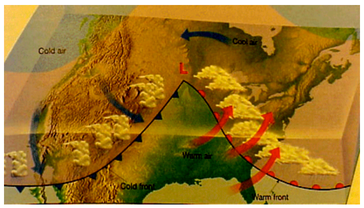
Midlatitude Cyclones

Equator-to-pole temperature gradient tilts pressure surfaces and produces westerly jets in midlatitudes

Waves in the jet induce divergence and convergence aloft, leading to surface highs and lows

Surface circulations amplify the wave by transporting heat to the north and south around the surface low



Resulting "cyclones" are crucial to the transport of energy through the middle latitudes

Lowers center of mass of atmosphere

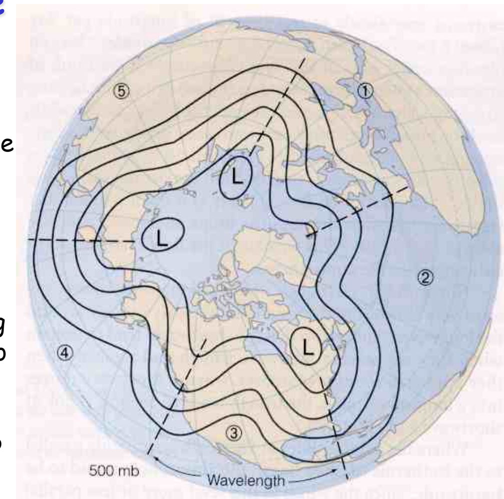
Large-Scale Setting

Very cold (and dark!) near the pole

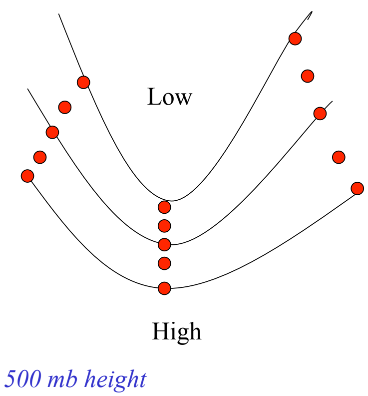
Polar air is dense and "shrinks" to form a hollow bowl

Warmer air moving into bowl spins into a big jet stream

Jet wobbles in 4-6 "long waves



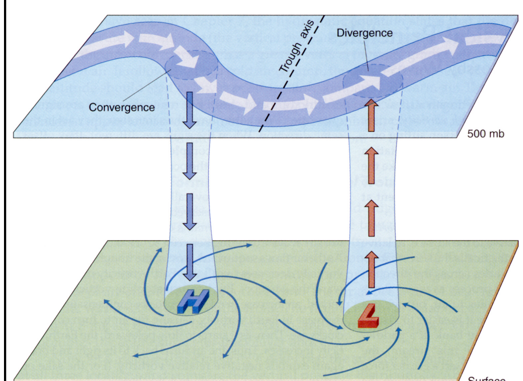
Convergence and Divergence



What initiates "cyclogenesis?"

*When upper-level **divergence** is stronger than lower-level **convergence**, more air is taken out at the top than is brought in at the bottom. Surface **pressure drops**, and the **low intensifies**, or "deepens."*

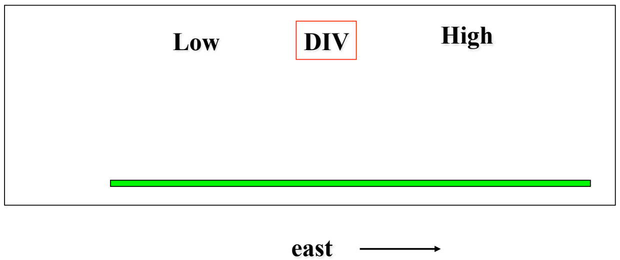
Divergence, Spin, and Tilt



- Maximum upper level convergence and divergence are *between* ridges and troughs
- Phase of developing wave "tilts" to the west with height

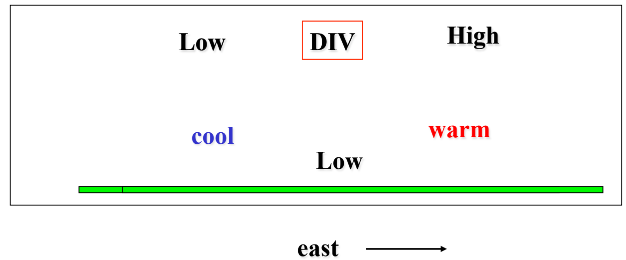
Before the Storm

- Vertical cross-section looking North
- Imagine a jet-stream wiggle passes overhead
- Where will surface low develop?



