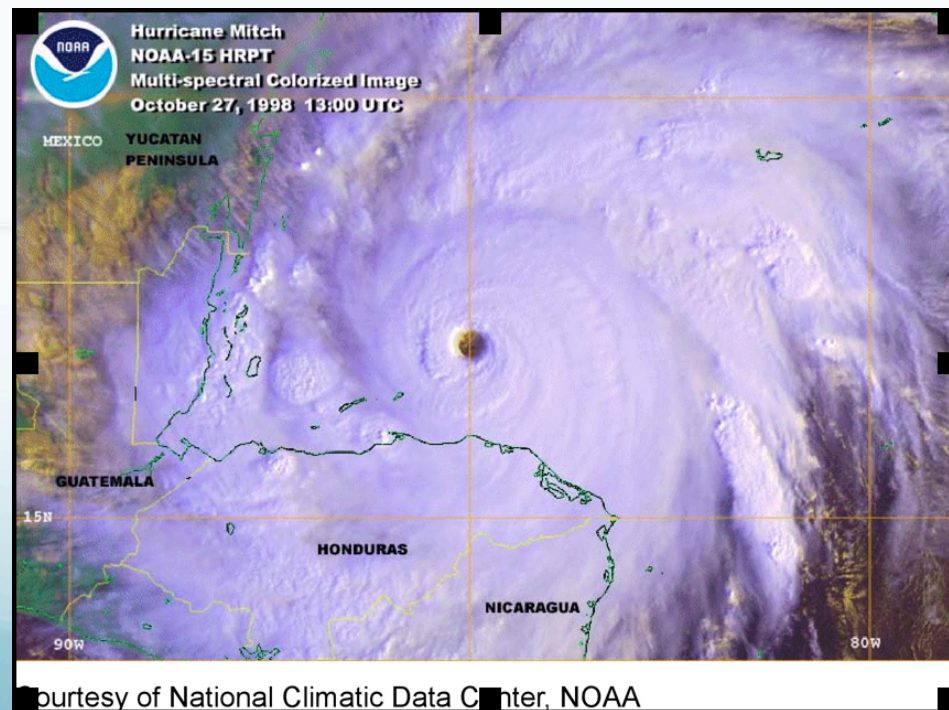


Chapter 24

Tropical Cyclones



Tropical Weather Systems

- **Tropical disturbance** – a cluster of thunderstorms about 250 to 600 km in diameter, originating in the tropics or sub-tropics
- **Tropical depression** – a cluster of thunderstorms with an identifiable surface pressure drop and closed wind circulation with wind speeds **up to 34 kts** (39 mph)
- **Tropical storm** – a cluster of thunderstorms with a wind speed between **34 and 64 kts** (39 and 74 mph)
- **Hurricane** – an organized cluster of thunderstorms with a wind speed **greater than 64 kts** (74mph)

Other names for hurricanes

- **Hurricane** – Atlantic Ocean and eastern Pacific Ocean
- **Typhoon** – western Pacific Ocean
- **Cyclone** – Indian Ocean and Australia

Naming of tropical systems

- When is a name given to a tropical weather system?
 - Tropical depressions: when a storm reaches this level it is assigned a number
 - Tropical storms: A storm is given a name when it reaches this level and keeps its name for the rest of its lifecycle
 - Hurricanes: Named the same name as was given to it when it was a tropical storm
 - <http://www.nhc.noaa.gov/aboutnames.shtml>

Intensity scale

- Saffir-Simpson hurricane intensity scale

| Rating | Central Pressure (mb) | Wind Speed (mph) | Storm Surge (ft) |
|--------|--------------------------|------------------|---------------------|
| 1 | >980 | 74-95 | 4-5 |
| 2 | 965-979 | 96-110 | 6-8 |
| 3 | 945-964 | 111-130 | 9-12 |
| 4 | 920-944 | 131-155 | 13-18 |
| 5 | <920 | >155 | >18 |

What is the average value for sea level pressure? **1013.25 mb**

How does the central pressure in a hurricane compare to average sea level pressure?

Much lower!

Impact of tropical cyclones

- In what regions are fatalities from tropical cyclones greatest?
 - Southern Asia; India and Bangladesh
- A tropical cyclone killed 500,000 people in Bangladesh in 1970.
- Hurricane Mitch killed nearly 20,000 people in Central America in 1998.
- Tropical storm Jeanne killed more than 2,000 people in Haiti in September 2004.
- How has the loss of life due to tropical cyclones changed with time in the United States?
 - Decreased
 - Why have these changes occurred?
 - Advances in technology (satellite and computer forecast models), improved warnings, evacuation procedures and public education

Cost impacts

- Hurricane damage costs in the United States:
 - Hurricane Katrina: \$81.2 billion (2005)
 - Hurricane Andrew: \$44.9 billion (1992)
- Florida Hurricanes in 2004
 - Charley: \$15.4 billion
 - Ivan: \$14.2 billion
 - Frances: \$9.1 billion

Clicker Question

- A cluster of thunderstorms in the tropics with a wind speed of 50 knots would be classified as a _____.
- A. tropical disturbance
 - B. tropical depression
 - C. tropical storm
 - D. hurricane

Clicker Question

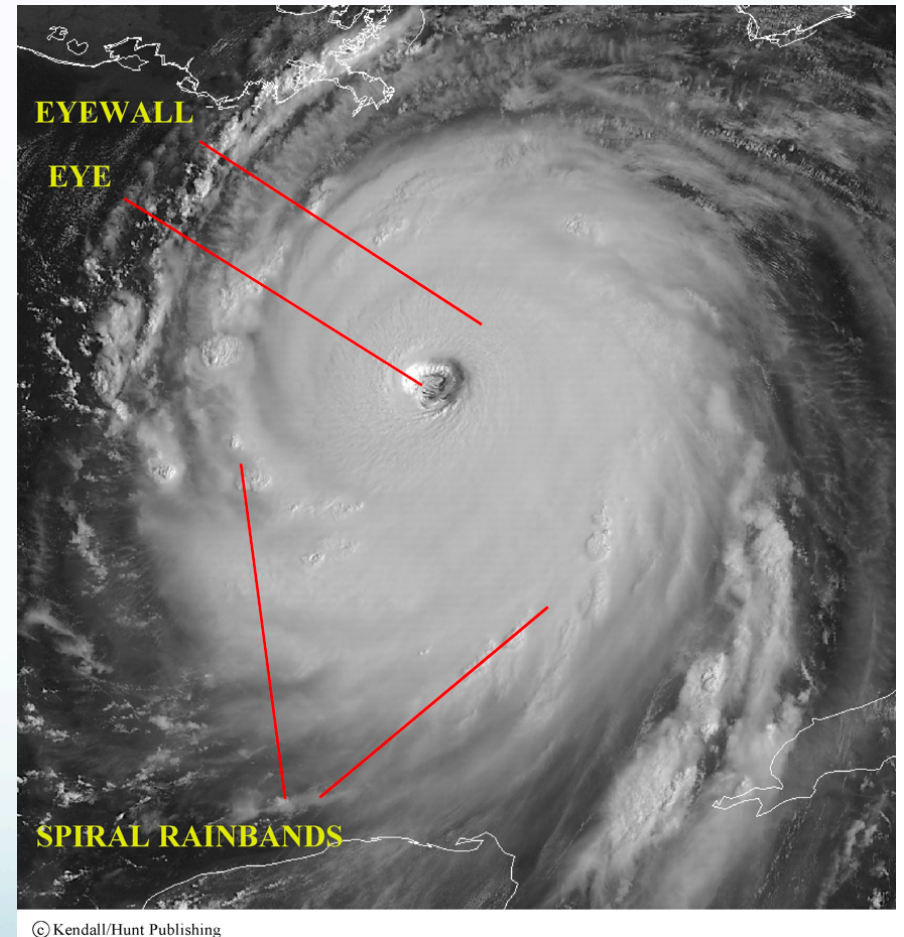
- In the Atlantic Ocean tropical storms are _____ and tropical depressions are _____.
 - A. given names, given names
 - B. assigned numbers, given names
 - C. assigned numbers, assigned numbers
 - D. given names, assigned numbers

