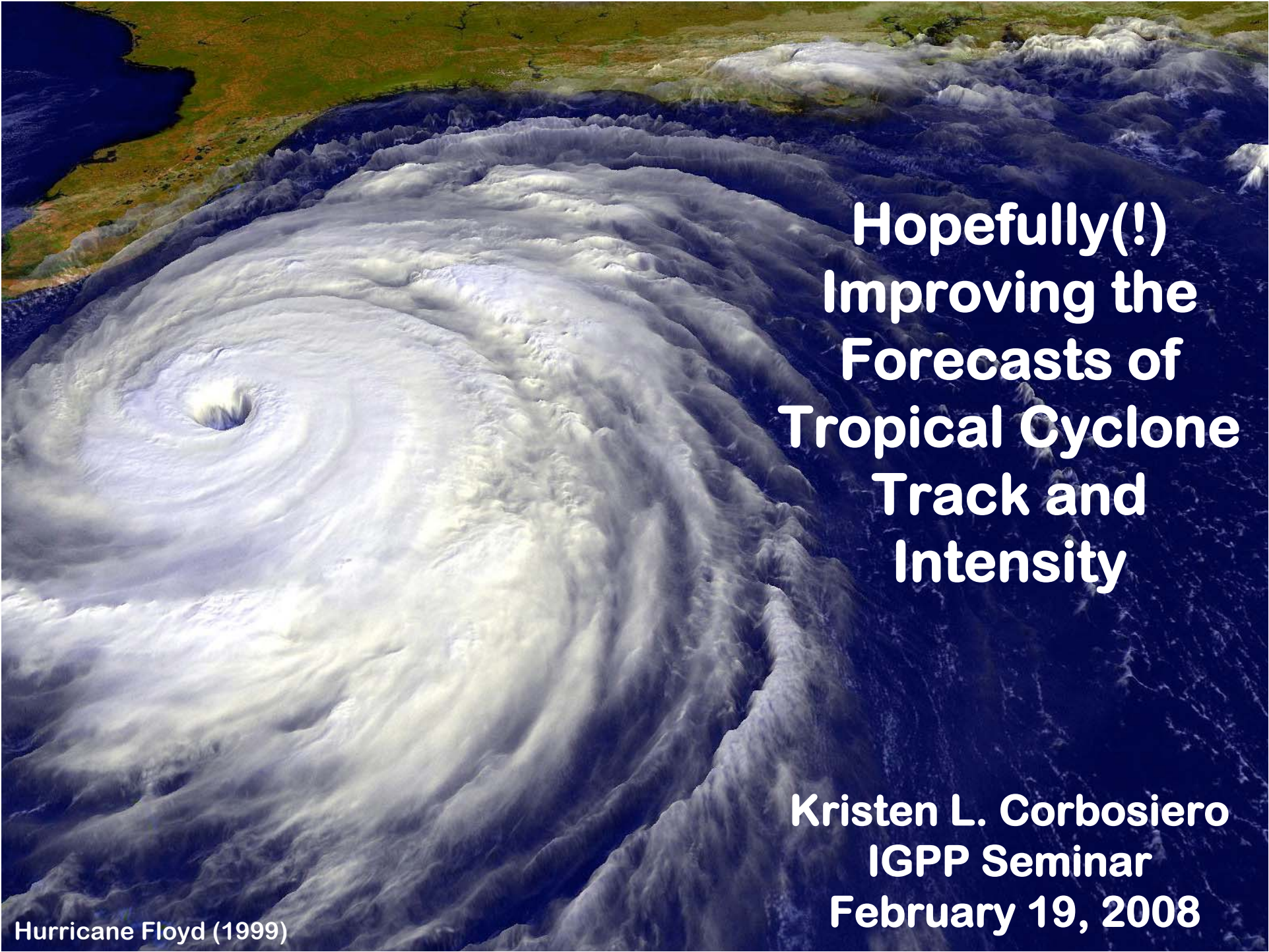


**Investigating
Tropical Cyclone
Structure
and
Intensity Change
with the
Advanced
Hurricane WRF
Model**

**Kristen L. Corbosiero
IGPP Seminar
February 19, 2008**

Hurricane Floyd (1999)



**Hopefully(!)
Improving the
Forecasts of
Tropical Cyclone
Track and
Intensity**

**Kristen L. Corbosiero
IGPP Seminar
February 19, 2008**

Hurricane Floyd (1999)

Outline

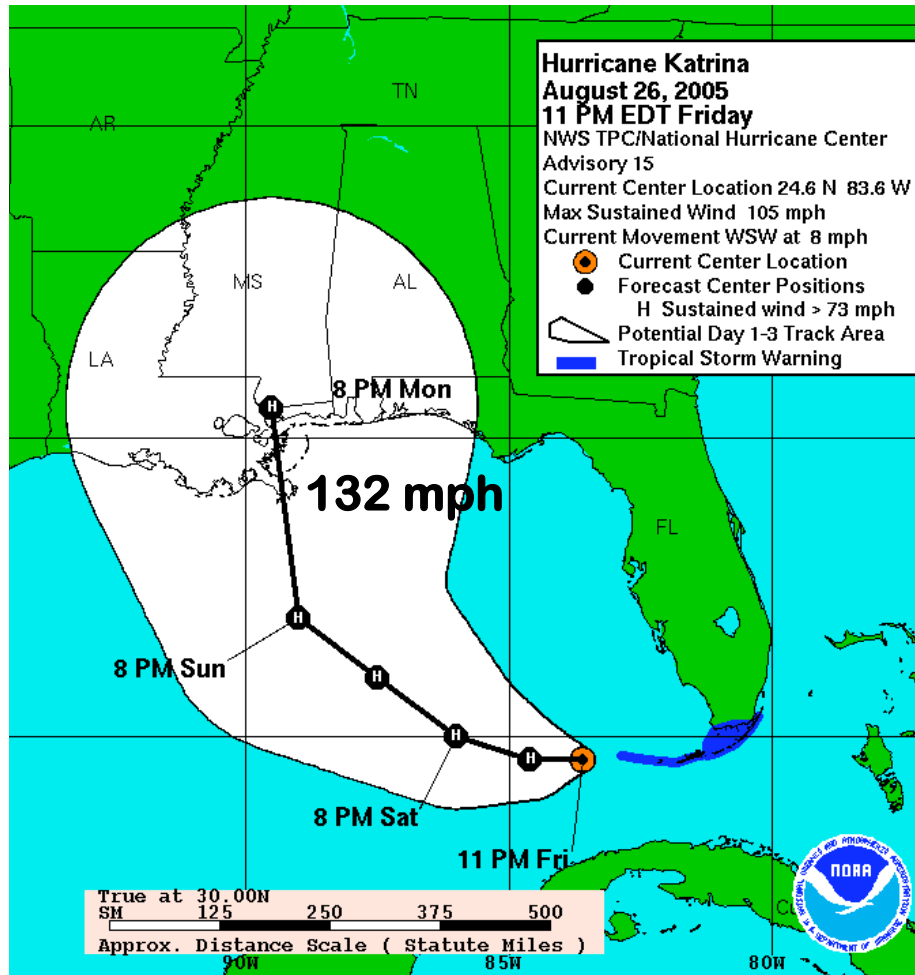
- **Why do we need better hurricane forecasts?**
 - ~ Societal impacts, climate change
 - ~ Skill and limitations of current forecasts
 - ~ Intensity versus track forecasts
- **Observations of Tropical Cyclones**
- **The Advanced Hurricane Weather Research and Forecasting (WRF) Model**
- **Current (and future) research on hurricane structure and its relationship to intensity change**

Motivation:

Why do we need better forecasts of tropical cyclones?

Katrina

Rita



Landfall: 6 AM Monday
Intensity: 125 mph

Landfall: 2 AM Saturday
Intensity: 115 mph

Motivation:

Why do we need better forecasts of tropical cyclones?

Katrina

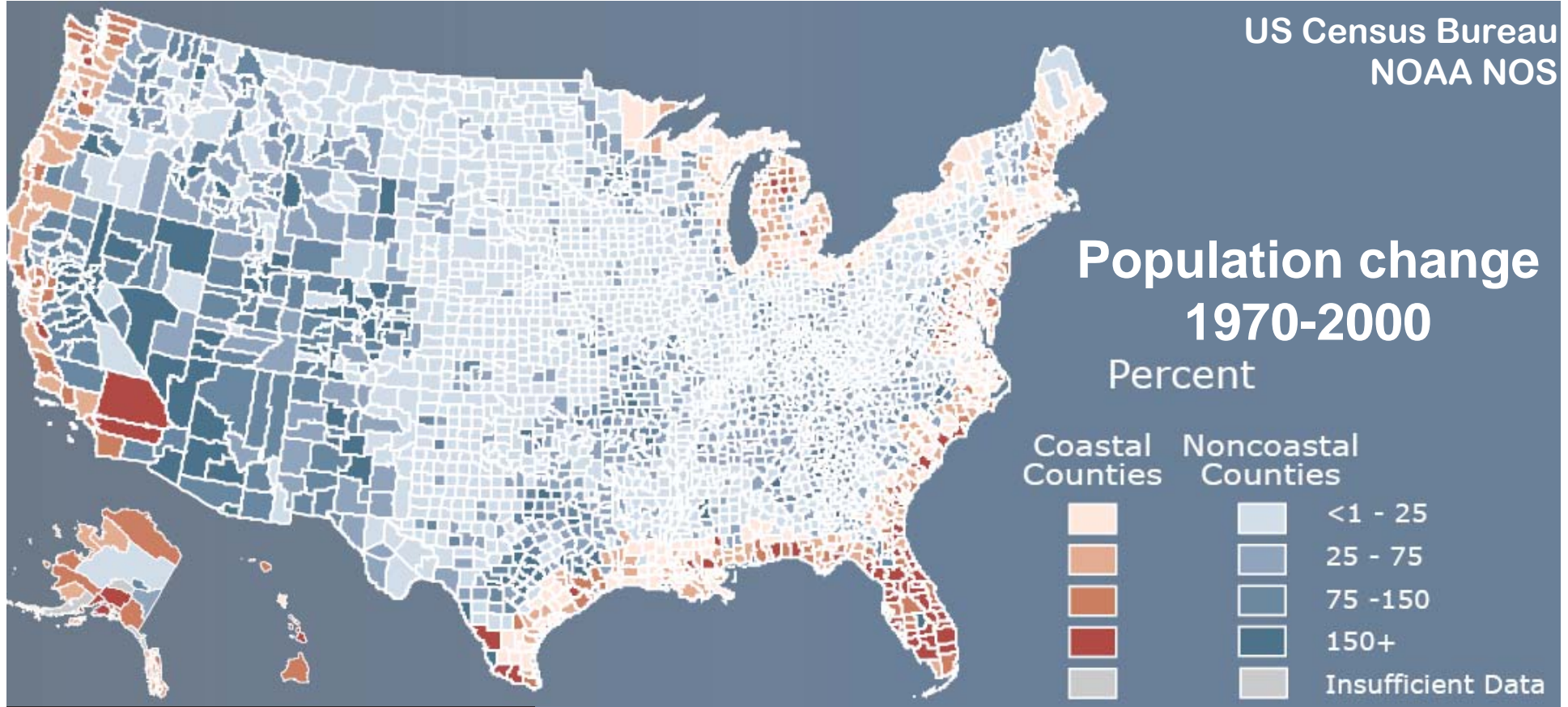


Rita

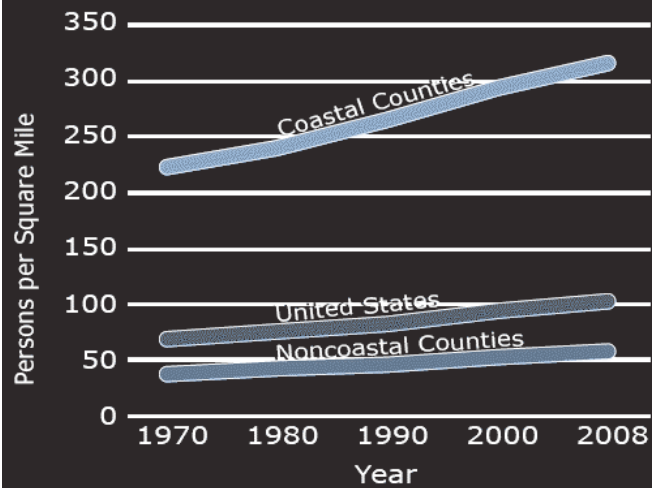


★ To better inform and protect the public ★

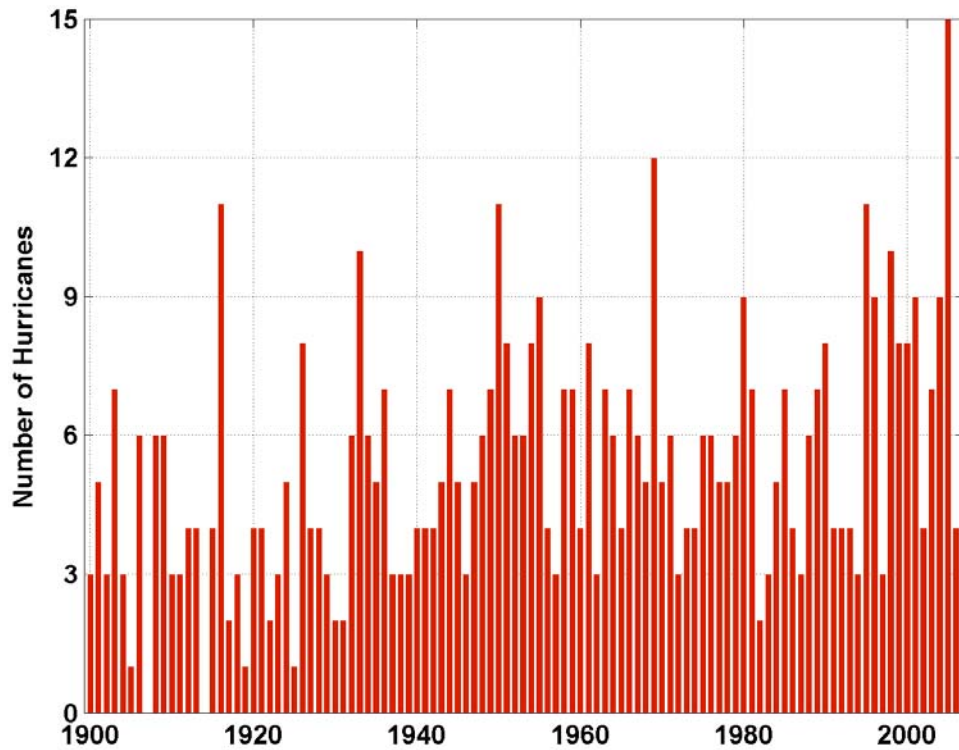
US Census Bureau
NOAA NOS



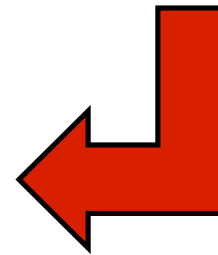
Population Density



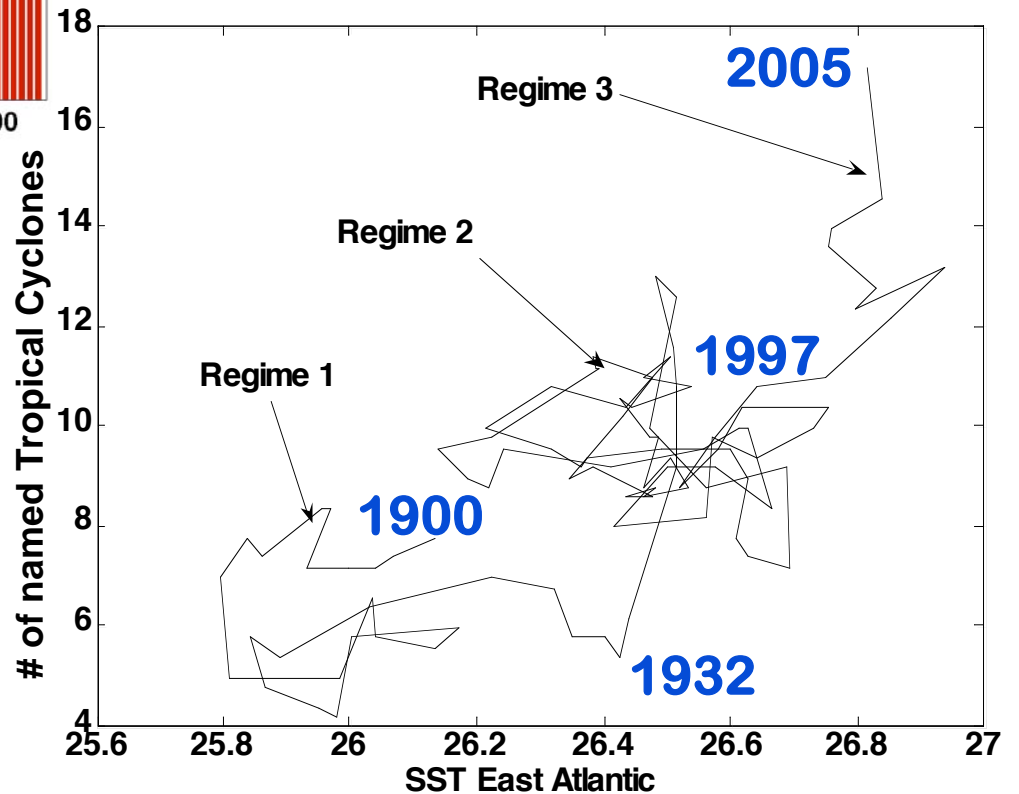
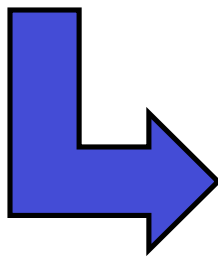
- **Coastal counties contain 53% of the US population, yet account for only 17% of the US land area**
- **Five of the six counties with the fastest growing coastal populations are in Florida and Georgia**