Birth of a Storm

- Surface winds respond to surface pressure gradient … transport cold air southward behind the low and warm air northward ahead of low
- This amplifies the upper level trough and ridge
- Enhances upper-level divergence



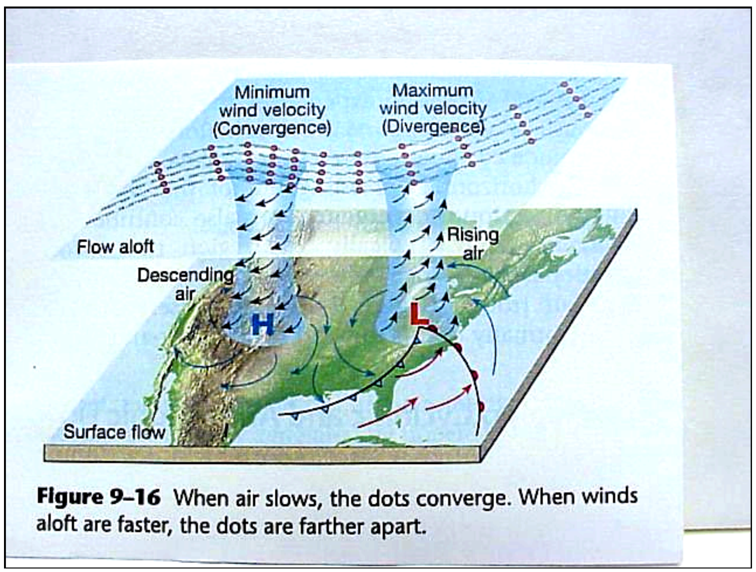
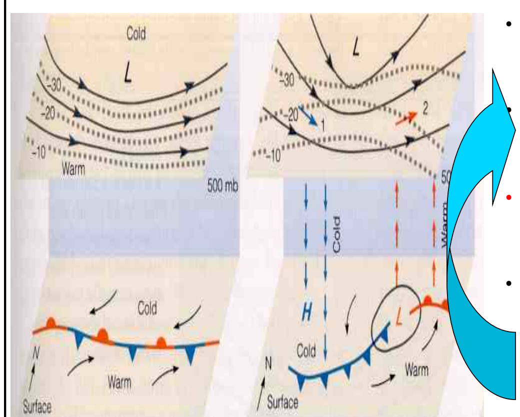


Figure 9–16 When air slows, the dots converge. When winds aloft are faster, the dots are farther apart.

How to "Grow" a Storm



- Upper level shortwave passes
- Upper level divergence -> sfc low
- Cold advection throughout lower troposphere
- Cold advection intensifies upper low
- Leads to more upper level divergence

Temperature advection is key!

Fronts

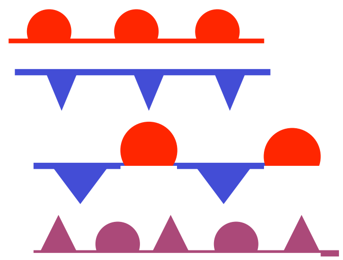
A Front - is the **boundary between air masses**; normally refers to where this interface intersects the ground (in all cases except stationary fronts, the **symbols are placed pointing to the direction of movement of the interface** (front)

Warm Front

Cold Front

Stationary Front

Occluded Front



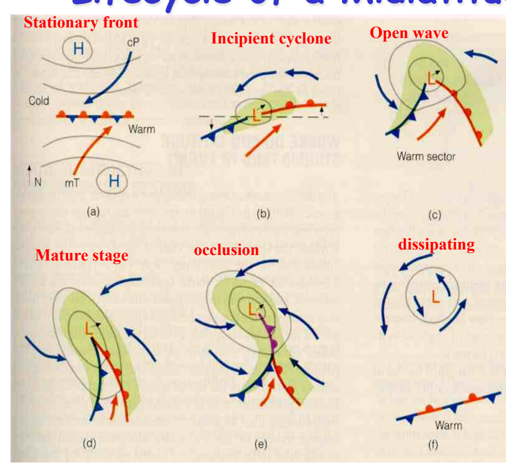
Characteristics of Fronts

- Across the front - look for one or more of the following:
  - Change of Temperature
  - Change of Moisture
  - Change of Wind Direction
  - Change in direction of Pressure Gradient
  - Characteristic Precipitation Patterns

How do we decide what kind of front it is?