Clicker Question

- A Saffir-Simpson rating of _____ is given to the weakest hurricanes and a rating of _____ is given to the strongest hurricanes.
 - A. 0; 10
 - B. 1; 5
 - C. 10; 0
 - D. 5; 1

Hurricane structure

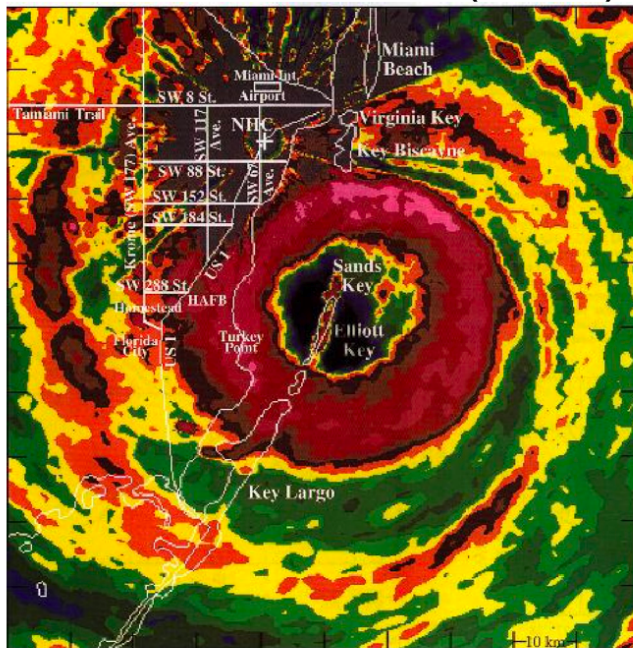
- **Eye** – a nearly cloud free area at the center of a hurricane
- **Eyewall** – a ring of deep convective clouds that surrounds the eye
- **Spiral rainbands** – bands of heavier rainfall that extend outward from the eyewall



Symmetry

- Not all hurricanes are symmetric

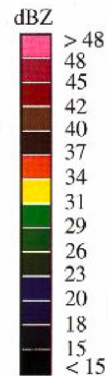
Hurricane Andrew (1992)



