

# **MET 3502/5561 Synoptic Meteorology**

## **Lecture 7**

### **AIRMASSES, FRONTS and FRONTAL ANALYSIS**

# Airmasses

- An airmass is a large body of air with relatively uniform thermal and moisture characteristics.
- Airmasses cover large regions of the earth, typically several hundred thousand square kilometers.
- Airmasses can be as deep as the depth of the troposphere or as shallow as 1 to 2 km.
- Airmasses form when air remains over a relatively flat region of the earth\* with homogeneous surface characteristics for an extended period of time.

(\* Canadian and Siberian plains, cool oceanic regions such as the North Atlantic and Pacific, deserts, such as the Sahara and the American southwest, and tropical oceanic regions including the equatorial Atlantic and Pacific, and smaller water bodies such as the Caribbean Sea and the Gulf of Mexico).

# Sources of North American Airmasses

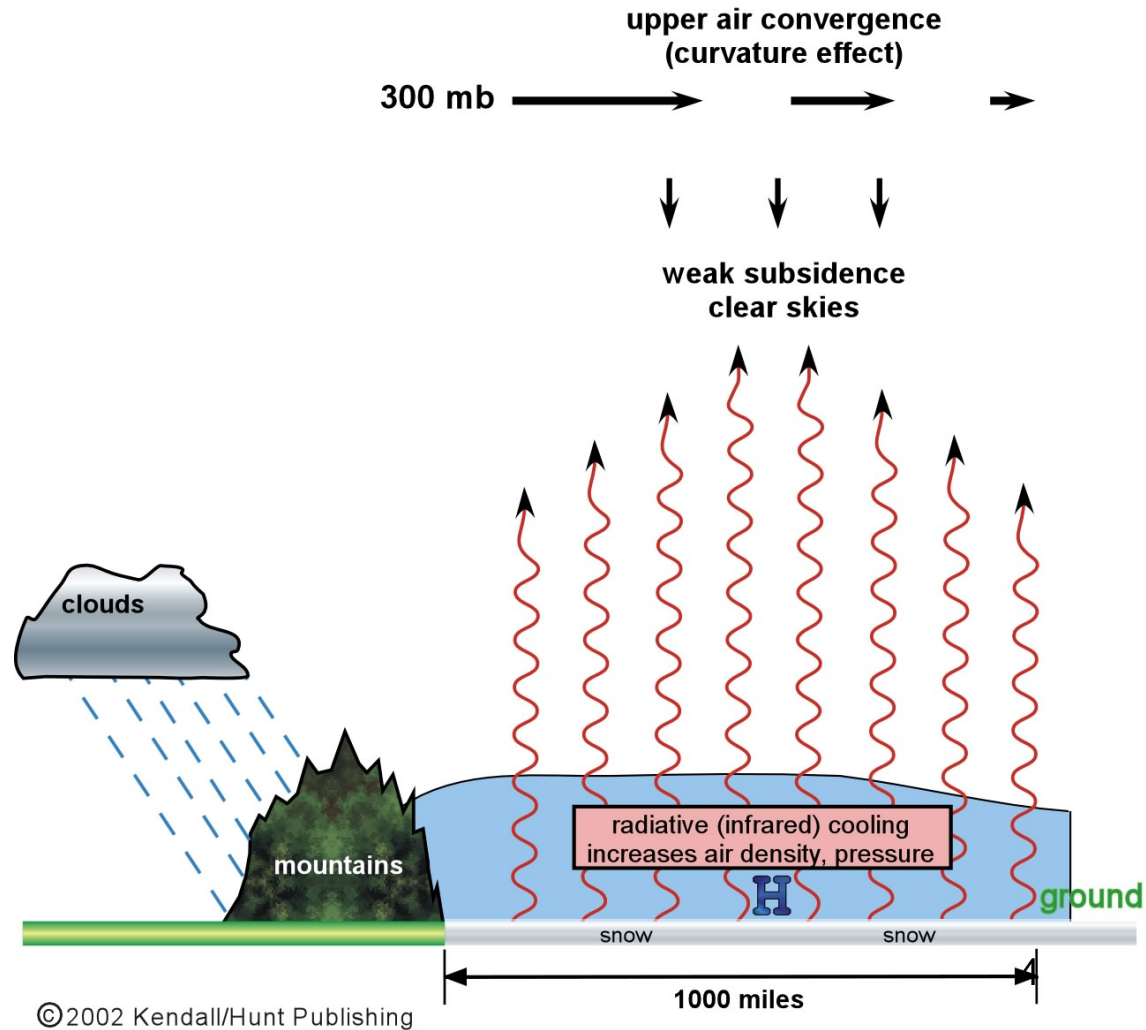
- **Continental Arctic (cA):** bitter cold, form over Canada and the frozen Arctic sea (north of 60N) in winter
- **Continental Polar (cP):** form over northern part of North America continent in all season.
- **Maritime Polar (mP):** High-latitude sea (N. Atl or N. Pac.)
- **Maritime Tropical (mT):** Tropical (Trade-Wind) sea (Atl. Or Pac., Gulf of Mexico, Caribbean sea)
- **Continental tropical (cT):** Desert
- **Air-Mass Modification** takes place outside source region
- North American weather is dominated by alternation of cP and mT air



# Key features of an airmass on weather maps:

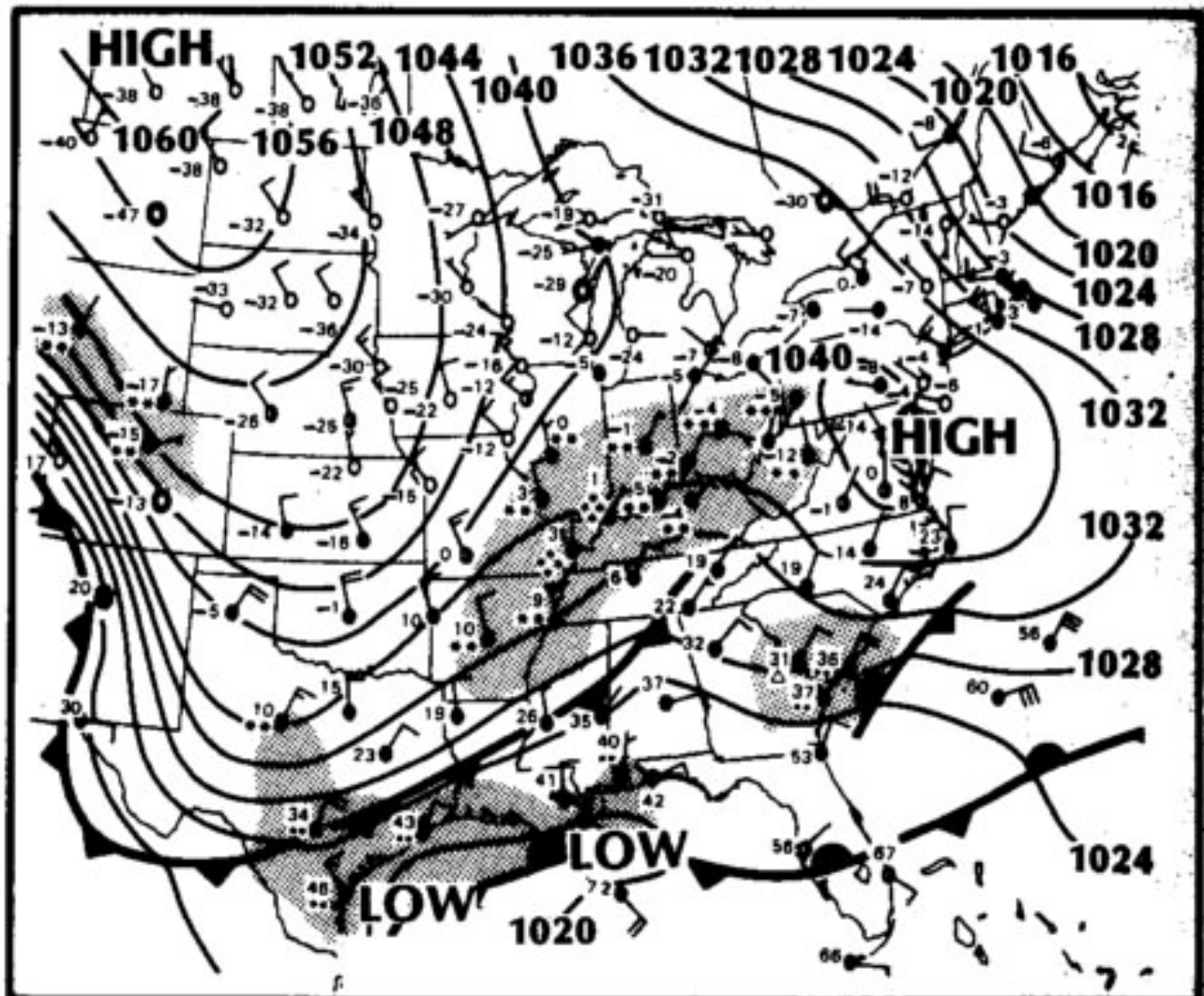
The centers of cold airmasses are associated with high pressure on surface weather maps. High pressure develops in response to cooling.

Cooling of the whole layer → increase air density → pressure surface fall at upper level → an inward pressure gradient force aloft → upper air convergence → air fills the column → creating surface high pressure.



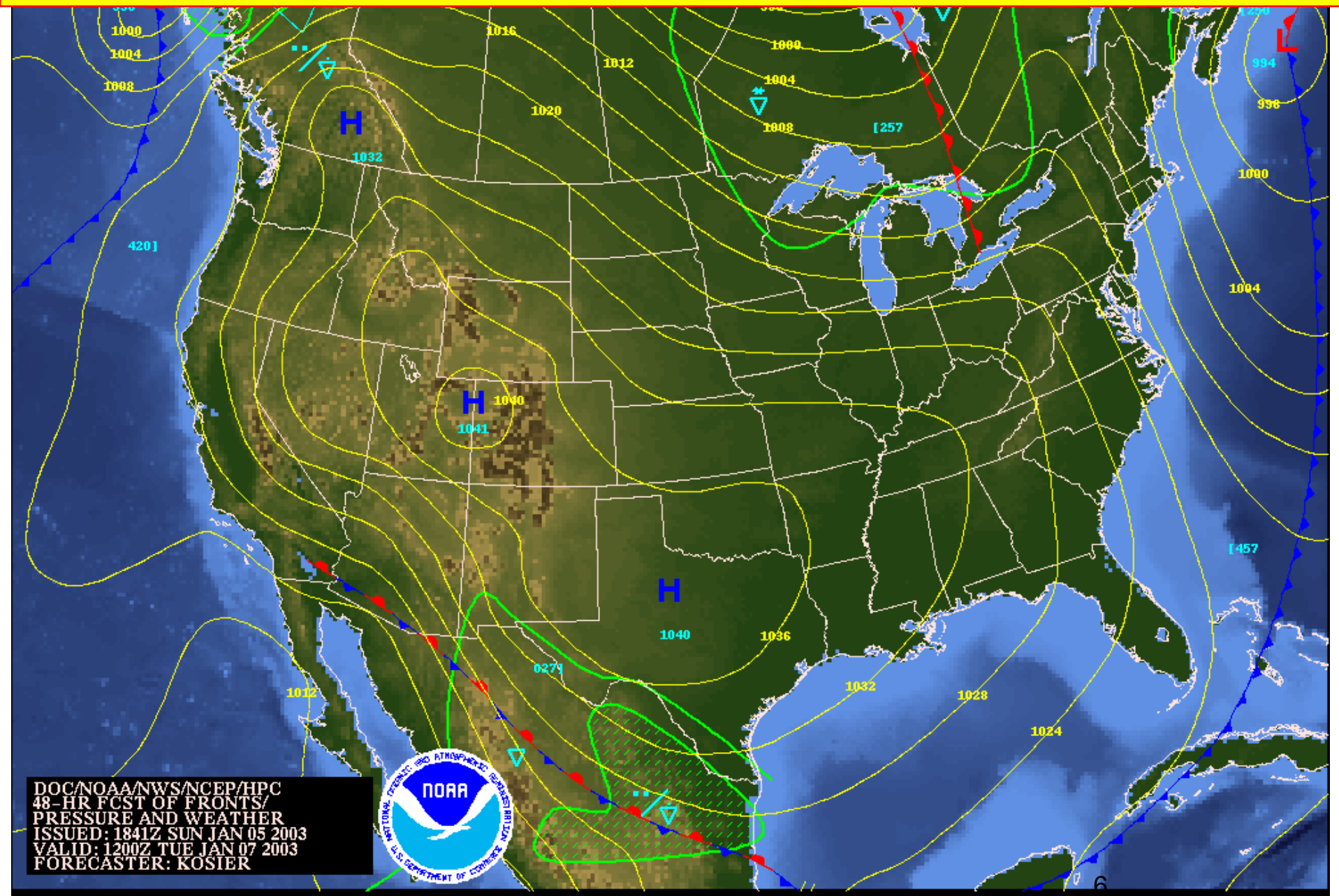


In winter, high-pressure centers form and are the dominant feature over the northern parts of the continents of Asia and North America.

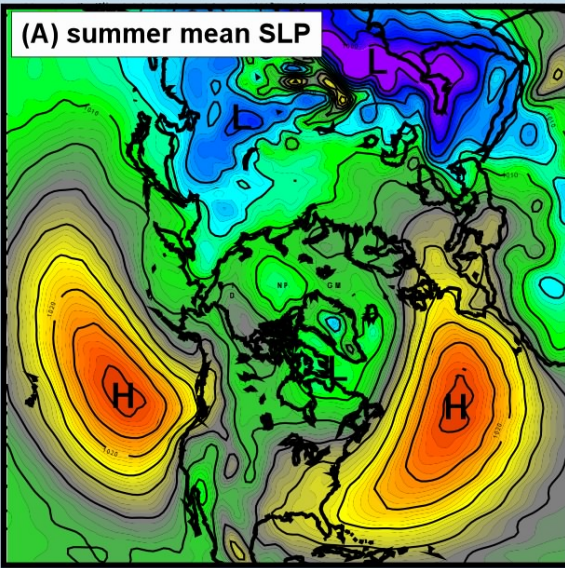


Courtesy of the American Meteorological Society

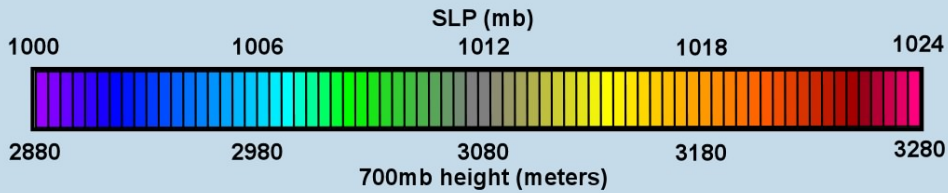
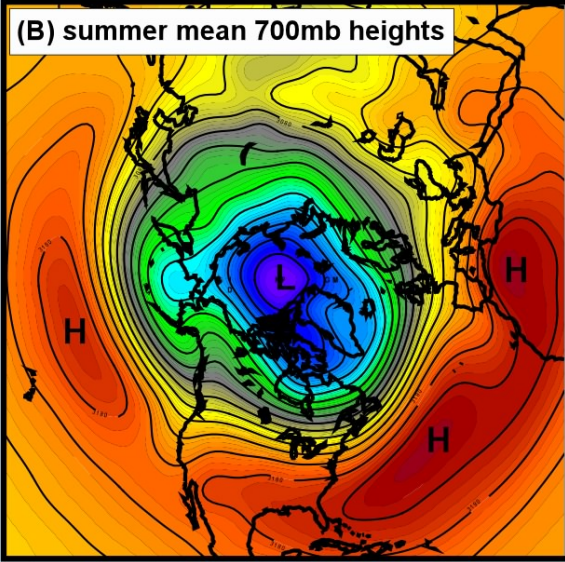
# Example of a high pressure system that moved southward into the central US in winter



(A) summer mean SLP



(B) summer mean 700mb heights



In summer, when the oceans are cooler than the landmasses, large high-pressure centers are the dominant feature of the atmosphere over the North Atlantic and Pacific Oceans.

The high-pressure center over the Atlantic is called the “Bermuda High” because it is centered near Bermuda, while its Pacific counterpart is called the “Pacific High”

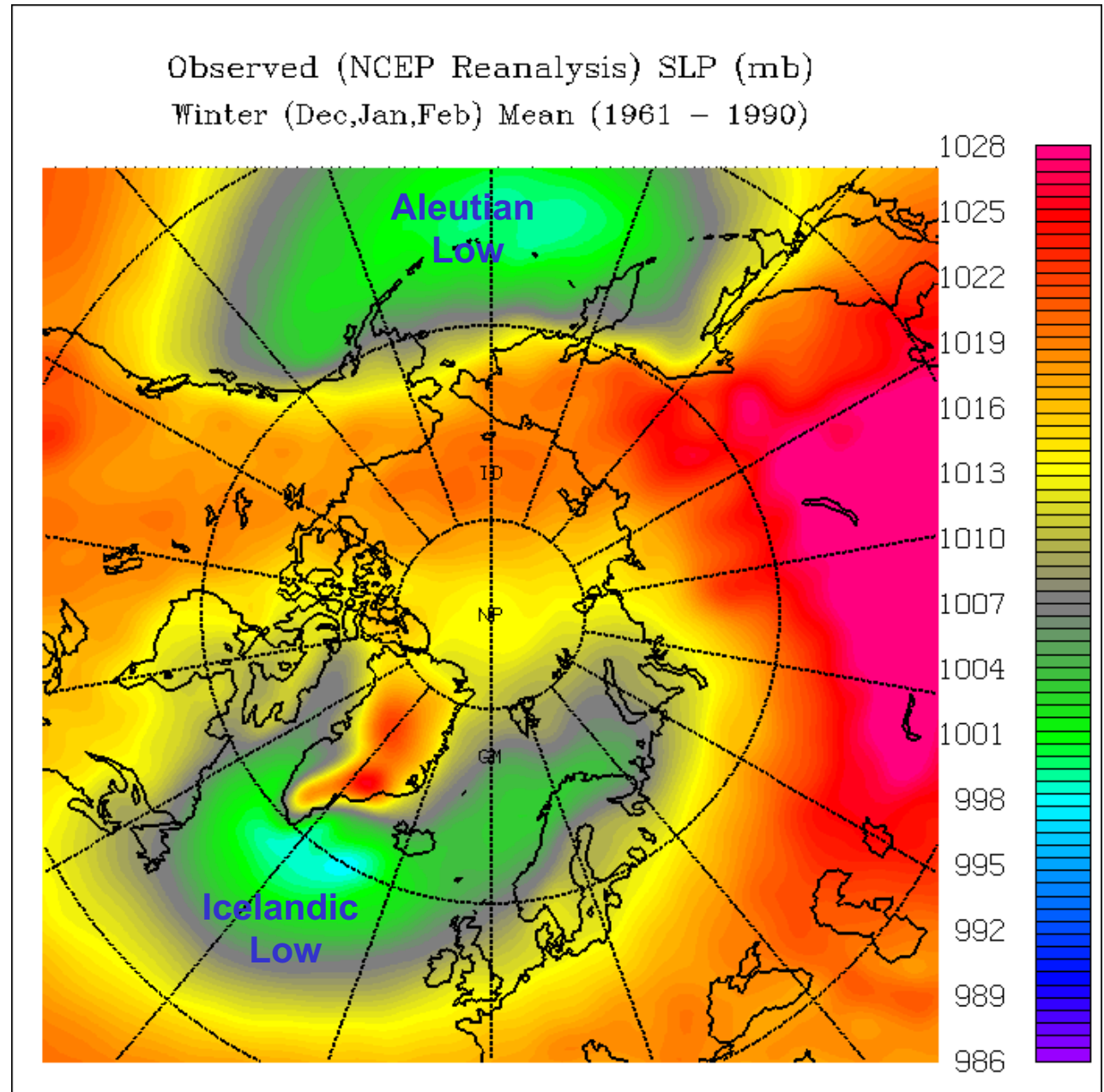


The centers of very warm airmasses appear as semi-permanent regions of low surface pressure.

