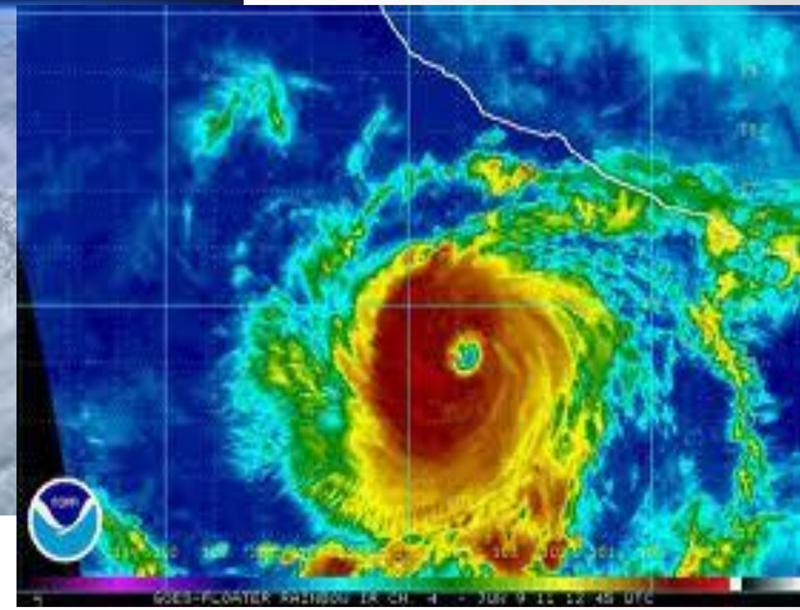


Inner core dynamics: Eyewall Replacement and hot towers

FIU Undergraduate Hurricane Internship

Lecture 4

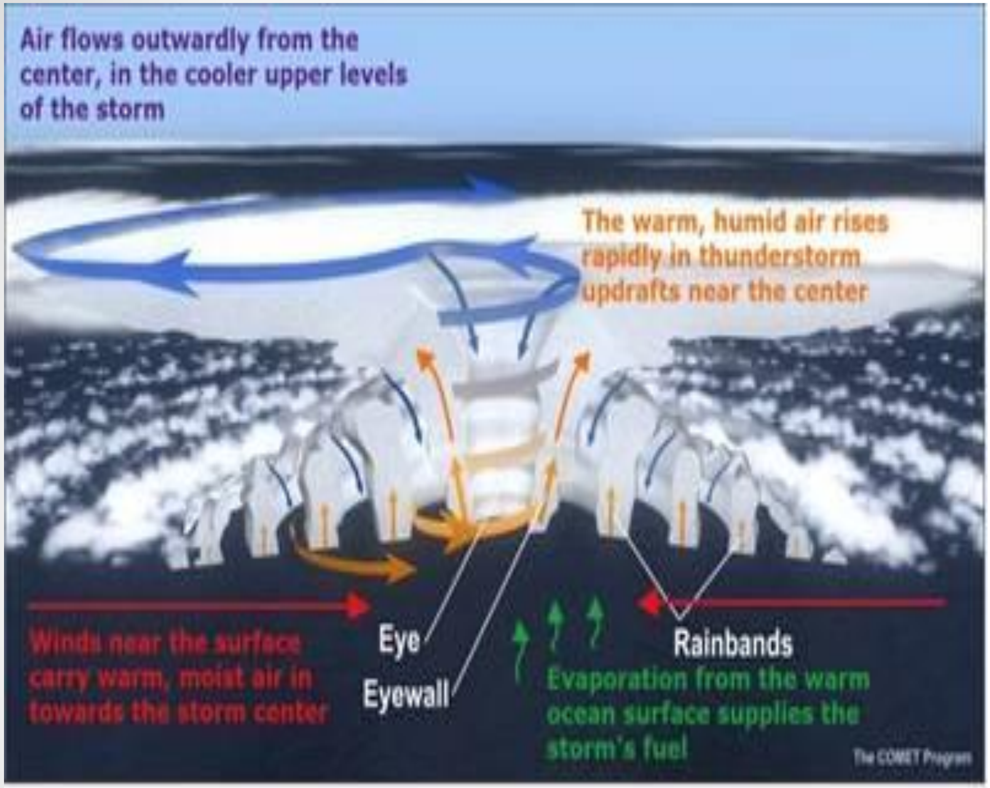
8/13/2012

Why inner core dynamics is important?

- Current TC intensity and structure forecasts contain large uncertainty, compared to the improvement of the forecasts of tracks in the past 20-30 years. *(DeMaria et al., 2005)*

- Both environmental (warm sea surface temperature, high low- to midlevel moisture, low vertical wind shear and so on) and storm internal processes are important for the prediction of the TC intensity.

Flows of Hurricane



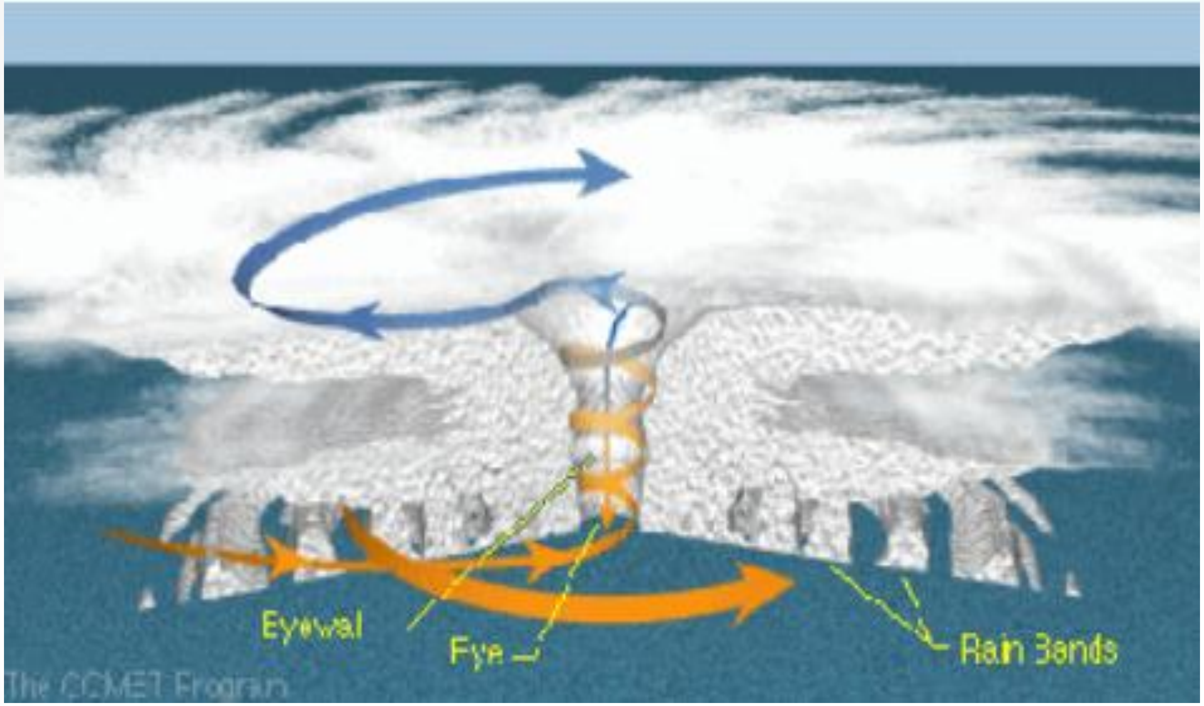
- Warm, moist air drawn into the hurricanes.
- Evaporation from sea water supplies energy to storms.
- Large amount of latent heat released with condensation of water vapor in the rising air.
- Allows rising air parcels to reach even higher levels.
- Pressure at the surface falls, and density of the air column decreases.
- Encourages an increase in the volume of warm, moist air entering the hurricane.

Kinds of heat

Latent heat: the heat released or absorbed by a chemical substance or a thermodynamic system during *a change of state that occurs without a change in temperature*, meaning a phase transition such as the melting of ice or the boiling of water.

