# Cyclones and Anticyclones in the Mid-Latitudes

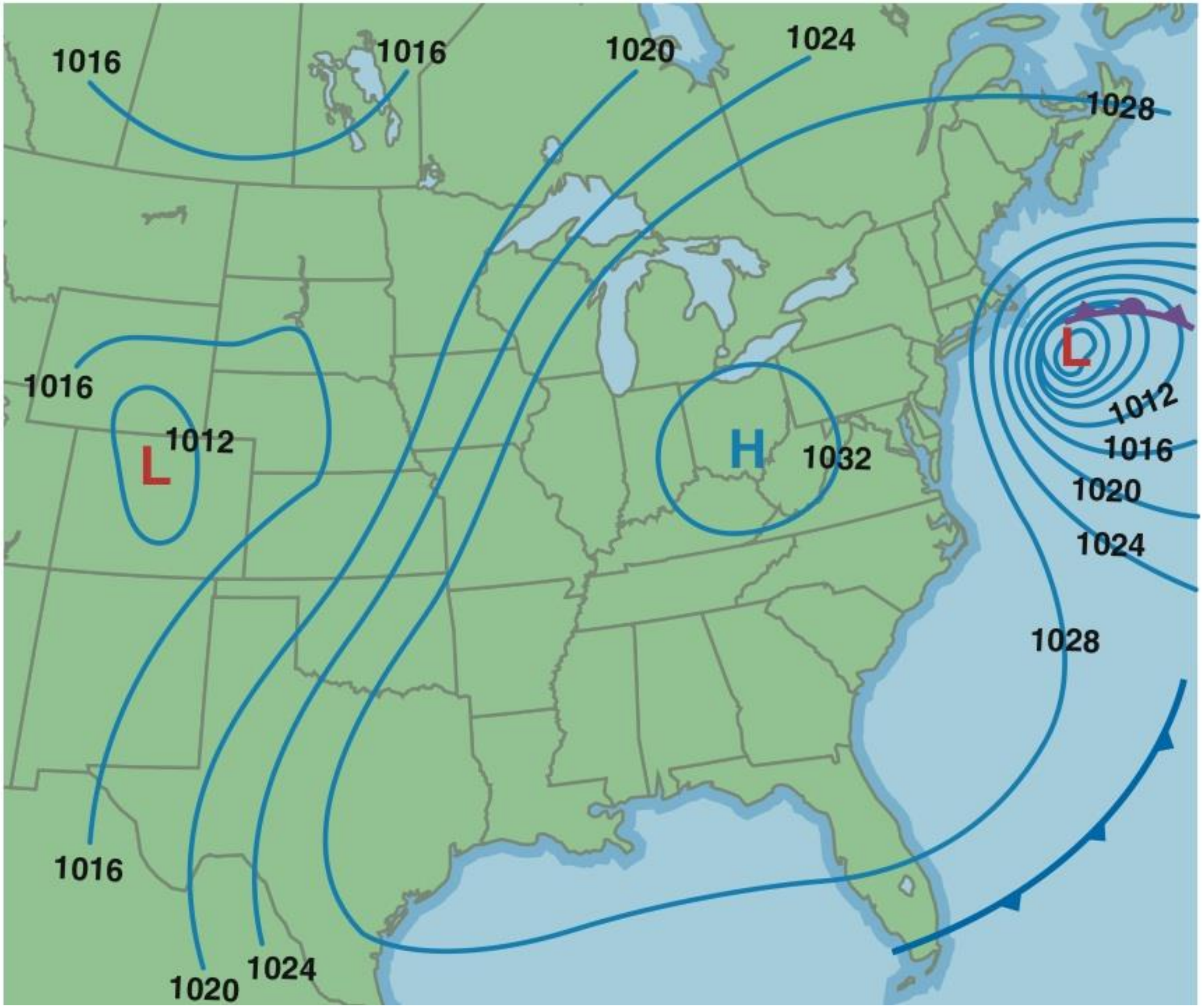
Val Bennington

November, 2008

# Anticyclones

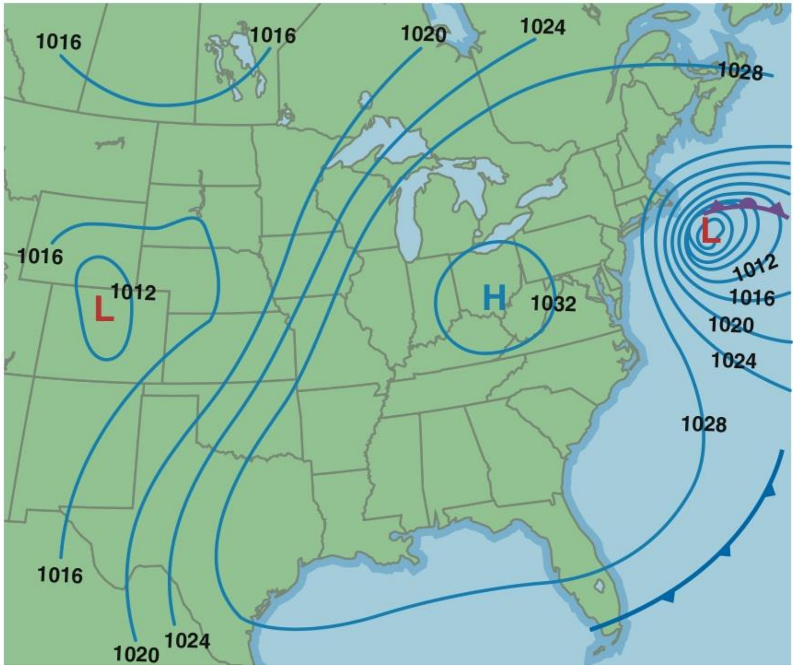
- High pressure systems
- Just air masses with temperature and moisture varying slightly over large area
- Clear, calm, pretty dry
- Blob-like, with small pressure gradients and slower winds

# Anticyclone



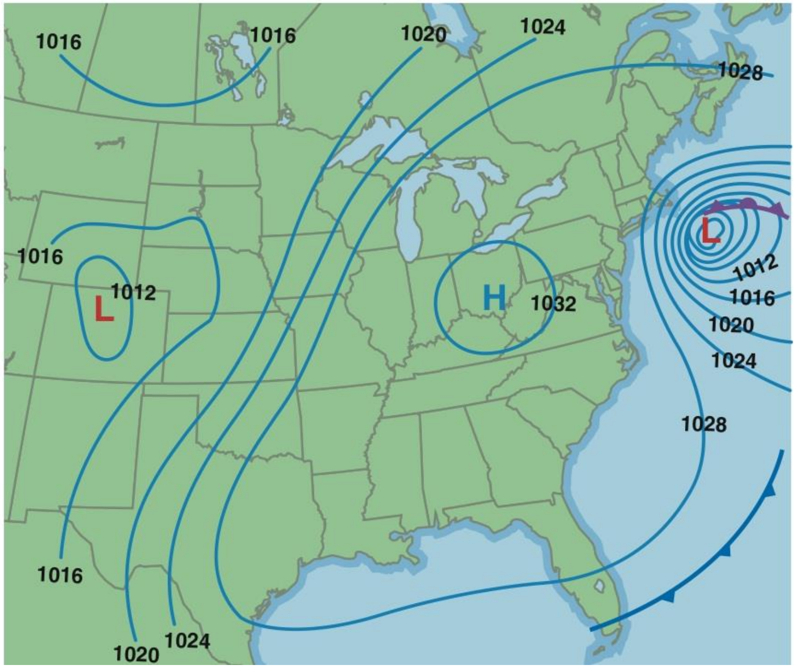
# Anticyclone (High)

- Which way does the wind blow?
- Does air diverge or converge at the surface?
- Does air converge or diverge above the high?

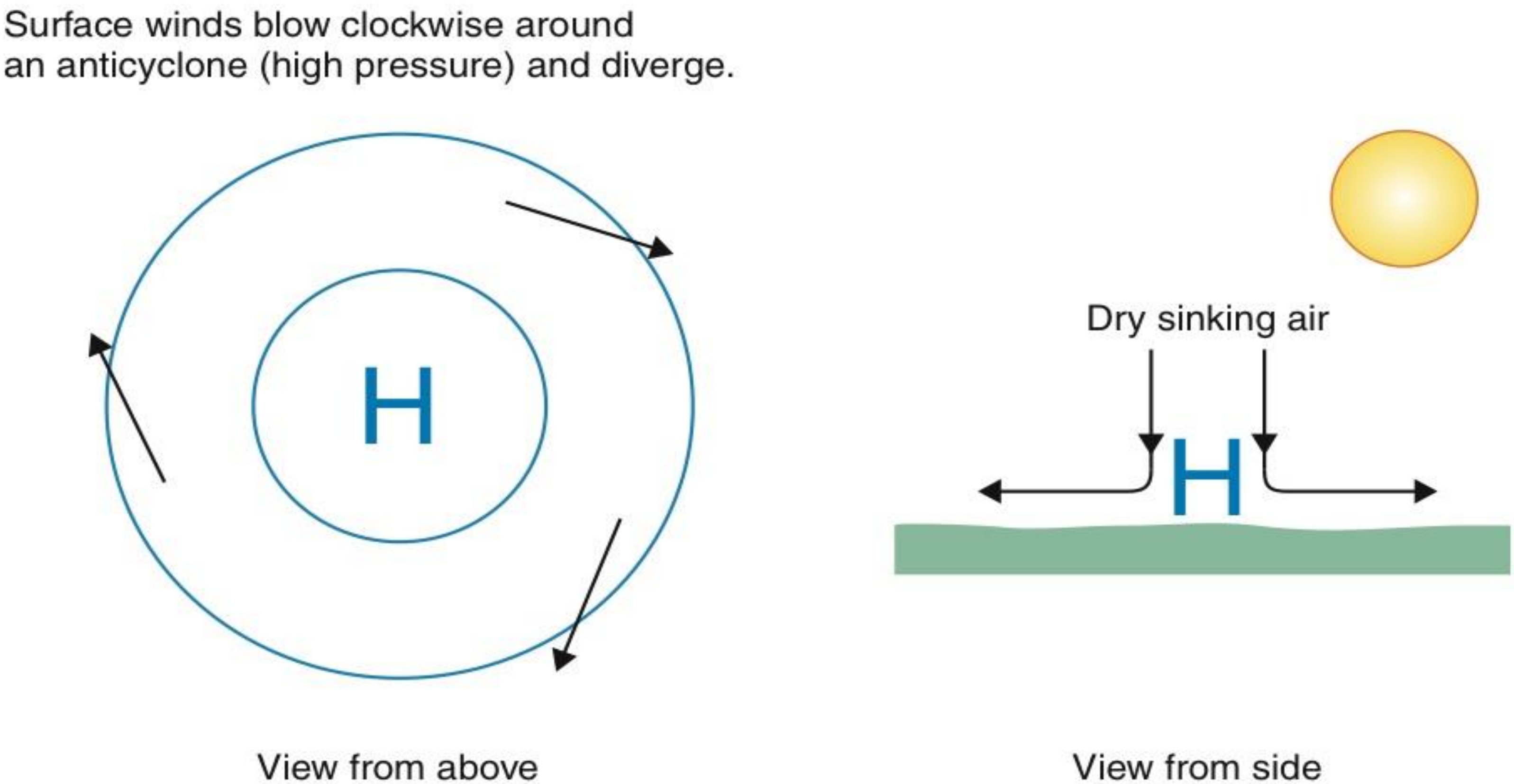


# Anticyclone (High)

- Which way does the wind blow? --> anti-cyclonic = clockwise!
- Does air diverge or converge at the surface? -->Diverges!
- Does air converge or diverge above the high? -->Converges!



# Anticyclones (Highs)



# Anticyclones (Highs)

- Generally boring weather - clear, calm
- Linger for a while, but can be nice
- Trap air near surface (sinking motion)
- Blob-like air masses
- Air mass stays long can take on characteristics of land it is over

# Fronts and Cyclones!

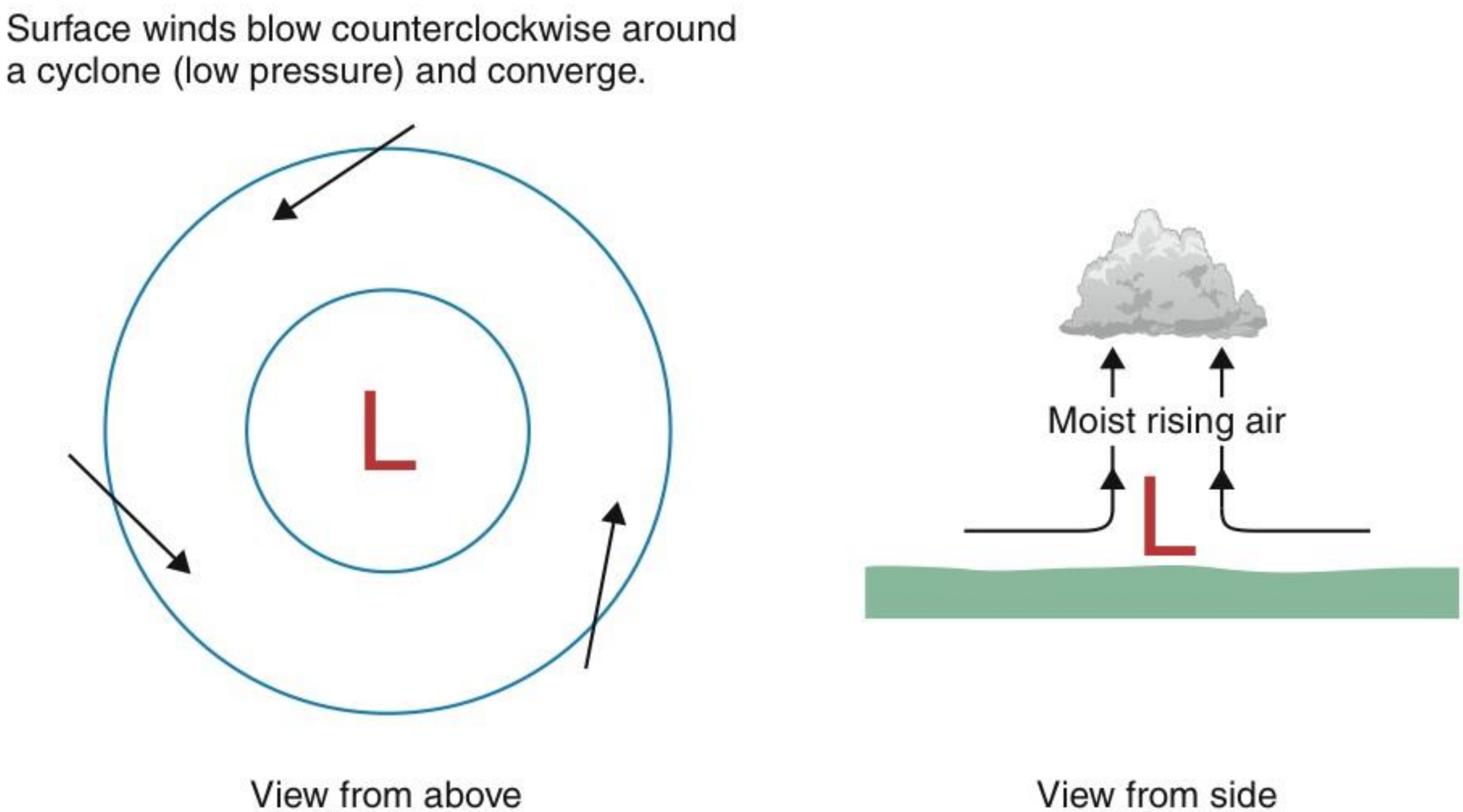
# Fronts

- What about when two air masses meet?
- We get a front - large changes in temperature and moisture over small area

# What is a Cyclone?

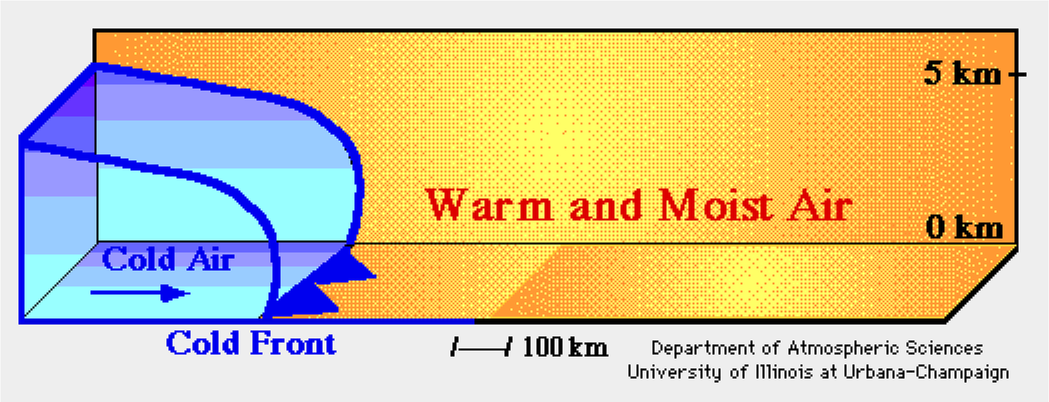
- A cyclone is simply an area of low pressure around which the winds flow counterclockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere
- Cyclones form and grow near the front
- Cyclones (lows) are cloudy, wet, stormy

# Cyclones have converging air at surface that rises!



# COLD FRONTS

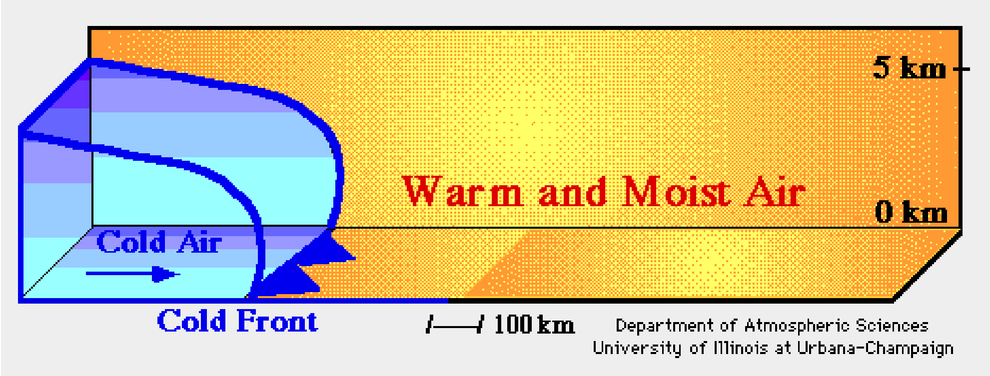
## Cold Front




- A transition zone where a cold air mass replaces a warm air mass
- Drawn as a blue line with blue triangles pointing in the direction of the front's movement

# Cold Fronts

## Cold Front




• Cold air is more dense than warm air!

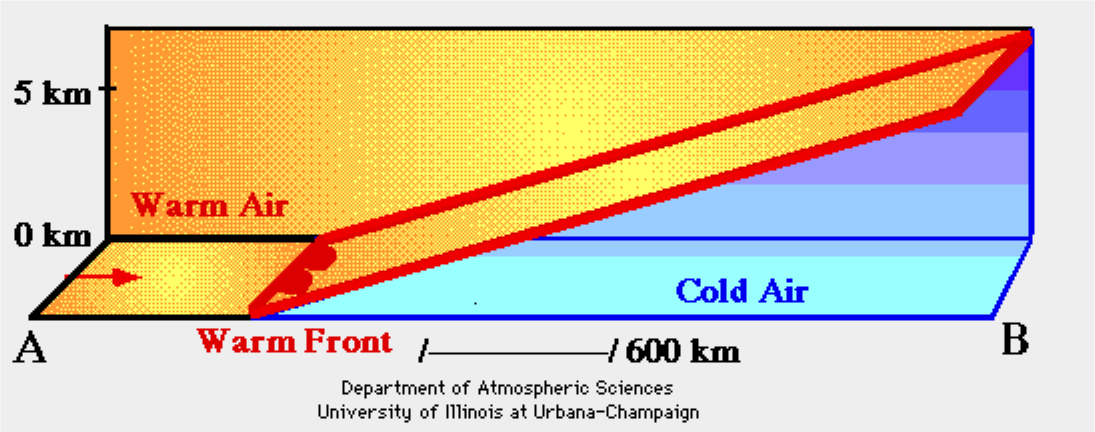
• As the dense, cold air moves into the warm air region, it forces the warm air to rapidly rise just ahead of the cold front.