- Examples:
- 1) Monsoon Low in summer over S.E. Asia
  - 2) North American Monsoon Low over Deserts of the U.S. southwest
  - 3) Equatorial low pressure belt
  - 4) Icelandic Low over the N. Atlantic
  - 5) Aleutian Low over the N. Pacific in winter.

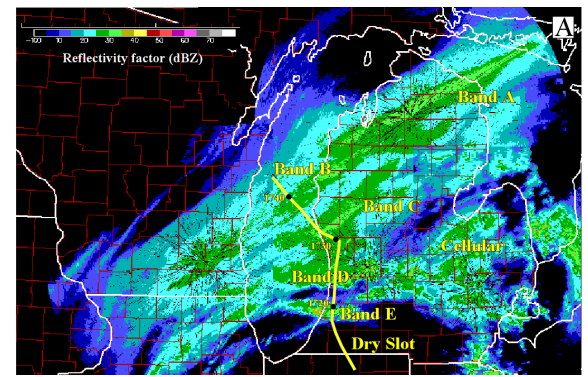
**Note:** Semi-permanent low-pressure centers differ substantially from migrating tropical and extratropical low-pressure centers associated with cyclones and hurricanes.

The Aleutian Low and the Icelandic Low are associated with airmasses that are warm relative to the surrounding continental airmasses in winter.

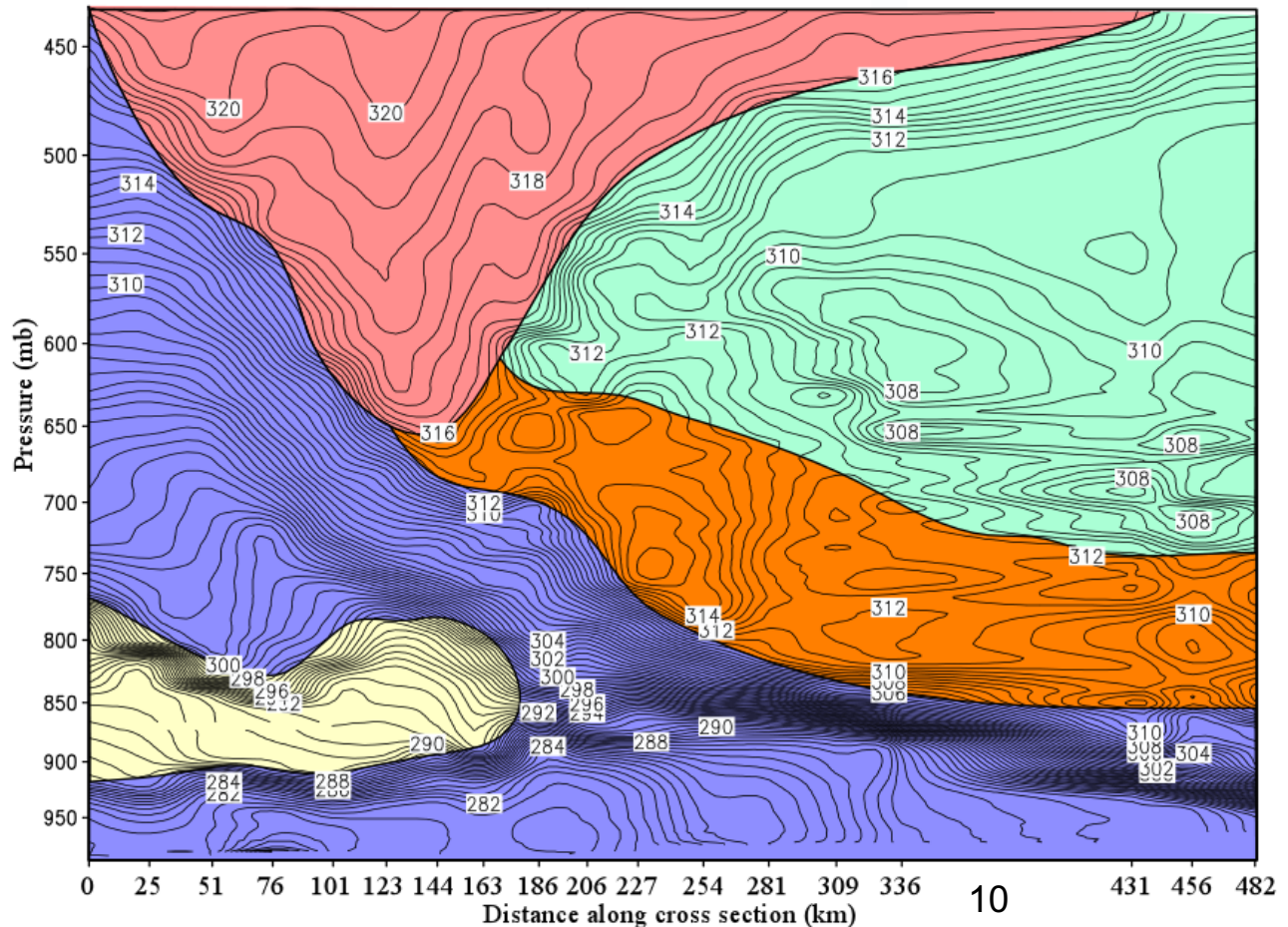


# Not all airmasses are in contact with the ground

Airmasses sometime exist aloft in the troposphere, residing on top of other airmasses.



Equivalent potential temperature and airmasses (color)



Airmasses are three-dimensional, and the boundaries between airmasses are often quite sharp and distinct

Stratosphere: a large airmass that covers the entire globe

# **Fronts: Boundaries between airmasses**

**Meteorologists classify fronts based on:**

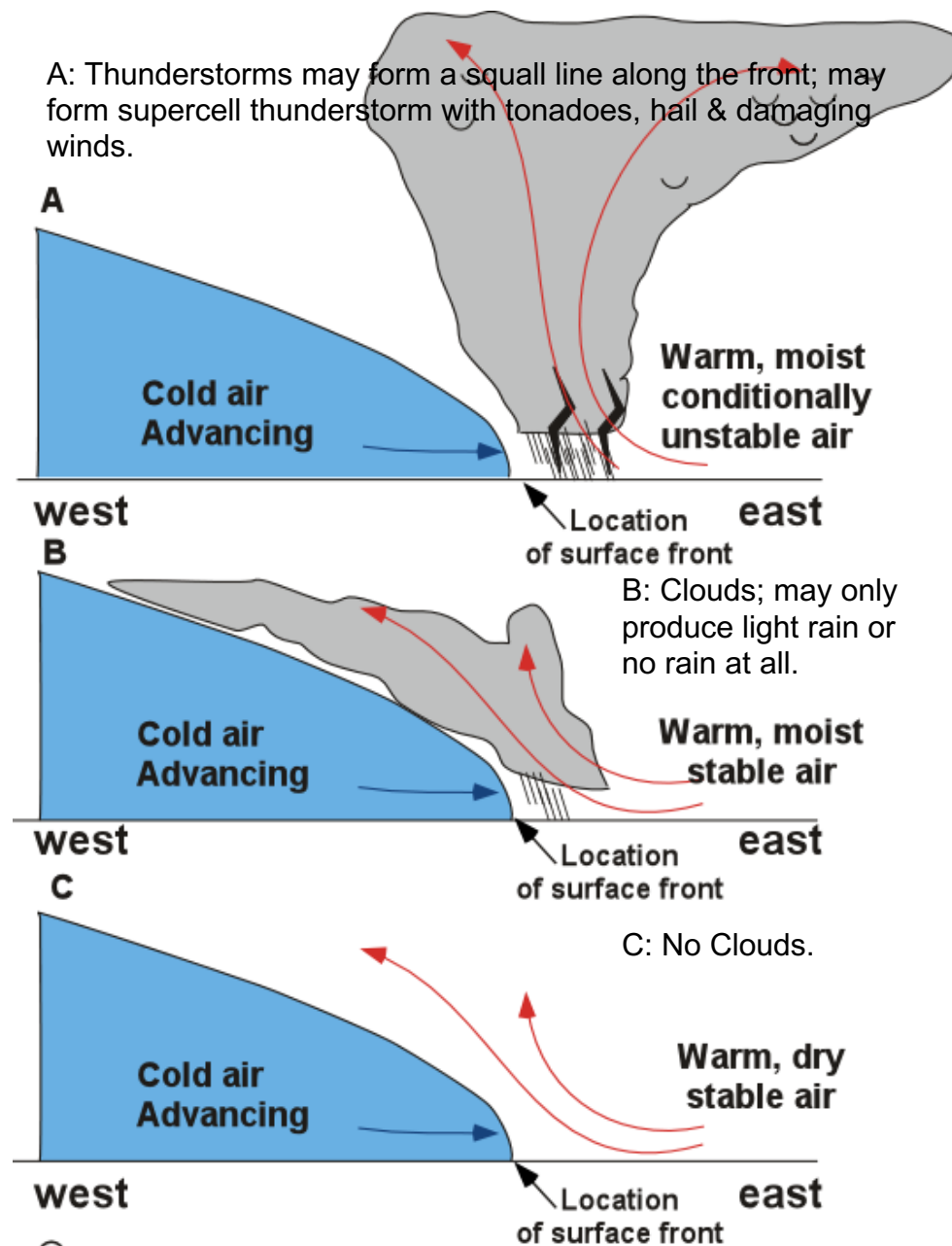
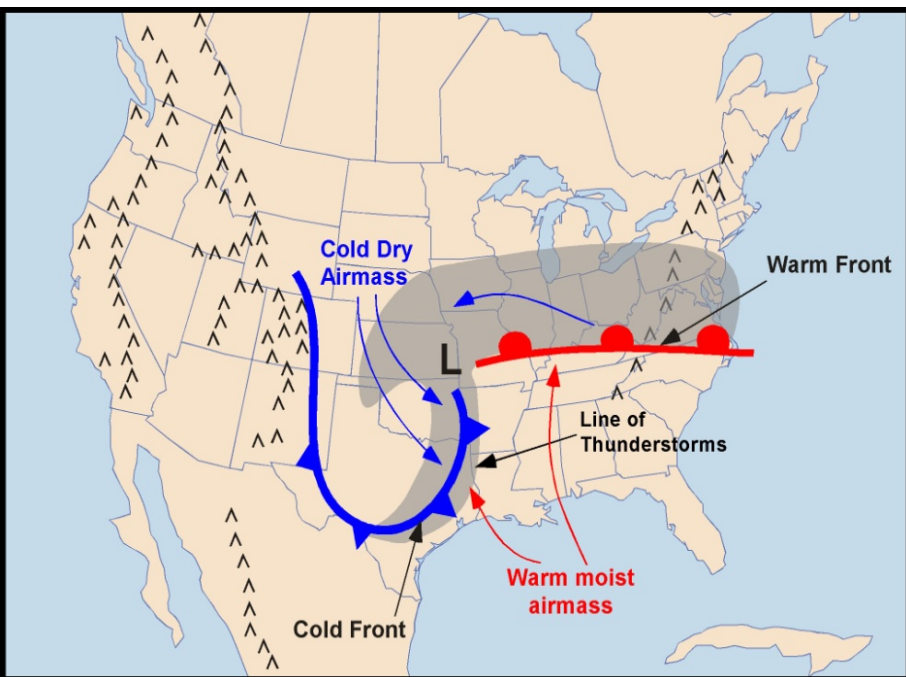
- a) the thermal and moisture characteristics of the airmasses**
- b) the direction of movement of the airmasses**
- c) whether the boundary between the airmasses is in contact with the ground (a surface front), or can only be found aloft (an “upper level front”).**



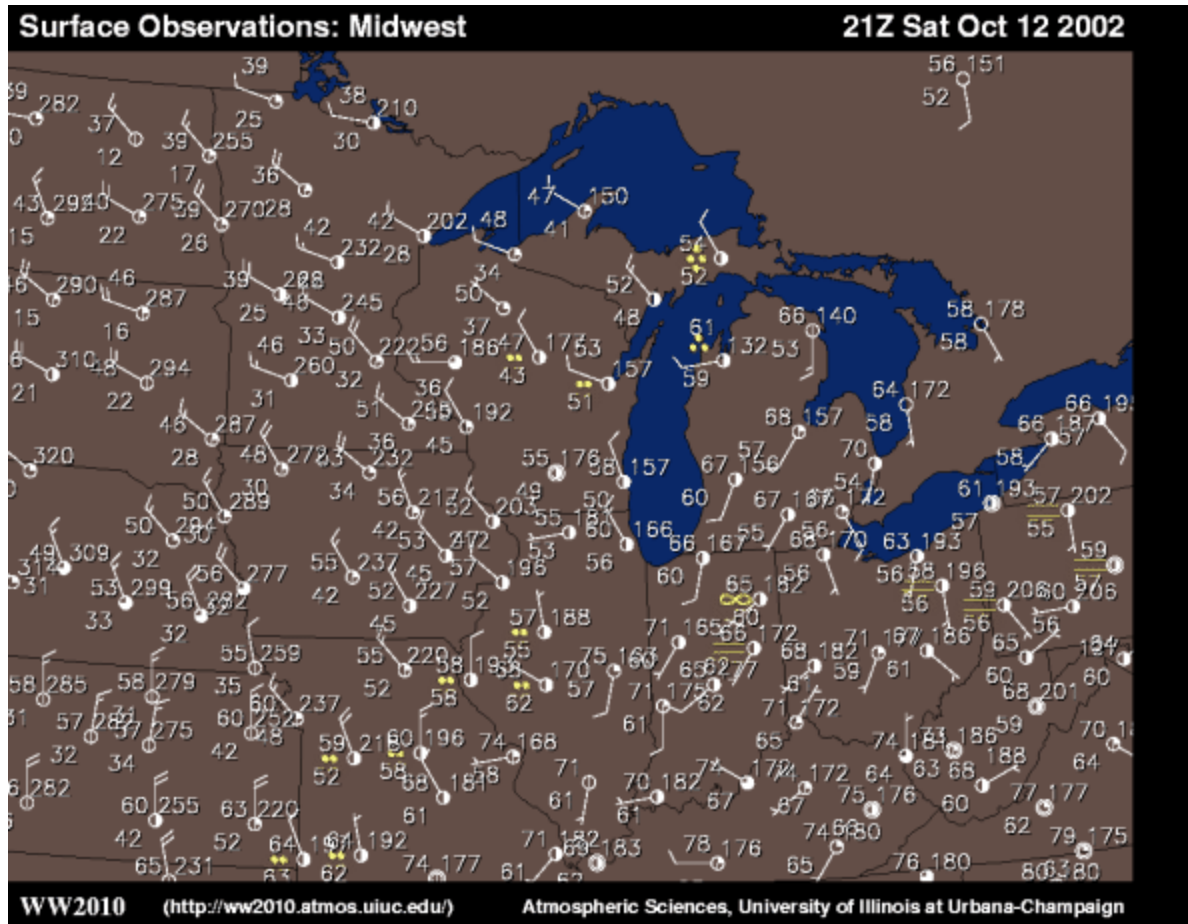
# Cold Front:

The boundary between two air masses is called a **cold front** if the cold air is advancing forward, lifting the warm air.

The leading edge of the cold air mass typically has a shape like a dome, as shown in the figure.

