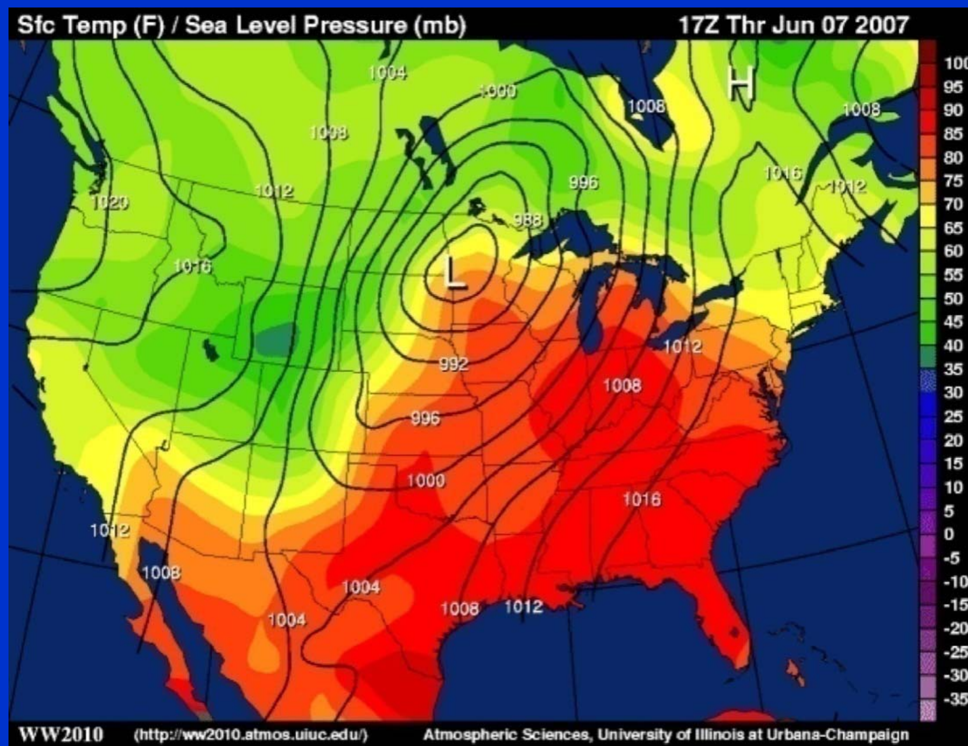
Chapter 8: Development of High- and low-Pressure Systems



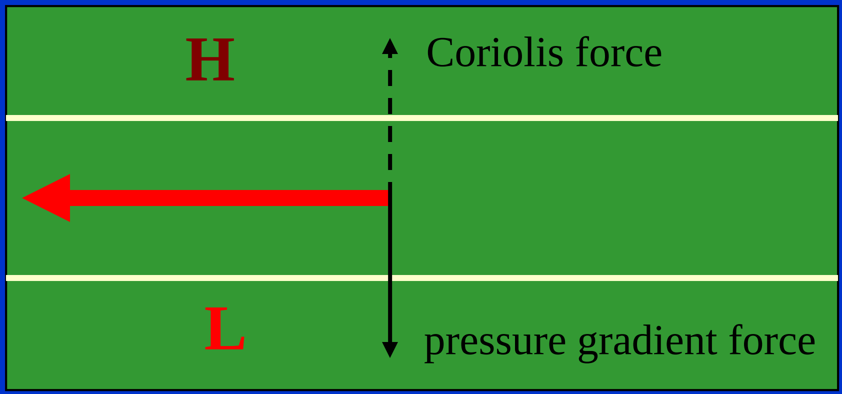
Courtesy of the Department of Atmospheric Sciences
University of Illinois at Urbana-Champaign

- Force Imbalance
- Frictional Layer
- Development of High and Low

Main Points to Learn

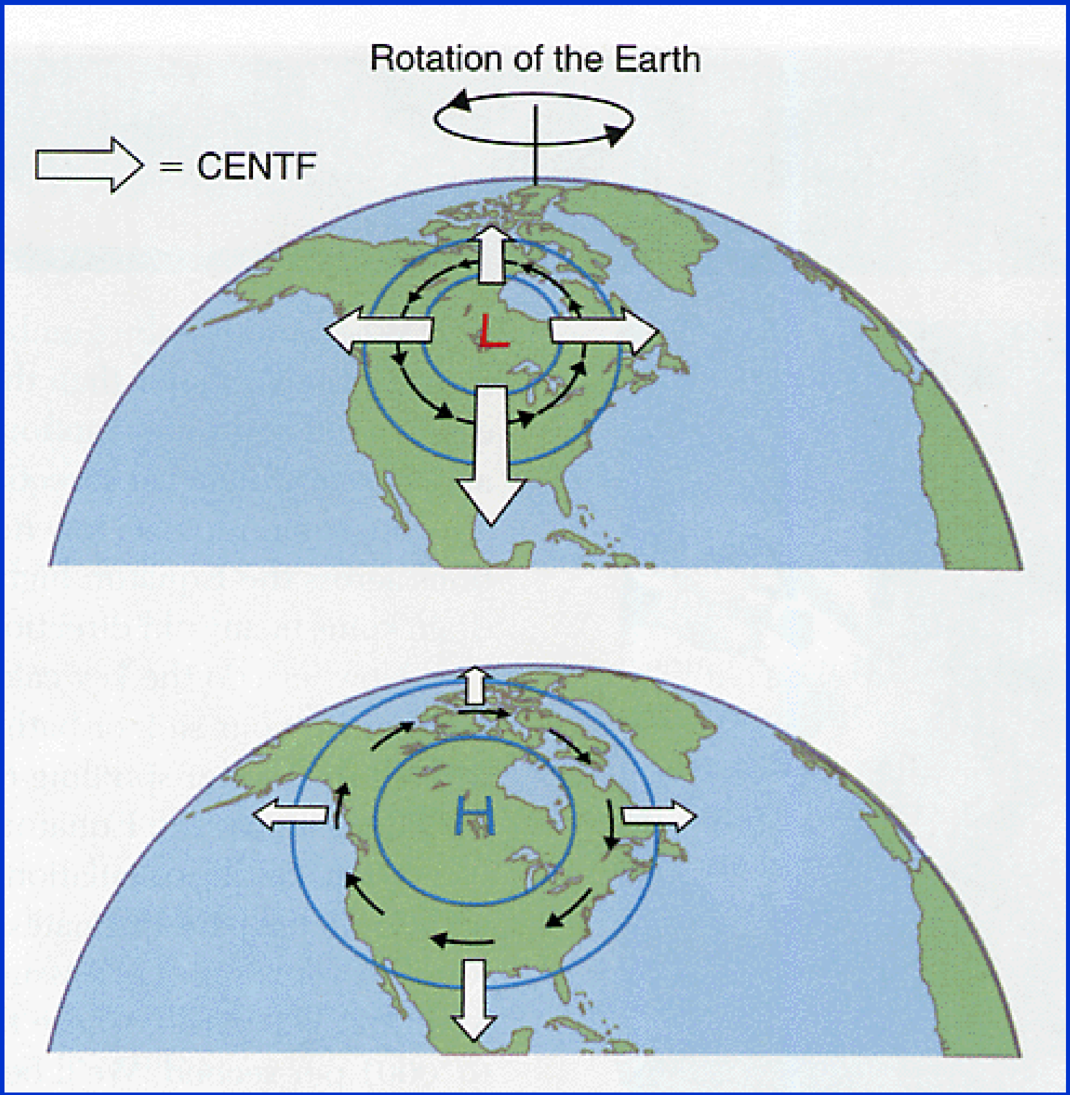
- Because extratropical cyclones are the parent storms for many hazardous weather, it is essential to understand how they are created and demised.
- Extratropical cyclones (i.e., low-pressure systems) develop as a direct result of acceleration created by the imbalance between the pressure gradient force and the Coriolis force.
- Frictional force in the boundary layer ultimately destroys extratropical cyclones.
- High-pressure systems also evolve in response to force imbalance, although cooling and heating play more important roles.