- If warm air replaces colder air, the front is a warm front
- If cold air replaces warmer air, the front is a cold front
- If the front does not move, it is a stationary front
- Occluded fronts do not intersect the ground; the interface between the air masses is aloft

Lifecycle of a Midlatitude Cyclone

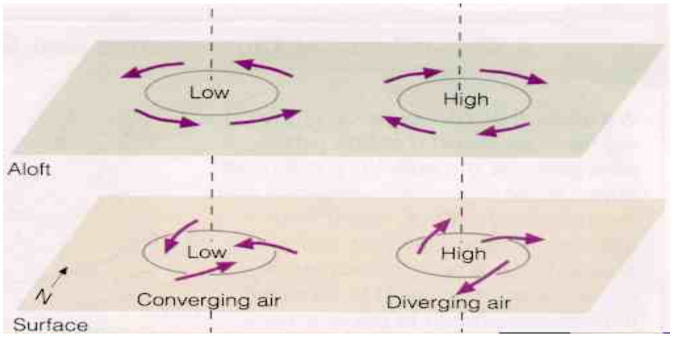


Green shading indicates precipitation

Takes several days to a week, and moves 1000's of km during lifecycle

What maintains the surface low?

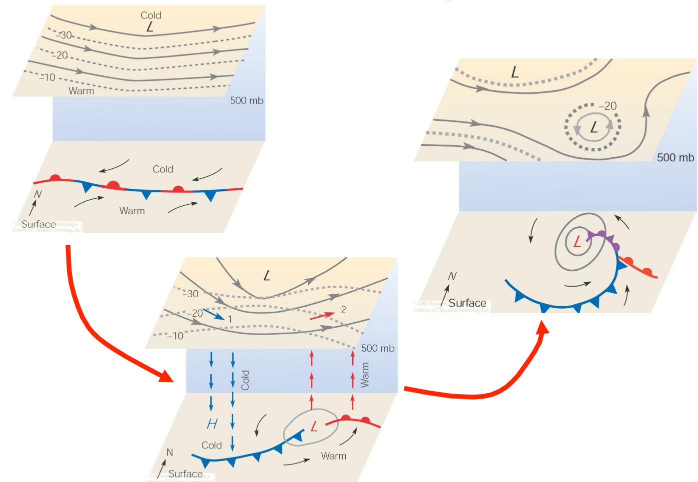
Imagine a surface low forming ***directly below*** upper level low

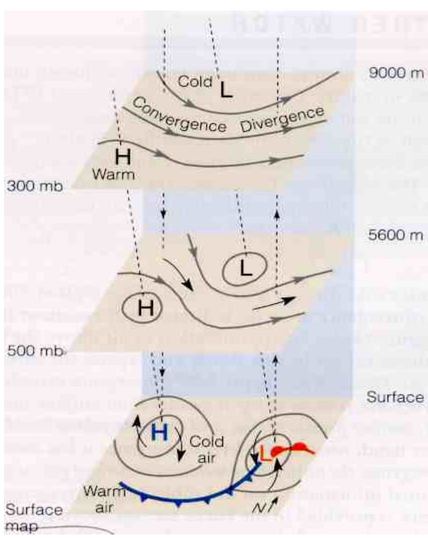


Surface convergence "fills in" the low

Surface divergence "undermines" the high

Storm Development





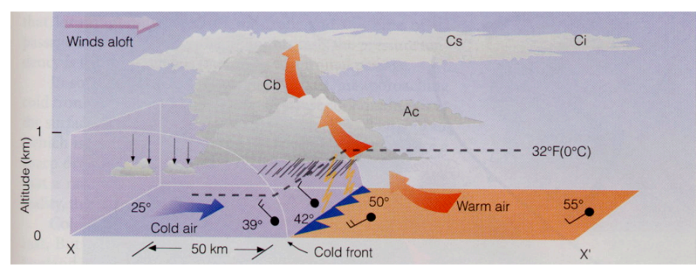
Actual vertical structure

Upper level low is ***tilted westward with height*** with respect to the surface.

