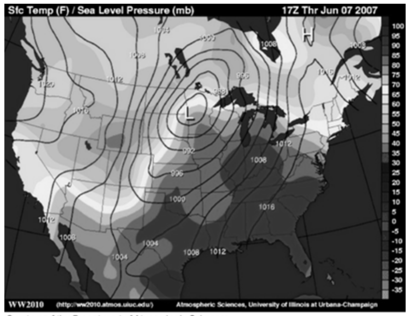
Chapter 8: Development of High- and low-Pressure Systems



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

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

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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.

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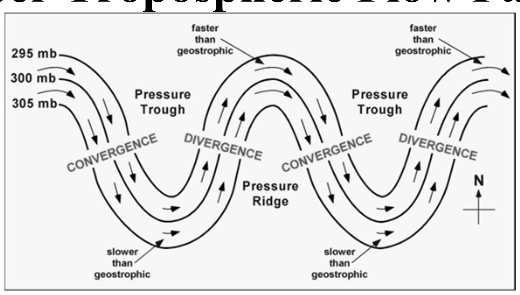
Upper Tropospheric Flow Pattern



- 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.

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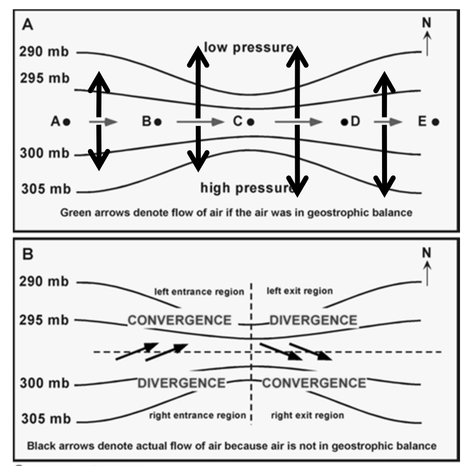
Convergence/Divergence in Jetstreak



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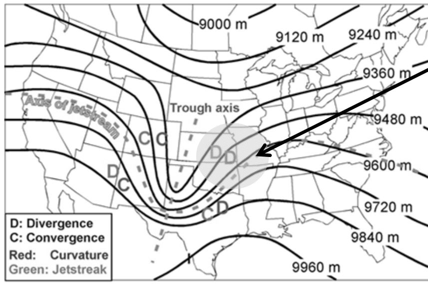
Combined Curvature and Jetstreak Effects



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 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.

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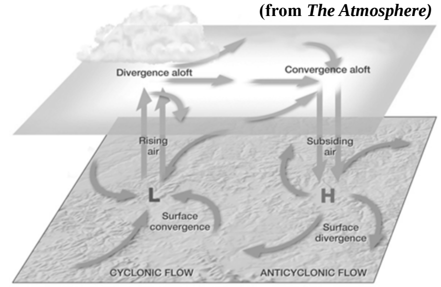
Friction and Development of Surface Low and high

(from *The Atmosphere*)



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

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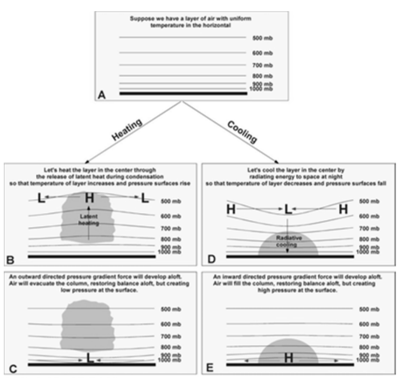
Surface Heating and Cooling



- Surface heating by solar energy causes ascending motion, which tends to produce 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.

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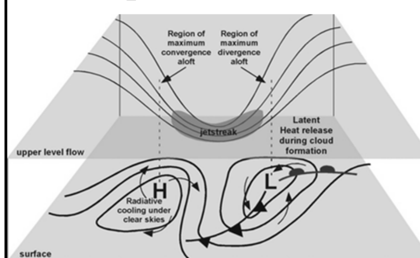
Developments of Low- and High-Pressure Centers



- ***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.