Sensible heat: the energy exchanged by a thermodynamic system that has as its sole effect *a change of temperature*.

Structure of Hurricane



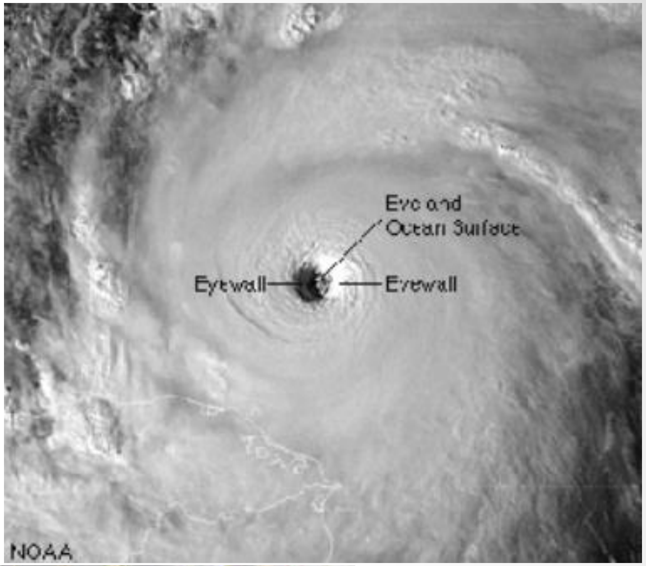
• Typically about 300 miles in diameter, however, the size can vary dramatically (from 300 to 1500 km).

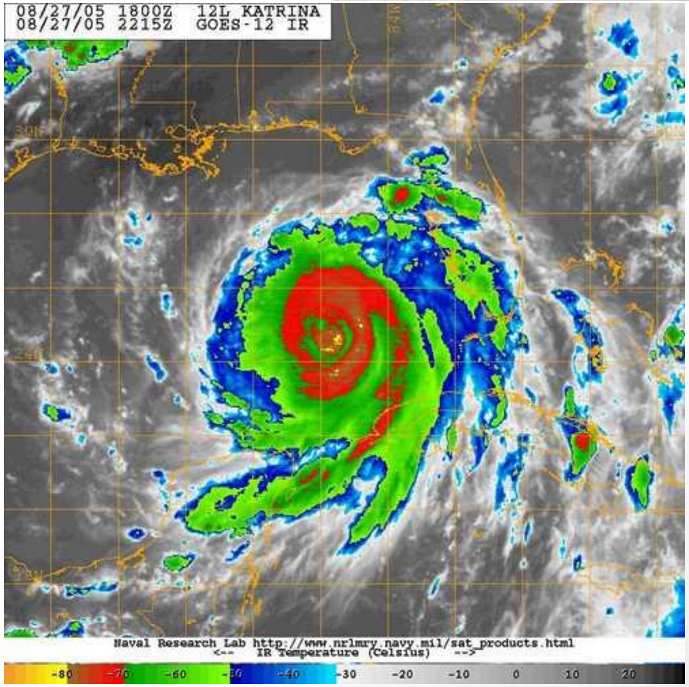
• The main parts of a hurricane are the rainbands on its outer edges, the eye, and the eyewall.

• Air spirals in toward the center in a counter-clockwise pattern, and out the top in the opposite direction.

Inner core: Eye

- Inner core includes eye and eye wall.
- A relatively calm, clear area.
- Usually 20-40 miles across.
- relatively warm
- light winds
- low surface pressure





Inner core: Eye wall

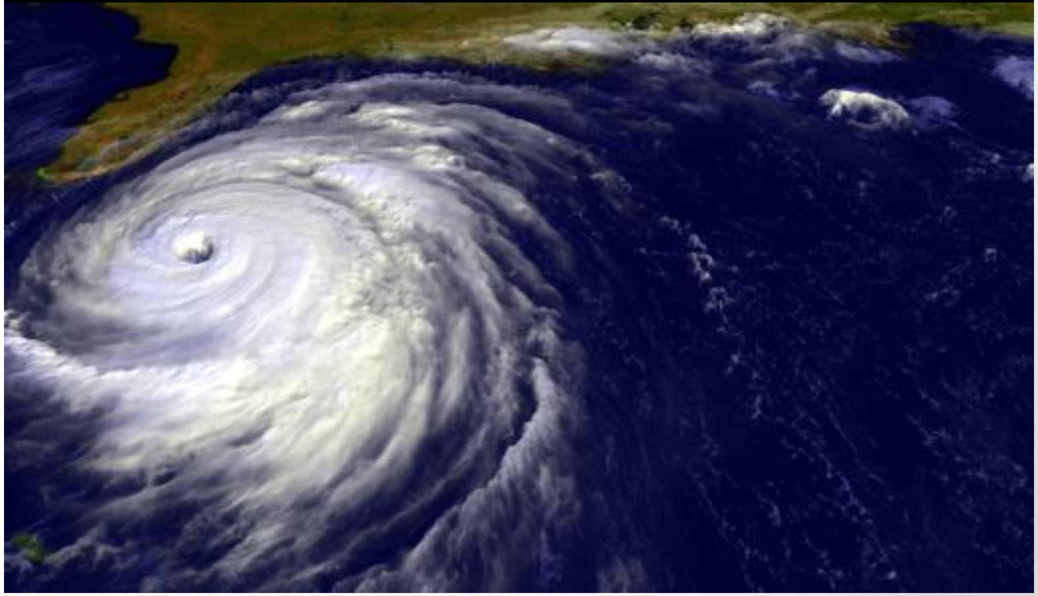
- Eye wall: Immediately outside of the eye is the eye wall region, an area of vigorous tall/deep clouds, heavy rainfall, and the strongest observed winds.
- The structure of the eye and eyewall can cause changes in the wind speed.
- The eye can grow or shrink in size, and double (concentric) eyewalls can form.
- Eye wall in VIS imagery: the eye wall is a bright white ring of clouds associated with tall convective thunderstorms immediately outside the eye.
- Eye wall in IR imagery: the eye wall region is a ring of the coldest cloud tops corresponding to the tops of deep convective cumulonimbus clouds.

Hurricane: Rainbands

- Rainbands are rings of clouds and thunderstorms that spiral out from the eye wall, first direct evidence of the system’s approach.

- They are responsible for most of the rain and tornadoes associated with a hurricane.

- They can extend a few hundred miles from the center.

