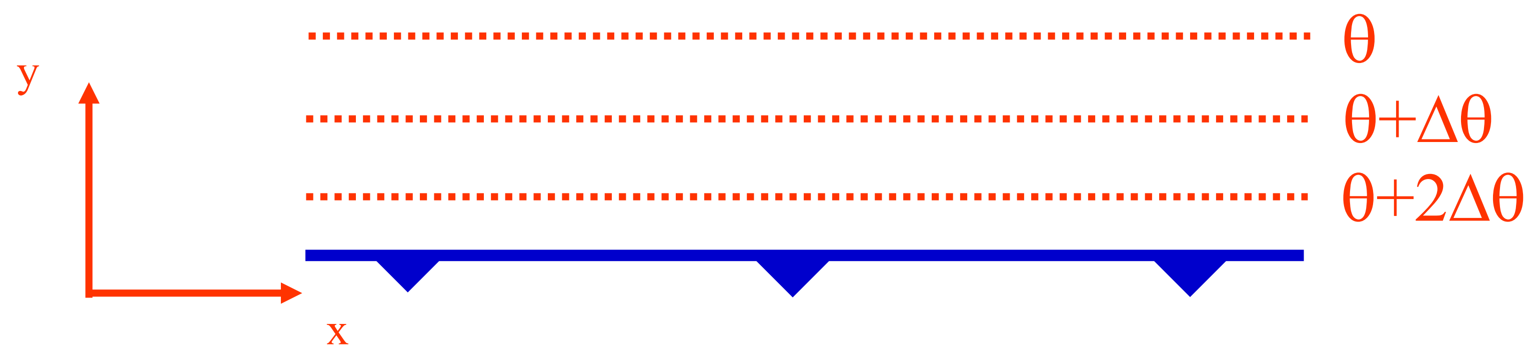
$$Fr = \frac{D}{DT}|\nabla_2 \theta|$$

$$Fr > 0 \;\rightarrow \text{Frontogenesis}$$

$$Fr < 0 \;\rightarrow \text{Frontolysis}$$

Basic Frontal Dynamics

- Consider a zonally oriented front with a meridional temperature gradient



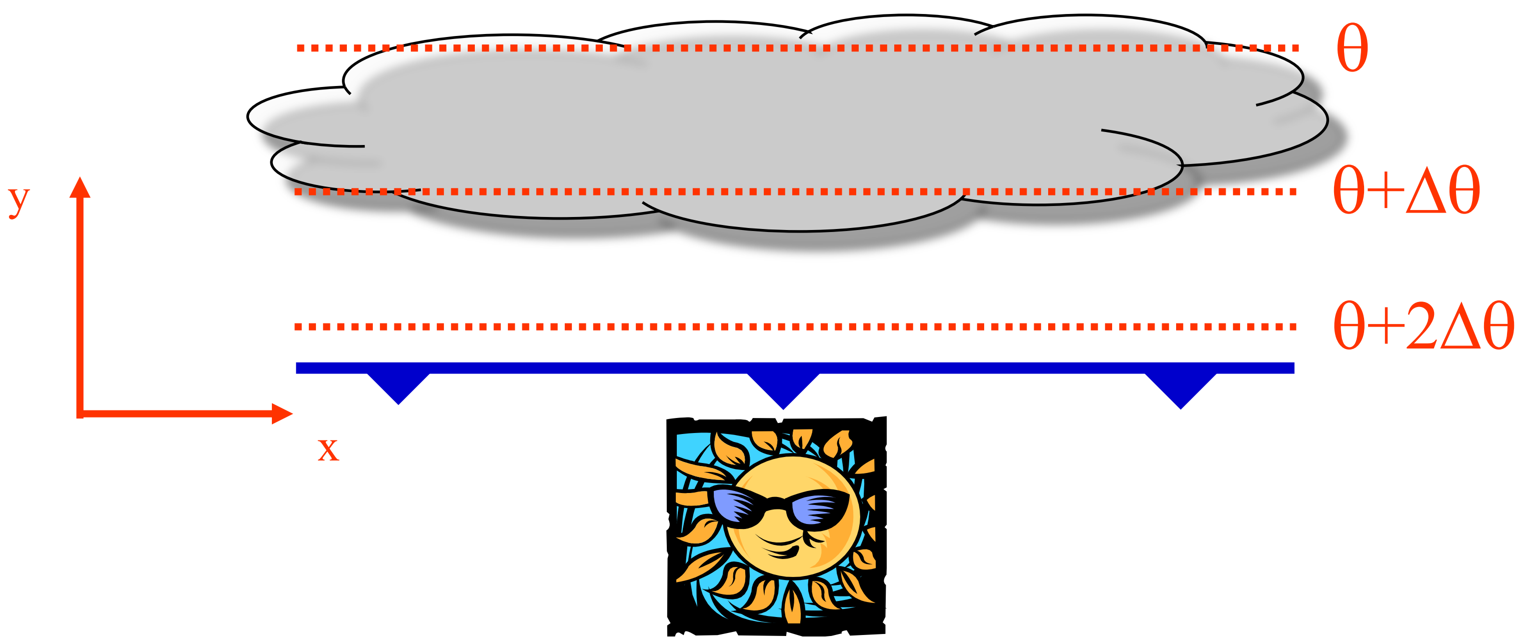
- In this case, frontogenesis is

$$Fr = \frac{D}{DT}|\nabla_2\theta| = \frac{\partial\theta/\partial y}{|\partial\theta/\partial y|}\left[\underbrace{\frac{\partial}{\partial y}\left(\frac{D\theta}{Dt}\right)}_{\boxed{\text{Differential diabatic heating/cooling}}} - \underbrace{\frac{\partial\theta}{\partial y}\frac{\partial v}{\partial y}}_{\boxed{\text{Confluence}}} - \underbrace{\frac{\partial\theta}{\partial z}\frac{\partial w}{\partial y}}_{\boxed{\text{Tilting}}}\right]$$

Basic Frontal Dynamics

- Differential heating & cooling: Horizontal gradients in heating/cooling strengthen or weaken the temperature gradient

$$Fr = \frac{D}{DT}|\nabla_2\theta| \propto -\left[\frac{\partial}{\partial y}\left(\frac{D\theta}{Dt}\right)\right]$$



Basic Frontal Dynamics

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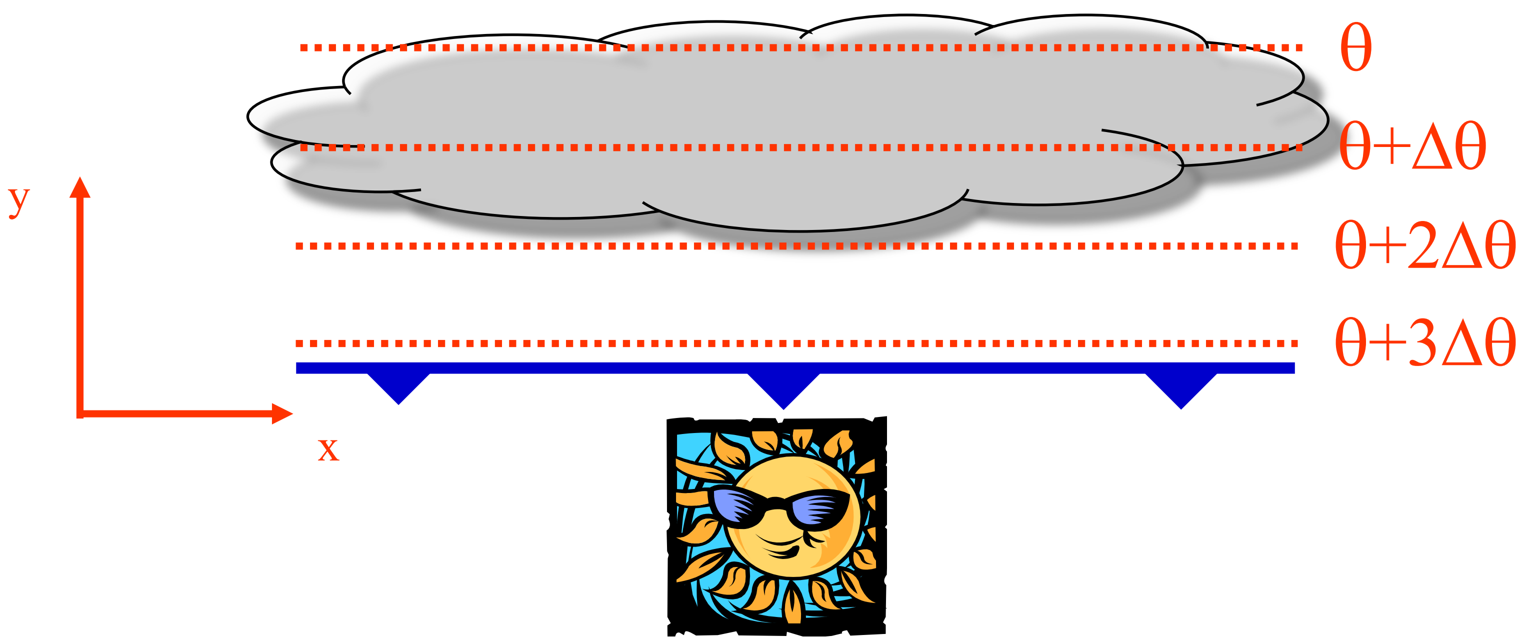
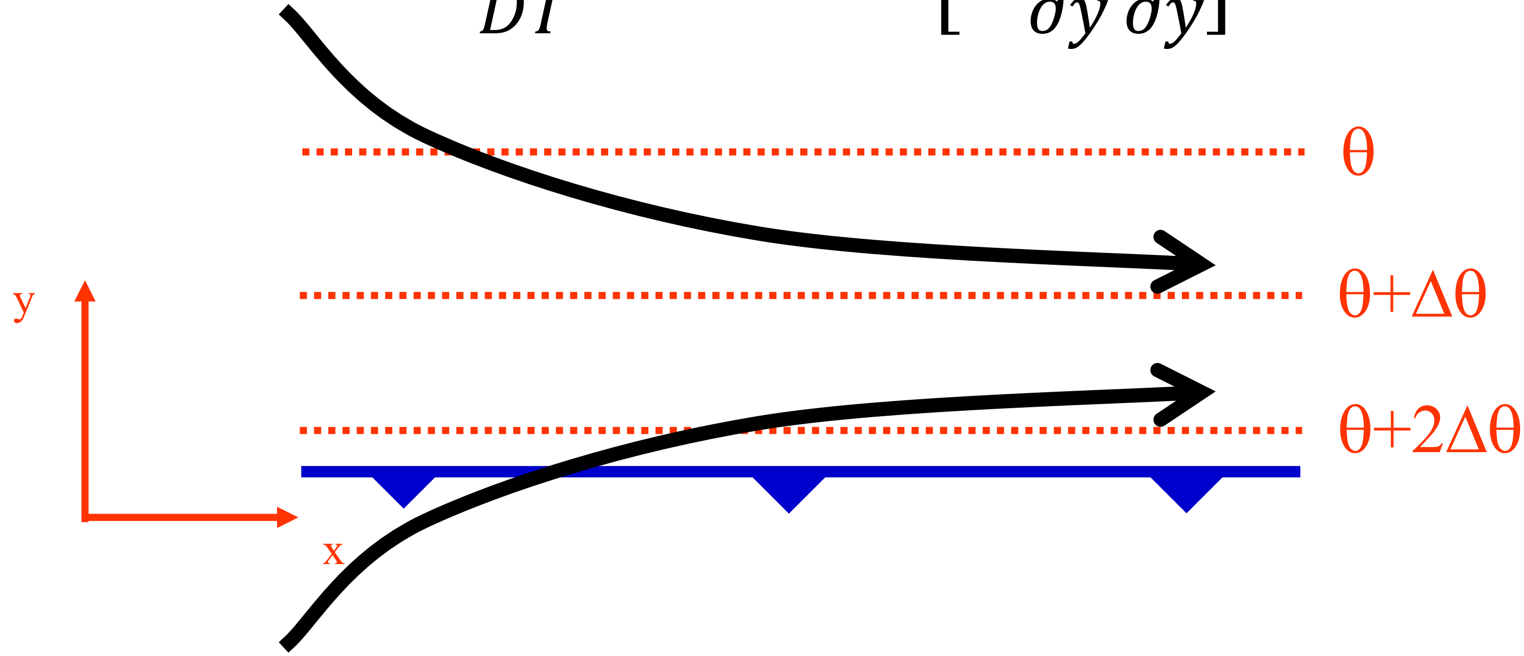
Frontogenesis!