Courtesy NOAA/National Climate Data Center

HURRICANE ANDREW

NWS MIAMI RADAR
August 24, 1992
08:35 UTC 04:35 EDT



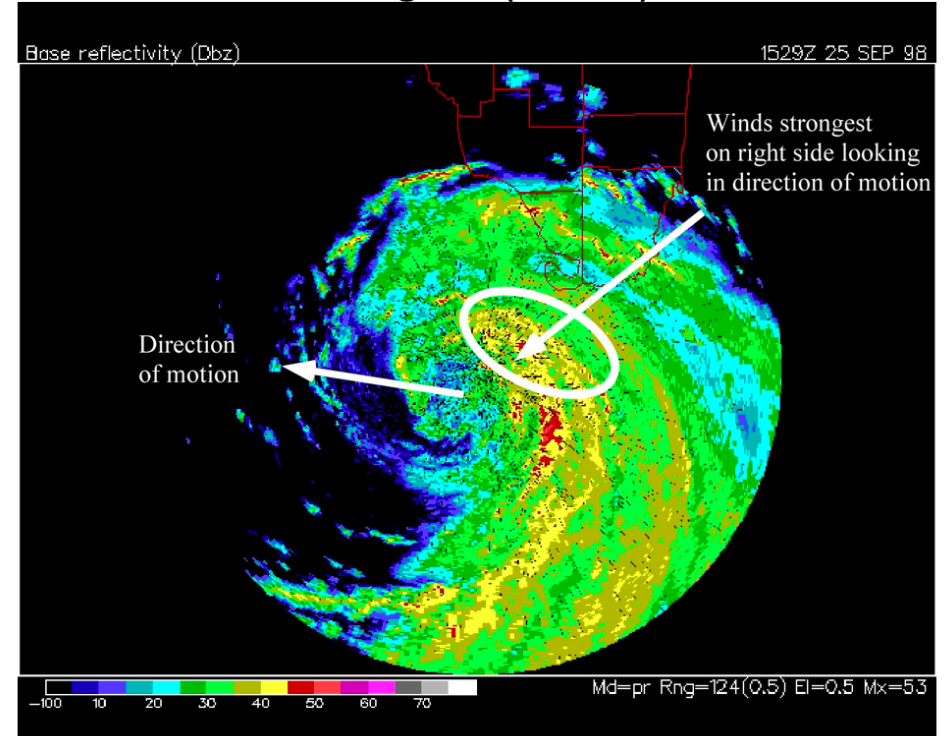
Hurricane
Research
Division



NOAA/AOML
Miami, FL

Domain: 100 x 100 km

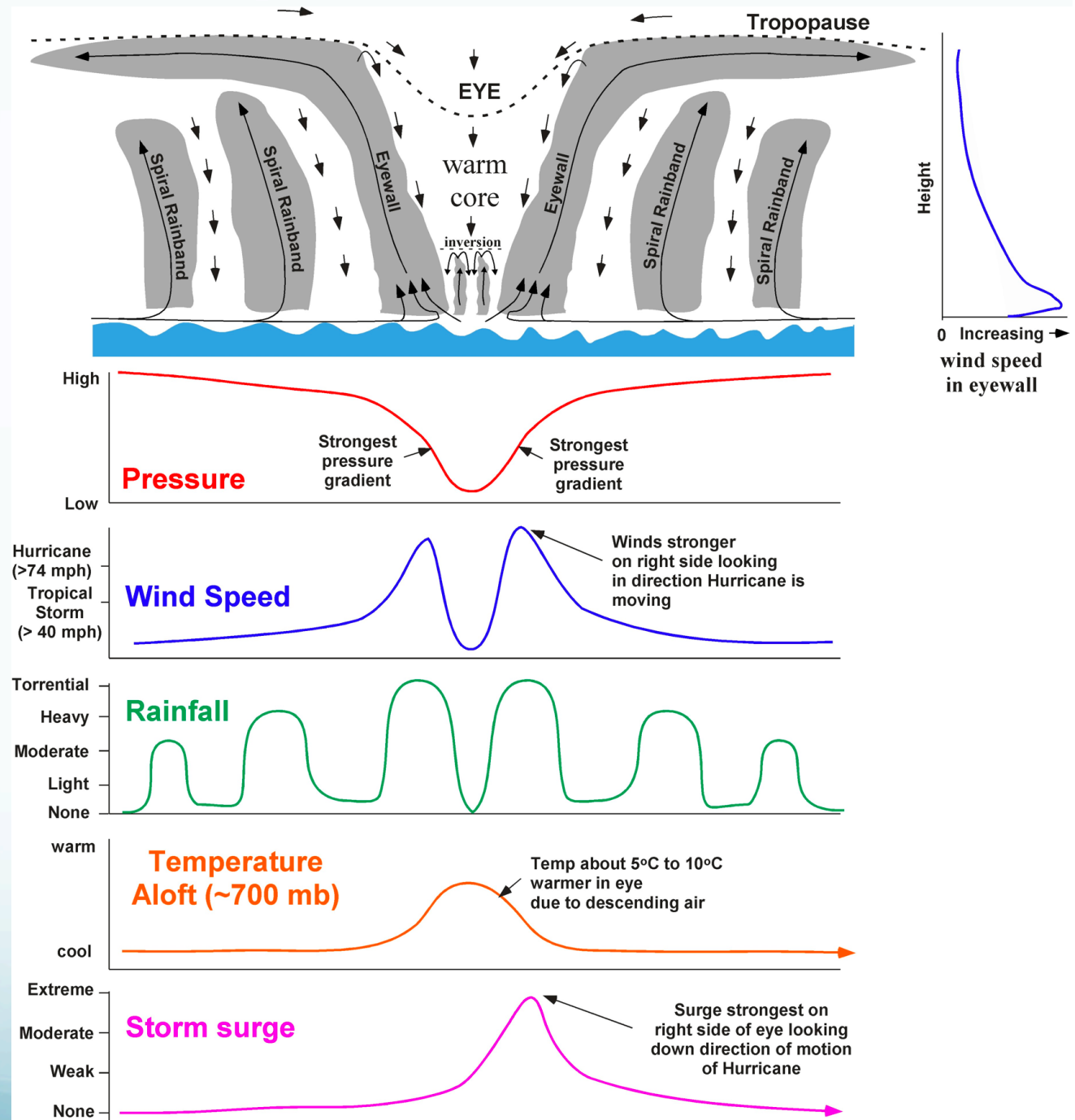
Hurricane Georges (1998)



© 2002 Kendall/Hunt Publishing

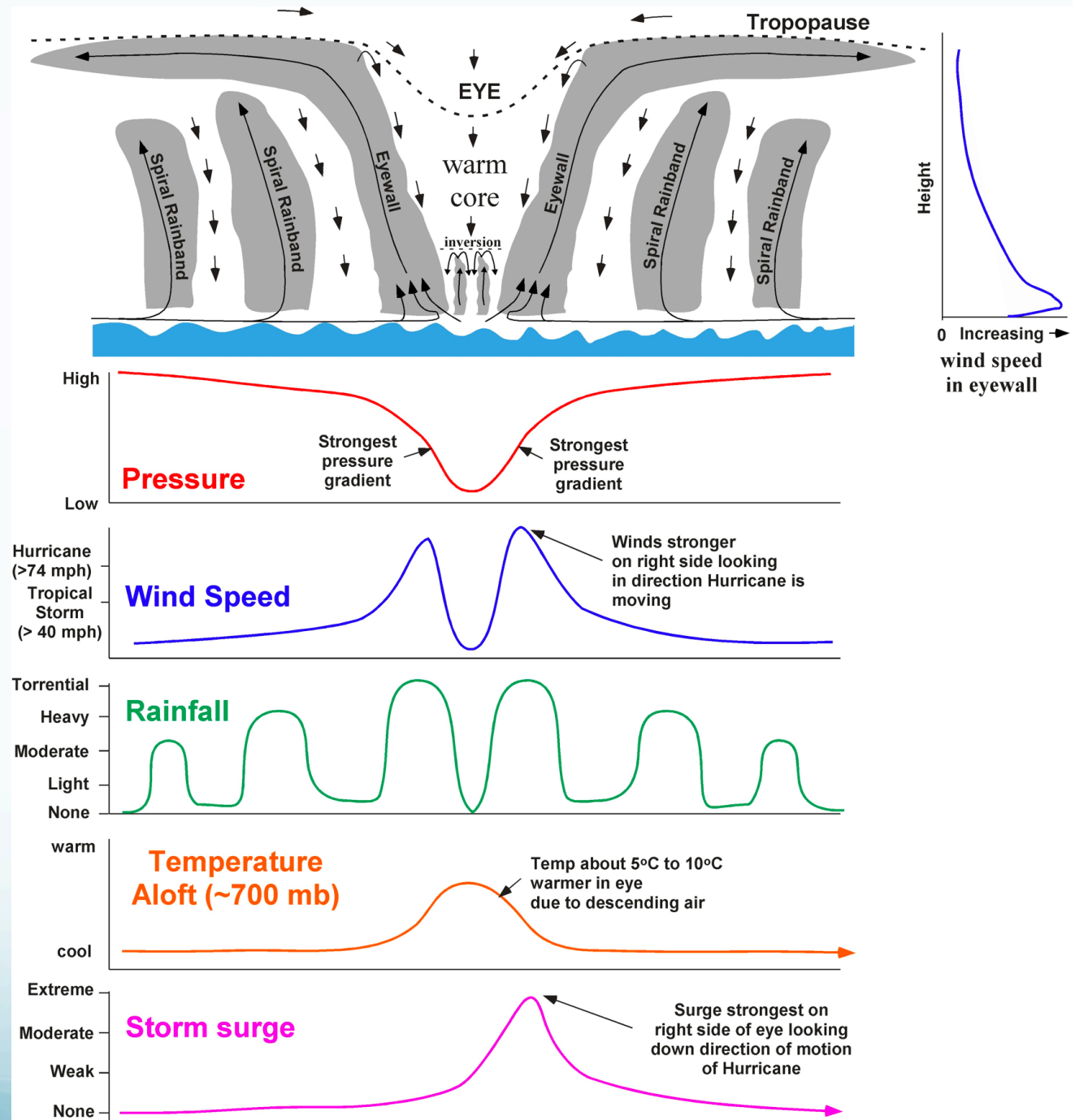
Vertical Structure

- Where is air rising / sinking in a hurricane?
- Where is air flowing in towards/ out from the center of a hurricane?
- What is the impact of sinking air in the eye of a hurricane?