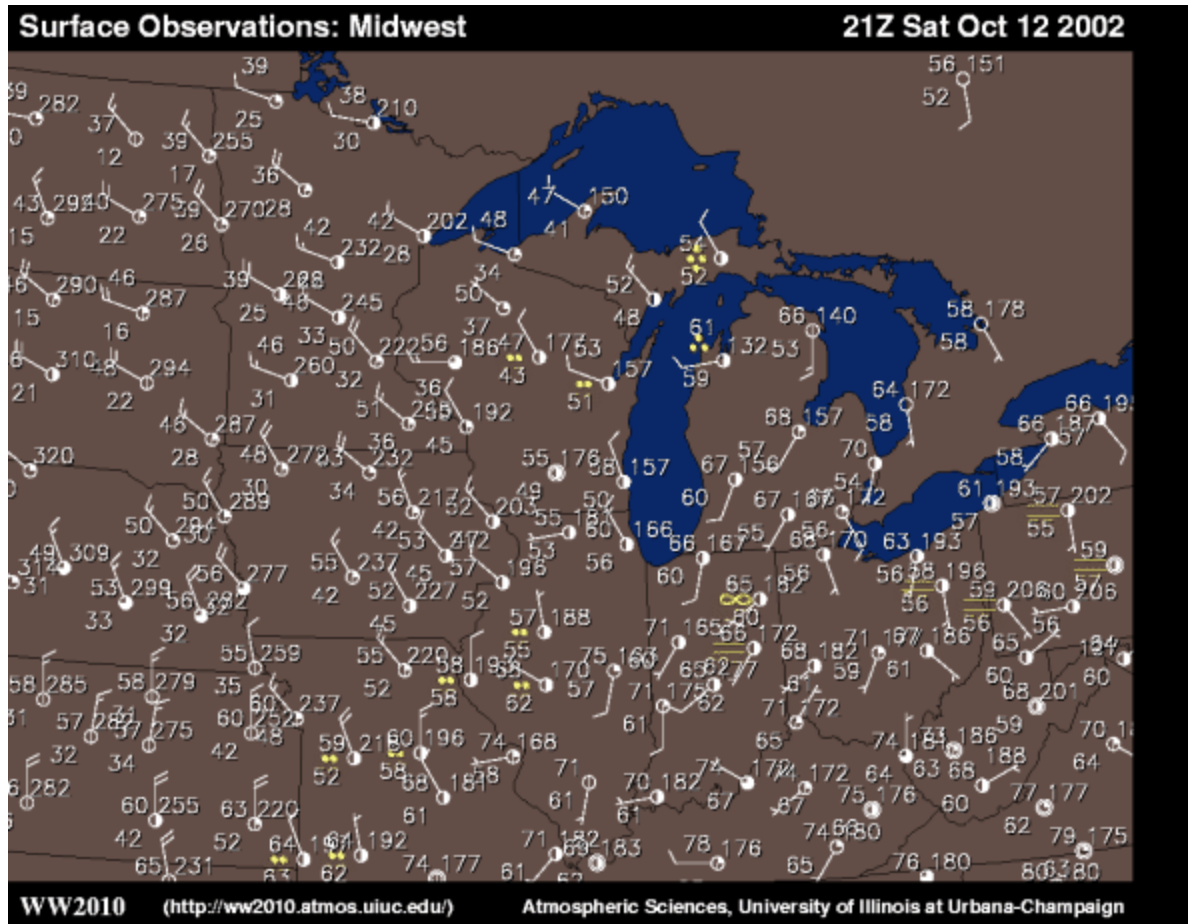


# Identifying a cold front on a surface weather map:



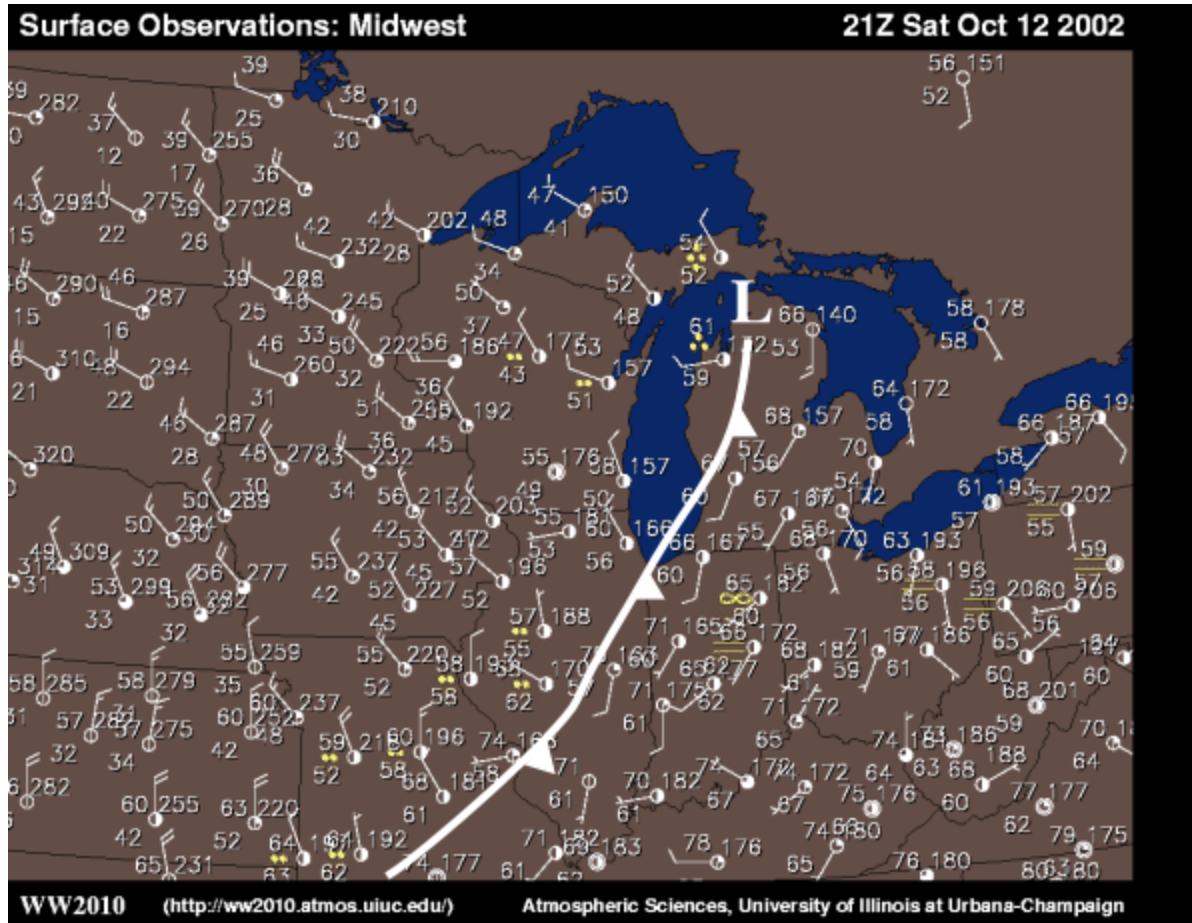
1. Surface front is located at the leading edge of the **strong temperature gradient**.
2. Surface front is located at the leading edge of accompanying **strong dewpoint gradient**.
3. Surface front coincides with **pressure trough** – pressure dropping as the front approaches and rising after it passes.

# Identifying a cold front on a surface weather map:



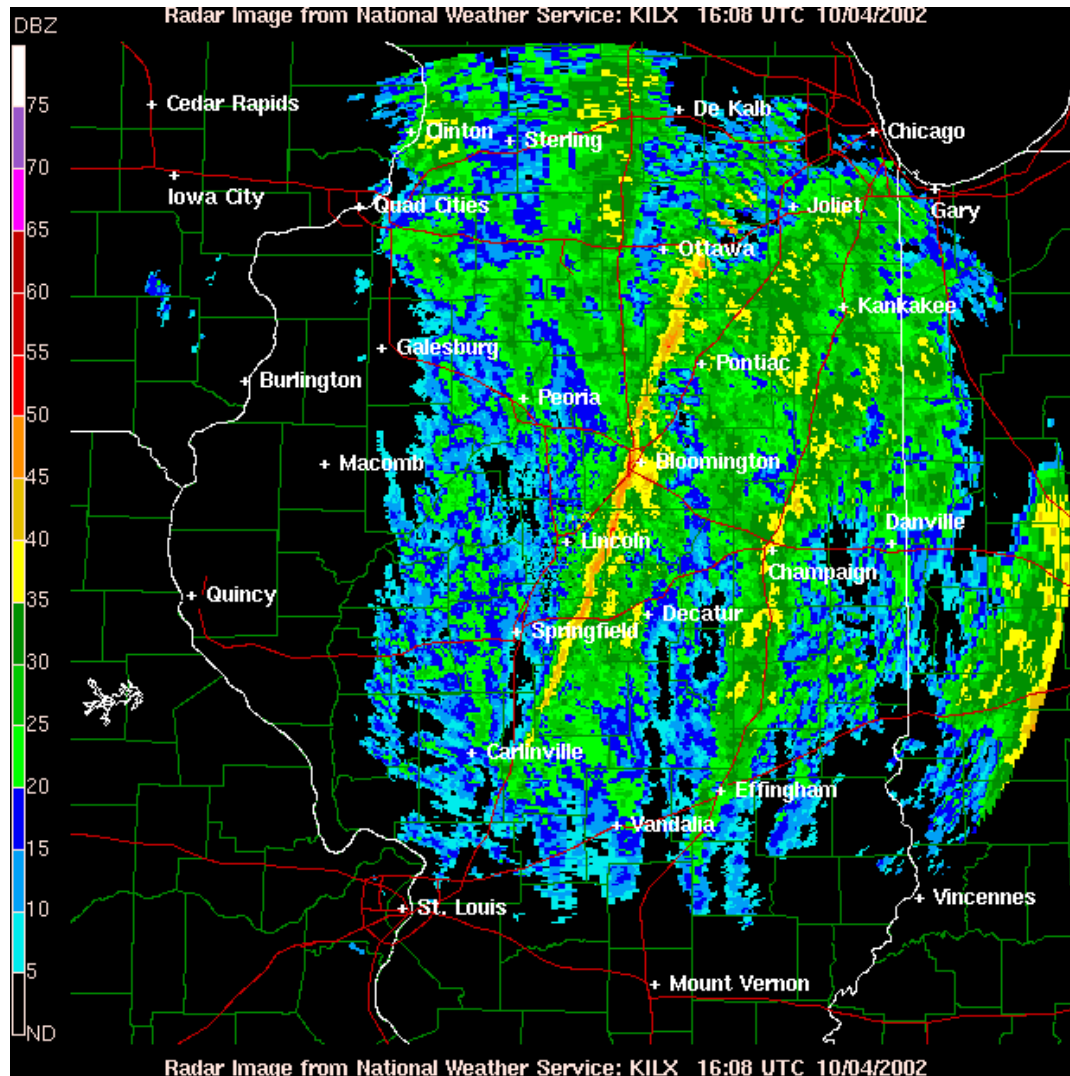
4. Cold air is advancing with time, replacing warm air.
5. A sharp wind shift, generally from winds with southerly component to winds with westerly or northwesterly component, will occur at front.
6. Precipitation may be behind, along, or ahead of front (or may not be present) but when present, it will be organized along a line.

# Identifying a cold front on a weather map:

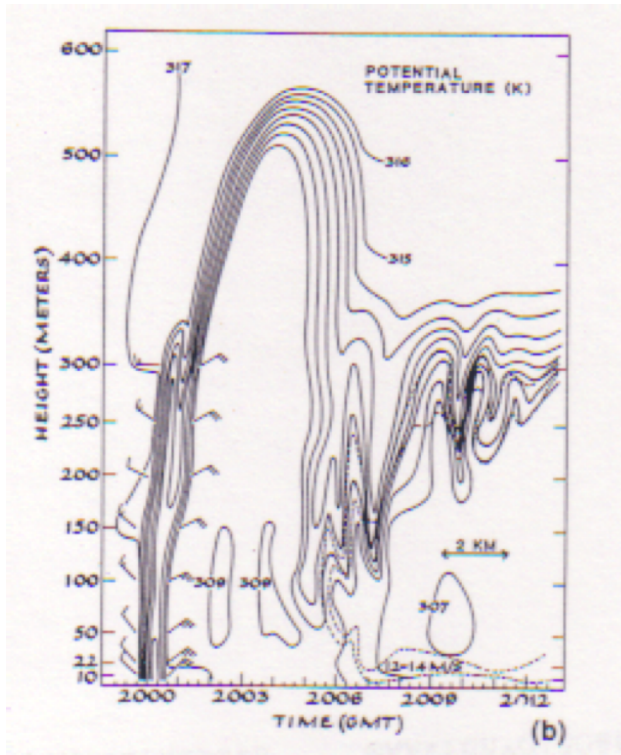




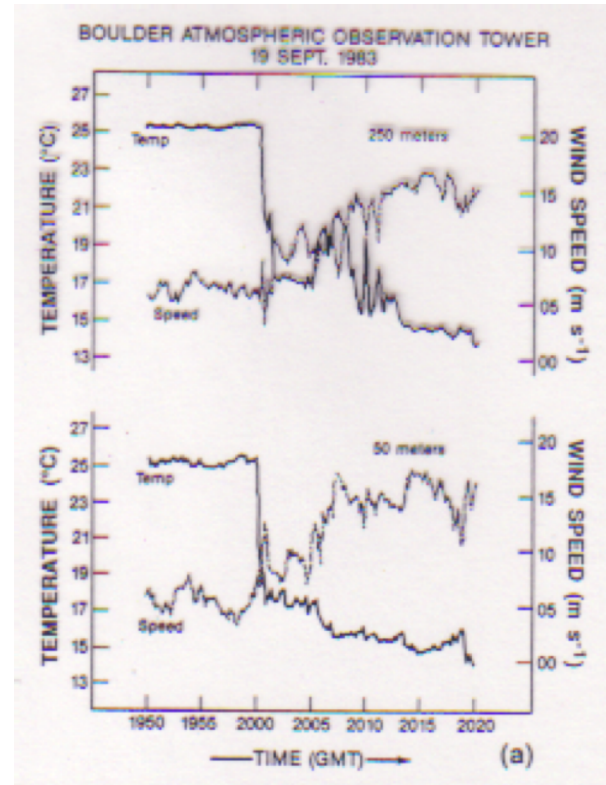
Leading edge of a cold front on radar often appears as a very long narrow line of high reflectivity



**Cold Fronts:** The leading edge of a cold front often appears like a density current, with a head, waves, and accompanying sharp discontinuity in temperature, wind, and moisture content.



Potential Temperature  
Wind Barbs

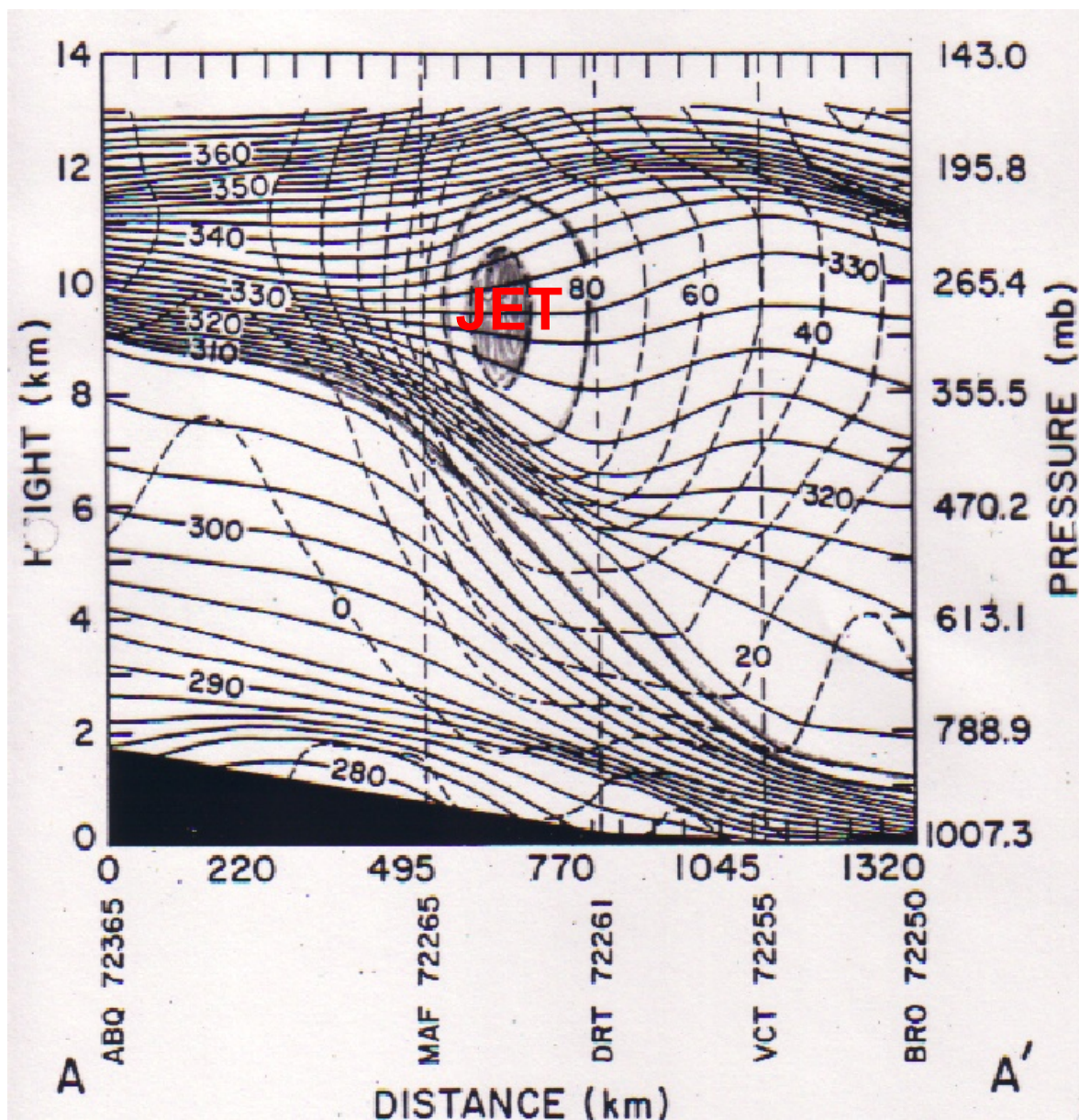


Temperature  
Wind Speed

Data from 600 m high tower called the Boulder Atmospheric Observatory. A cold Front passed the tower On 19 Sep 83.



# Deep Tropospheric Cold Front and Jetstream



Potential temperature and isotachs

Fronts and jetstreams are related dynamically by thermal wind relationship

Keyser and Shapiro 1978  
August MWR

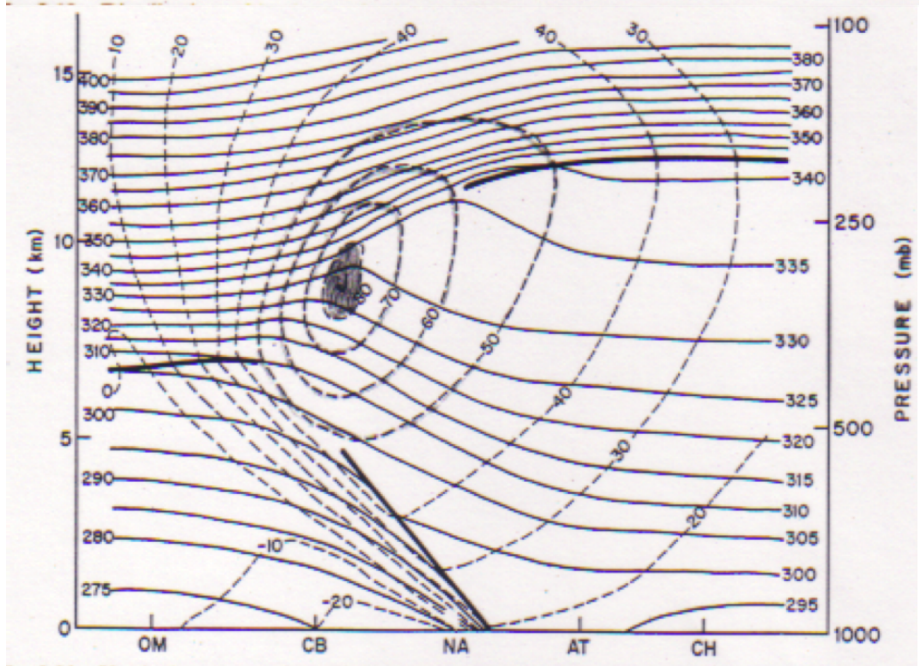
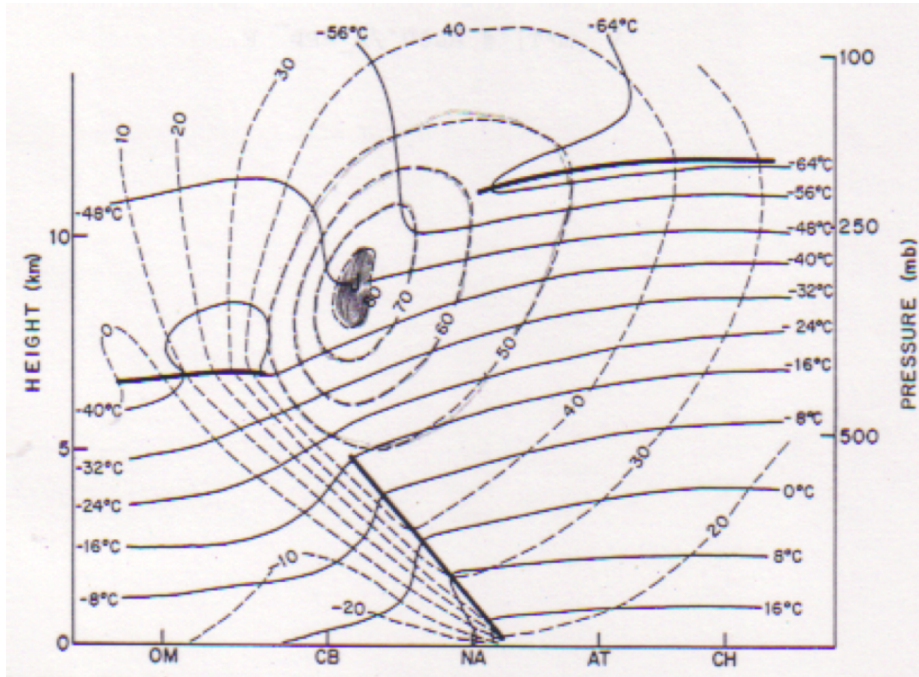


