Water, Weather, and Climate Systems

Weather

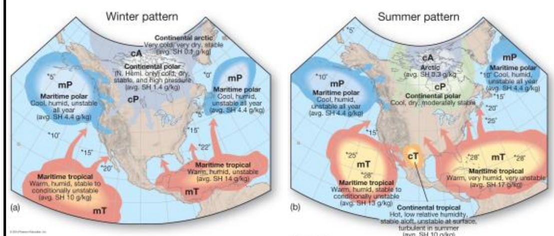
Weather

- **Air Masses**
- **Atmospheric Lifting Mechanisms**
- **Mid-latitude Cyclonic Systems**
- **Violent Weather**

Air Masses

- **An air mass reflects the characteristics of its source region**
- **Examples:**
  - **Cold Canadian air mass**
  - **Moist, tropical air mass**
- **Air masses are generally classified according to the temperature and moisture characteristics of their source regions:**
  - **Moisture designated as maritime (m) (wetter) or continental (c) (dryer)**
  - **Temperature designated by latitude as arctic (A), polar (P), tropical (T), equatorial (E) or Antarctic (AA)**

Principal Air Masses

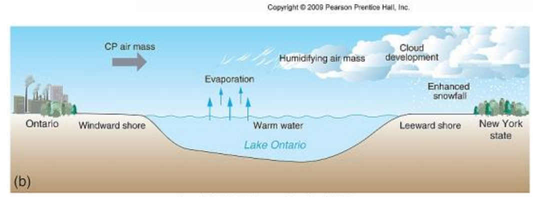


Air Mass Modification

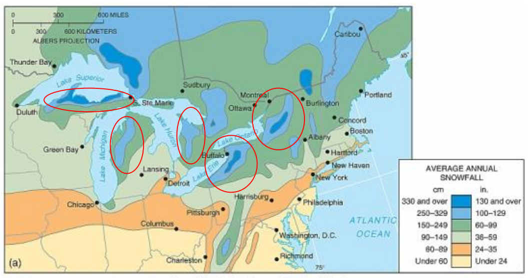
- **As air masses migrate from their source regions, their temperature and moisture characteristics are modified by the areas over which they pass**
- **Examples:**
  - **Warm, humid maritime air mass passes into cooler continental areas**
  - **Dry, cold continental air masses from polar regions move south and east over the Great Lakes**
- **Air masses eventually lose their initial characteristics due to migration into areas of different moisture and temperature characteristics**

Lake-effect Snow Belts


(c)



Lake-effect Snow Belts

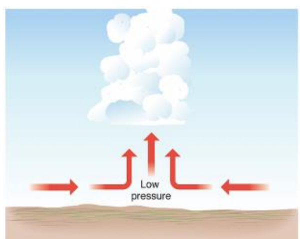


Atmospheric Lifting Mechanisms

- **Convergent Lifting:**
  - **Air flows toward an area of low pressure**
- **Convectional Lifting:**
  - **Air lifting stimulated by local surface heating**
- **Orographic Lifting:**
  - **Air is forced over a barrier such as a mountain range**
- **Frontal Lifting:**
  - **Air lifted along the leading edges of contrasting air masses**

Convergent Lifting

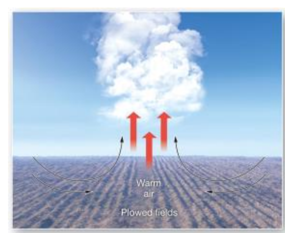
- Air flows from different directions into the same low pressure area
- Converging air is forced upward
- Uplifted air undergoes adiabatic cooling, cloud formation, and possibly precipitation
- Example: Trade winds converge along the Intertropical Convergent Zone



(a) Convergent

Convectional Lifting

- Caused by relatively cooler air mass moving over warmer land
- Heating from the warmer land causes lifting and convection in air mass
- Warmer land can include:
  - Urban heat island
  - Area of darker soil in a plowed field

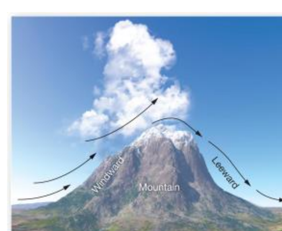


(b) Convectional lifting

Convectional activity over the Florida peninsula; The land mass of Florida is warmer than the surrounding Gulf of Mexico and Atlantic Ocean