• This results in deep convective clouds, occasionally producing strong to severe thunderstorms (depending on how unstable the atmosphere ahead of the cold front is).

• Often, the precipitation along a cold front is a very narrow line of thunderstorms

# Warm Fronts

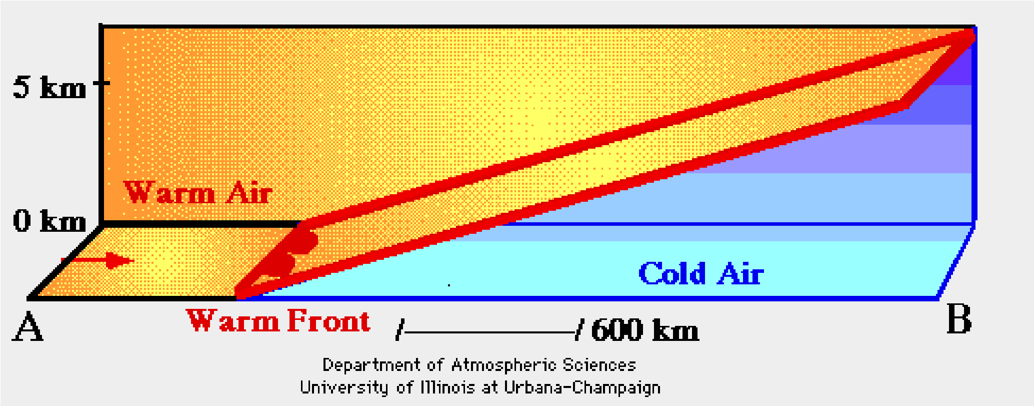
## Warm Front




- A transition zone where a warm air mass replaces a cold air mass
- Drawn as a red line with red half-circles pointing in the direction of the front's movement
- TEMPERATURE CONTRAST ALONG WARM FRONTS IS GENERALLY LESS DISTINCT (SMALLER GRADIENT)

# Warm Fronts

## Warm Front




• Again, warm air is less dense than cold air.

• As the warm air moves north, it slides up the gently sloping warm front.

• Because warm fronts have a less steep slope than cold fronts, the precipitation associated with warm fronts is more "stratiform" (less convective), but generally covers a greater area.

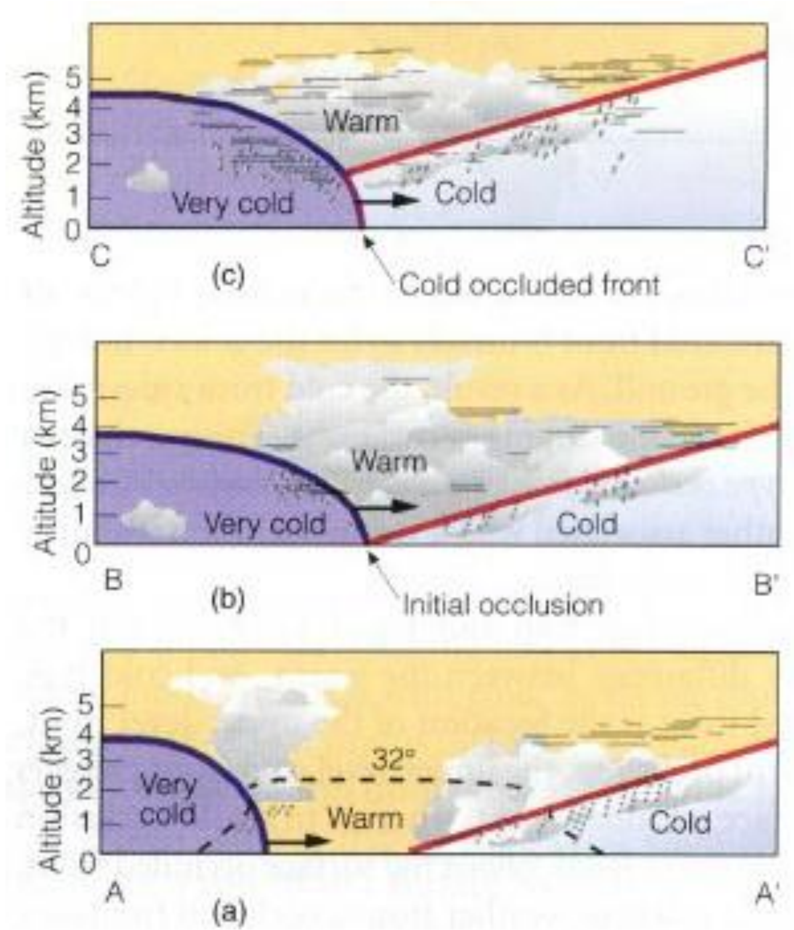
# Occluded Fronts

## Occluded Front

• A region where a faster moving cold front has caught up to a slower moving warm front.

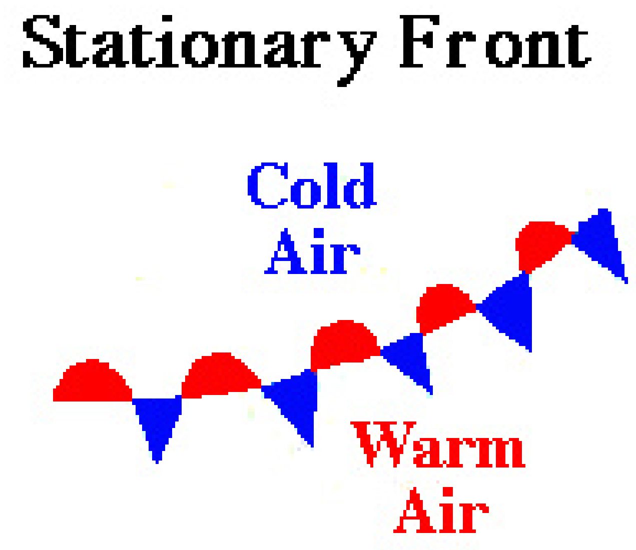
• Generally occurs near the end of the life of a cyclone

• Drawn with a purple line with alternating semicircles and triangles



# Stationary Fronts

- Front is stalled
- No movement of the temperature gradient
- But, there is still convergence of winds, and forcing for ascent (and often precipitation) in the vicinity of a stationary front.
- Drawn as alternating segments of red semicircles and blue triangles, pointing in opposite directions



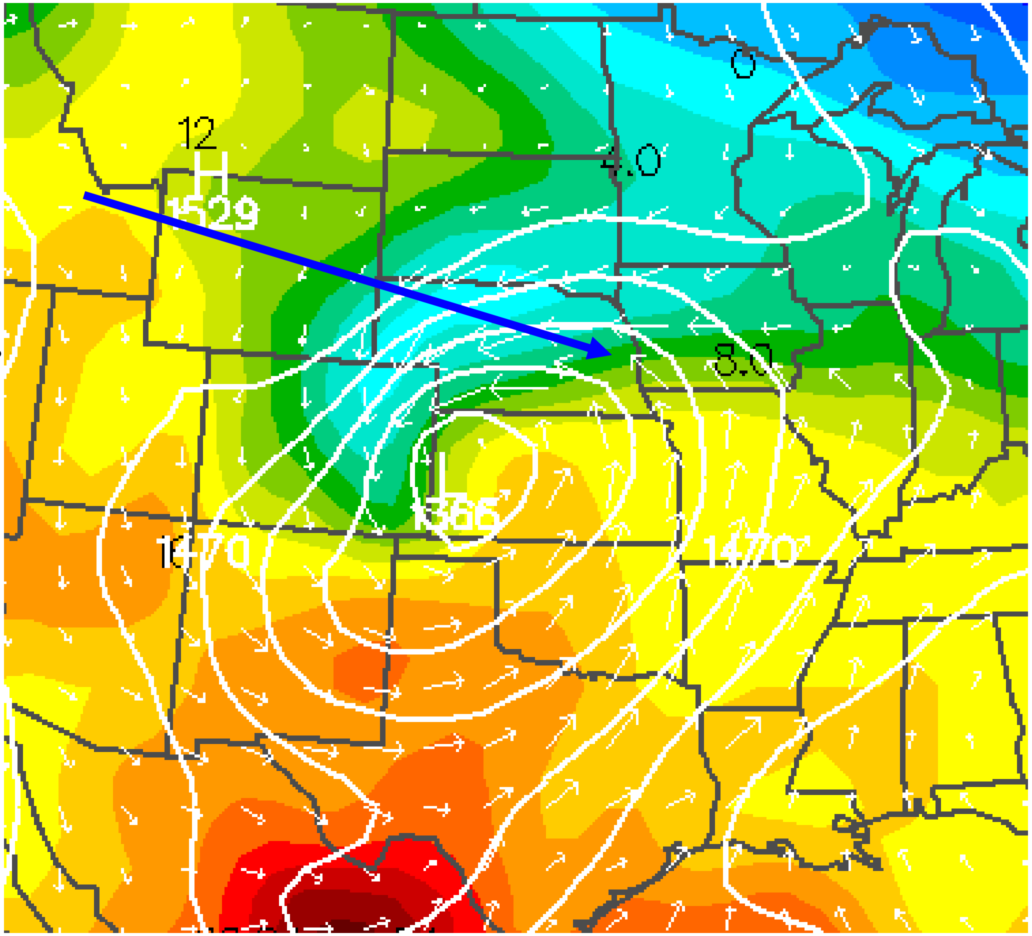
# Locating Fronts

Fronts are associated with . . .

- Strong temperature gradients
- Positive vorticity (counter-clockwise rotation)
- Lower pressure
- Regions of convergence of the winds
- Often precipitation and clouds (regions of ascent)

# Locating Fronts

Here, the winds are rapidly changing counterclockwise across this temperature gradient.



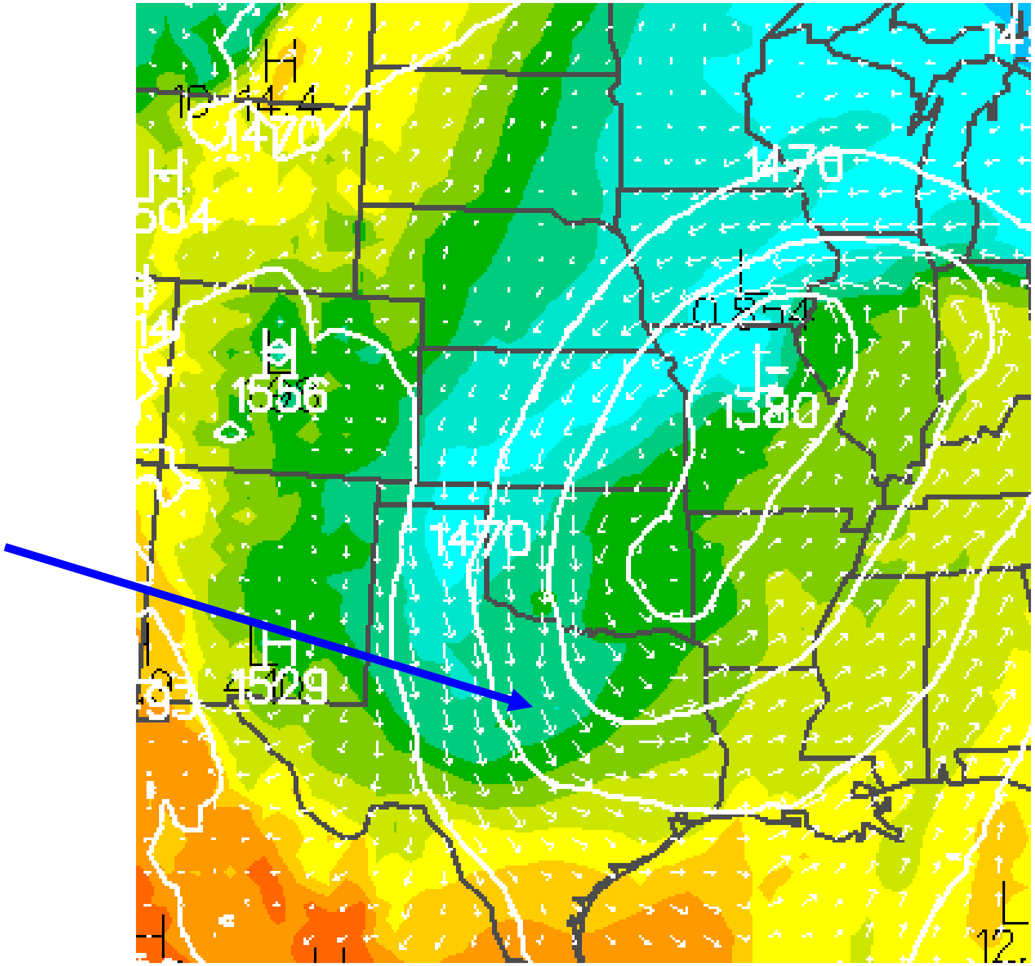

The winds are blowing warm air from the south.

This is a **warm front**.

# Locating Fronts

In this case, the winds are also rapidly changing counterclockwise across this temperature gradient, indicating positive vorticity.

The winds are blowing cold air from the northwest.




This is a **cold front.**

# Locating Fronts

**To find the cyclone**:

• Find the center of cyclonic circulation

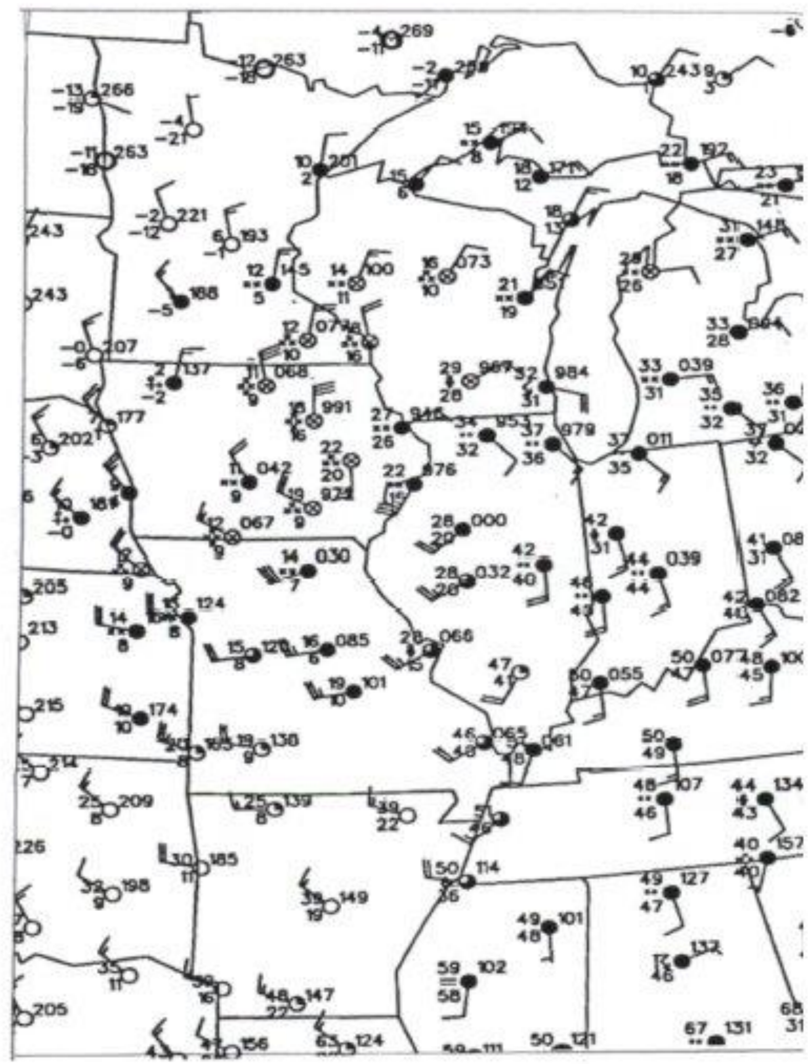
**To find the fronts:**

• Find large temperature gradients

• Identify regions of wind shifts

• Look for specific temperature advection (warm/cold)

• Look for kinks in the isobars (regions of slightly lower pressure)



27 Jan 1996 0000 UTC

# Locating Fronts

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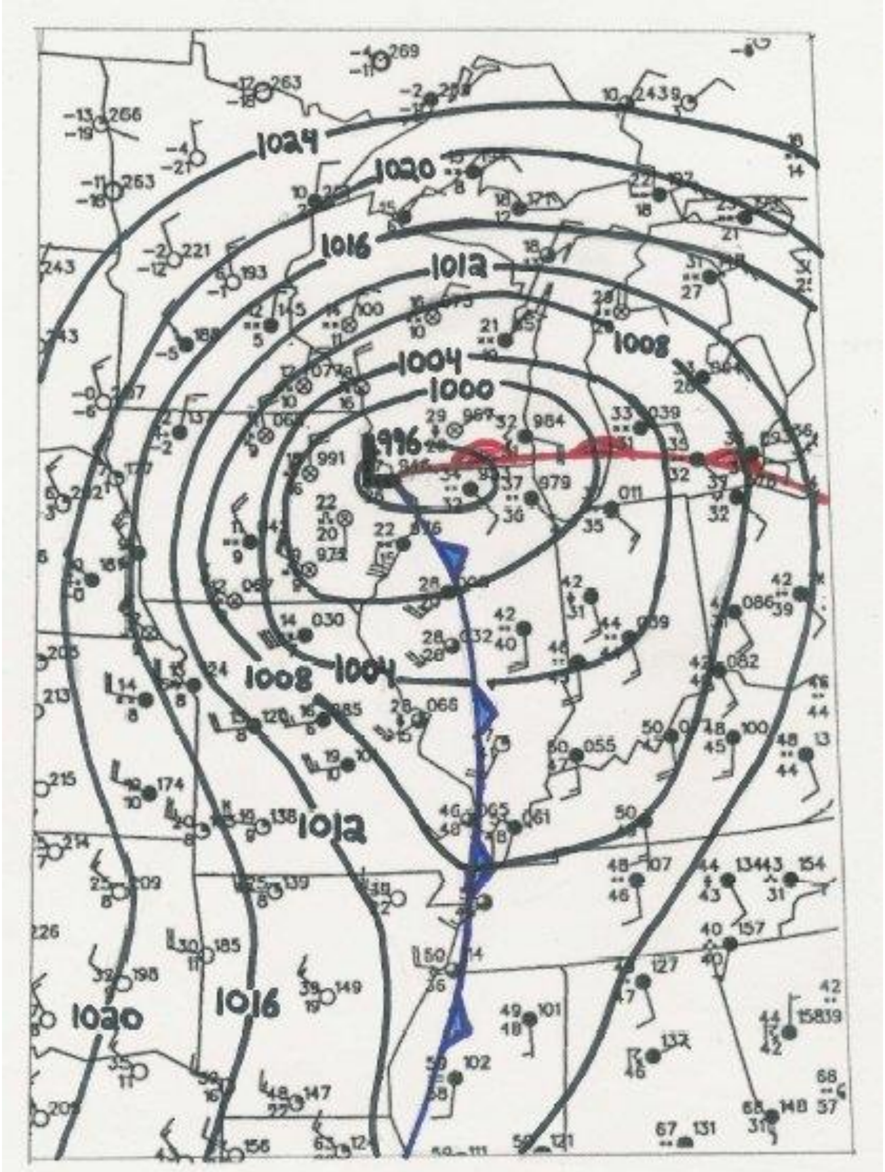