Atlantic Ocean Hurricanes 1900-2006

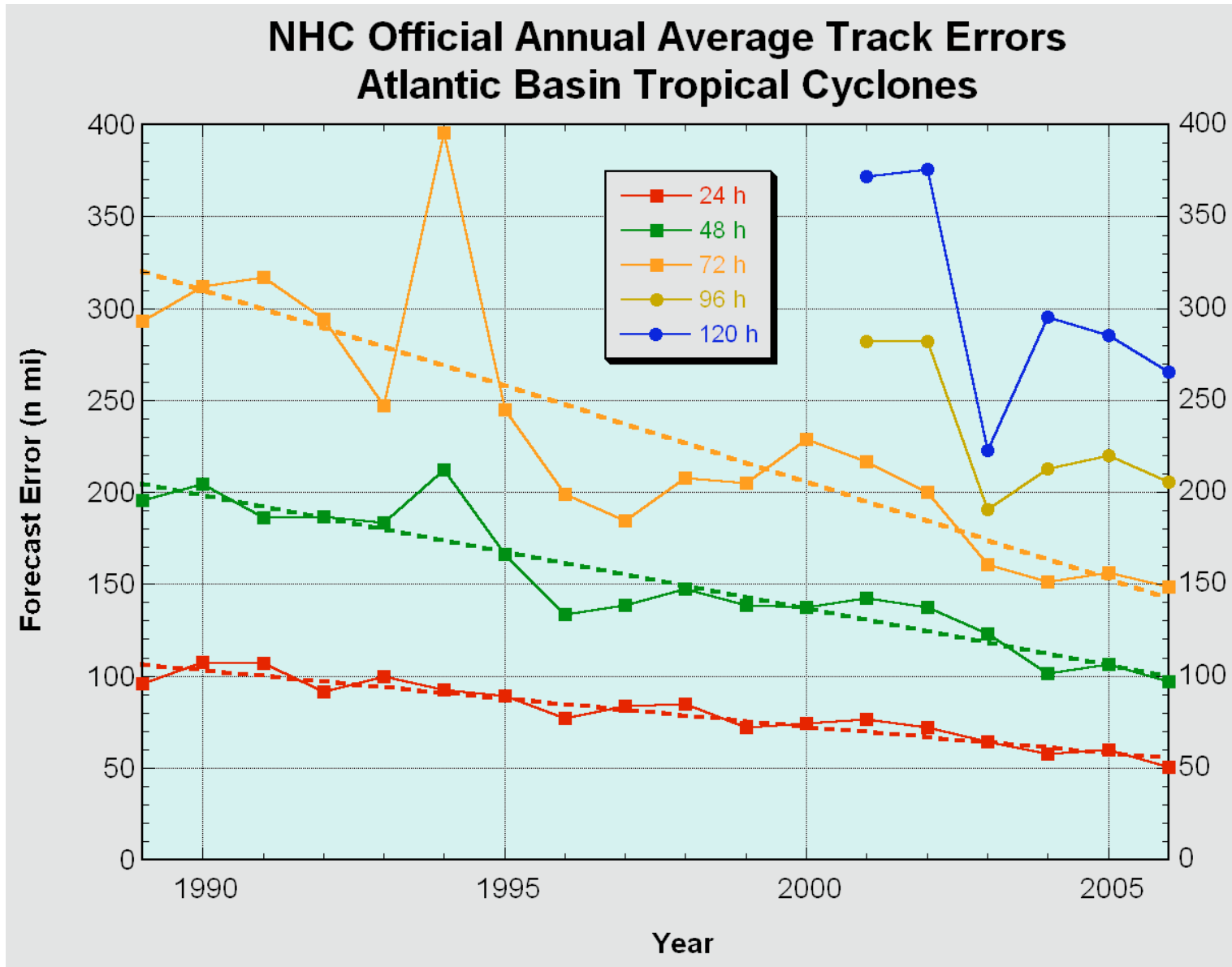


Atlantic Ocean Named tropical cyclones Sea surface temperature 1900-2005



After Holland and Webster (2007)

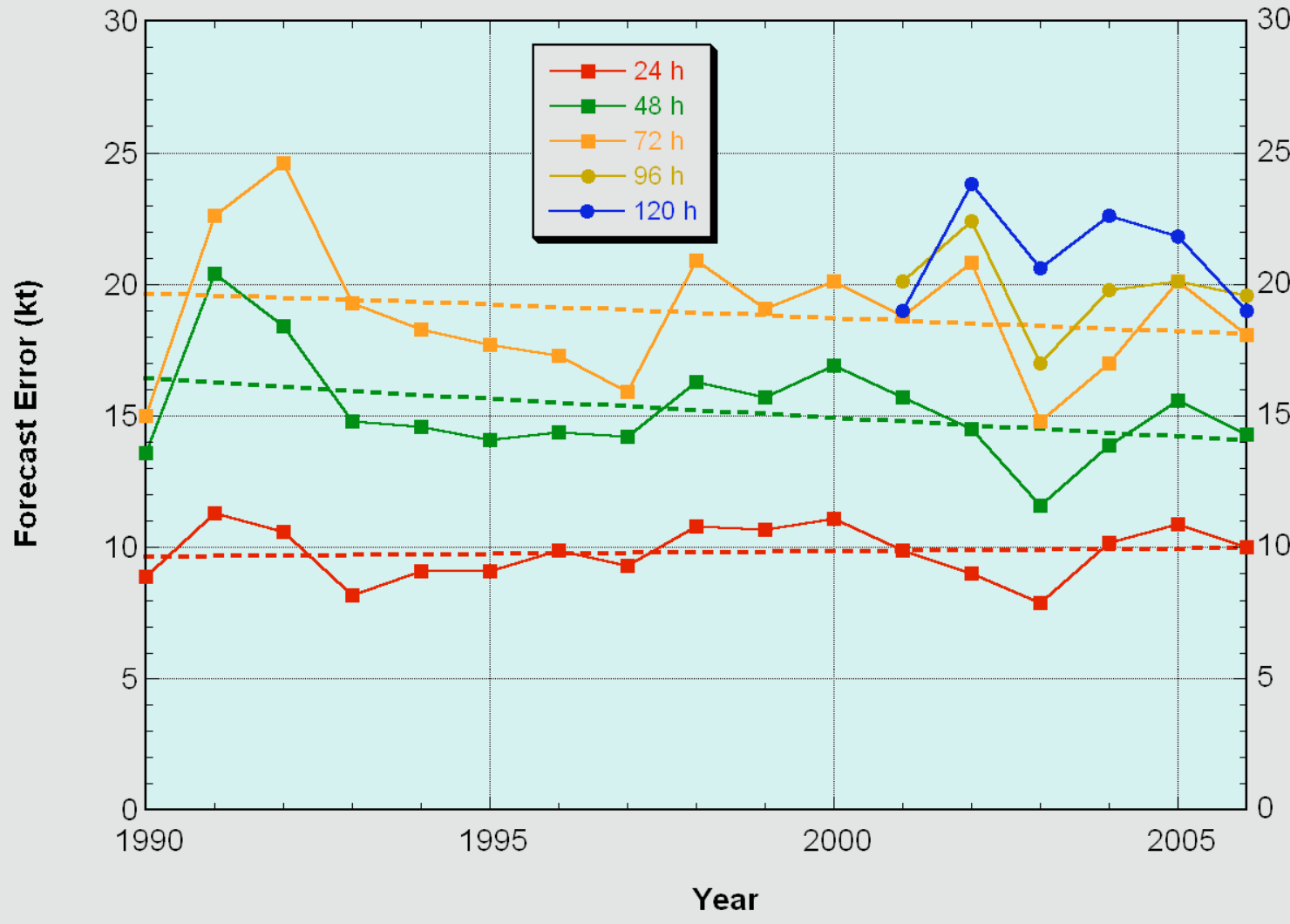
1 n mi = 1.15 mi = 1.85 km



Forecast track errors have been cut in **HALF**

NHC Official Annual Average Intensity Errors Atlantic Basin Tropical Cyclones

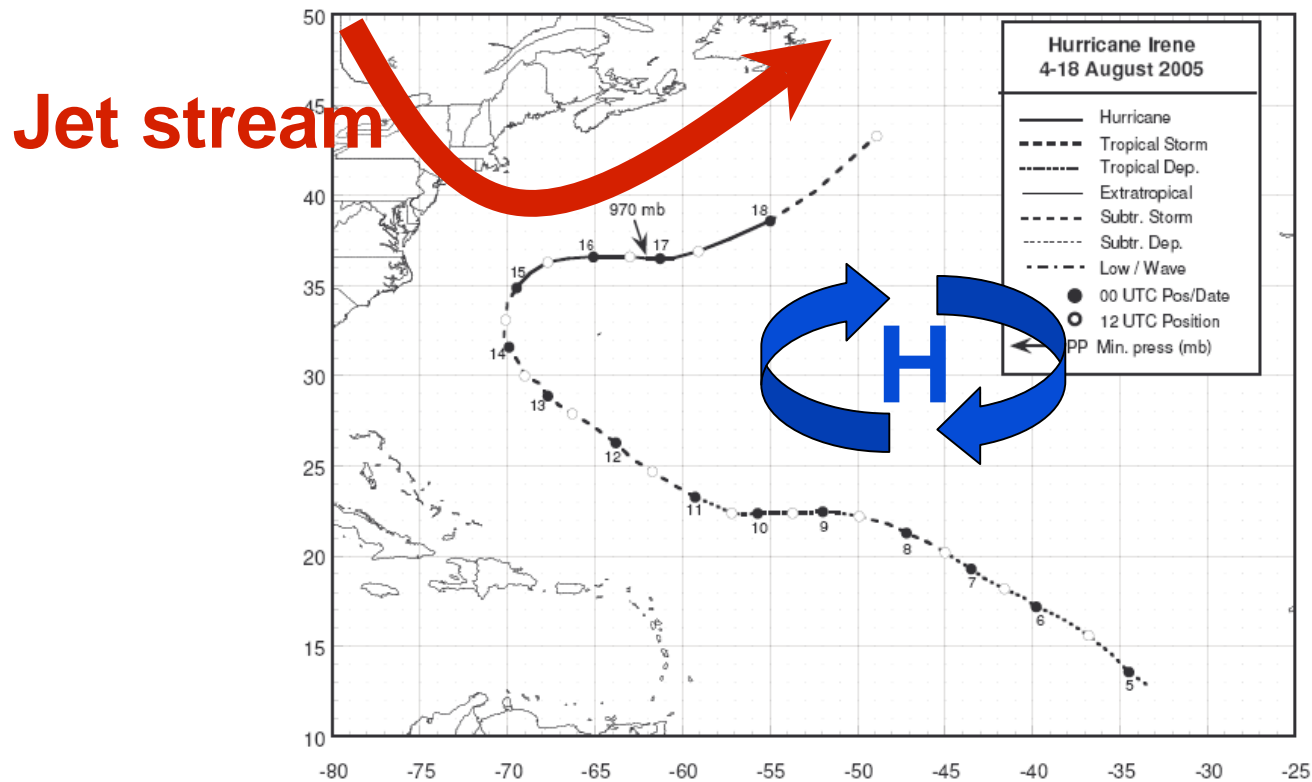
1 kt = 1.15 mph = .5 m s⁻¹



Forecast intensity errors have **NOT** improved

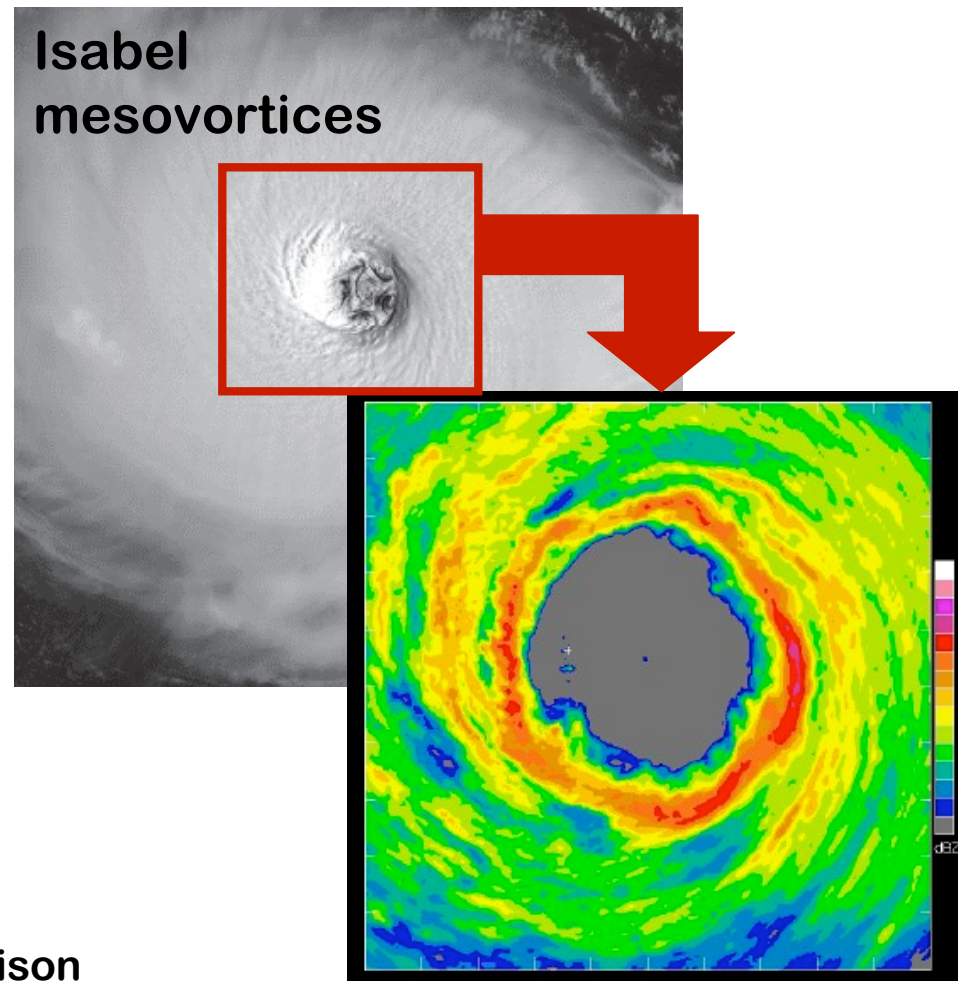
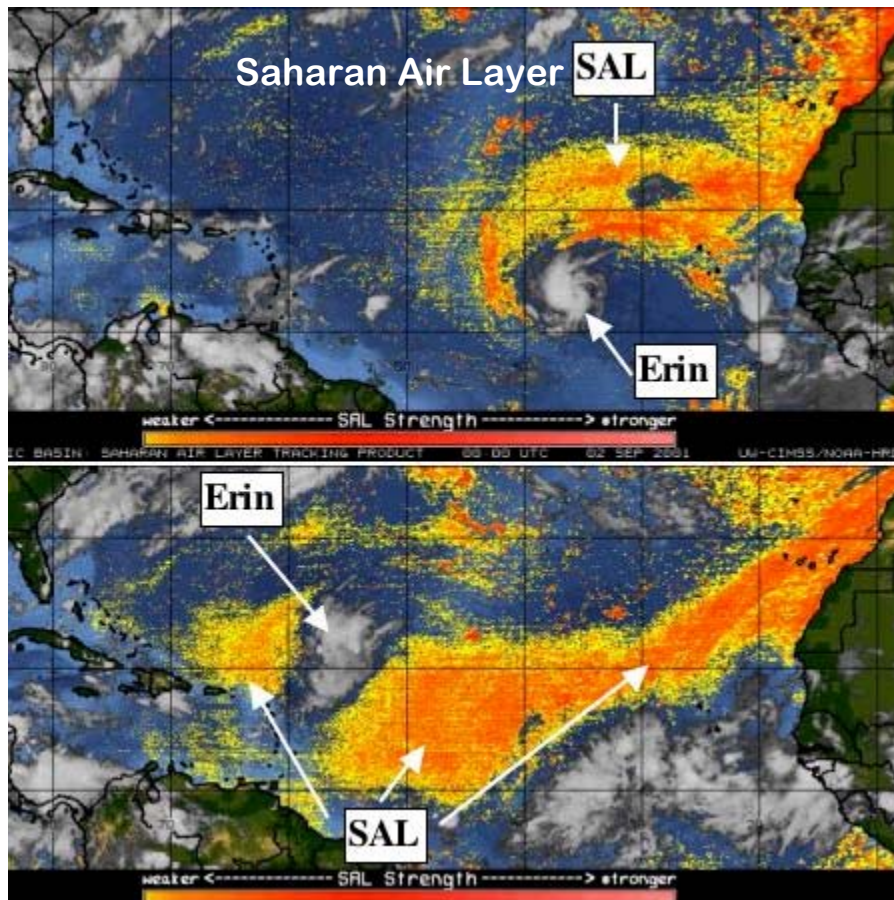
Why does this discrepancy exist between tropical cyclone track and intensity forecasting?