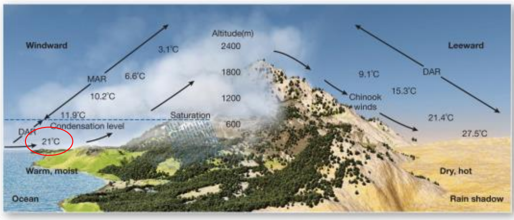
Orographic Lifting

- Mountain acts as a topographic barrier to migrating air mass:
  - Air forcibly lifted upslope on the windward side
  - Lifting air cools adiabatically: Precipitation may result
  - Descending air mass on leeward side undergoes adiabatic heating and becomes dryer



(c) Orographic lifting

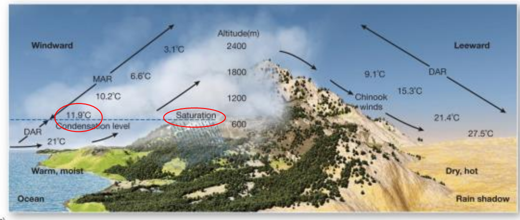
Orographic Precipitation



(a)

Dry region on the leeward side of mountain referred to as a rain shadow

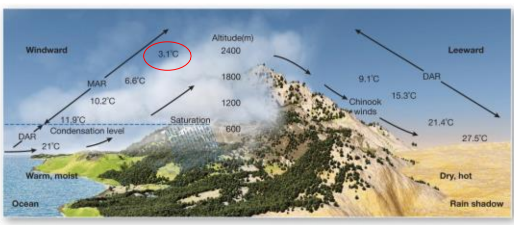
Orographic Precipitation



(a)

Dry region on the leeward side of mountain referred to as a rain shadow

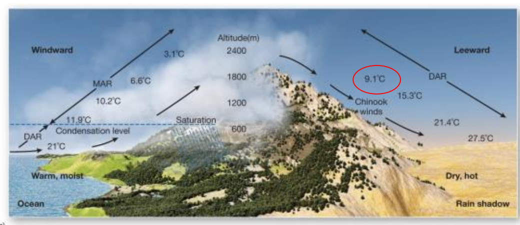
Orographic Precipitation



(a)

Dry region on the leeward side of mountain referred to as a rain shadow

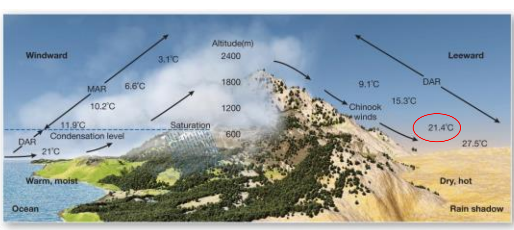
Orographic Precipitation



(a)

Dry region on the leeward side of mountain referred to as a rain shadow

Orographic Precipitation

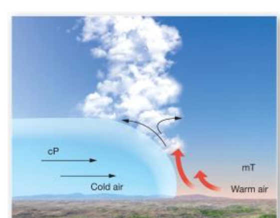


(a)

Dry region on the leeward side of mountain referred to as a rain shadow

Frontal Lifting

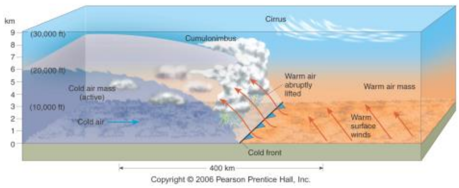
- Fronts are boundaries between HIGH PRESSURE air masses with differing properties:
  - COLD and DRY (high density).
  - WARM and MOIST (low density).
- The less-dense warm mT air is lifted up and over the denser cold cP air:
  - Frontal boundary is often the site of storm activity and precipitation



(d) Frontal lifting, cold front example

Cold Front

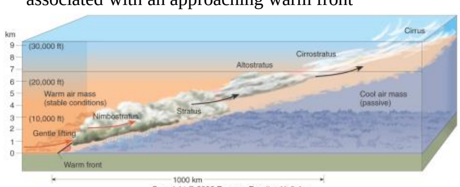
- Cold fronts:
  - Cold dense air pushing low density warmer air
  - Cold air forces warm air aloft
  - 400 km wide (250 mi)
  - Relatively rapid movement
  - Convective activity (thunderstorms)
- Cumulonimbus clouds are commonly associated with cold fronts