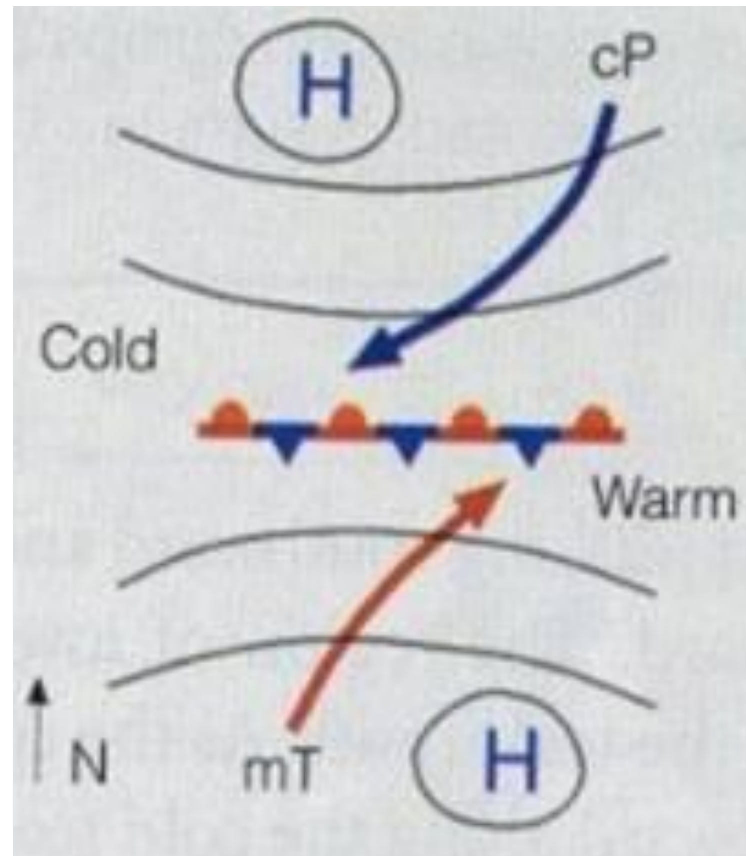

27 Jan 1996 0000 UTC

# The Life Cycle of Extra-tropical (Mid-Latitude) Cyclones

# The Birth of a Cyclone

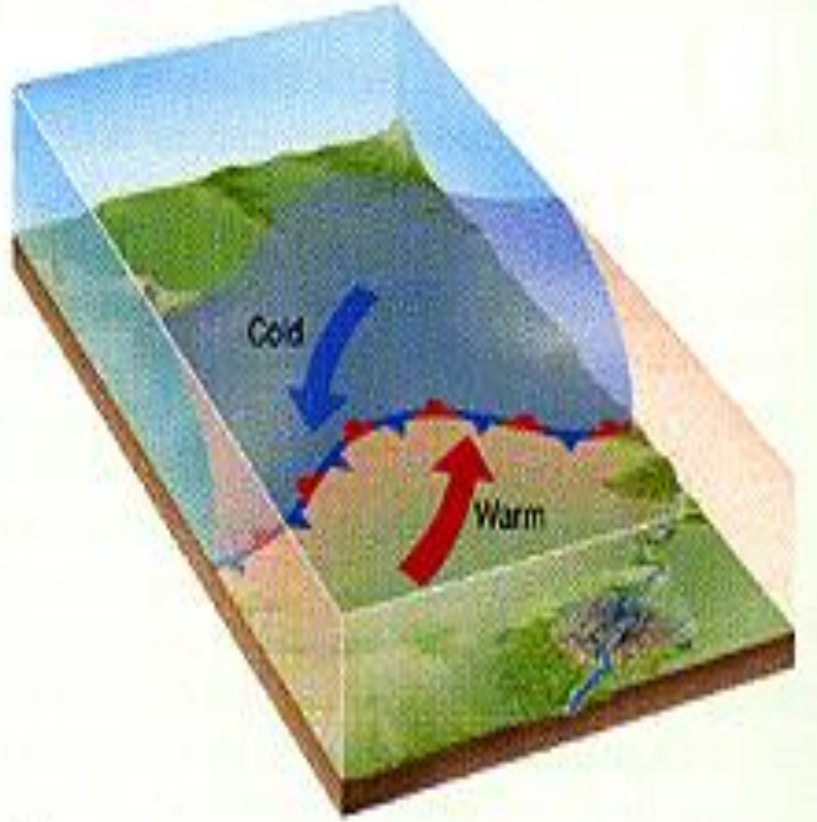
- A mid-latitude cyclone is born in a region where their is a strong temperature gradient with forced lifting, perhaps an old stationary front

- At the polar front!



# Stage Two

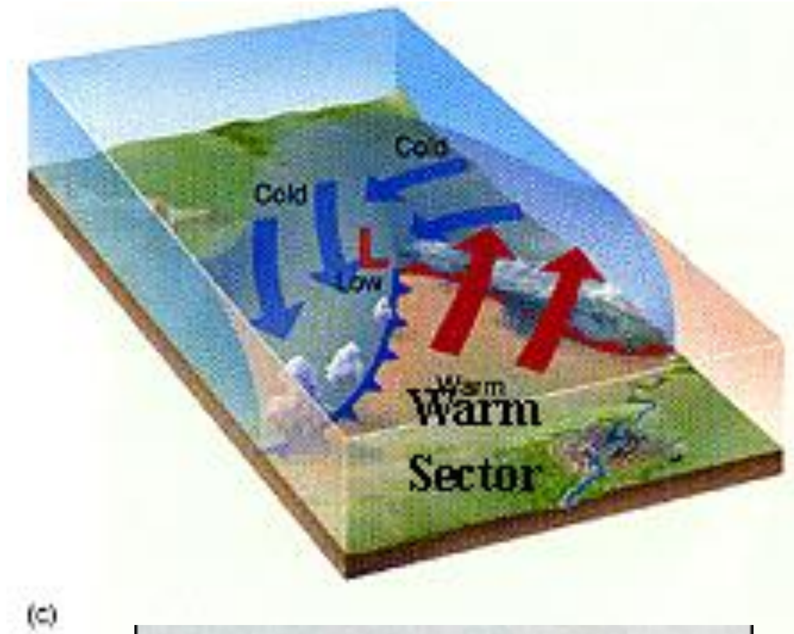
- An instability (kink) forms
- Warm air pushes to the northeast
- Cold air pushes to the southwest
- This will create the fronts!



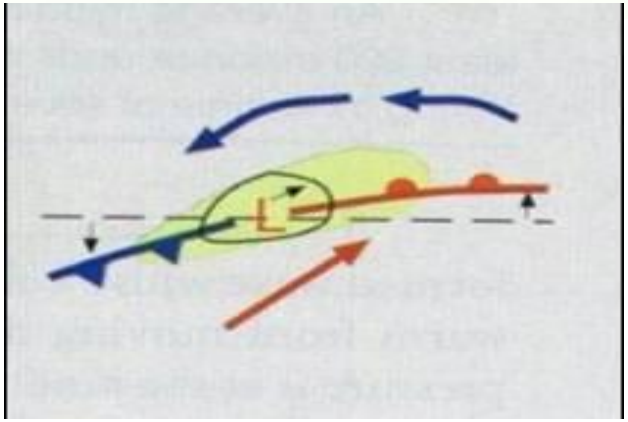

(b)

# Mature Stage

- Takes 12-24 hours to develop
- Warm front moves NE
- Cold front moves SE
- Region between fronts called warm sector
- Low pressure lowers (deepens)
- Wide-spread precip ahead of warm front
- Narrow band of precip at cold front
- Wind speeds increase

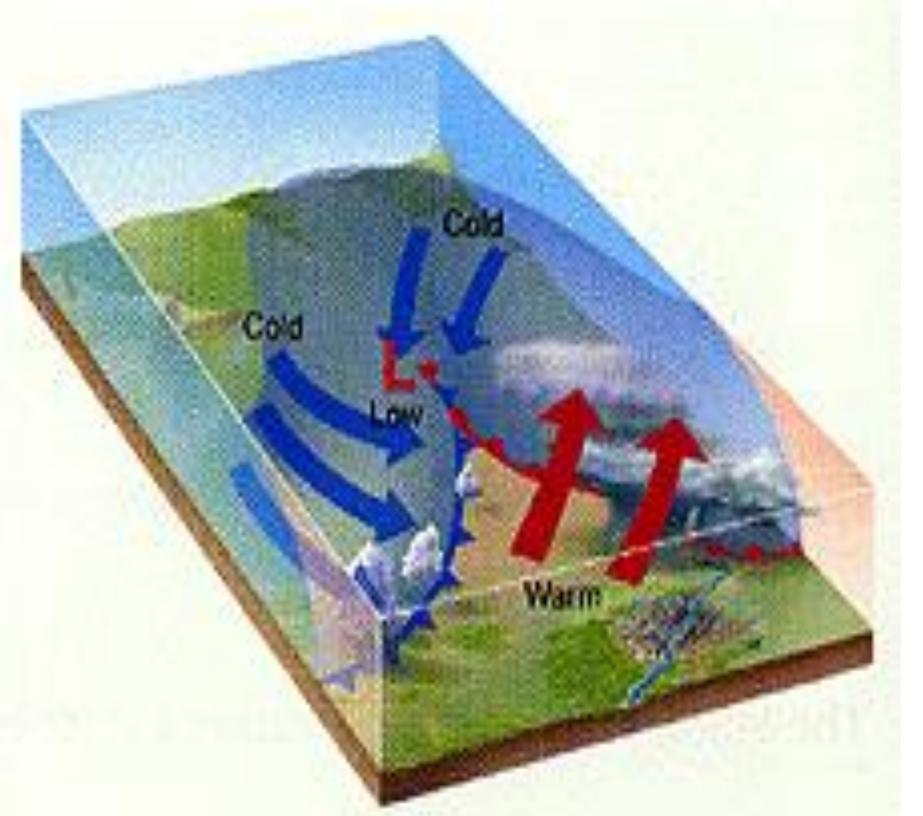



(c)



# Cyclone Movement

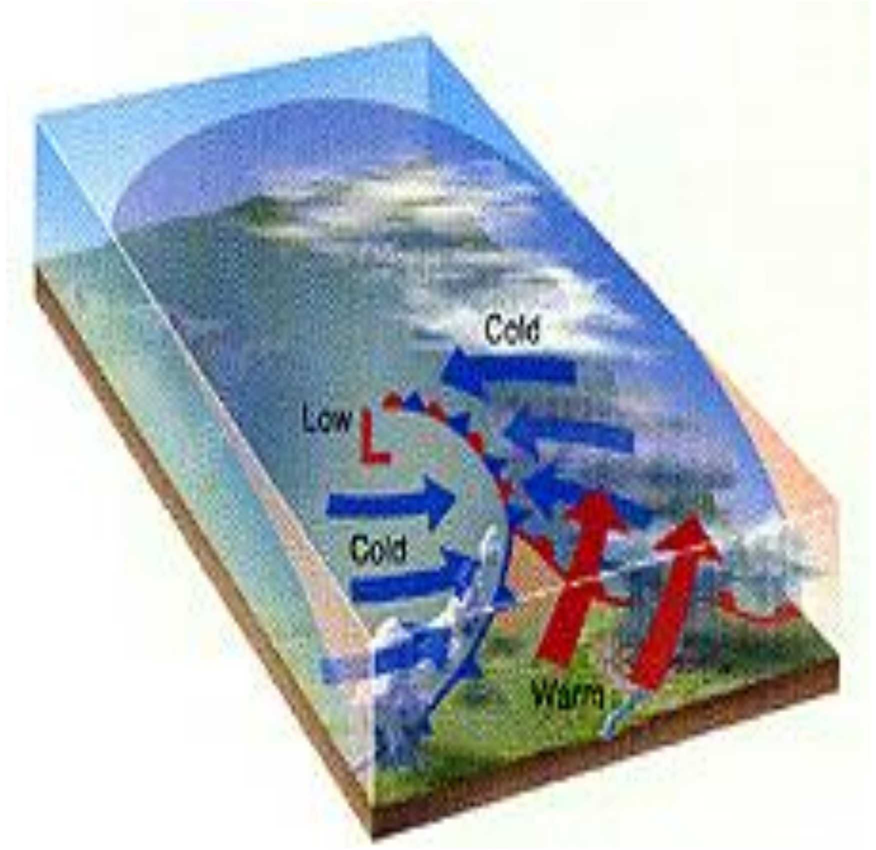
- Cyclone moves eastward (or to NE)
- Starts to occlude (cold front catching up)
- Storm most intense
- Triple point is where cold, warm, and occluded fronts meet



(d)

# Final Stage

- Warm sector shrinks
- Occlusion grows
- All energy from temperature contrast has been used up
- Warm air has been lifted
- Cold air has sunk
- STABLE



## Polar Front Theory – Norwegian Model

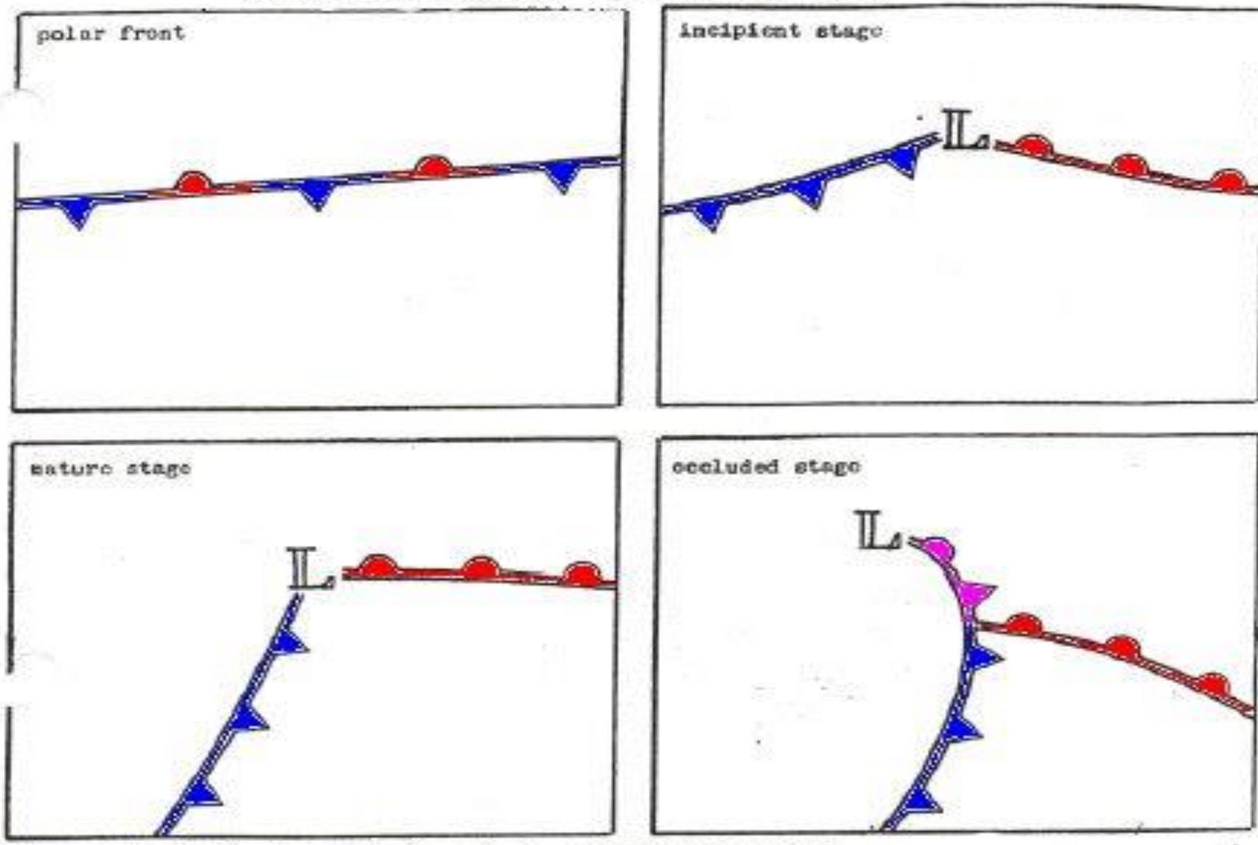
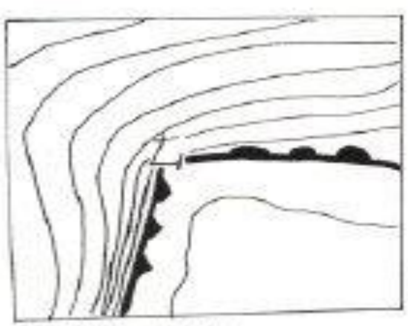
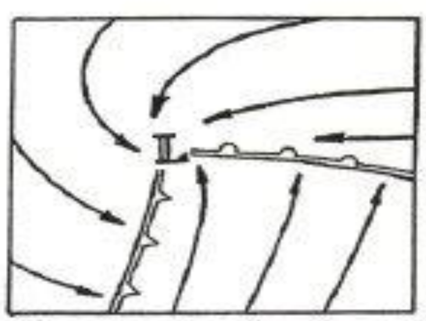



Figure 1: The development and occlusion of a frontal cyclone.





