Lecture 4: Pressure and Wind

- Pressure, Measurement, Distribution
- Forces Affect Wind

- Geostrophic Balance
- Winds in Upper Atmosphere
- Near-Surface Winds

- Hydrostatic Balance (why the sky isn't falling!)
- Thermal Wind Balance

Wind is moving air.

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Force that Determines Wind

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

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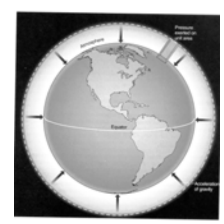
Thermal Energy to Kinetic Energy



Pole

cold | **H** (high pressure)

pressure gradient force

warm | **L** (low pressure)

Eq

(on a horizontal surface)

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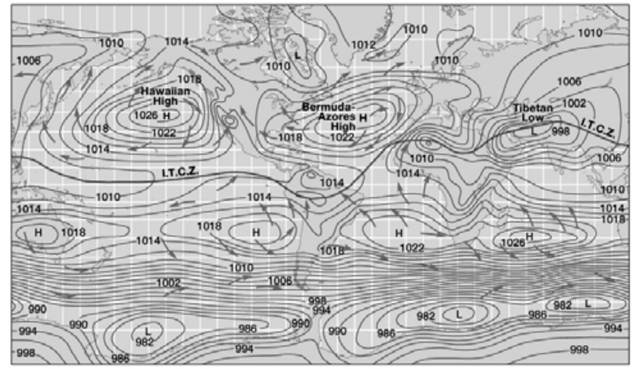
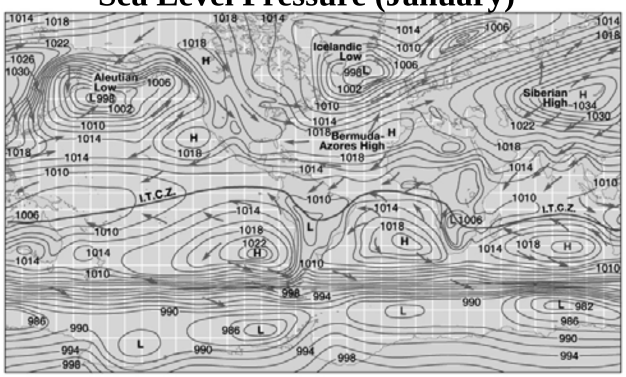
Sea Level Pressure (July)

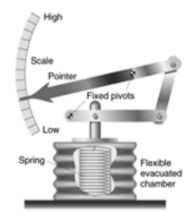


Sea Level Pressure (January)



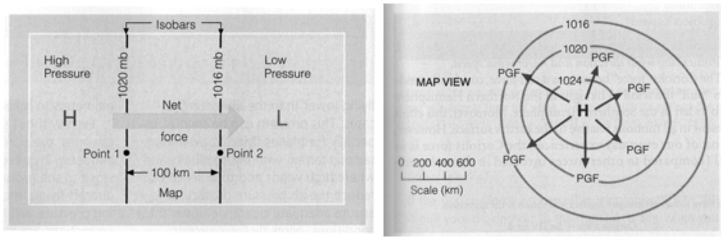
Measurement of Pressure

Aneroid barometer (left) and its workings (right)



A barograph continually records air pressure through time

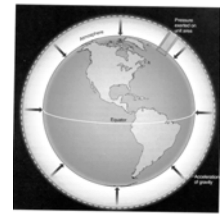
Pressure Gradient Force



(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.

Thermal Energy to Kinetic Energy



Pole

Eq

cold

warm

H (high pressure)

pressure gradient force

L (low pressure)

(on a horizontal surface)

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Balance of Force in the Horizontal

H (high pressure)

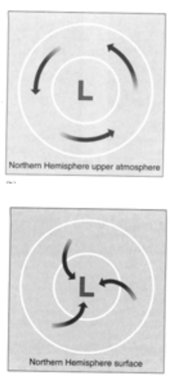
pressure gradient force

L (low pressure)

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

geostrophic balance

geostrophic balance plus frictional force



Upper Troposphere (free atmosphere)

Surface

(from *Weather & Climate*)