Geostrophic Balance



- By doing scale analysis, it has been shown that large-scale and synoptic-scale weather system are in geostropic balance.
- Geostrophic winds always follow the constant pressure lines (isobar). Therefore, we can figure out flow motion by looking at the pressure distribution.

Centrifugal Force



(from *The Atmosphere*)

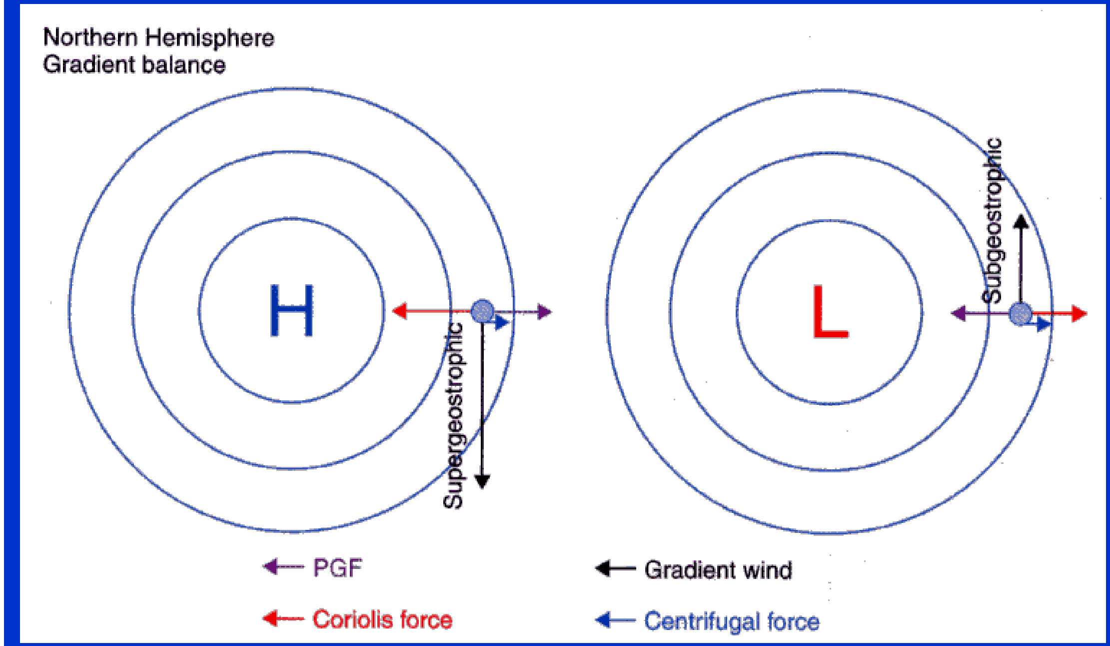
❑ The force that change the direction (but not the speed) of motion is called the centrifugal force.

❑ Centrifugal Force = V^2 / R.
V = wind speed
R = the radius of the curvature

Gradient Wind Balance

- The three-way balance of horizontal pressure gradient, Coriolis force, and the centrifugal force is call the ***gradient wind balance***.
- The gradient wind is an excellent approximation to the actual wind observed *above* the Earth's surface, especially at the middle latitudes.

Super- and Sub-Geostrophic Wind



(from *Meteorology: Understanding the Atmosphere*)

❑ For high pressure system

➔gradient wind > geostrophic wind

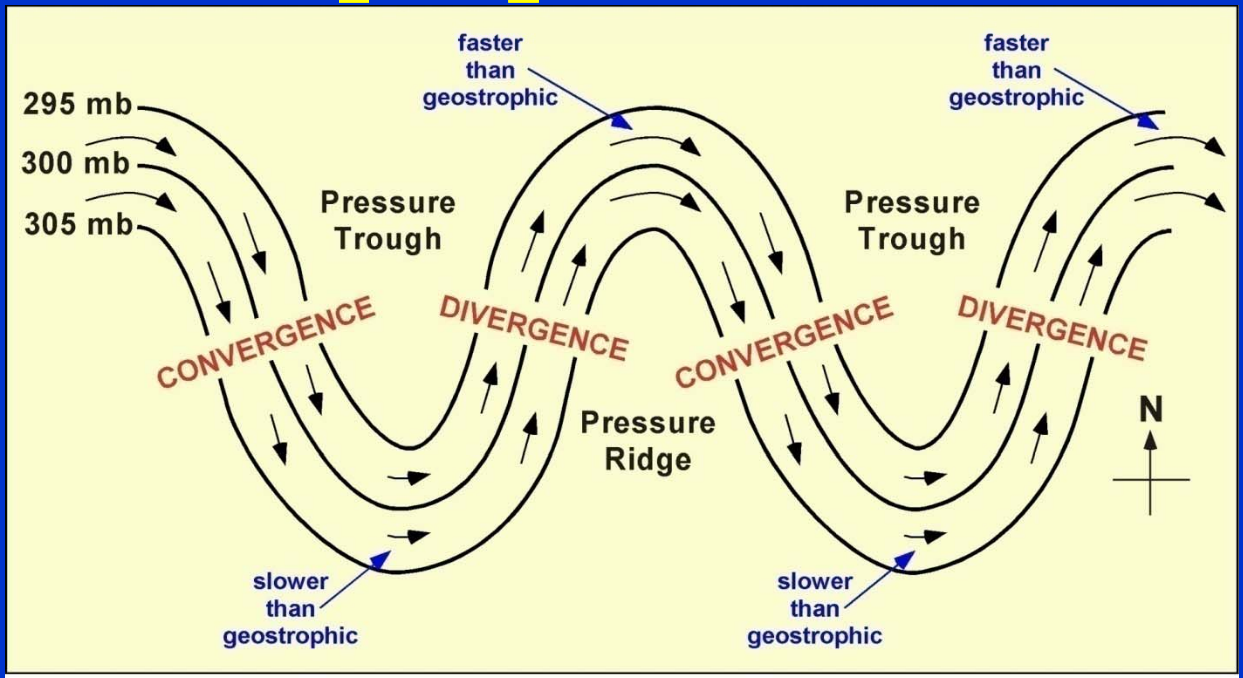
➔supergeostropic.