UPPER LEVEL DIVERGENCE INITIATES AND MAINTAINS A SURFACE LOW.

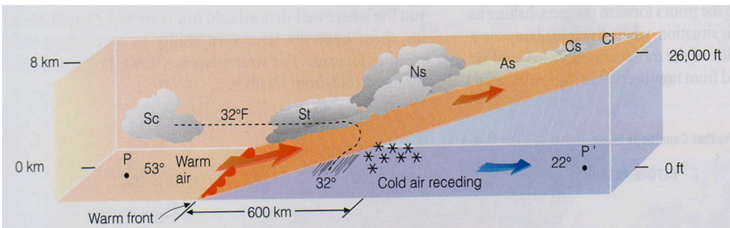
Cold Front Structure

- Cold air replaces warm; leading edge is steeper due to friction at the ground
- Strong vertical motion and unstable air forms cumule clouds (thunderstorms!)
- Upper level winds blow ice crystals downwind creating cirrus and cirrostratus

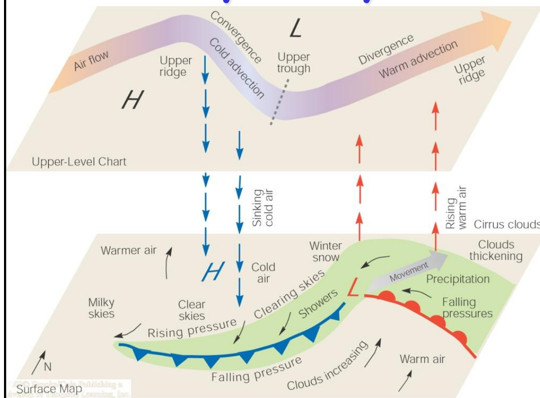


Warm Front Structure

- In an advancing warm front, warm air rides up over colder air at the surface; slope is not usually very steep
- Lifting of the warm air produces stratus clouds and precipitation well in advance of boundary
- At different points along the warm/cold air interface, the precipitation will experience different temperature histories as it falls to the ground



Summary of Cyclone Weather



Roles of convergence and divergence aloft

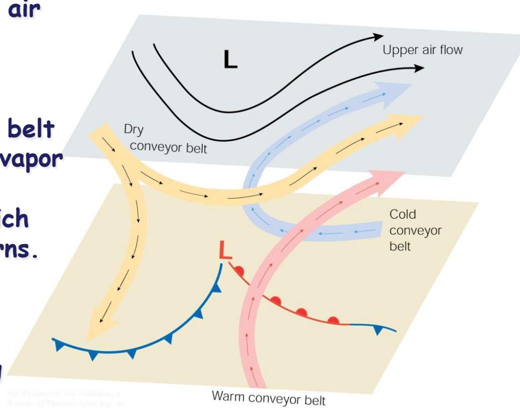
Pattern of clouds, precipitation, and temperatures on the ground

"Conveyor Belts"

This model describes rising and sinking air along three "conveyor belts"

A warm conveyor belt rises with water vapor above the cold conveyor belt which also rises and turns.

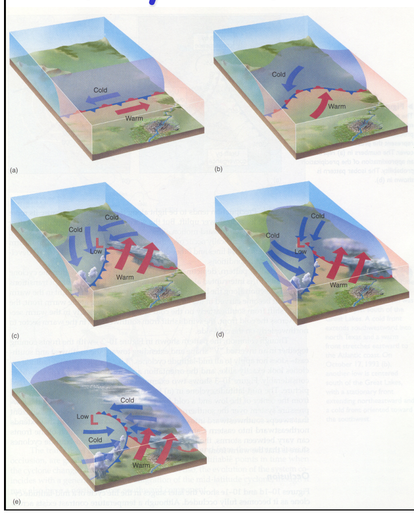
Finally the dry conveyor belt descends bringing clearer weather behind the storm.