Basic Frontal Dynamics

- Confluence: Horizontal deformation acts to increase or decrease the horizontal temperature gradient

$$Fr = \frac{D}{DT}|\nabla_2\theta| = -\left[-\frac{\partial\theta}{\partial y}\frac{\partial v}{\partial y}\right]$$



Basic Frontal Dynamics

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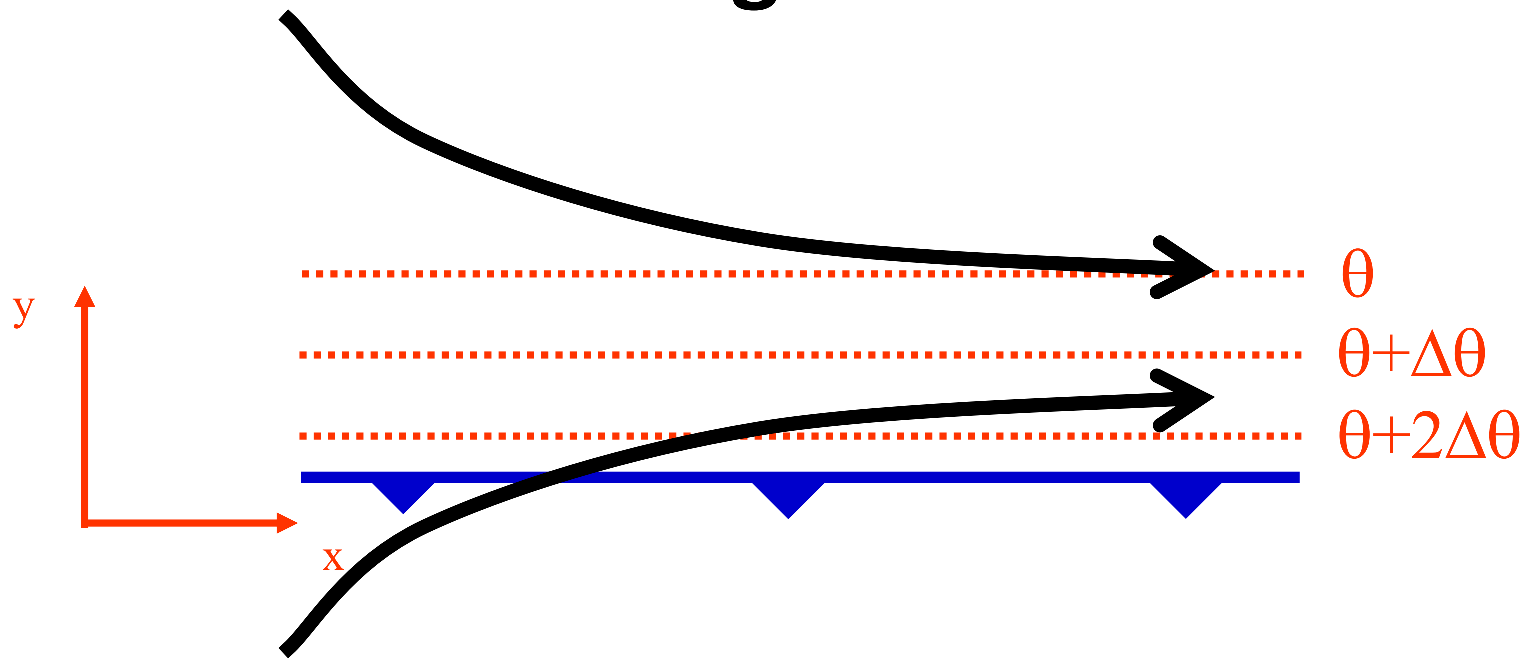
Frontogenesis!



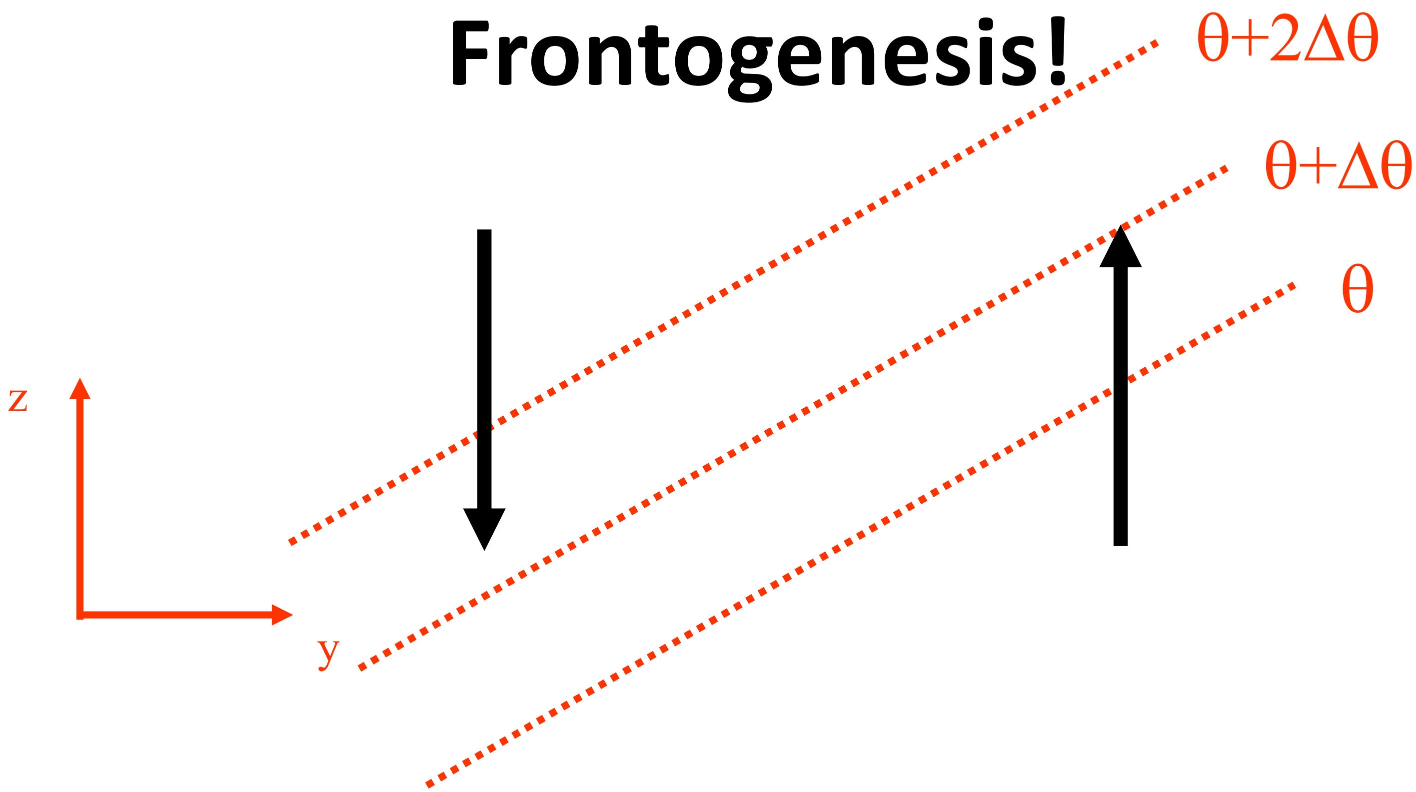
Basic Frontal Dynamics

- Tilting: Differential vertical motion strengthens or weakens the horizontal temperature gradient

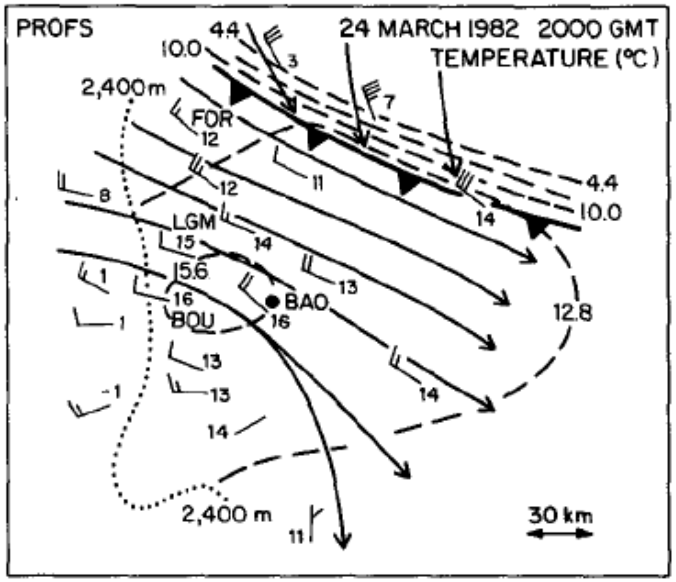
$$Fr = \frac{D}{DT}|\nabla_2\theta| = -\left[-\frac{\partial\theta}{\partial z}\frac{\partial w}{\partial y}\right]$$

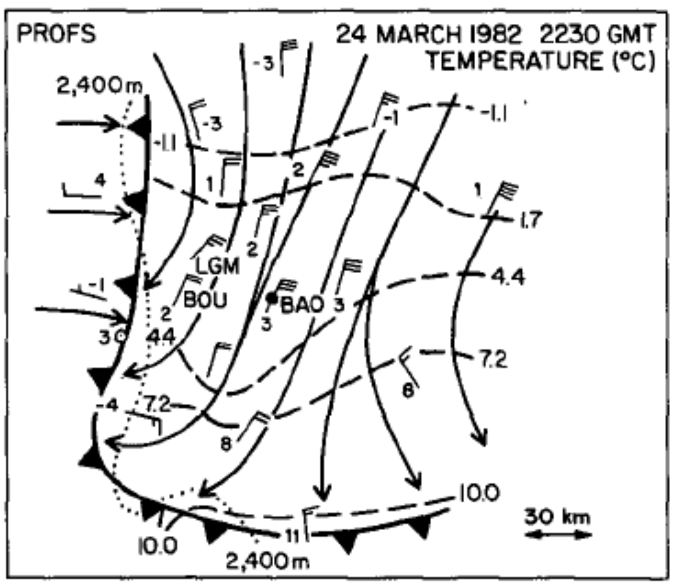
Basic Frontal Dynamics

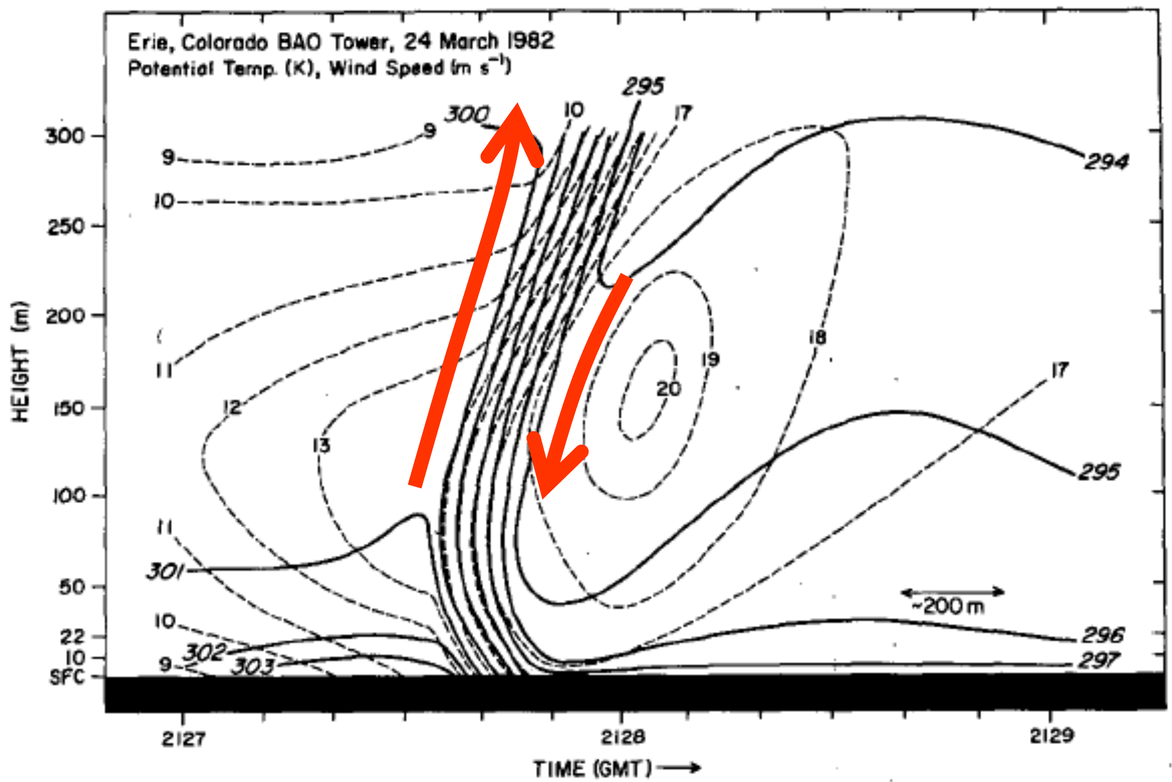
- Tilting: Differential vertical motion strengthens or weakens the horizontal temperature gradient