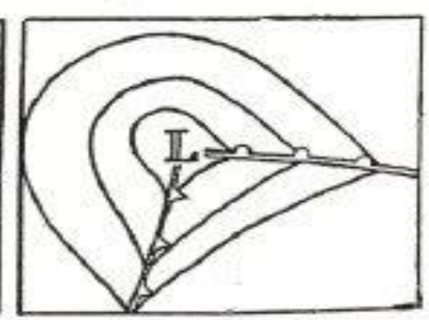
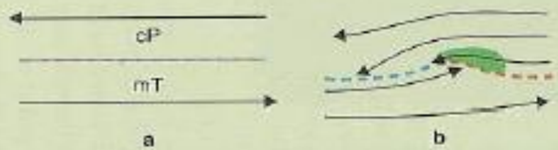
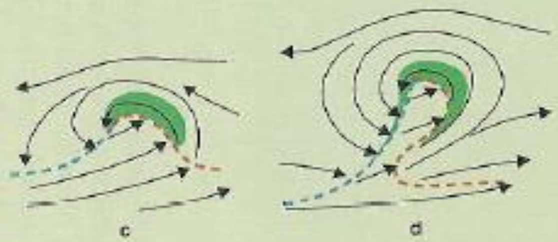
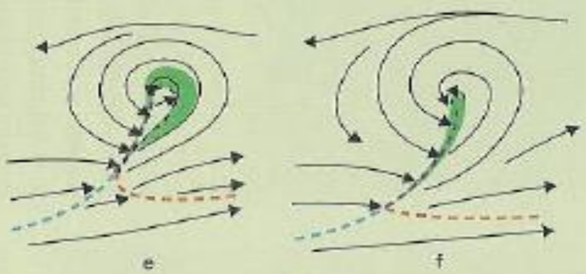
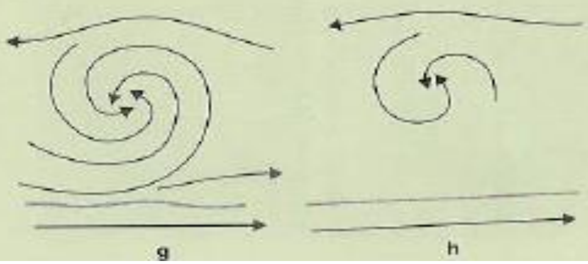



**TABLE 10.1** The Life Cycle of the Extratropical Cyclone, based on the Bergen School model.

| *Stage* | *Weather Map Depiction of Norwegian Cyclone Model* | *Typical Satellite Image of Life-Cycle Stage* | *Typical Sea-Level Pressure at Cyclone Center* |
|---|---|---|---|
| Birth (frontal wave) |  |  | 1000–1010 mb |
| Young adult (open wave) |  |  | 990–1000 mb |
| Mature (occluded cyclone) |  |  | 960–990 mb |
| Death (cut-off cyclone) |  |  CIMSS, University of Wisconsin-Madison | Slowly rising from 960–990 mb up to 1010 mb |

# Weather with the Cyclone of late fall or early spring

Top View:

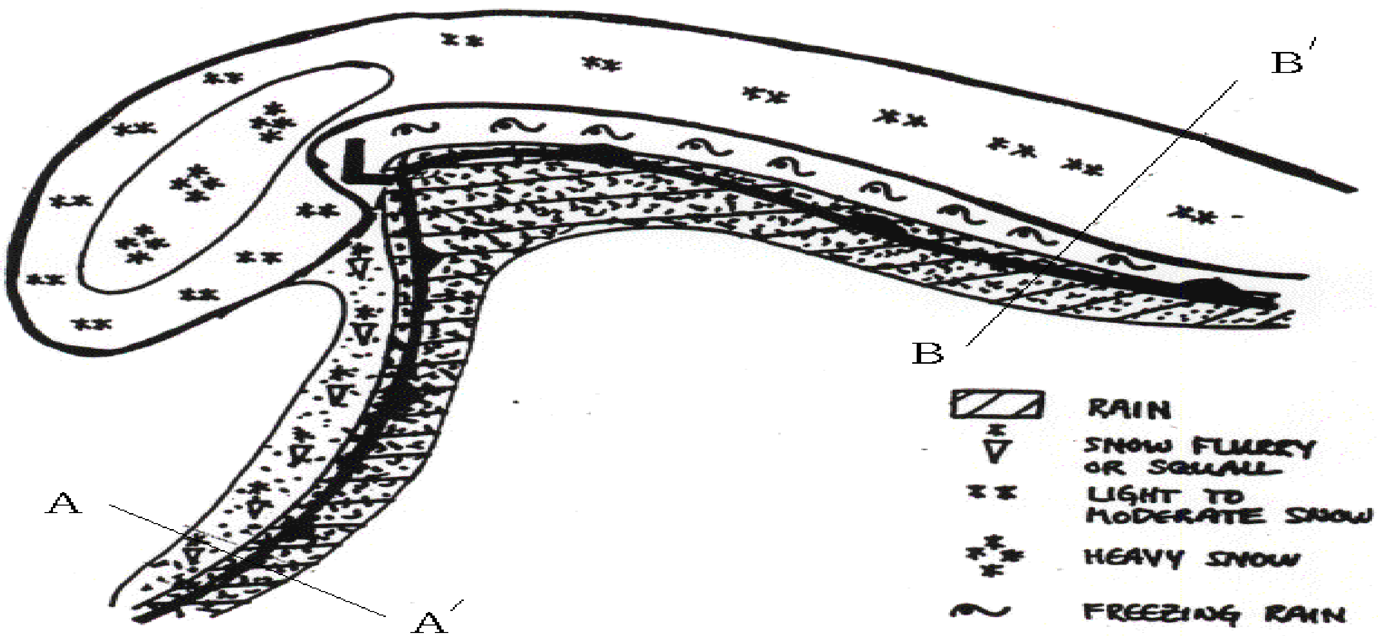



*figure courtesy of Dr. Jon Martin

**Fig. 2** Schematic plan view of the winter cyclone showing precipitation type and its general location in the storm. "L" indicates the position of the low pressure center and the cold and warm fronts are marked by solid lines.

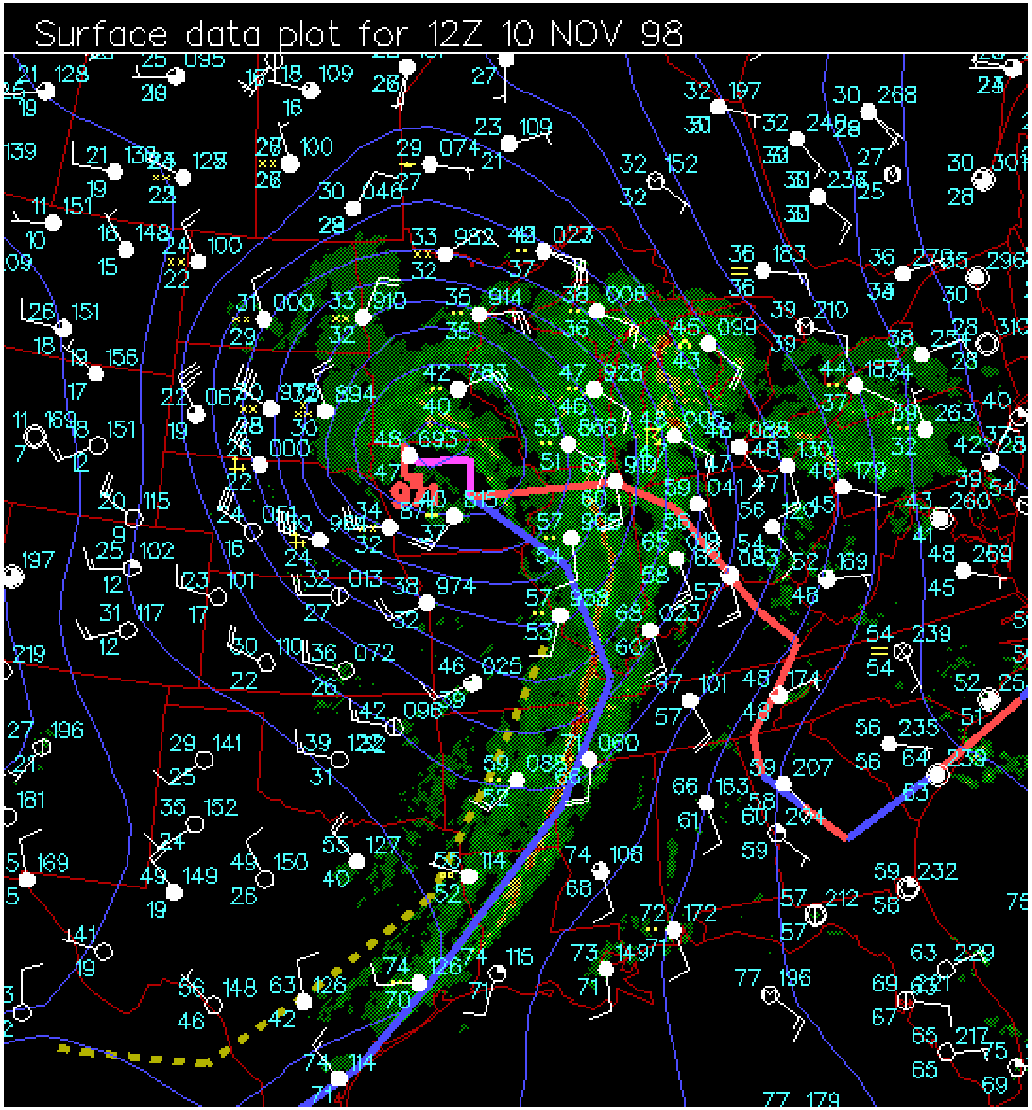
Side View: (Cross section through fronts):

# Precipitation Around a Cyclone and its Fronts

To the right is a major cyclone that affected the central U.S. on November 10, 1998.

Around the cold front, the precipitation is more intense, but there is less areal coverage.

North of the warm front, the precipitation distribution is more “stratiform”:  Widespread and less intense.



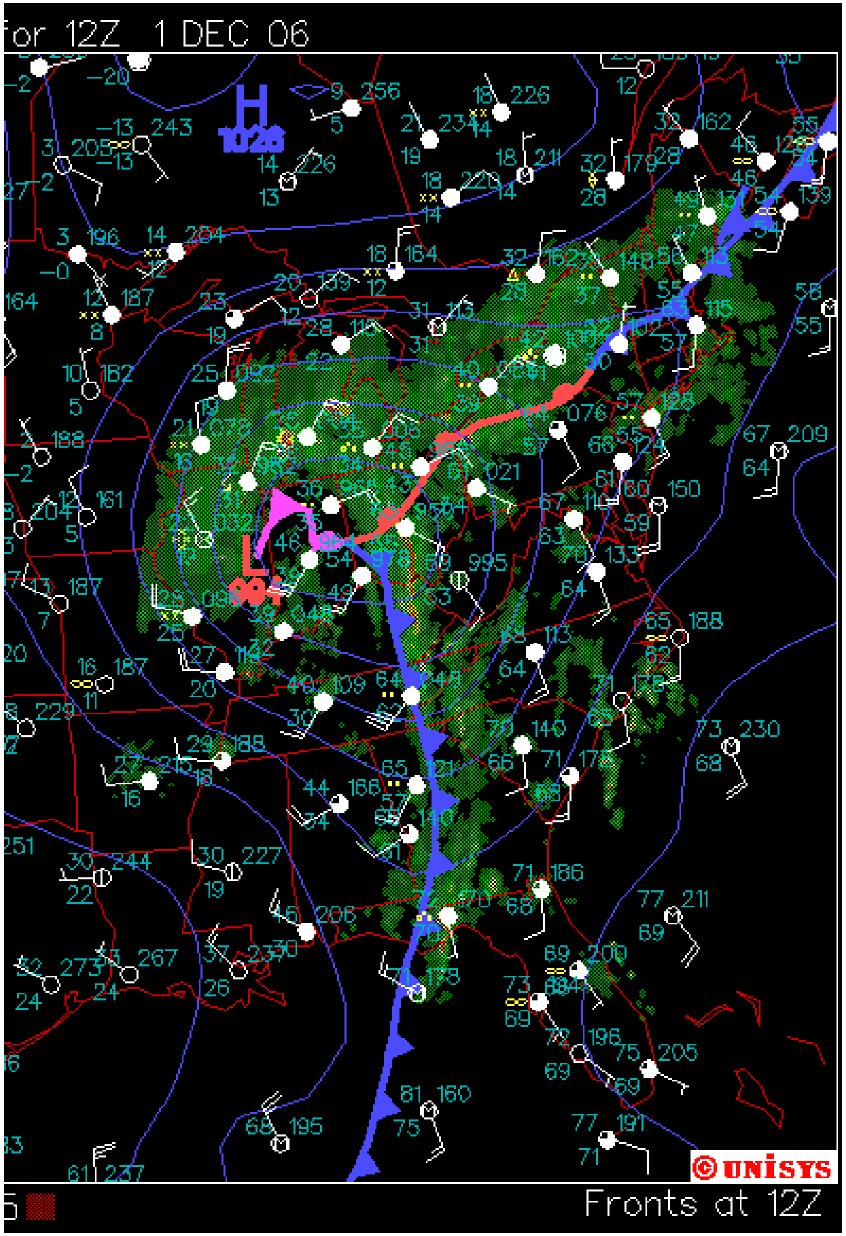

http://weather.unisys.com

# Precipitation Around a Cyclone and its Fronts

Again, in this radar and surface pressure distribution from December 1, 2006, the precipitation along the cold front is much more compact and stronger.

North of the warm front, the precipitation is much more stratiform.

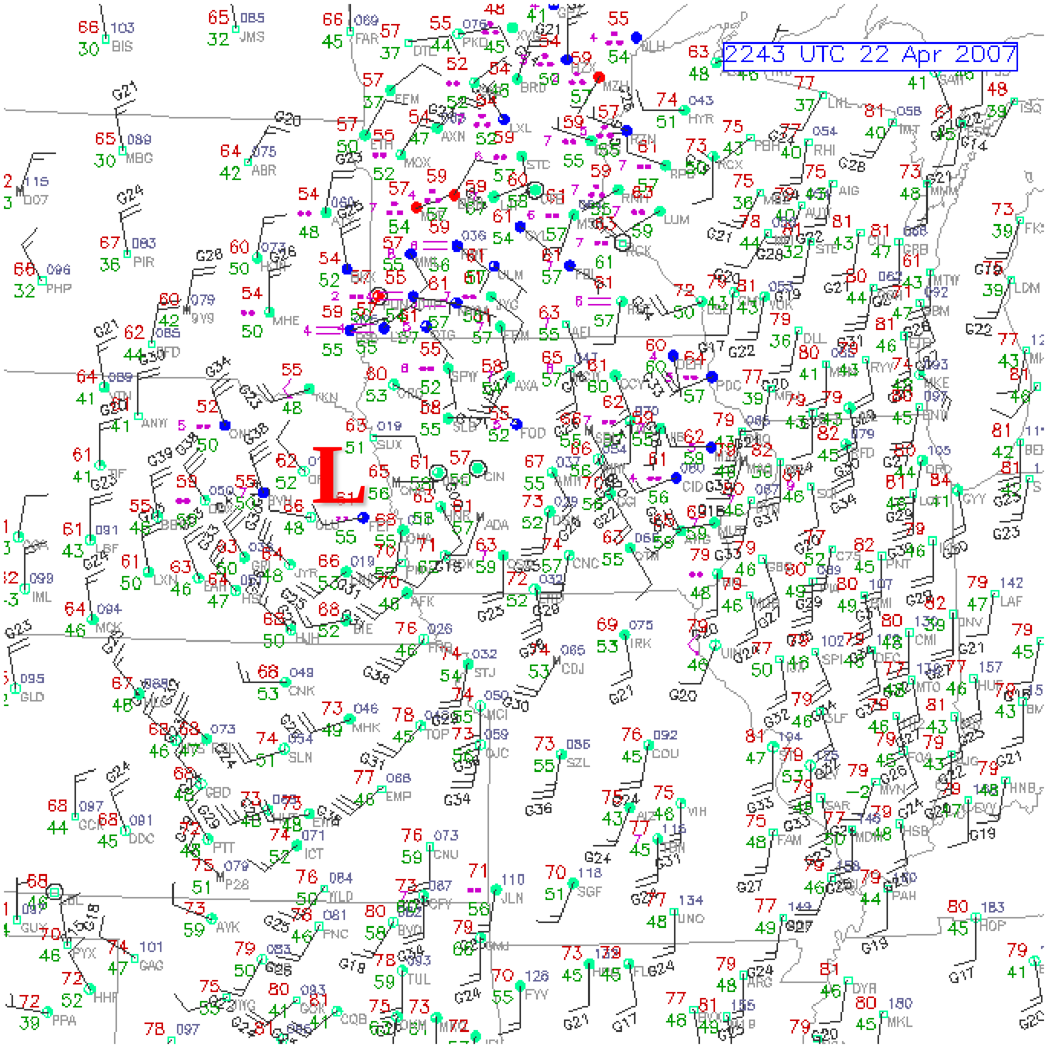
Also note the kink in the isobars along the cold front!



# Locating a Cyclone

1. Find the region of lowest sea level pressure

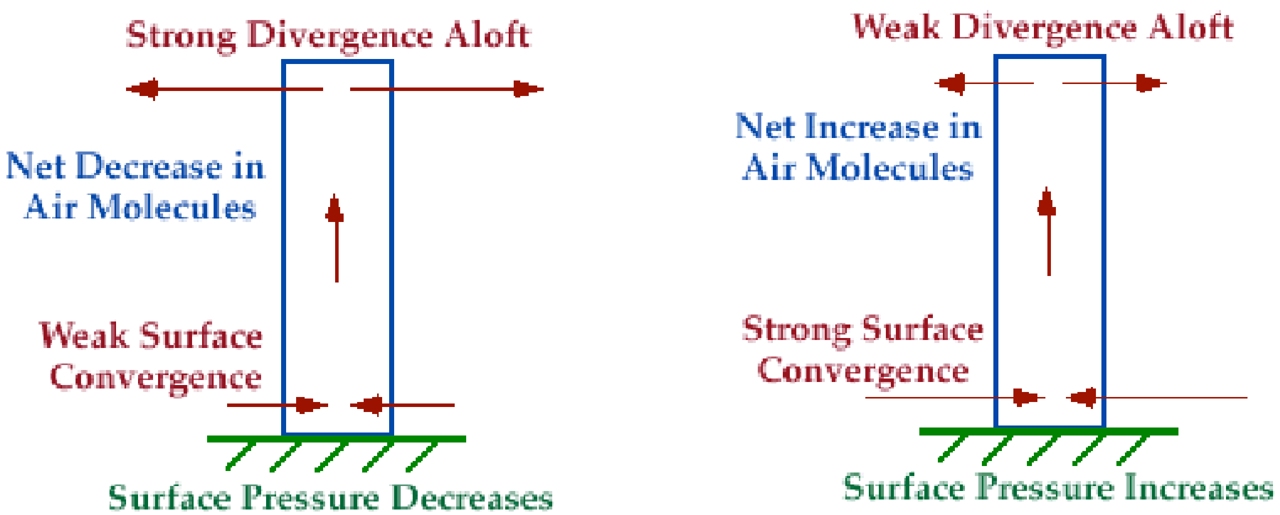
2. Find the center of the cyclonic (counter-clockwise) circulation



# What about Vertical Structure?

# Pressure…

- If we have converging air at the surface, must have divergence aloft!
- Otherwise, air would “fill up” the low and the pressure would rise




Intensifying
Sfc Cyclone

Weakening
Sfc Cyclone

# Review

- Winds converge at a surface low pressure center
- Winds diverge from a surface high pressure center

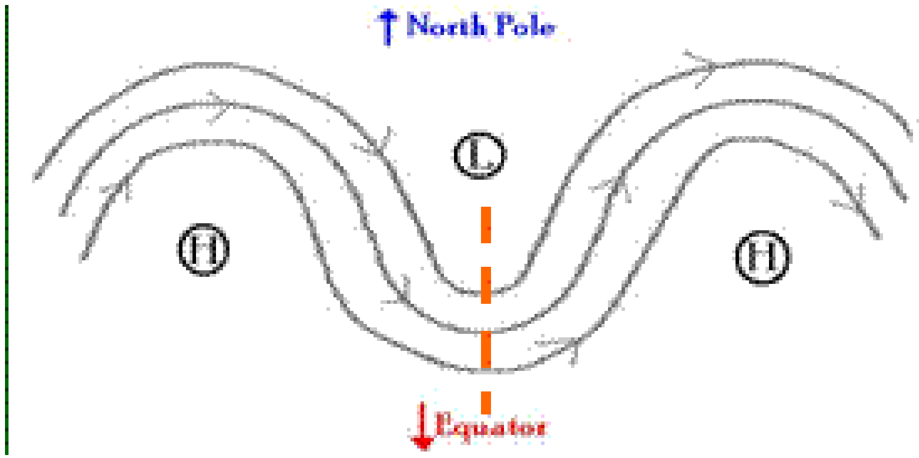
  (this is because of the **frictional force** at the surface)

- This Convergence/Divergence suggests that there must be movement of air in the vertical (can't lose air parcels)

- Flow in the upper troposphere is generally in **geostrophic balance,** so we do not get divergence/convergence high up caused by friction

- How do we get divergence/converge up high?