Cold Front and Squall Line

Warm Front

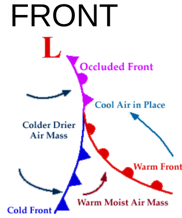
- Warm fronts:
  - Warm low density air pushing cold dense air
  - Warm air moves up and over cold air
  - 1000 km wide (600 mi)
  - Relatively slow movement
  - Slow steady rain or snow
- Cirrus clouds followed by stratus clouds are commonly associated with an approaching warm front

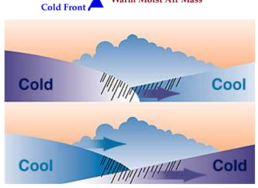


Cold Fronts _ Warm Fronts

OCCLUDED FRONT

- Faster moving cold front overtakes a warm front:
  - Two bodies of cold air associated with each front collide.
  - This forces the warm air between them to rise.
  - Results in uplift of warm air that is no longer in contact with ground.
  - This uplift of warm air results in cloud formation even though frontal system has no contact with the ground.

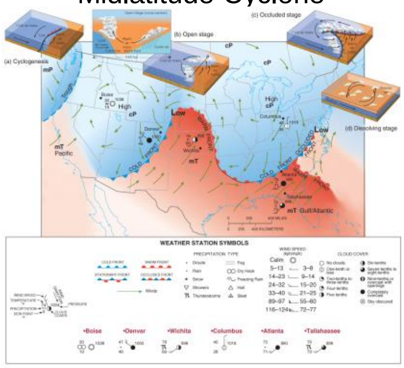




Life Cycle of a Midlatitude Cyclone

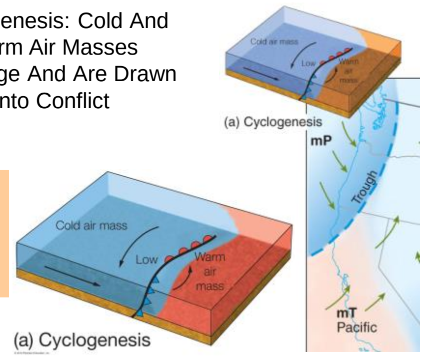
- **Cyclogenesis**
- **Open stage**
- **Occluded stage**
- **Dissolving stage**

Midlatitude Cyclone

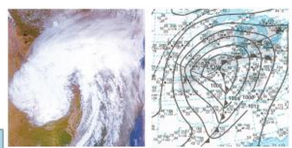


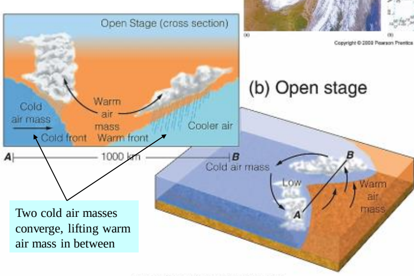
Cyclogenesis: Cold And Warm Air Masses Converge And Are Drawn Into Conflict

The rotation of the earth and the jet stream aloft induce spinning (vorticity) along the stationary front



Opening Stage: Warm Air Moves Northward And Cold Air Advances Southward



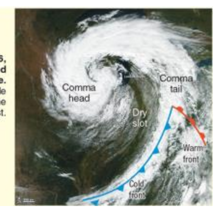


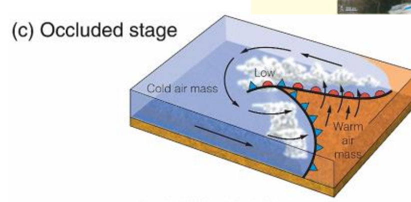
Two cold air masses converge, lifting warm air mass in between

---

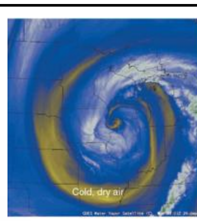
Occluded Stage: Cold Air Mass Overtakes The Warm Front

September 26, 2011: Occluded stage. A midlatitude cyclone over the U.S. Midwest.

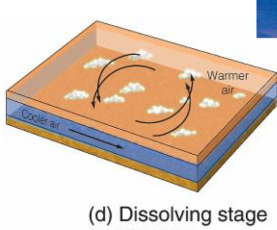




Dissolving Stage: Lifting Mechanism Of Cyclone Results In Continuous Layer Of Cooler Air Beneath Warmer Air



September 26, 2011: Water vapor image. The cold conveyor belt delivers cold, dry air (in yellow) that will soon cut off the storm's supply of warm, moist air.