❑ For low pressure system

➔gradient wind < geostrophic wind

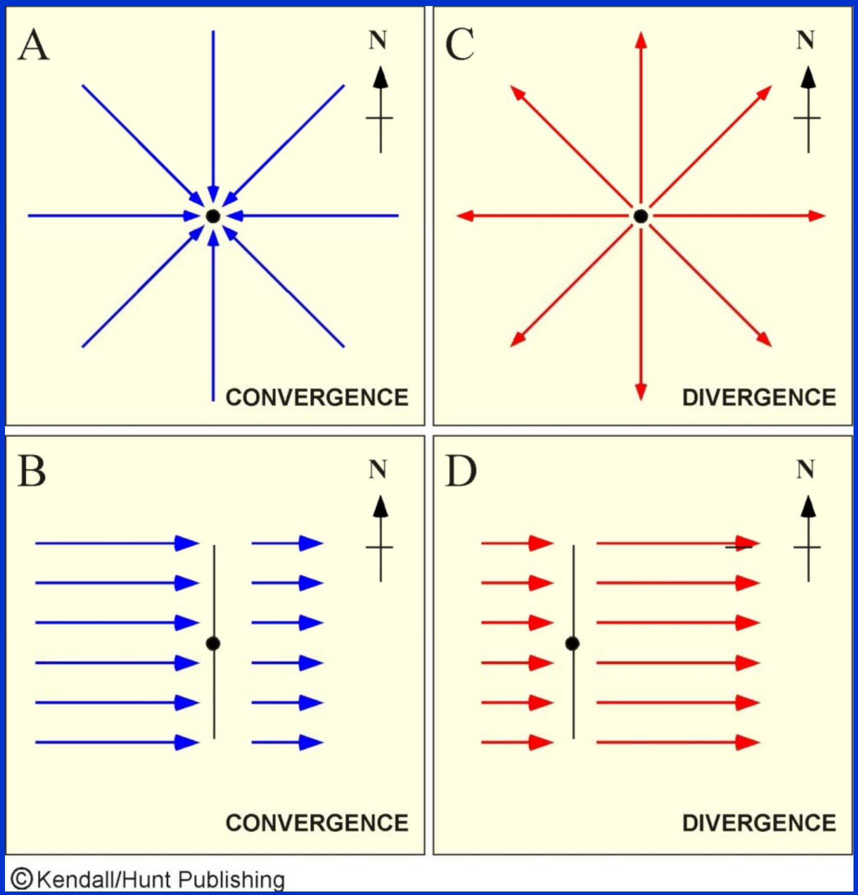
➔subgeostropic.

Upper Tropospheric Flow Pattern



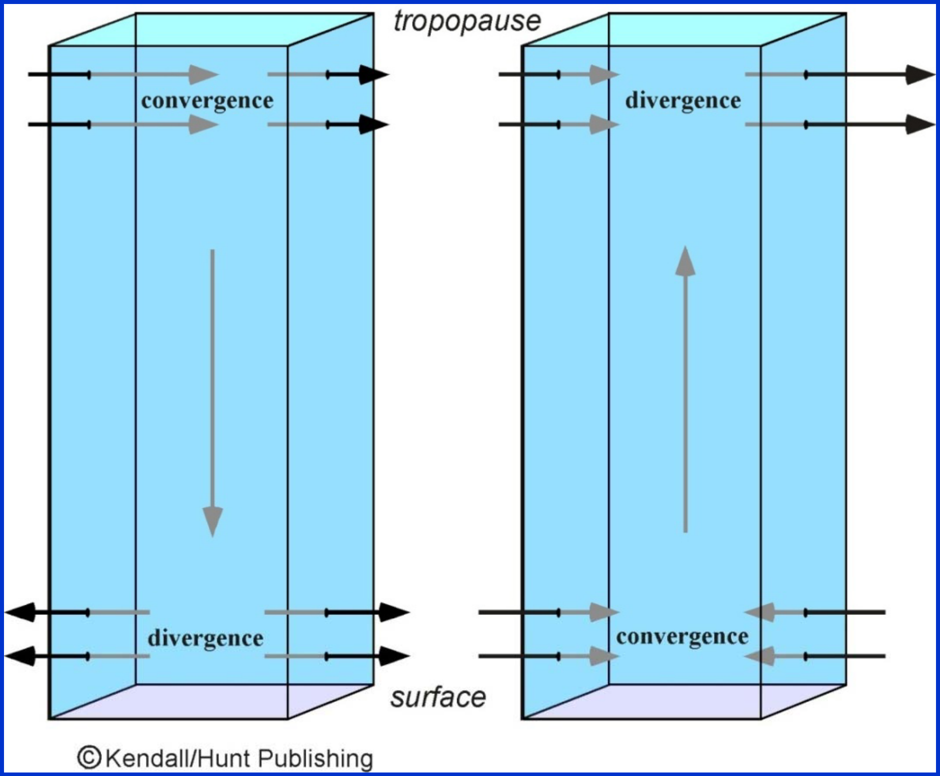
- Upper tropospheric flows are characterized by trough (low pressure; isobars dip southward) and ridge (high pressure; isobars bulge northward).
- The winds are in gradient wind balance at the bases of the trough and ridge and are slower and faster, respectively, than the geostrophic winds.
- Therefore, convergence and divergence are created at different parts of the flow patterns, which contribute to the development of the low and high systems.