- The track of tropical cyclones is controlled by the large scale atmospheric circulation pattern
- Atmospheric models run at increasingly finer resolution (10-40 km) and the assimilation of satellite and aircraft data into models capture the large scale very accurately



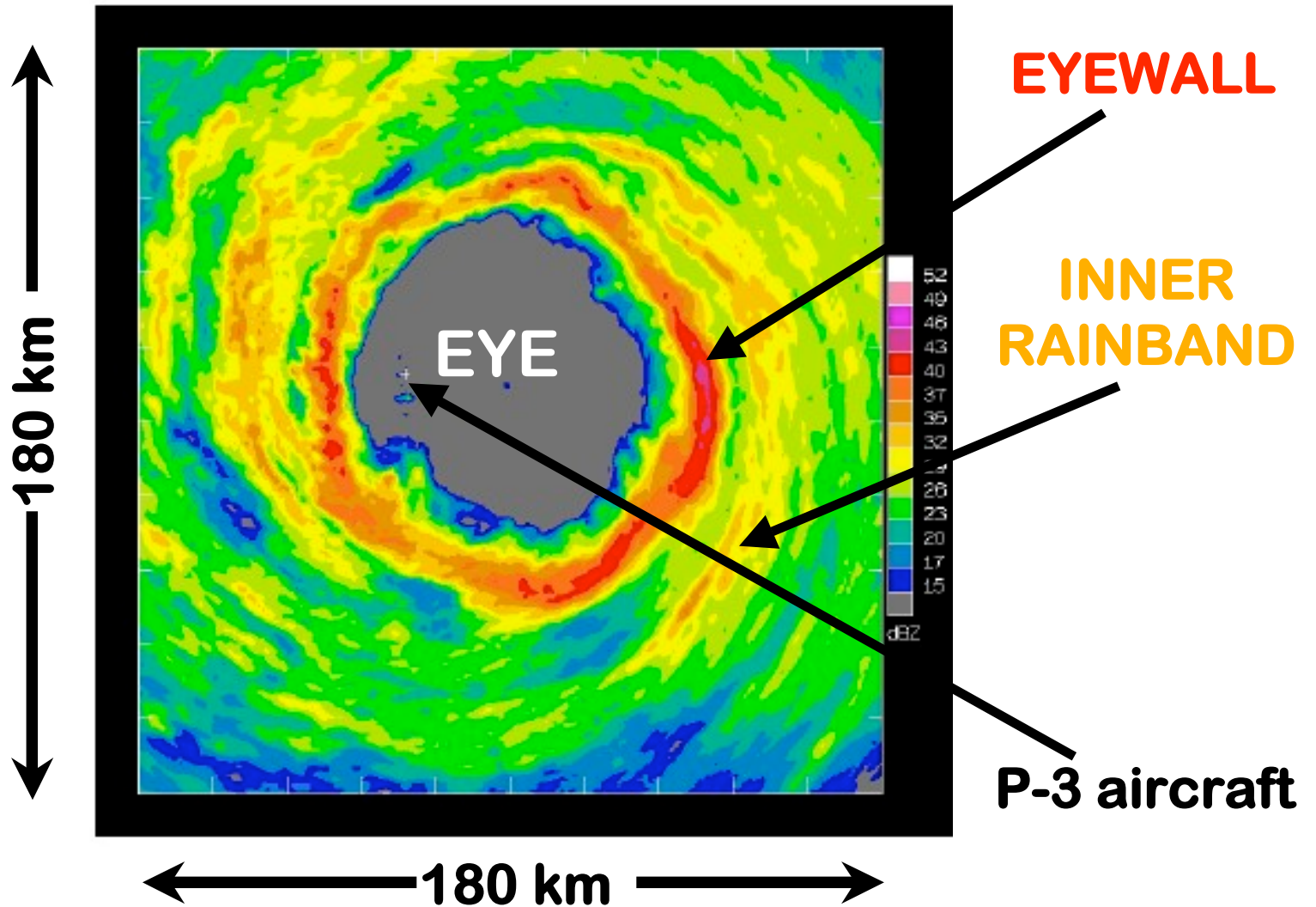
Why does this discrepancy exist between tropical cyclone track and intensity forecasting?

- The intensity of a tropical cyclone is controlled by both the large scale environment (the intrusion of dry air, vertical wind shear) and internal storm dynamics



Images courtesy NOAA HRD and UWisc-Madison

Radar reflectivity NOAA P-3 Aircraft Hurricane Isabel





C-130

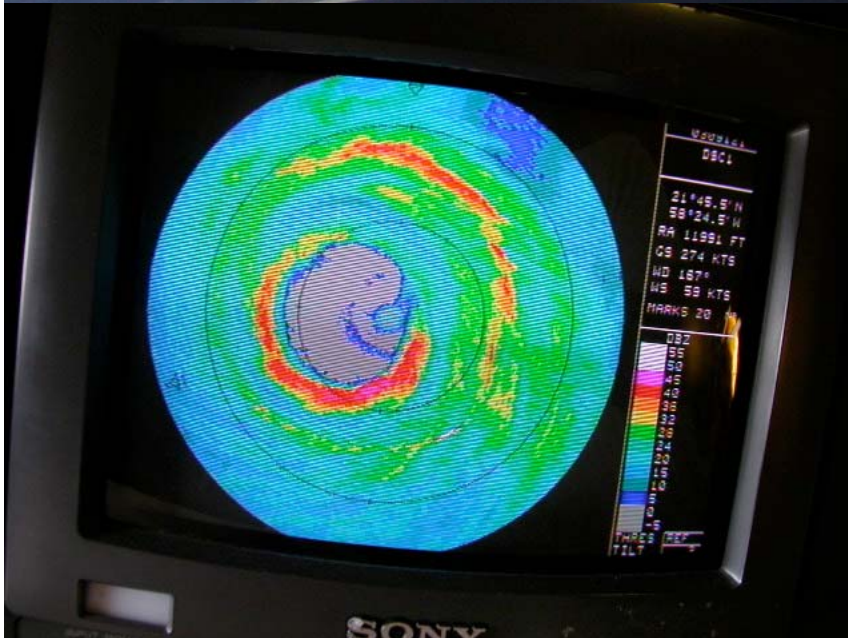


NOAA P-3s



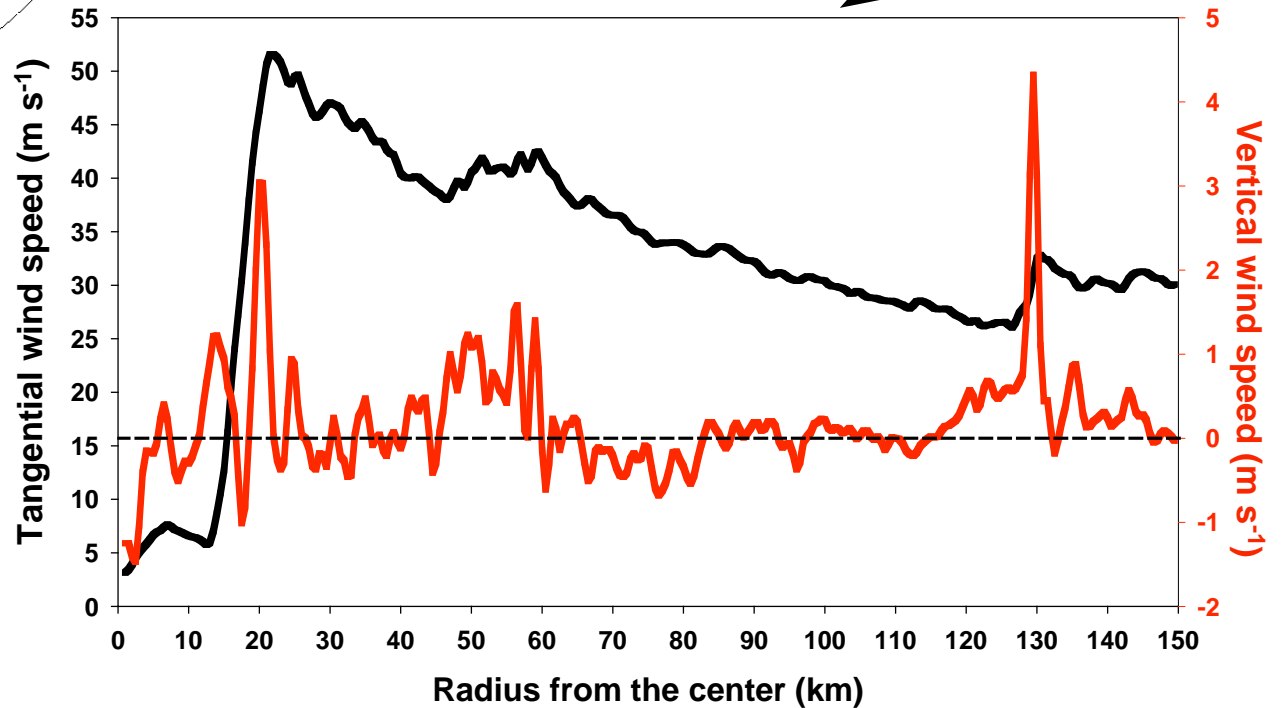
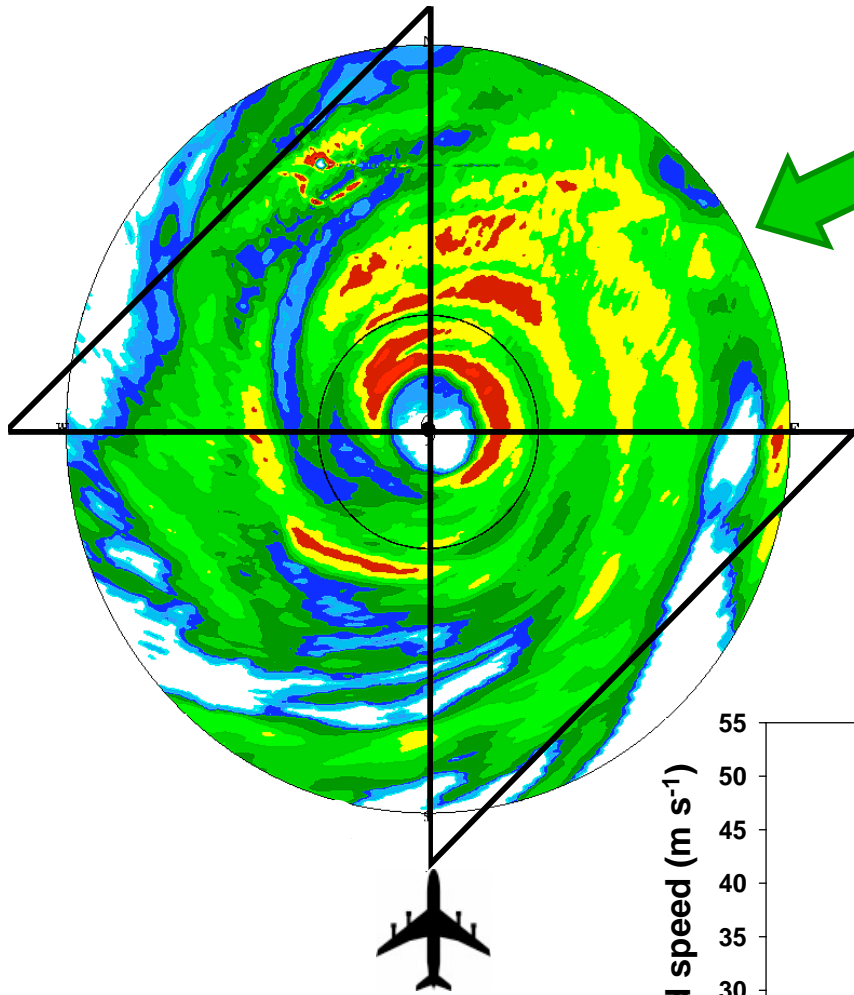
Photographs of Hurricane Katrina's eye and eyewall from the NOAA P-3

(courtesy of F. Roux and M. Black)

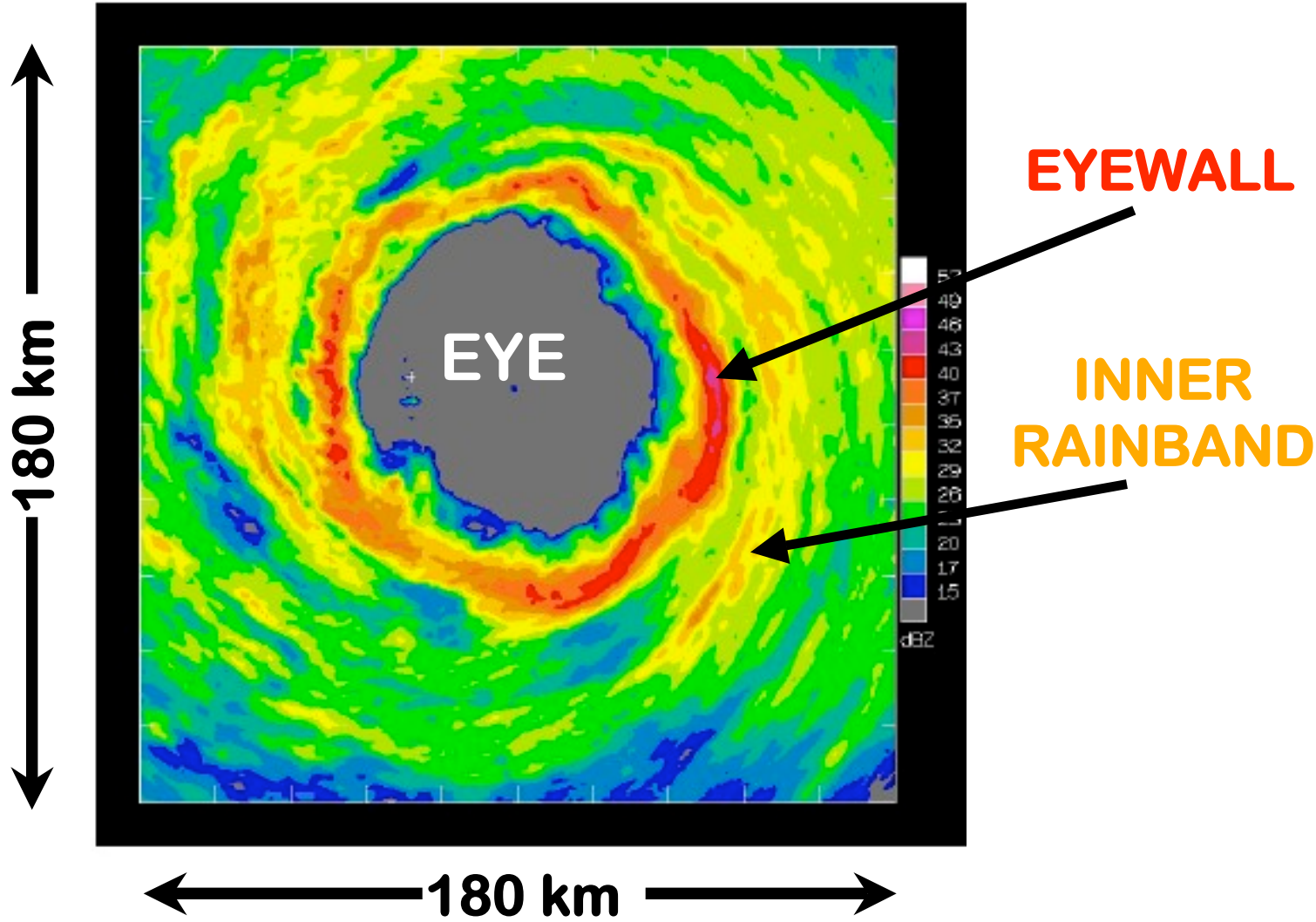


“Figure 4” flight path and radar reflectivity from Hurricane Elena (1985)

Tangential and vertical wind profiles at 850 hPa (~1.5 km) from the southern flight leg



Radar reflectivity NOAA P-3 Aircraft Hurricane Isabel

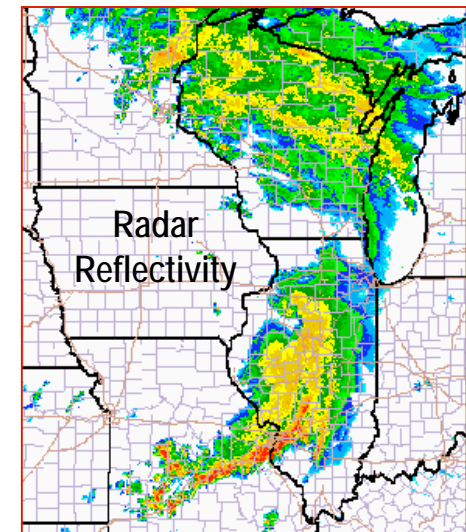
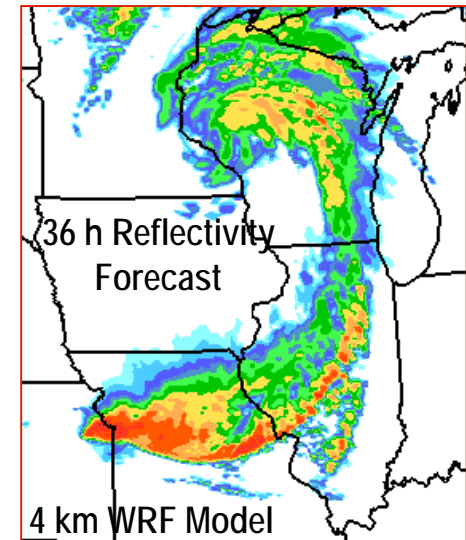


The eyewall and inner rainbands are 5-10 km wide. A model grid size of ~1 km is necessary to fully resolve these features.