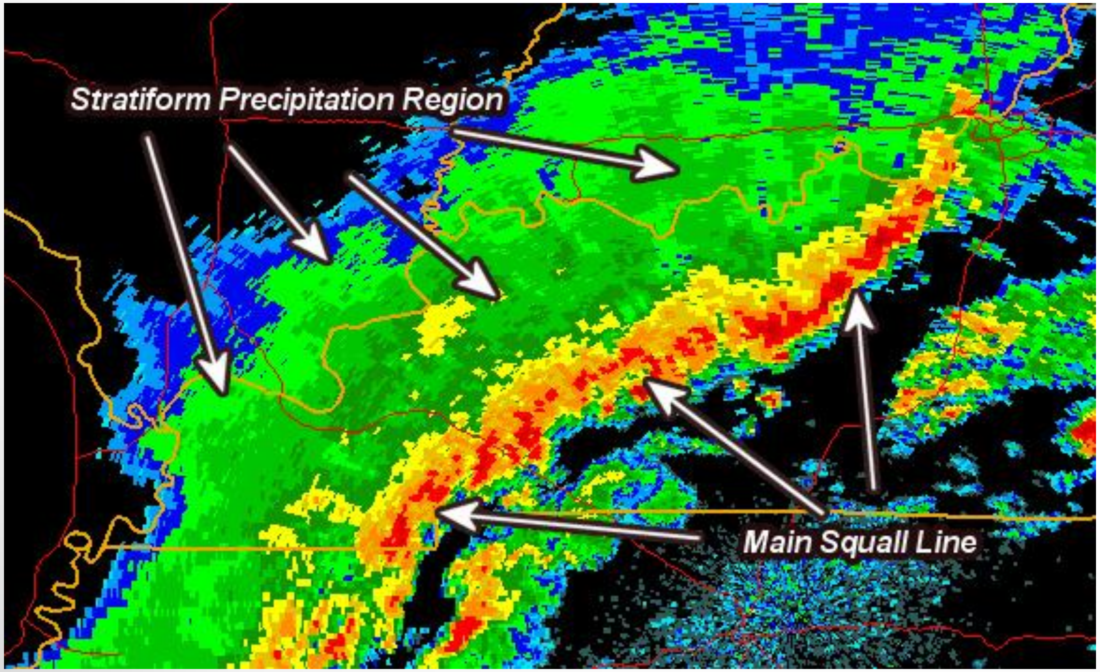


Hurricane Hazard

- The main hazards are storm surge, high winds, heavy rain, and flooding, as well as tornadoes.
- Storm surge is the greatest threat to life and property.
- Damaging winds begin well before the hurricane eye makes landfall.
- A typical hurricane brings at least 6 to 12 inches of rainfall.
- As a hurricane moves shoreward, tornadoes often develop.

Precipitation in tropical cyclones

- Two types of precipitation: convective and stratiform.
- Distinguishing between convective and stratiform precipitation is important.
  - **-** different precipitation growth mechanisms
  - - different vertical distribution of diabetic heating processes



Physical Differences

• Convective precipitation: Vertical velocity ≥ the typical fall speeds of ice crystals or snow.

- Grow primarily by accretion of liquid water
- Characterized by a strong radar echo ***(Steiner et al. 1995).***

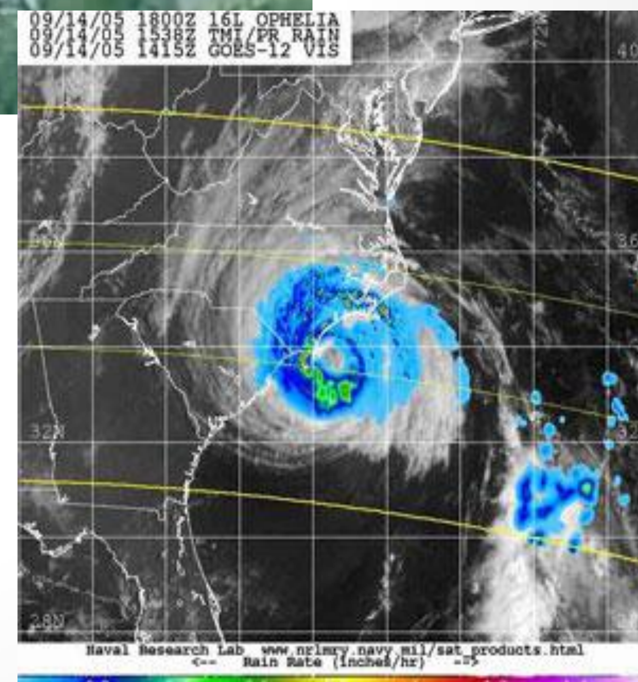
• Stratiform: Vertical velocity < the terminal fall velocity of snow particles

- Ice particles cannot be suspended or carried aloft by the air motion
- Characterized by a bright band just below the 0^oC level

Precipitation in tropical cyclones

- Jorgensen found that over 90% of the rain areas in tropical cyclones were stratiform in type

- However, the convective rainfall contributes about 40% of the total storm precipitation



Forecast of TC's intensity

- Inner core (eye and eyewall) dynamics
- Environmental conditions, including vertical wind shear, moisture distribution, and sea surface temperature (upper ocean heat content), etc.

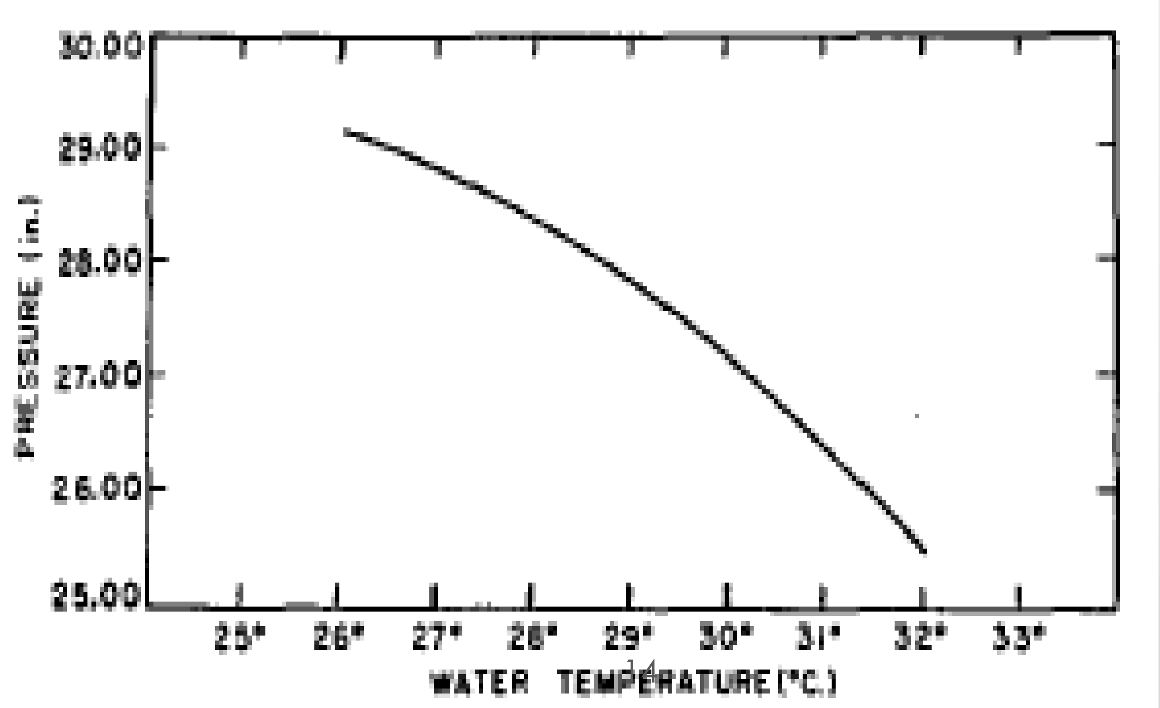
Maximum potential intensity (MPI)

- The maximum potential intensity (MPI) is the theoretical upper limit of intensity that a TC can achieve.

- MPI=f $\{(C_k/C_D), \varepsilon, SST, RH\}$

- $\varepsilon = (T_B - T_o)/T_B$ (thermodynamic efficiency)