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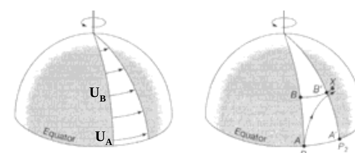
Coriolis Force



(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*Ω*Sin(lat) and Ω=7.292x10^{-5} rad s^{-1}

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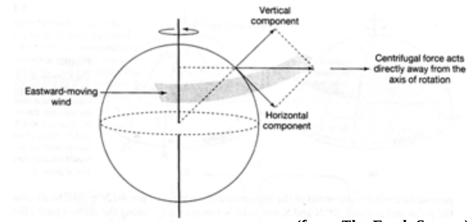
Coriolis Force

- Coriolis force causes the 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.

Another Kind of Coriolis Force



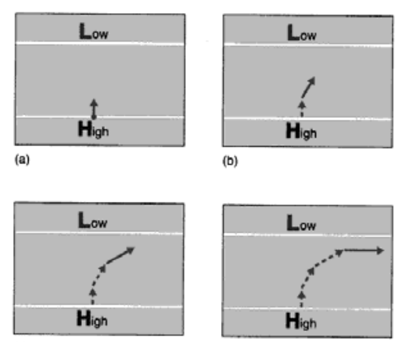
(from *The Earth System*)

- The Coriolis force also causes the east-west wind to deflect to the right of its intent path in the Northern Hemisphere and to the left in the Southern Hemisphere.
- The deflections are caused by the centrifugal force associated with the east-west motion, and , therefore, related to rotation of the Earth, and are also considered as a kind of Coriolis force.
- Although the description of the deflection effect for north-south and east-west motions are very different, their mathematical expressions are the same.

Coriolis Force Change with latitudes

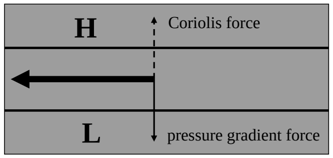
(from *The Atmosphere*)

How Does Coriolis Force Affect Wind Motion?



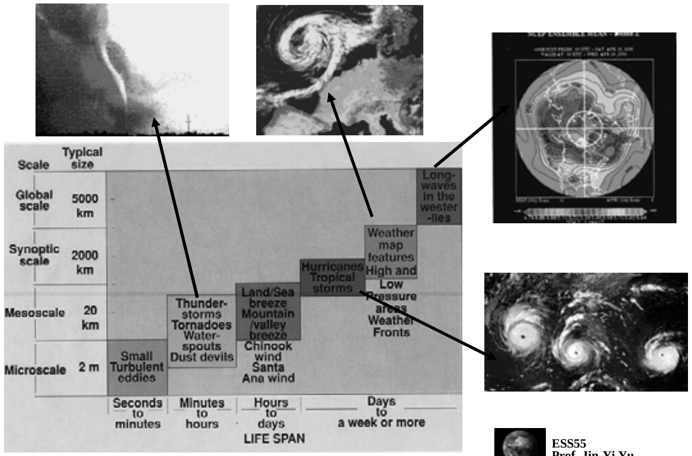
(from *Weather & Climate*)

Geostrophic Balance



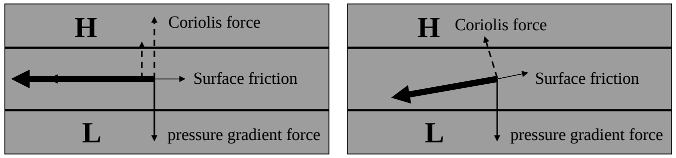
- ❑ By doing scale analysis, it has been shown that large-scale and synoptic-scale weather system are in geostropic balance.
- ❑ Geostrophic winds always follow the constant pressure lines (isobar). Therefore, we can figure out flow motion by looking at the pressure distribution.

Scales of Motions in the Atmosphere



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

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.

