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

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 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 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

(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
  - supergeostrophic.

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

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 tropospheric flow pattern causes ascending motion in the air column. → surface pressure decreases (low pressure) → cloudy weather

Example: A 300mb Weather Map

- 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

- The convergence/divergence produced by the curvature and jetstream effects cancels each other to the south of the jetstream axis but enhances each other to the north of the jetstream.
- 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 than this upper-level convergence in affecting the development of high pressure systems.

Combined Curvature and Jetstreak Effects

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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.

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.

Friction and Development of Surface Low and High

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

Developments of Low- and High-Pressure Centers

- **Dynamic Effects**: Combined curvature and jet streak effects produce upper-level convergence on the west side of the trough to the north of the jet streak, 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.
**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)