Lecture 5: Atmospheric Motions

- Pressure Gradient Force
- Coriolis Force
- Surface Friction
- Geostrophic Balance
- Thermal Wind Balance
- Scales of Motion

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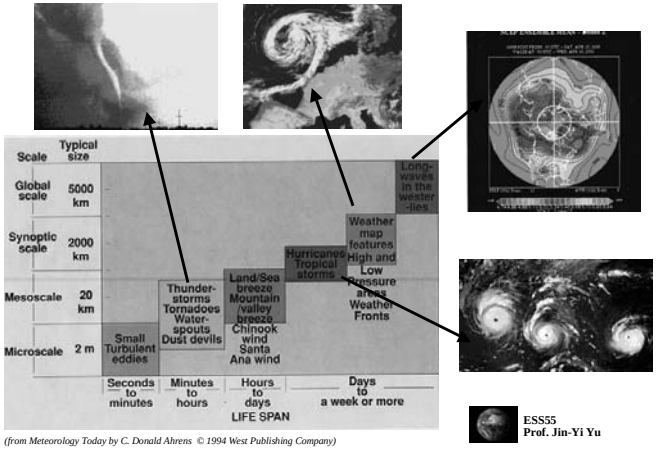
Scales of Motions in the Atmosphere



(from Meteorology Today by C. Donald Ahrens © 1994 West Publishing Company)

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Force that Determines Wind

- Pressure gradient force
- Coriolis force
- Friction
- Centrifugal force

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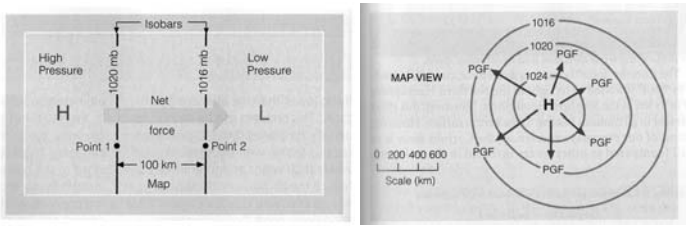
Pressure Gradient Force



(from Meteorology Today)

- PG = (pressure difference) / distance
- Pressure gradient force force goes from high pressure to low pressure.
- Closely spaced isobars on a weather map indicate steep pressure gradient.

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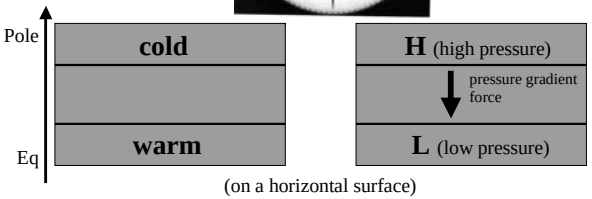
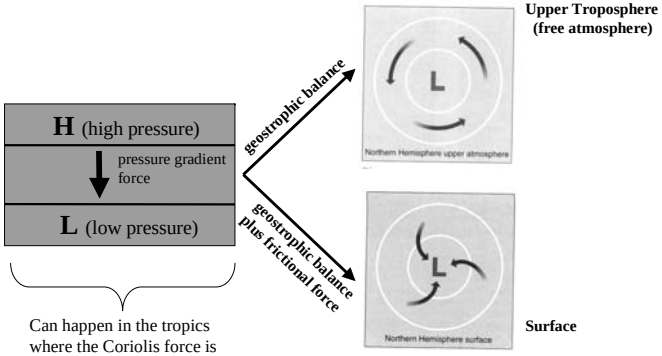
Thermal Energy to Kinetic Energy



(on a horizontal surface)

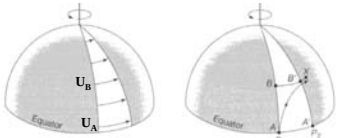
Balance of Force in the Horizontal



Can happen in the tropics where the Coriolis force is small.

(from *Weather & Climate*)

Coriolis Force



(from *The Earth System*)

- First, Point A rotates faster than Point B ($U_A > U_B$)
- ➔ $U_A > U_B$
- ➔ A northward motion starting at A will arrive to the east of B
- ➔ It looks like there is a "force" pushing the northward motion toward right
- ➔ This apparent force is called "Coriolis force":