# Upper Tropospheric Flow




**<u>Typical 500 mb height pattern</u>**

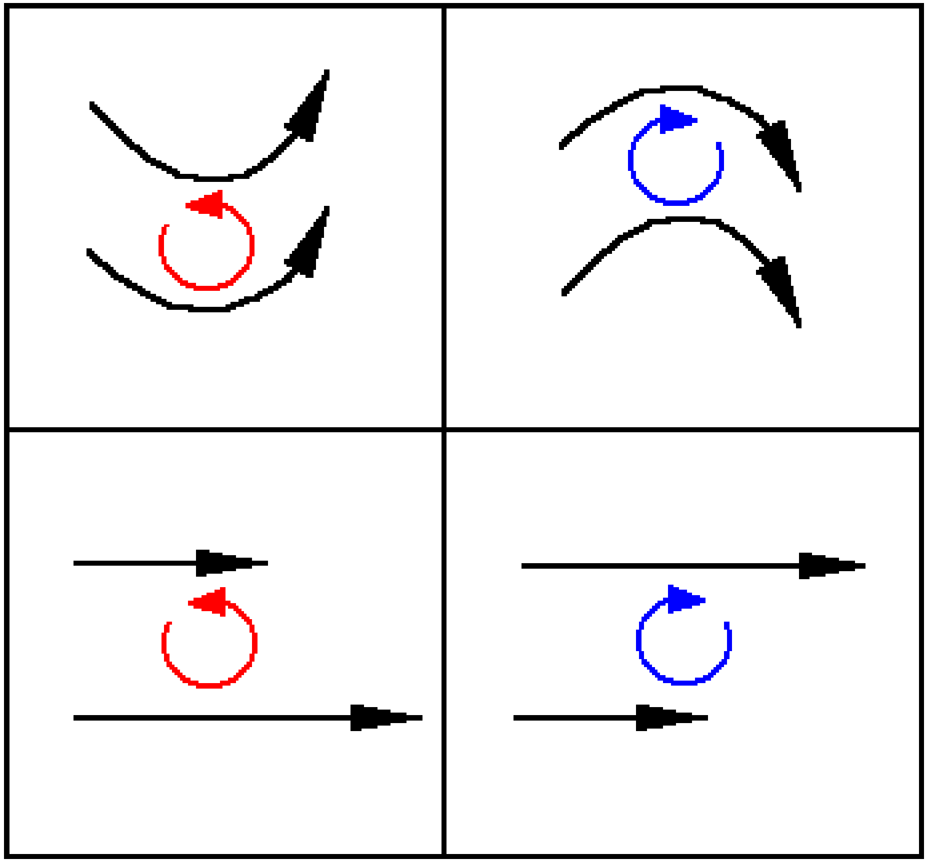
- Notice the troughs (dotted line) and ridges
- The troughs and ridges are successive
- In the northern hemisphere, lower pressure is generally to the north of higher pressure

# Relative Vorticity

If the wind has counterclockwise spin, it has **positive vorticity** (left)

If the wind has clockwise spin, it has **negative vorticity** (right)

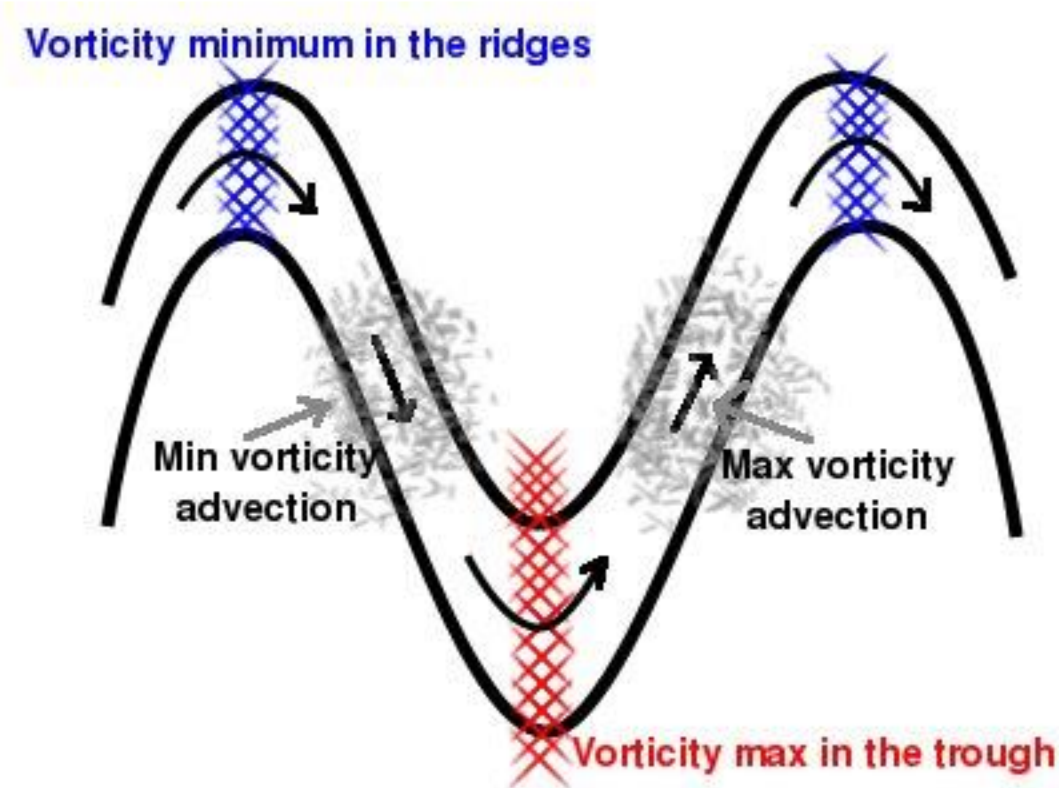
Vorticity can be directional (top), or speed shear vorticity (bottom)



# Vorticity in the Upper Troposphere

Where is there vorticity advection?

Pinpoint vorticity **minima** and **maxima**




Negative vorticity advection (**NVA**) occurs just "downstream" from a ridge axis (vorticity minimum)

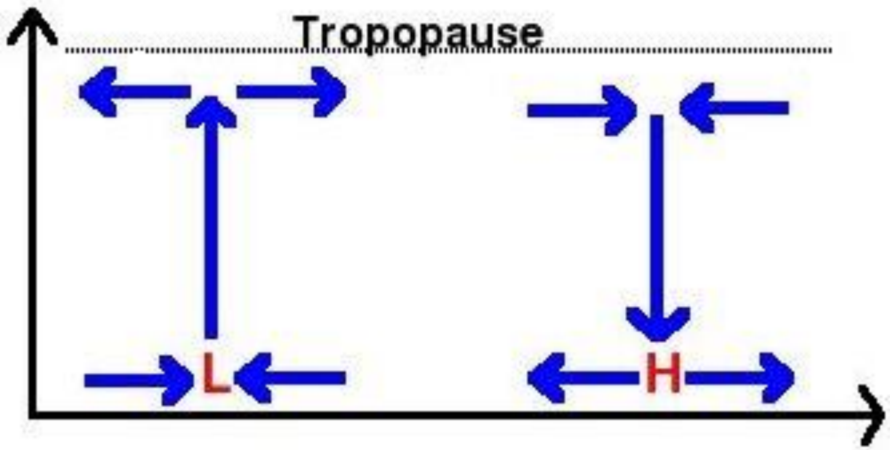
Positive vorticity advection (**PVA**) occurs just "downstream" from a trough axis (vorticity maximum)

# Vorticity Advection and Vertical Motion

* Positive vorticity advection (**PVA**) results in ***divergence*** at that level

* Negative vorticity advection (**NVA**) results in ***convergence*** at that level

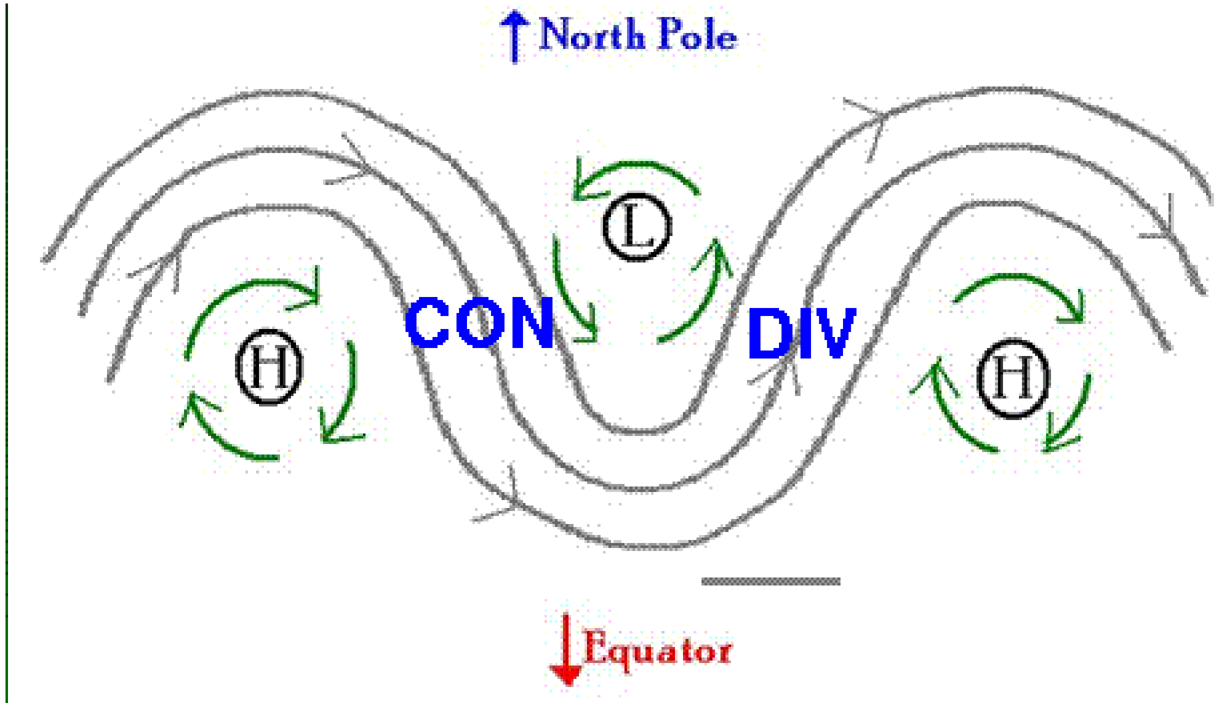
# Vorticity Advection and Vertical Motion




Remember that ***convergence*** at upper levels is associated with downward vertical motion (subsidence), and ***divergence*** at upper levels is associated with upward vertical motion (ascent).

Then, we can make the important argument that . . .

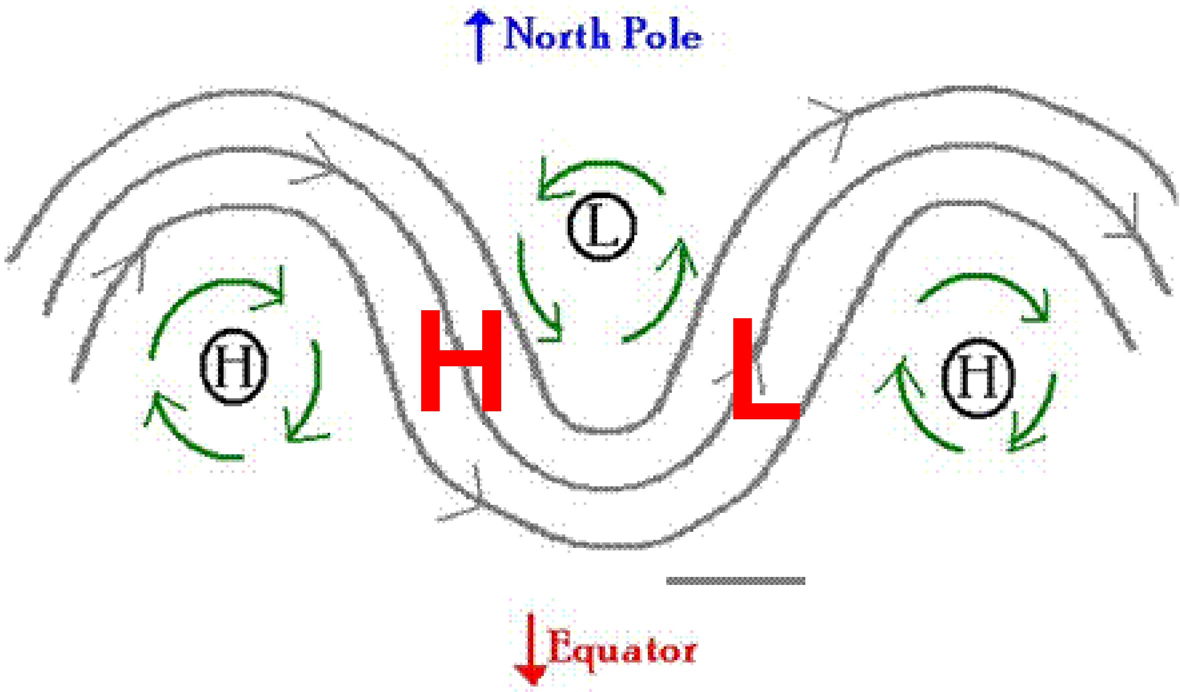
# Upper Tropospheric Flow and Convergence/Divergence




• Downstream of an upper tropospheric ridge, there is convergence, resulting in subsidence (downward motion).

• Likewise, downstream of an upper tropospheric trough, there is divergence, resulting in ascent (upward motion).

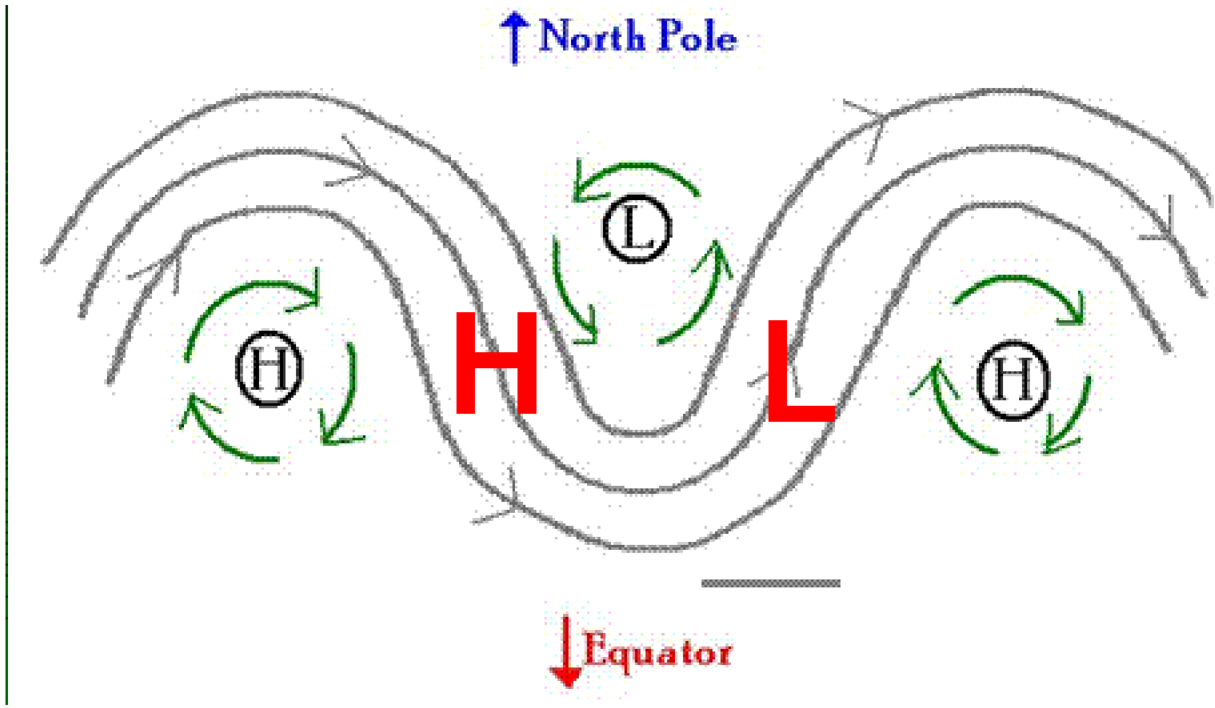
# Upper Tropospheric Flow and Convergence/Divergence




• Downstream of an upper tropospheric ridge axis is a favored location for a **surface high pressure.**

• Downstream of an upper tropospheric trough axis is a favored location for a **surface low pressure** center.

# Upper Tropospheric Flow and Convergence/Divergence




• Surface cyclones move in the direction of the upper tropospheric flow!

•The storm speed and direction can also be identified on the 500 mb map. Cyclones move in the direction of the 500 mb flow, the 500 mb flow is also called the *steering flow*. The cyclone also moves at about half the speed of the 500 mb flow.

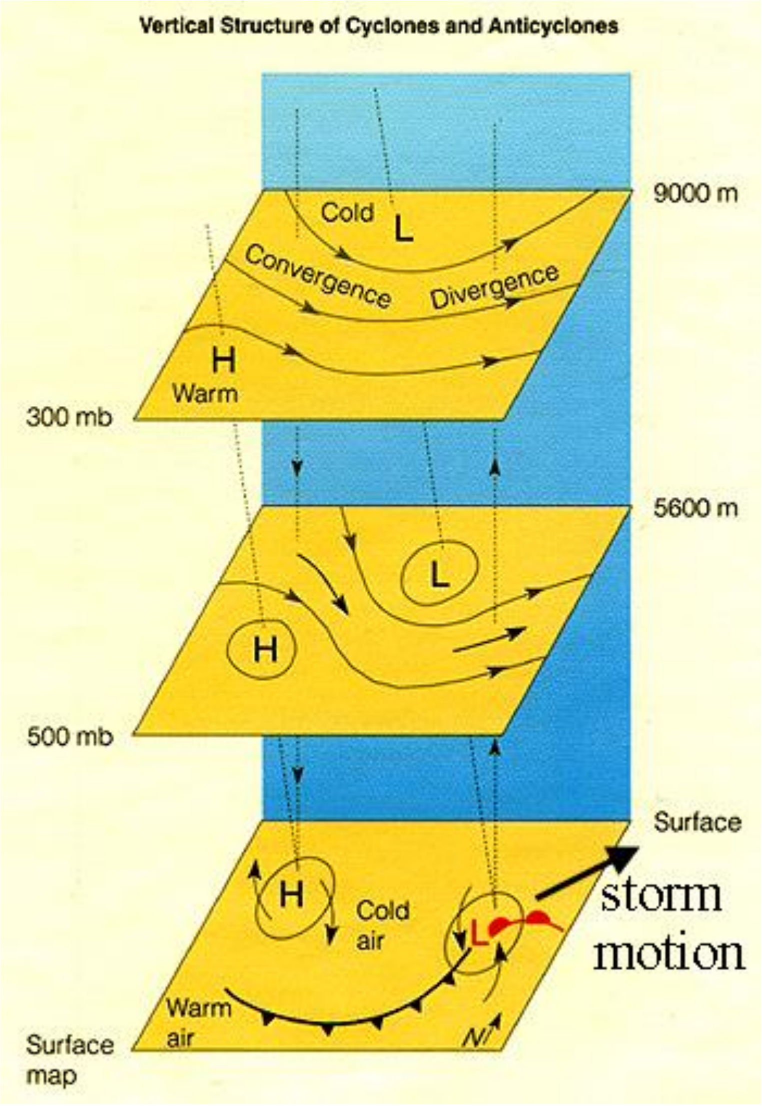
• The surface low pressure center in diagram above will track to the northeast along the upper tropospheric jet
(along the surface temperature gradient)

# Vertical Structure of Cyclones

What else do these diagrams tell us?

• Surface cyclone is downstream from the upper tropospheric (~500 mb) trough axis

• Mid-latitude cyclones generally tilt westward with height!