Real World Example





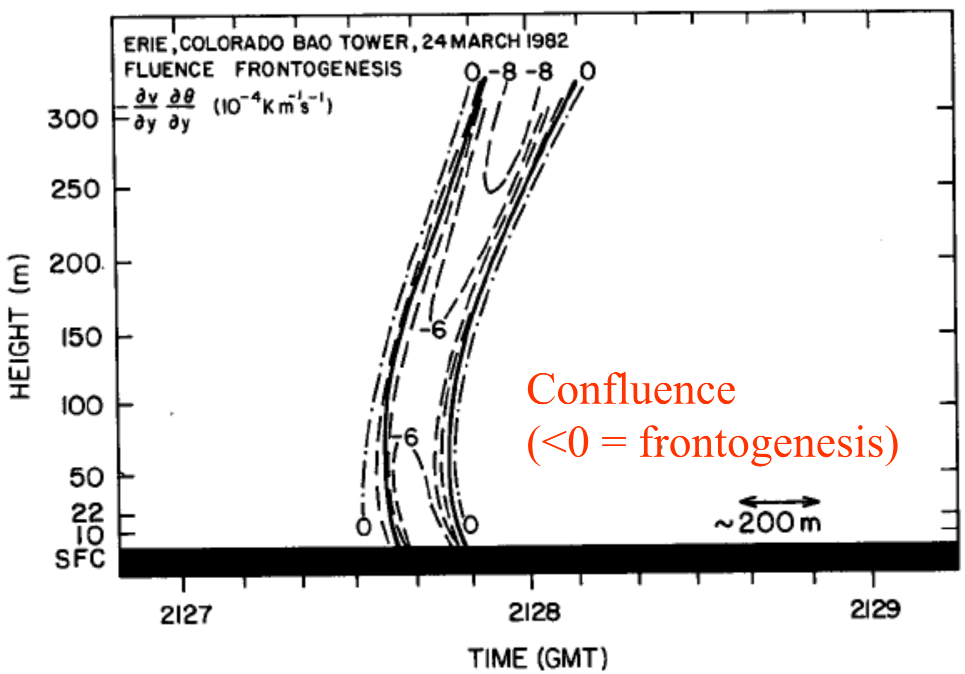


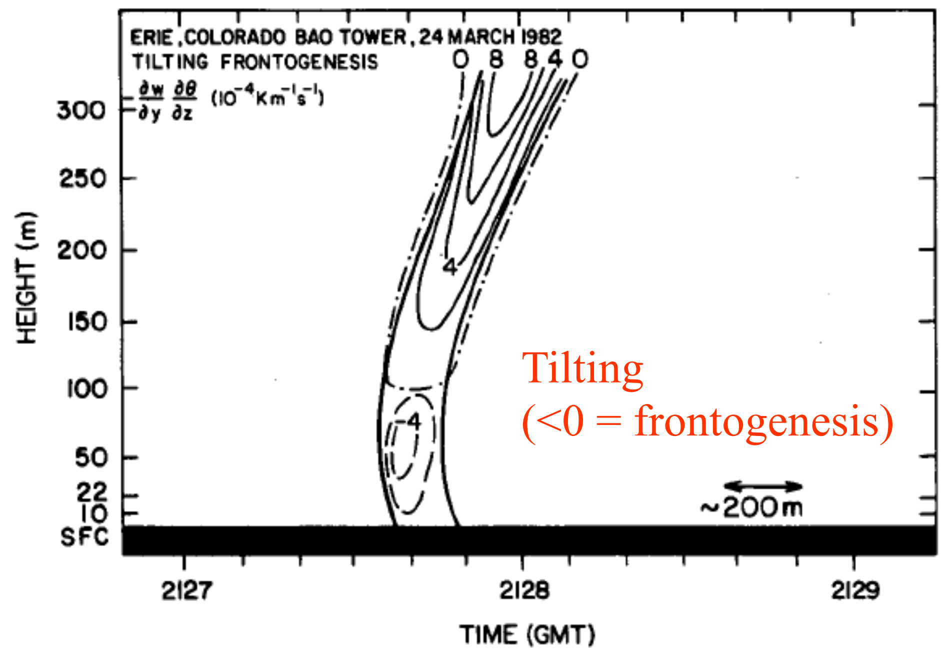
Time-height section showing frontal nose, potential temperature hypergradient, and vertical motion

Surface cold front passage near Boulder (BOU)

Source: Shapiro (1984)

Real World Example

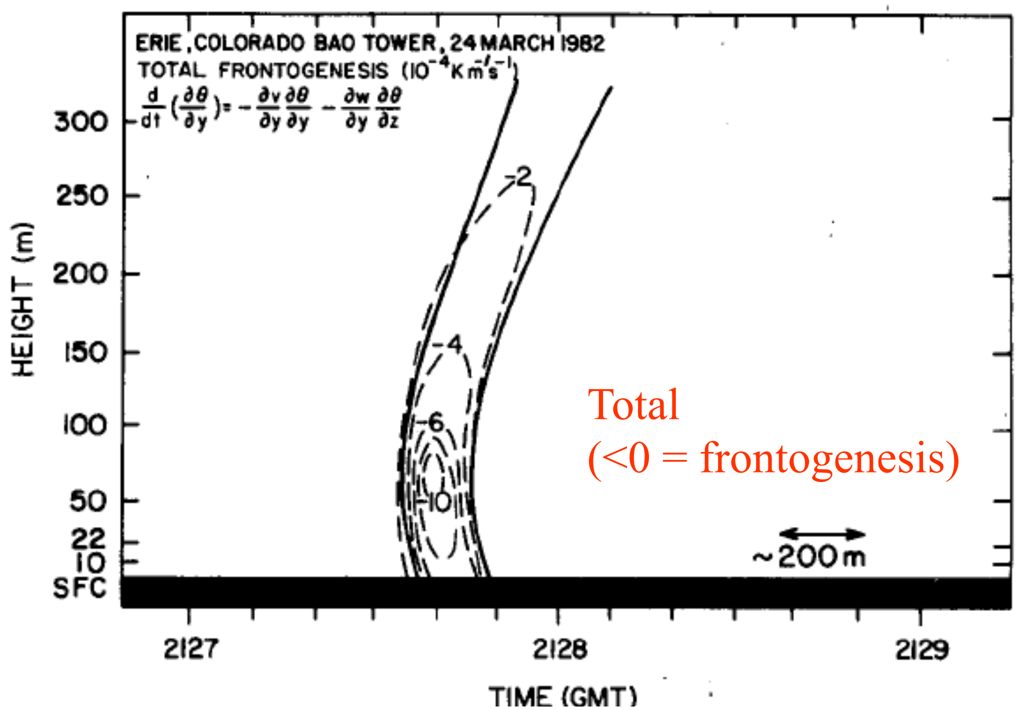




- Horizontal confluence acts to strengthen front
- Tilting weakens fron (above 100 m)

Source: Shapiro (1984)

Real World Example



- In total, confluence term wins and front is characterized by frontogenesis
- Gradient doesn't further strengthen, however, due to turbulent mixing

Source: Shapiro (1984)

Discussion

How Does Orography Affect Fronts?

Orographic Impacts on Frontal Movement

- The mountain-induced flow advects and distorts a front (Egger and Hoinka 1992)
- Examples
  - Pre-frontal downslope (Foehn) and low-level blocking of the post-frontal wind can retard the progression of a front on the windward side of a mountain range
  - A mountain-induced anticyclone can act to rotate a front anticyclonically upwind of a mountain range
  - Terrain-channeled flow along a valley, plain, or gap can produce acceleration of a front
  - Ageostrophic flow along a mountain barrier can result in equatorward surges of cold air known as cold-air surges, coastally trapped disturbances, or cold-air damming