Convergence and Divergence



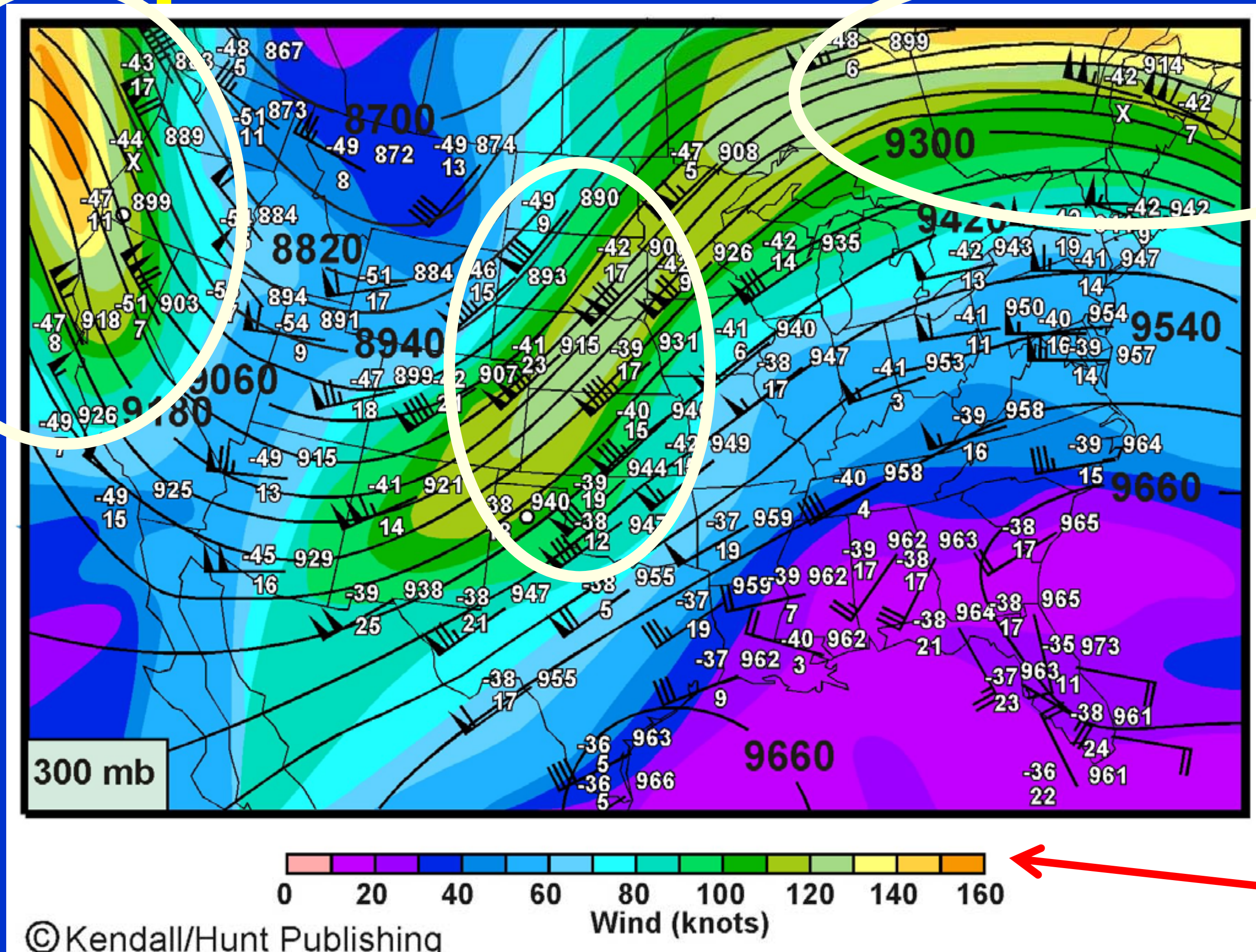
- Air is said to converge into an air column whenever the flow of air is such that the mass of air in the column increases with time.
- Conversely, air is said to diverge out of an air column if the flow pattern causes the mass of air in the column to decrease with time.

Convergence/Divergence and Vertical Motion



- Convergence in the upper tropospheric flow pattern can cause descending motion in the air column. ➔ surface pressure increase (high pressure) ➔ clear sky
- Divergence in the upper troposphric flow pattern ca cause ascending motion in the air column. ➔ surface pressure decreases (low pressure) ➔ cloudy weather