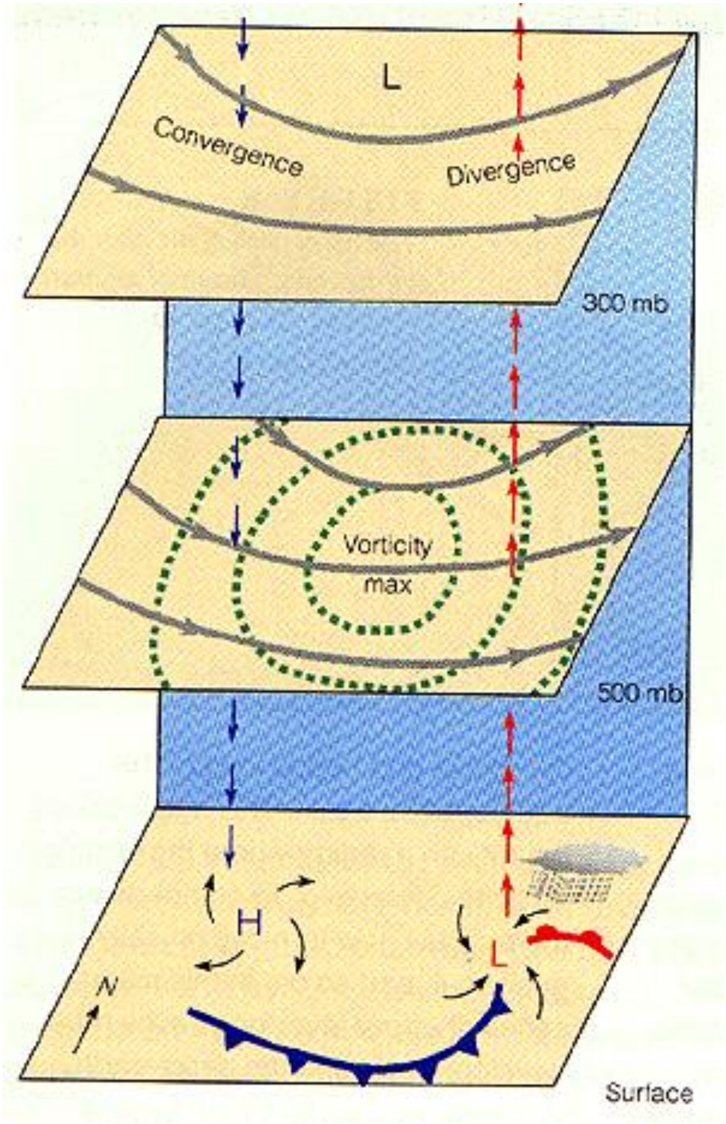


# Vertical Structure of Cyclones

•500 mb positive vorticity advection causes divergence and ascent

•This induces a surface cyclone

•Cyclone formation occurs because of this upper-level divergence!



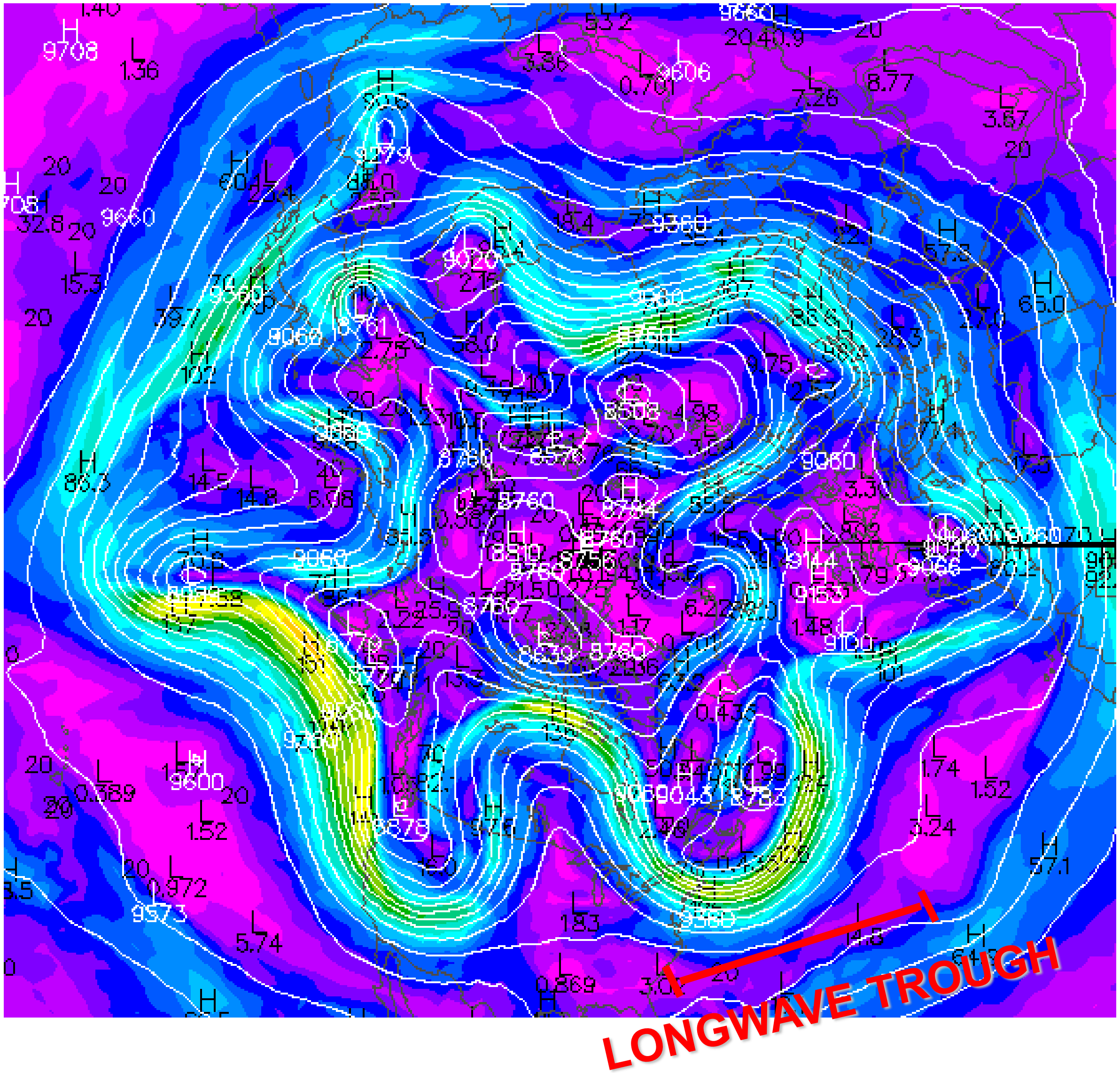
# Longwaves and Shortwaves

The flow in the upper troposphere is characterized as having . . .

• **Longwaves**:  There are typically 4-6 of these around the planet. The longwave pattern can last for as long as 2-3 weeks on occasion, and can result in long periods of anomalous weather

• **Shortwaves**:  Embedded in the longwave pattern are smaller scale areas of high vorticity (lots of curvature).  They move quickly east within the longwaves, and generally strengthen when they hit a longwave trough.  Often, shortwaves result in huge "cyclogenesis" events such as nor-easters or midwest snowstorms.

# Longwaves vs. Shortwaves



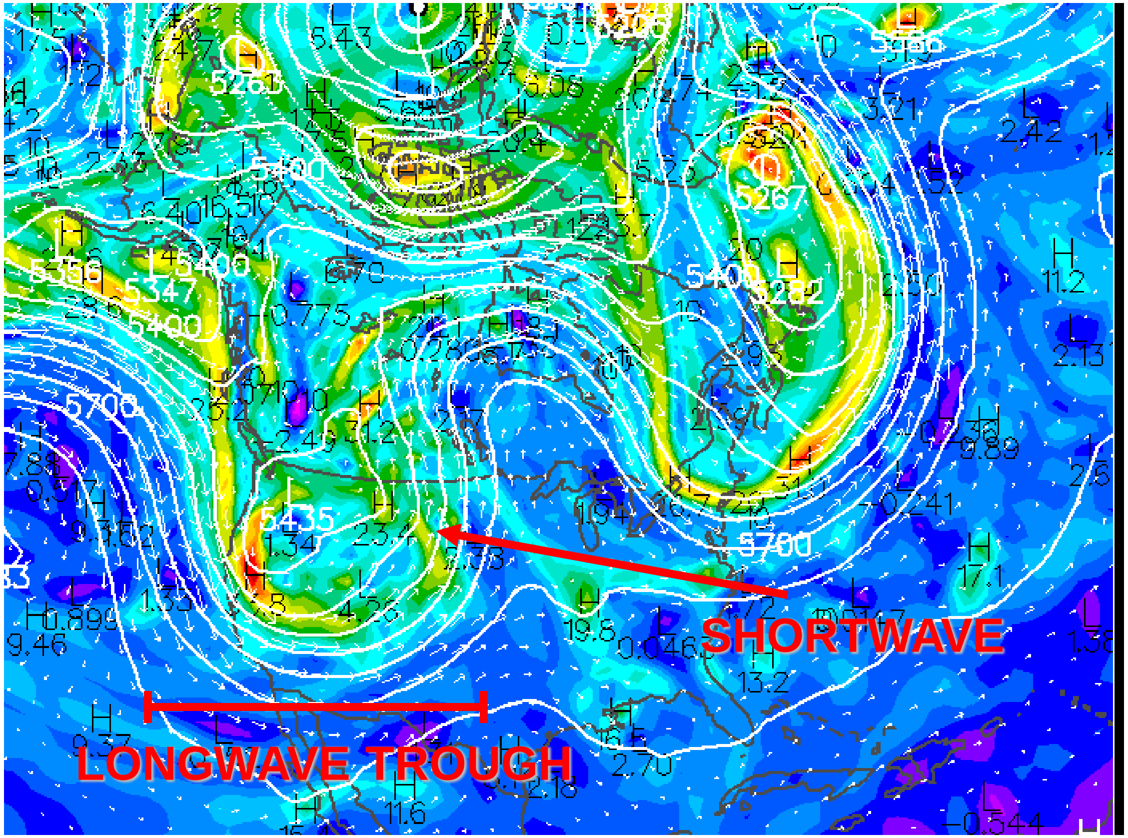

To the left is a North Pole projection of 300 mb heights (contoured) and wind speed (colors)

- North Pole is at the center, equator is at the edges
- Note the prominent longwave troughs and ridges---especially over North America

# Longwaves vs. Shortwaves

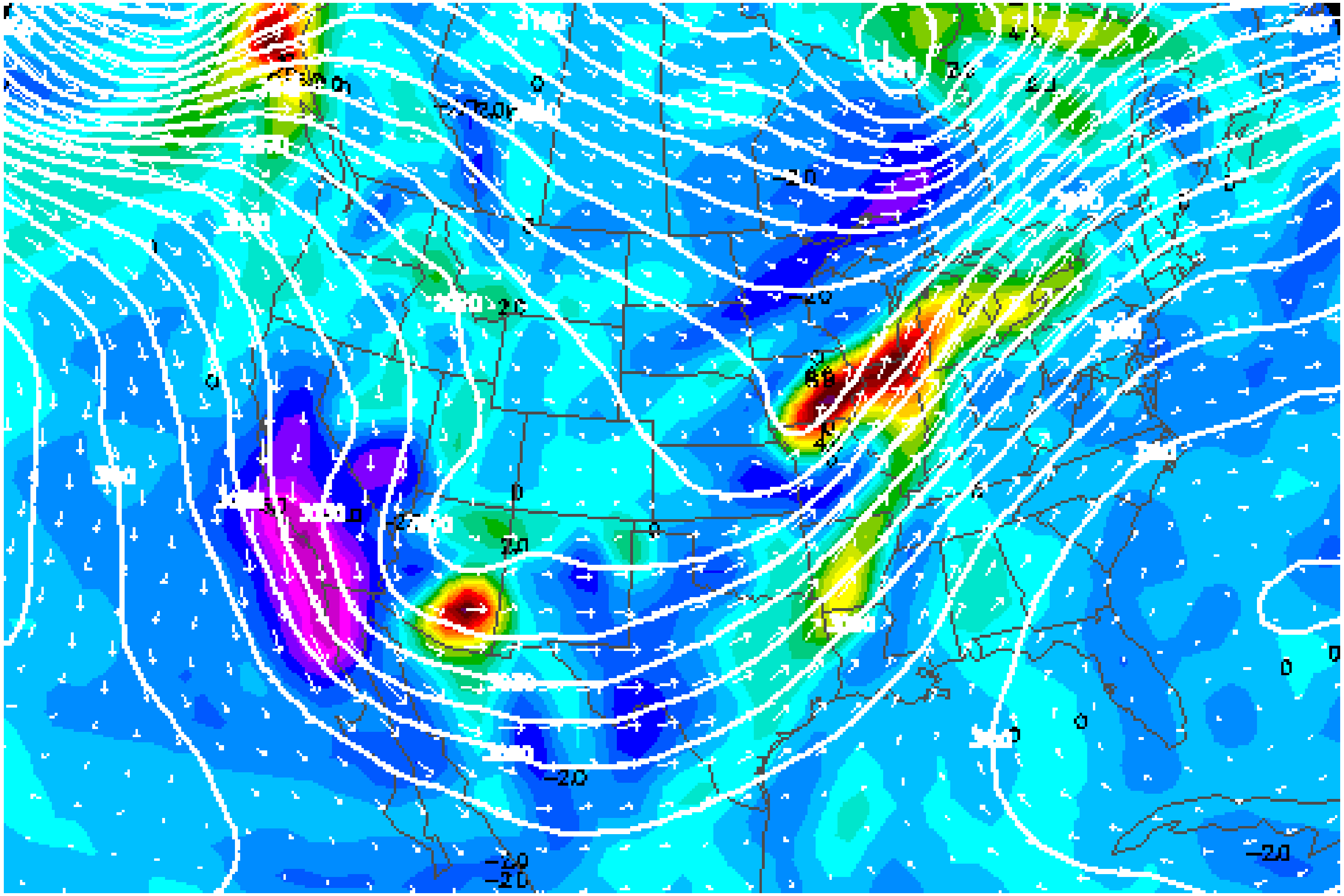
Notice two longwave troughs in this 500 mb height (contour) and vorticity (colored) map: One over the NW U.S., and one over eastern Canada.

Also, note a very subtle shortwave over Montana/Wyoming (you can see this in the vorticity field as a strip of anomalously large vorticity.



# Vertical Structure of Cyclones

700mb



- Downstream from **troughs** are favorable locations for **ascent** (red/orange)
- Downstream from **ridges** are good locations for **descent** (purple/blue)

# Cyclone Intensification/Weakening

How do we know if the surface cyclone will intensify or weaken?

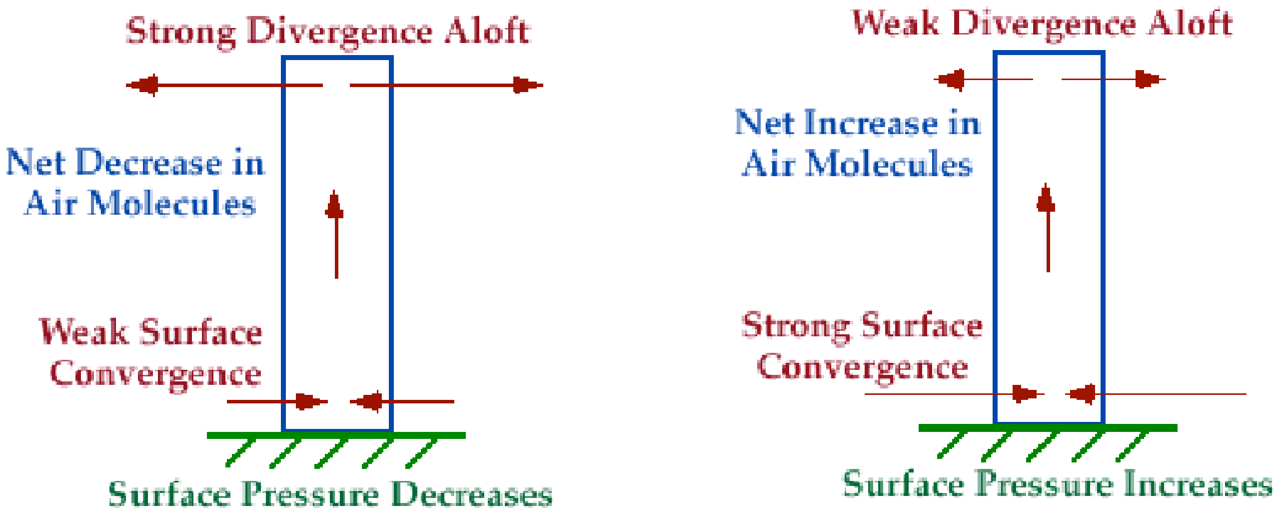
- If **upper tropospheric divergence** > **surface convergence**, the cyclone will intensify (the low pressure will become lower)

- If **surface convergence** > **upper tropospheric divergence**, the cyclone will weaken, or "fill."

- Think of an intensifying cyclone as exporting mass, and a weakening cyclone as importing mass.

# Pressure…

- If we have converging air at the surface, must have divergence aloft!
- Otherwise, air would “fill up” the low and the pressure would rise

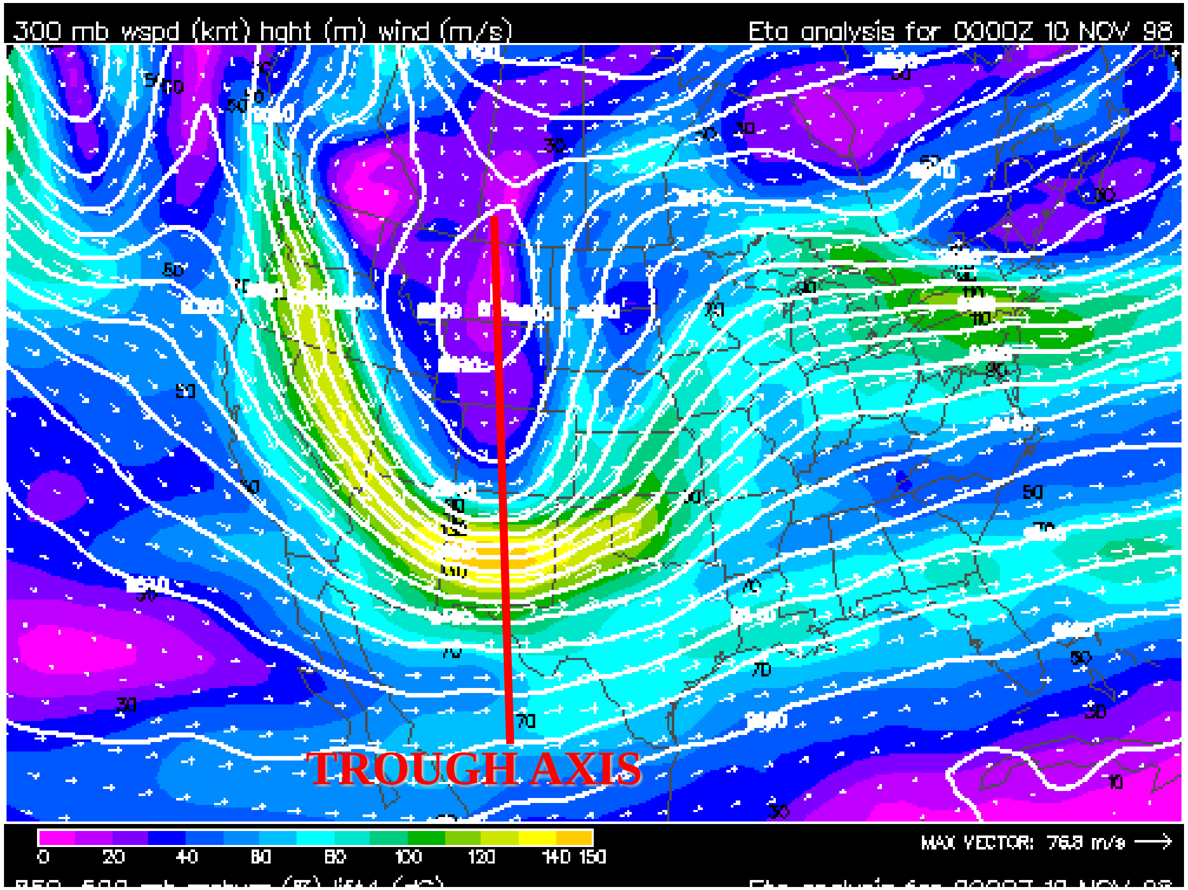



Intensifying Sfc Cyclone

Weakening Sfc Cyclone

# Example of Cyclone Development Forced by Upper Flow

Example 300 mb flow which resulted in a massive cyclone development over the midwest.