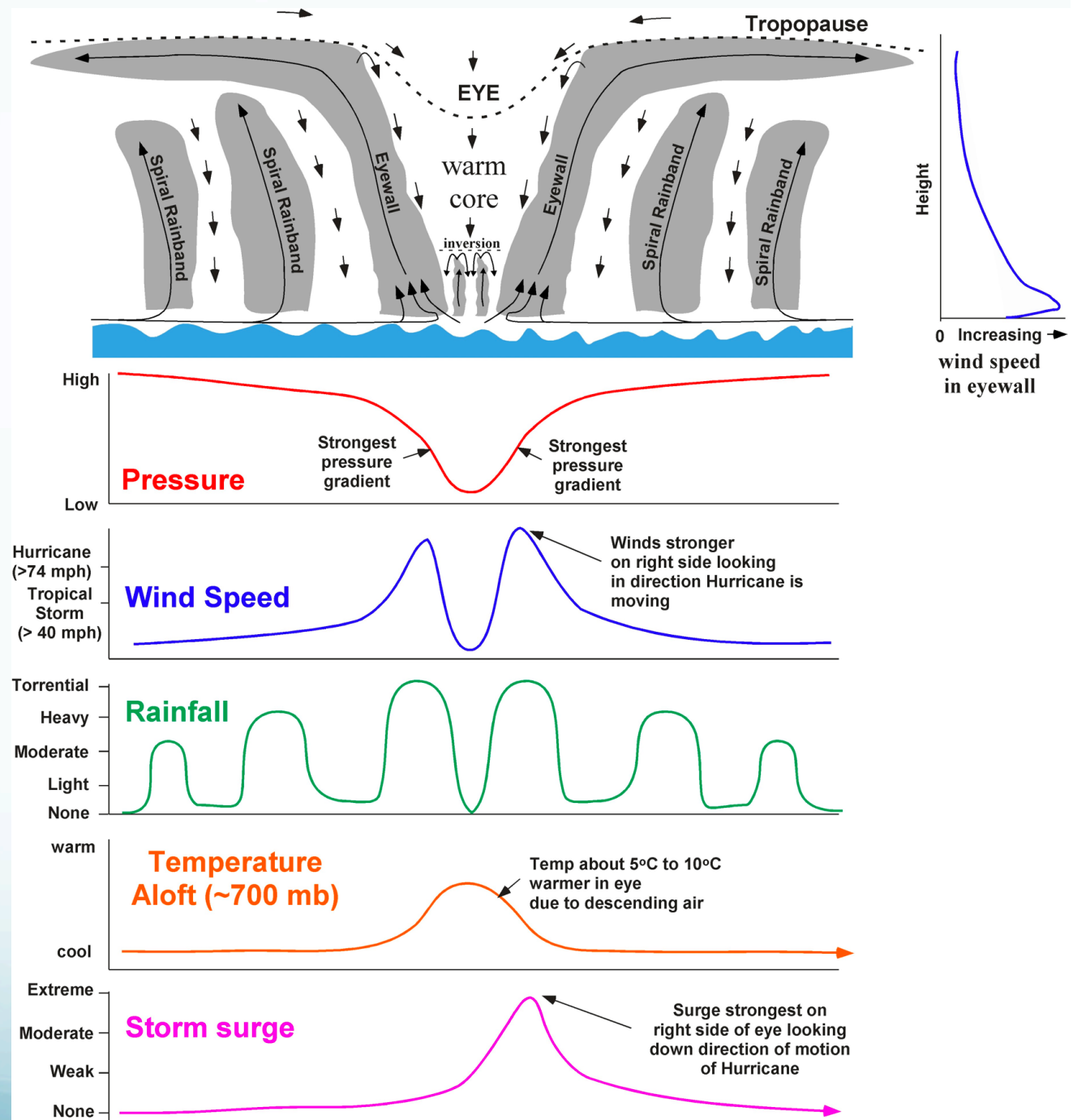


Vertical Structure

- How does pressure change as you move from the edge to the center of a hurricane?
- Where is the largest horizontal pressure gradient?

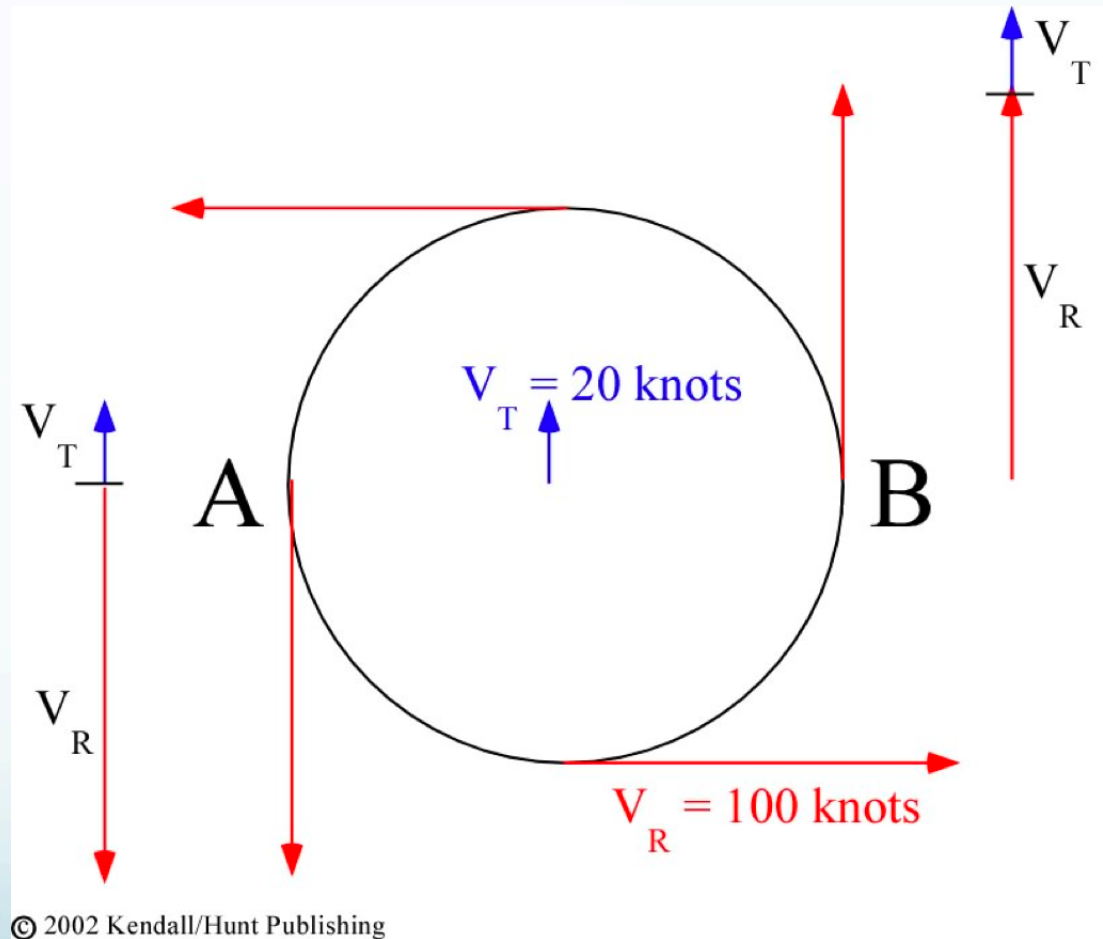


- Where does the heaviest rain fall in a hurricane?
- Where else does heavy rain fall in a hurricane?
- How does the temperature change as you move from the edge to the center of a hurricane?
- What causes this change?
- Where is the largest storm surge in a hurricane?



Hurricane winds

- Where are the strongest winds in a hurricane?
- Is the wind speed the same on the right and left side of hurricane?