THE WEATHER RESEARCH & FORECASTING MODEL

- Developed by the National Center for Atmospheric Research (NCAR) and NOAA as the next generation, mesoscale model to simulate continental weather systems on grid scales of less than 10 km
- WRF is an open source, community supported model currently being used around the globe (R. Fovell)
- Since the summer of 2004, NCAR has been conducting real time forecast runs of all Atlantic basin tropical cyclones



10 June 2003 12Z

The Advanced Hurricane WRF

- Run in real-time at NCAR since 2004 when a tropical cyclone (TC) threatened to make landfall within 3-5 days
- Two or three domains (12, 4, 1.33 km) with two-way moveable nests that follow the hurricane center
- Initialized from the Geophysical Fluid Dynamics Laboratory (GFDL) model at 00 UTC and/or 12 UTC
- Kain-Fritsch cumulus parametrization (12 km only), WSM3(5) microphysics, YSU planetary boundary layer scheme, drag (Donelan) and surface enthalpy coefficients (Carlson-Boland) over the ocean
- Available on the web at http://www.wrf-model.org/plots/realtime_main.php

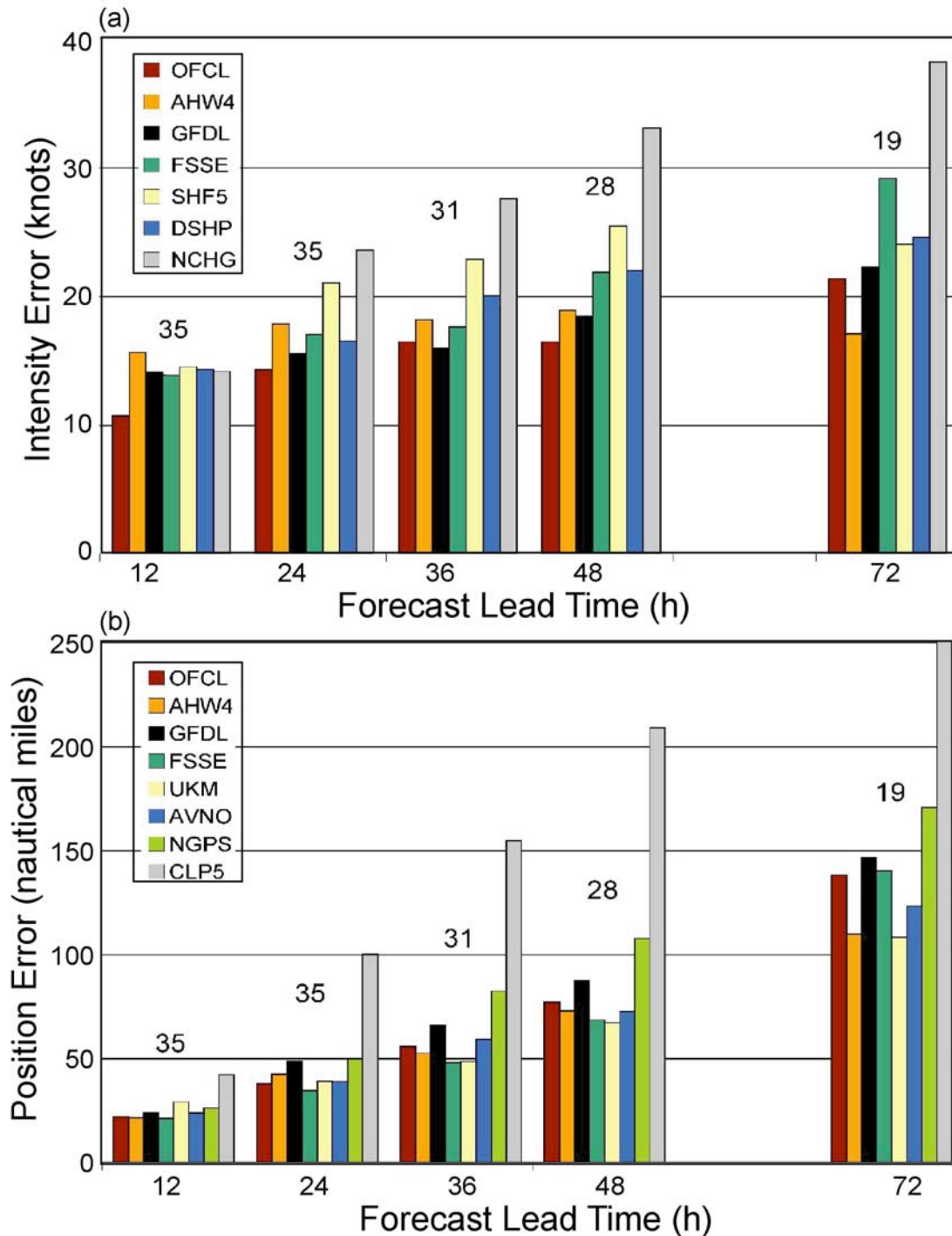
2005 performance Seven tropical cyclone forecast systems

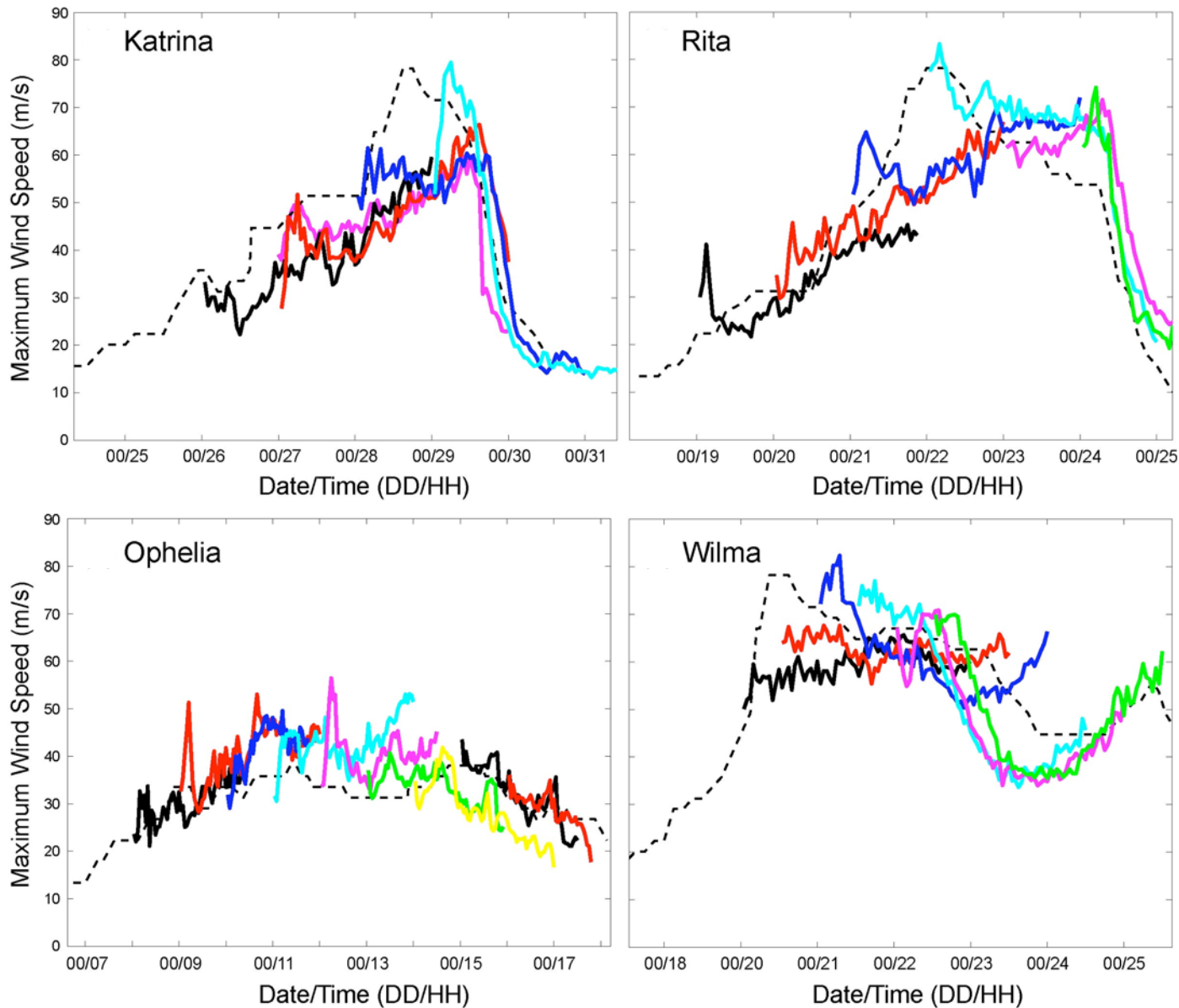
AHW4
WRF 4 km

OFCL
**National Hurricane
Center official**

GFDL
**Geophysical Fluid
Dynamics Laboratory**
1/9th °

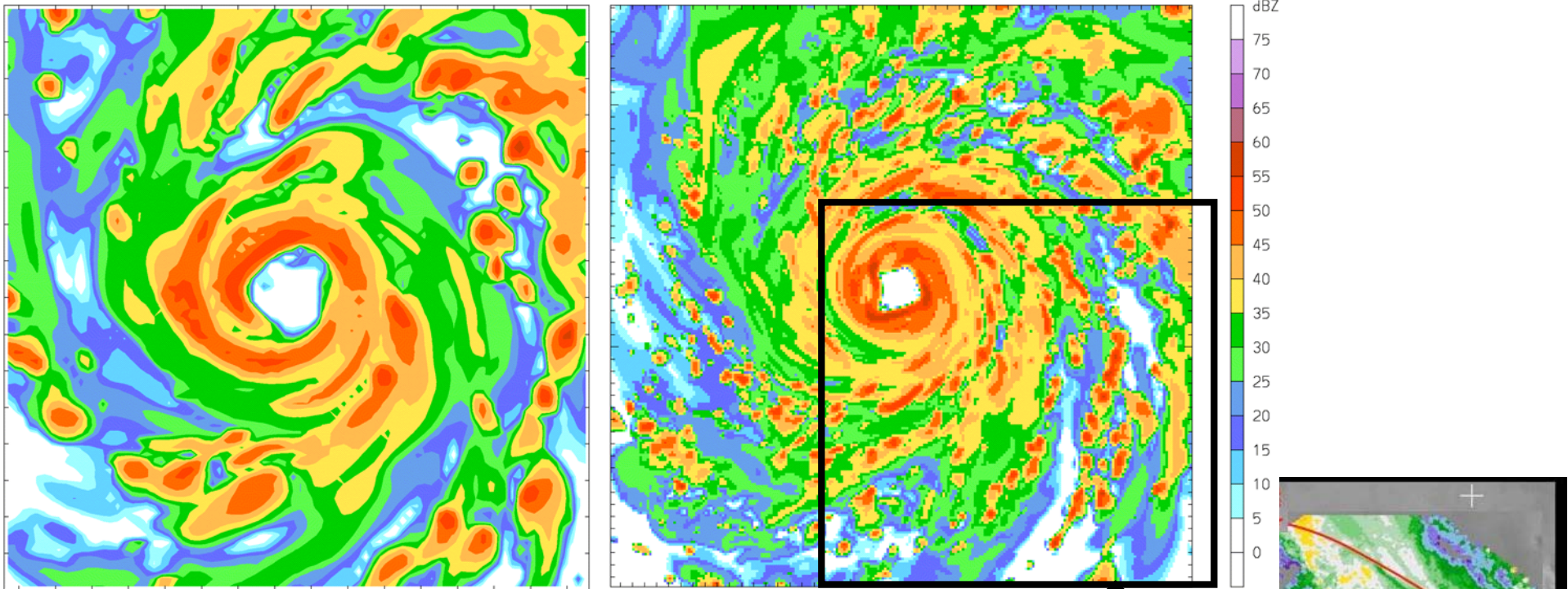
Davis et al. (2008)





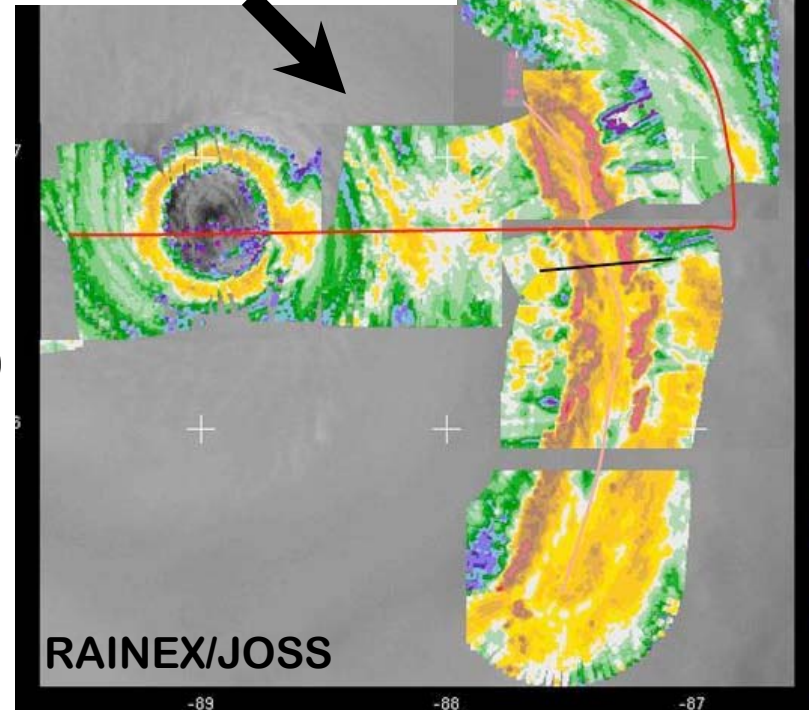
Maximum sustained wind speed from the observations (dashed) and from 25 forecasts covering four 2005 TCs from the AHWRF 4 km grid.