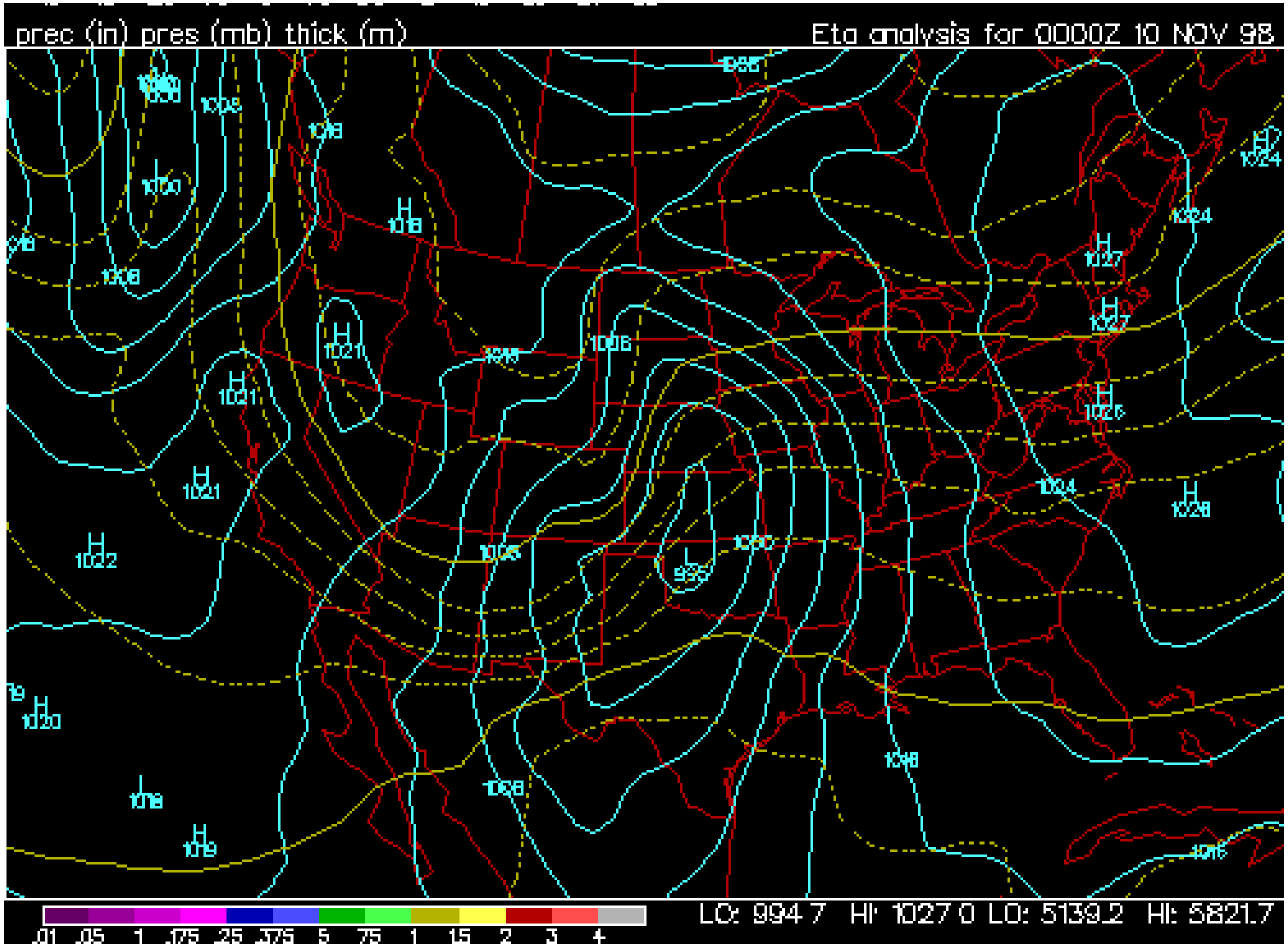



http://weather.unisys.com

# Example of Cyclone Development Forced by Upper Flow

Surface cyclone (over NW Oklahoma) is positioned just downstream of the trough axis in the previous image.

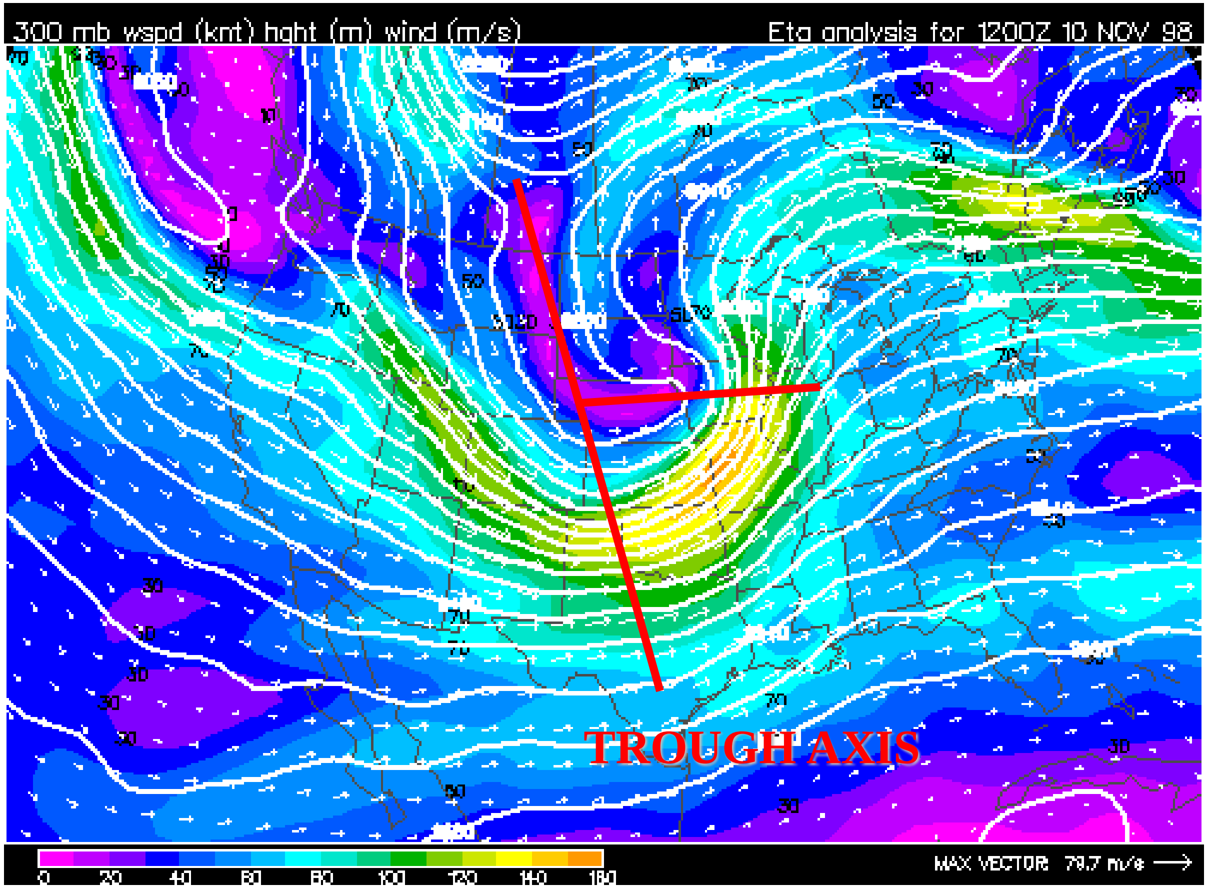
**Same time** as the previous image.



# Example of Cyclone Development Forced by Upper Flow

12 hours later, the jet speed maximum has shifted downstream with the trough, and there appear to be two trough axes.

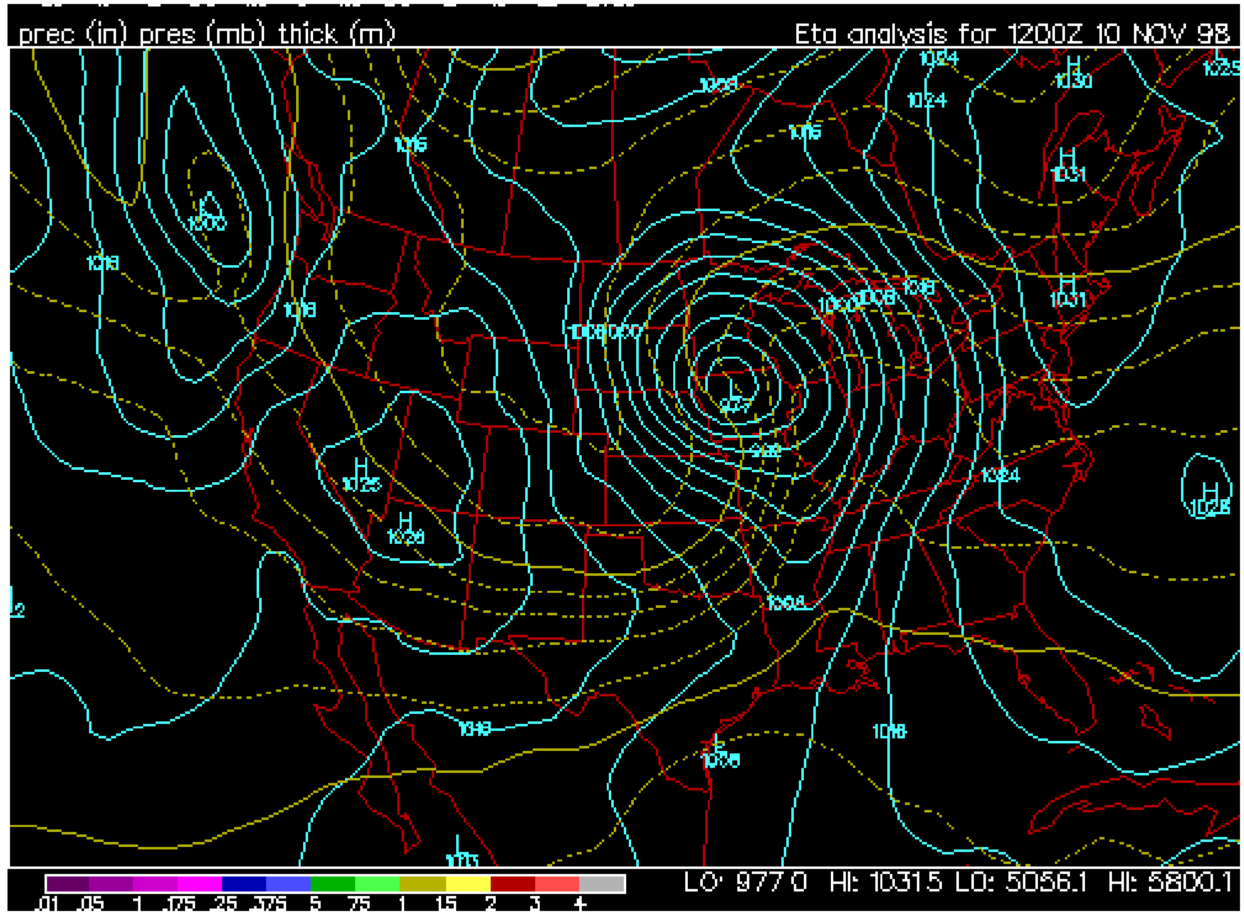
The trough is "**negatively tilted**," (NW-SE in orientation) often a sign of very strong PVA and forced ascent.



# Example of Cyclone Development Forced by Upper Flow

Now, the surface cyclone has deepened to a very low 977 mb.

In general, it is still located downstream of the trough axis, but the trough axis appears to be catching up to the surface cyclone.

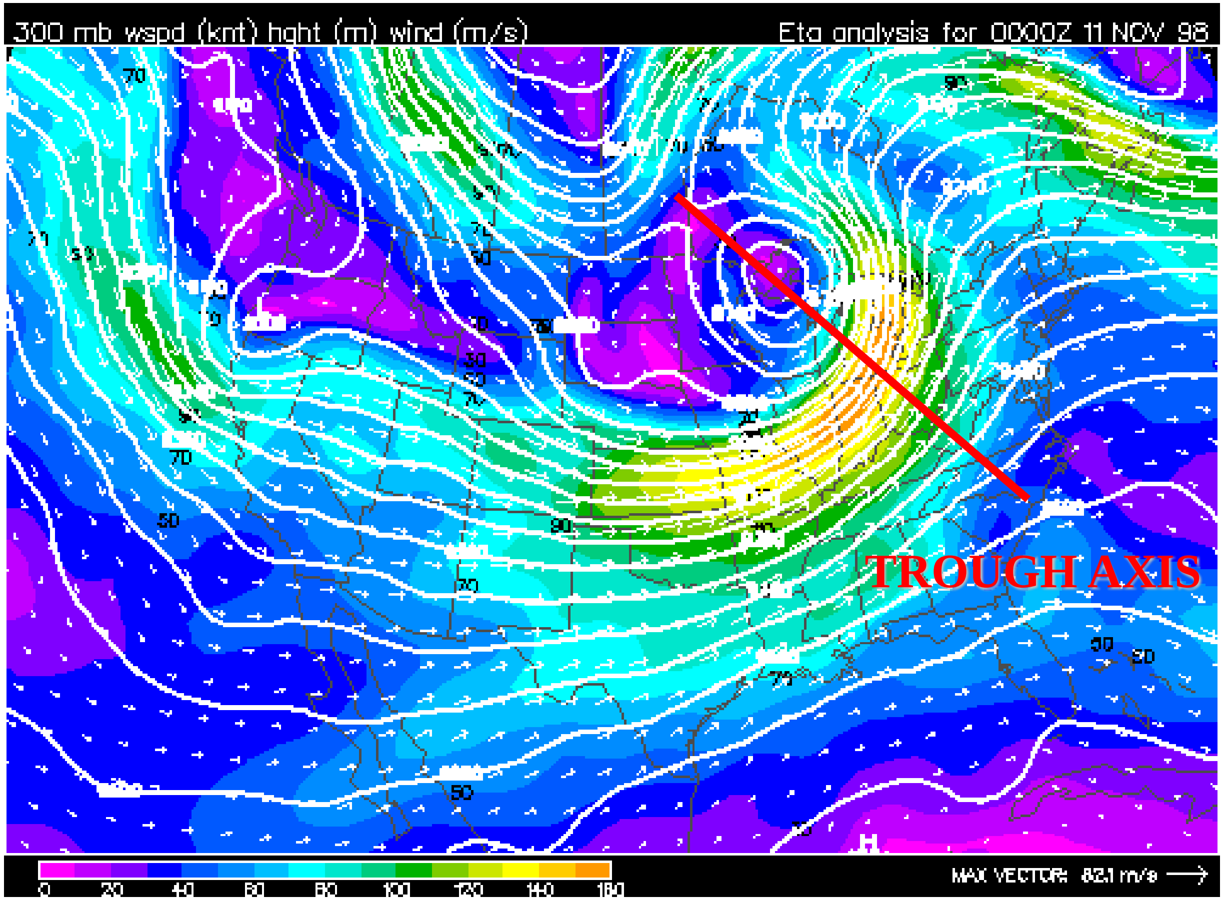


# Example of Cyclone Development Forced by Upper Flow

**12 hours later**:

• 300 mb upper tropospheric low hasn't moved too much

• Upper low is situated over eastern Lake Superior.



# Example of Cyclone Development Forced by Upper Flow

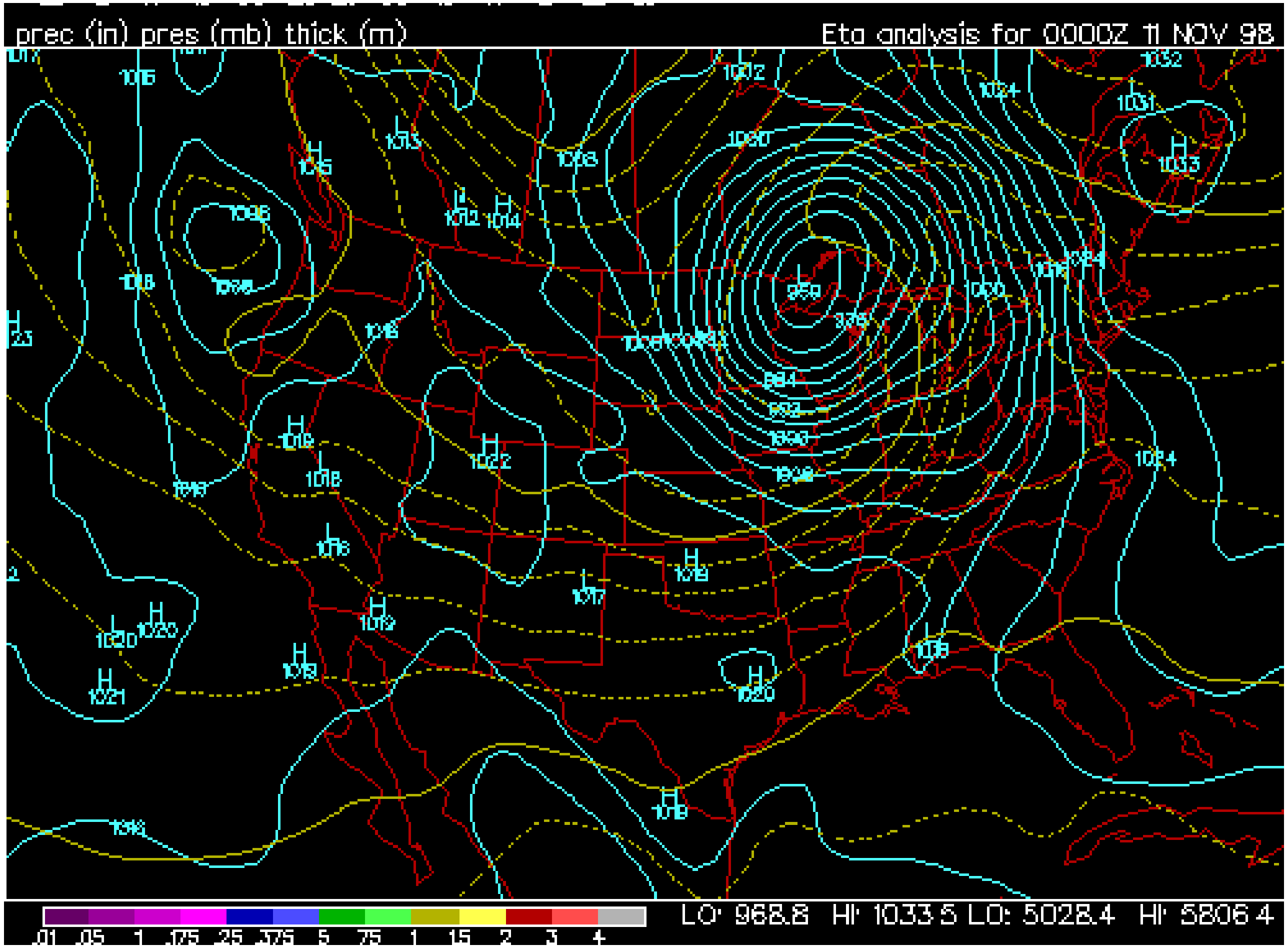
**SFC at same time:**

•Surface cyclone is also over eastern Lake Superior!

