Inner core dynamics: Eyewall Replacement and Hot tower

FIU Undergraduate Hurricane Internship

Lecture 5

8/15/2011

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Outlines

- Three main features of hurricanes
- Maximum potential intensity (MPI)
- Eyewall replacement cycle (ERC)
- Rapid intensification (RI)
- Convective bursts
- Hot towers

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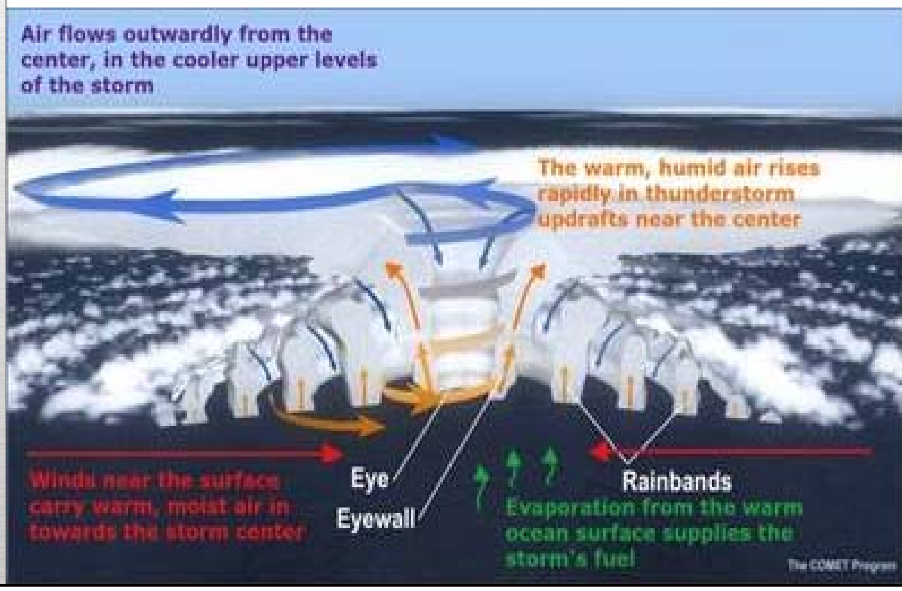
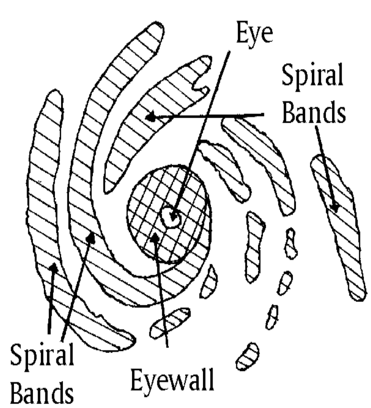
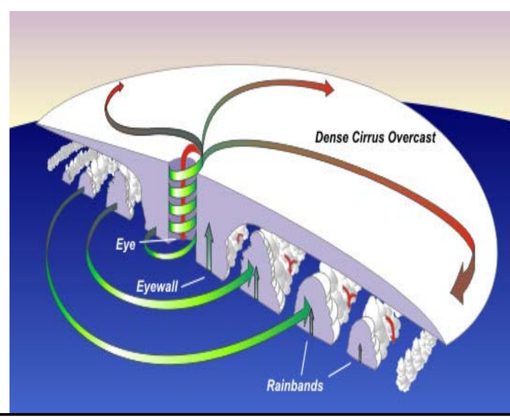
Structure of Hurricane



Three main features of Hurricane

- Typically about 300 miles in diameter.
- A hurricane is an extremely complicated structure comprised of three main features: outer rainbands, an eyewall and the eye.