Example: A 300mb Weather Map

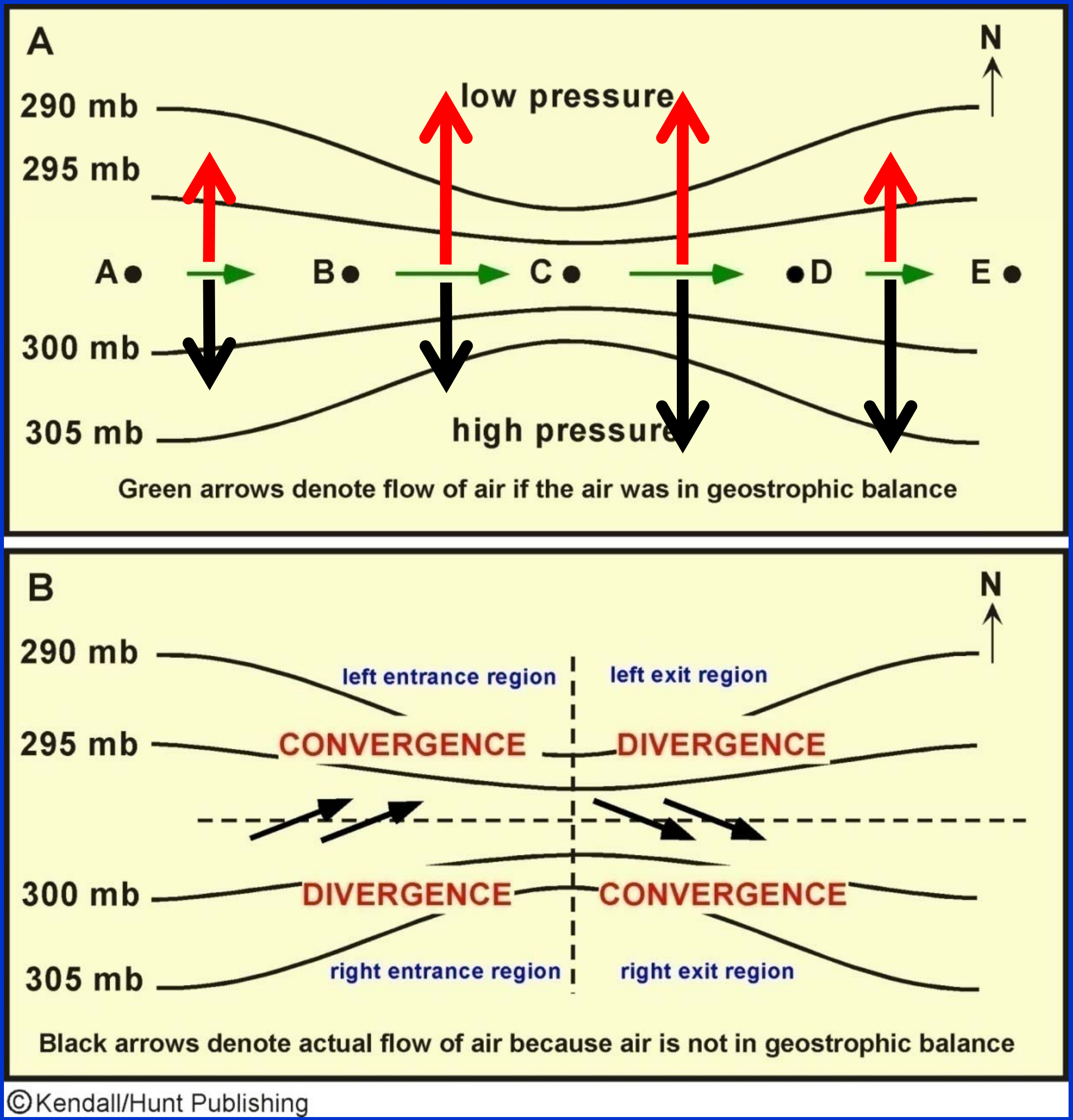


jetstreaks

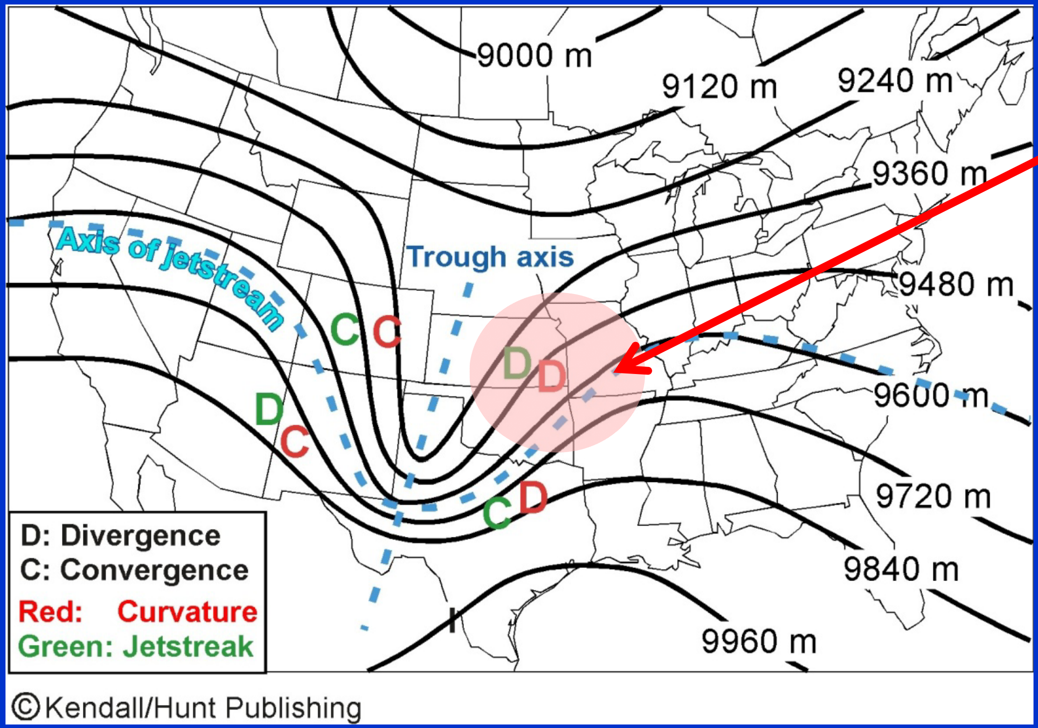
isotachs

- The 850mb map is particularly useful to identify the location of jetsreams.
- In this example, a jetstream flows northeastward from the west cost of the US, into the Great Lakes, and to the Atlantic Coast of Canada.

Convergence/Divergence in Jetstreak



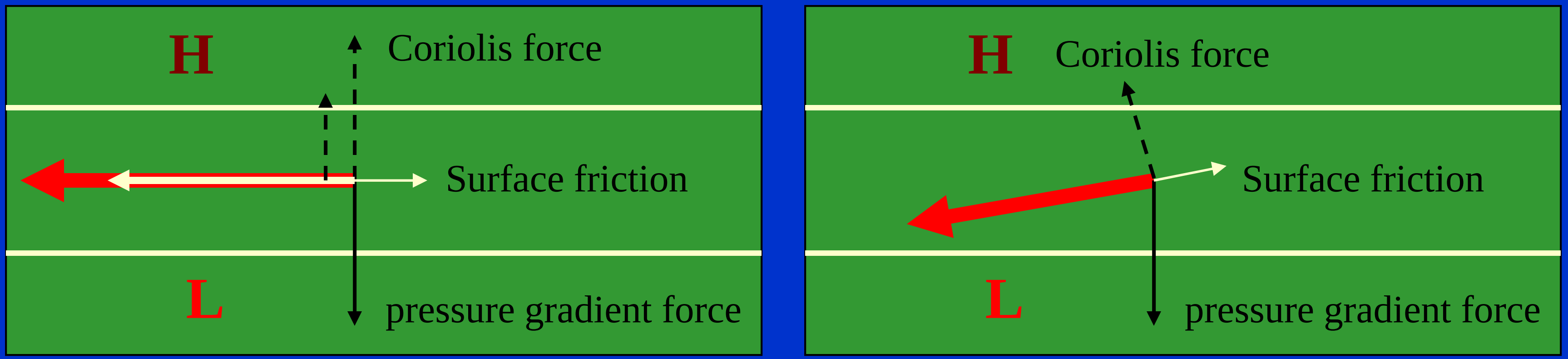
Combined Curvature and Jetstreak Effects



Surface low will develop ahead of the upper-level trough.