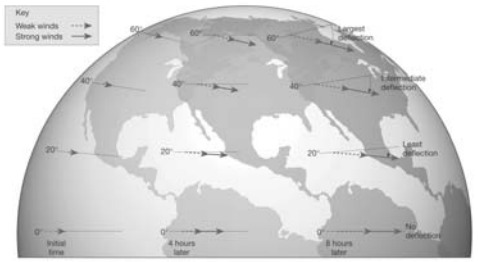
Coriolis Force = $f\ V$

where $f = 2*\Omega*\sin(lat)$ and $\Omega=7.292\times10^{-5}$ rad s^{-1}

Coriolis Force

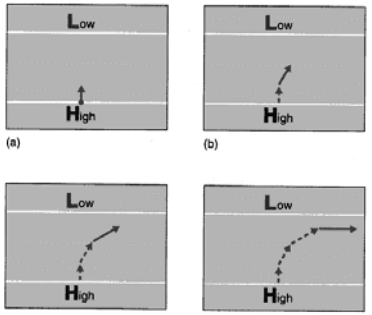
- Coriolis force causes thw wind to deflect to the right of its intent path in the Northern Hemisphere and to the left in the Southern Hemisphere.
- The magnitude of Coriolis force depends on (1) the rotation of the Earth, (2) the speed of the moving object, and (3) its latitudinal location.
- The stronger the speed (such as wind speed), the stronger the Coriolis force.
- The higher the latitude, the stronger the Coriolis force.
- The Corioils force is zero at the equator.
- Coriolis force is one major factor that determine weather pattern.

Coriolis Force Changes with latitude



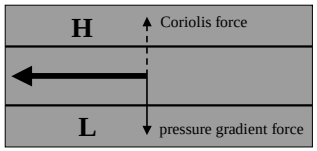
(from *The Atmosphere*)

How Does Coriolis Force Affect Wind Motion?



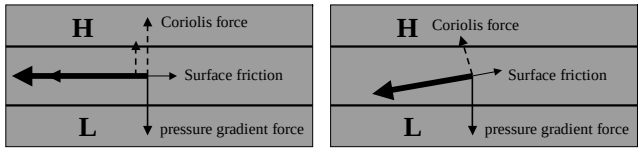
(from *Weather & Climate*)

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.

Frictional Effect on Surface Flow



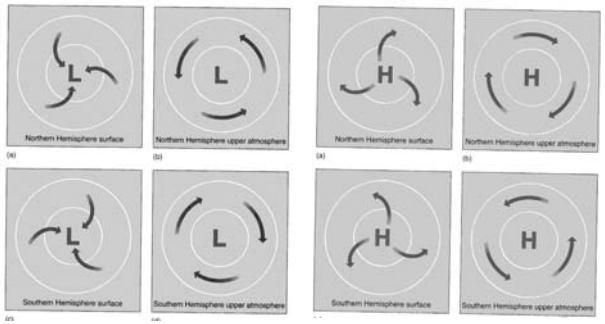
- Surface friction force slows down the geostrophic flow.
- The flow turns into (out of) the low (high) press sides.
- Convergence (divergence) is produced with the flow.

Friction Force

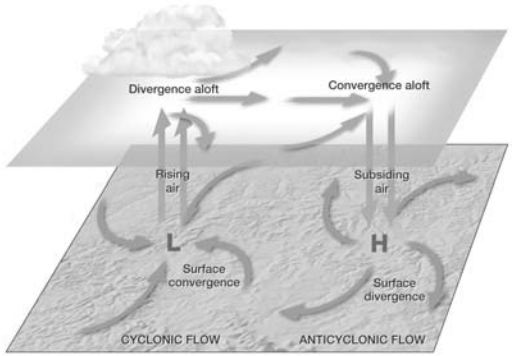
- Friction Force = c * V
  - c = friction coefficient
  - V = wind speed

Surface Geostrophic Flow

Cyclonic Flow **Anticyclonic Flow**

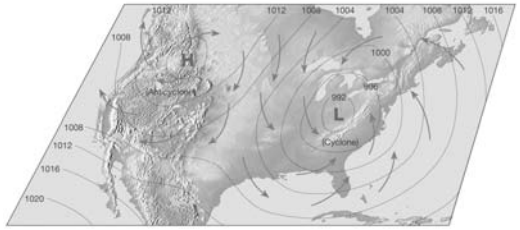


(figures from *Weather & Climate*)



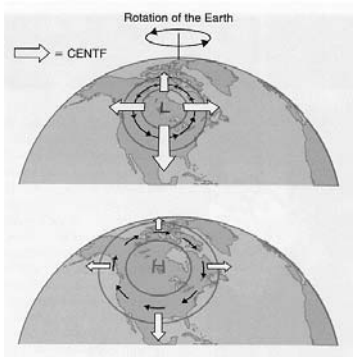
(from *The Atmosphere*)

Surface High and Low Pressure Systems



(from *The Atmosphere*)

Centrifugal Force



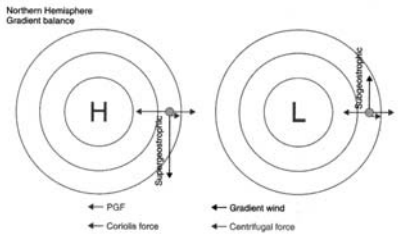
(from *Meteorology: Understanding the Atmosphere*)

- 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.