# Deep Tropospheric Cold Front

Boundary between airmasses is marked by a sharp gradient in temperature

Temperature (C)

Potential Temperature (K)

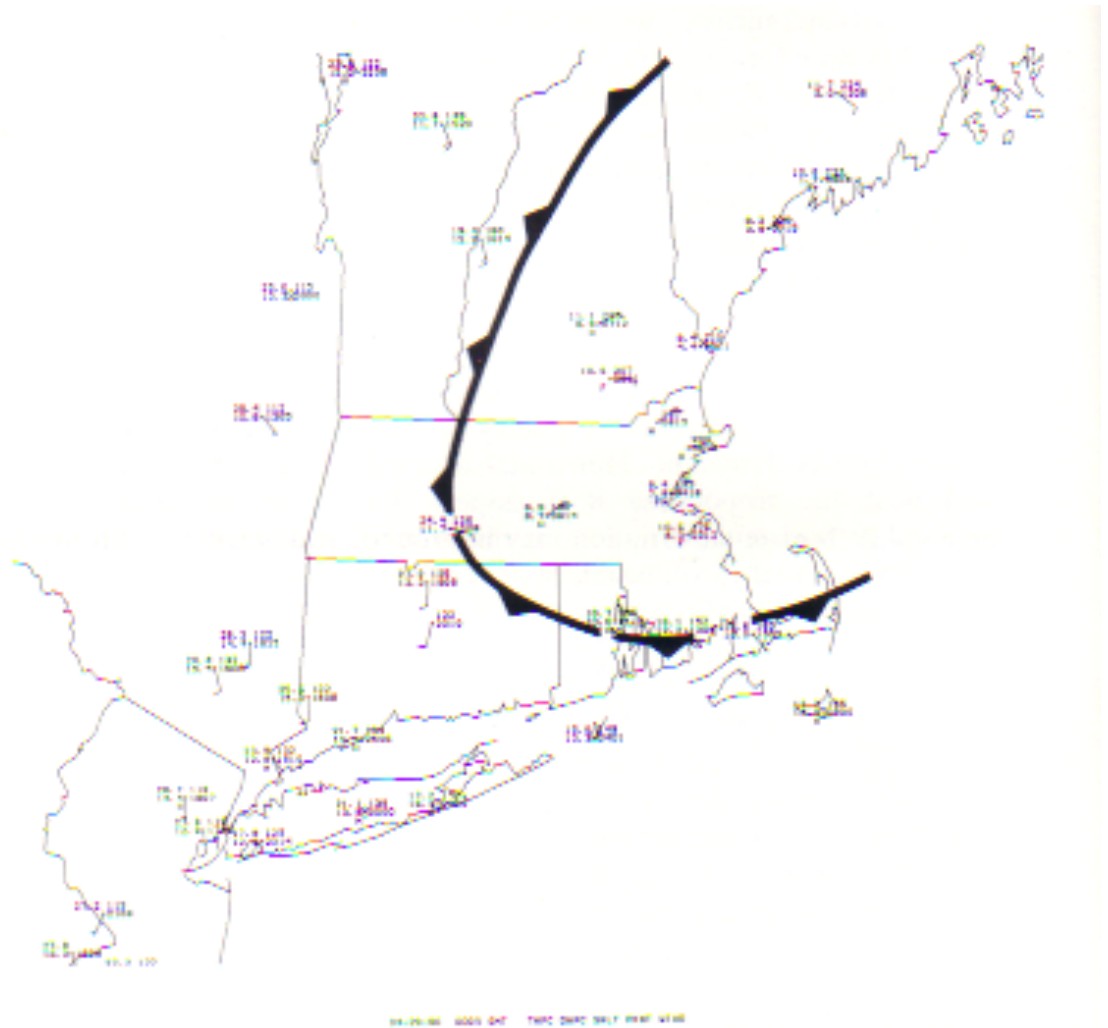


Wallace and Hobbs 1977 Fig. 3.19/3.20

## “Back-Door” cold front:

A cold front that approaches an area from the east

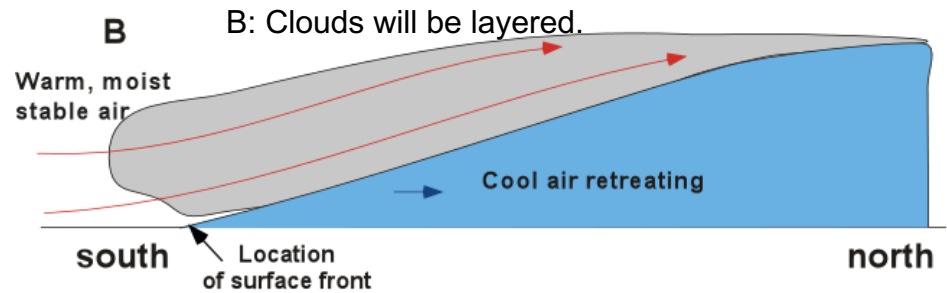
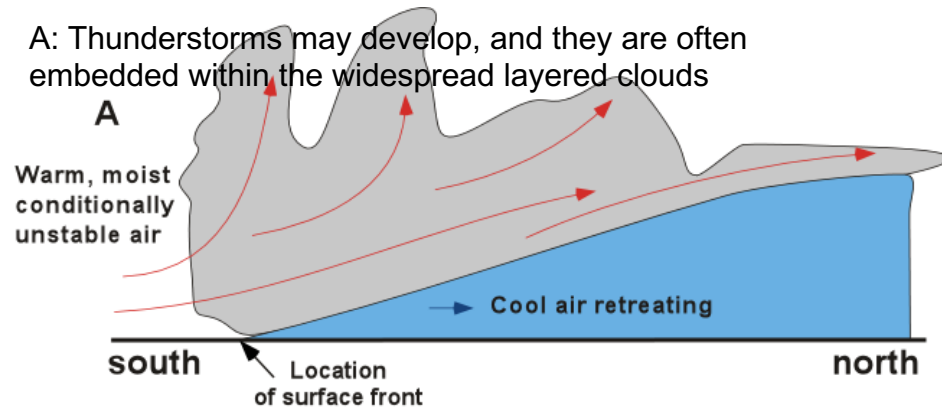
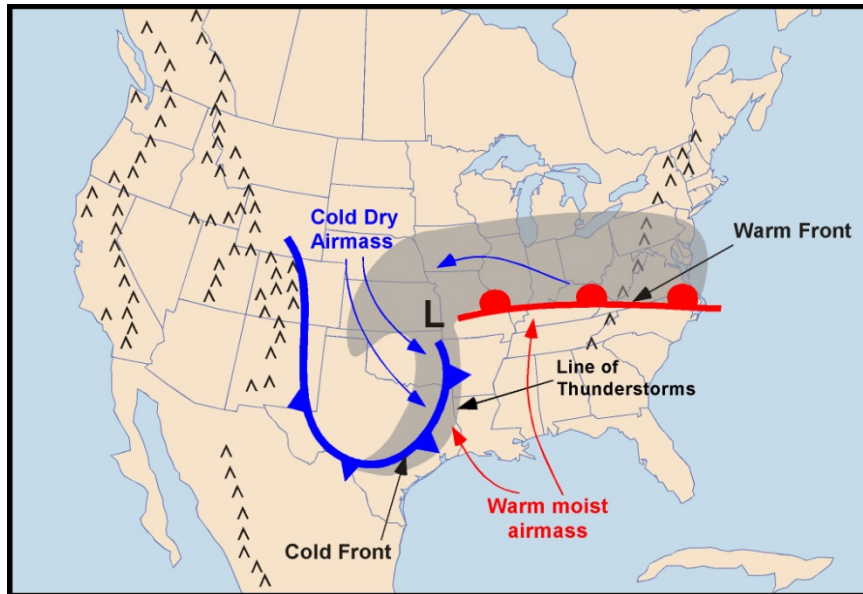
Back door cold fronts are common in New England and along the east side of the Rocky Mountains



**Figure 2.16** Example of a New England back-door cold front 0000 UTC, April 29, 1990. Winds east of the front are off the cold Atlantic; winds west of the front are off the warmer land. Temperature and dew point ( $^{\circ}\text{C}$ ) plotted according to convention. Pressure plotted is altimeter setting in tens of mb without the leading “10.” Full wind barb =  $5 \text{ m s}^{-1}$ ; half wind barb =  $2.5 \text{ m s}^{-1}$ .

**Warm front:** Regardless of the cloud formations or precipitation, we say that a front is a warm front if the cold air is retreating and the warm air is advancing.

The leading edge of the cold airmass typically has a shape like a dome, as shown in the figure.



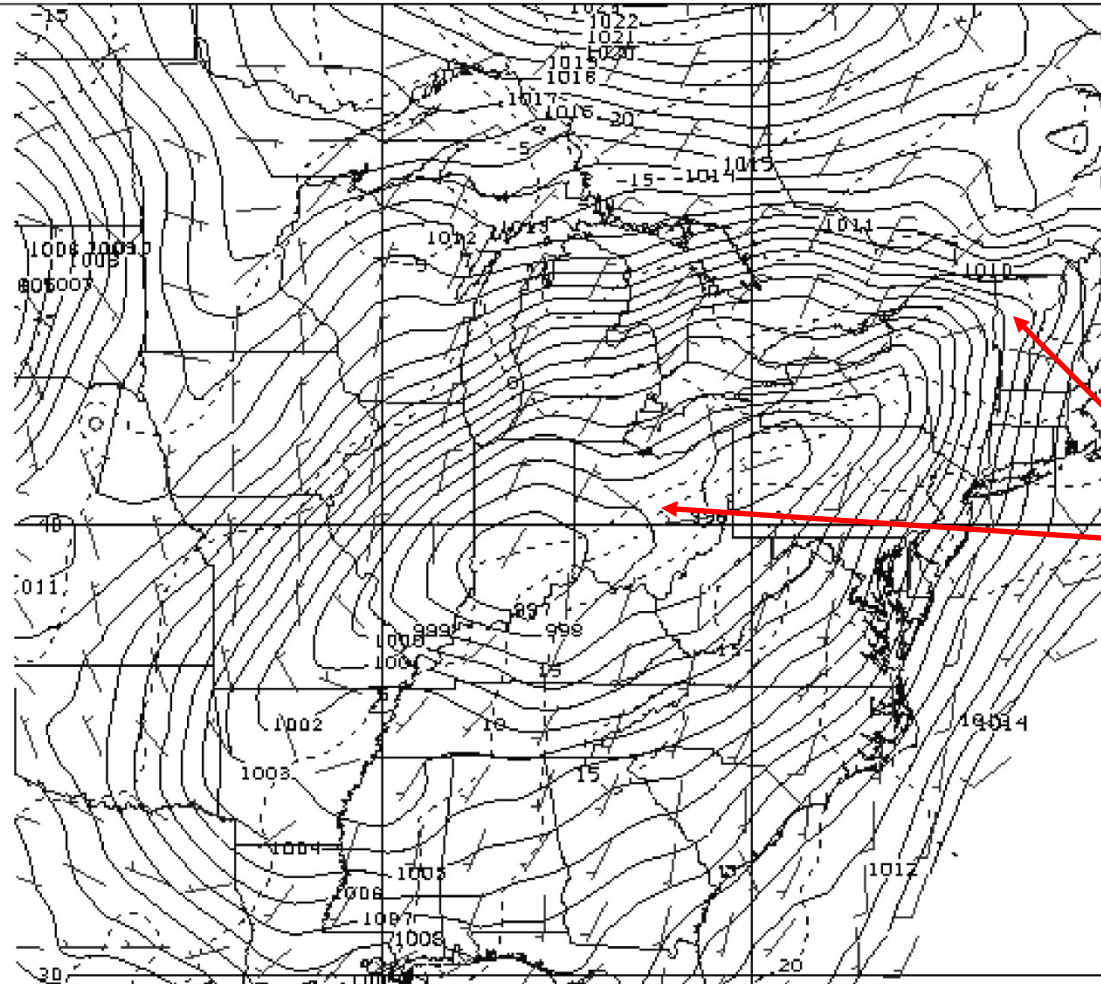
©2002 Kendall/Hunt Publishing

The type of weather along a warm front depends on the stability and moisture content of the warm air.

Widespread layered clouds will develop. These clouds are deepest just north of the frontal boundary and progressively become thinner and higher toward north. Precipitation is heaviest closer to the frontal boundary & lighter to the north.



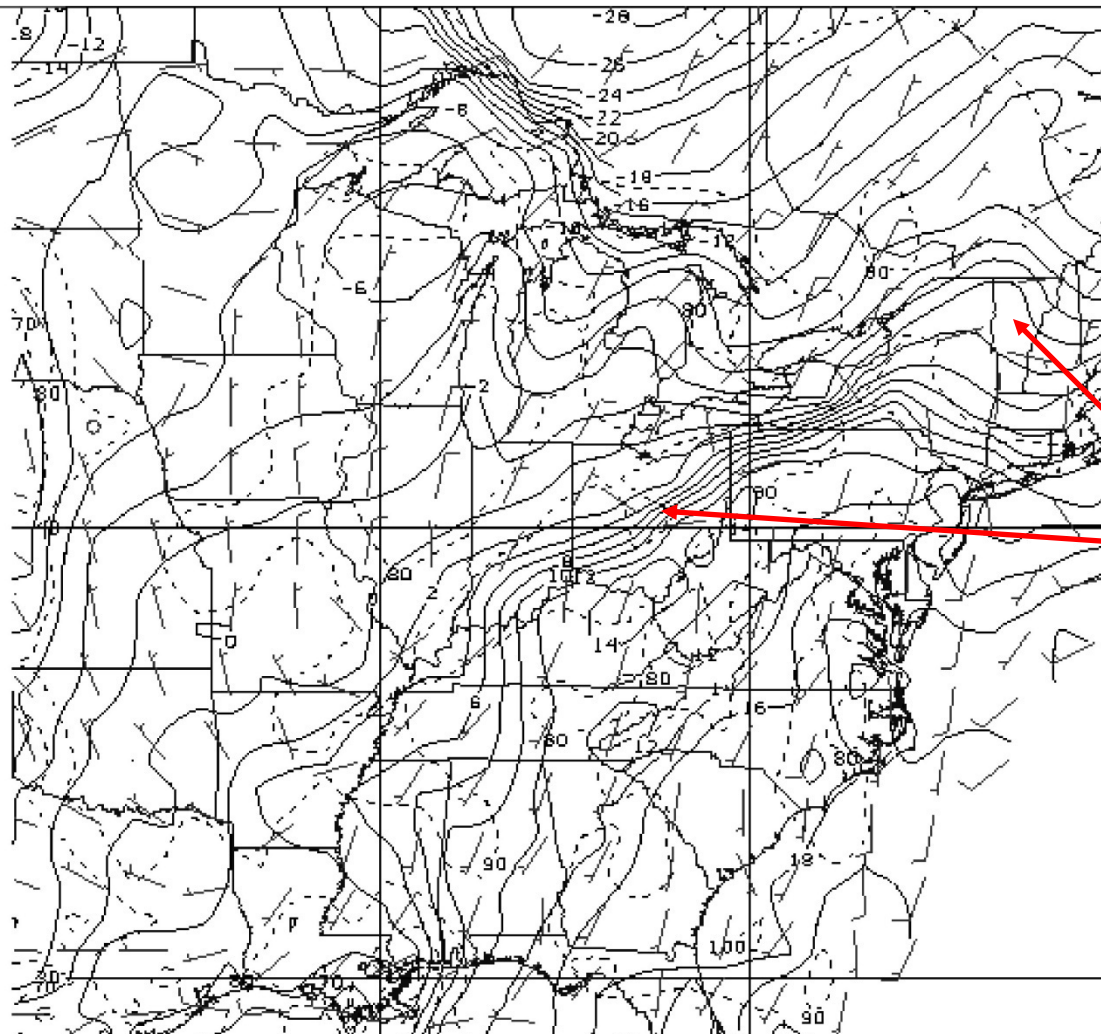
## Analyzing warm fronts



Pressure  
(solid lines)  
Temperature  
(dashed lines)

1. Warm front will often lie along a distinct pressure trough
2. Front is (normally) at southern edge of a moderate-strong N-S temperature gradient  
[warm fronts are occasionally oriented NW-SE on Great Plains (i.e. an NE-SW temperature gradient)]