Examples of Frontal Deformation/Distortion

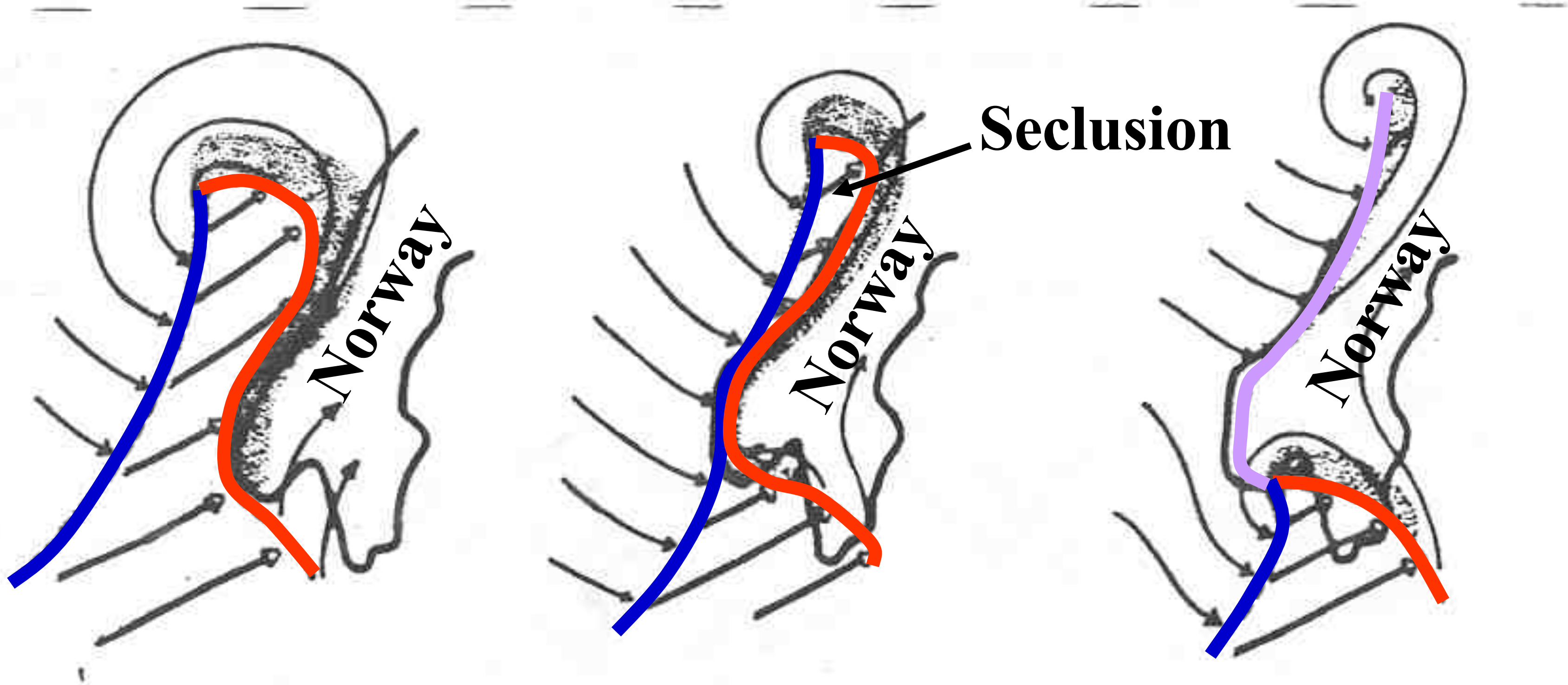
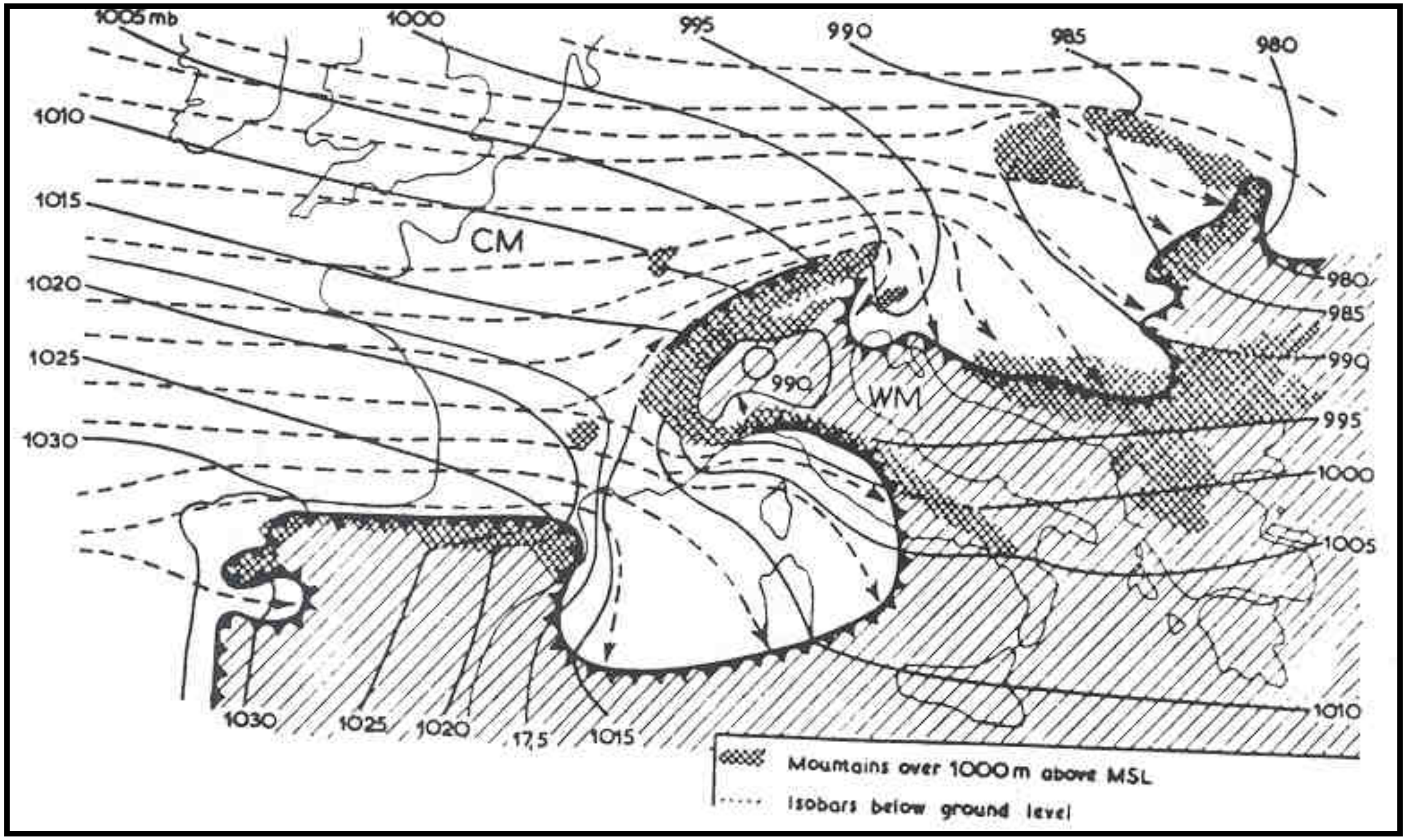


Fig. 7. Formation of a »Skagerak cyclone.«

Norwegian Cyclone Model: Skagerak Mountains retard a warm front, resulting in the formation of a warm-core seclusion and secondary cyclogenesis

Source: Bjerknes and Solberg (1922)

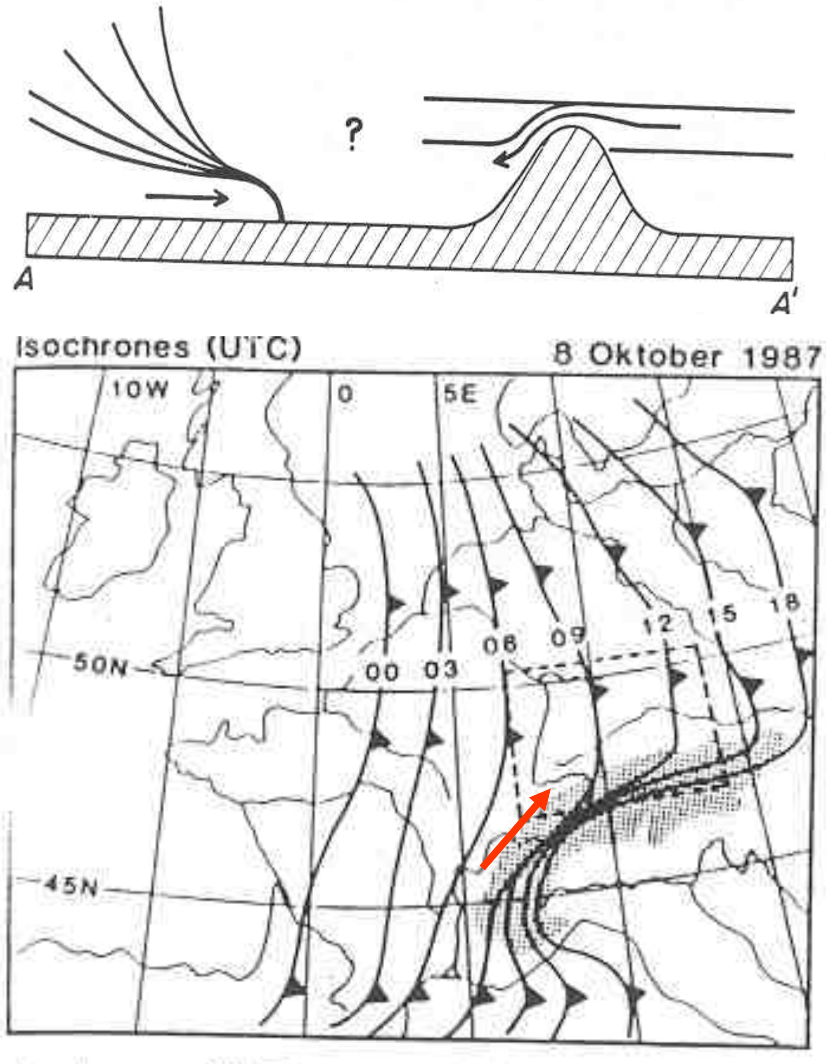
Examples of Frontal Deformation/Distortion



Orographic distortion of a cold front by European topography including frontal retardation by Alps and acceleration in Rhone Gap between Alps/Pyrenees (Mistral) and east of Alps

Source: Bergeron (1928), also available in Godske et al. (1957)

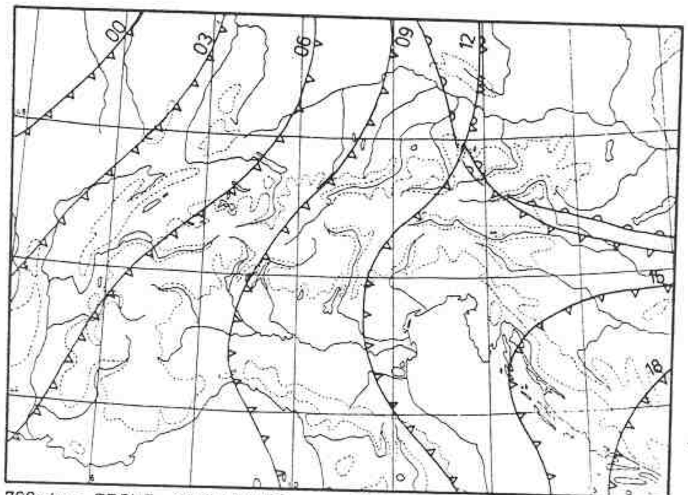
Impact of Pre-Frontal Foehn & Blocking



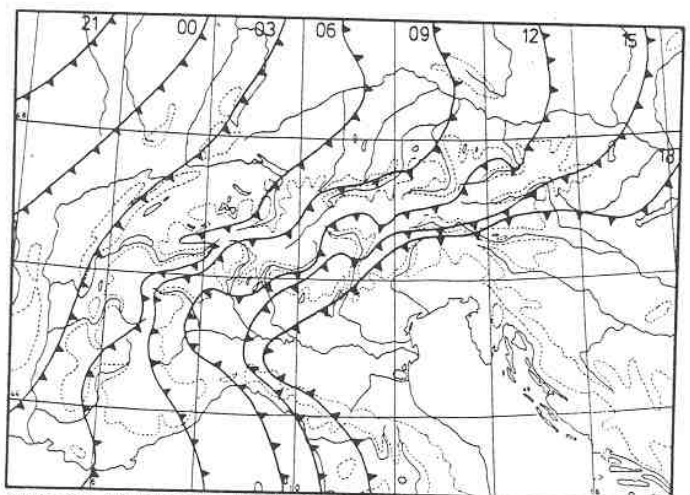
- Windward retardation of cold front due to
  - Competition with pre-frontal Foehn
  - Blocking of post-frontal wind, which becomes along barrier and along front
- Most dramatic with low Froude numbers (i.e., $U/NH < 1$)

Source: Smith (1986), Hoinka and Volkert (1991)

Impact of Pre-Frontal Foehn & Blocking



700mbar FRONT ISOCHRONES 1982 MARCH 2 0000-1800 GMT



SURFACE COLDFRONT ISOCHRONES 1982 MARCH 1 2100-2 1800 GMT

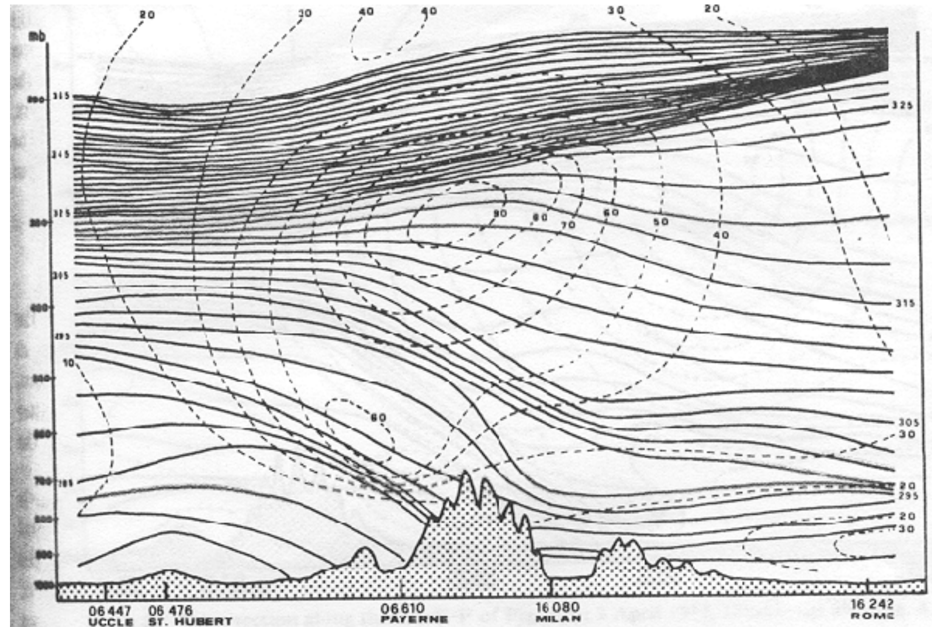
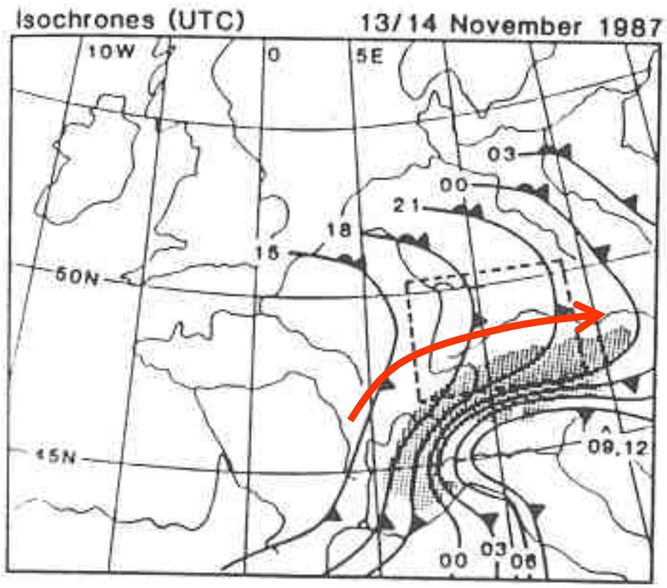