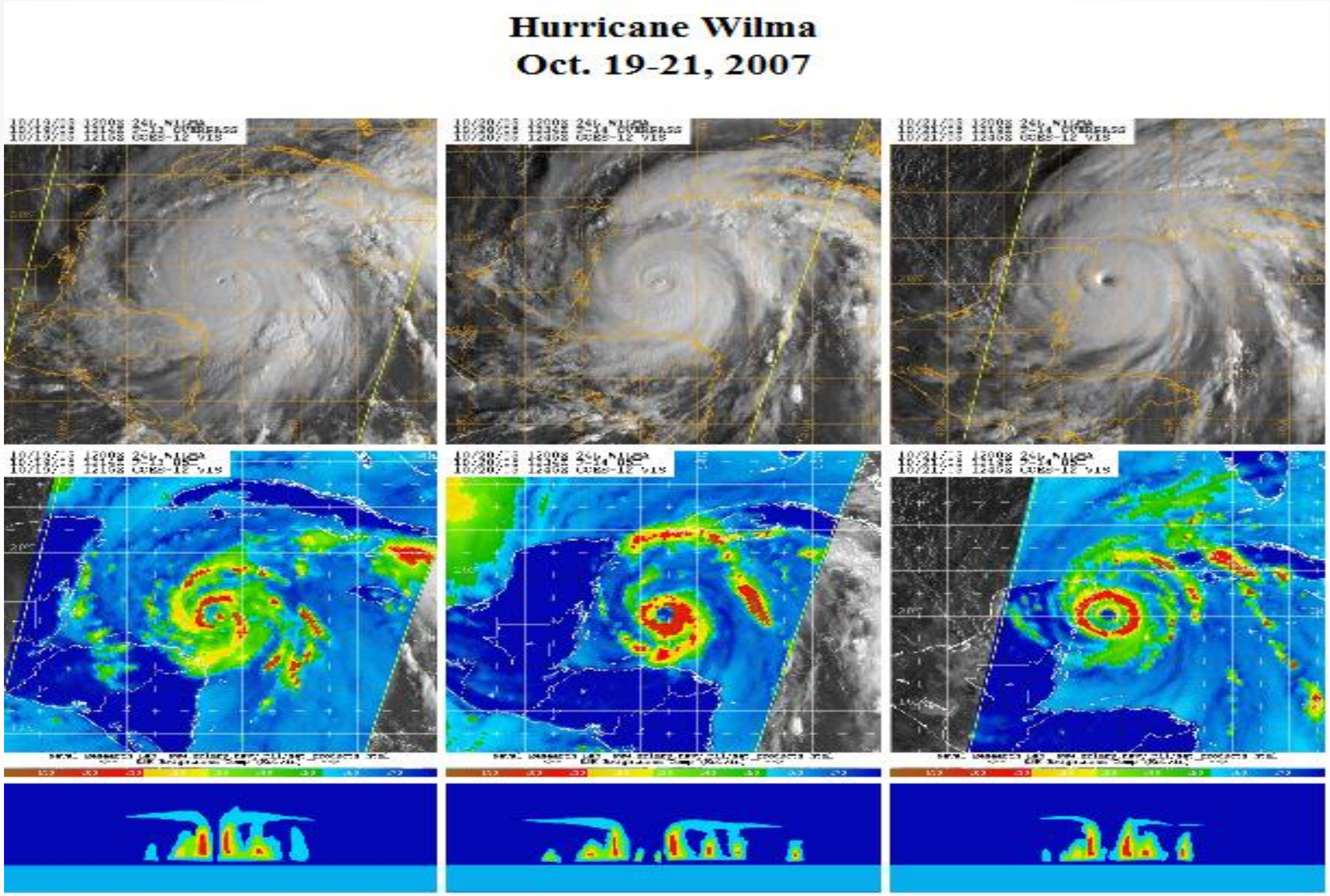
- C_k and C_D are exchange coefficients of enthalpy and momentum fluxes



Researches on MPI

- Banner Miller *(1958)* first proposed the concept of MPI, lower the SST and the amount of energy available to the storm drops.
- Emanuel *(1986, 1988)* envisioned the intensity of TC is due to the difference in the surface temperature and the temperature at the "outflow" level of the atmosphere.
- Miller's MPI also relies on the existence of Convective Available Potential Energy (CAPE) in the tropical atmosphere.
- On average, storms reach about 55% of their MPI. Storms that are farther west and farther north tend to reach a larger fraction of their MPI. *(Mark Demaria and John Kaplan, 1994)*

Definition of ERCs

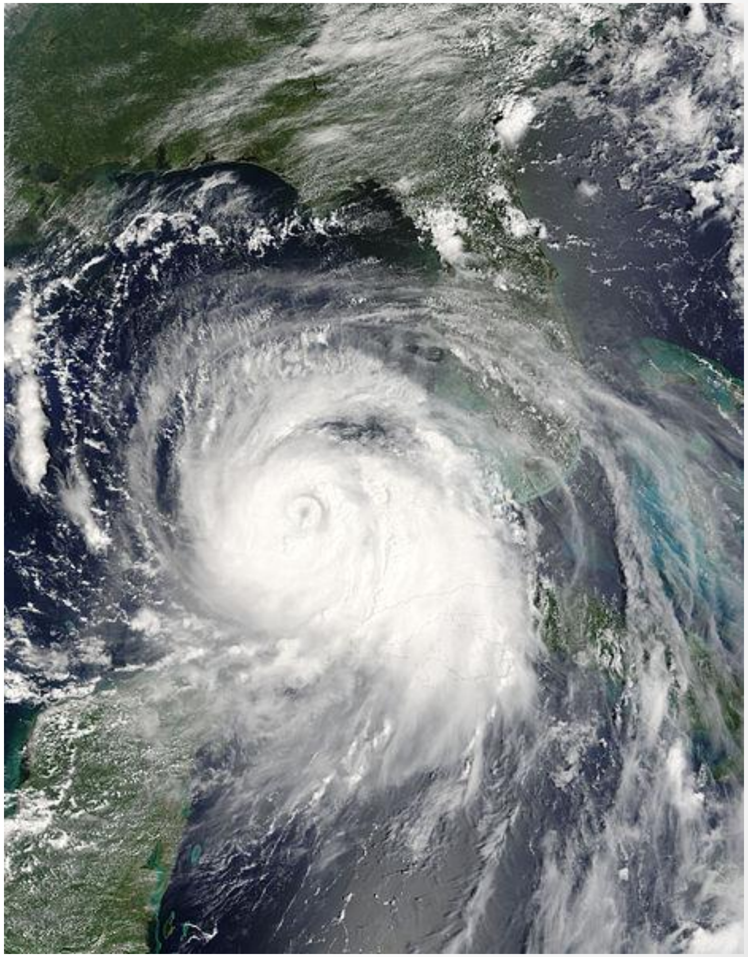


• **A full cycle of eyewall replacement includes the genesis of a secondary eyewall, the dissipation of the inner eyewall, and the organization of the new eyewall.** ***(Willoughby et al.1982)***

Eyewall Replacement Cycles (ERCs)

- A video of concentric eyewall cycles

  http://www.youtube.com/watch?v=LIRLn2CZQwA



Eyewall Replacement Cycles (ERCs)