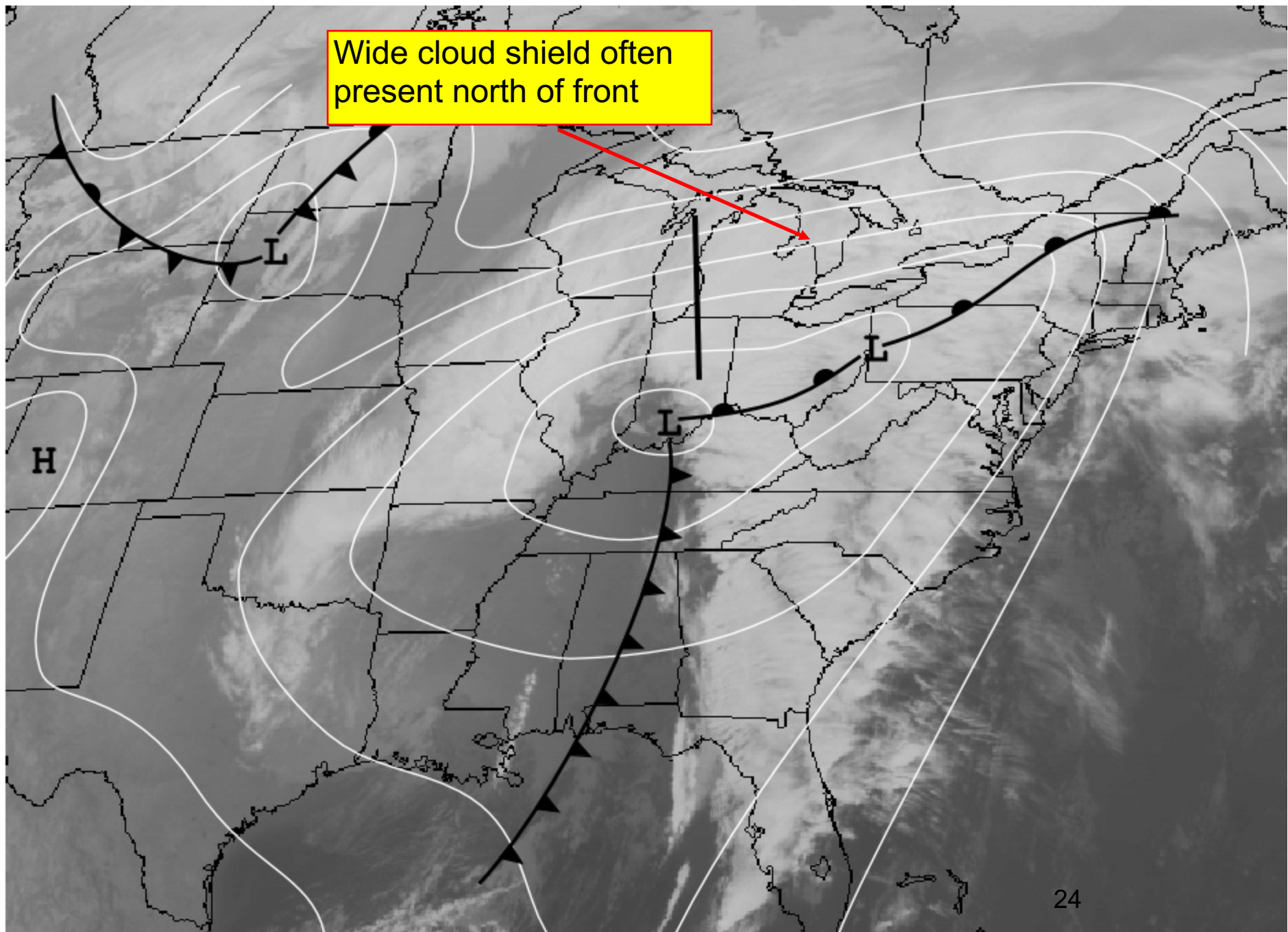
## Analyzing warm fronts



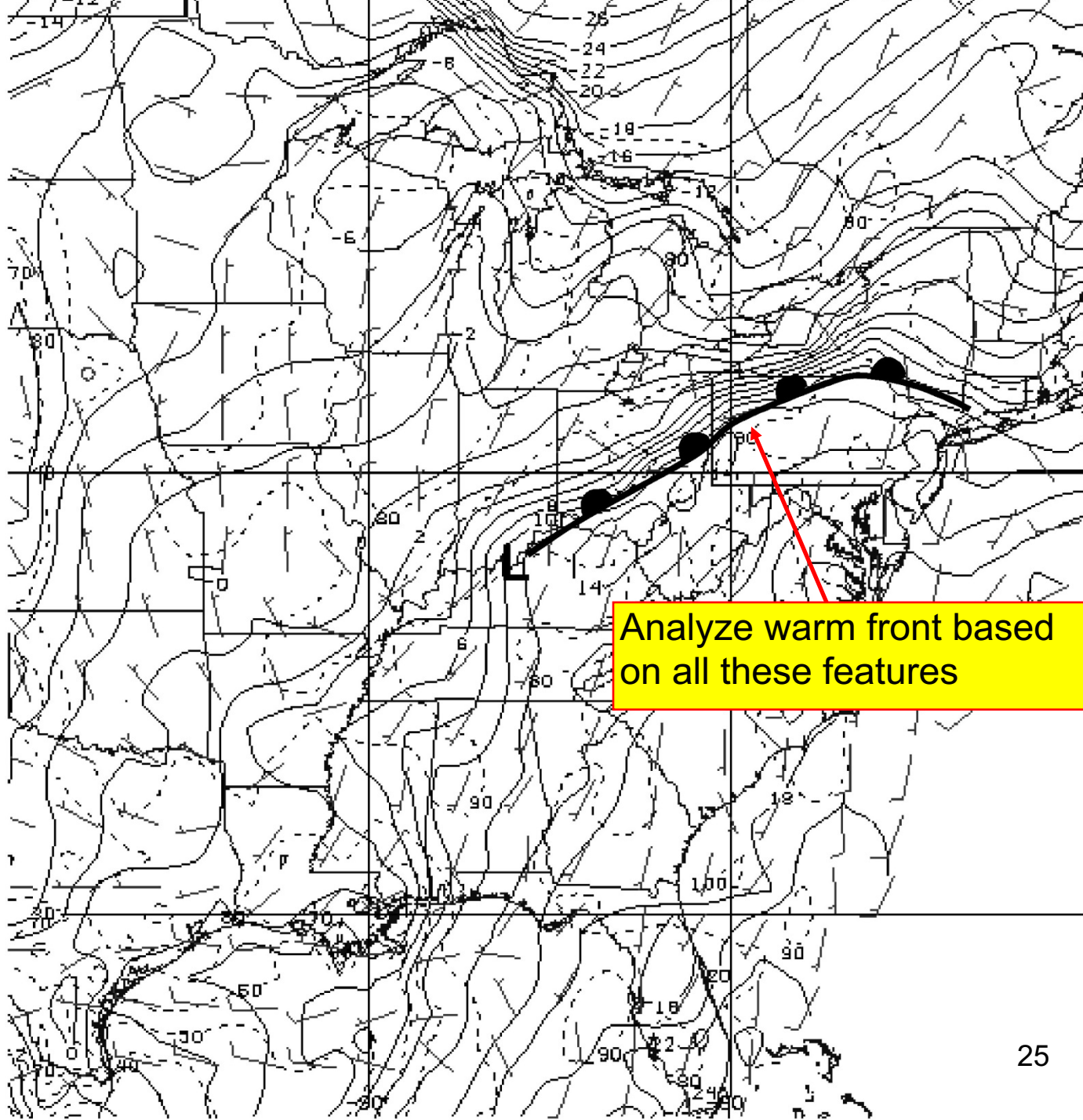
Dewpoint  
(solid lines)  
wind barbs

1. Warm front marked by wind shift – typically easterly or northeasterly winds north of the front, southerly winds south of the front.
2. Front is (normally) at southern edge of a moderate-strong N-S dewpoint gradient

Wide cloud shield often present north of front









# Summary of Cold Fronts & warm Fronts

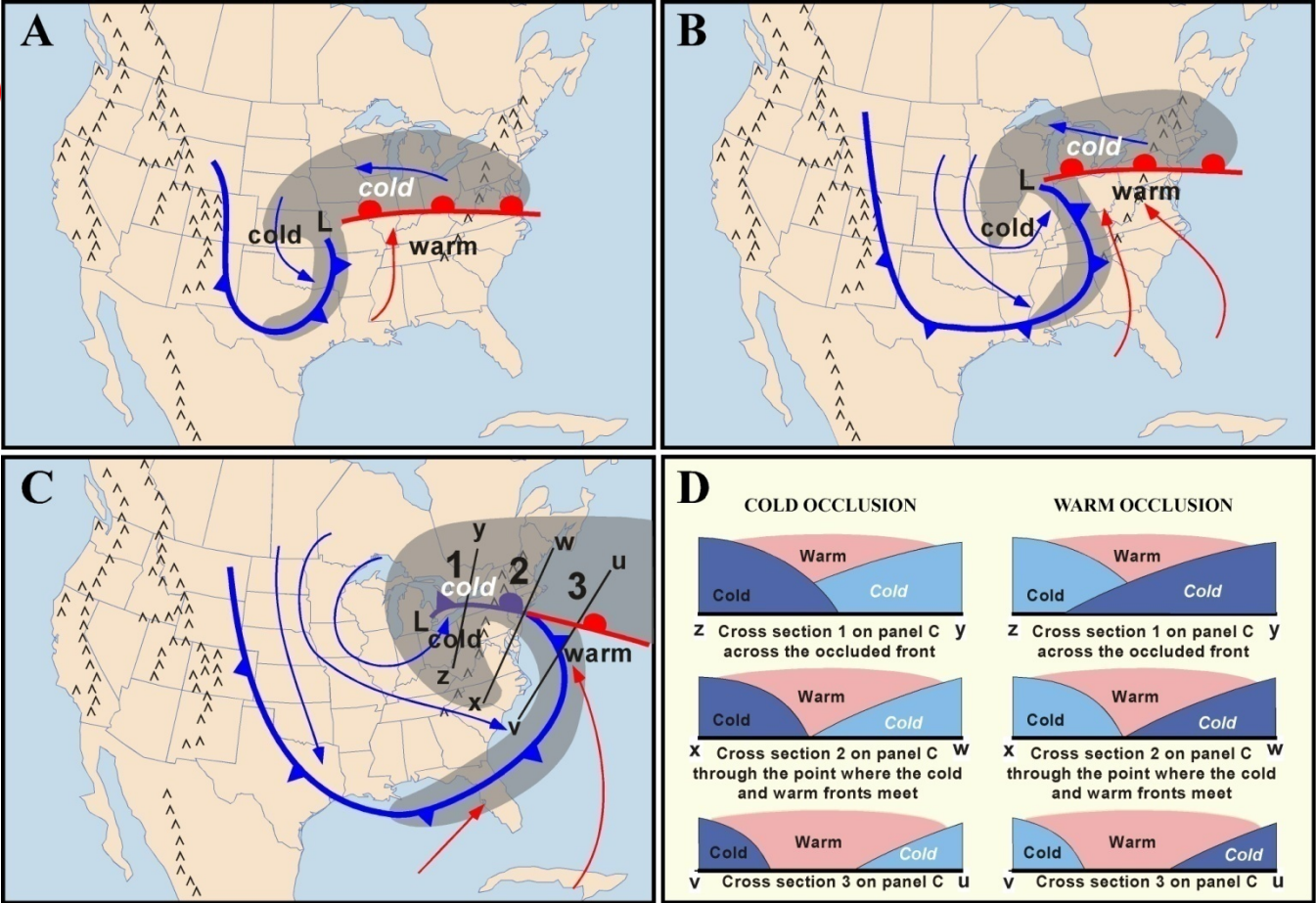
## Locations:

- a) Cold fronts are typically located in the southwest quadrant of a cyclone early in its lifecycle.
- b) Warm fronts are usually found on the east side of a cyclone.
- c) Because of the tilt of the airmass boundary, the front's horizontal position varies with elevation.

# Occluded fronts (Classical description)

As cyclones develop, cold air to the west of the cyclone advances rapidly southward around the center of low pressure

While the cold air to the north of the warm front retreats northward slowly.



The cold front will progress around the south side, then progress northeastward, approaching the warm front. When the cold air behind the cold front comes in direct contact with the cold air north of the warm front, a new airmass boundary is created called an *occluded front*.

As the fronts meet, warm air is forced aloft over both the cold air masses

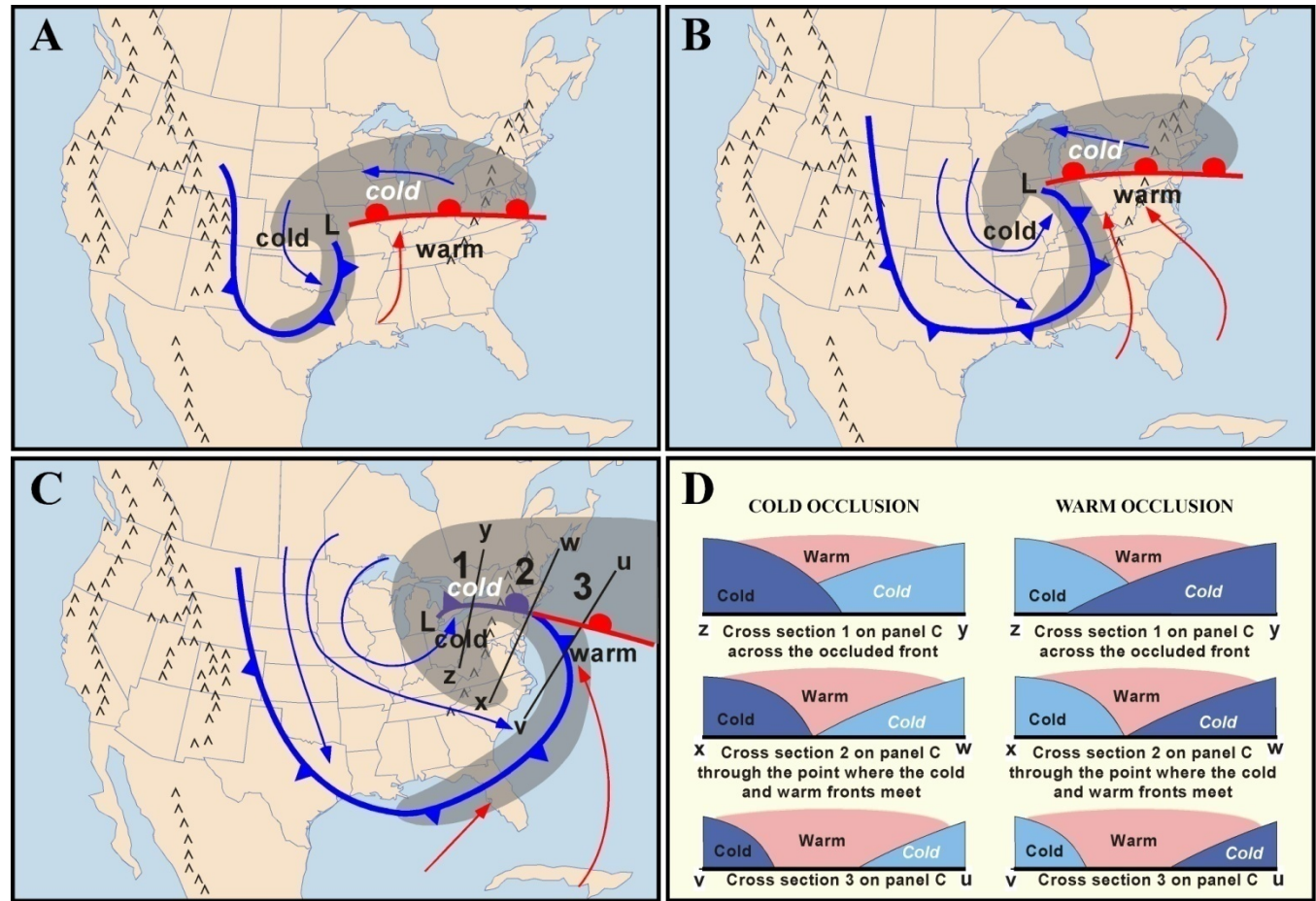
# Warm & Cold Occlusion

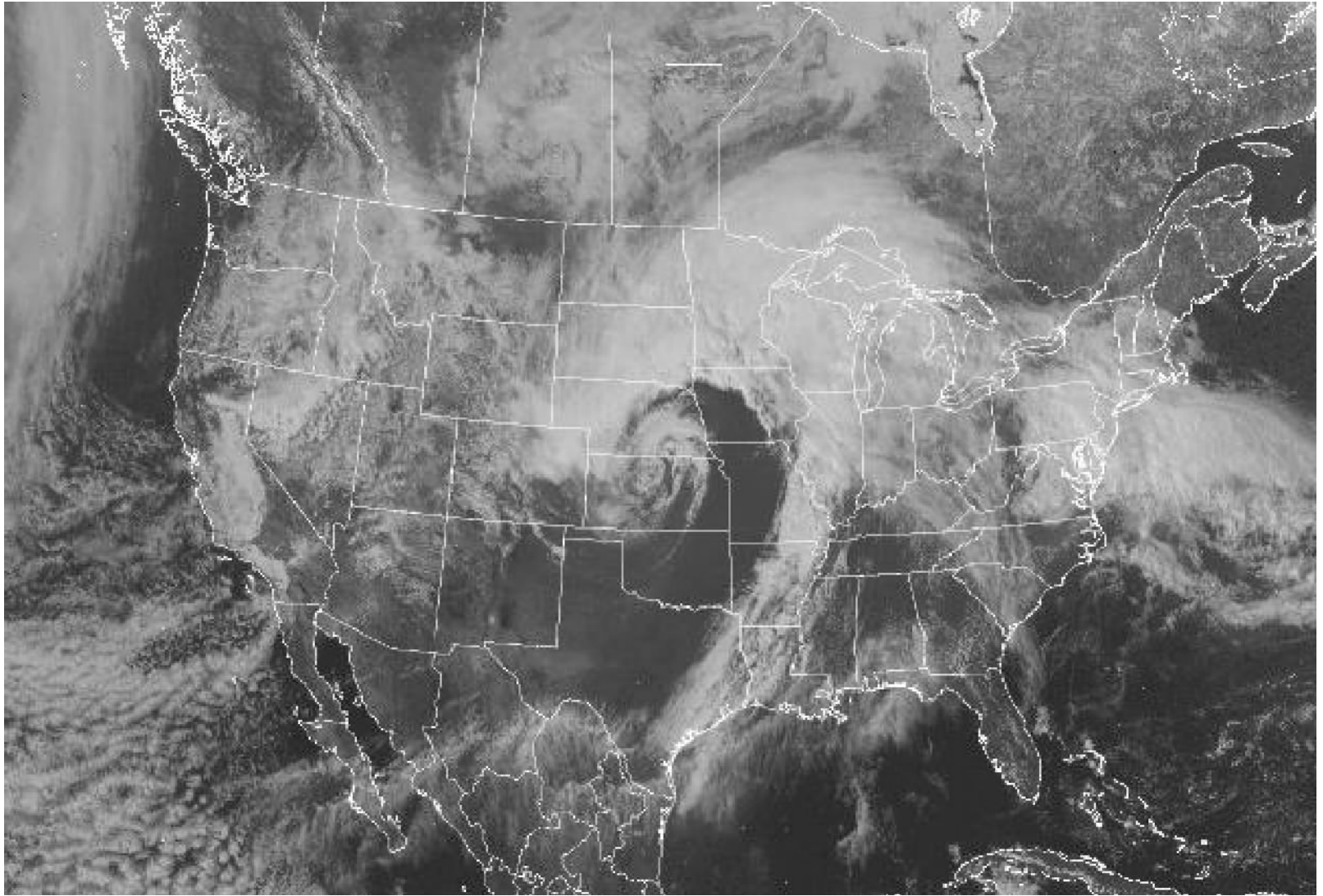
The 3D structure of an occluded front depends on the temperatures within the cold air behind the cold front and north of the warm front.

In **cold occlusion**, the air behind the cold front is colder than air north of the warm front.

In **warm occlusion**, air north of the warm front is colder than the air behind the cold front.

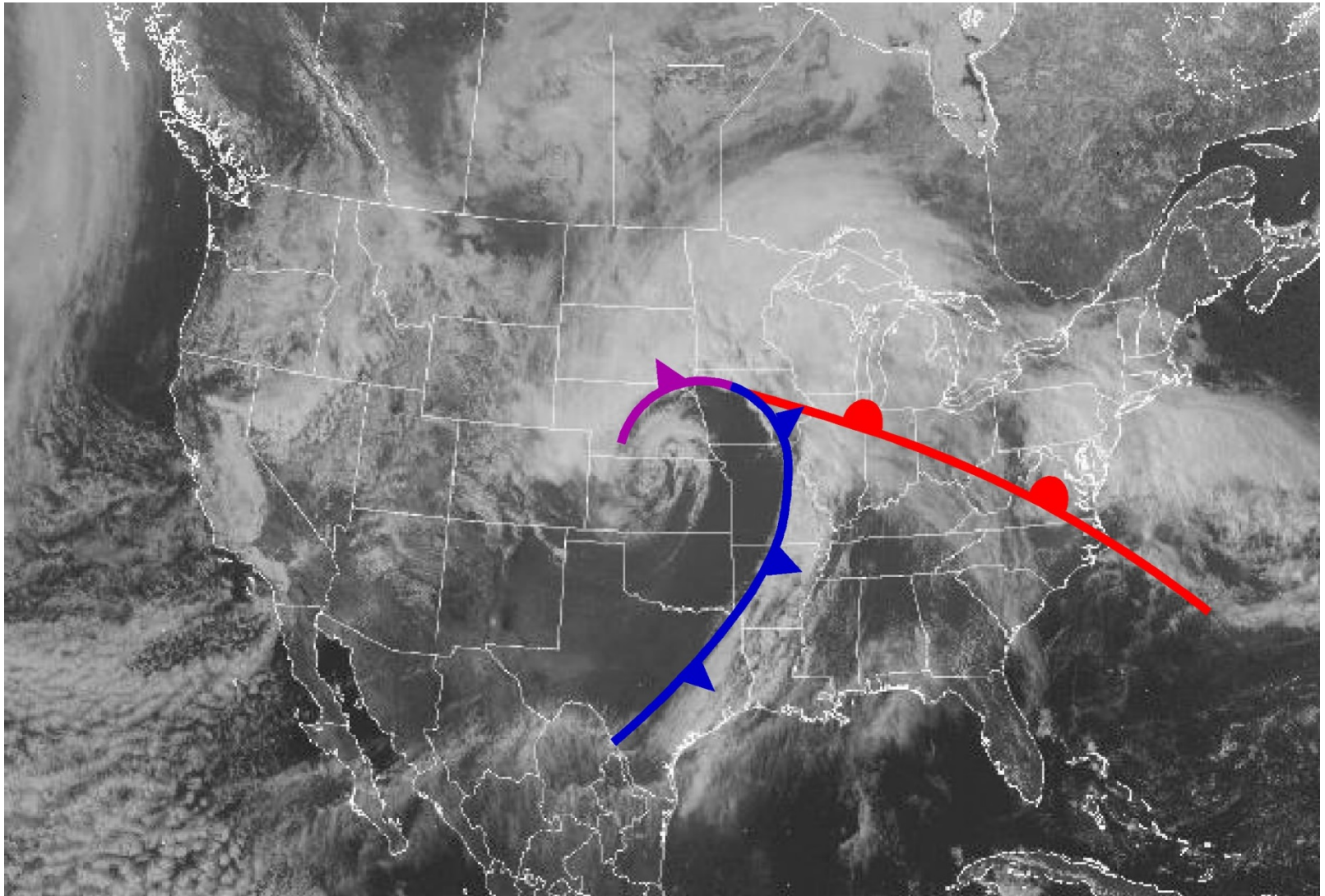
Warm occlusions appear to be more common than cold occlusions. Occluded fronts develop during the mature & dissipating stages of cyclones. They are typically characterized by widespread cloudiness & rain or snowfall.