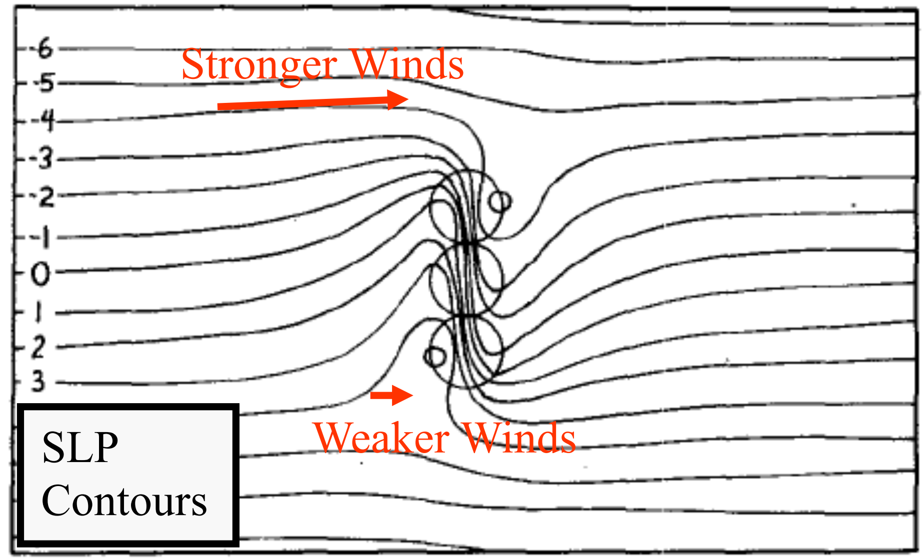
Figure 5. Cross-section along the line C–D of Fig. 1(b); 3 April 1973, 00 GMT; see also Fig. 4.

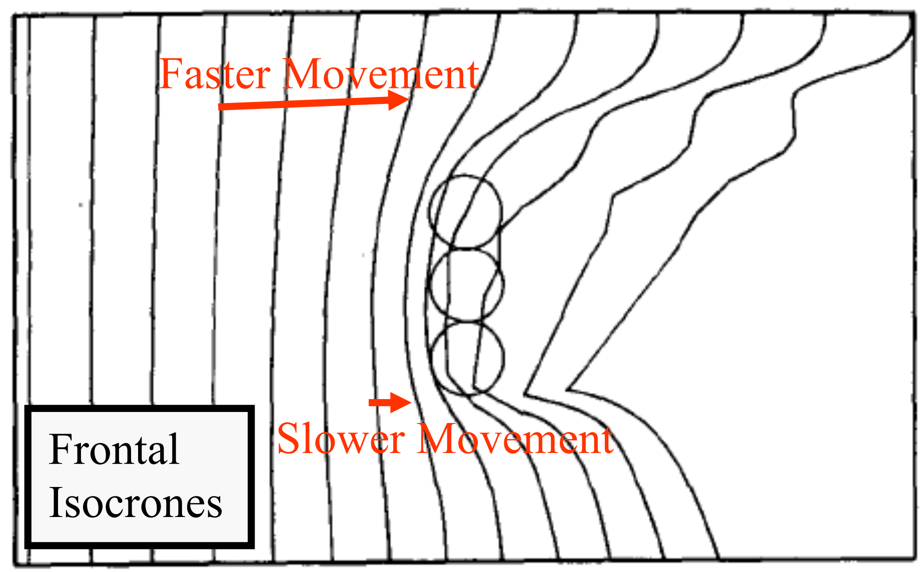
- Decoupling of near surface and upper-level portions of front

Source: Buzzi and Speranza (1978), Steinacker (1982)

Frontal Rotation



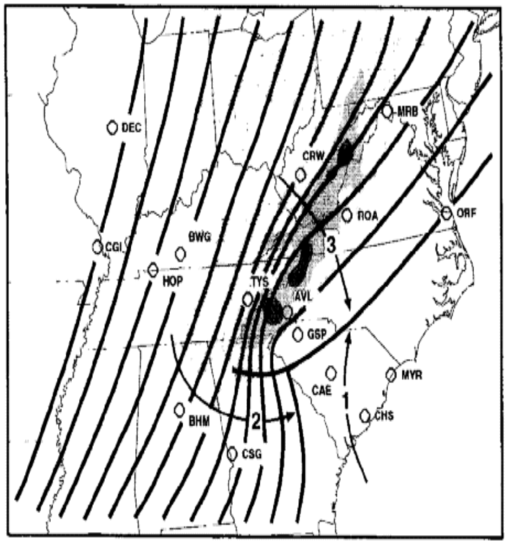




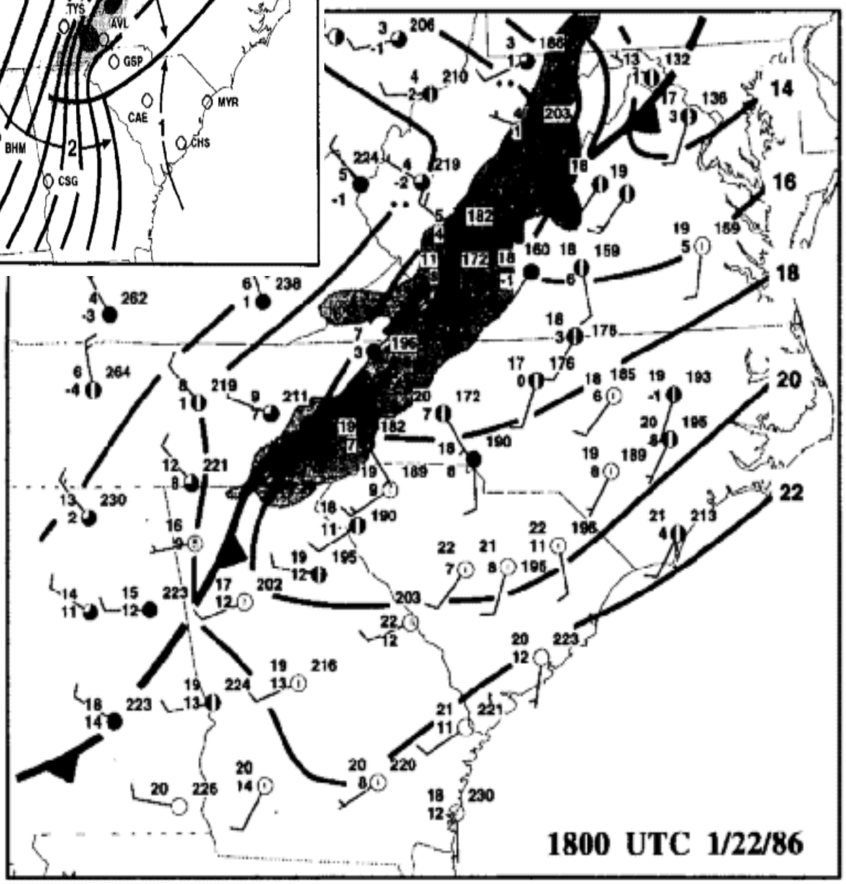
- Fronts rotate anticyclonically as they approach mountain barrier
  - Poleward portion
- Result of superposition of mountain anticyclone with large-scale flow
- Opposite affect equatorward portion

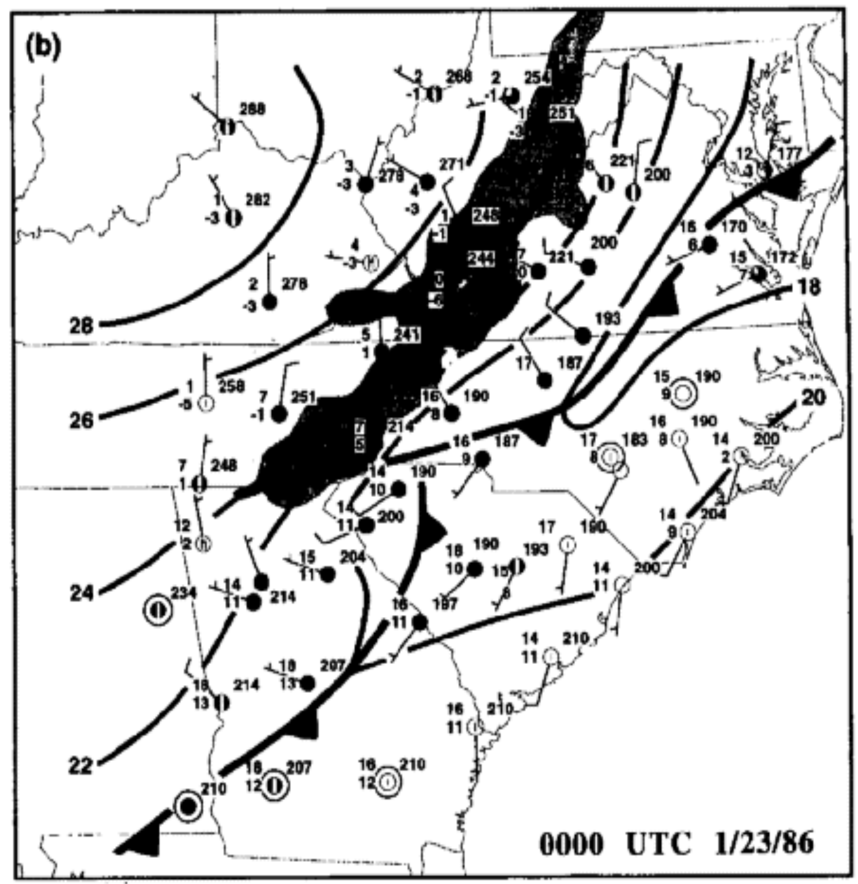
Source: Smith (1982), Hoinka and Volkert (1992)