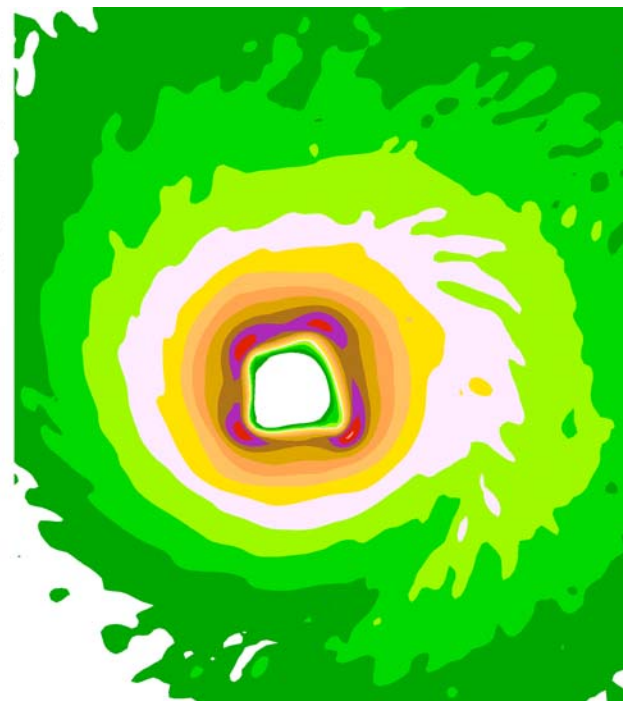
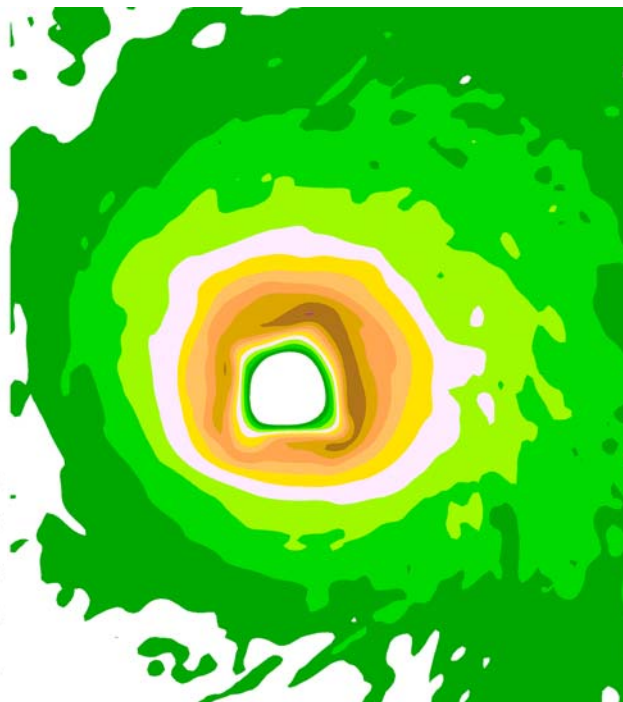
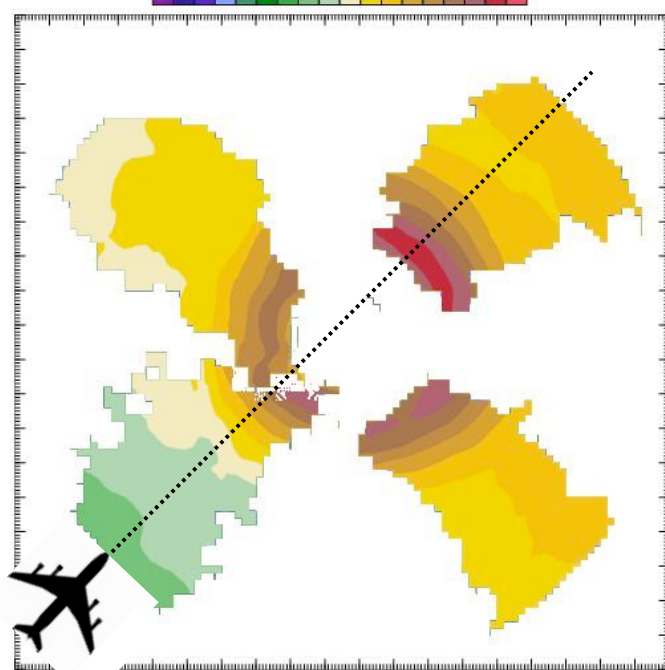
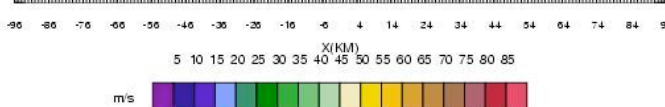
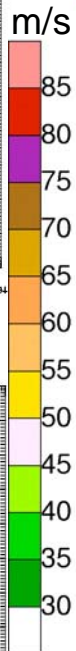
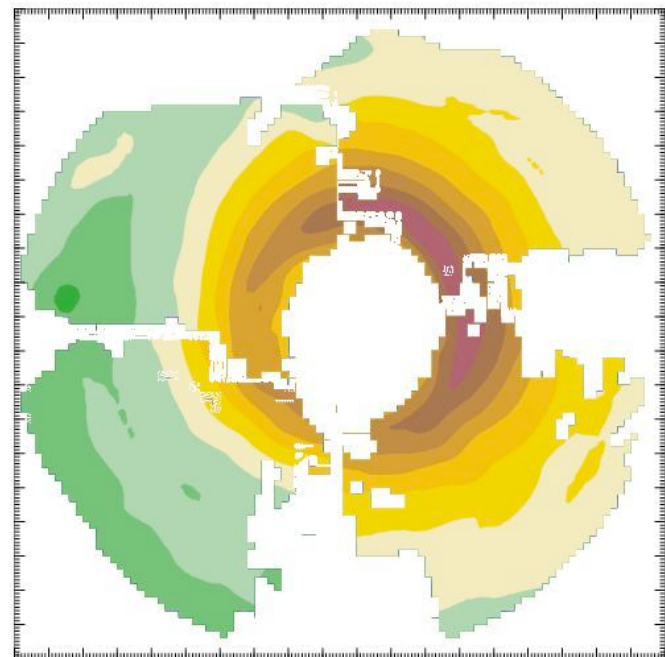
Davis et al. (2008)



Katrina Radar Reflectivity
20 UTC 28 August

Top: WRF 4 km(left), 1.33 km(right)
Right: ELDORA radar





Katrina Wind speed

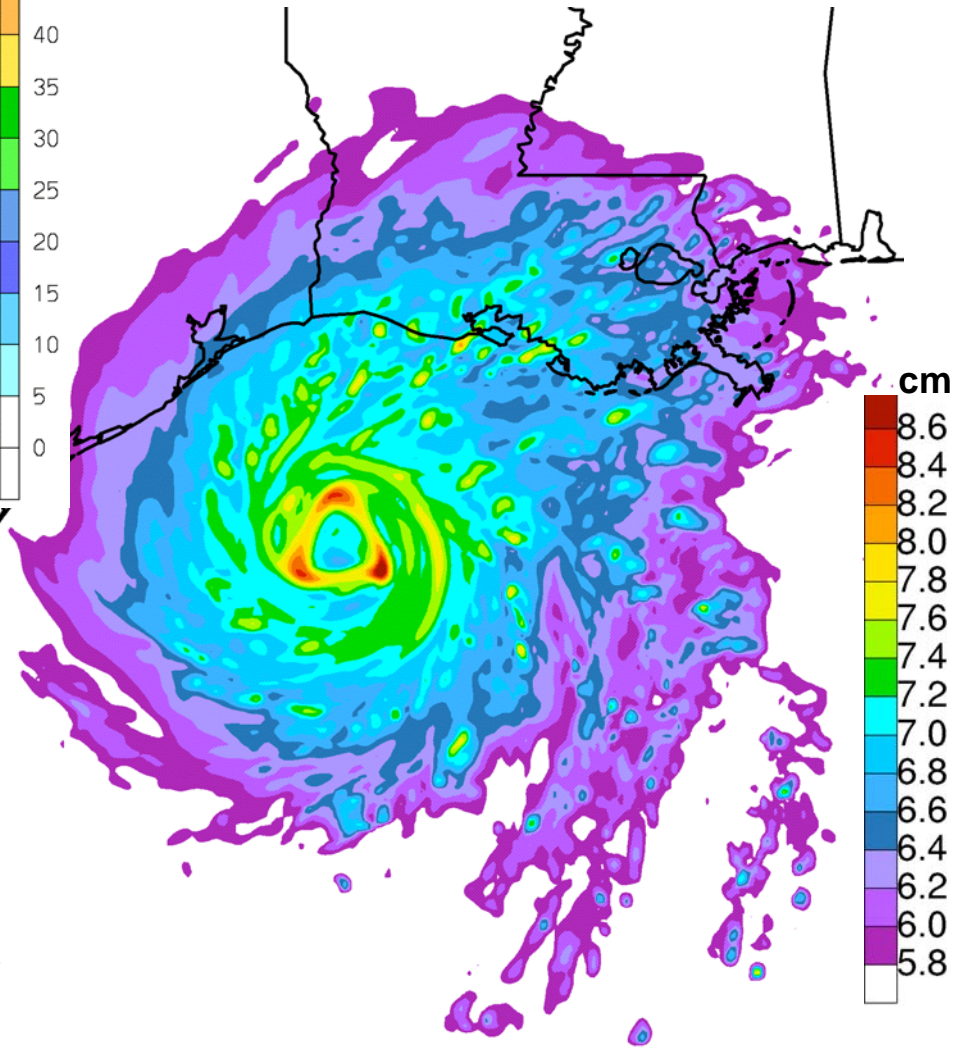
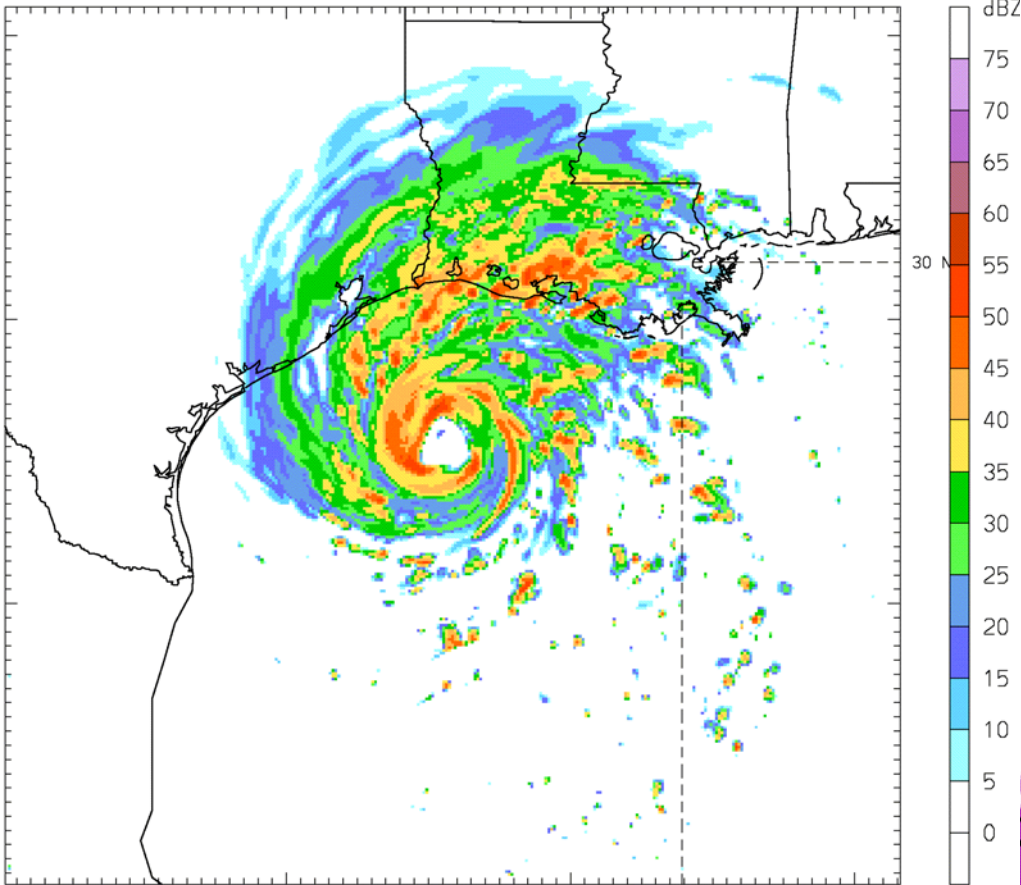
Left:
Dual Doppler
1725-1946 UTC
28 August

Right:
WRF 1.33 km
18 UTC

Top: 700 hPa
Bottom: 900 hPa

Hurricane Rita

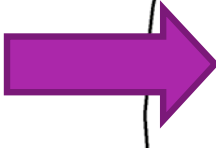
**03 UTC 24 September
39 hr forecast**

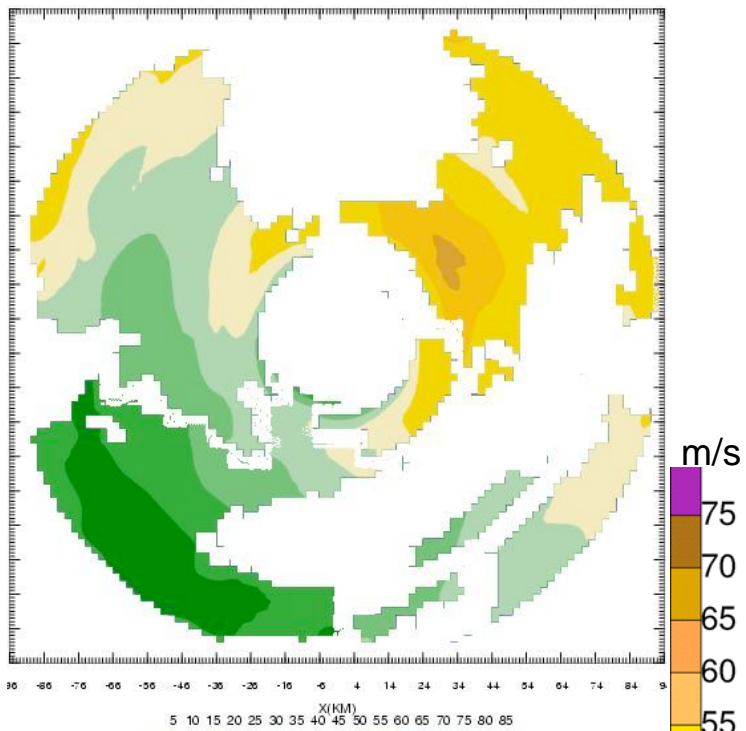


**Column maximum
reflectivity**

4 km

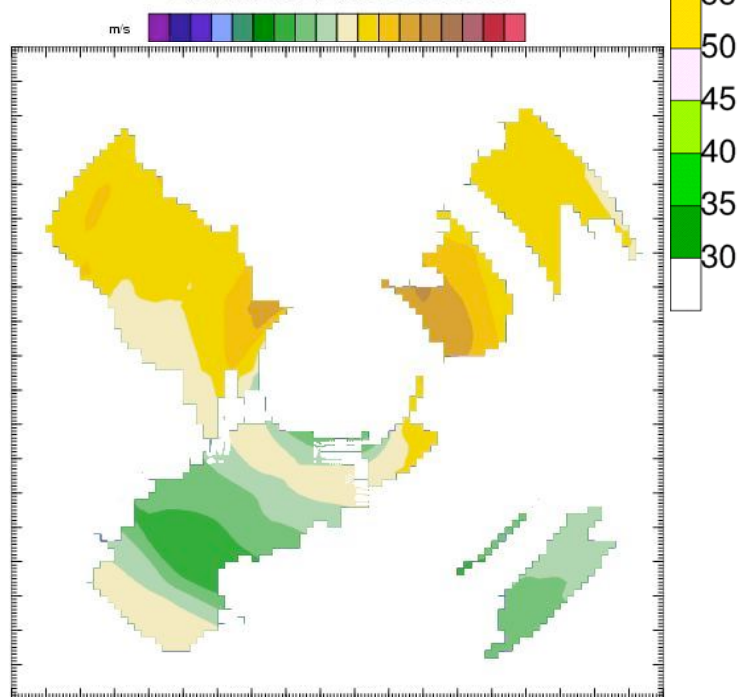
Precipitable water





Rita
Wind speed

Left:
Dual Doppler
2015-2208 UTC
23 September



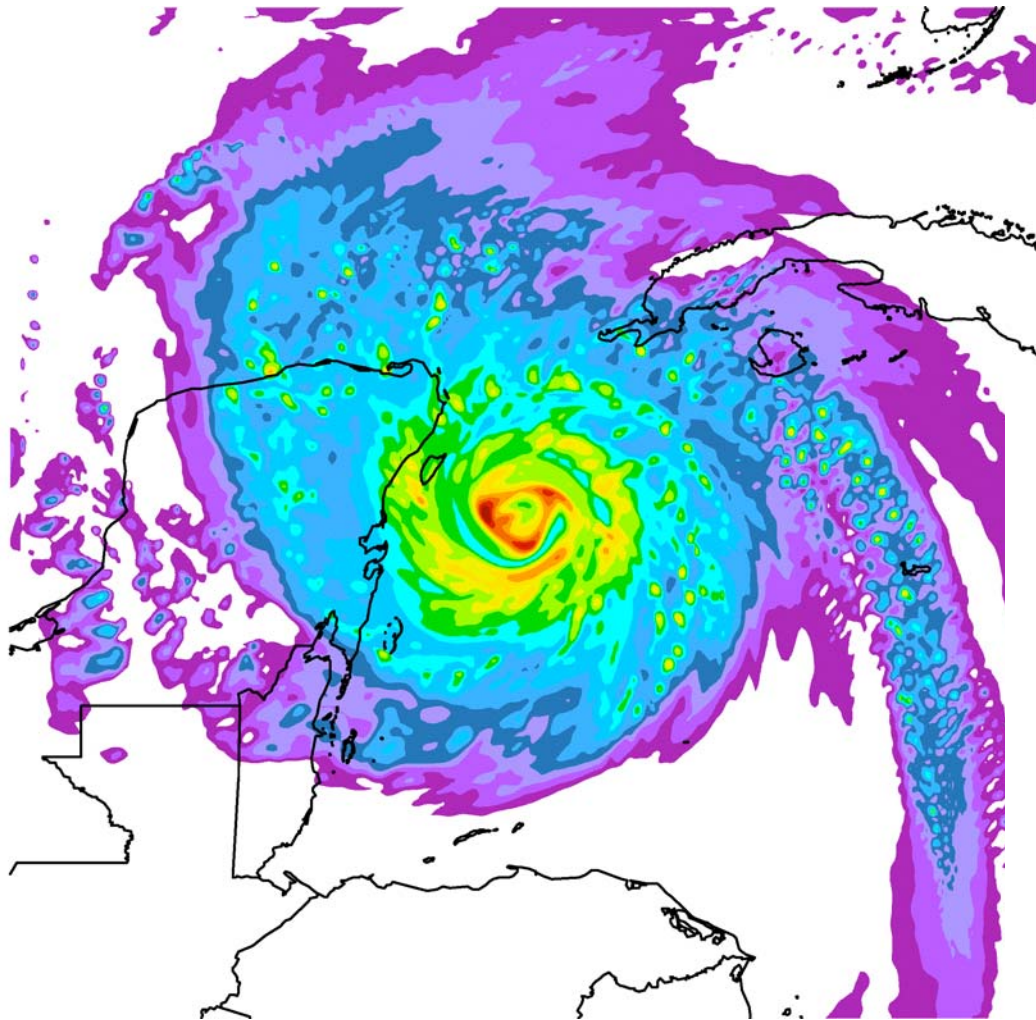
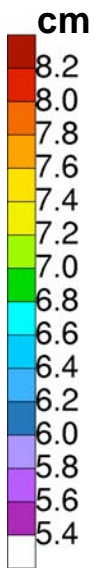
Right:
WRF 4 km
01 UTC
24 September