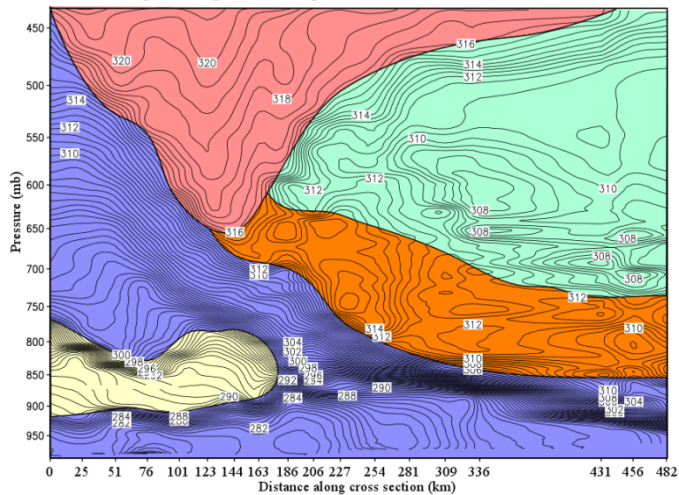




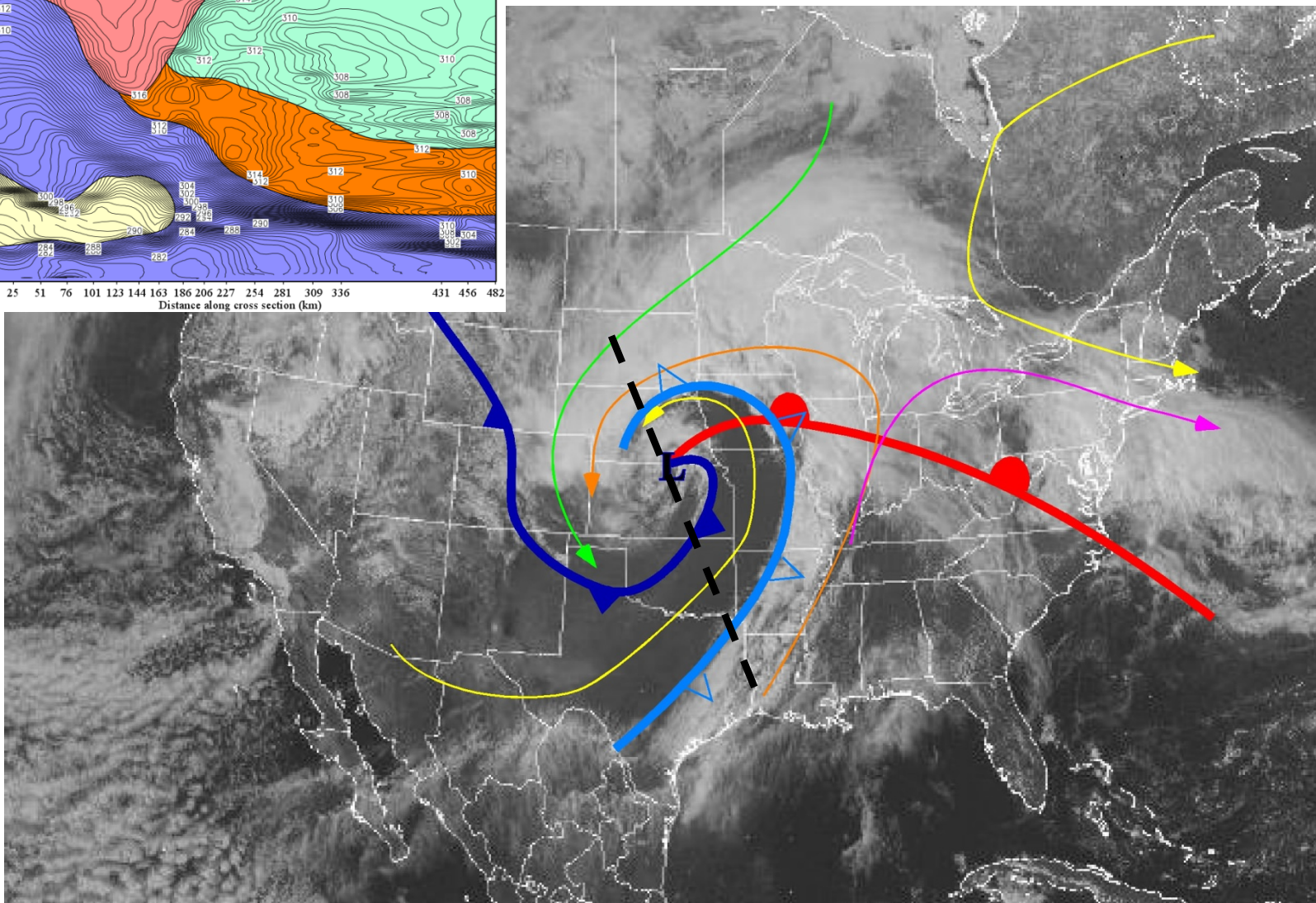
# Classic; Traditional



Equivalent potential temperature and airmasses (color)



# New Findings on Lee Cyclones





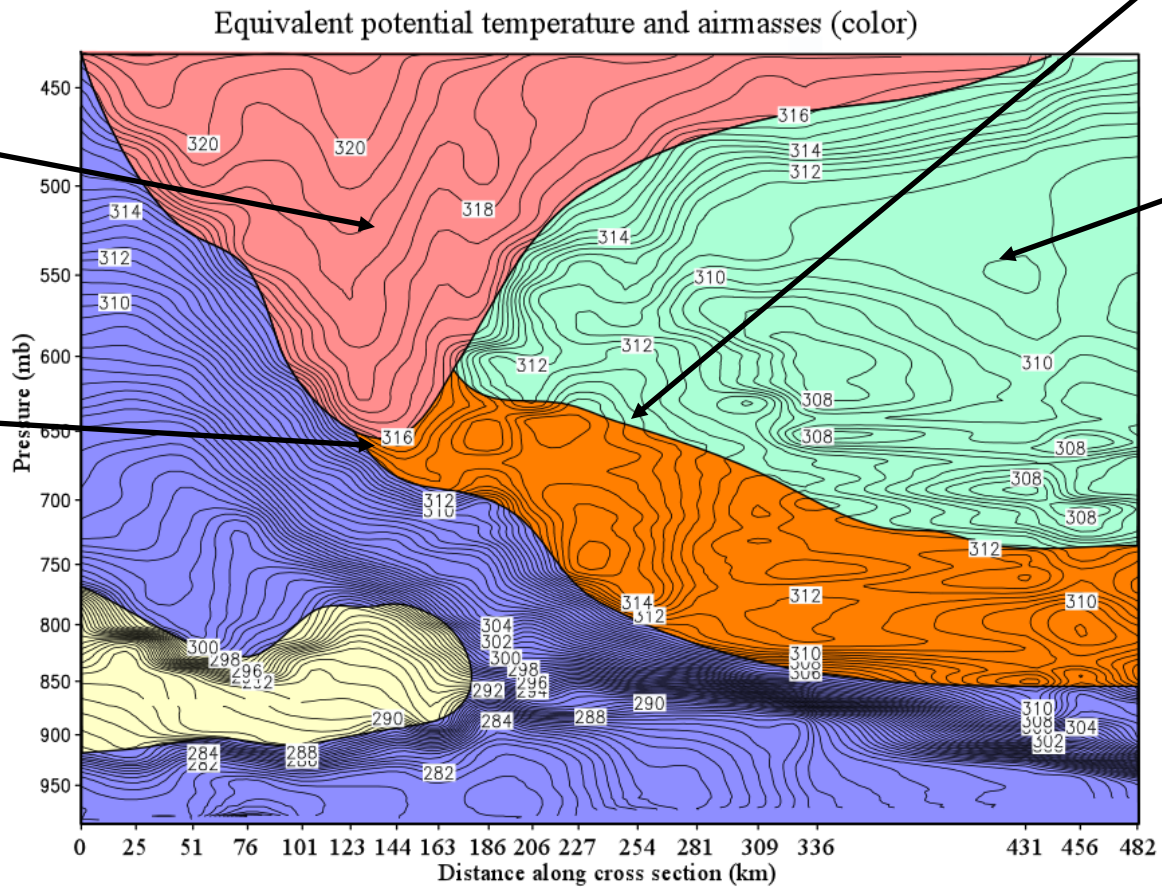
# Vertical Cross Section of a Lee Cyclone Showing Airmass Structure not as simple as the previous conceptual model suggests

**TROWAL:** Trough of warm air aloft – primary generator of precipitation

Cyclone Center: Intersection point of Warm front & cold front

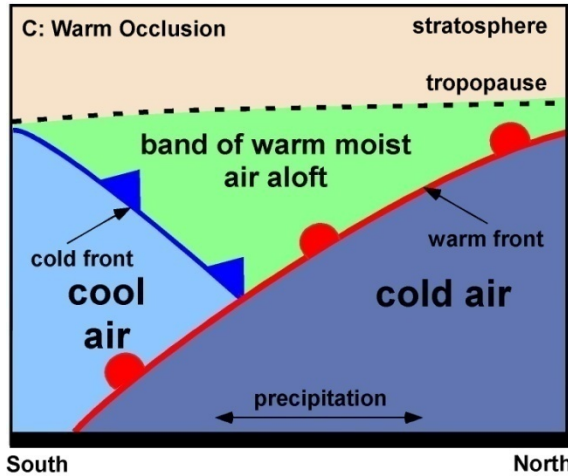
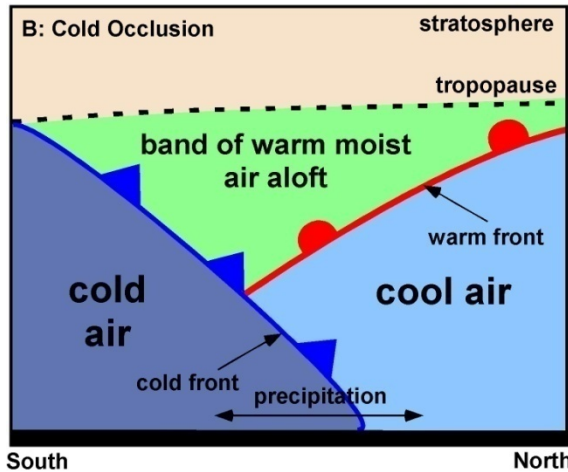
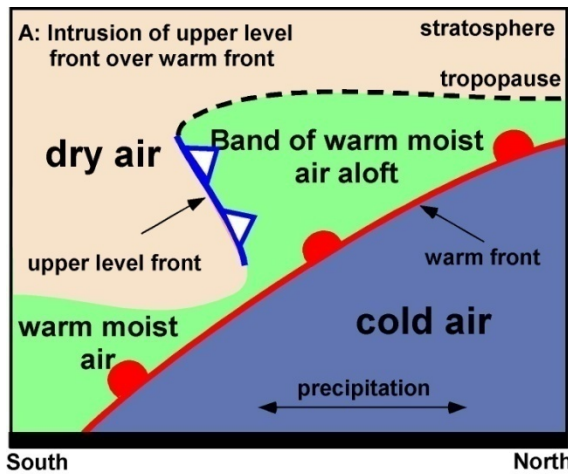
Upper level front (Cold Front Aloft)

Dry slot





# New findings about occlusion structure in many cyclones forming east of the Rocky mountains



Cold Occlusion: Classical occlusion structure

Warm Occlusion: Classic occlusion structure

# Upper level front

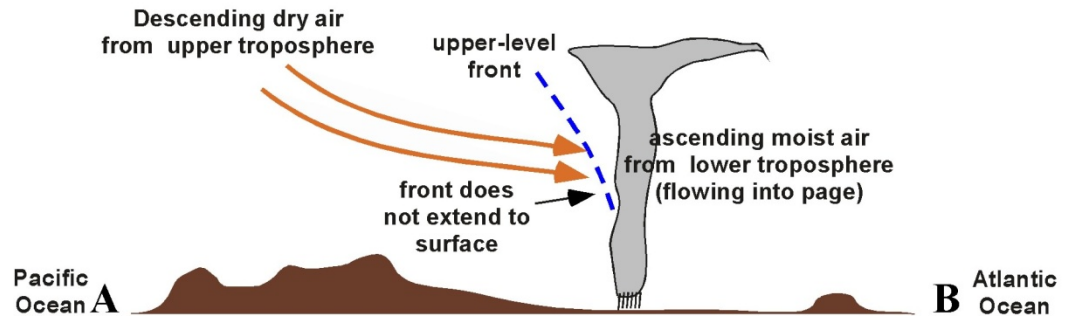
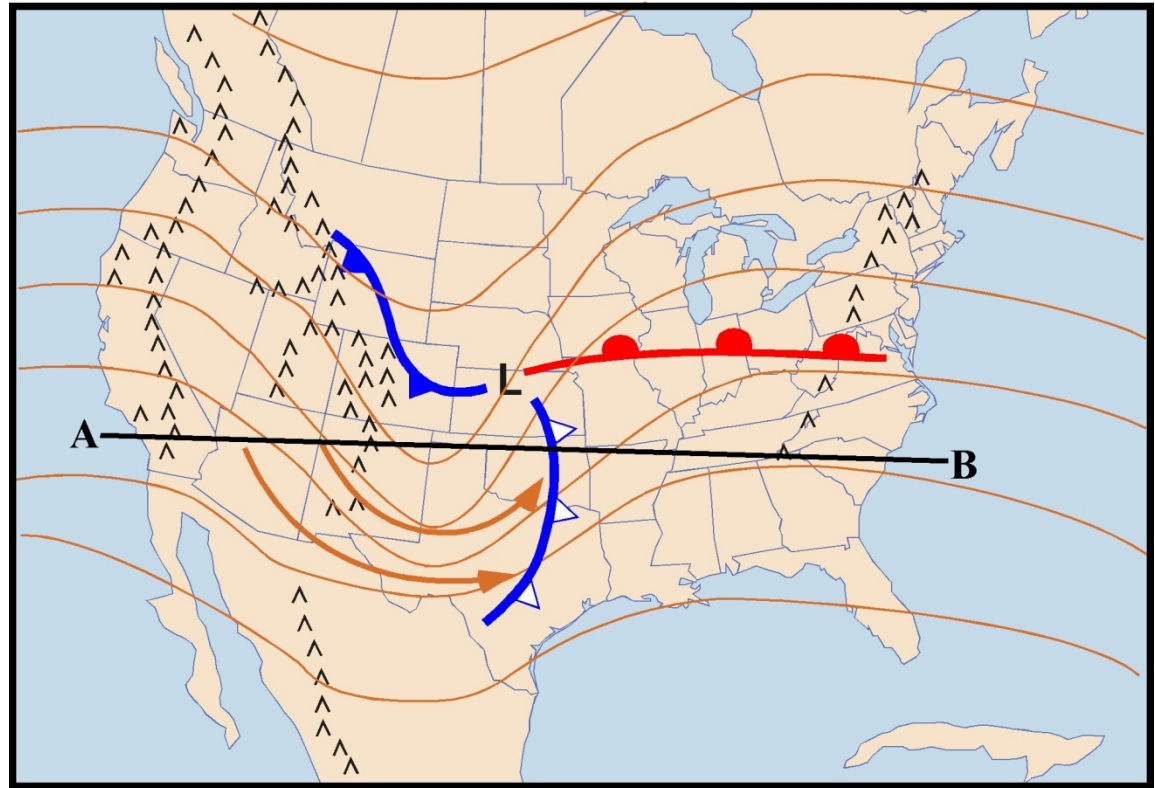
(Also called Cold Front Aloft)  
Common feature within  
cyclones that form east of the  
Rockies.