Appalachian Frontal Evolution



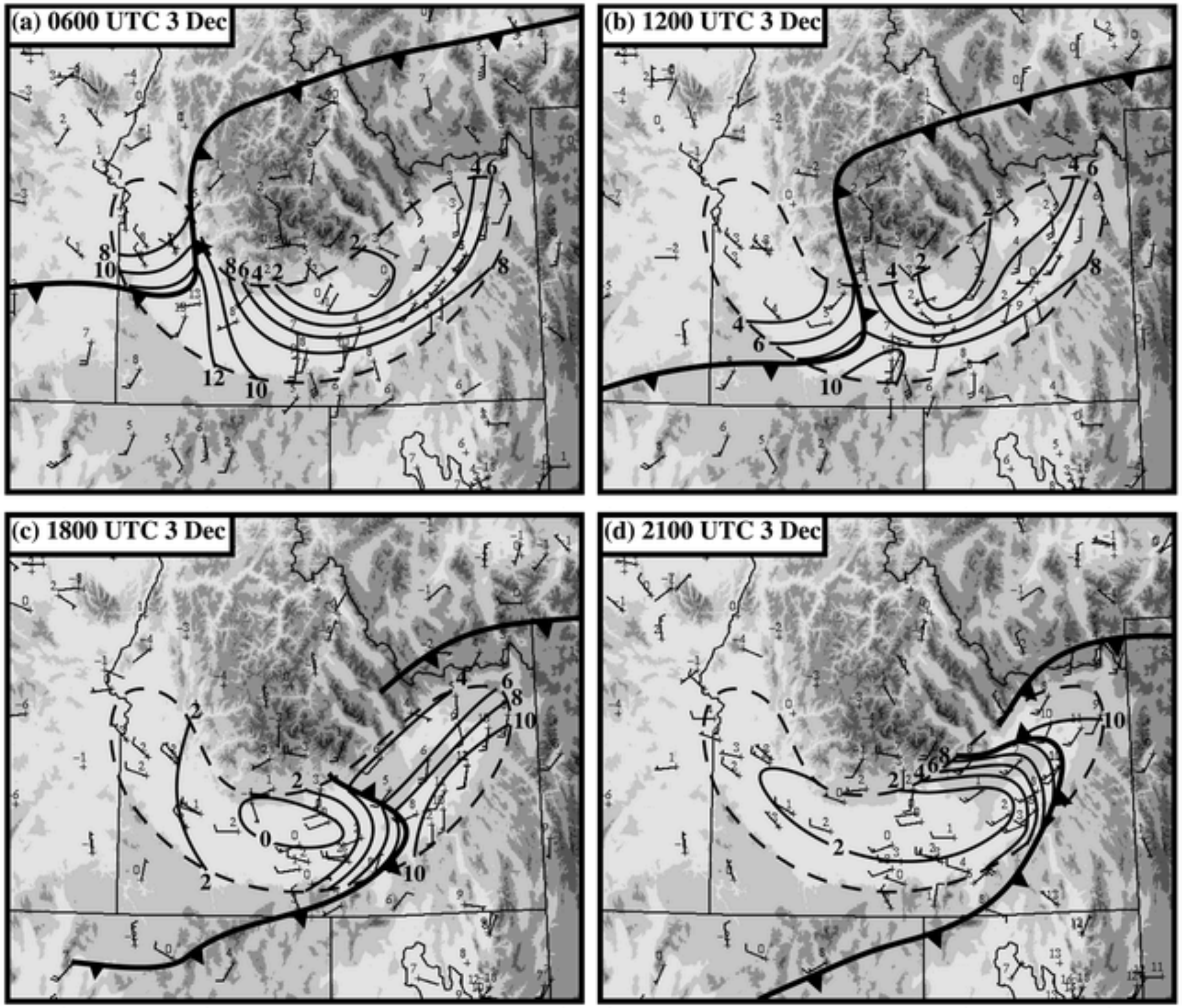
"Average" cold front

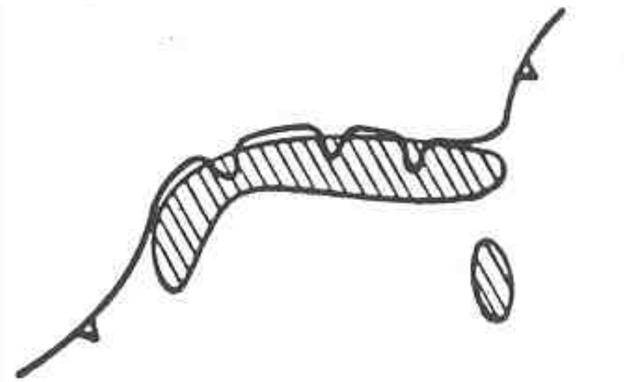




Source: O'Handley and Bosart (1996)

Terrain Channeling

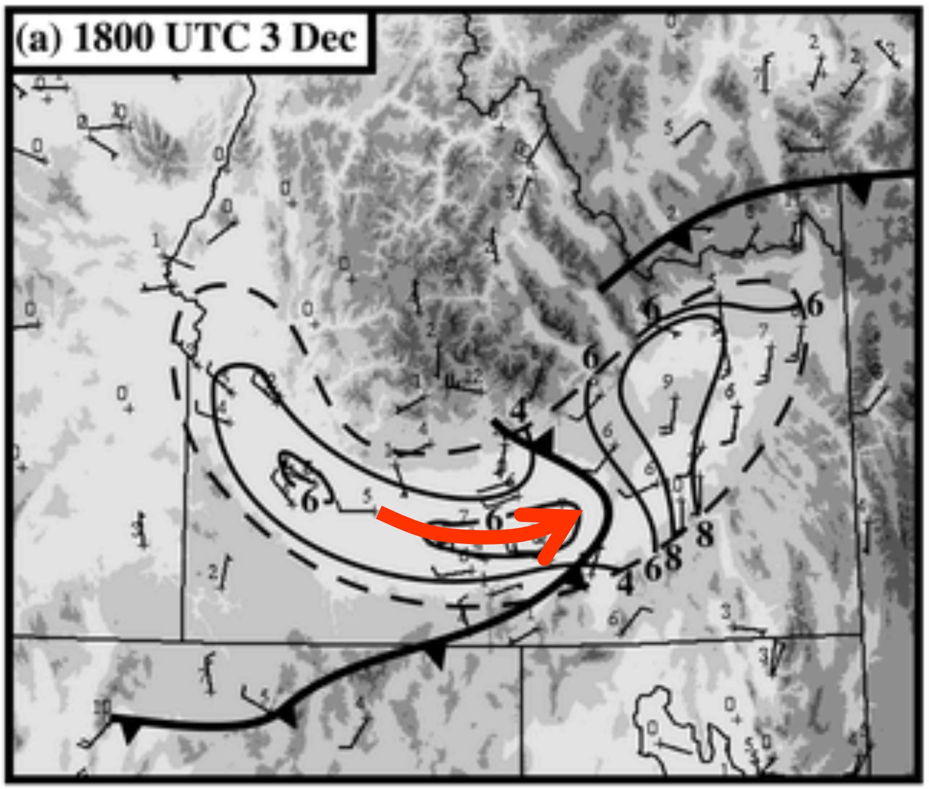


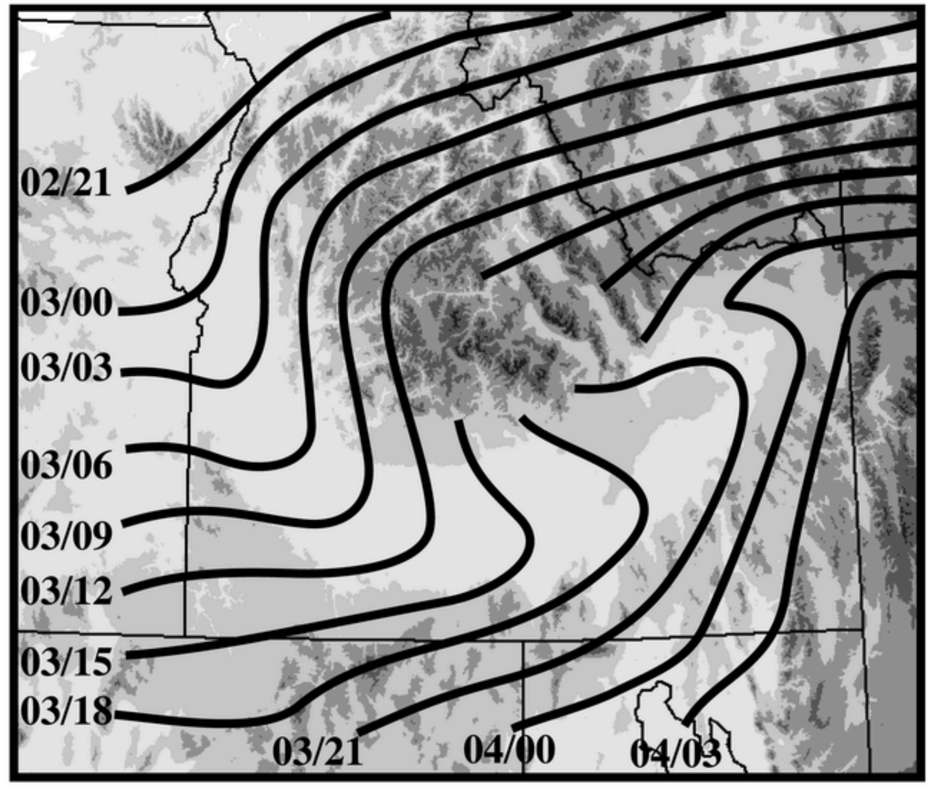


- Stable low-Froude number post-frontal flow becomes oriented along valley axis
- Cold air advected rapidly up valley

Source: Smith (1986), Steenburgh and Blazek (2001)

Terrain Channeling

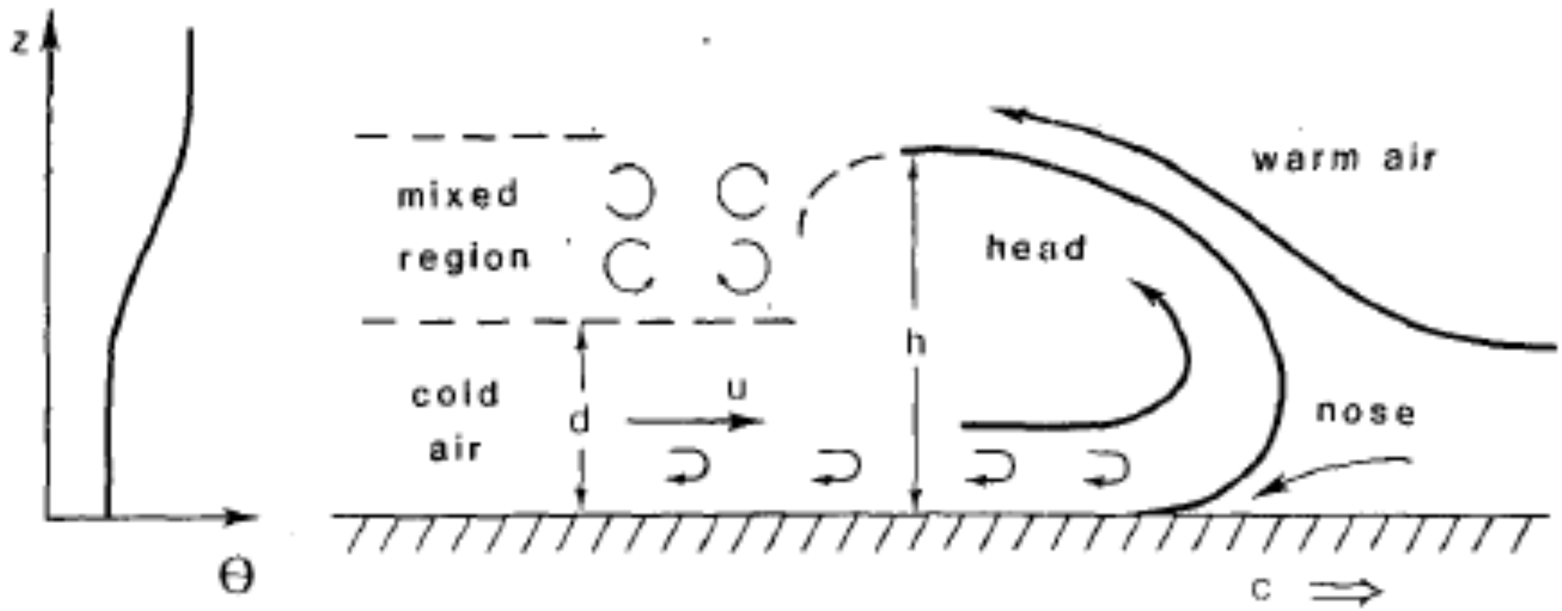




- Terrain-parallel jet may develop in post-frontal environment
- Contributes to development of frontal surge in valley

Source: Steenburgh and Blazek (2001)