Surface Friction

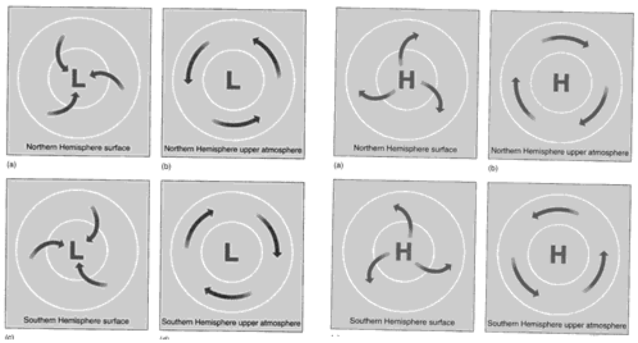
❑ Friction Force = c * V

c = friction coefficient

V = wind speed

Surface Geostrophic Flow

Cyclonic Flow | **Anticyclonic Flow**



(figures from *Weather & Climate*)

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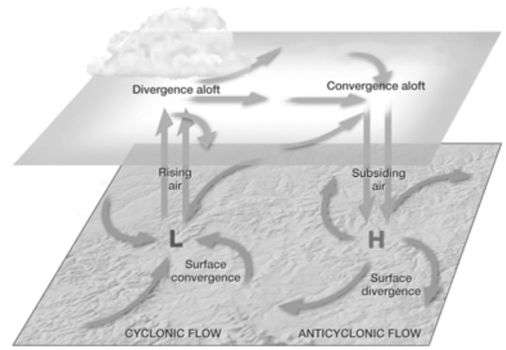

(from *The Atmosphere*)

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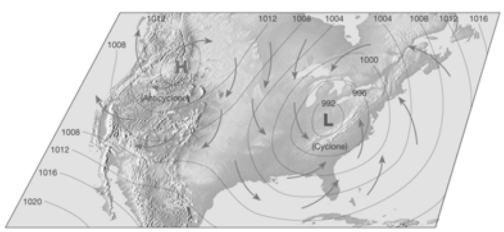
Surface High and Low Pressure Systems



(from *The Atmosphere*)

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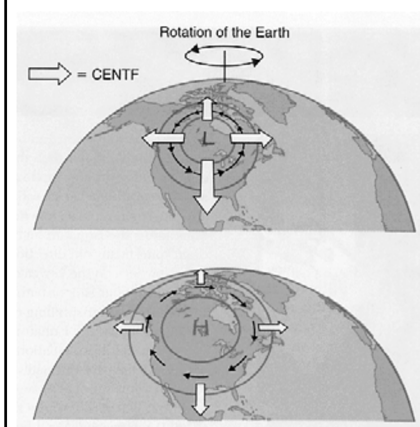
Centrifugal Force



- ❑ 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*)

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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.

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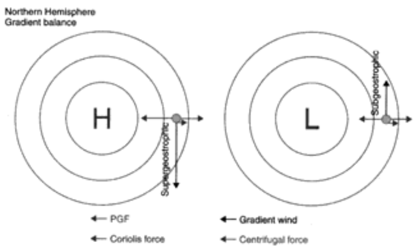
Super- and Sub-Geostrophic Wind



(from *Meteorology: Understanding the Atmosphere*)

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

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Pressure Gradients

- Pressure Gradients
  - The pressure gradient force initiates movement of atmospheric mass, wind, from areas of higher to areas of lower pressure
- Horizontal Pressure Gradients
  - Typically only small gradients exist across large spatial scales (1mb/100km)
  - Smaller scale weather features, such as hurricanes and tornadoes, display larger pressure gradients across small areas (1mb/6km)
- Vertical Pressure Gradients
  - ***Average vertical pressure gradients are usually greater than extreme examples of horizontal pressure gradients*** as pressure always decreases with altitude (1mb/10m)

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- Why didn't the strong vertical pressure gradient push the air rise?

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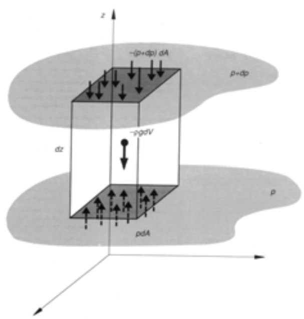
Hydrostatic Balance in the Vertical



- vertical pressure force = gravitational force

$$-(dP) \times (dA) = \rho \times (dz) \times (dA) \times g$$

$$dP = -\rho g dz$$

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

The hydrostatic balance !!

(from *Climate System Modeling*)

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What Does Hydrostatic Balance Tell Us?

- The hydrostatic equation tells us how quickly air pressure drops wit height.