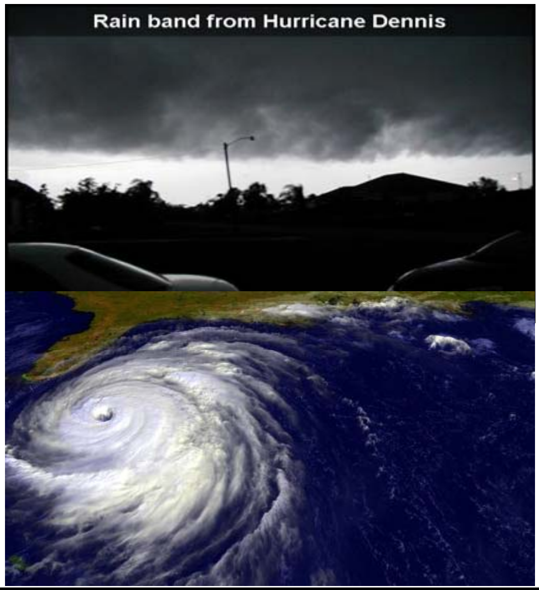




Hurricane: Rainbands

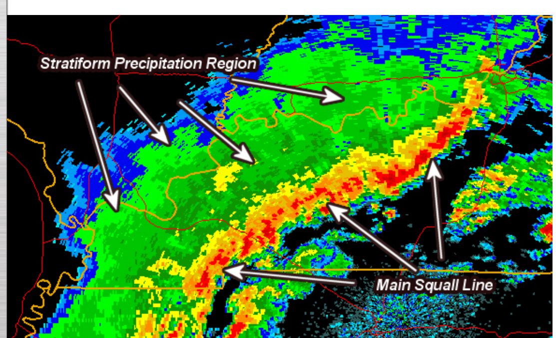
- Rainbands are rings of thunderstorms that spiral in towards the eye.

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



Convective VS. Stratiform

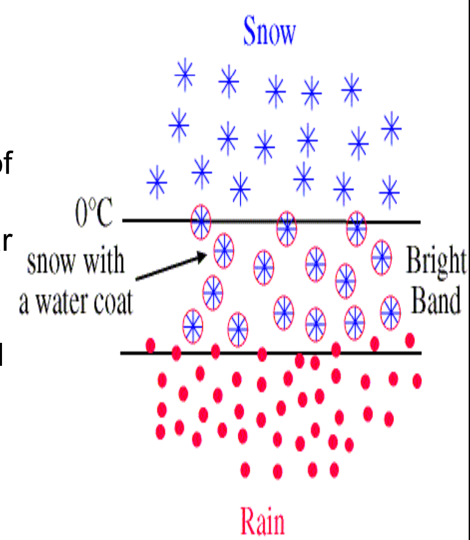
- Distinguishing between convective and stratiform precipitation is important.
  - different precipitation growth mechanisms
  - different vertical distribution of diabatic heating processes



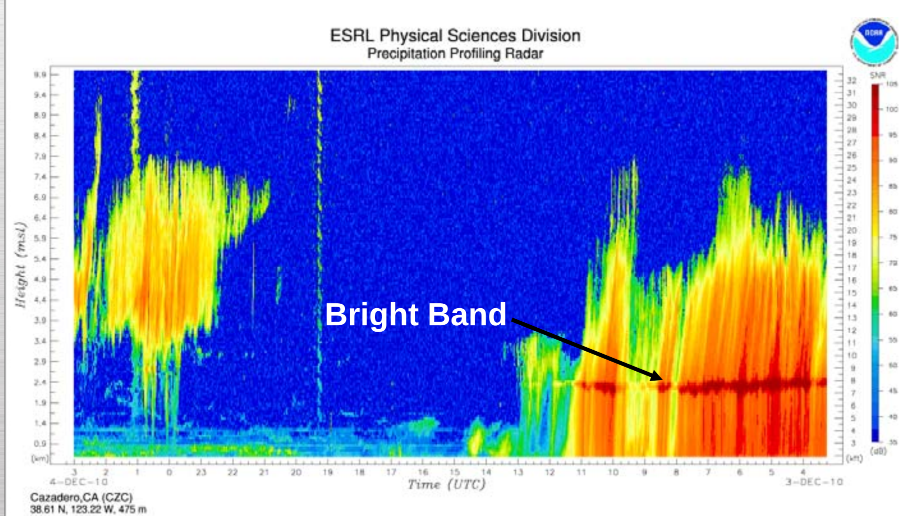
Physical Differences

• Convective :
- Vertical velocity ≥ the typical fall speeds of ice crystals or snow.
- Grow primarily by accretion of liquid water, and are characterized by a strong radar echo **(Steiner et al. 1995).**

• Stratiform:
-Vertical velocity < the terminal fall velocity of snow particles
-When the large snowflakes melt, a bright band just below the 0°C level can be detected.