Midlatitude Cyclones

Storm Tracks

- Cyclonic storms and associated air masses move across the continent along storm tracks guided by the jet stream
- Storm tracks shift in latitude with the seasons:
  - Northward shift in spring occurs when cP and mT air masses are in greatest conflict
  - Strongest frontal activity thus occurs in spring and often associated with thunderstorms and tornadoes

(a) Average storm tracks

Violent Weather

- Thunderstorms
- Tornadoes
- Tropical Cyclones
- Hurricanes

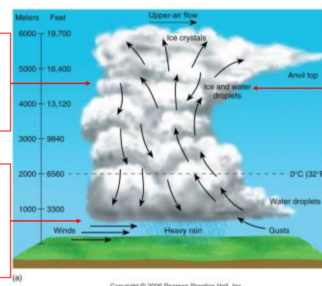
Thunderstorms

- Thunderstorms may develop within an air mass, along a cold front, or result from orographic lifting along a mountain slope
- Large quantities of water vapor in clouds condense, releasing tremendous amount of latent heat:
  - Liberated heat lowers density and increases buoyancy of surrounding air

Cumulonimbus Development

Larger raindrops and ice crystals descend in downdrafts

Heavy precipitation, lightening, thunder, hail, strong winds, and possibly tornadoes

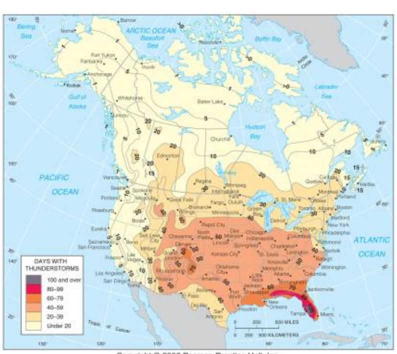


Raindrops and ice crystals form aloft and grow while suspended by updrafts

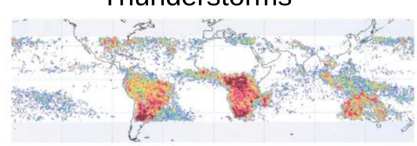
Violent updrafts pull surrounding air into the cumulonimbus system

(a)

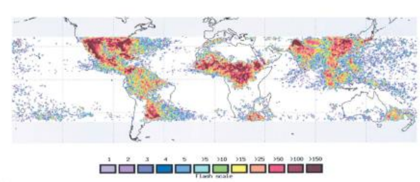
Thunderstorms



Thunderstorms



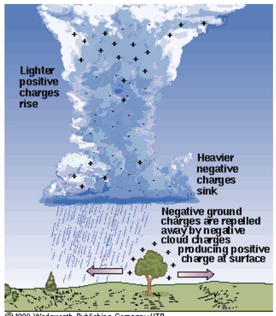
(b) Winter (Dec. 1999, Jan. and Feb. 2000)



(c) Summer (June, July, August 2000)

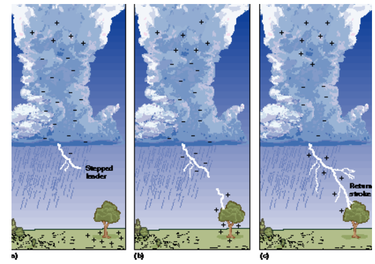
How Lightening Possibly Forms

- Precipitation formation and turbulence within cumulonimbus cloud causes positive and negative charges to develop on different- sized water droplets and/or ice crystals:
  - Lighter positive charges rise while heavier negative charges sink within the cloud
  - Negative charges at base of cloud repel negative charges on ground surface, leaving a net positive charge on ground
  - Charge difference is then neutralized by lightning bolt.