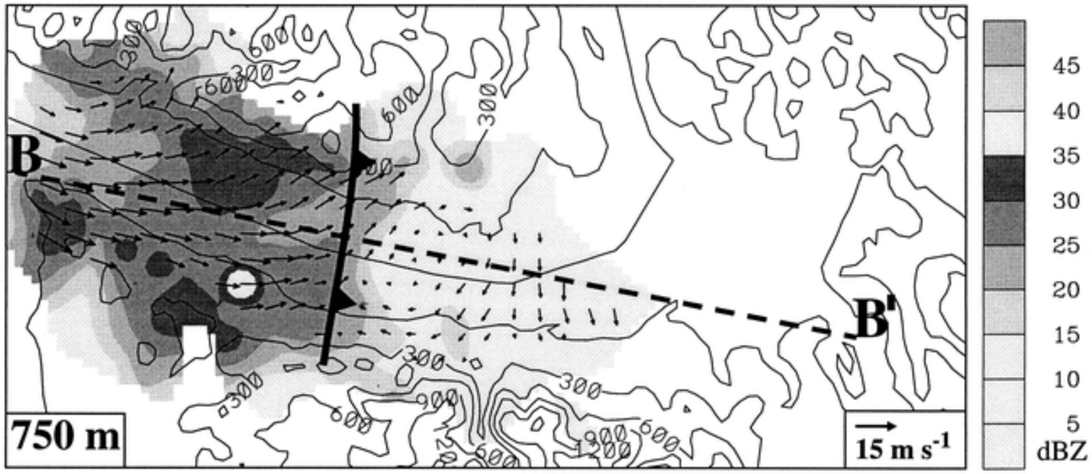
Terrain Channeling

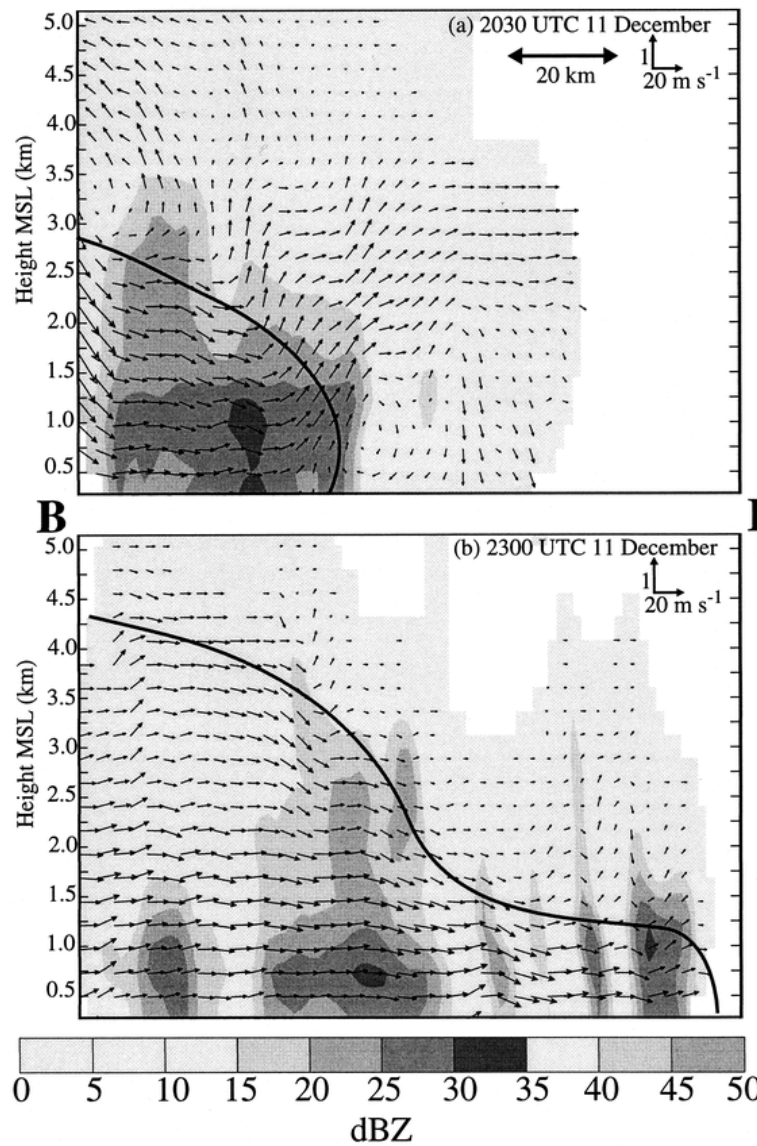


- Front may develop gravity current like structure
  - Pronounced frontal nose
  - Low-level rear-to-front flow; prefrontal warm air ascends nose
  - Rapid increase in pressure and fall in temperature with fropa

Source: Simpson (1982), Smith and Reeder (1988)

Terrain Channeling





- Gravity current stucture revealed over Strait of Juan de Fuca by dual-Doppler analysis

Source: Colle et al. (1999)

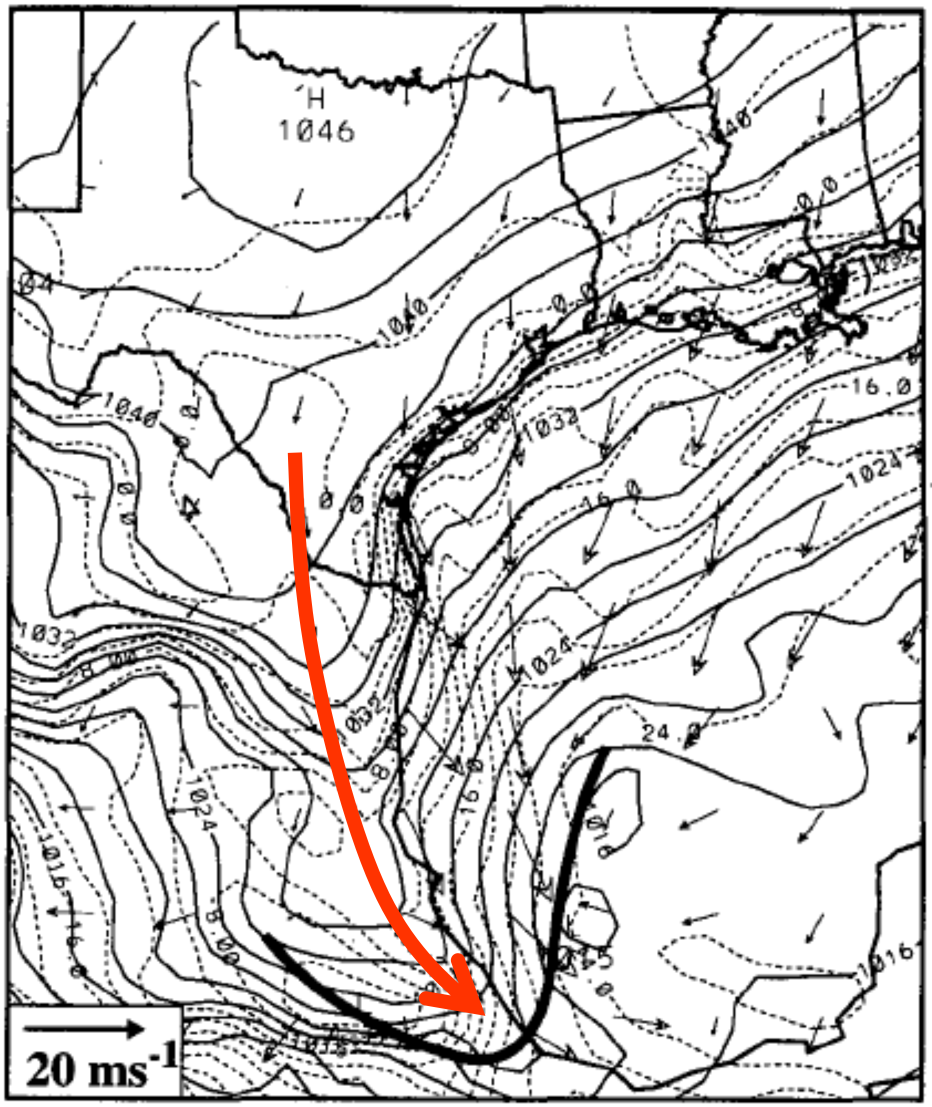
Cold Surges

- Surges of cold air frequently move along a mountain range with cold air to the right in the Northern Hemisphere and left in the Southern Hemisphere

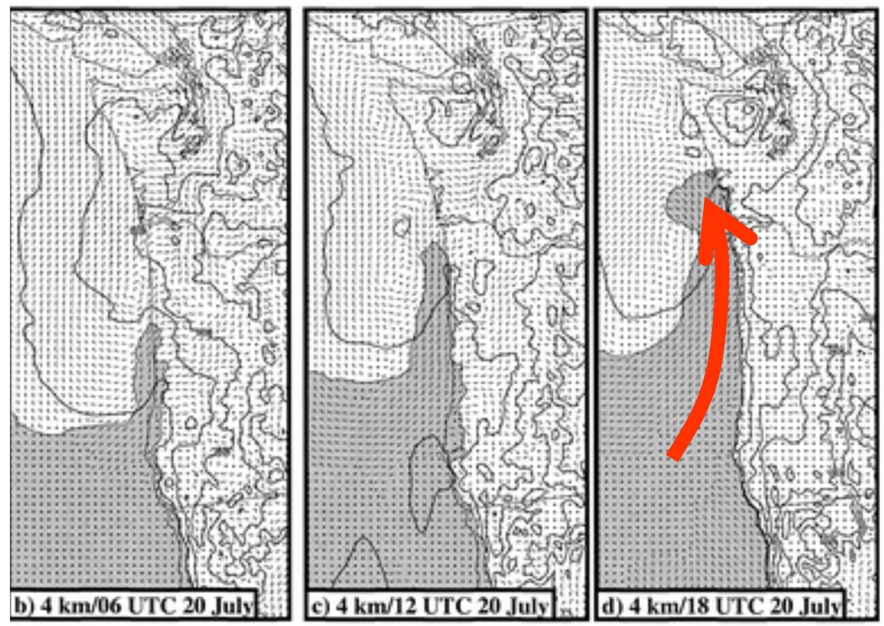
- Examples
  - Southerly Buster/Cool Change (Australia)
  - Marine Surge (U.S. West Coast)
  - North American Cold Surges (east of Rockies)
    - Affect Canada, US, Central America

- Mechanism
  - Topography disrupts geostrophic balance, resulting in enhanced along-barrier flow and cold advection

Cold Surges



North American Cold Surge



West Coast Marine Push or Surge

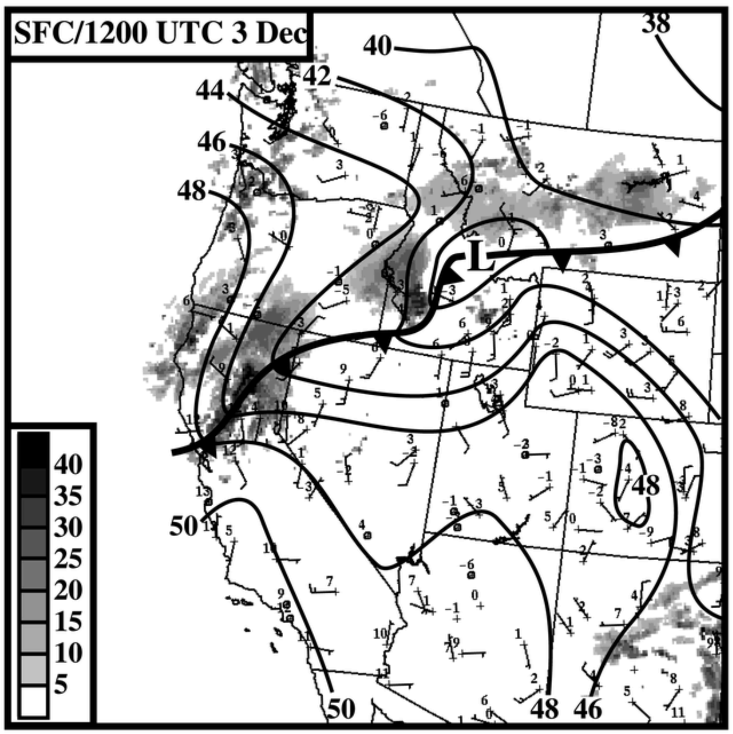
Source: Colle and Mass (1995), Mass and Steenburgh (2000)

Discussion

What are the challenges of frontal analysis in complex terrain?