Bright band



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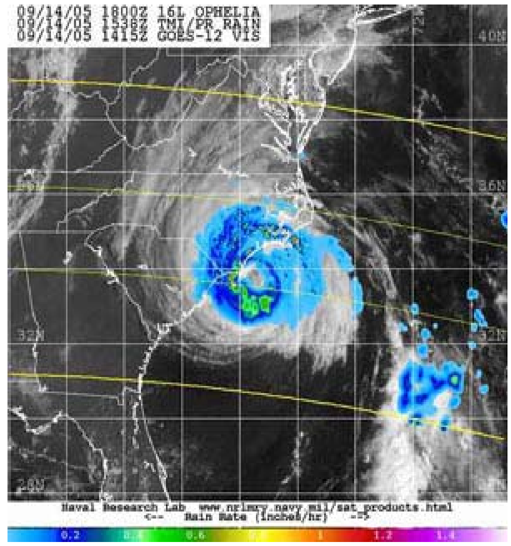
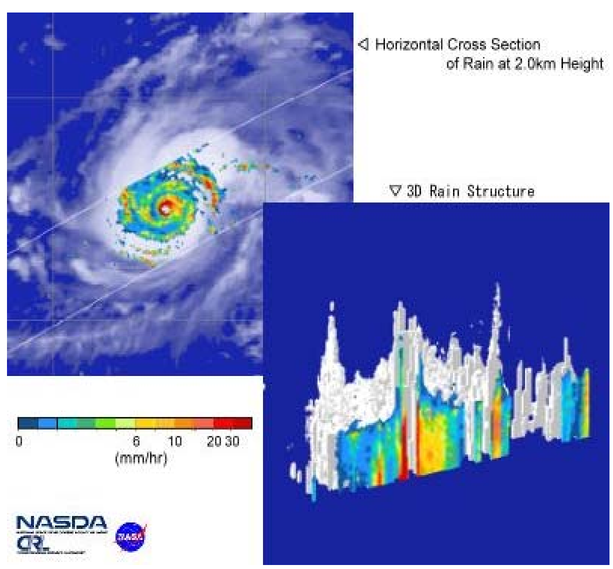
Precipitation in TC

- 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



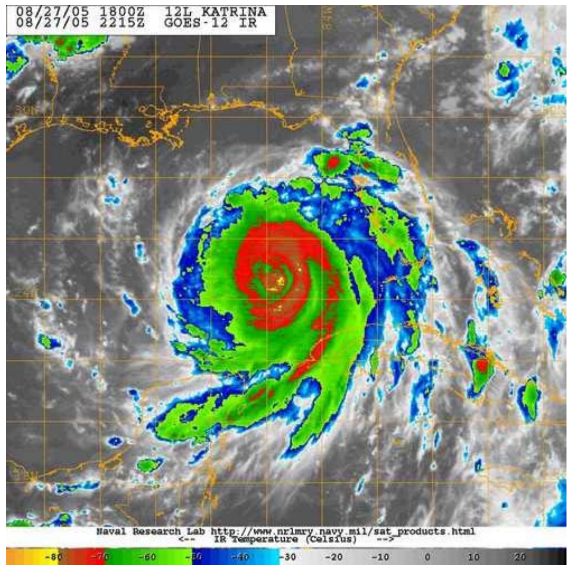
Hurricane: Eyewall

- **A ring of intense convection surrounding the center**
- Strongest wind speeds
- Heaviest precipitation occur



Hurricane: Eye

- 30-60 km in diameter
- relatively warm
- light winds
- clear/broken clouds
- low surface pressure



Factors controlling intensity change

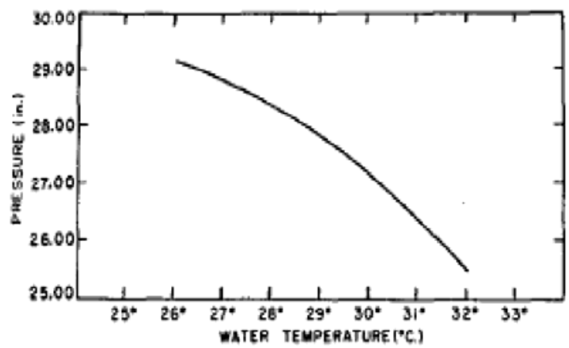
- Inner core (eye and eyewall) dynamics
- Environmental conditions, including vertical wind shear, moisture distribution, and sea surface temperature (upper ocean heat content), etc.