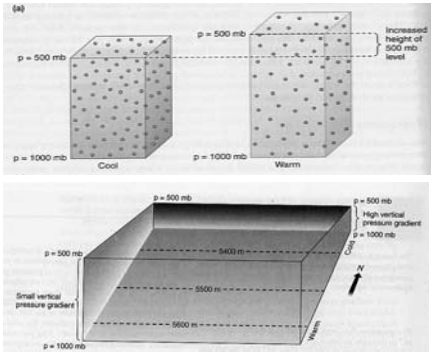
Super- and Sub-Geostrophic Winds



(from *Meteorology: Understanding the Atmosphere*)

- For high pressure system
  ➔ gradient wind > geostrophic wind
  ➔ supergeostropic.
- For low pressure system
  ➔ gradient wind < geostrophic wind
  ➔ subgeostropic.

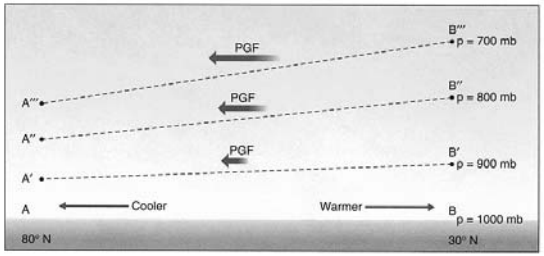
Temperature and Pressure



(from *Weather & Climate*)

- Hydrostatic balance tells us that the pressure decrease with height is determined by the temperature inside the vertical column.
- Pressure decreases faster in the cold-air column and slower in the warm-air column.
- Pressure drops more rapidly with height at high latitudes and lowers the height of the pressure surface.

Thermal Wind Relation



(from *Weather & Climate*)

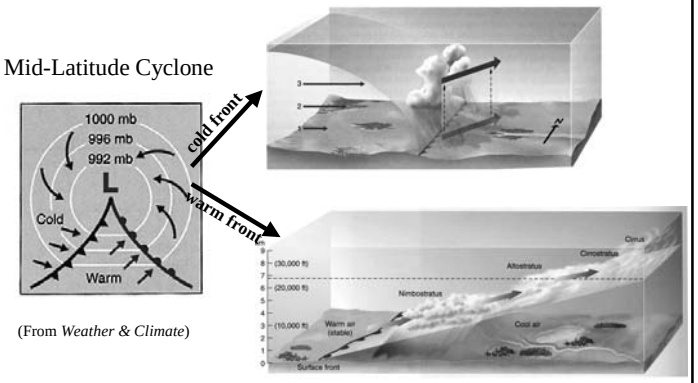
Thermal Wind Equation

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

- 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).

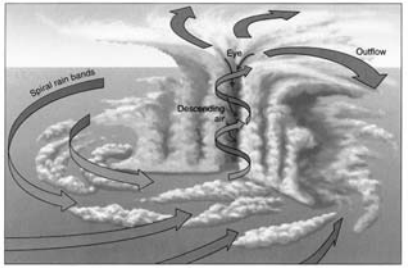
Cold and Warm Fronts

Mid-Latitude Cyclone



(From *Weather & Climate*)

Tropical Hurricane



- The hurricane is characterized by a strong thermally direct circulation with the rising of warm air near the center of the storm and the sinking of cooler air outside.

(from Understanding *Weather & Climate*)

Monsoon: Another Sea/Land-Related Circulation of the Atmosphere

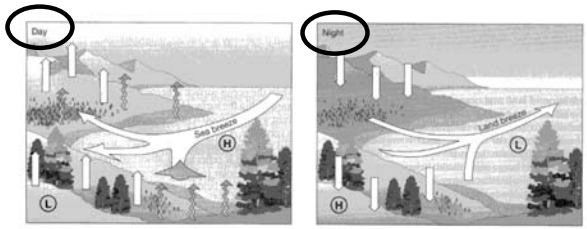
Winter

Summer

- Monsoon is a climate feature that is characterized by the ***seasonal reversal in surface winds***.
- The very different heat capacity of land and ocean surface is the key mechanism that produces monsoons.
- During summer seasons, land surface heats up faster than the ocean. Low pressure center is established over land while high pressure center is established over oceans. Winds blow from ocean to land and bring large amounts of water vapor to produce heavy precipitation over land: A rainy season.
- During winters, land surface cools down fast and sets up a high pressure center. Winds blow from land to ocean: a dry season.

(figures from *Weather & Climate*)

Sea/Land Breeze



- Sea/land breeze is also produced by the different heat capacity of land and ocean surface, similar to the monsoon phenomenon.
- However, sea/land breeze has much shorter timescale (day and night) and space scale (a costal phenomenon) than monsoon (a seasonal and continental-scale phenomenon).

(figure from *The Earth System*)