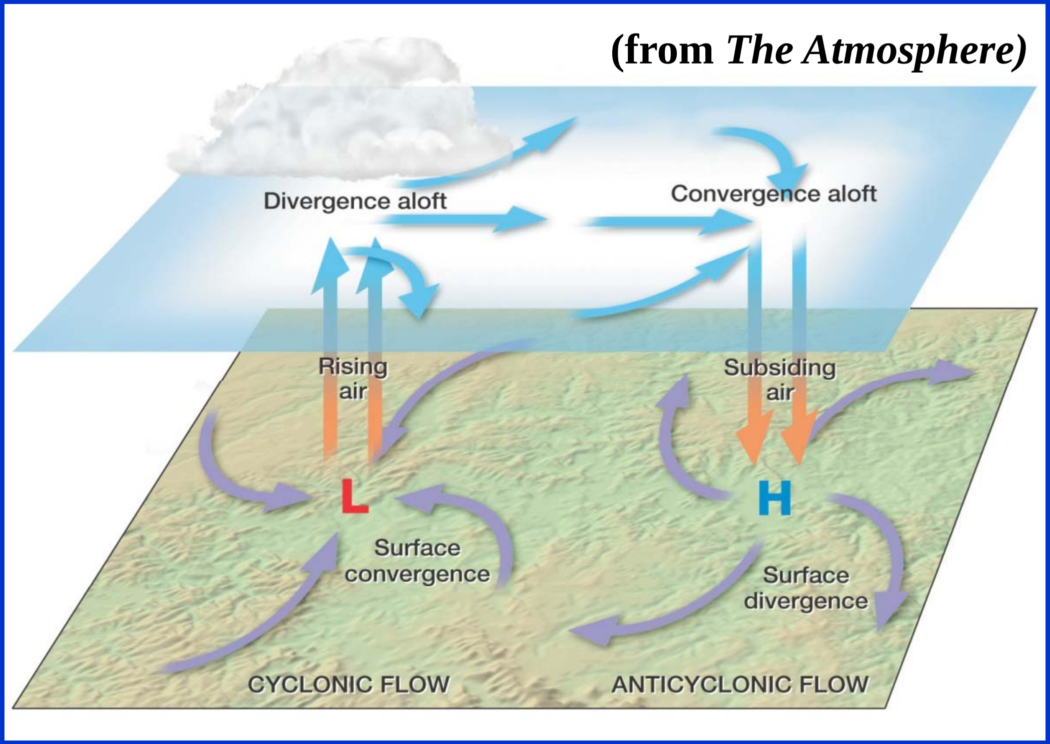
- The convergence/divergence produced by the curvature and jetstreak effects cancels each other to the south of the jetstream axis but enhances each other to the north of the jetsream.
- The strongest divergence aloft occurs on the northeast side of the trough, where a surface low pressure tens to develop.
- The strongest convergence aloft occurs on the northwest side of the trough, where a surface high pressure tends to develop. However, other processes are more important that this upper-level convergence in affecting the development of high pressure system.

Frictional Effect on Surface Flow



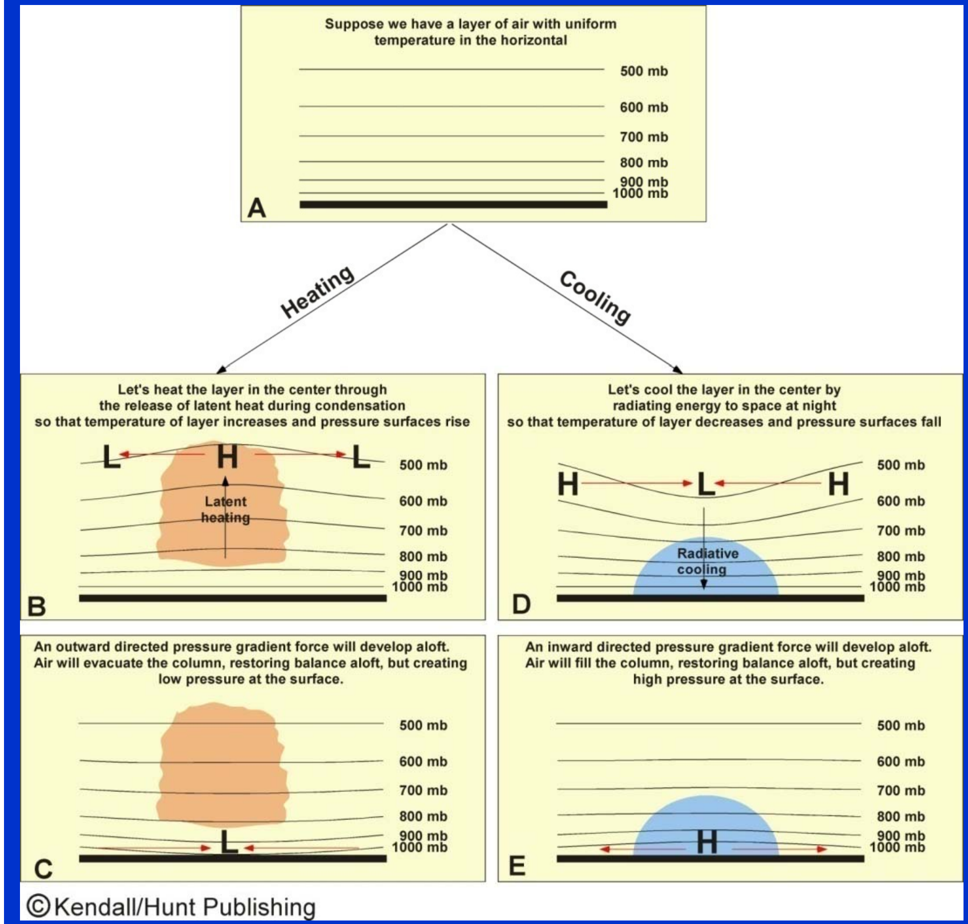
- Surface friction force slows down the geostrophic flow.
- The flow turns into (out of) the low (high) press sides.
- Surface friction produces convergence into the center of a low-pressure system and divergence out of the center of a high-pressure system.

Friction and Development of Surface Low and high



- Friction always contributes to weakening of both surface high-pressure enters and low-pressure centers.