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), ε, 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)*

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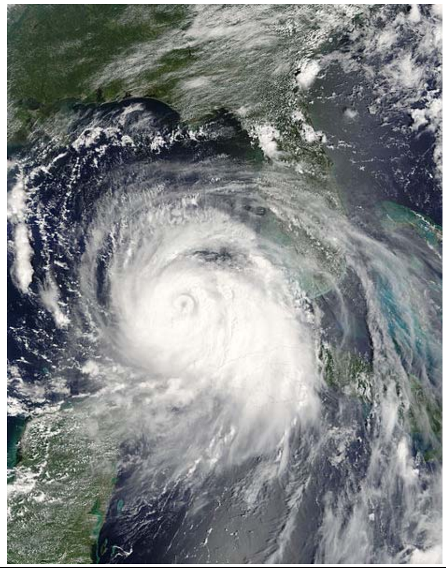
Eyewall Replacement Cycles (ERCs)

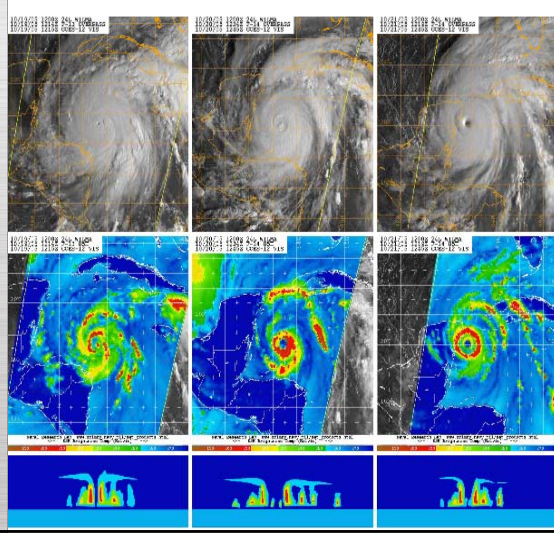
- A video of concentric eyewall cycles

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



Definition of ERCs

Hurricane Wilma
Oct. 19-21, 2007



- **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)***

- **Very common in intense tropical cyclones**

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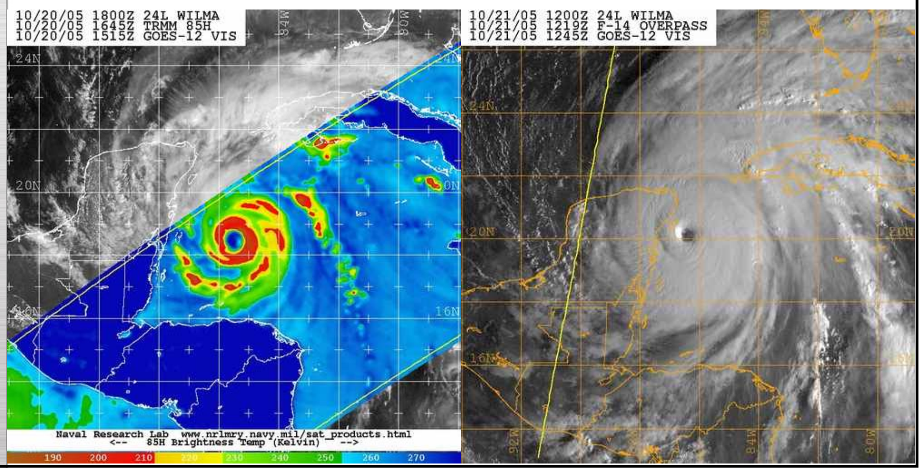
Observation of ERCs

• 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. 18

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)*
- 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)*
- 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.

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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.

