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

- 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.
By doing scale analysis, it has been shown that large-scale and synoptic-scale weather system are in geostrophic 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

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

- Centrifugal Force $= \frac{V^2}{R}$.
  - $V =$ wind speed
  - $R =$ the radius of the curvature

(from *The Atmosphere*)
Gradient Wind Balance

- The three-way balance of horizontal pressure gradient, Coriolis force, and the centrifugal force is called 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

- For high pressure system
  - gradient wind > geostrophic wind
  - supergeostropic.

- For low pressure system
  - gradient wind < geostrophic wind
  - subgeostropic.

(from Meteorology: Understanding the Atmosphere)
• 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.
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 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 tropospheric flow pattern can cause ascending motion in the air column. ➔ surface pressure decreases (low pressure) ➔ cloudy weather
The 850mb map is particularly useful to identify the location of jetstreams.

In this example, a jetstream flows northeastward from the west coast of the US, into the Great Lakes, and to the Atlantic Coast of Canada.
Convergence/Divergence in Jetstreak

A

290 mb
295 mb
300 mb
305 mb

low pressure
high pressure

A • B • C • D • E •

Green arrows denote flow of air if the air was in geostrophic balance

B

290 mb
295 mb
300 mb
305 mb

left entrance region
left exit region
CONVERGENCE
CONVERGENCE
DIVERGENCE
DIVERGENCE

right entrance region
right exit region

Black arrows denote actual flow of air because air is not in geostrophic balance

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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 tends 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.
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 jet streak effect and (2) surface friction.
Developments of Low- and High-Pressure Centers

• **Dynamic Effects:** Combined curvature and jetstream effects produce upper-level convergence on the west side of the trough to the north of the jetstream, 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

convergence

H

tropopause

surface

divergence

L

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Rotating Annulus Experiment

Cooling Outside

Heating Inside

(from “Is The Temperature Rising?”)
New Understanding of Cyclone after WWII

- 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” instability associated with the north-south temperature differences in middle latitudes.

Carl Gustav Rossby (1898-1957)