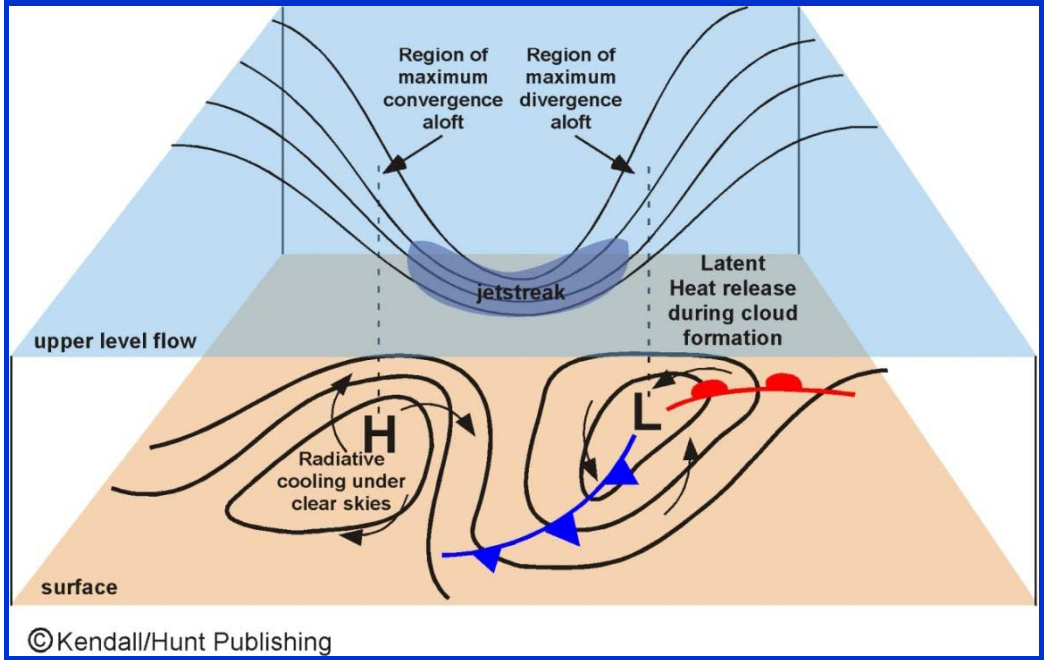
Surface Heating and Cooling



- Surface heating by solar energy causes ascending motion, which tends to decrease a surface low-pressure center.
- In contrary, surface cooling produces a surface high-pressure center.
- Surface heating and cooling are the third mechanisms to affect the developments of low- and high-pressure systems.

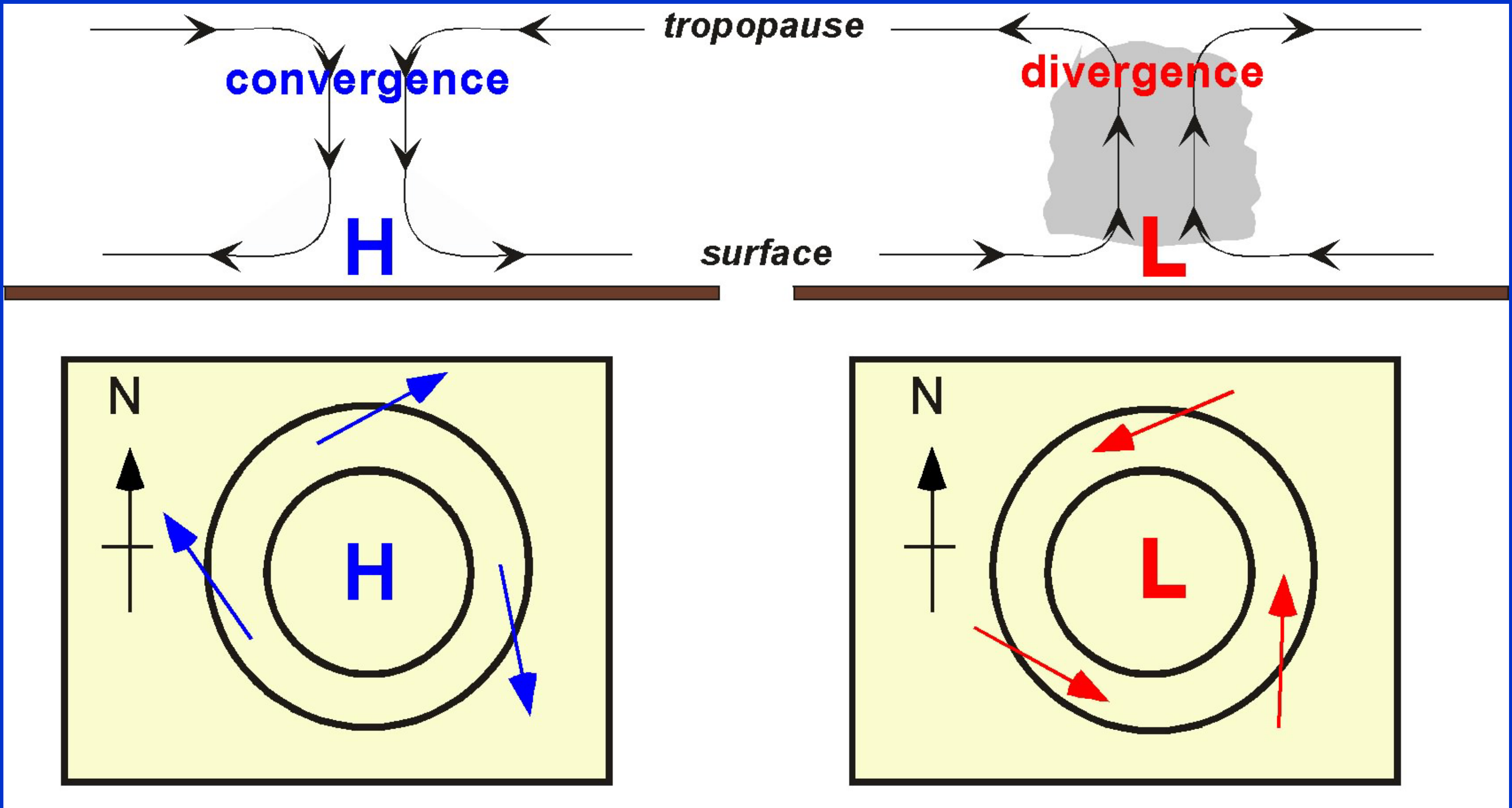
• The other two processes are the (1) upper-level convergence/divergence causes by curvature effect and jetstreak effect and (2) surface friction.