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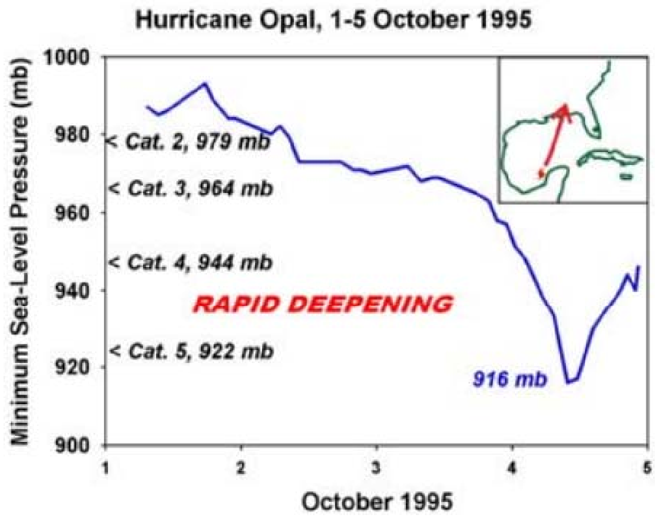
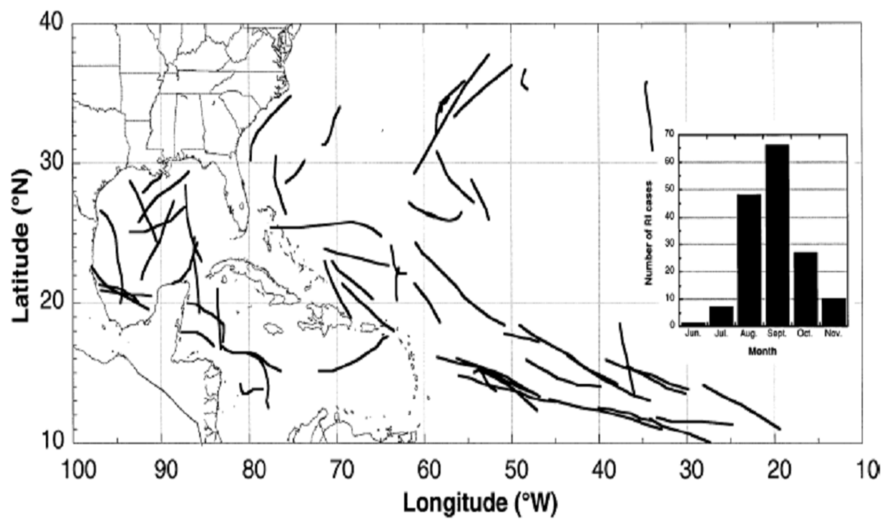
Forecast of RI is very important, but ...

- Rapid deepening causes most major hurricanes
- Time-scale is so short that adequate warnings are difficult



Kaplan et al. (2003) reseach on RI



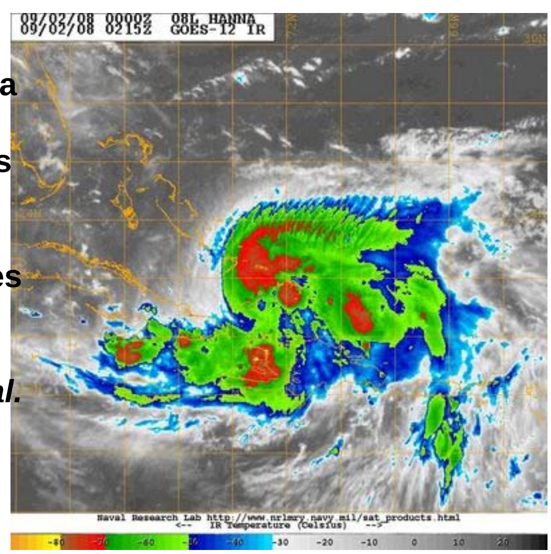
Forecast of RI

- 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).