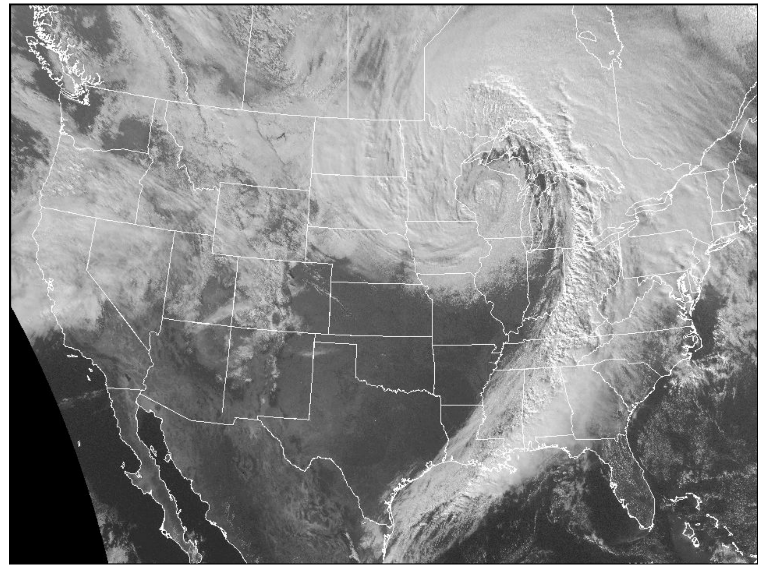
Follow the Energy!

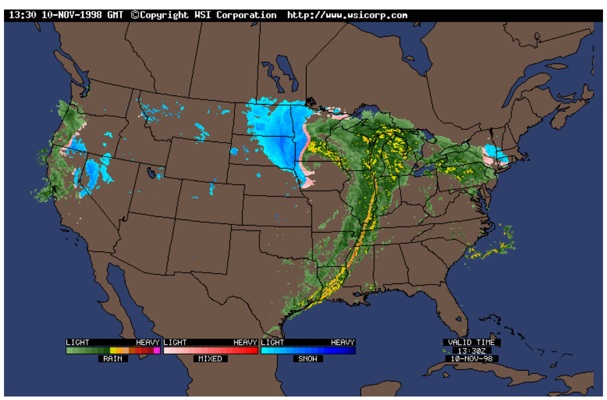
- Midlatitude storms release gravitational potential energy arising from the temperature differences found in the different air masses north and south of the polar front
- Cold, dense air pushes warmer, less dense air up and out of the way
- "Up warm, down cold"
- These storms let the atmosphere lower its center of mass … "air falling down"

Lifecycle of a Midlatitude Cyclone



- Pressure surfaces tilt because of N-S temperature contrast
- Passing wave initiates divergence and cyclonic vorticity
- Cold air undercuts warm, and flows south
- Cold air advection undermines upper trough, deepening it
- N-S mixing in cyclone eventually consumes the available potential energy, and cyclone dies

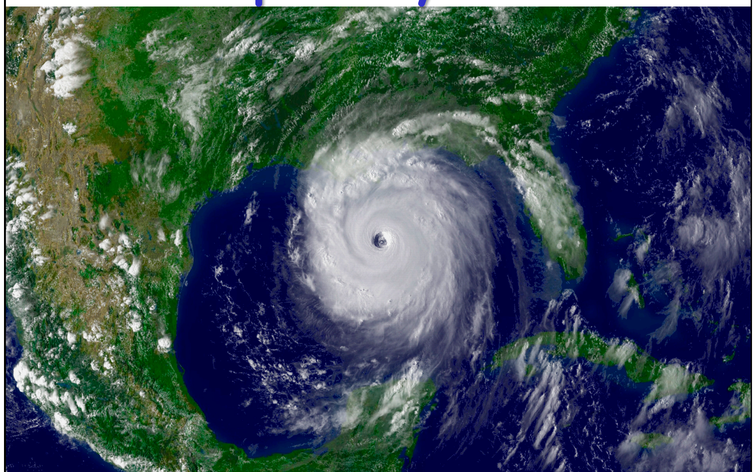




The "Big Picture"

- We've emphasized horizontal transport of energy to balance the planetary energy budget:
  - Hadley Cell
  - Subtropical divergence
  - Midlatitude cyclones and conveyor belts
- What about vertical motion?
  - "Up-warm, down cold"
  - "Up moist, down-dry"
- Severe weather is all about vertical motion, and represents local release of energy that contributes to planetary energy balance