Clicker Question

- The nearly cloud free area at the center of a hurricane is the _____.
 - A. Eye
 - B. Eyewall
 - C. Spiral rainband
 - D. Storm surge

Clicker Question

- You would expect air to be flowing _____ near the surface and to be flowing _____ at upper levels in a hurricane.
 - A. Inward, outward
 - B. Outward, inward
 - C. Inward, inward
 - D. Outward, outward

Clicker Question

- You would expect air to be _____ in the eyewall of a hurricane and to be _____ in the eye.
 - A. Sinking, sinking
 - B. Sinking, rising
 - C. Rising, rising
 - D. Rising, sinking

Clicker Question

- The sea level pressure _____ as you move from the edge to the center of a hurricane.
 - A. Decreases
 - B. Remains constant
 - C. Increases

Clicker Question

- The strongest winds occur in the _____ on the _____ side of the hurricane when looking in the direction the hurricane is moving.
 - A. eye, right
 - B. eye, left
 - C. eyewall, right
 - D. eyewall left

Tropical cyclone development

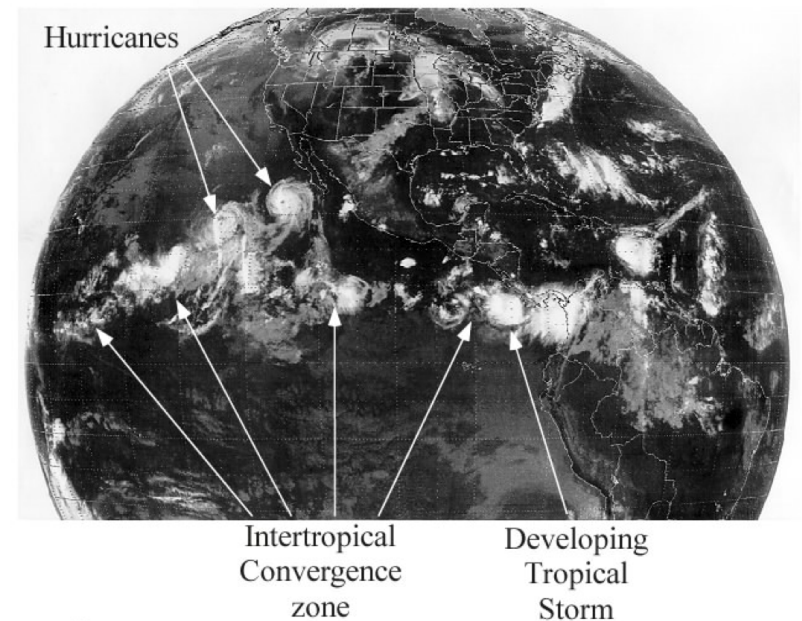
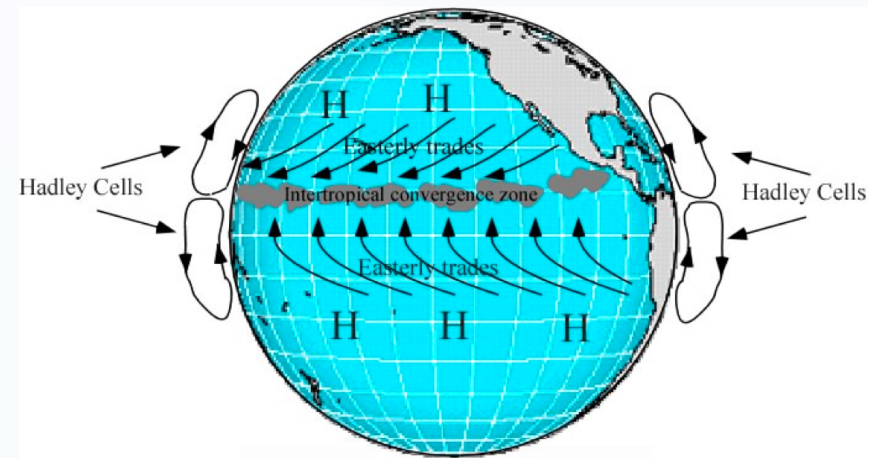
- For a tropical cyclone to form, a cluster of thunderstorms must form and these thunderstorms must become organized.

Trigger Mechanisms for Thunderstorms in the Tropics

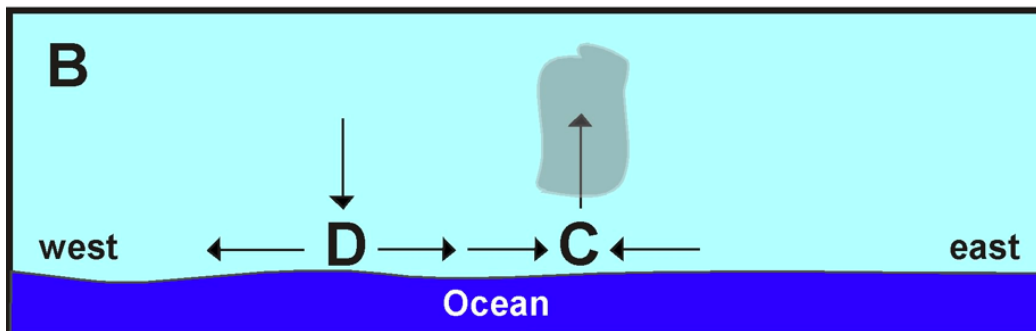
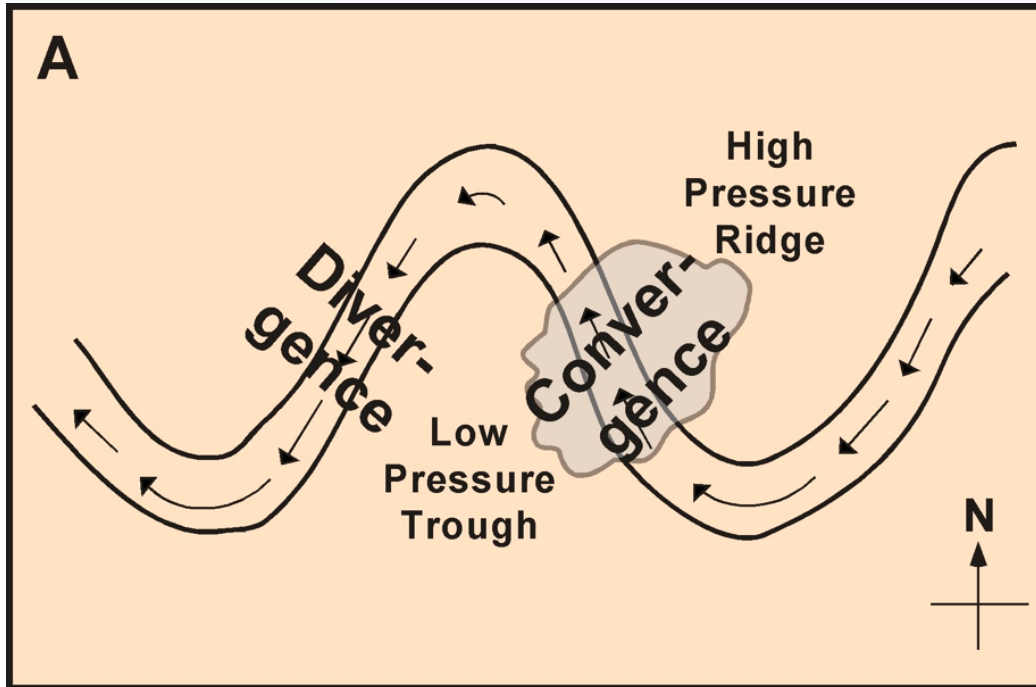
- What can cause a cluster of thunderstorms to form in the tropics?
 - 1. Intertropical Convergence Zone (ITCZ)
 - 2. Easterly Waves
 - 3. Mid-latitude cold front

ITCZ

- Intertropical Convergence Zone
- The ITCZ is where the easterly trade winds from the Northern and Southern hemispheres meet.
- How does the position of the ITCZ change throughout the year?
 - Based on zone of maximum heating
- How important is the ITCZ for hurricane formation?
 - The convergence within this zone provides a lifting mechanism
 - When far enough north (or south) of Equator, the Coriolis force is strong enough to help organize the storms into a hurricane



Easterly Waves



- An easterly wave is a ripple in the low-level atmospheric flow that causes convergence.