➔ The rate at which air pressure decreases with height ($\Delta P/\Delta z$) is equal to the air density (ρ) times the acceleration of gravity (g)

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The Ideal Gas Law

- An ***equation of state*** describes the relationship among pressure, temperature, and density of ***any material***.
- All gases are found to follow approximately the same equation of state, which is referred to as the ***"ideal gas law (equation)"***.
- Atmospheric gases, whether considered individually or as a mixture, obey the following ideal gas equation:

$$\boxed{P = \rho R T}$$

pressure *Density=m/V* *temperature* *(degree Kelvin)*

gas constant *(its value depends on the gas considered)*

R=287 J deg^{-1} kg^{-1} for dry air

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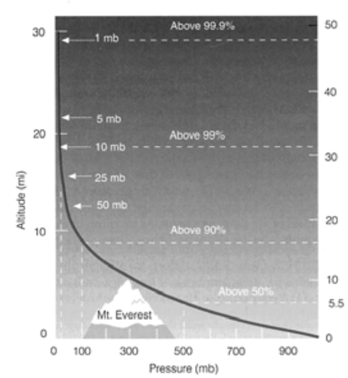
Hydrostatic Balance and Atmospheric Vertical Structure



(from *Meteorology Today*)

- Since P= ρRT (the ideal gas law), the hydrostatic equation becomes:

$$dP = -P/RT \times g dz$$

➔ $dP/P = -g/RT \times dz$

➔ $\boxed{P = P_s \exp(-gz/RT)}$

➔ $P = P_s \exp(-z/H)$

- The atmospheric pressure decreases exponentially with height

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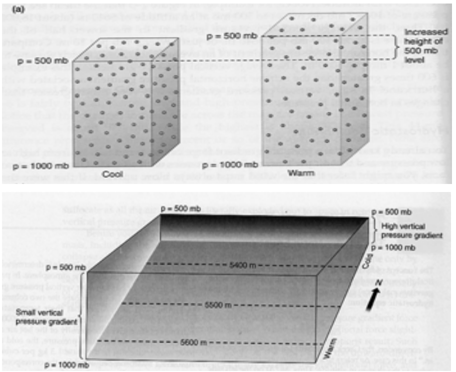
Temperature and Pressure



▪ 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.

(from *Weather & Climate*)

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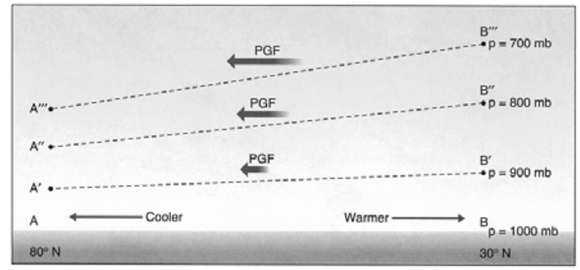
Thermal Wind Relation



(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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Subtropical and Polar Jet Streams

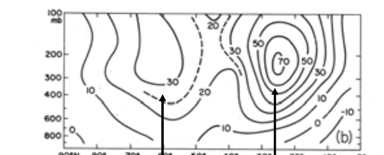
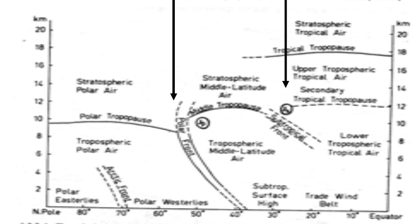


FIG. 3.8 Winter (December–February) zonal mean wind components (knots), Northern Hemisphere, at (a) 140°E and (b) 0° longitude. (Redrawn from Crutcher, 1961.)