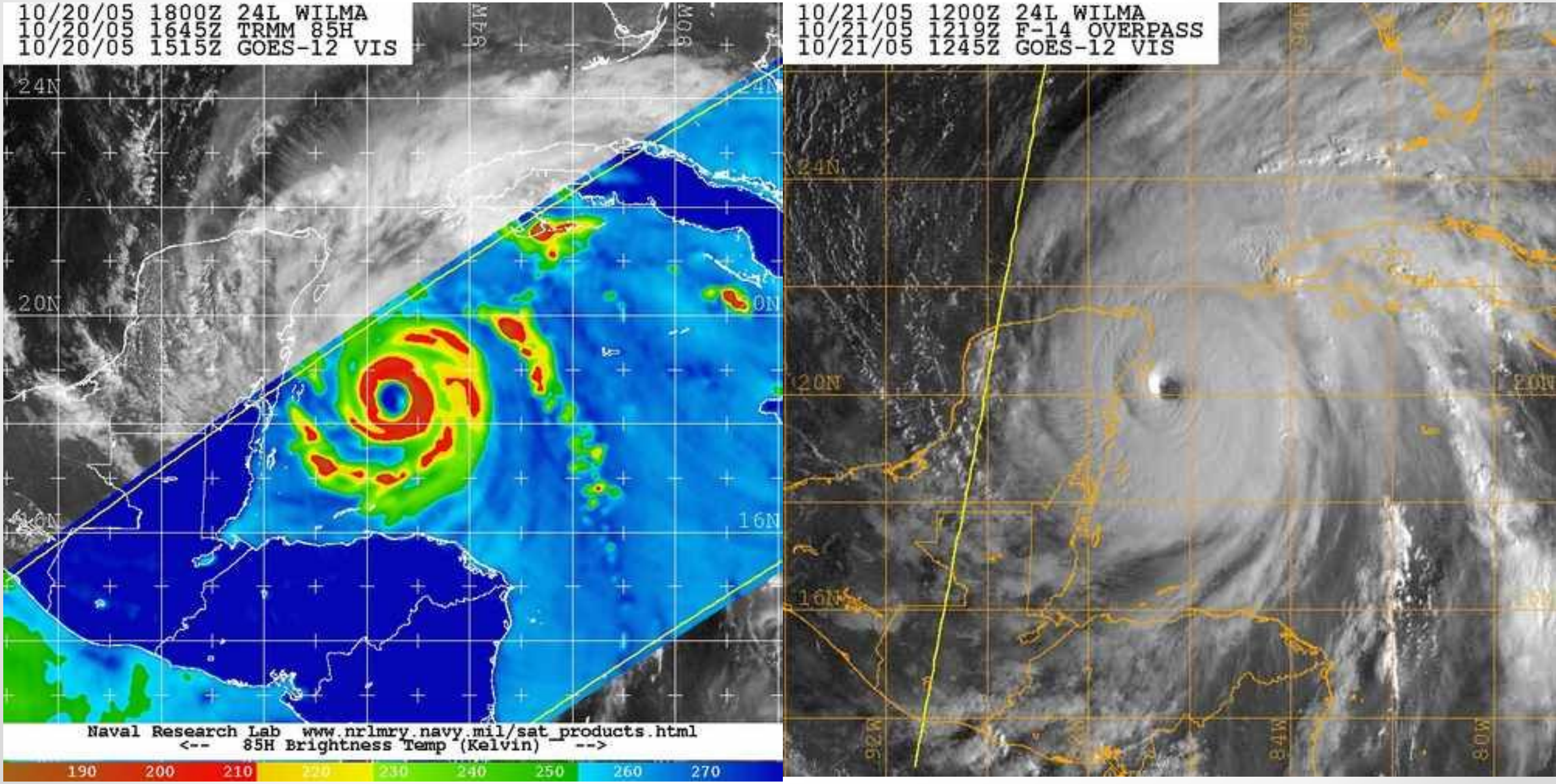
Usually, at what kinds of TC intensify can you find the Eyewall replacement cycles?

Intense tropical cyclones (> 185 km/h), or major hurricanes.

- The eyewall contracts or is small
- Outer rainbands strengthen, thunderstorms form
- An outer eyewall moves inward and robs the inner eyewall
- Leading the tropical cyclone weakens
- The outer eyewall replaces the inner one completely
- The storm can re-intensify

Observation of ERCs

- Two concentric rings of enhanced convection



Formation of ERCs

- When the eye diameter gets too small then the eyewall convection is not able to stay organized. New convection and a new eyewall develop outside the old one.

- Once the winds become too strong, turbulent breakdown occurs. This turbulence breaks apart portions of the eyewall which lead to its weakening. A new eyewall develops where the wind field remains less turbulent and more organized outside the old eyewall.

- The band of convection outside the inner eyewall begins to rob the inner eyewall of moisture and energy. The inner eyewall weakens and the outer eyewall replaces it.

ERCs with TC intensity

- The storm often weakens as a result of the gradual erosion of the inner eyewall, but it may reintensify when the outer eyewall contracts and gains organization. *(Willoughby et al. 1982)*

- Willoughby (1995) found that the time required for a cycle of weakening and reintensifying can range from a few hours to more than a day.

- TC intensity changes associated with concentric eyewall cycles vary considerably from case to case. About 28% of TCs actually intensify after the secondary eyewall formation. *(Kuo et al. 2009)*

Rapid Intensification (RI)

- Rapid intensification (RI) is the explosive deepening of a tropical cyclone.

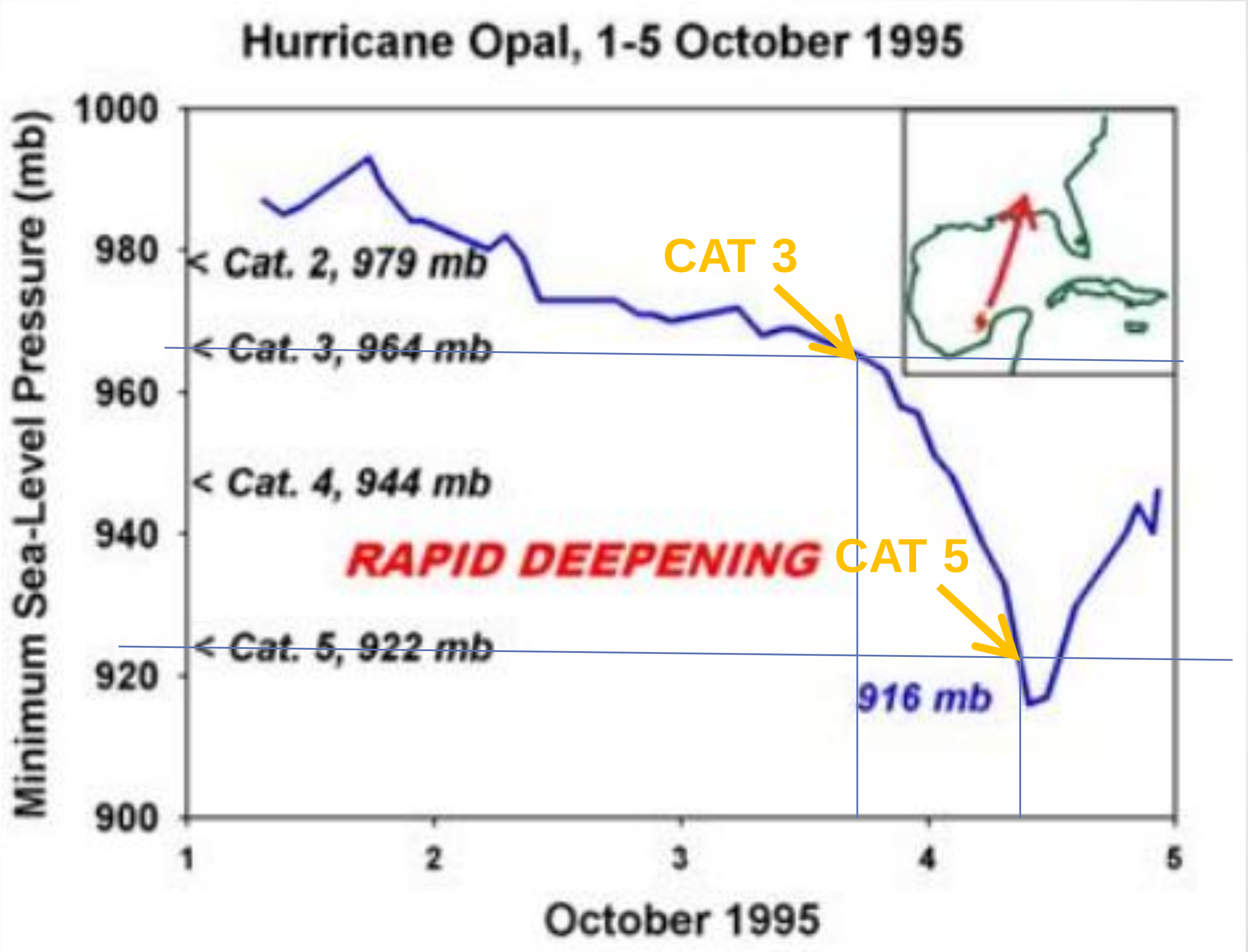
- Kaplan and DeMaria *(2003)* define RI as a maximum sustained surface wind speed increase of 15.4 m/s (30 kt) over a 24-hour period.

- All category 4 and 5 hurricanes, 83% of all major hurricanes (category 3, 4, 5), 60% of all hurricanes, and 31% of all tropical cyclones experienced at least one RI period during their lifetime.