- Where does convergence occur relative to an easterly wave?

Where air slows entering trough

- Where do clouds form relative to an easterly wave?

Where there is low-level convergence

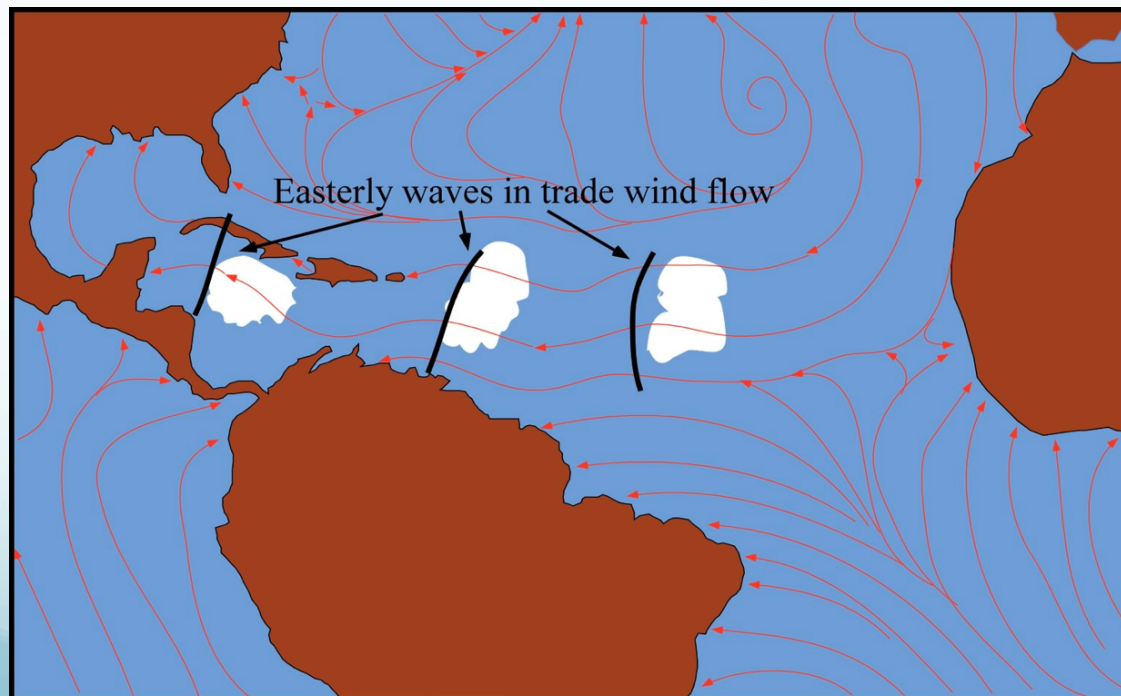
Easterly wave formation

- Where do easterly waves typically originate?

Over continents as air moves over mountains and/or deserts

- What is the main source region for easterly waves in the Atlantic Ocean?

Sahara desert



Mid-latitude cold fronts

- What time of year are mid-latitude cold fronts most important for tropical cyclone development?
 - Fall, when the cold fronts are strongest and can propagate farther into the Tropics
- Where are mid-latitude cold fronts most important for tropical cyclone development?
 - For late-season Gulf of Mexico hurricanes

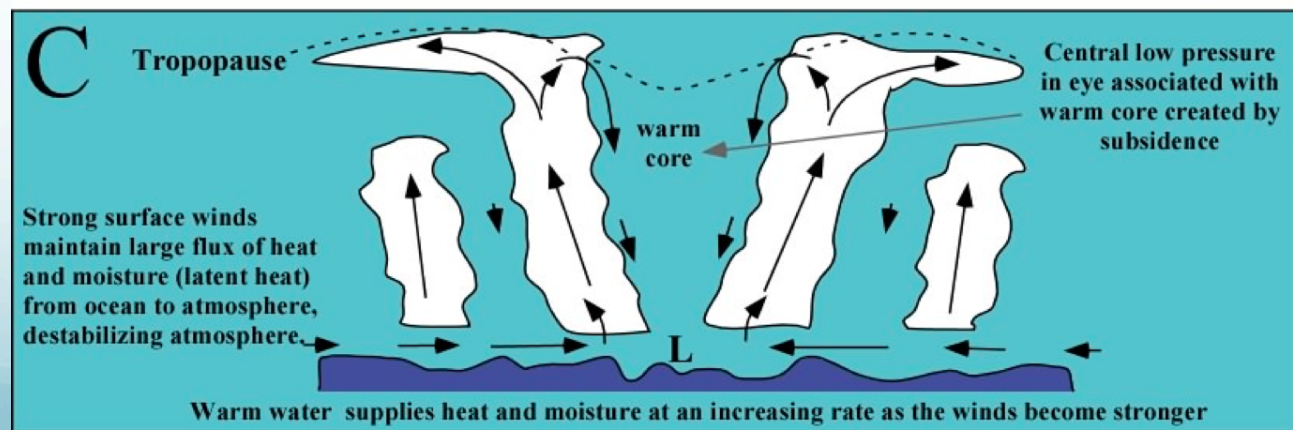
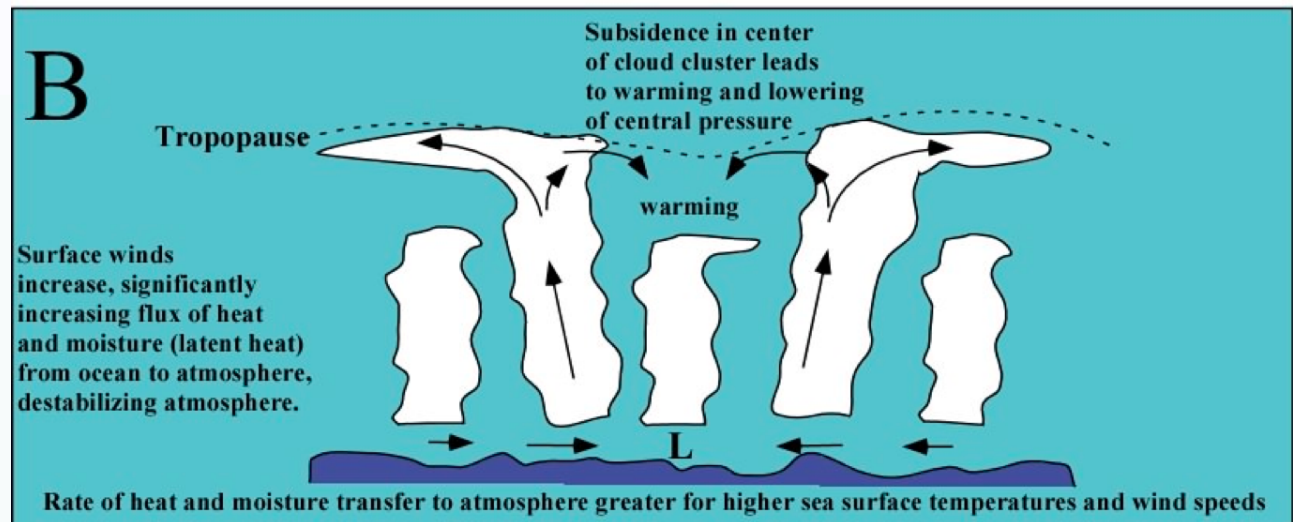
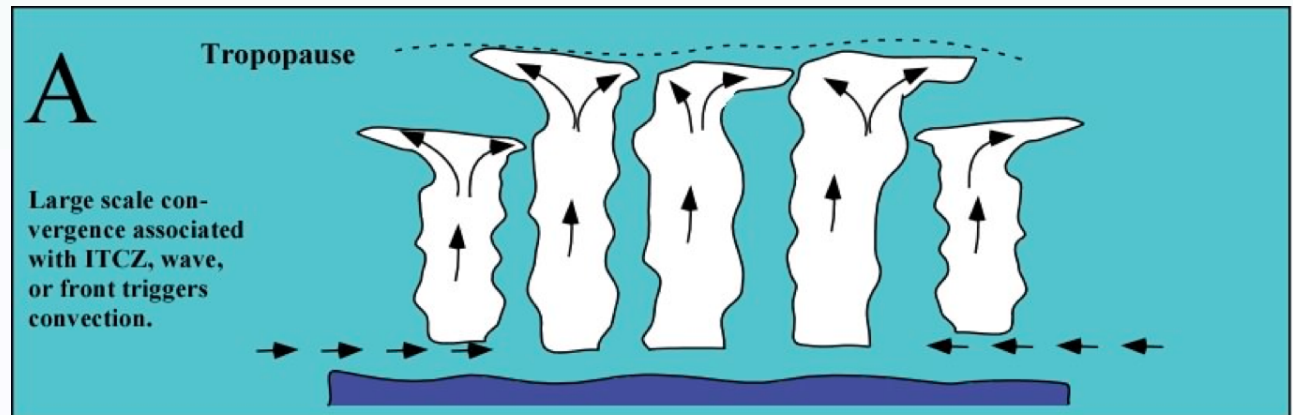
Environment for formation