Tropical Cyclones

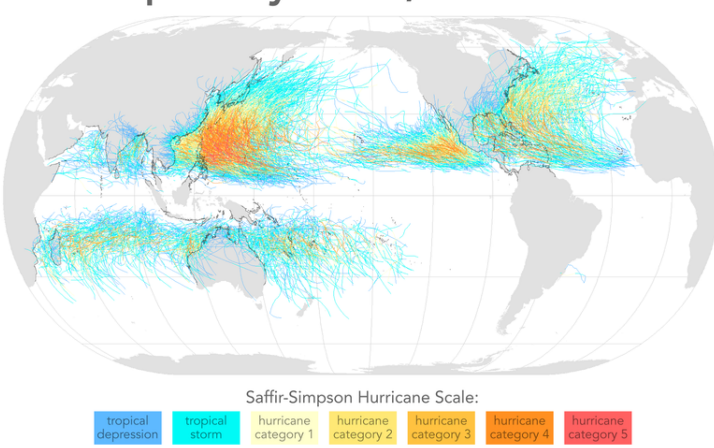


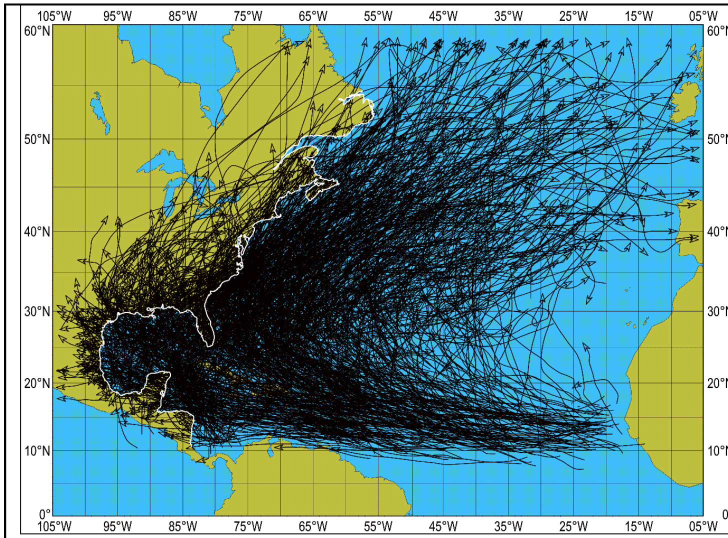
Hurricanes, Typhoons, Cyclones

Tropical Cyclones

- Large, organized vortices of embedded thunderstorms which form only over warm oceans (SST > 27 C)
- May develop from "easterly waves" associated with the ITCZ
- "In, up, and out" circulation driven by very intense release of latent heat
- Well-defined clear "eye," with most intense winds around the "eyewall"
- Damaging winds, torrential rain, coastal flooding due to storm surge