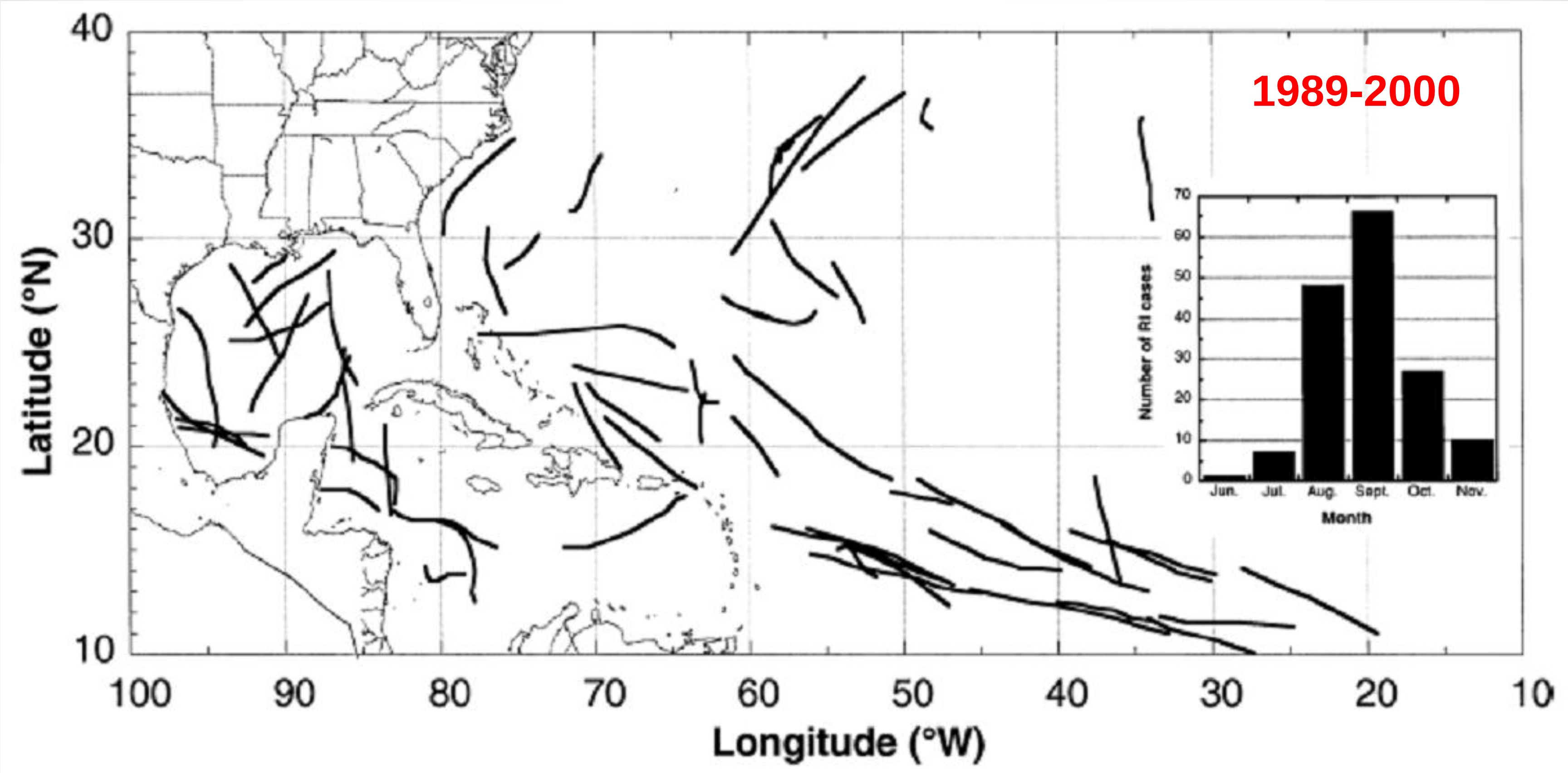
Rapid Intensification (RI)

- Rapid deepening causes most major hurricanes

- Time-scale is so short that adequate warnings are difficult



Kaplan et al. (2003) research on RI



- Most occur south of 30°N
- Lack in the eastern Gulf of Mexico and eastern Caribbean
- About 72% of all cases in August and September
- RI cases in the late season (Oct & Nov) is much more than in the early (June and July)

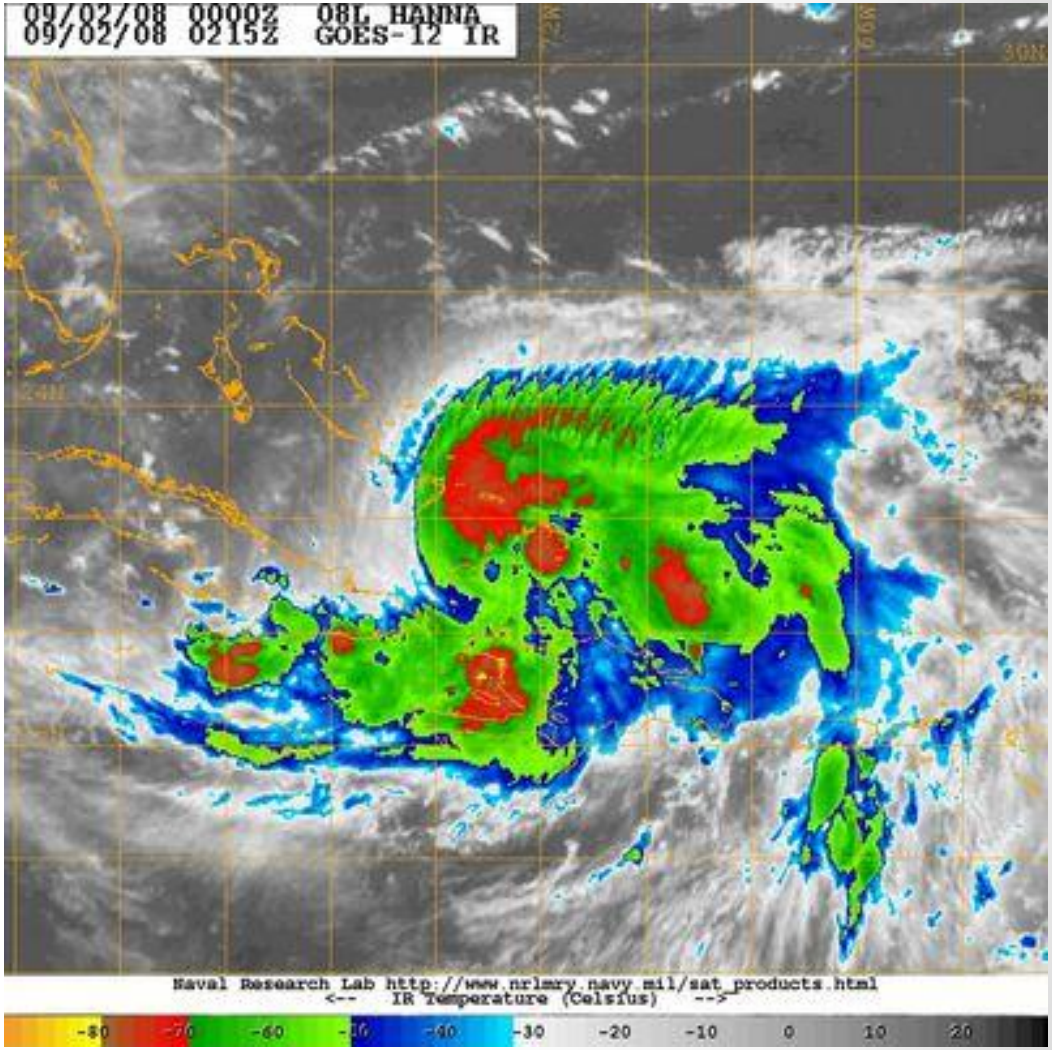
Forecast of RI

RI probability can be estimated through the analysis of five predictors:

- previous 12-hour intensity change (already deepening storms more likely),
- SST (higher more likely),
- low-level relative humidity (higher more likely),
- vertical shear (lower is better),
- difference between current intensity and MPI (larger is better).