A Lightening Stroke Creates Thunder

- A lightening stroke can heat air to 30,000 ºC, causing rapid expansion of the air and formation of a compression wave that we hear as thunder



(a)

Hailstones

- Hail generally forms within a cumulonimbus cloud
- Hail typically pea- or marble-sized, but can occasionally achieve the size of golf balls and even baseballs

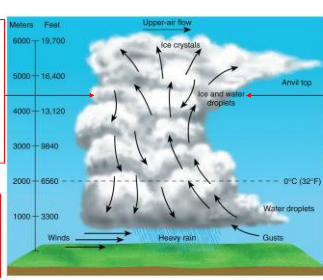
(a)

(b)

Formation Of Hail

Circulation above and below freeze level adds layers of ice to hailstones until updrafts can no longer support weight

For larger hail, frozen pellets must stay aloft longer



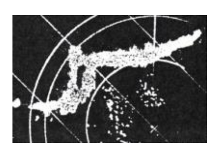
(a)

Raindrops circulate repeatedly above and below the freezing level in the cloud

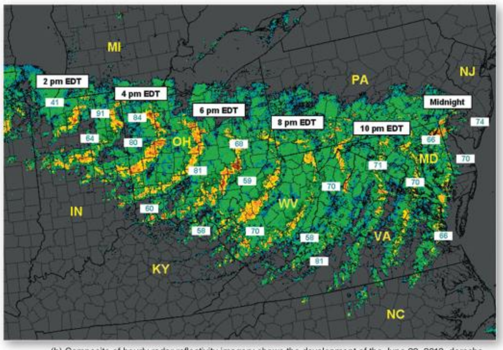
Violent updrafts pull surrounding air into the cumulonimbus system

Derechos

- Derechos are strong linear winds in excess of 26 m/s (58 mph) associated with thunderstorms and bands of showers
- Capable of overturning boats, hurling flying objects, and breaking tree limbs
- Form when strong downbursts in a thunderstorm system blast strong winds outward:
  - Linear paths fan out along curved-wind fronts over a wide area of land



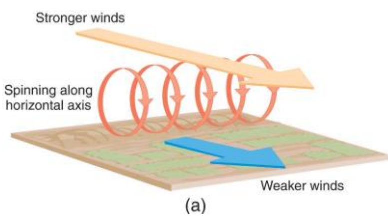
Radar (top) showing bow structure



(b) Composite of hourly radar reflectivity imagery shows the development of the June 29, 2012, derecho event, including selected wind gusts (mph), beginning at 2 P.M. Eastern Daylight Time (far left) and ending at midnight (far right).

Derechos

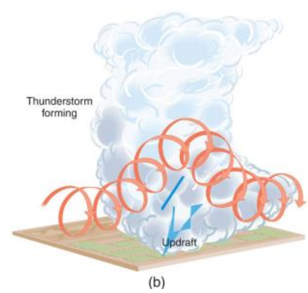
Formation Of A Mesocyclone



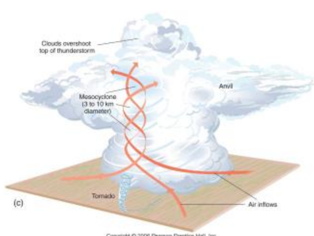
Strong winds aloft flow over weaker winds below; shear causes spinning along a horizontal axis

Formation Of A Mesocyclone

Updraft from thunderstorm development tilts the rotating air along a vertical axis



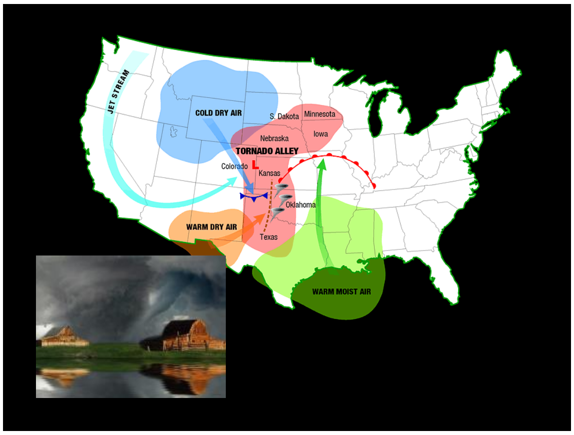
Formation Of A Mesocyclone



Mesocyclone forms as a rotating updraft within the thunderstorm; tornado descends from the lower portion

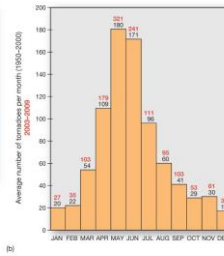
Formation Of A Tornado

- Begins with a layer of unstable warm, moist air trapped beneath a ceiling of cold, dense air
- Warm buoyant air suddenly finds an opening in the overlying ceiling
- Warm air rushes rapidly and violently upward through the opening to create a narrow zone of very intense low pressure
- Surrounding air and associated debris near ground level rushes in from all directions, creating a vortex