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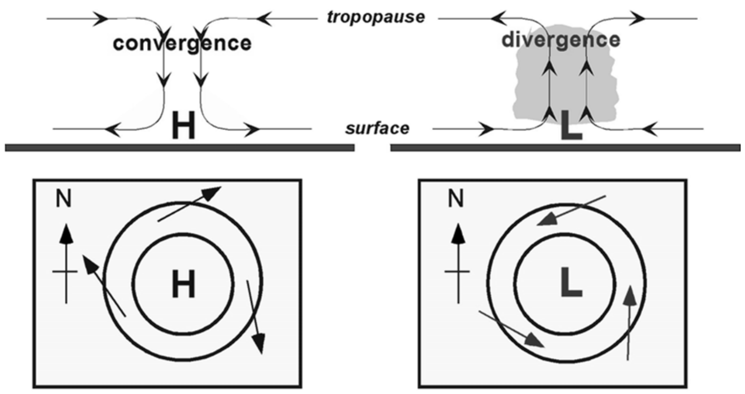
Vertical View of High/Low Developments



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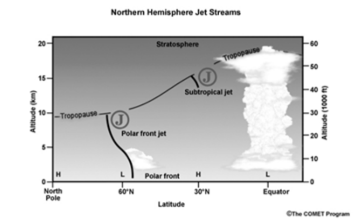
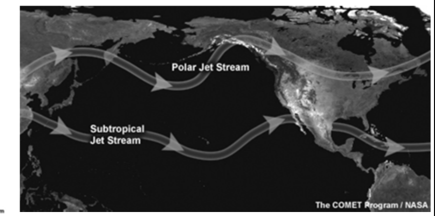
Jetstream





- The jetstream is a narrow band of strong winds that encircles the Earth in the mid-latitude.
- The band of strongest winds is typically 300 to 500 km wide and can extend from near the tropopause to about 500mb.
- The jetstream typically follows a wavelike pattern.
- The fastest jetstreams are the **Polar Front Jet**, commonly known as the Polar Jet, and the **Subtropical Jet** (STJ), which flow from west to east.

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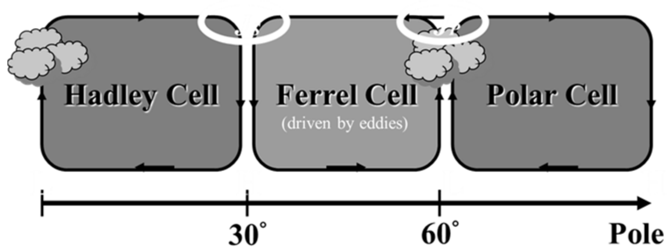
Two Jet Streams



❑ **Subtropical Jet**

Located at the higher-latitude end of the Hadley Cell. The jet obtain its maximum wind speed (westerly) due the conservation of angular momentum.

❑ **Polar Jet**

Located at the thermal boundary between the tropical warm air and the polar cold air. The jet obtain its maximum wind speed (westerly) due the latitudinal thermal gradient (thermal wind relation).

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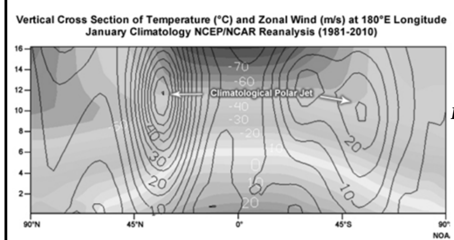
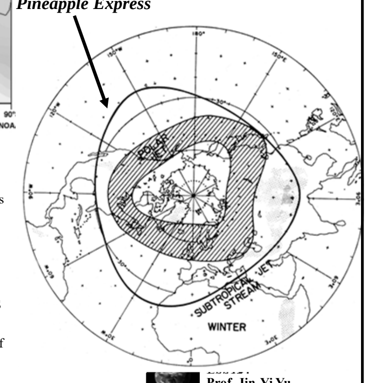
Vertical Structure of Jetstream



Cyclones preferentially form in five locations in North America:
(1) East of the Rocky Mountains
(2) East of Canadian Rockies
(3) Gulf Coast of the US
(4) East Coast of the US
(5) Bering Sea & Gulf of Alaska

Pineapple Express



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(from *Riehl (1962)*, *Palmen and Newton (1969)*)

Extratropical Cyclones in North America

Cyclones preferentially form in five locations in North America:

(1) East of the Rocky Mountains

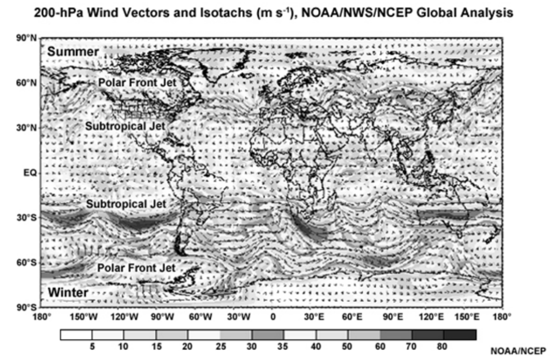
(2) East of Canadian Rockies

(3) Gulf Coast of the US

(4) East Coast of the US

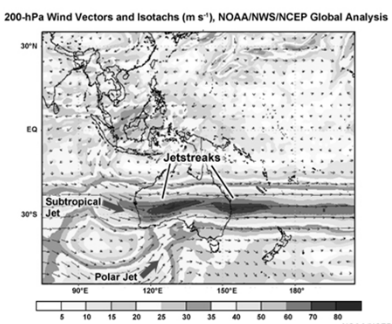
(5) Bering Sea & Gulf of Alaska

Polar Jet



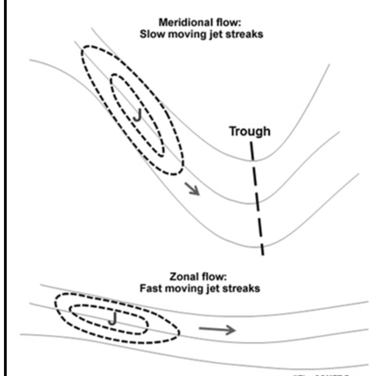
- Polar jetstreams are found at latitudes from 30 to 70° and between 300 and 200 hPa pressure surfaces (about 7.5–11 km above sea level).
- he Polar Jet is strongest during winter when it occasionally migrates to tropical latitudes and merges with the subtropical jet.

Jet Streaks



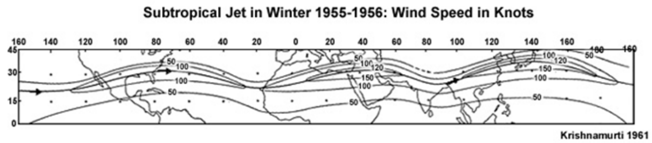
- The position and orientation as well as the strength and continuity of the Polar Jet governs weather events on time scales from a day to weeks.
- Local maxima, called jet streaks, occur along the jet, especially where the Polar Jet merges with the STJ or in regions of strong temperature gradients.
- Jet streaks are usually identified as oval-shaped maxima in the 300-200 hPa isotach analysis

Jet Streaks



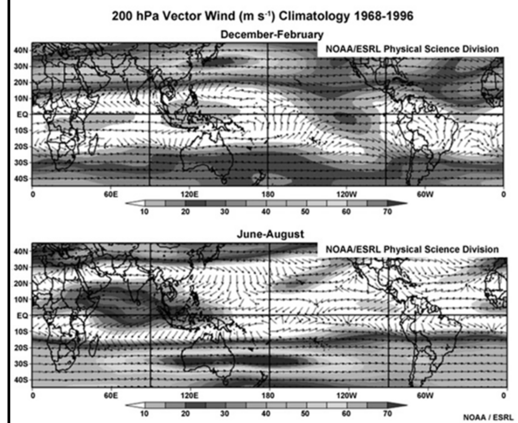
- When the jetstream is zonal, nearly directly west to east, short-wave disturbances and jet streaks move quickly along the jet track.
- In contrast, when the jetstream pattern is meridional, upper-level wave troughs and ridges are common, warm air flows poleward, and cold air flows equatorward, and the movement of disturbances is usually slower.
- Strong temperature gradients develop over limited longitude ranges and result in low pressure systems (cyclones) and high pressure systems (anticyclones) which cause persistent wet and dry conditions respectively.