- There are four conditions required for a cluster of thunderstorms to become a tropical cyclone
- 1. Sea surface temperature (SST) > 26.5 °C (80 °F)
 - Why are warm SSTs important for tropical cyclone formation? **Provides energy for storms from heat and moisture**
 - When is the SST > 27 °C in the N. Atlantic, eastern Pacific, and western Pacific Oceans? **July-Nov, but all year in West Pacific**
- 2. Sufficiently deep (>60 m) layer of warm ocean water
 - What impact do tropical cyclones have on water near the surface of the ocean? **“Stirs” the ocean leading to upwelling**
 - What happens to the SST if the layer of warm water in the ocean is shallow? **The upwelling with bring cold water to surface shutting off energy source for storm**

Environment for formation

- 3. Weak vertical wind shear
 - What impact does strong vertical wind shear have on tropical cyclones? **“Tear apart” the circulation that’s forming**
- 4. Location at least 5 degrees of latitude poleward of the equator
 - How does the Coriolis force change as you move away from the equator toward the poles? **Increases!**
 - What is the role of the Coriolis force in creating a tropical cyclone? **Provide source of rotation**

- What causes a cluster of thunderstorms to form?
- What causes the low pressure center to form?
- What happens to the rising air in thunderstorms when it reaches the tropopause?
- What impact does descent in the center of the cluster have on the temperature and pressure at the center?



Last steps

- How does the wind speed change as the low pressure center becomes stronger?
- What impact does this have on the transfer of heat and moisture from the ocean to the atmosphere?
 - **WISHE** – Wind Induced Surface Heat Exchange
- How does the rotation of a hurricane begin?
 - As central low pressure develops, the pressure gradient and Coriolis forces produce the rotation

Summary of hurricane formation

HURRICANE FORMATION

Trigger Mechanisms for initial Thunderstorms

1. Intertropical convergence zone
2. Easterly waves in trade wind flow
3. Cold fronts extending into tropics

Environment required for Hurricane formation

1. Sea surface temp $> 27^{\circ}\text{C}$
2. Deep layer of warm water
3. Weak wind shear
4. At least 5° from equator

Spin up of thunderstorm clusters into Hurricane

1. Wind induced transfer of heat from the ocean to the atmosphere
2. Conservation of angular momentum

Clicker Question

- _____ is where easterly trade winds from the Northern and Southern hemisphere meet.
 - A. The ITCZ
 - B. The subtropical jetstream
 - C. An easterly wave
 - D. A mid-latitude front

Clicker Question

- Rotation in a hurricane is due to _____.
 - A. the pressure gradient force
 - B. the gravitational force
 - C. the Coriolis force
 - D. the frictional force

Tropical cyclone lifecycle

- How long can a tropical cyclone survive? **Many days to weeks**
- What causes a tropical cyclone to weaken?
 - Decreased SST
 - Increased vertical wind shear
 - Movement over land

Destructive Forces

- **Storm surge** – an abnormal rise in sea level associated with a tropical cyclone or strong extratropical cyclone as it moves over a coastal region
- Heavy rain
- High winds