Improving Frontal Analysis

- Use altimeter setting and reduce/extrapolate pressure to the mean elevation of western U.S. surface stations

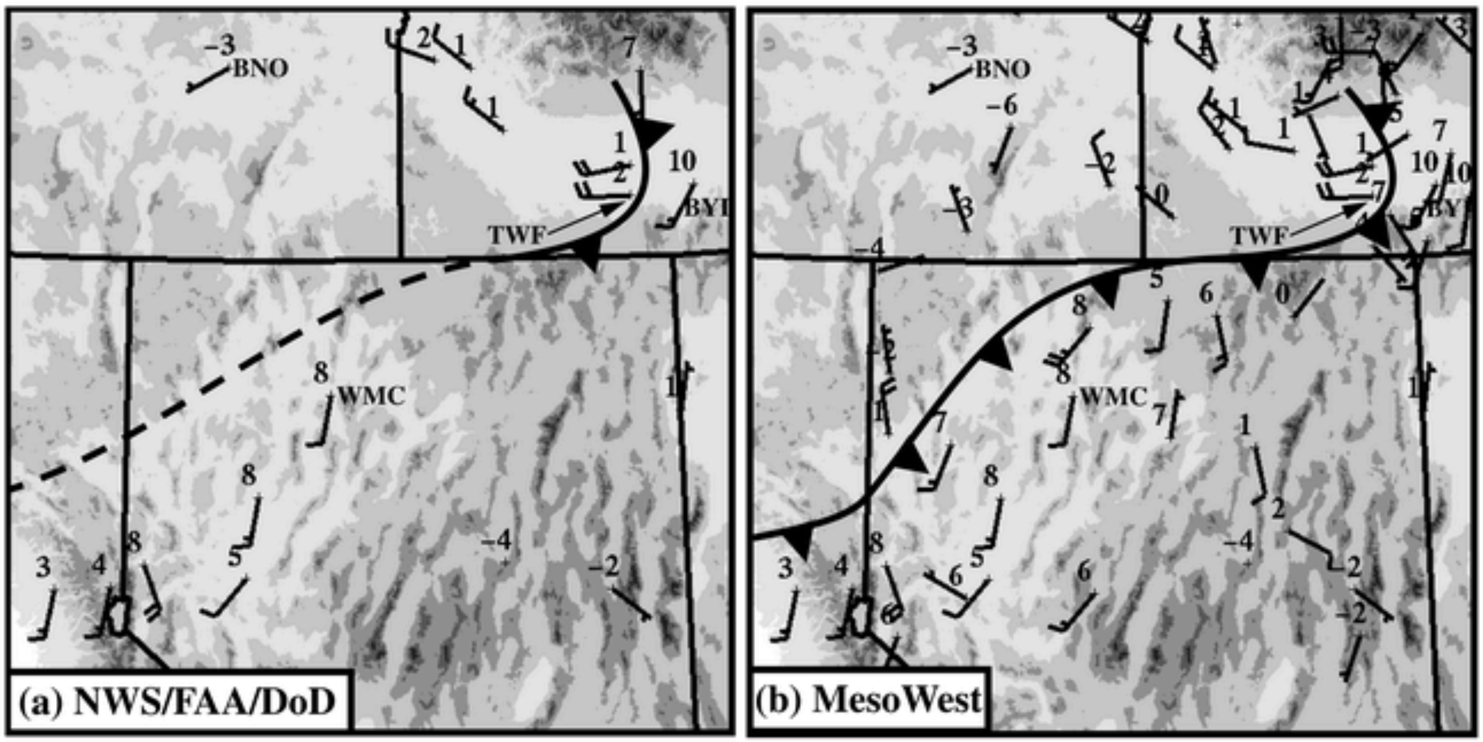


Sample 1500-m pressure analysis

Source: Steenburgh and Blazek (2001)

Improving Frontal Analysis

- Use MesoWest: High station density

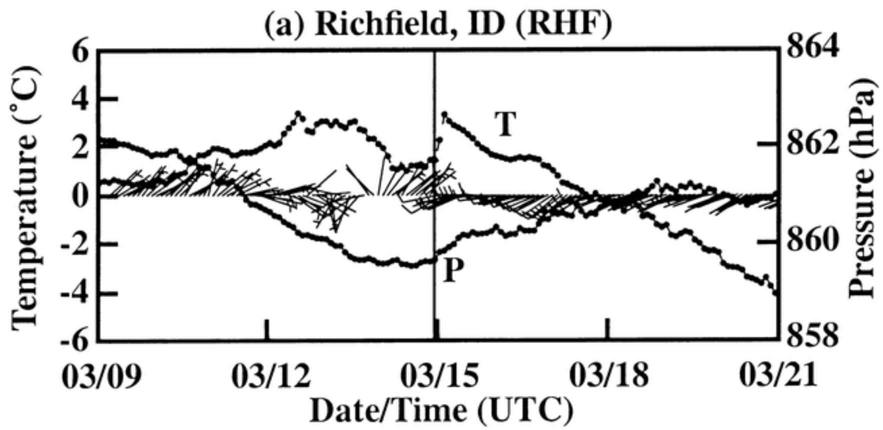


Conventional vs. MesoWest frontal analysis

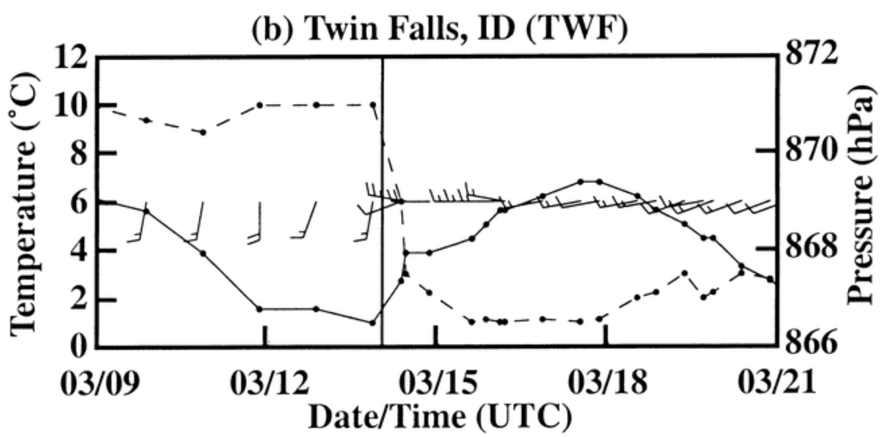
Source: Steenburgh and Blazek (2001)

Improving Frontal Analysis

- Use MesoWest: High station density



Site with nocturnal inversion
(frontal temperature change masked)

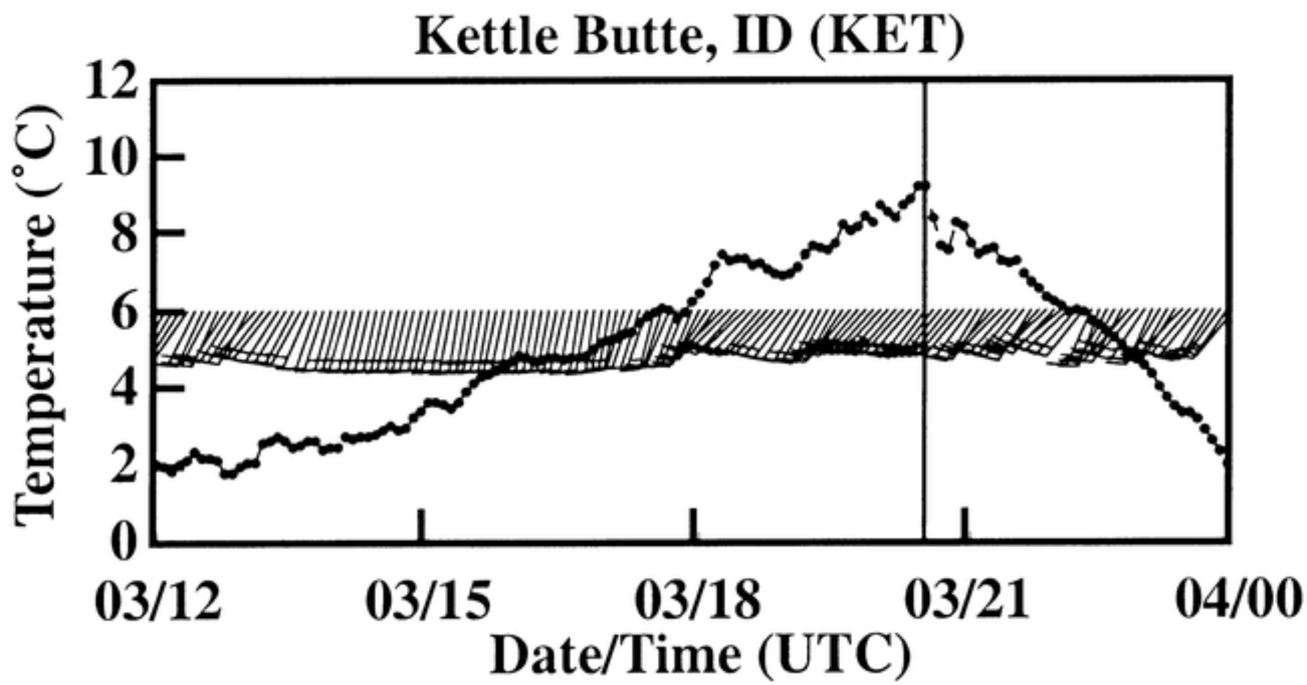


Site without nocturnal inversion
(frontal temperature change evident)

Source: Steenburgh and Blazek (2001)

Improving Frontal Analysis

- Use MesoWest: Rich climatology



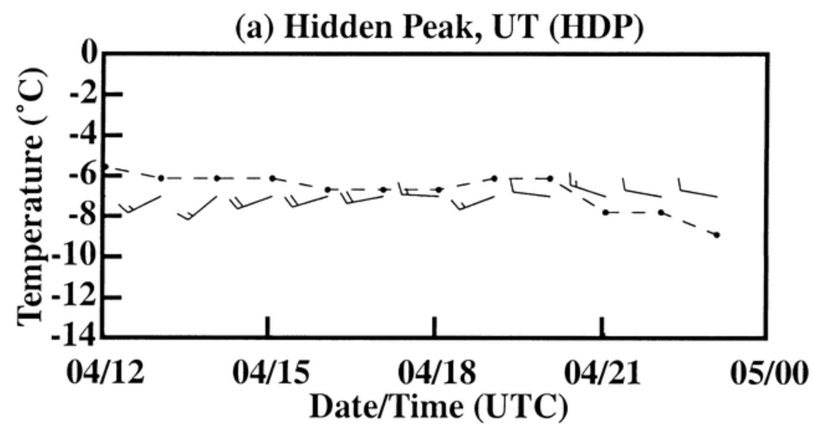
Use climatologies to understand when terrain-induced flows mask cyclonic wind shifts associated with fronts

At Kettle Butte, terrain channeling in Snake River Plain results in SW post-frontal wind

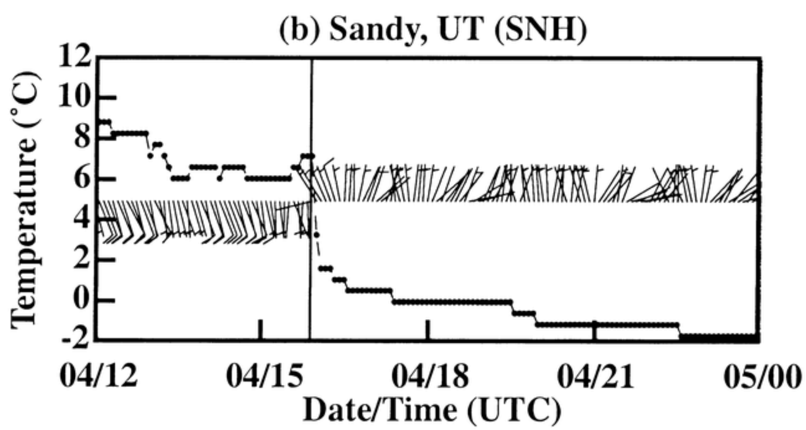
Source: Steenburgh and Blazek (2001)

Improving Frontal Analysis

- Use MesoWest: Multielevation stations



High elevation
Weak Fropa



Low Elevation
Strong Fropa

Source: Steenburgh and Blazek (2001)

Summary

- Topography can affect the structure of a low-level cold front in several ways
  - Fronts can be retarded by pre-frontal downslope (e.g., Foehn) and blocking of the post-frontal airmass windward of the topography
  - Fronts may rotate anticyclonically (poleward portion of mountain) or cyclonically (equatorward portion of mountain) due to development of mountain anticyclone
  - Along-valley or gap winds may accelerate fronts through lowland regions
  - Low-level and upper-level portions of a front may become decoupled
- Frontal analysis in complex terrain is difficult, but can be aided over western U.S. by MesoWest
- Let's learn more by beginning this lab (turn in later for grade)