Tropical Cyclones, 1945–2006

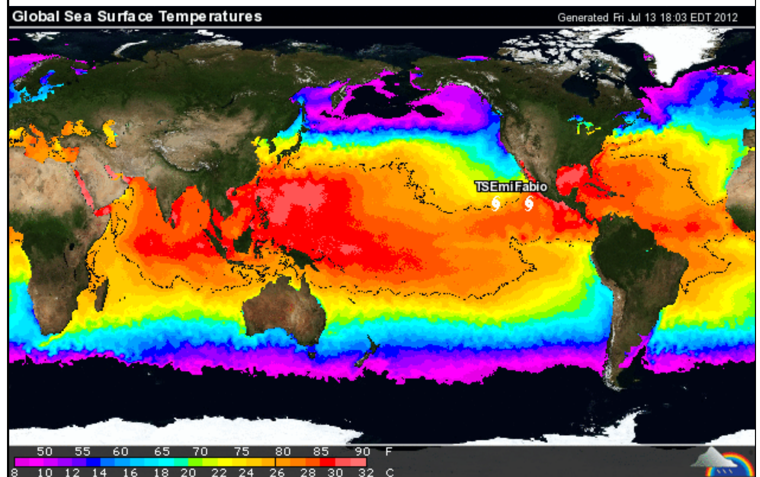




NORTH ATLANTIC TROPICAL STORMS AND HURRICANES, 1851-2004 (1325 STORMS)
NOAA

Tropical Cyclone Conditions

- Warm ocean waters (at least 80°F / 27°C) throughout a depth of about 150 ft. (46 m).
- An atmosphere which cools fast enough with height such that it is potentially unstable to moist convection.
- Relatively moist air near the mid-level of the troposphere
- Generally a minimum distance of at least 300 miles from the equator (otherwise not enough Coriolis).
- A pre-existing near-surface disturbance.
- Low values (less than about 23 mph / 37 km/h) of vertical wind shear between the surface and the upper troposphere. Vertical wind shear is the change in wind speed with height.



Hurricane Structure

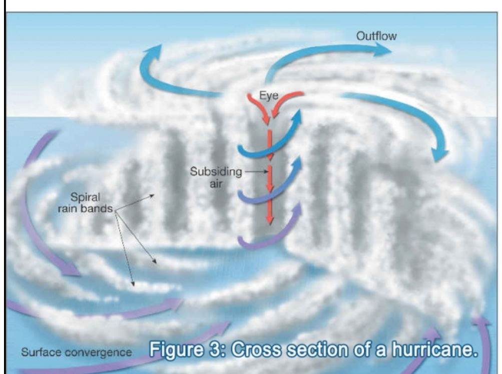
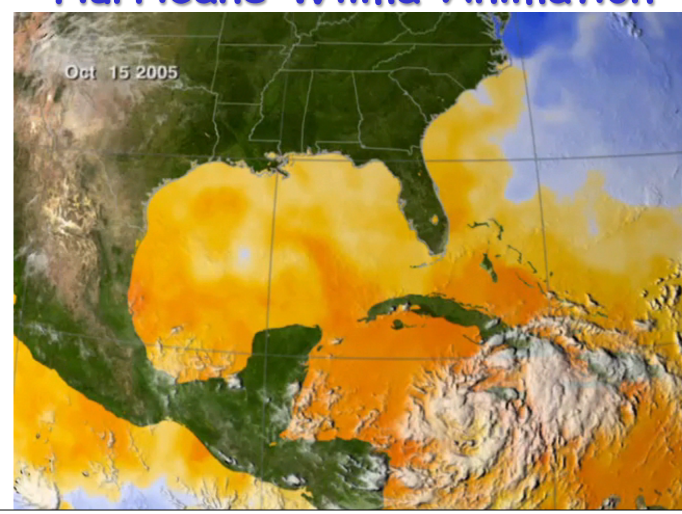


Figure 3: Cross section of a hurricane.

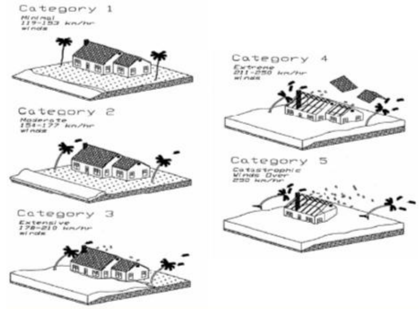
- "Warm Core" due to condensation
- Rotation
- Surface Friction
- Surface Convergence / Upper-level divergence

Hurricane Wilma Animation



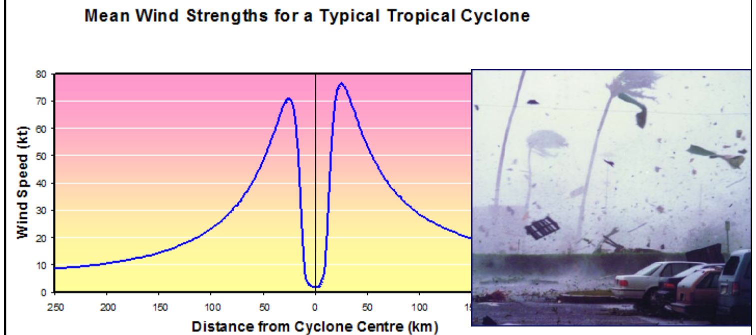
Tropical Cyclone Classification

Saffir-Simpson Hurricane Scale		
Category	Wind Speed	
	mph	knots
5	≥156	≥135
4	131-155	114-134
3	111-130	96-113
2	96-110	84-95
1	74-95	65-83
Non-Hurricane Classifications		
Tropical Storm	39-73	34-64
Tropical Depression	0-38	0-33