Tornadoes

(a)



(b)

The 7 years from 2003 to 2009 show a significant increase in the average number of tornadoes per month

Tornado Ratings Based on Damage and Wind Speeds

TABLE 5.1 The Enhanced Fujita Scale

EF-Number	3-Second-Gust Wind Speed; Damage
EF-0 Gale	105–137 kmph (65–85 mph); *light damage*: branches broken, chimneys damaged.
EF-1 Weak	138–177 kmph (86–110 mph); *moderate damage*: beginning of hurricane wind-speed designation, roof coverings peeled off, mobile homes pushed off foundations.
EF-2 Strong	178–217 kmph (111–135 mph); *considerable damage*: roofs torn off frame houses, large trees uprooted or snapped, boxcars pushed over, small missiles generated.
EF-3 Severe	218–266 kmph (136–165 mph); *severe damage*: roofs torn off well-constructed houses, trains overturned, trees uprooted, cars thrown.
EF-4 Devastating	267–322 kmph (166–200 mph); *devastating damage*: well-built houses leveled, cars thrown, large missiles generated.
EF-5 Incredible	>322 kmph (>200 mph); *incredible damage*: houses lifted and carried distance to disintegration, car-sized missiles fly farther than 100 m, bark removed from trees.

Note: See **http://www.spc.noaa.gov/faq/tornado/ef-scale.html** for details.

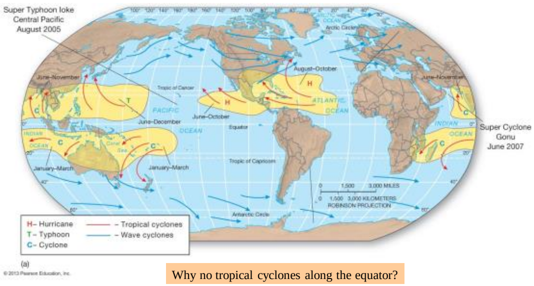
Tornado Path

(d)

[Tornadoes]

[Birth Of A Tornado]

Tropical Cyclones Originate Within Tropical Air Masses



Why no tropical cyclones along the equator?

Development Of Cyclonic Motion

- Cyclonic motion begins with slow-moving easterly wave of low pressure in the trade wind belt and sea-surface temperatures greater than 26 °C (79° F):
  - Cyclone forms on eastern side of migrating trough of low pressure

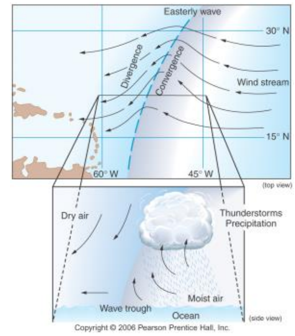
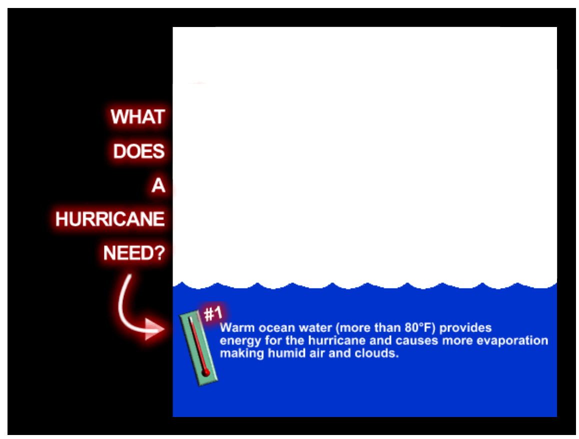
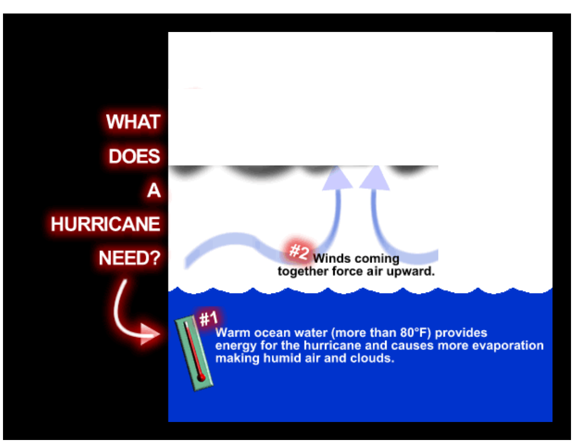