Subtropical Jet



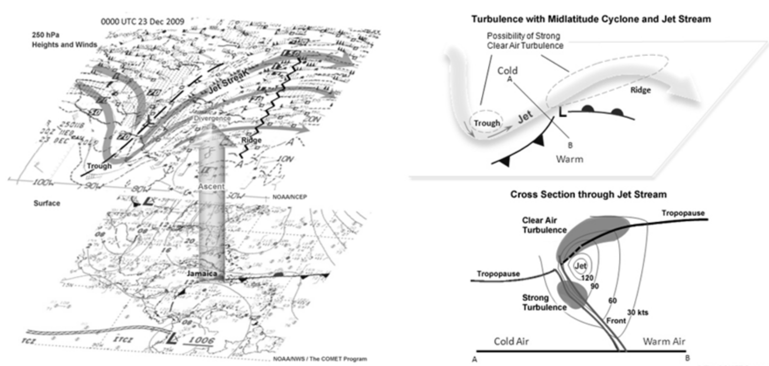
- During winter, the STJ is nearly continuous in both hemispheres and can attain wind speeds of 75 to 100 m s^{-1}.
- In the Northern Hemisphere, the jet exhibits a quasi-stationary 3-wave pattern with ridges and maximum wind speeds occurring over the southeastern United States, the Mediterranean Sea, and the northwest Pacific, which has the strongest winds. The troughs are usually located over the central Pacific Ocean, the central Atlantic Ocean, and between the Arabian Sea and India.
- The mean position of the STJ in the Northern Hemisphere during winter is approximately 27.5°N, ranging from 20° to 35°N.
- The STJ exists all year in the southern hemisphere. Ho[redacted] the northern hemisphere during summer when it migrat[redacted] position being close to 40°N and average speed decrea[redacted].

Subtropical Jet



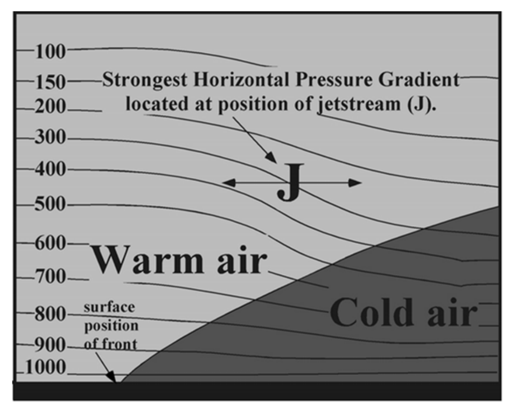
- High wind speeds emanating from the east coasts of Asia and North America. The pattern is more zonal and jets are stronger over the southern hemisphere because of the smaller land mass.
- Departures from the mean position are more pronounced over the America-Atlantic sector than in the Africa-Asia sector.
- The STJ can be temporarily displaced when strong mid-latitude troughs extend into subtropical latitudes. When these displacements occur, the subtropical jet can merge with the polar front jet.
- The mean latitude of the southern [redacted]ble, [redacted]er.

Jet Stream and Winter Storm



- In this case, the meridional jet stream pattern and the st[redacted]ak aided in the development of a surface cyclone to the ea[redacted].

Jetstream and Front



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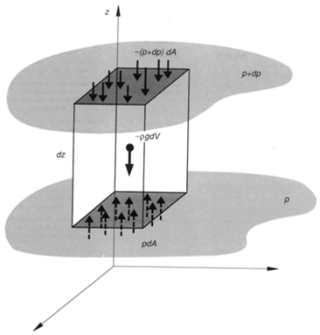
Hydrostatic Balance in the Vertical



(from *Climate System Modeling*)

- vertical pressure force = gravitational force

- (dP) x (dA) = ρ x (dz) x (dA) x g

dP = -ρgdz

$$\boxed{dP/dz = -\rho g}$$

The hydrostatic balance !!

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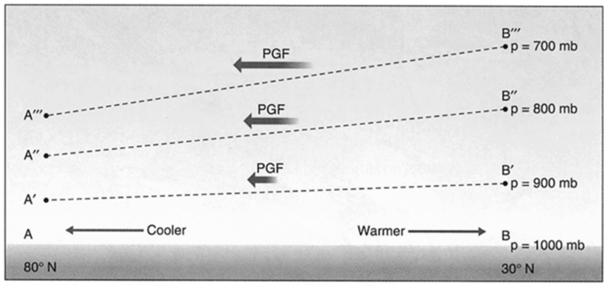
Thermal Wind Relation



(from *Weather & Climate*)

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Thermal Wind Equation

$$\partial U/\partial z \propto \partial T/\partial y$$

- The vertical shear of zonal wind is related to the latitudinal gradient of temperature.
- Jet streams usually are formed above baroclinic zone (such as the polar front).

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