Top: 700 hPa
Bottom: 900 hPa

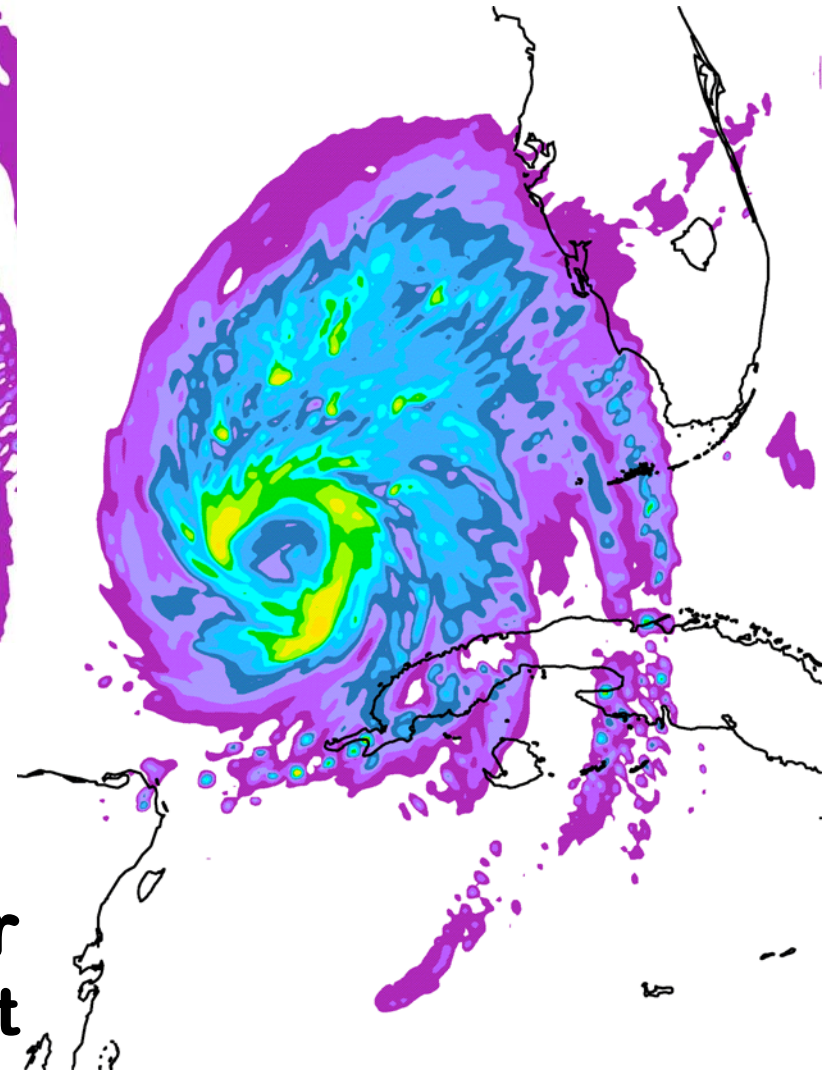
HRD/AOML/NOAA

Hurricane Wilma

4 km Precipitable water



22 UTC 20 October
22 hr forecast

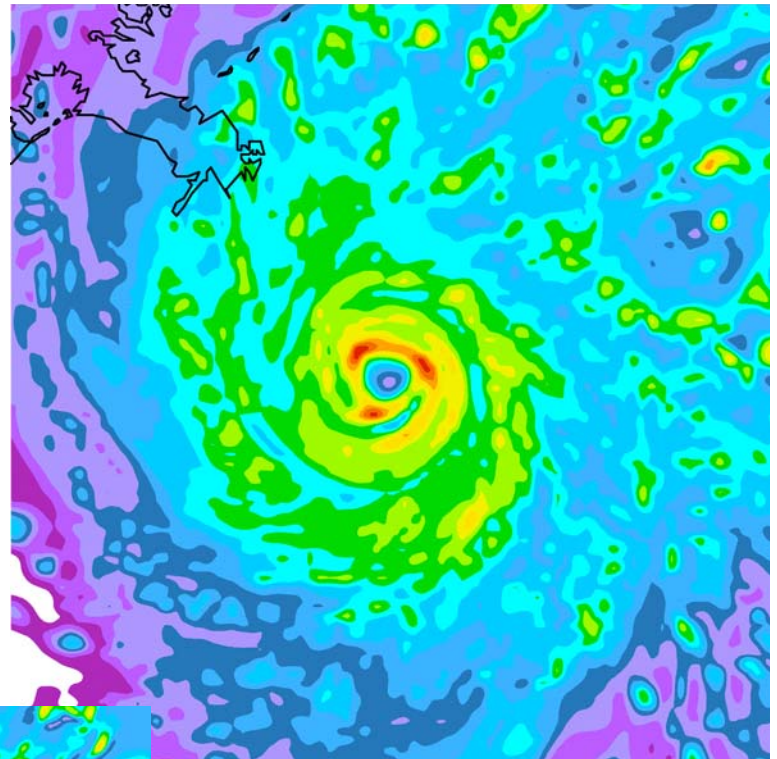
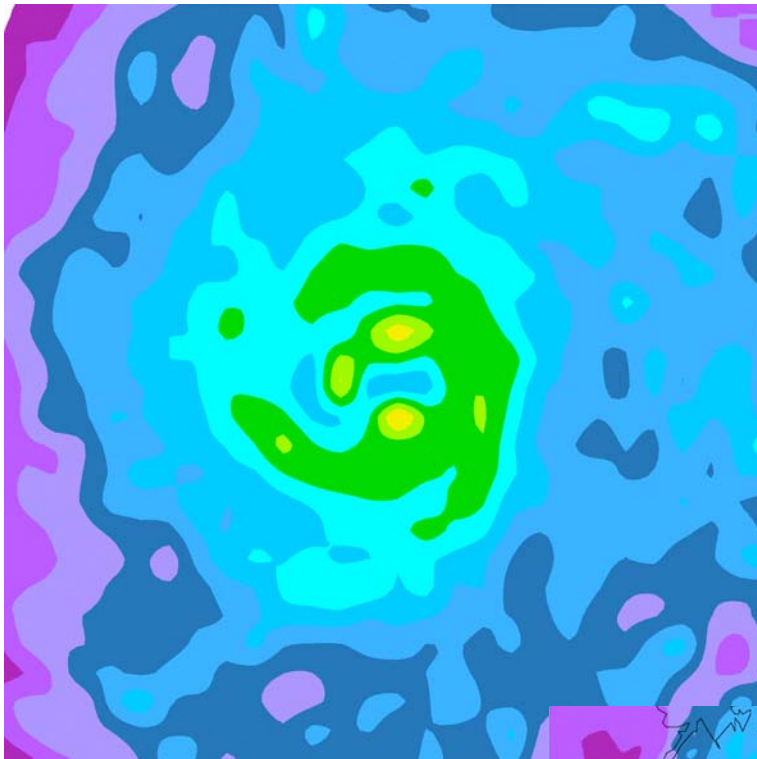
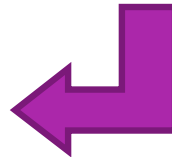


05 UTC 24 October
77 hr forecast

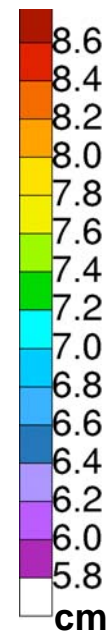
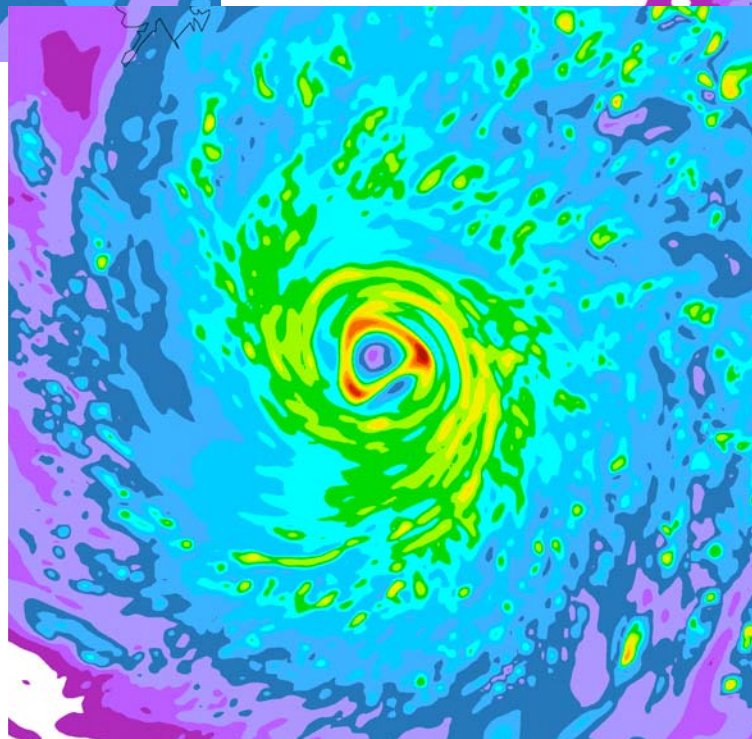
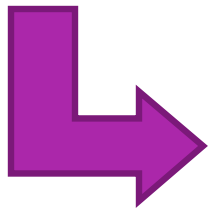
Hurricane Katrina

Precipitable water

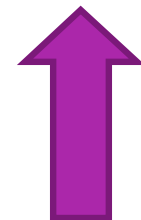
**12 km
21 UTC 8/28**

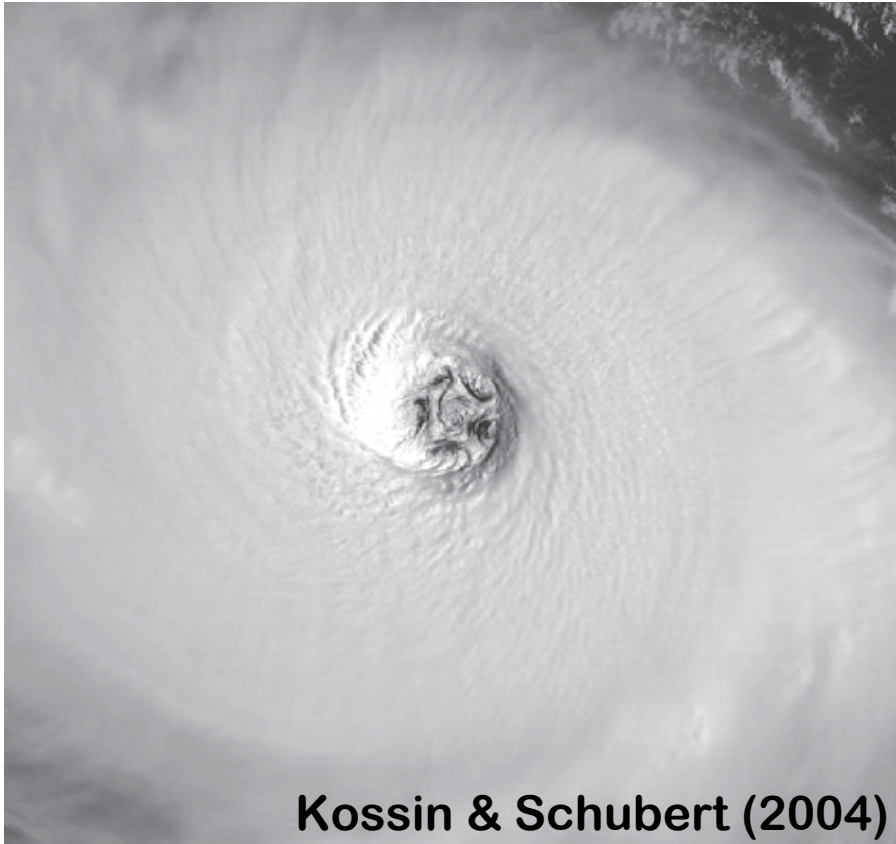


**1.33 km
00 UTC 8/29**

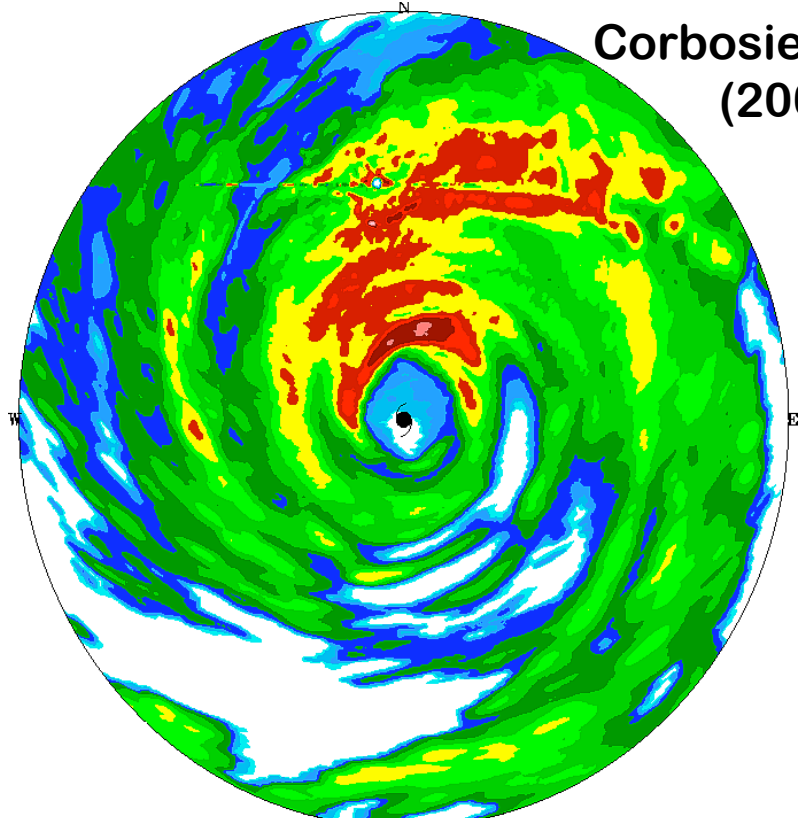


**4 km
03 UTC 8/29**

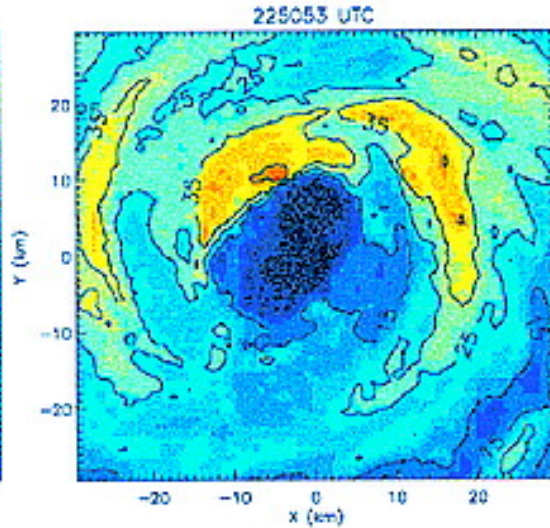
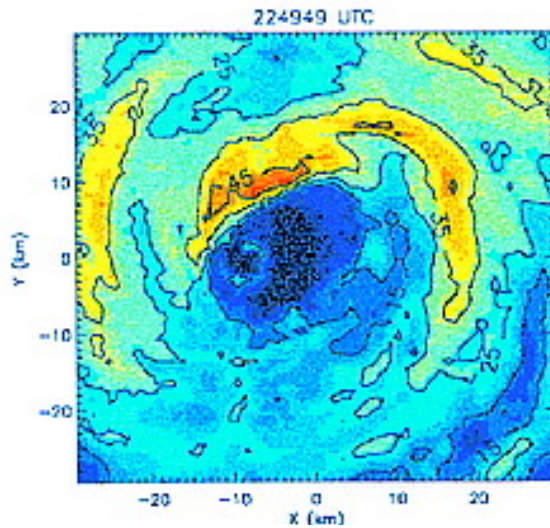




Kossin & Schubert (2004)