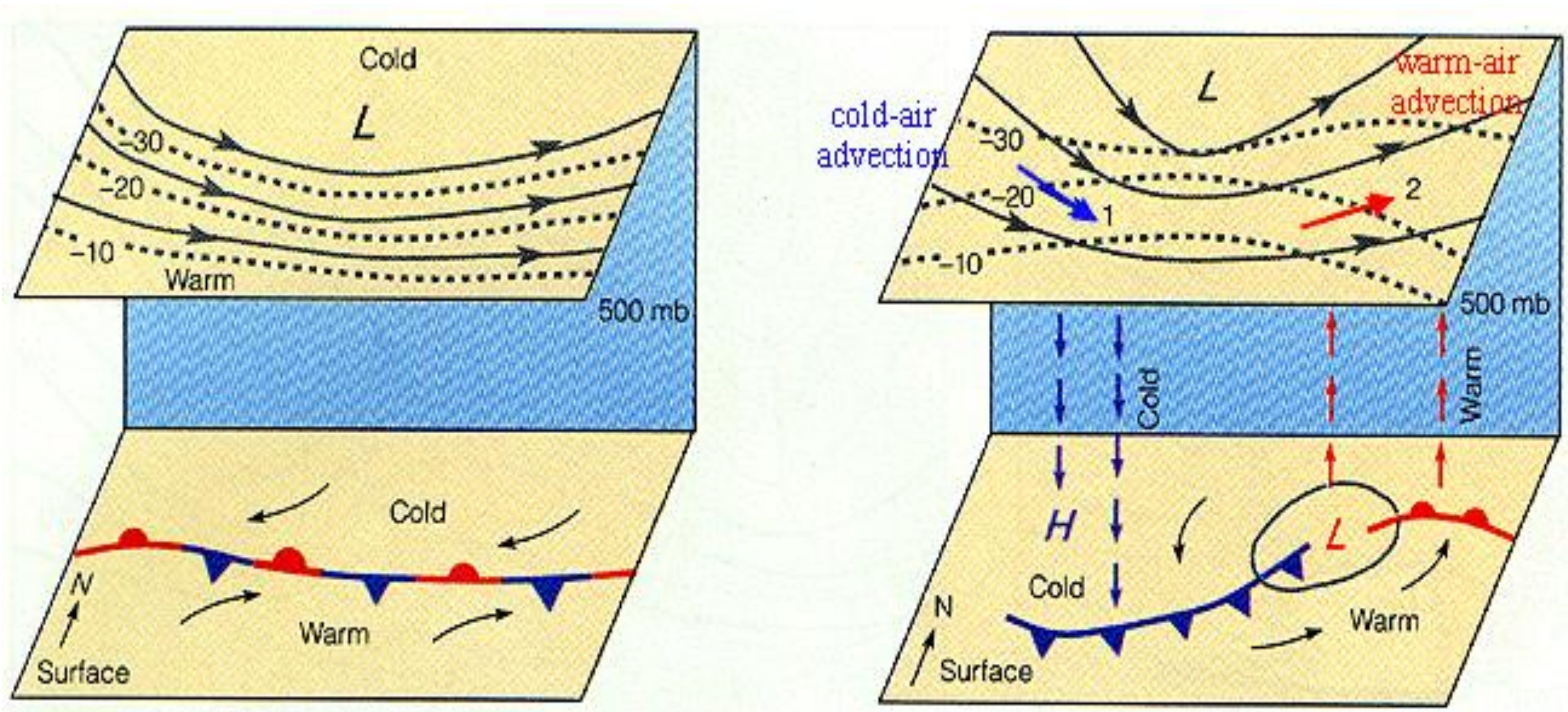
•This means that the surface cyclone is no longer in a favorable position for PVA (or upper divergence and ascent)

•At this point, the surface cyclone will weaken!

•Cyclone is "**vertically stacked**."



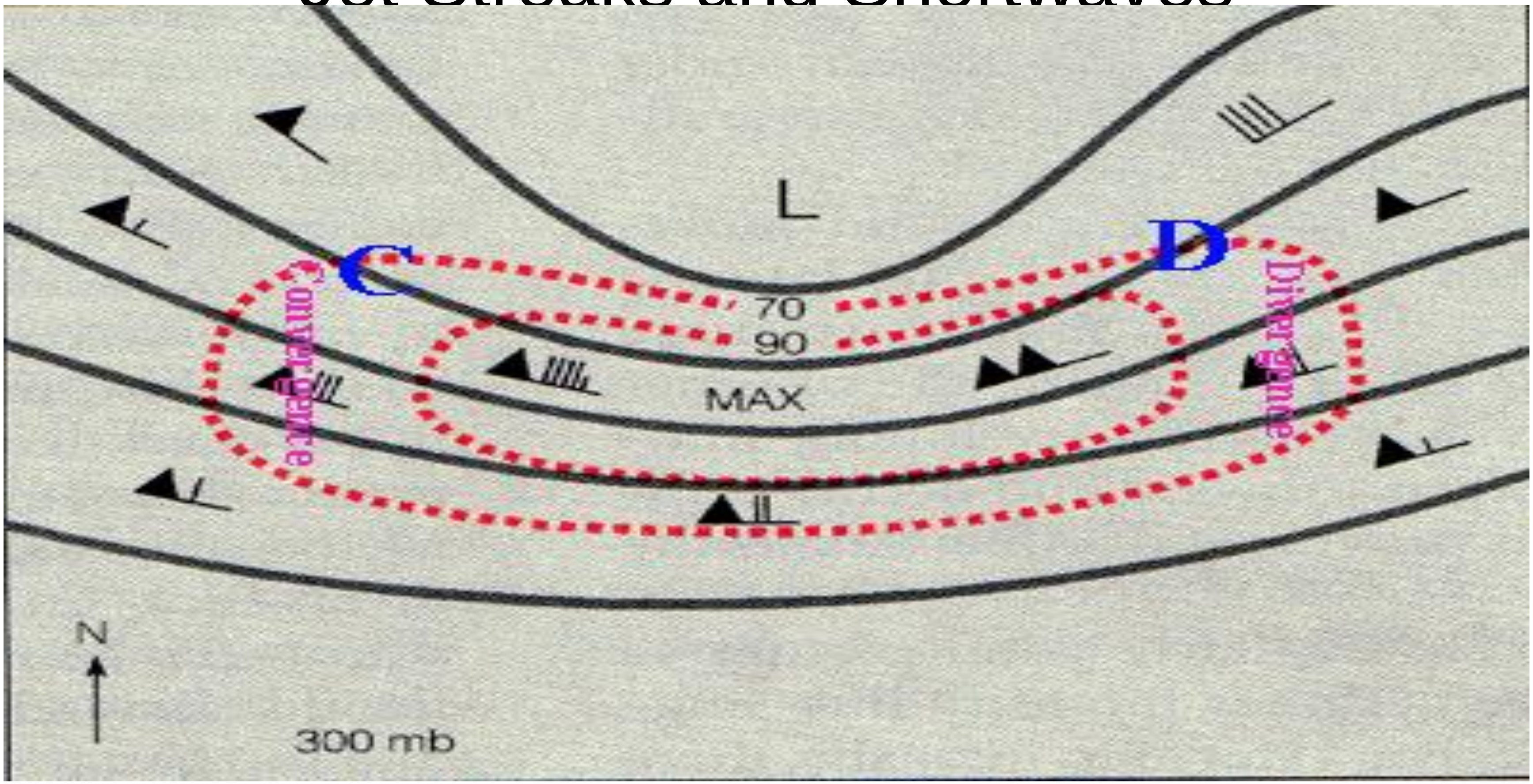
# Temperature Advection




Consider a longwave over a stationary front, seen in (a). The height lines and the isotherms are parallel to each other, we can say the atmosphere is ***barotropic***.

At time (b) a shortwave moves into the longwave trough and intensifies. The shortwave caused the isotherms to cross the height lines, thus the atmosphere is ***baroclinic***
West of the height trough, a region of (CAA). Here, the cold air is more dense and will cause sinking motions.
East of the trough, a region of (WAA). Here, the warm air will produce rising motions.

# Jet Streaks and Shortwaves

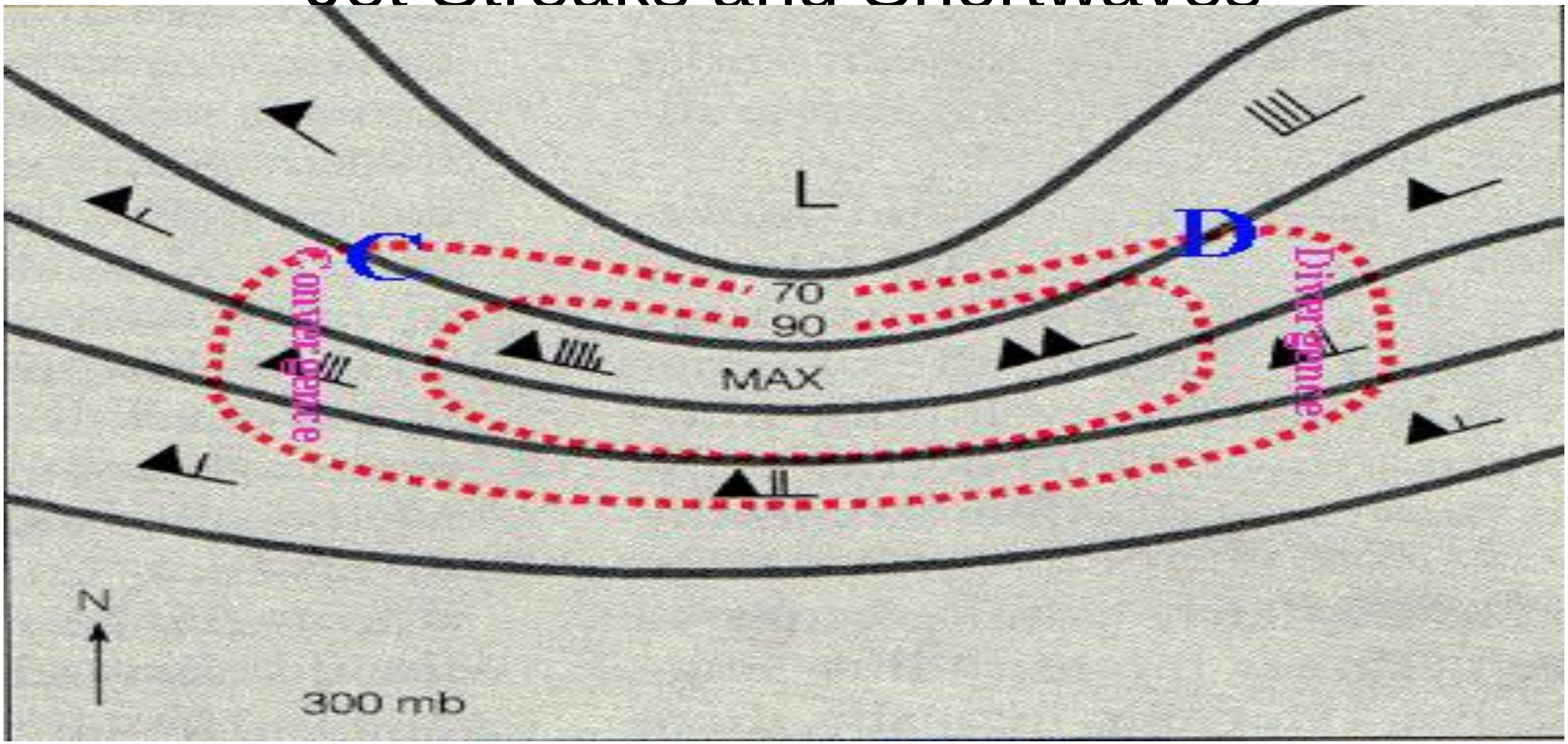



If a shortwave trough is intensified in a longwave trough, height lines are forced together:

•**large PGF** in the base of a shortwave trough

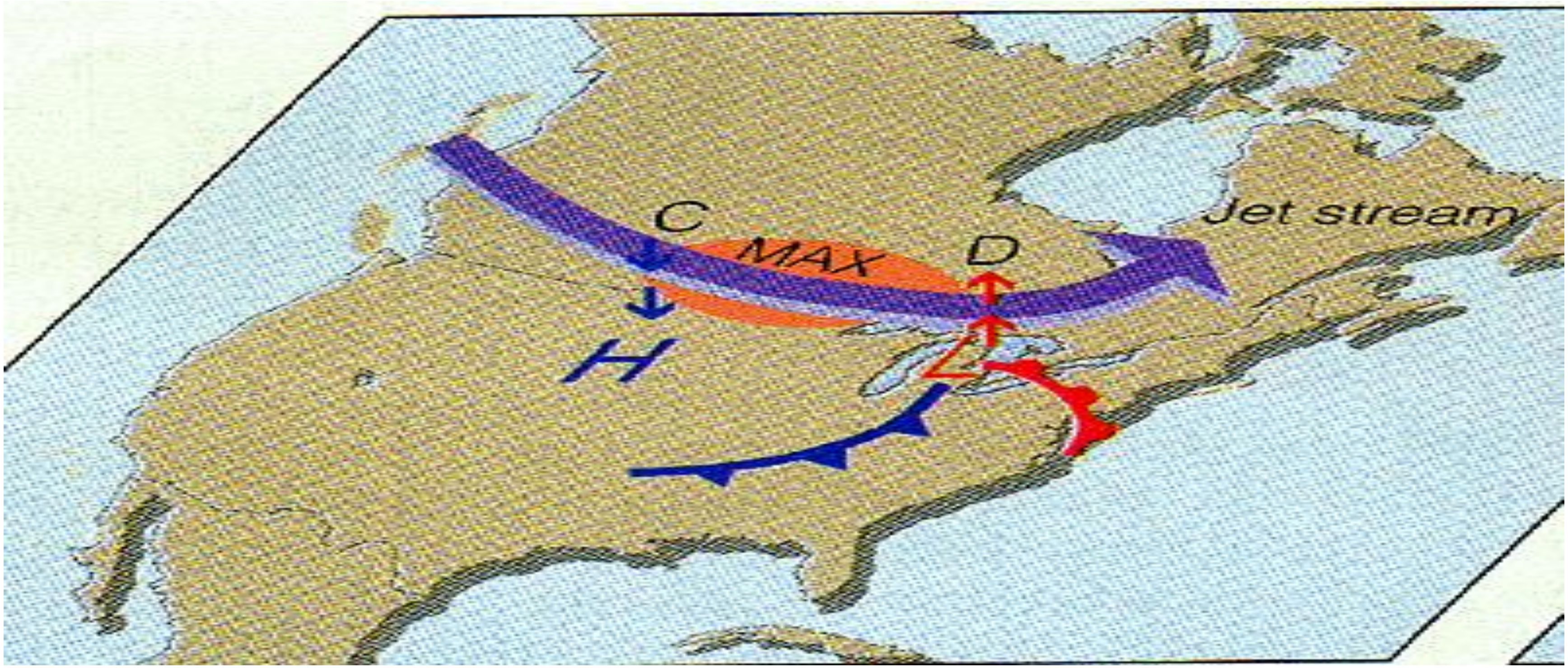
•We have seen before that large PGF corresponds to large wind speeds.

# Jet Streaks and Shortwaves



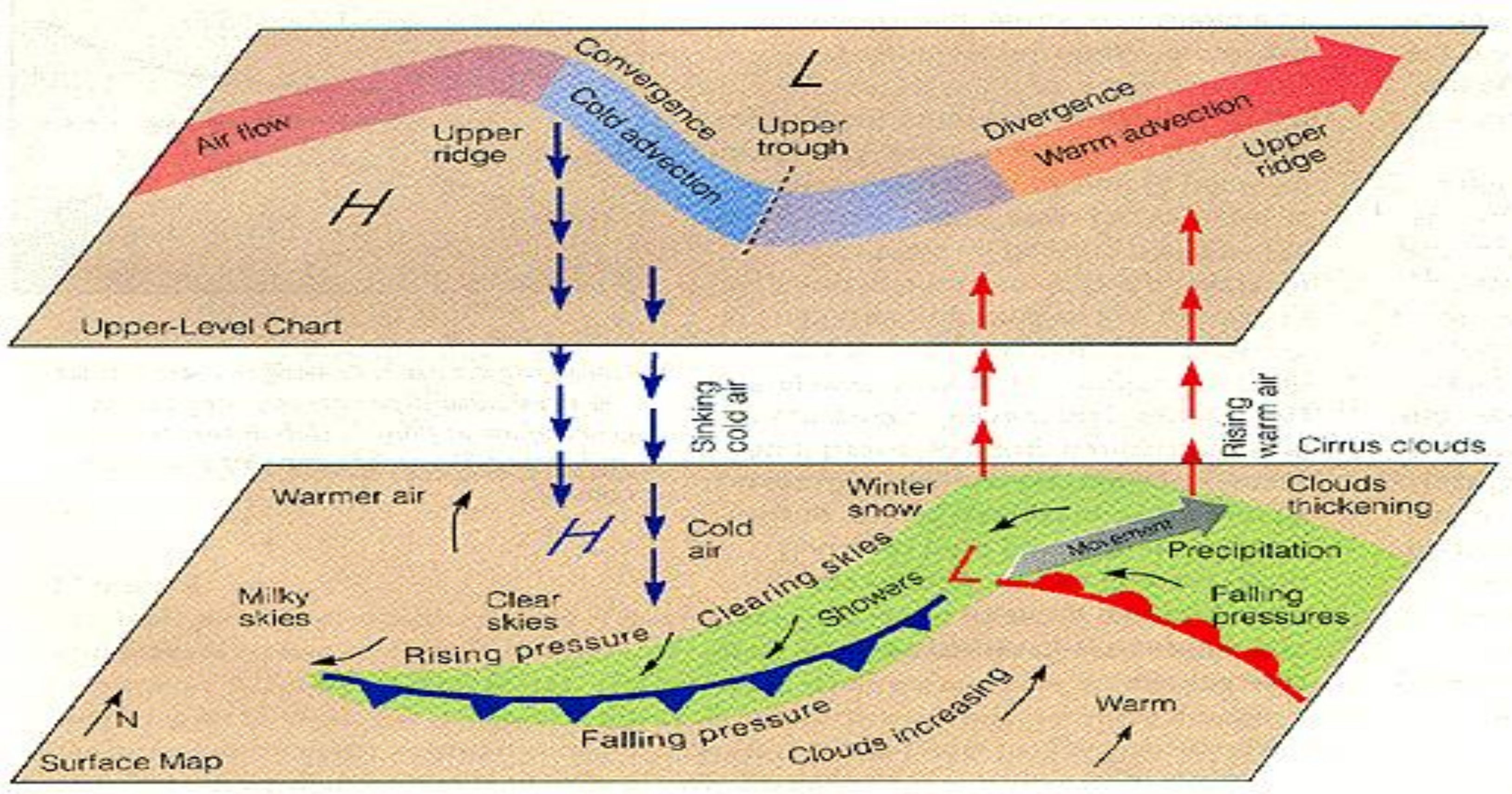

•Largest wind speeds where height lines are the closest together on an upper level map.
•Wind speed decreases outward from this point.
•Therefore we have a convergence of wind to the left/west of a trough and the divergence of wind to the east/right of a trough.

# Jet Streaks and Shortwaves




If we look at the full vertical structure we will see that the divergence and convergence associated with a jet streak are directly above the low and high pressures at the surface.

# The full picture



# Creating a Cyclone

If an upper level shortwave intensifies in a longwave :

- Jet streak creates upper level convergence and divergence
- Surface convergence occurs directly below upper level divergence
- Cyclone begins to develop

# Cyclone Intensifies and Fades

- Cyclone goes through its life cycle, intensifies, its low pressure decreases, warm front and cold front move
- Upper level low to west of surface low (westward tilt with height)
- Upper level trough begins to catch up to surface low (tilt decreases)
- When cyclone is vertically stacked (no tilt), cyclone begins to die

(no divergence above the surface convergence)