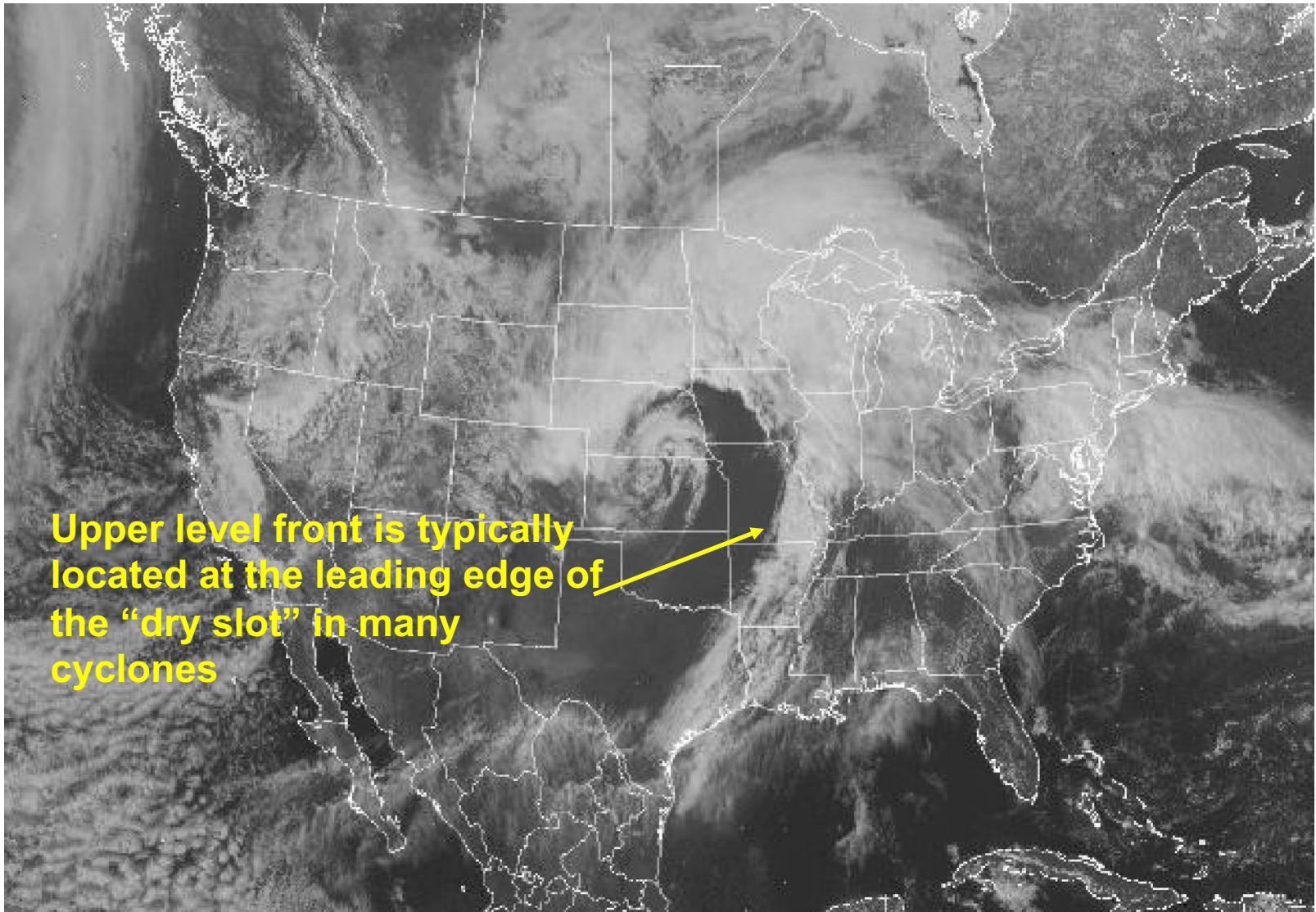
Boundary between:

Air descending from the  
upper troposphere that  
originates in the convergent  
region of the trough

and

Air ascending from the  
lower atmosphere in the  
southeastern quadrant of a  
cyclone

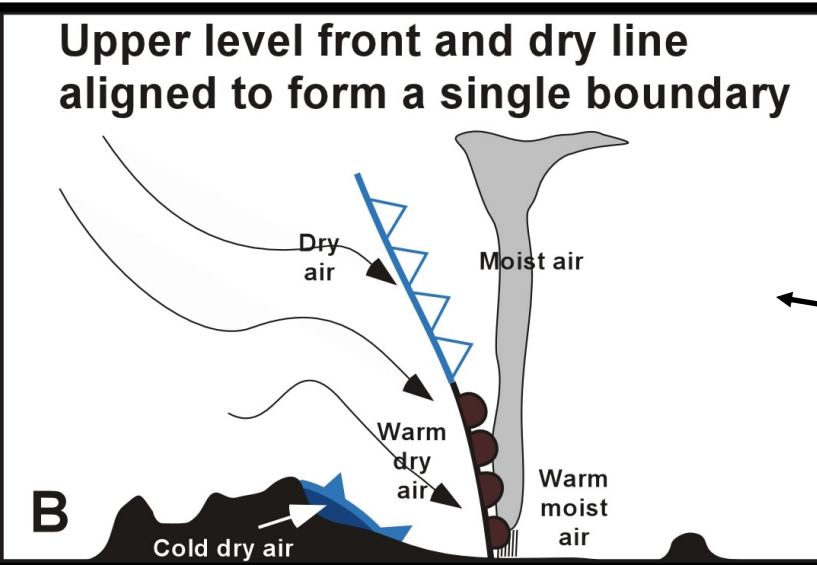
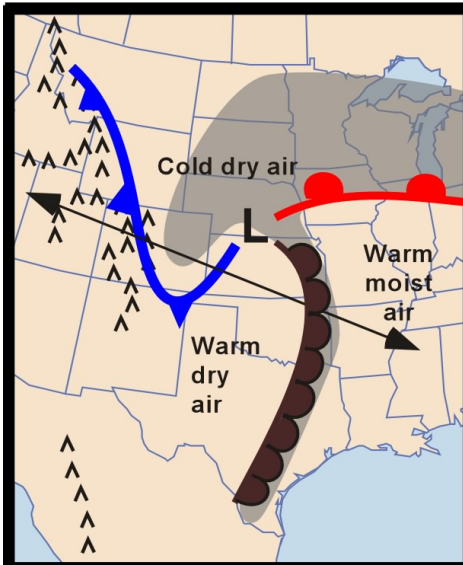
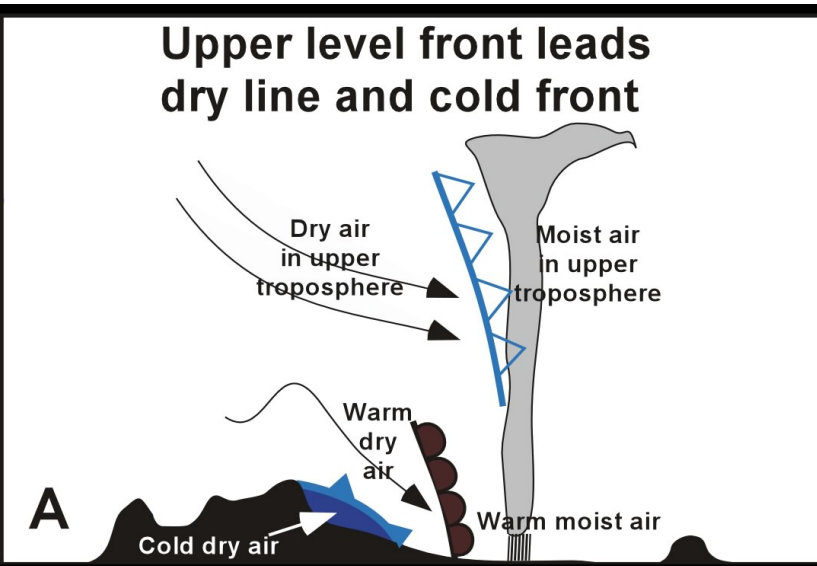
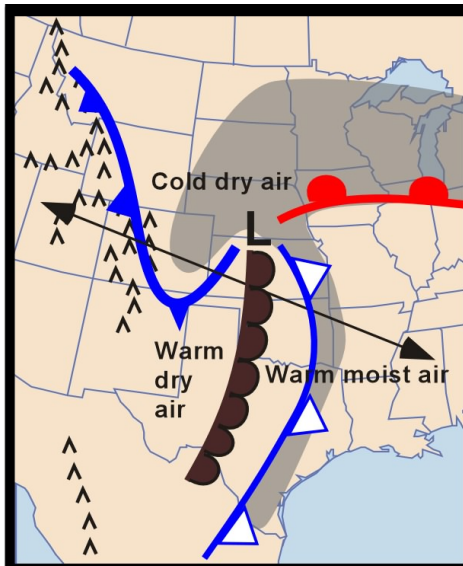




**Upper level front is typically located at the leading edge of the “dry slot” in many cyclones**



The upper level front is “upper level” in some cyclones, but may extend to the surface as a single front the boundary is sometimes analyzed as a surface dry line, while other times as a surface cold front.



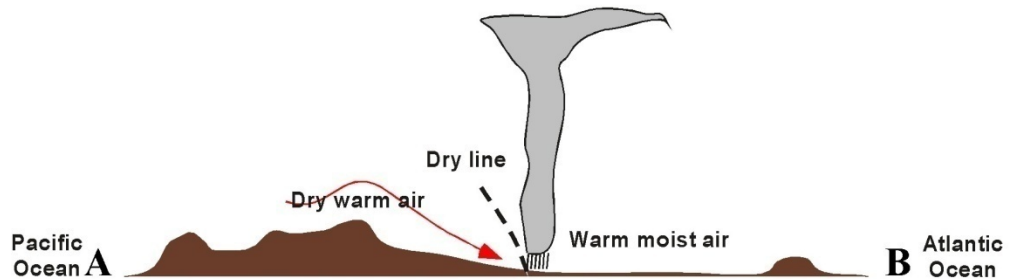
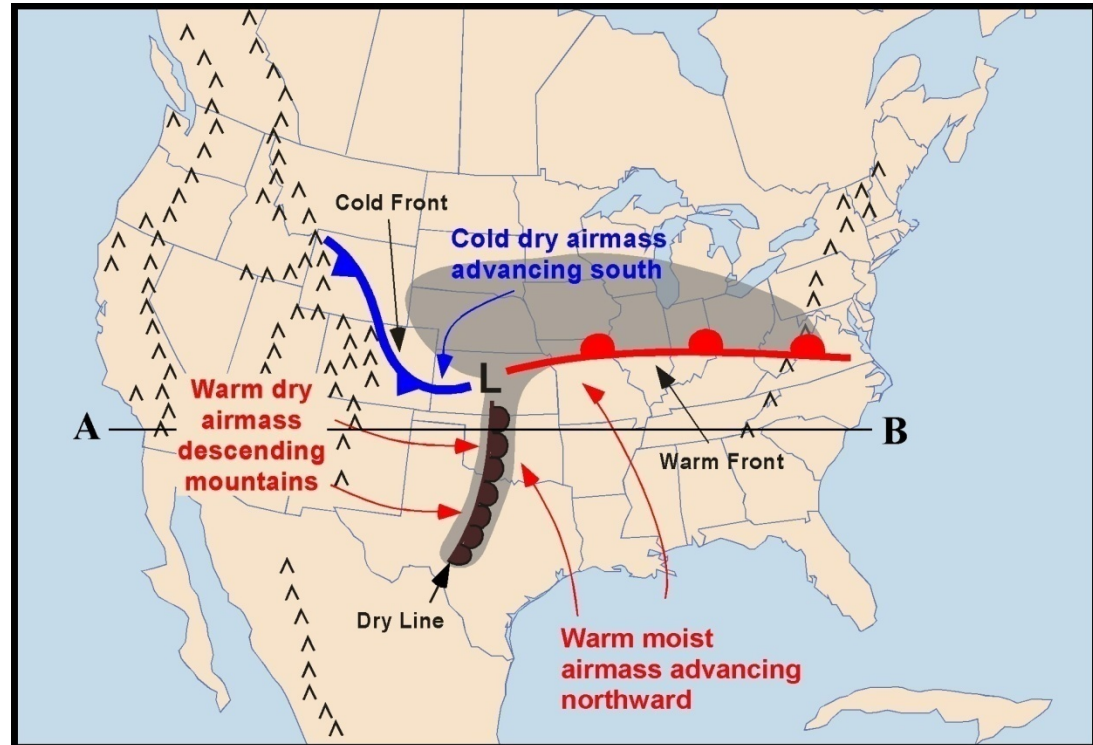
Often happens  
When a Pacific  
Cold front moves  
Across southern  
Rockies



# Dry Lines

Dry Line: A front characterized by a sharp moisture difference, but little temperature change

Dry lines develop when air flowing eastward from the high desert plateau regions of Arizona, Colorado, and New Mexico descends the Rockies into the southern plains and encounters moist air flowing northward from the Gulf of Mexico



# The Great Plains Dryline

Behind the dry line

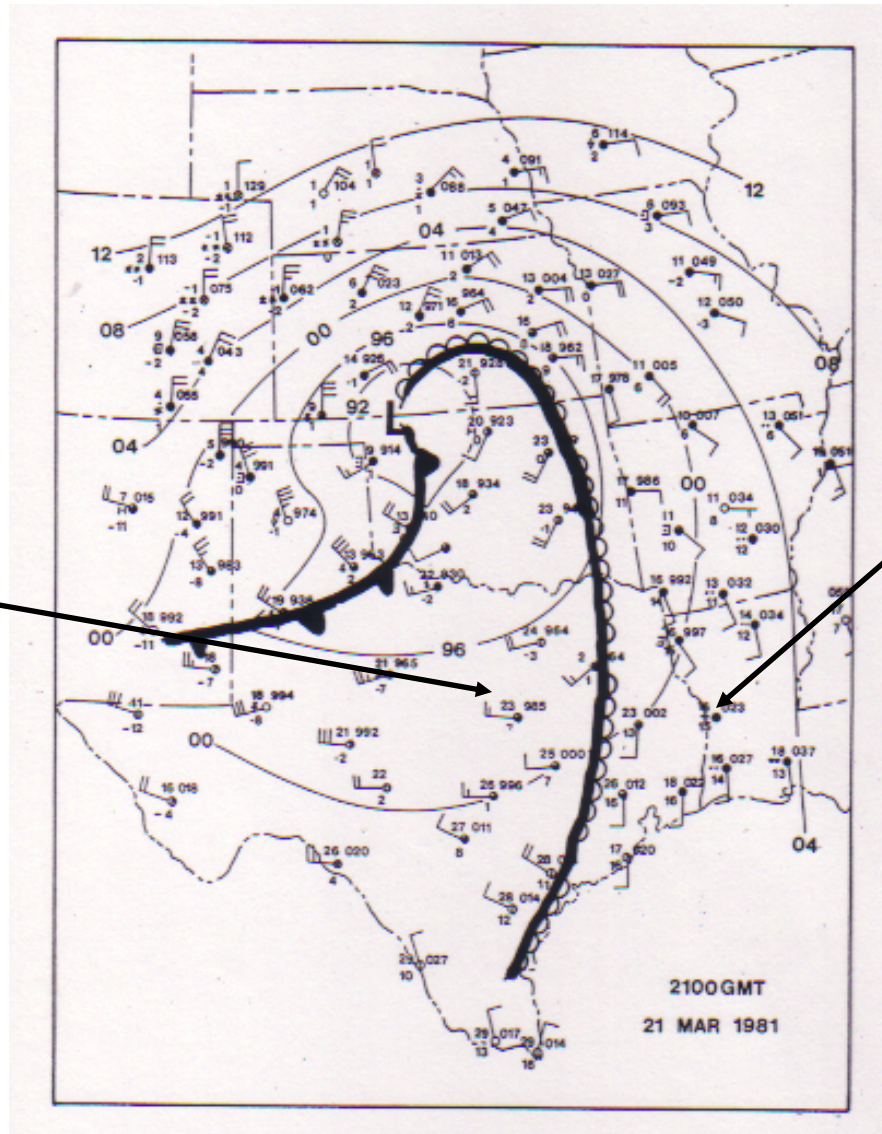
Westerly winds  
(often strong)

Clear skies

Daytime: Warm  
Temps

Large diurnal  
temperature  
range

Low moisture



Ahead of the dry line

South or southeast  
Winds

Hazy/cloudy skies

Daytime: warm  
temps

Small diurnal  
Temperature range

High moisture

Fig. 2.40 Bluestein II

**Severe thunderstorms often develop along dry lines in late afternoon, particularly when dry air is present aloft above the moist air east of the dry line.**

**Dry line boundary**



Courtesy of Bruce Lee



# Stationary Fronts

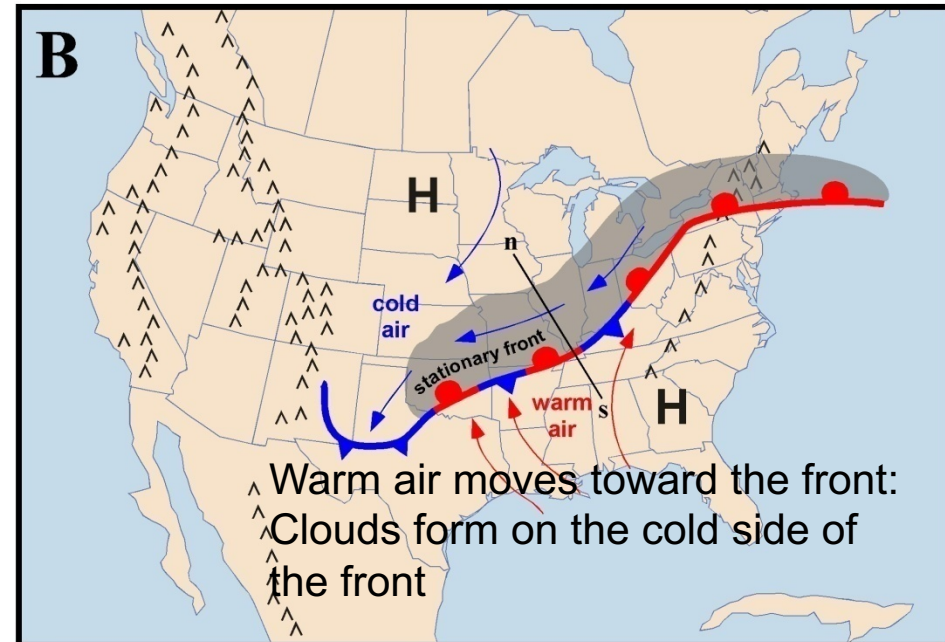
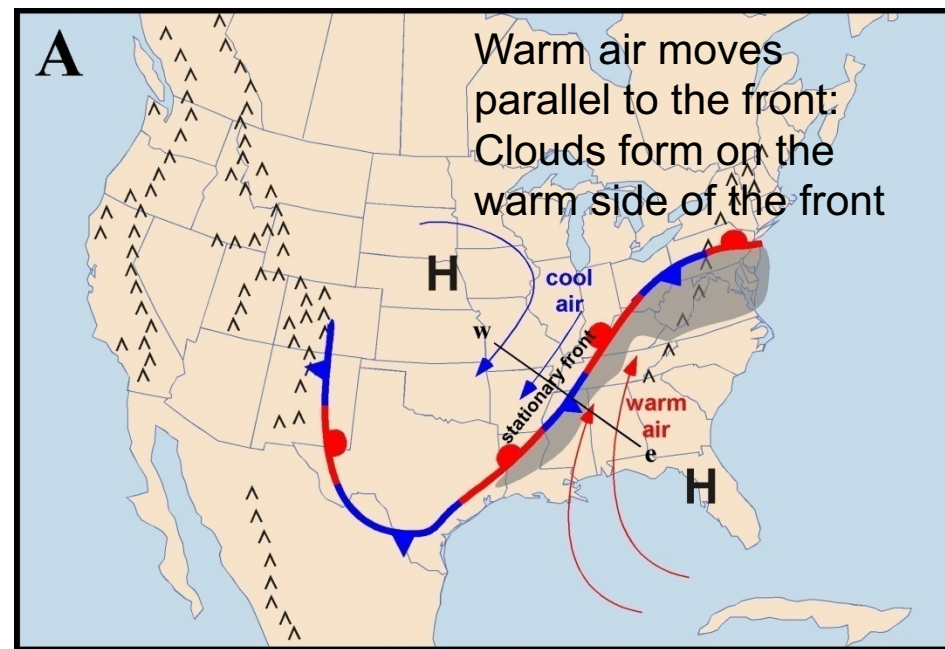
Fronts are sometimes stationary. Although the boundary is stationary, air on both sides of the boundary can be moving.

With a *stationary front*, air on the cold side of the front will always be flowing parallel to the front.

Regardless of the cloud formations or precipitation, we say that the front is a **stationary front** if the cold air is neither advancing or retreating.