Developments of Low- and High-Pressure Centers

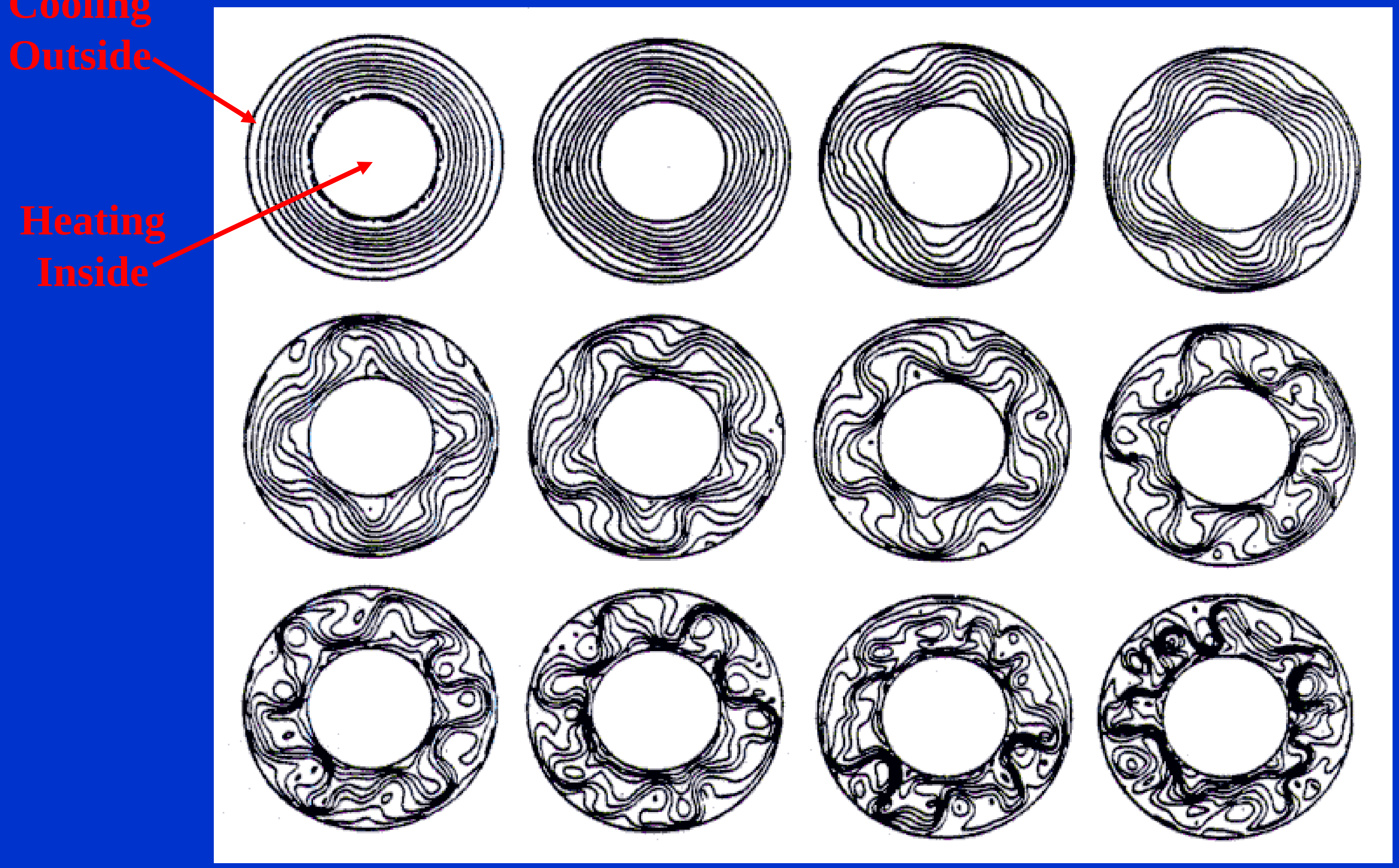


- ***Dynamic Effects***: Combined curvature and jetstreak effects produce upper-level convergence on the west side of the trough to the north of the jetsreak, which add air mass into the vertical air column and tend to produce a surface high-pressure center. The same combined effects produce a upper-level divergence on the east side of the trough and favors the formation of a low-level low-pressure center.
- ***Thermodynamic Effect***: heating ➔ surface low pressure; cooling ➔ surface high pressure.
- ***Frictional Effect***: Surface friction will cause convergence into the surface low-pressure center after it is produced by upper-level dynamic effects, which adds air mass into the low center to "fill" and weaken the low center (increase the pressure)
- ***Low Pressure***: The evolution of a low center depends on the relative strengths of the upper-level development and low-level friction damping.
- ***High Pressure***: The development of a high center is controlled more by the convergence of surface cooling than by the upper-level dynamic effects. Surface friction again tends to destroy the surface high center.

Vertical View of High/Low Developments

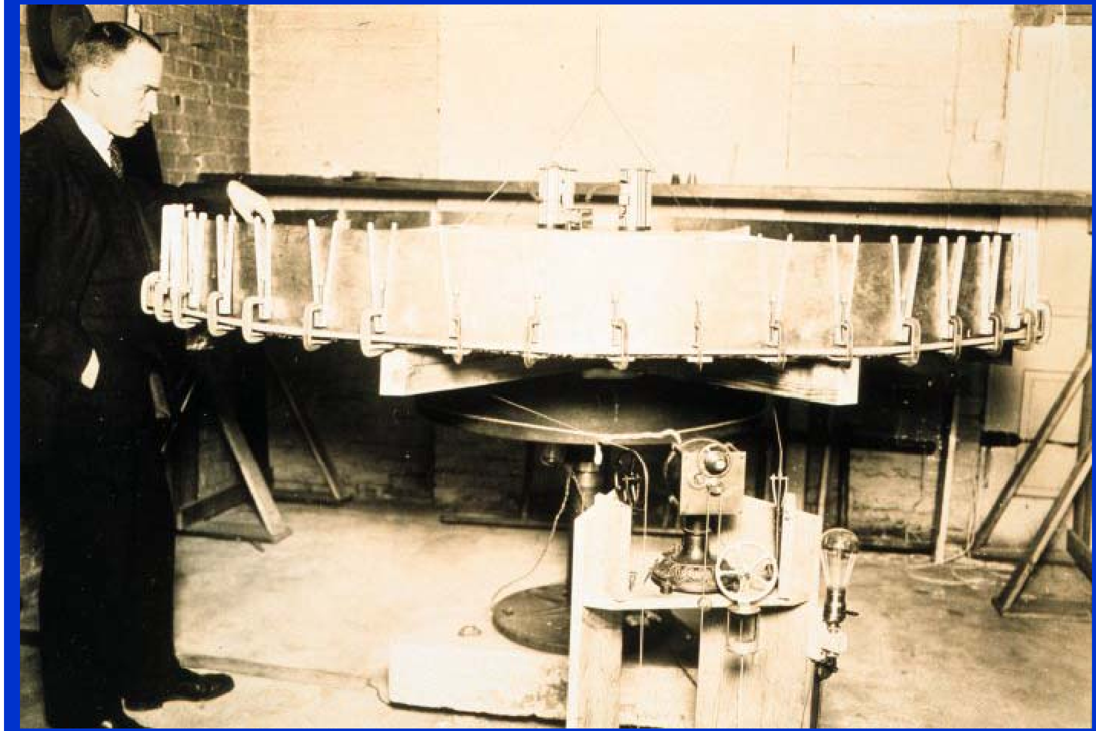


Rotating Annulus Experiment



(from *"Is The Temperature Rising?"*)

New Understanding of Cyclone after WWII



Carl Gustav Rossby (1898-1957)

- Carl Rossby mathematically expressed relationships between mid-latitude cyclones and the upper air during WWII.
- Mid-latitude cyclones are a large-scale waves (now called Rossby waves) that grow from the "baroclinic" instabiloity associated with the north-south temperature differences in middle latitudes.