- Winds are damaging, but
- Most damage and death due to storm surge

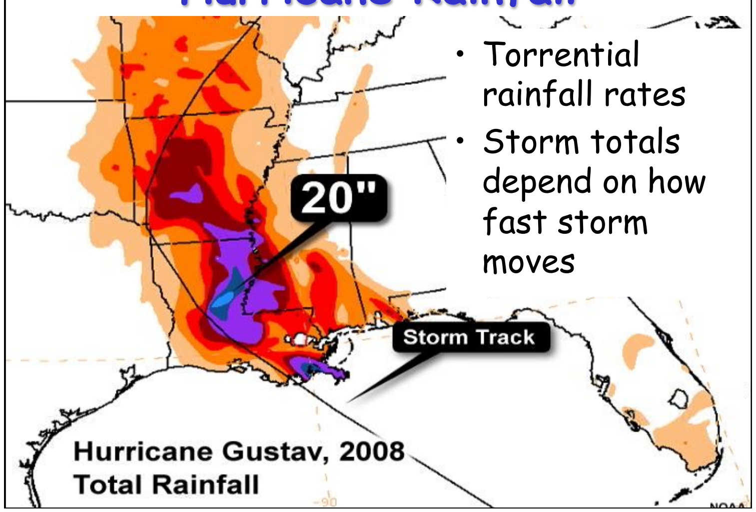
Hurricane Winds



Storms may be hundreds of miles wide, but damaging winds are pretty localized

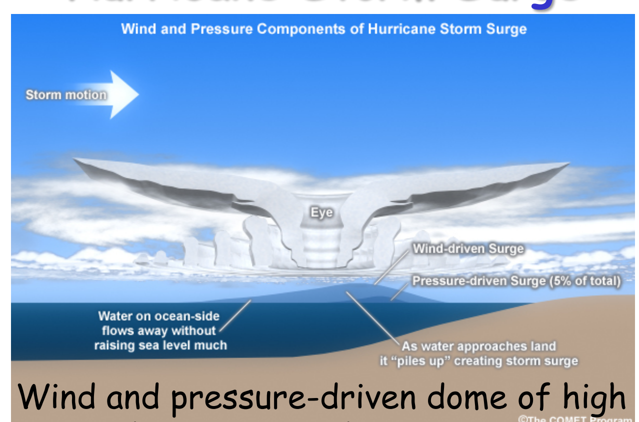
Worst damage on east side (in NH)

Hurricane Rainfall

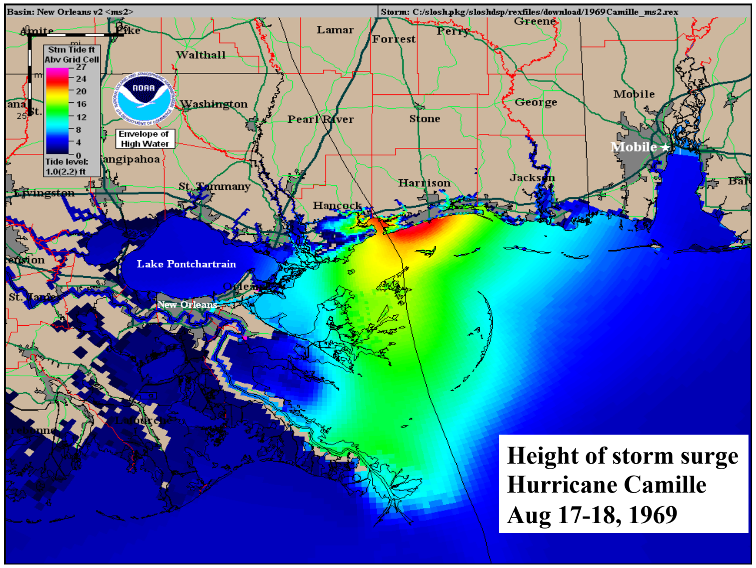


- Torrential rainfall rates
- Storm totals depend on how fast storm moves

Hurricane Storm Surge



- Wind and pressure-driven dome of high water that moves with storm
- Responsible for enormous damages



Height of storm surge
Hurricane Camille
Aug 17-18, 1969