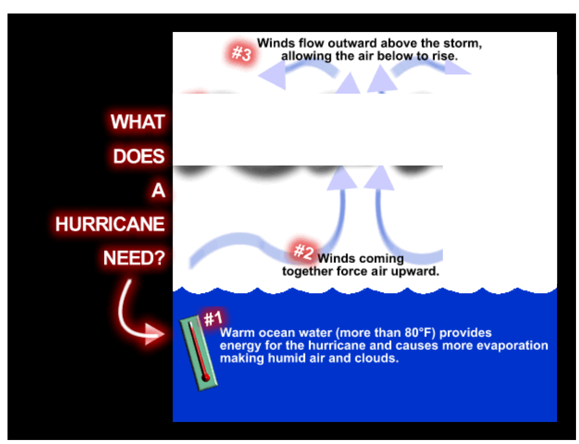
TABLE 5.2 Tropical Cyclone Classification

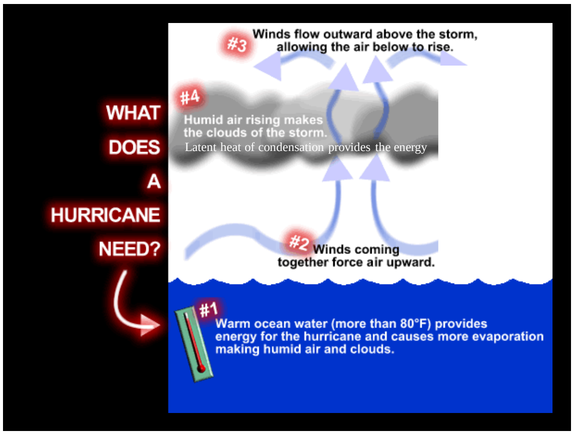
Designation	Winds	Features
Tropical disturbance	Variable, low	Definite area of surface low pressure; patches of clouds
Tropical depression	Up to 63 kmph (38 mph); up to 34 knots	Gale force, organizing circulation; light to moderate rain
Tropical storm	63–118 kmph (39–73 mph); 35–63 knots	Closed isobars; definite circular organization; heavy rain; assigned a name
Hurricane (Atlantic and East Pacific) Typhoon (West Pacific) Cyclone (Indian Ocean, Australia)	Greater than 119 kmph (74 mph); 65 knots	Circular, closed isobars; heavy rain, storm surges; tornadoes in right-front quadrant

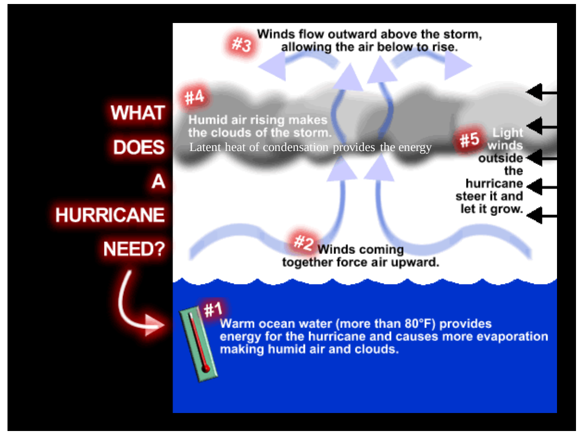
© 2013 Pearson Education, Inc.







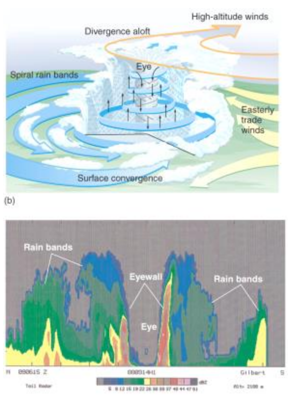




Cross Section Of Hurricane

- Counterclockwise rotation in Northern Hemisphere
- Strong winds spiral upward in eye wall
- Lowest pressure within eye where sinking air produces calm conditions