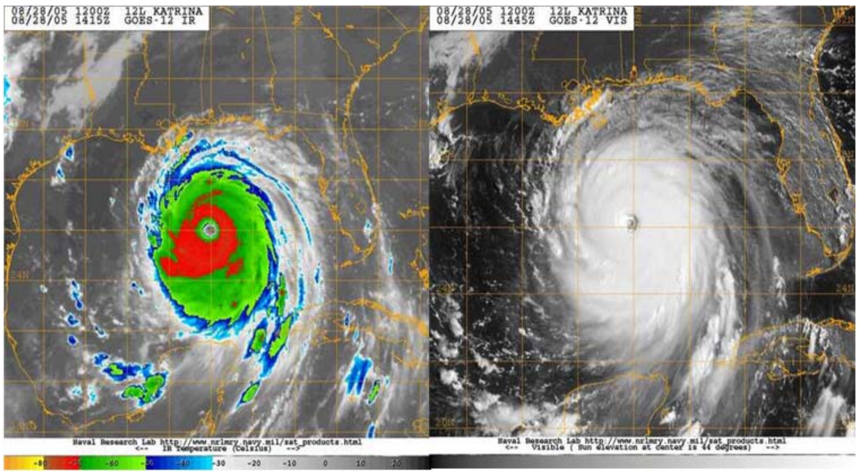
Definition of convective bursts

"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)***



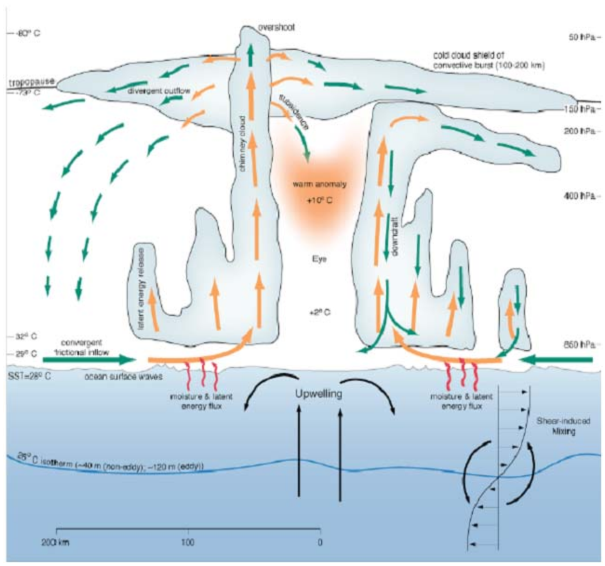
Observation of convective bursts

- They appear as large, circular, continuous areas of extremely cold (-80° C to -100° C) cloud tops.

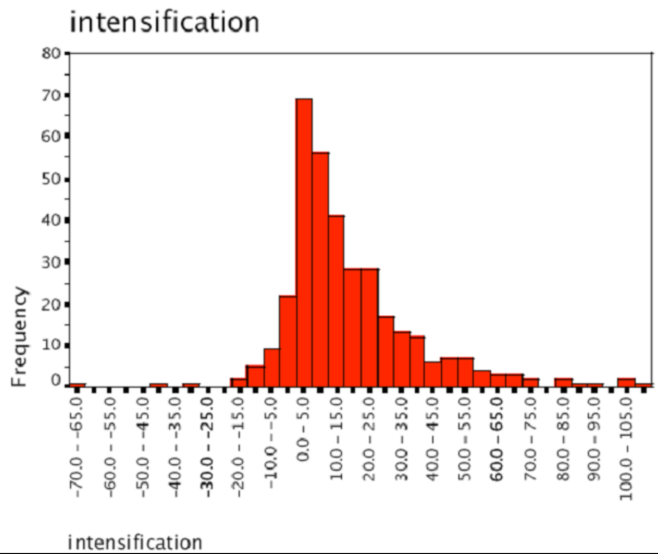


Vertical structure of convective bursts

- **Rapidly transfers latent and sensible heat into the upper troposphere.**
- **Enhances the warm-core anomaly aloft, accelerating upper-level divergence and spawning surface pressure falls.**



Convective bursts and TC intensity



• When a burst does occur, the TC will subsequently intensify 70% of the time. *(Hennon, 2006)*

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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

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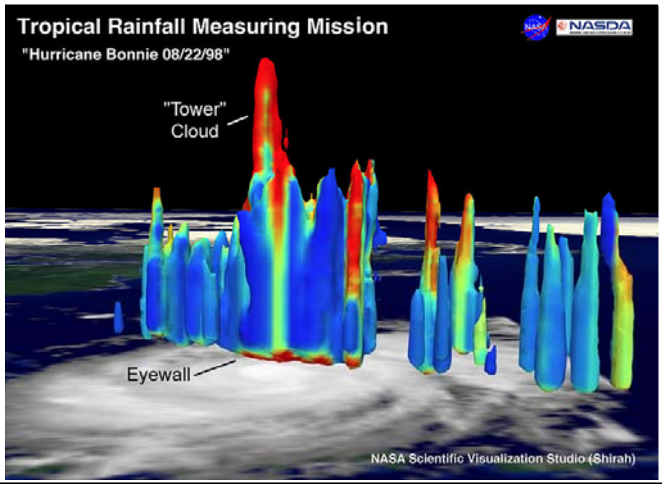
Definition of hot towers

• 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.