(from *Atmospheric Circulation Systems*)

❑ **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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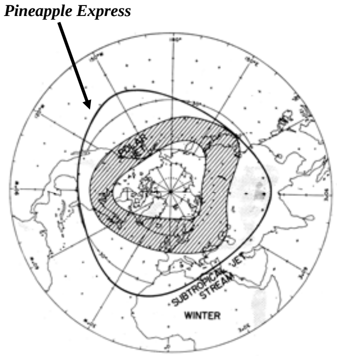
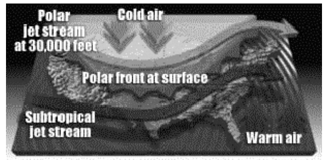
Jet Streams Near the Western US

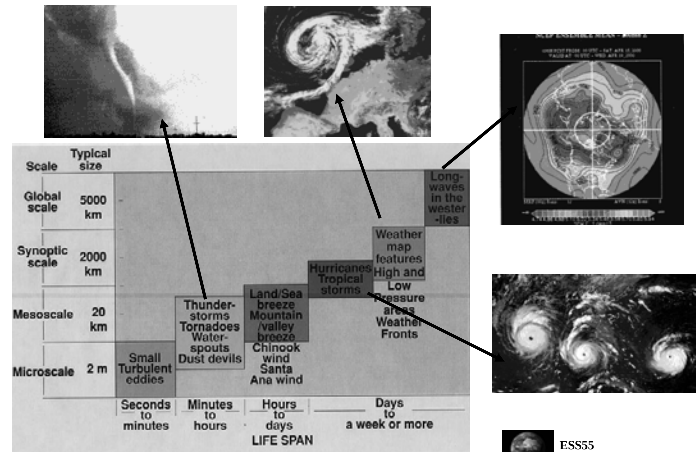




- Both the polar and subtropical jet streams can affect weather and climate in the western US (such as California).
- El Nino can affect western US climate by changing the locations and strengths of these two jet streams.

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

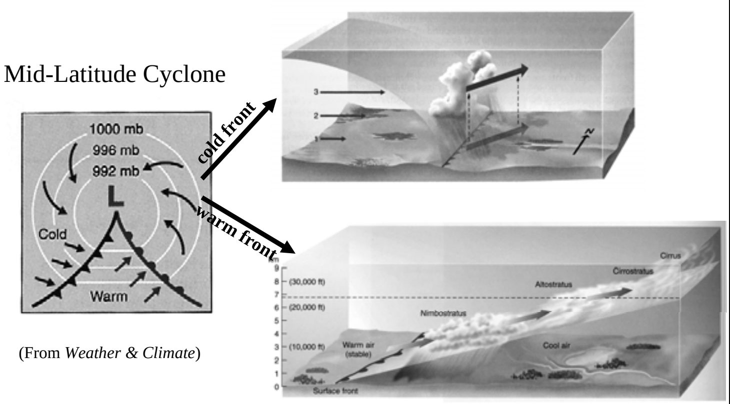
Scales of Motions in the Atmosphere



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

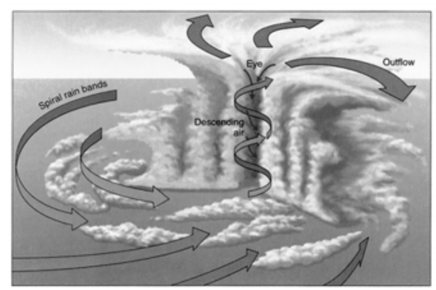
Cold and Warm Fronts

Mid-Latitude Cyclone



(From *Weather & Climate*)

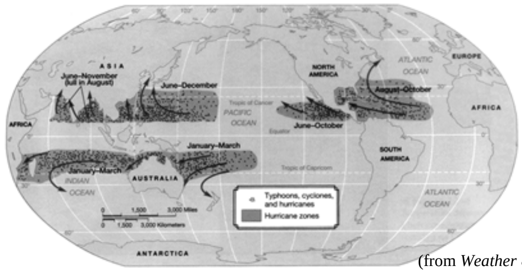
Tropical Hurricane



- 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*)

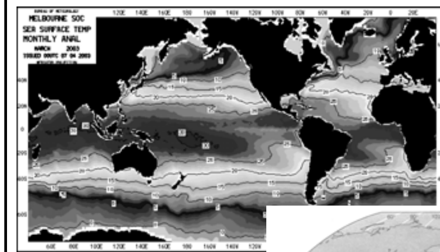
Naming Convention

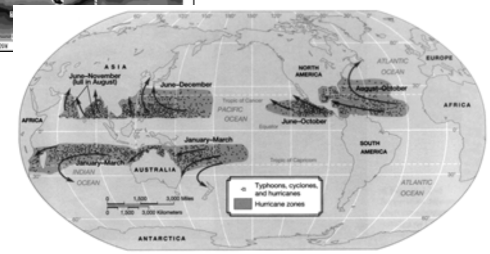


(from *Weather & Climate*)

- ❑ ***Hurricanes:*** extreme tropical storms over Atlantic and eastern Pacific Oceans.
- ❑ ***Typhoons:*** extreme tropical storms over western Pacific Ocean.
- ❑ ***Cyclones:*** extreme tropical storms over Indian Ocean and Australia.