Fig. 5.37

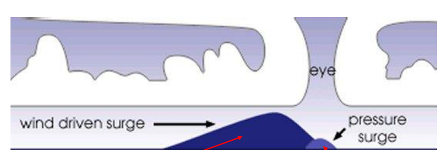


Hurricanes

TABLE 5.3 Saffir–Simpson Hurricane Wind Scale

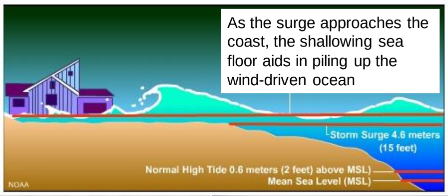
Category	Wind Speed	Notable Atlantic Examples (landfall rating)
1	119–154 kmph (74–95 mph) 65–82 knots [Dangerous, some damage]	
2	155–178 kmph (96–110 mph) 83–95 knots [Dangerous, extensive damage]	1954 Hazel; 1999 Floyd; 2003 Isabel (was a cat. 5), Juan; 2004 Francis; 2008 Dolly; 2010 Alex
3	179–210 kmph (111–130 mph) 96–113 knots [Devastating damage]	1985 Elena; 1991 Bob; 1995 Roxanne, Marilyn; 1998 Bonnie; 2003 Kate; 2004 Ivan (was a cat. 5), Jeanne; 2005 Dennis, Katrina, Rita, and Wilma (were cat. 5); 2007 Henrietta; 2008 Gustav and Ike (were cat. 4)
4	211–250 kmph (131–155 mph) 114–135 knots [Catastrophic damage]	1979 Frederic; 1985 Gloria; 1995 Felix, Luis, Opal; 1998 Georges; 2004 Charley; and 2005 Emily (was a cat. 5).
5	> 250 kmph (> 155 mph) > 135 knots [Catastrophic damage]	1935 No. 2; 1938 No. 4; 1960 Donna; 1961 Carla; 1969 Camille; 1971 Edith; 1977 Anita; 1979 David; 1980 Allen; 1988 Gilbert, Mitch; 1989 Hugo; 1992 Andrew; 2004 Ivan; 2007 Dean, Felix

Formation Of Storm Surge

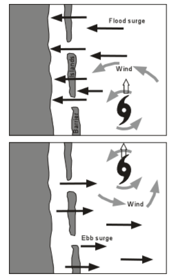


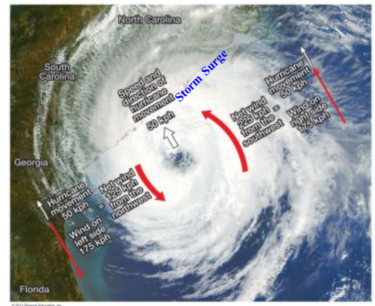
Out at sea, strong winds pile up a wall of water near the hurricane center

Also, low pressure in eye lifts a dome of water within eye

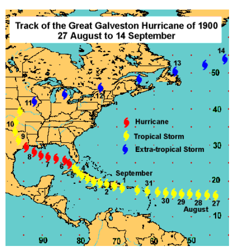


Incoming Storm Surge And Greatest Precipitation On The Right Side (Facing Land) Of Hurricane



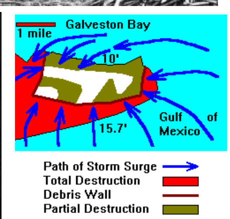


Galveston Hurricane of 1900



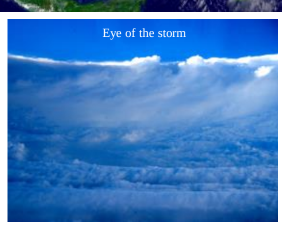
Category 4 Hurricane struck the Island September 8, 1900 with wind speeds of over 120 miles per hour. Over 6,000 people killed.

Hurricane-force waves and storm surge pushed a wall of debris, reaching 15 feet in height, inland over several blocks

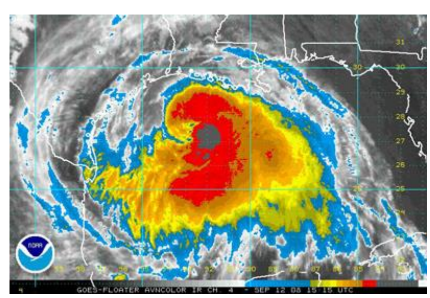


Hurricane Katrina (2005)

- Reached Category 5 status in Gulf of Mexico
- Made landfall on Louisiana coast August 29, 2005, as a Category 3 hurricane
- Most destructive storm in terms of economic loss (estimated up to $125 billion)



Hurricane Ike, 2008, Was An Unusually Large Category 2 Hurricane



Debris on Galveston Seawall After Ike

Crystal Beach, Before And After Ike