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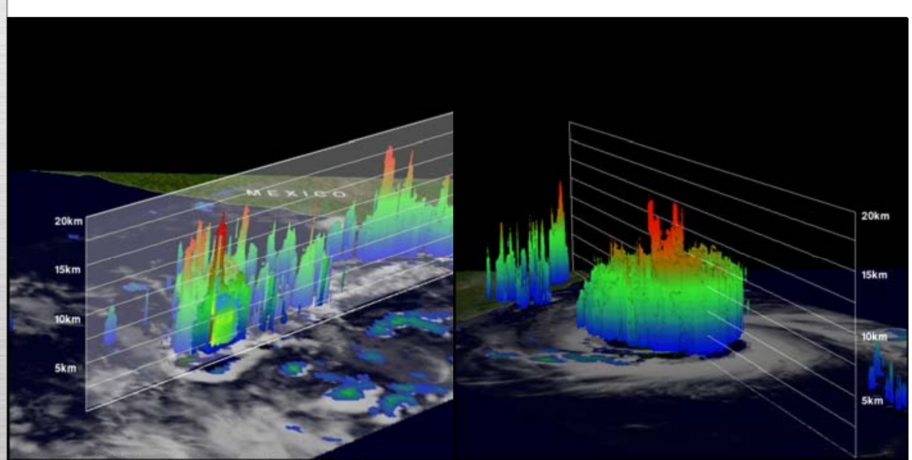
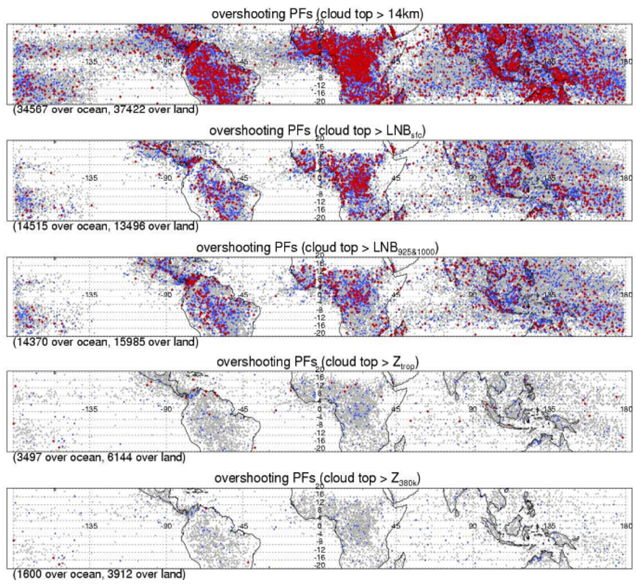
Observation of hot towers

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

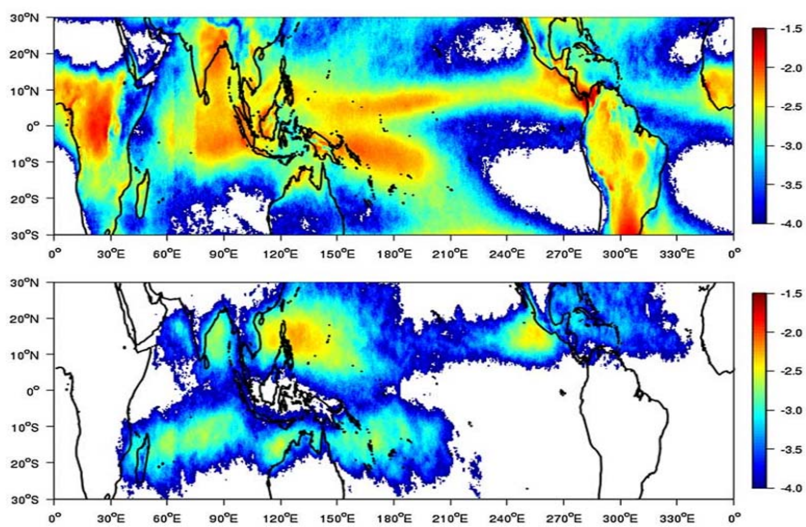


Global distribution of Hot tower

- Five different reference heights are used to identify hot towers
- Overshooting convection is more frequent over land than over water *(Liu et al. 2005)*



Hot towers in Tropical Cyclone



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Hot towers on TC intensity change

- Hot towers (Simpson et al. 1998) and convecitve bursts (Steranka et al. 1986) near the storm center were found to be related to TC intensitification.
- Kelley et al. (2004, 2005) found that the chance of TC intensification increases when one or more hot towers exist in the eyewall.
- Rogers (2010) and Guimond et al. (2010) also emphasize the importance of hot towers and convective bursts near the eye in TC rapid intensification.
- The chance of RI/IN increases when a hot tower exists, but not substantially. A hot tower is neither a necessary nor a sufficient condition for RI. (Jiang et al. 2009)

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