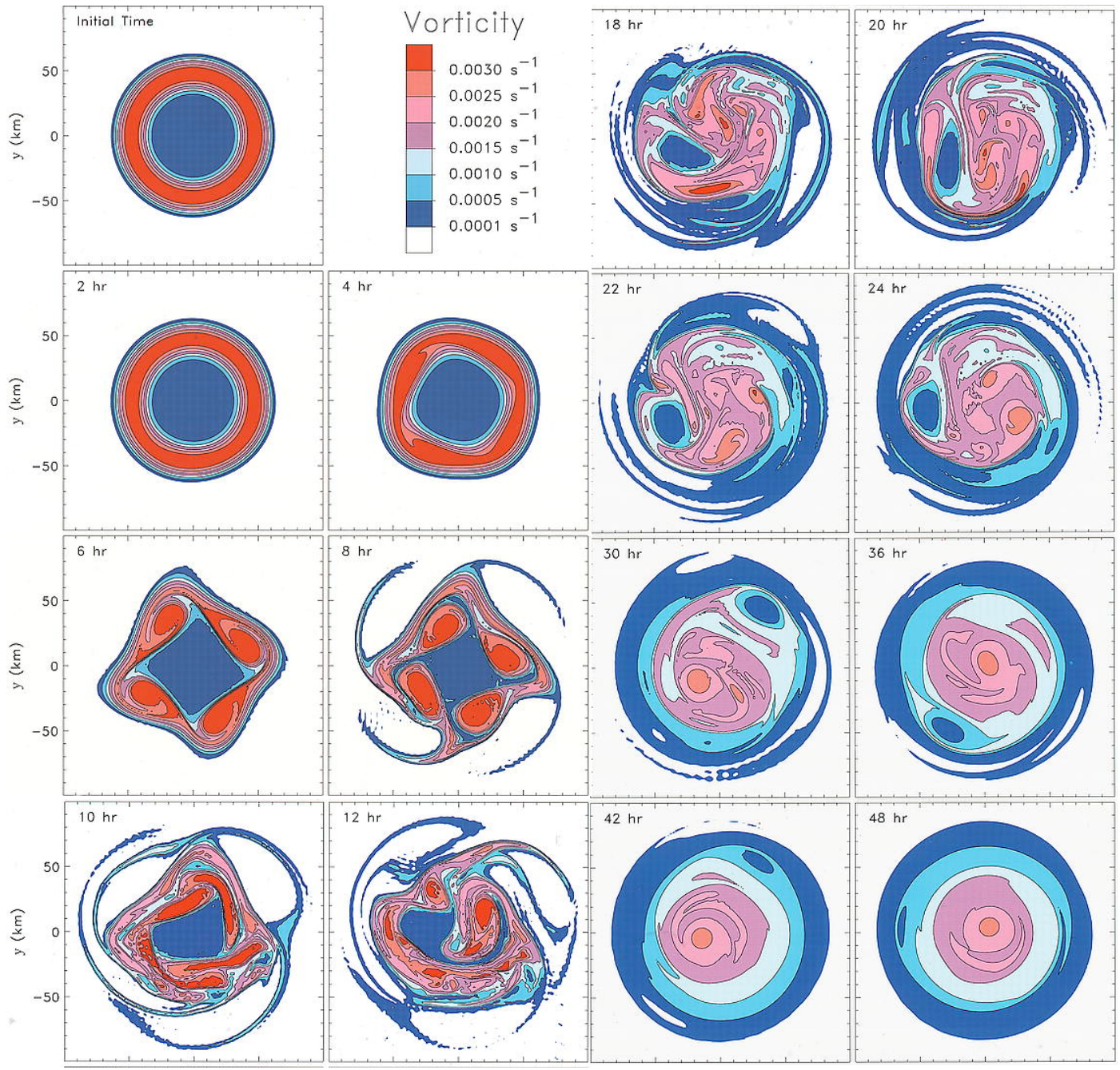
Corbosiero et al. (2006)



Lewis & Hawkins (1982)



Reasor et al. (2000)

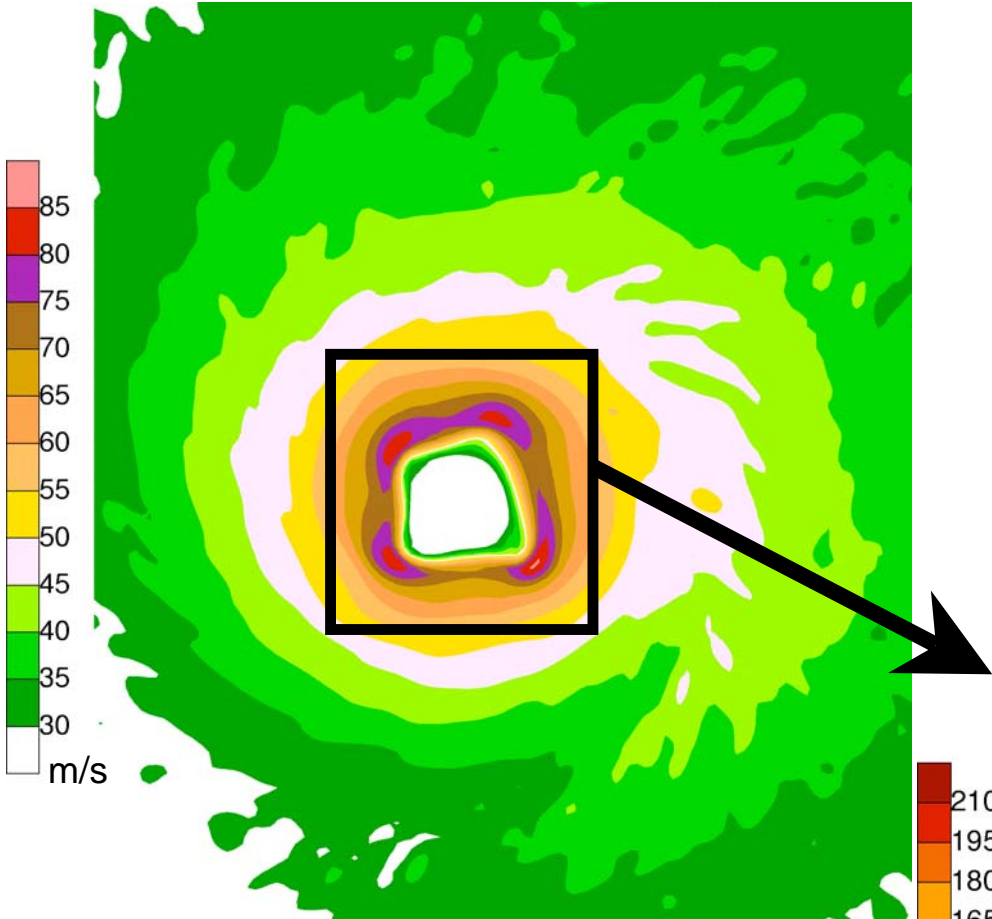


**Schubert et al.
(1999)**

**Barotropic,
unforced
simulation of
the evolution of
an elevated
ring of vorticity
similar to a
hurricane
eyewall**

Ring
↓
Monopole

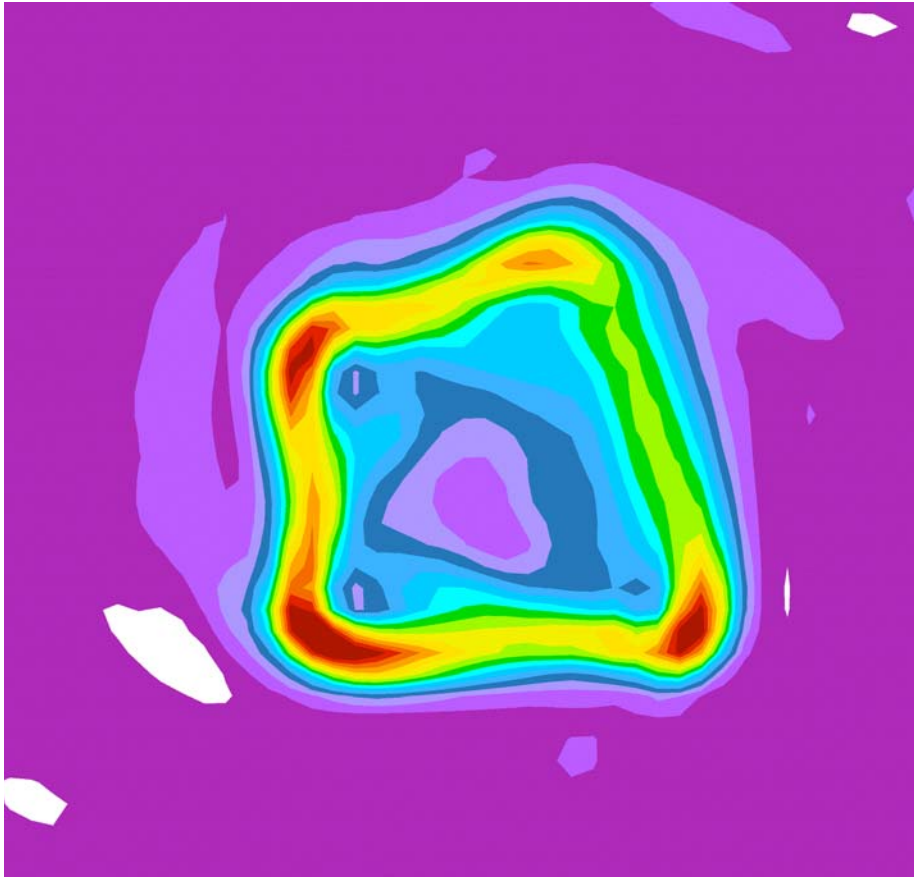
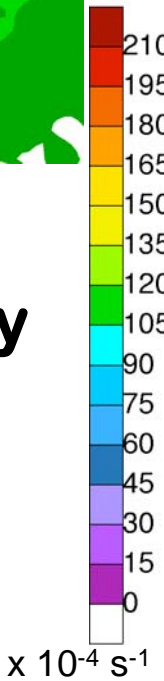
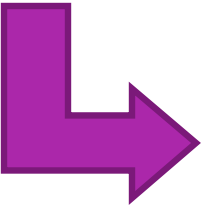
Katrina 1.33 km WRF

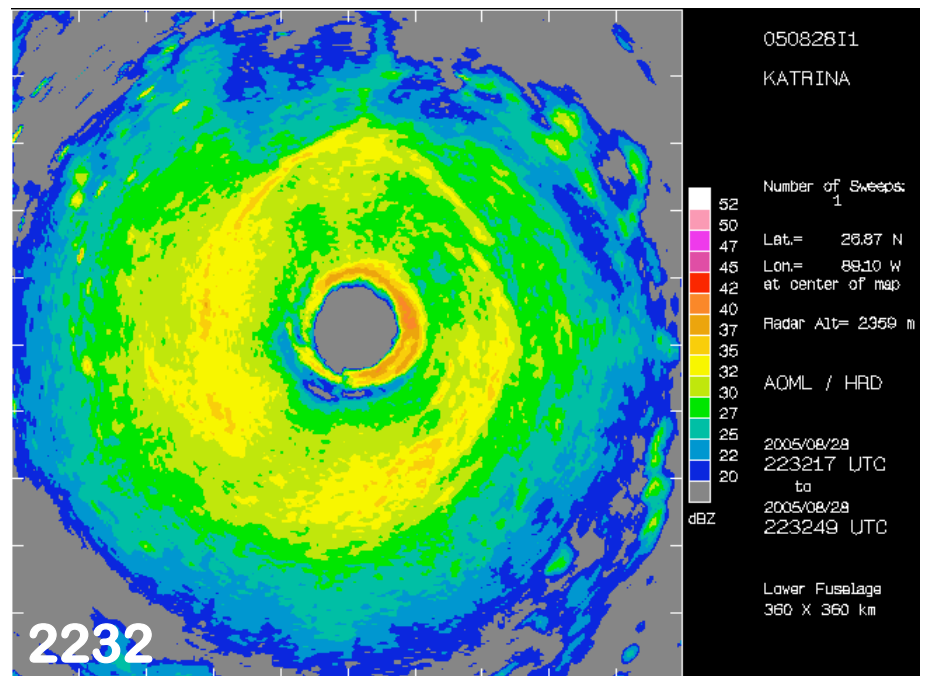
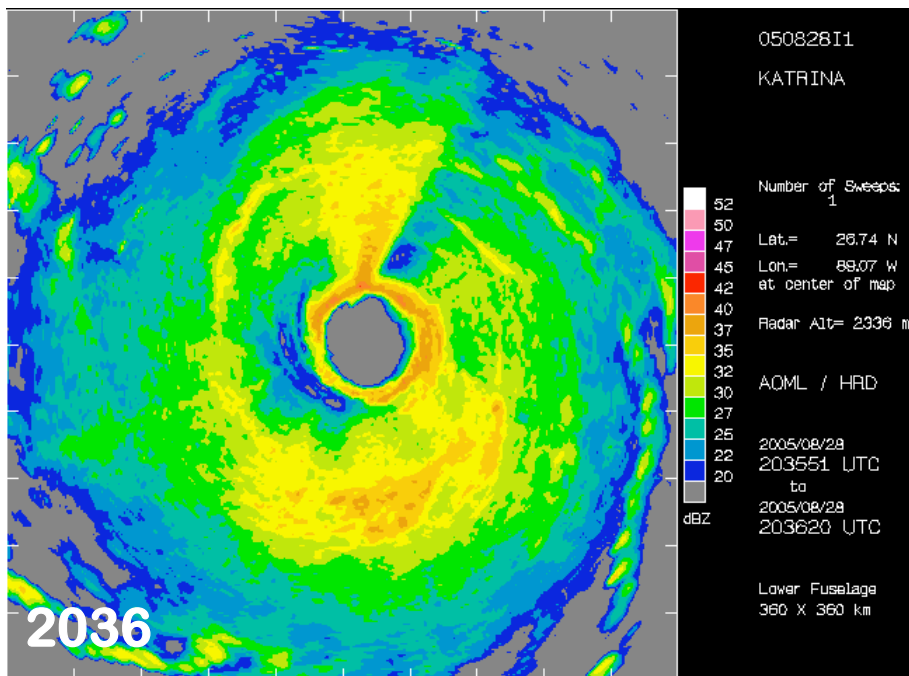
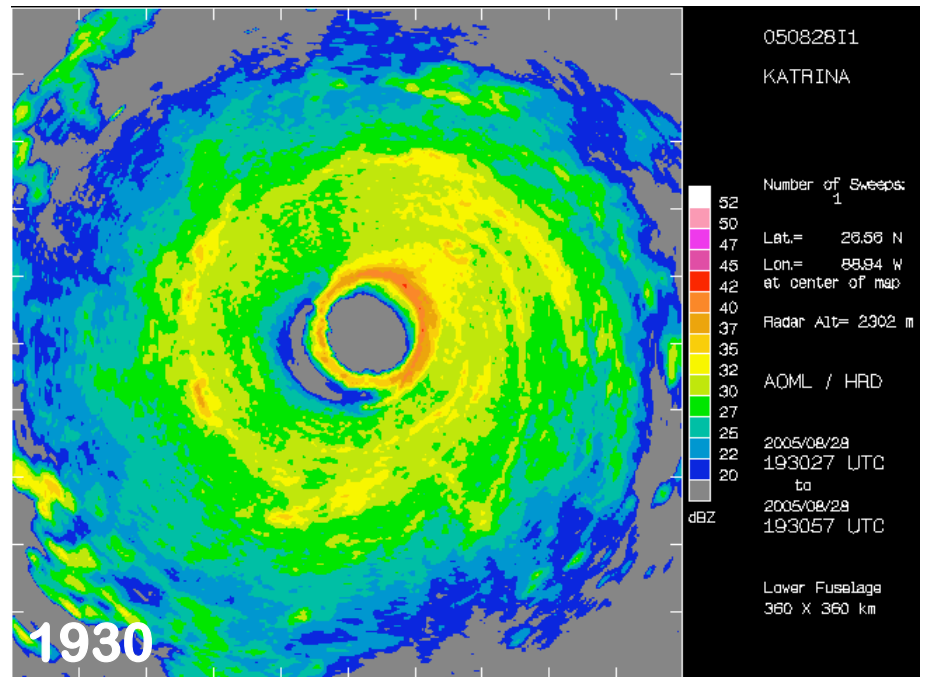
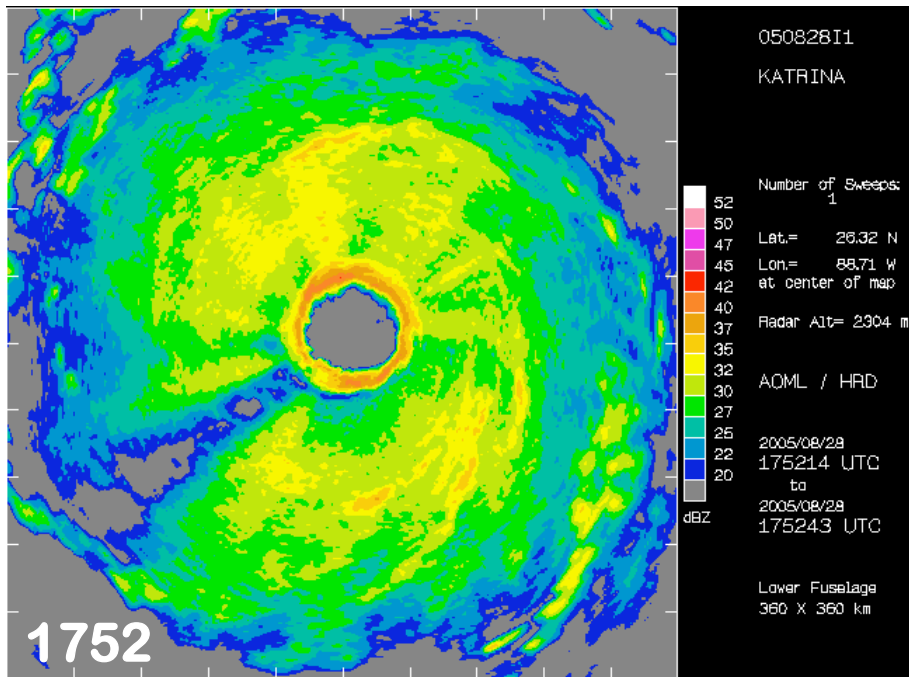