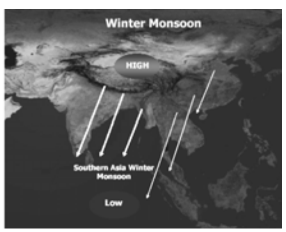
Ocean Temperature And Hurricane



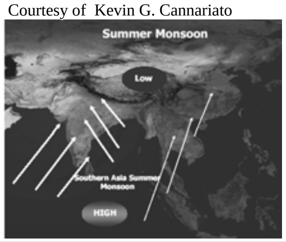


- ❑ **Hurricanes form over large pools of warm water.**

Monsoon: Sea/Land-Related Circulation

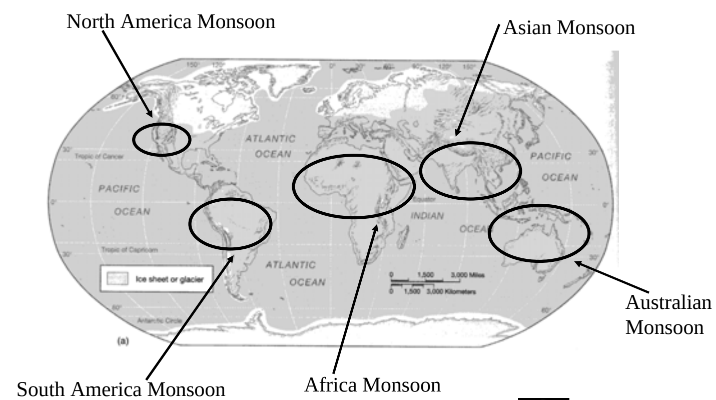


Courtesy of Kevin G. Cannariato



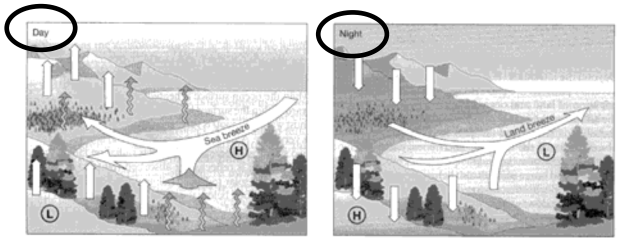
- ❑ Monsoon (Arabic "season")
- ❑ Monsoon is a climate feature that is characterized by the ***seasonal reversal in surface winds***.
- ❑ The very different heat capacity of land and ocean surface is the key mechanism that produces monsoons.
- ❑ During summer seasons, land surface heats up faster than 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.

How Many Monsoons Worldwide?



(figure 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*)

Santa Ana Wind

This is a picture of Fremont Canyon, located in the Santa Ana Mountains in Orange County. This canyon is known for its extremely high winds during Santa Ana wind events, where the winds can gust over 100 MPH during very strong Santa Ana wind events (picture from the Orange County Register).

DEFINITION

Strong warm and dry winds blow over the southern California from the Great Basin, with speeds exceed 25 knots (46 km/hr).

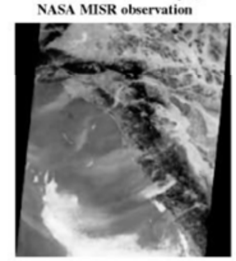
Generation Mechanism

(from NASA's Observatorium website)

Santa Ana Wind

Santa Ana Guide ©1999 Channel Crossings Press

Santa Ana winds on February 9, 2002
NASA MISR observation



Diurnal and Seasonal Variations

Diurnal variation:

Stronger Santa Ana wind at night and weaker Santa Ana wind on the day.

Seasonal Variation:

Occurs most frequently in winter (November to March).

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