Warm air conditionally unstable:  
*A line of showers & thunderstorms  
May develop in the warm air—  
flash flooding.*

Warm air stable:  
*widespread layered clouds may  
form over the front, with rain falling  
on the cold side.*

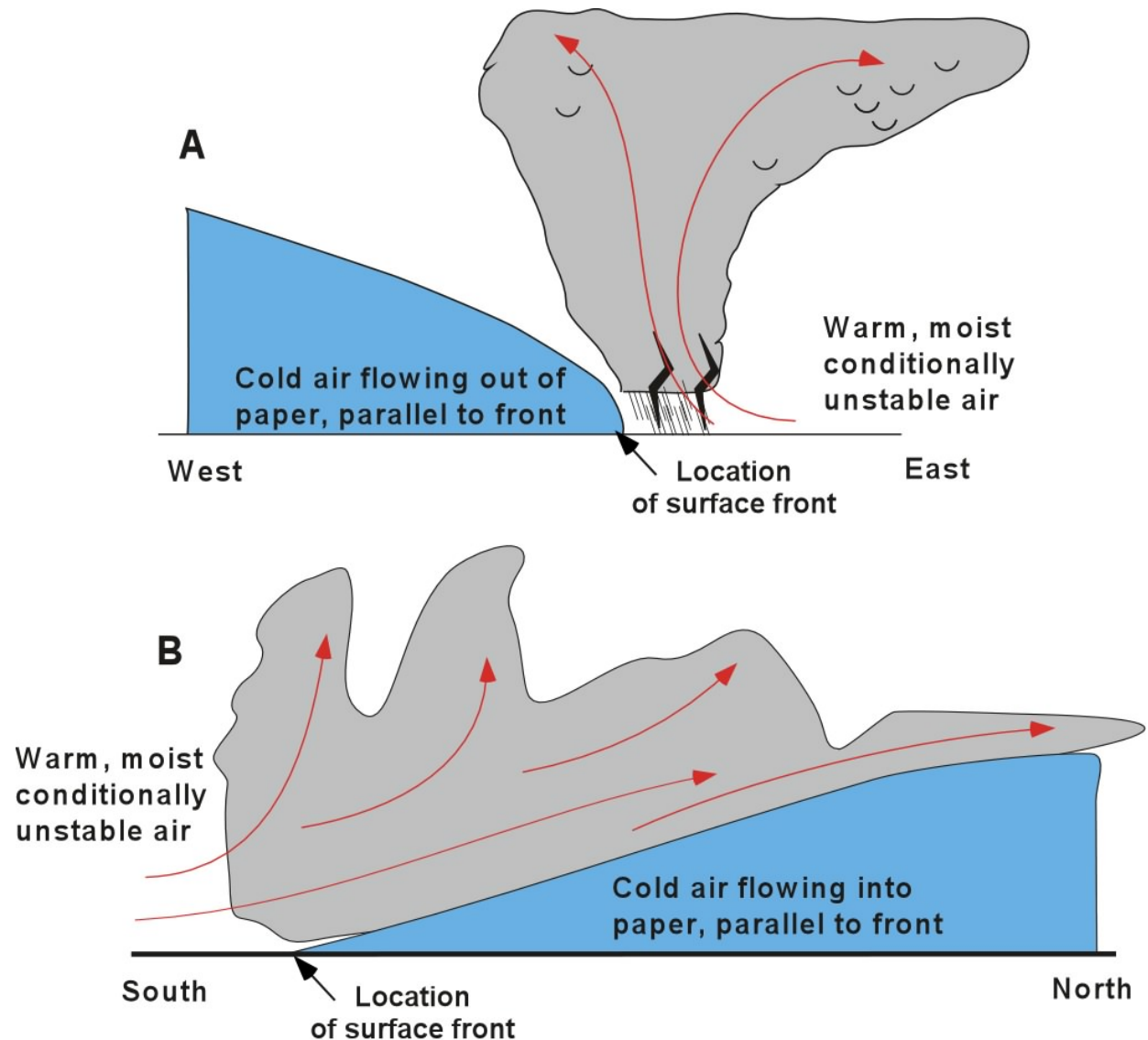


Stationary fronts may have **physical structure** similar to cold fronts or warm fronts

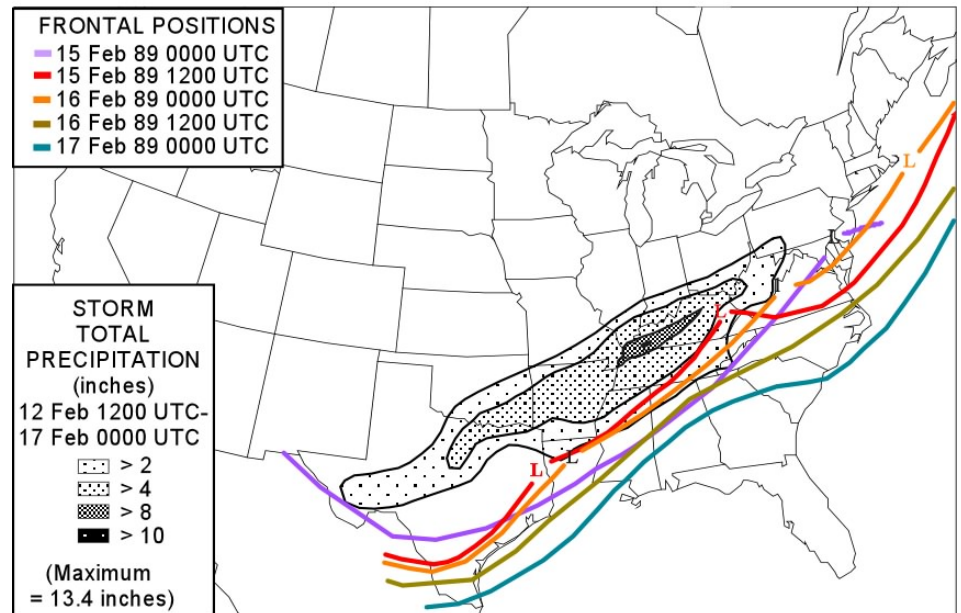
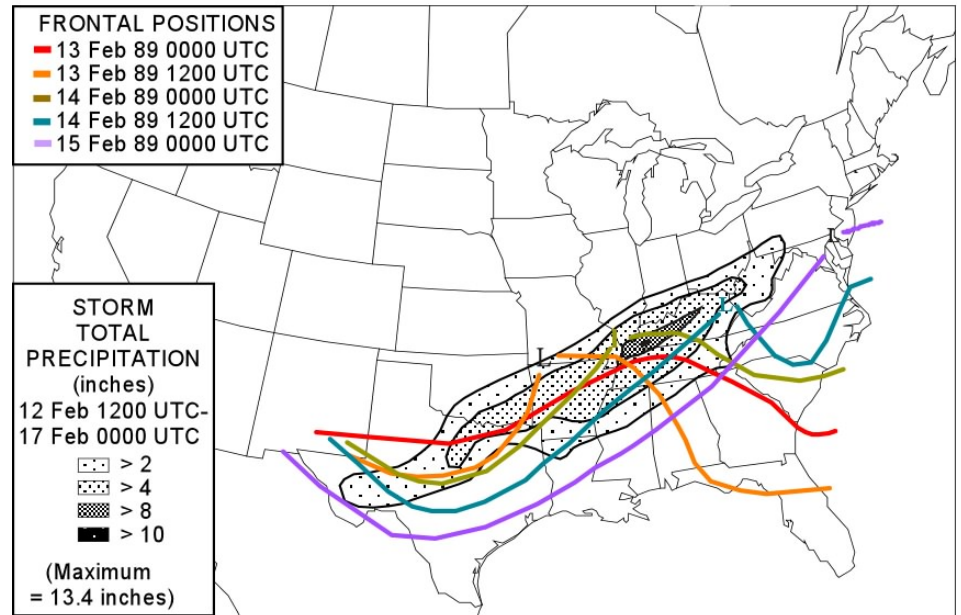
**Significant  
weather along  
stationary fronts**

**FLASH FLOODS**

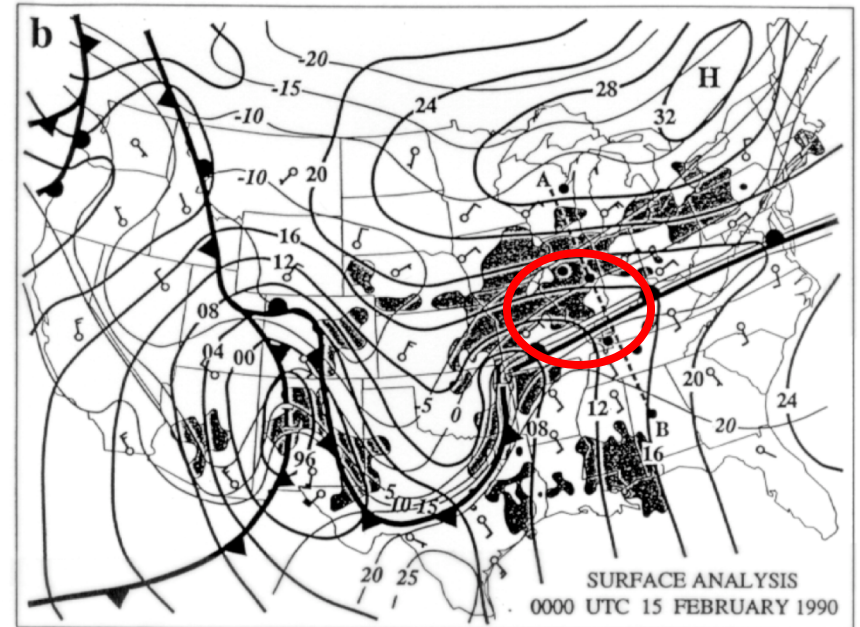
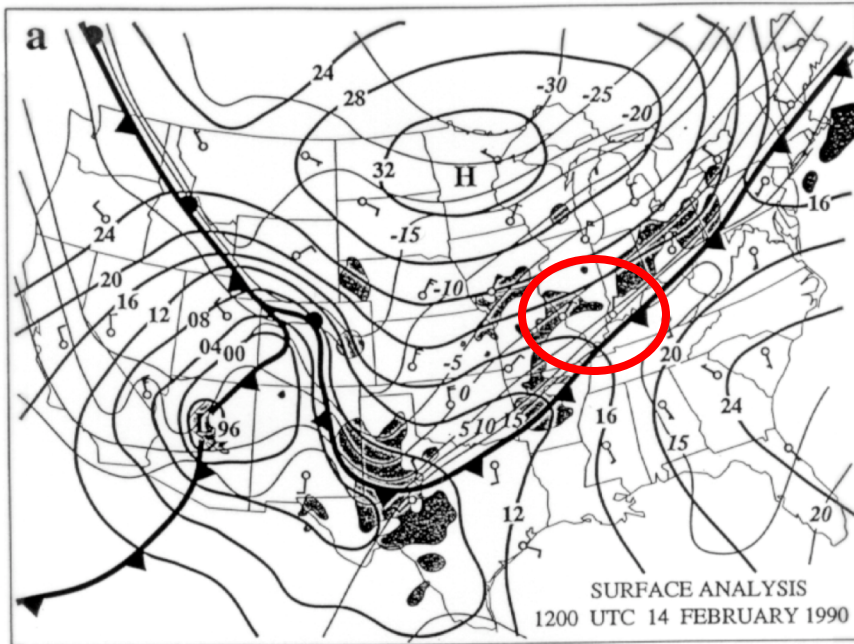
**ICE STORMS**



Example of a stationary front that produced a local flash flood in Kentucky in 1989



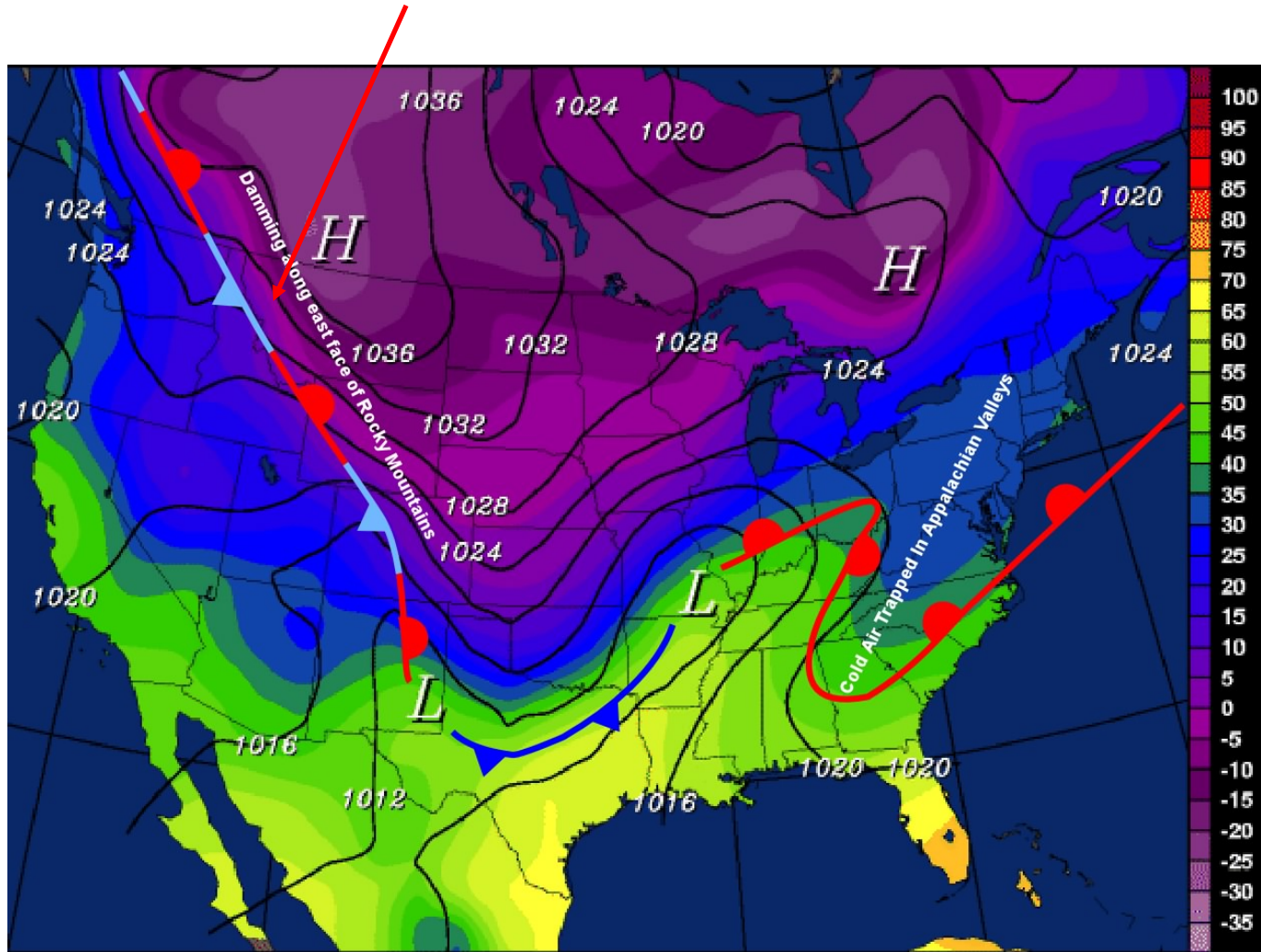




**Stationary front that led to 30 Million Dollar Ice storm in 1990**

# Topography and Fronts

Cold air dammed along the Colorado Rockies is often analyzed as a stationary front. It is a boundary between air and rock.

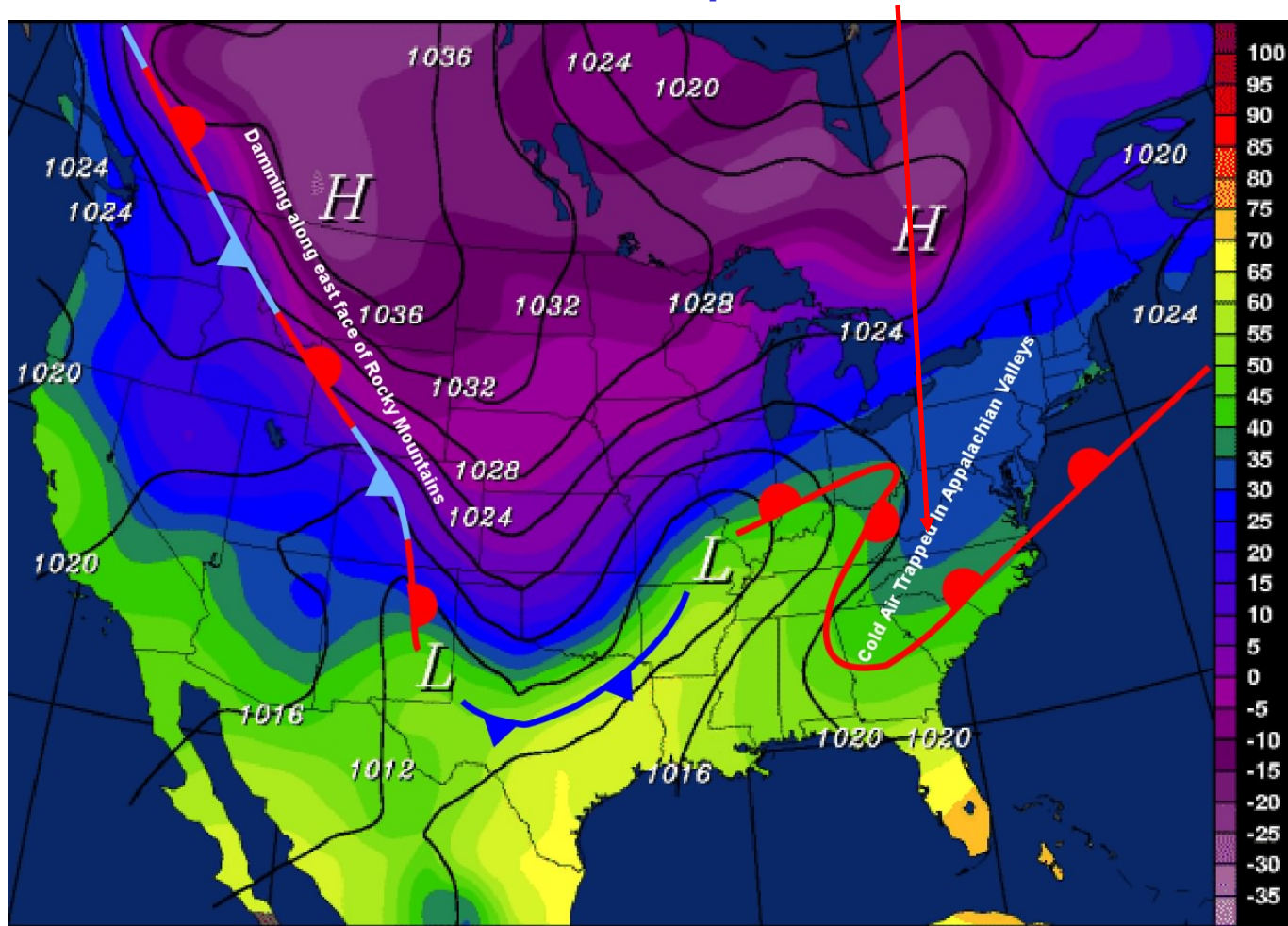


Courtesy of the Department of Atmospheric Sciences  
University of Illinois at Urbana-Champaign



# Topography and Fronts

Cold air trapped in Appalachian valleys is often analyzed as a distorted warm front. The cold air in the front's southward "dip" is quite shallow. Above the top of the shallow air the front does not dip southward.



Courtesy of the Department of Atmospheric Sciences  
University of Illinois at Urbana-Champaign