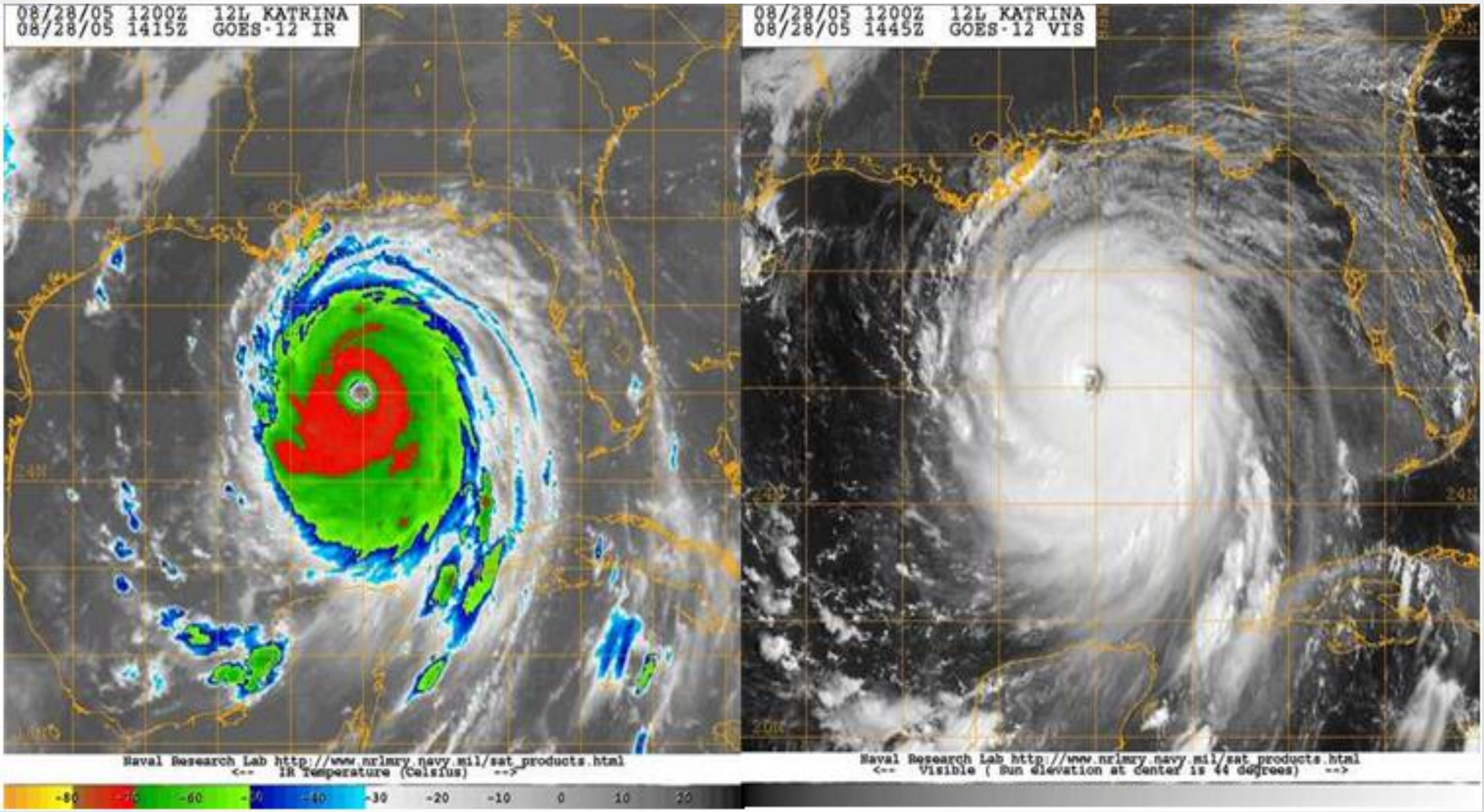
Definition of convective bursts

“A mesoscale cloud system consisting of a cluster of high cumulonimbus towers within the inner core region that approaches or reaches the tropopause with nearly undiluted cores.” ***(Rodgers et al. 2000)***

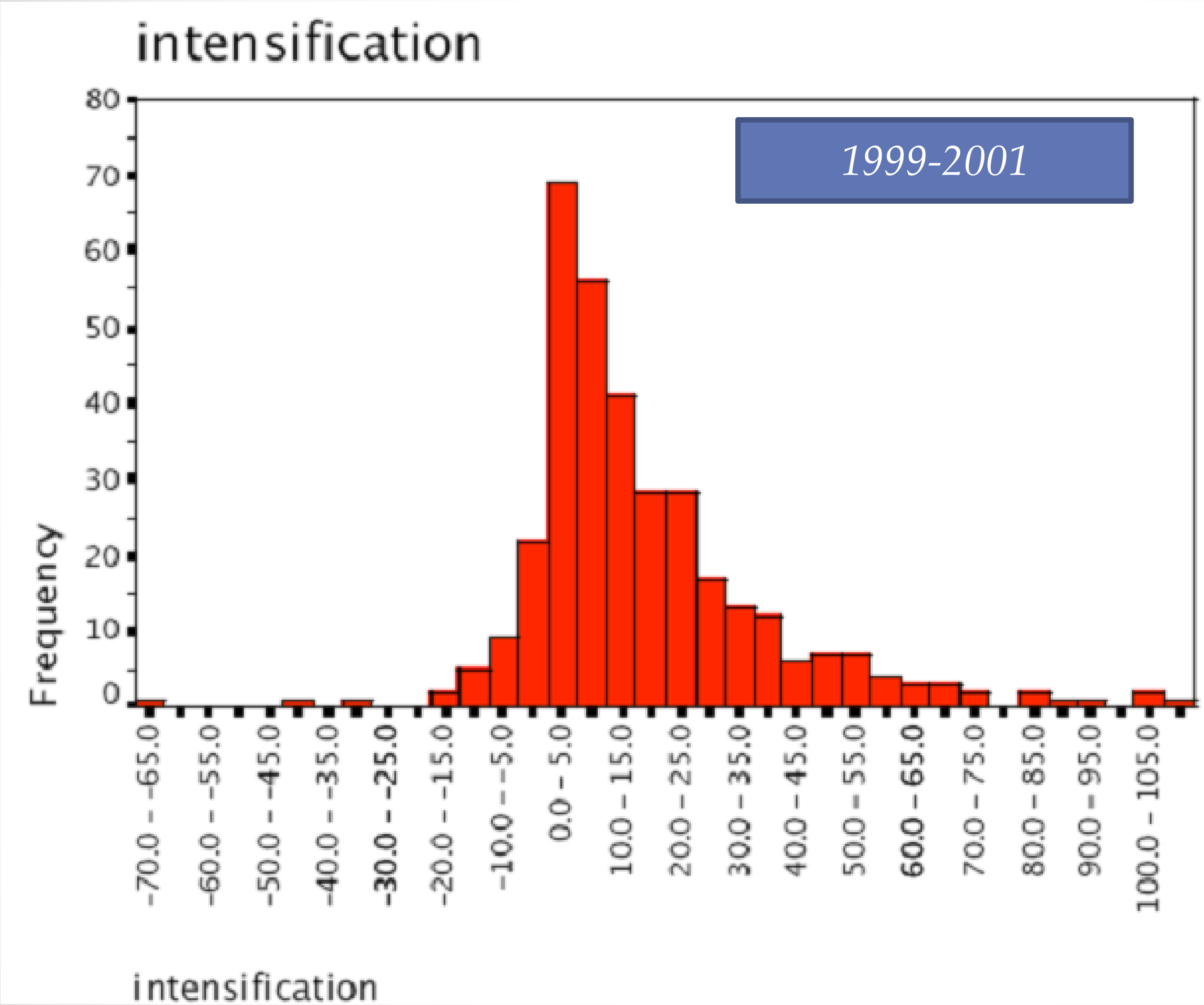


Observation of convective bursts

- They appear as large, circular, continuous areas of extremely cold cloud tops.