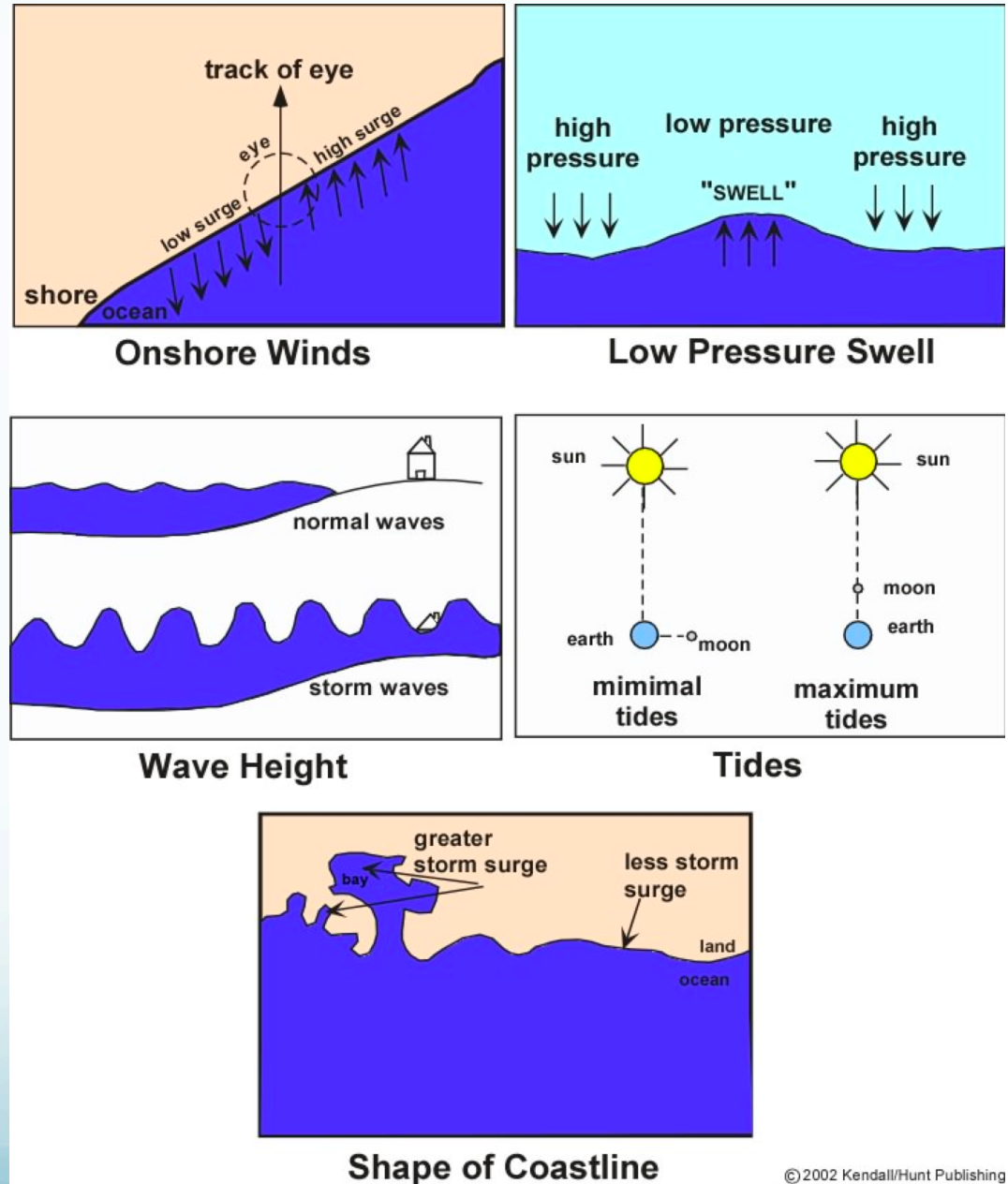
Storm surge

- The storm surge results in coastal flooding.
- What are the two primary causes of a storm surge?

Winds blowing onshore
Low pressure swell

- What three additional factors can enhance a storm surge?

Wave height
Tides
Shape of coastline

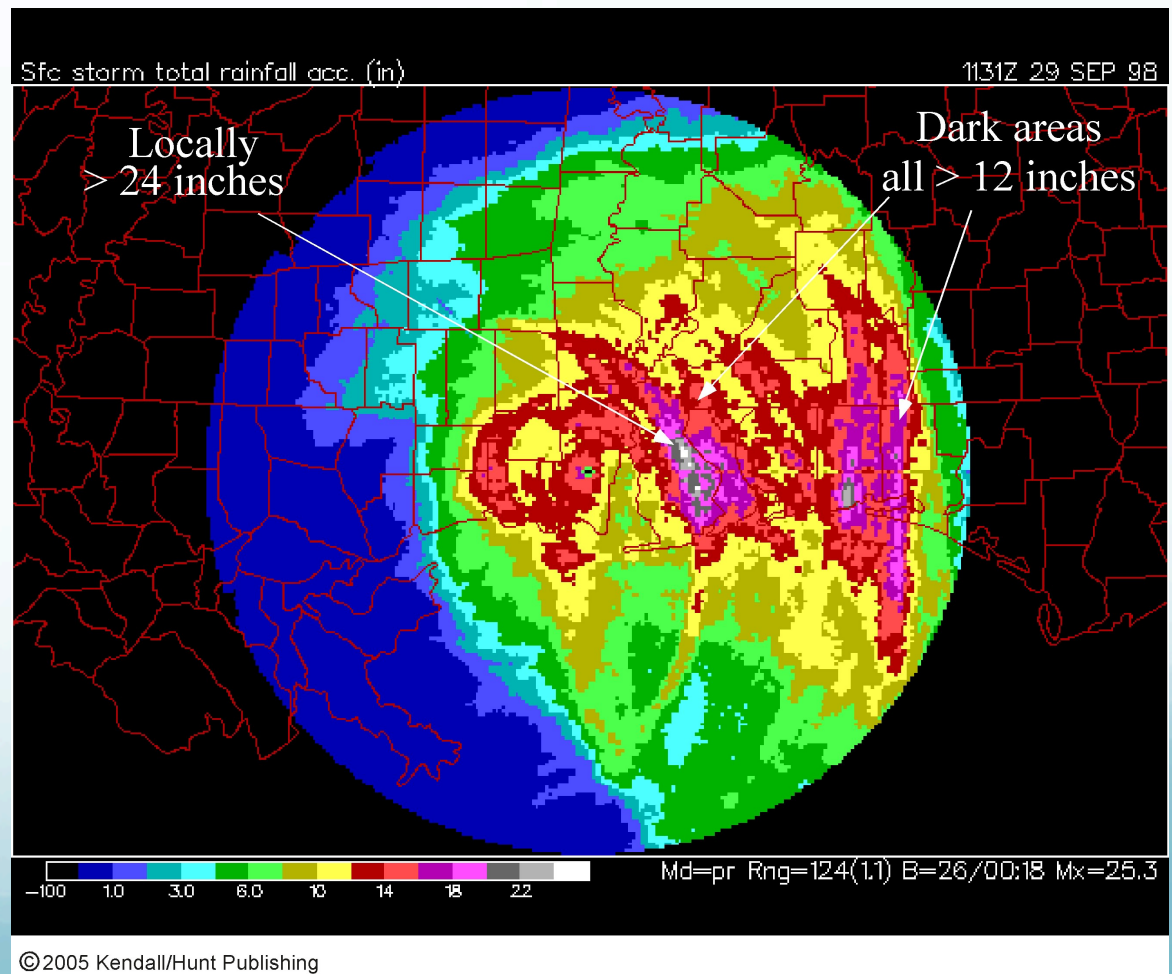


Heavy rain

How much rain can fall from a tropical cyclone after landfall?

- What can increase the total rainfall amount from a tropical cyclone?
- Nearly 20,000 people died as a result of flooding from heavy rains in Hurricane Mitch in 1998.

Ex. Hurricane Georges (1998)



High winds

- Do high winds or flooding typically cause the most damage in tropical cyclones?
- Tornadoes can form in landfalling tropical cyclones.
 - How strong are tornadoes that form in landfalling tropical cyclones?
 - Why are these tornadoes especially dangerous?

Hard to see because of heavy rain

Clicker Question

- A tropical cyclone can survive as long as _____.
 - A. 1 day
 - B. 5 days
 - C. 10 days
 - D. over 20 days

Clicker Question

- A tropical cyclone will weaken when it encounters _____.
- A. SST < 27 deg C
 - B. decreased vertical wind shear
 - C. movement over land
 - D. all of the above
 - E. both a) and c)

Clicker Question

- A storm surge can be enhanced by _____.
 - A. Tides
 - B. wave height
 - C. the shape of the coastline
 - D. all of the above can enhance a storm surge
 - E. none of the above can enhance a storm surge

Hurricane Hunters

- http://www.youtube.com/watch?v=3_AGi_kL4Xo
(1:20)
- <http://www.youtube.com/watch?v=GqpYgxWOMQg&playnext=1&list=PL3A7B5D03B60004D6> (1:50)
- Inside the eye of a hurricane
 - <http://www.youtube.com/watch?v=KbT-YpW-44w&playnext=1&list=PL3A7B5D03B60004D6>
(1:40)
 - <http://www.youtube.com/watch?v=jIFADyOg2vk>
(1:00)