Convective bursts and TC intensity



- Common events, 80% of storms experiencing at least one burst during their lifetime.
- When a burst does occur, the TC will intensify 70% of the time. *(Hennon, 2006)*

Hot towers/ Deep convective bursts

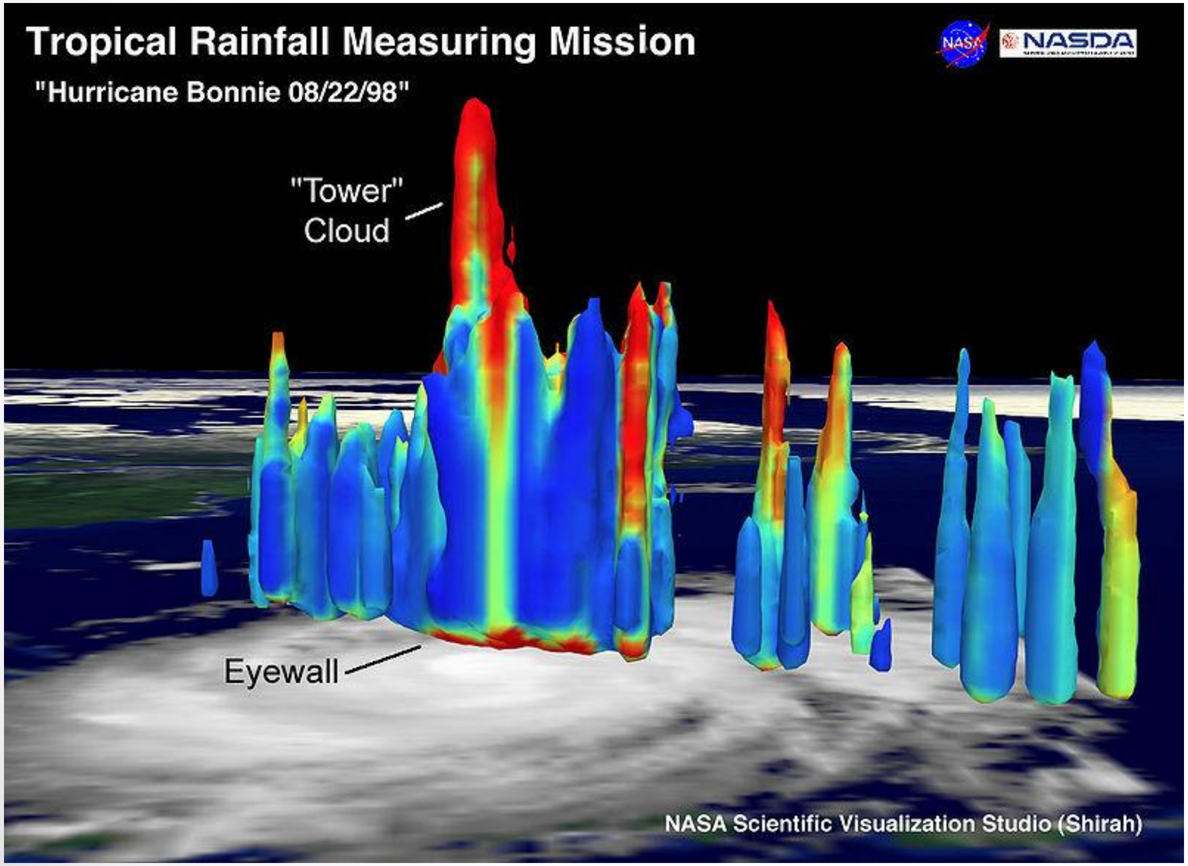
- Video http://www.youtube.com/watch?v=OQsKusqMdUU

- Consider the following while watching video:

- What is the hot tower
- Where you can find hot towers in hurricanes
- What is the role of hot towers in hurricanes
- What causes the hot tower

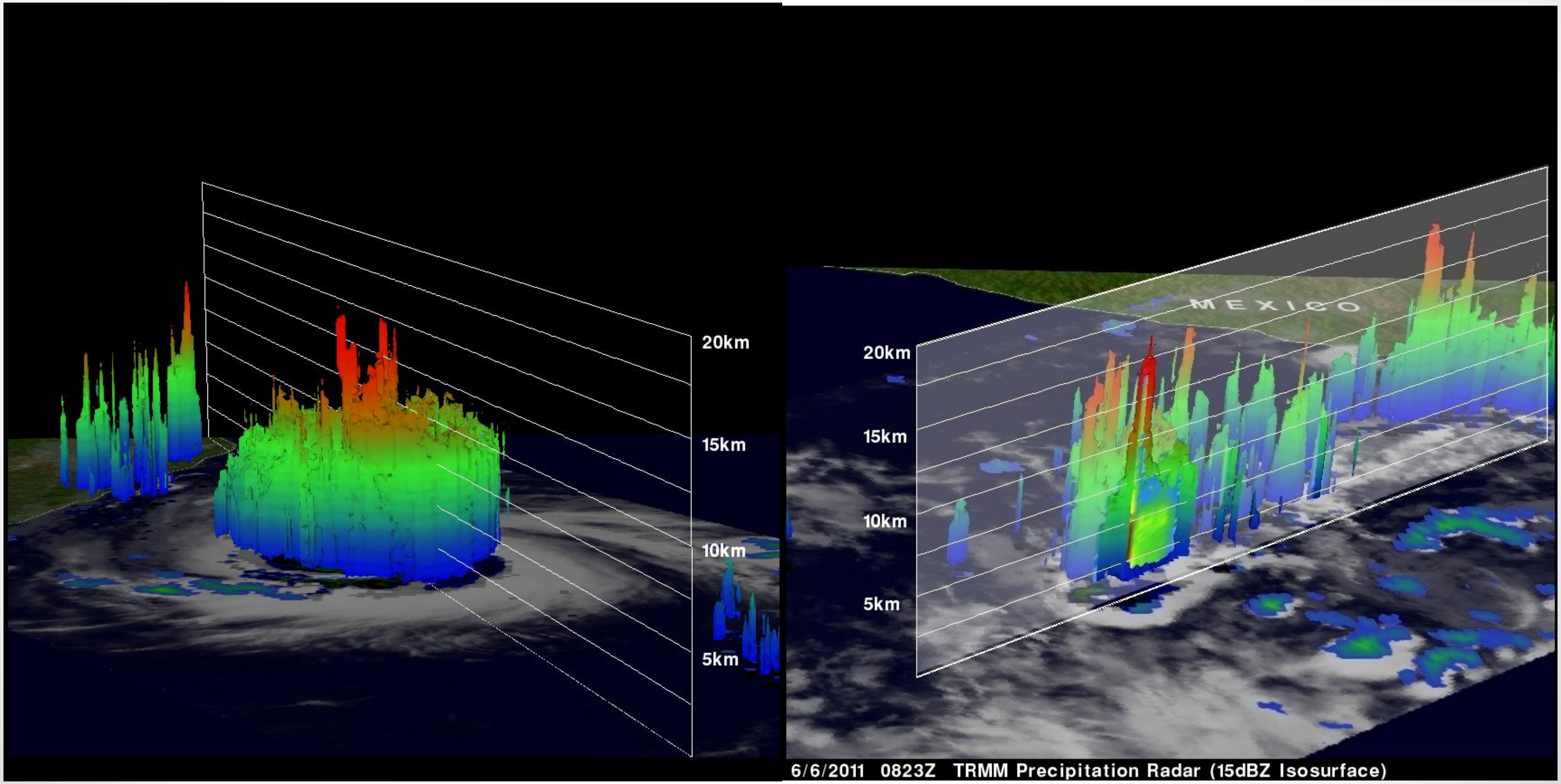
Definition of hot towers

- A hot tower is a tropical cumulonimbus cloud that penetrates the tropopause, i.e. it reaches out of the lowest layer of the atmosphere, the troposphere, into the stratosphere.



Observation of hot towers

- Up to now, TRMM's Precipitation Radar (PR) is one of the best instruments to observe hot towers.



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