900 hPa wind speed

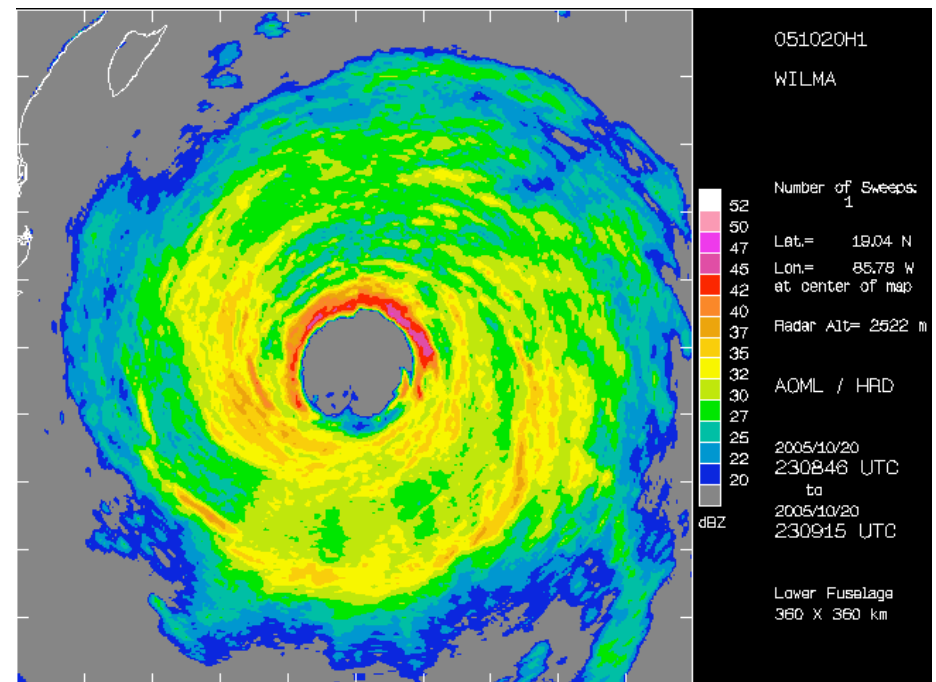
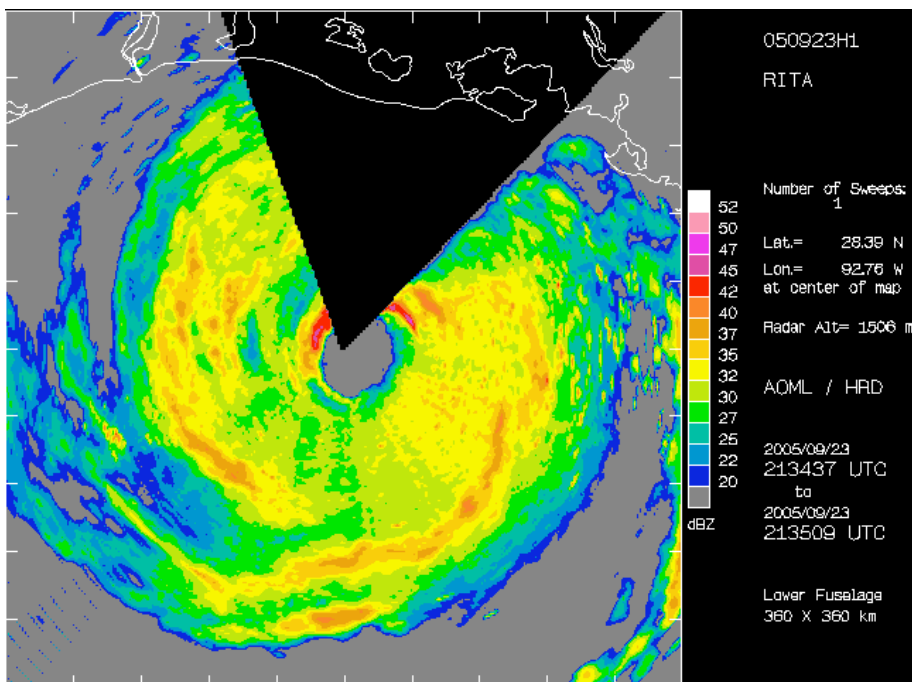
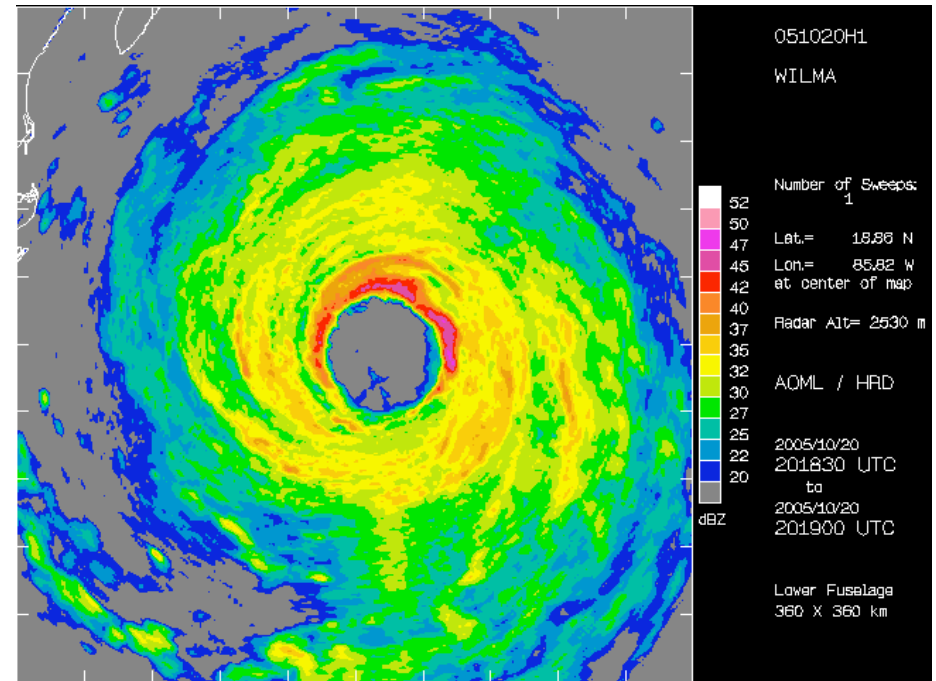
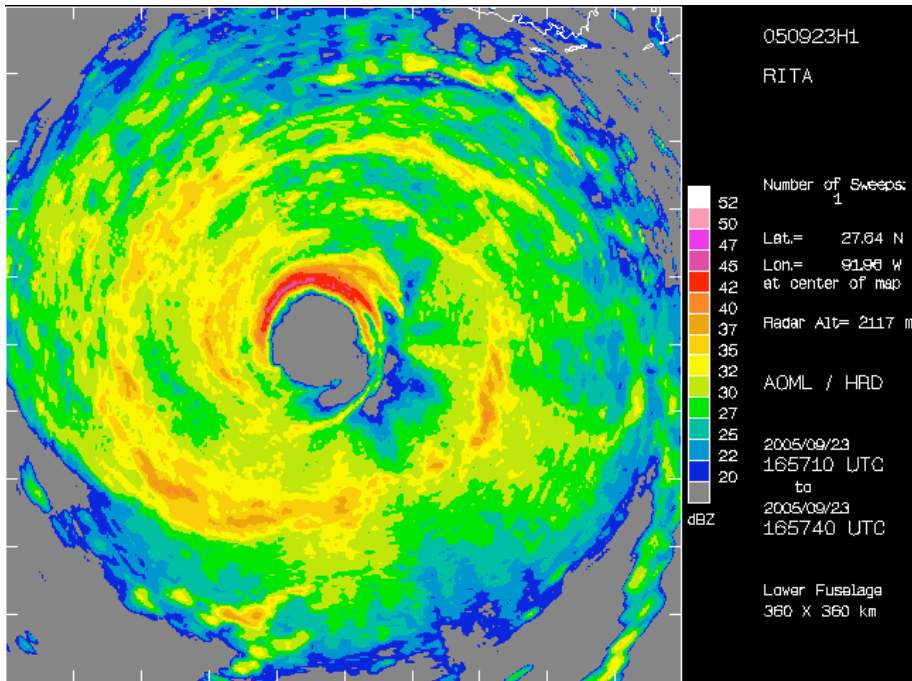


900 hPa relative vorticity

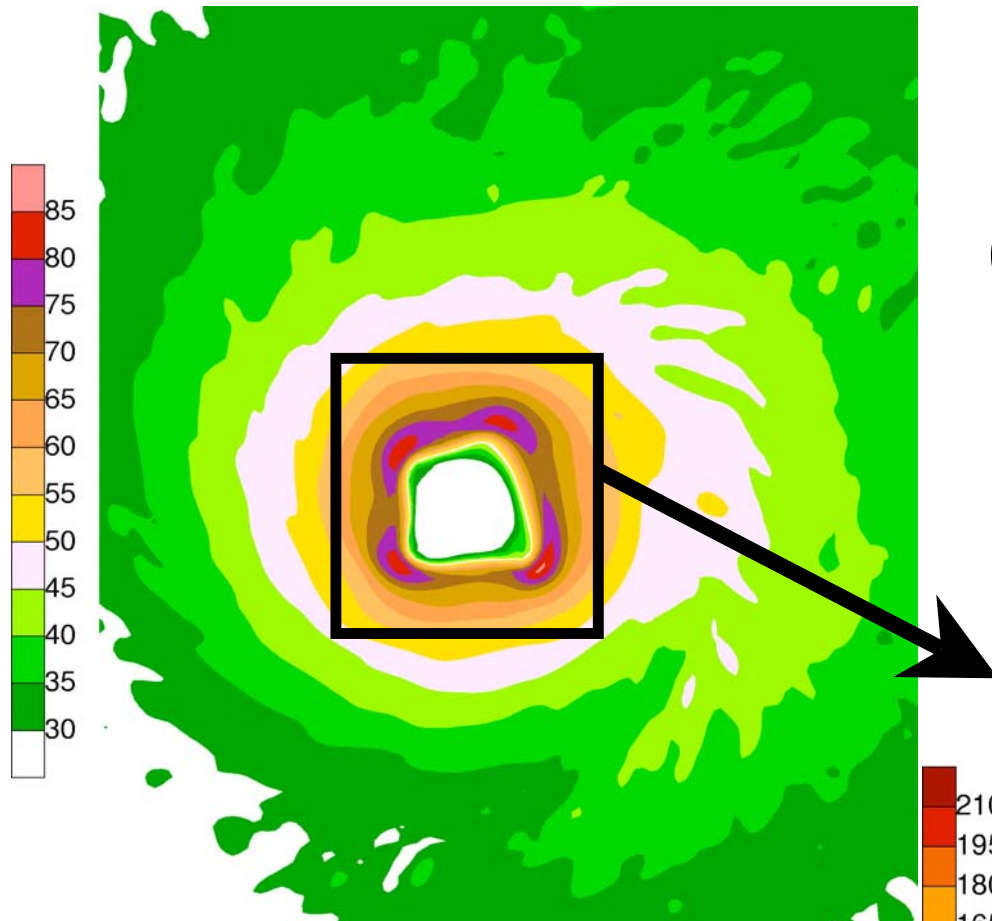




HRD/AOML/NOAA

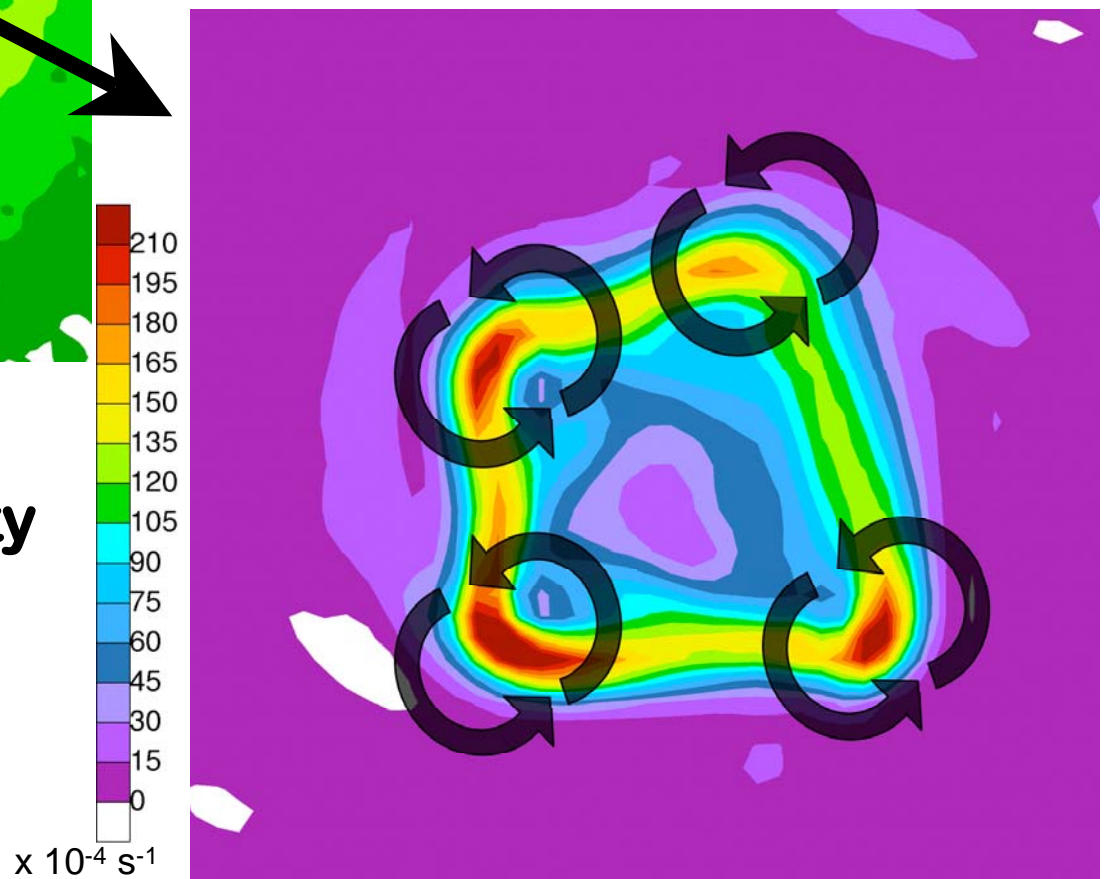
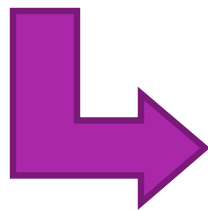


HRD/AOML/NOAA

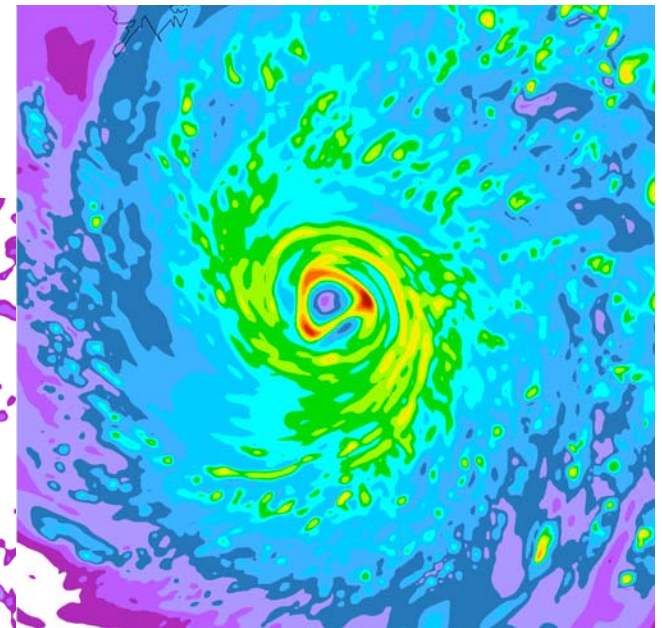
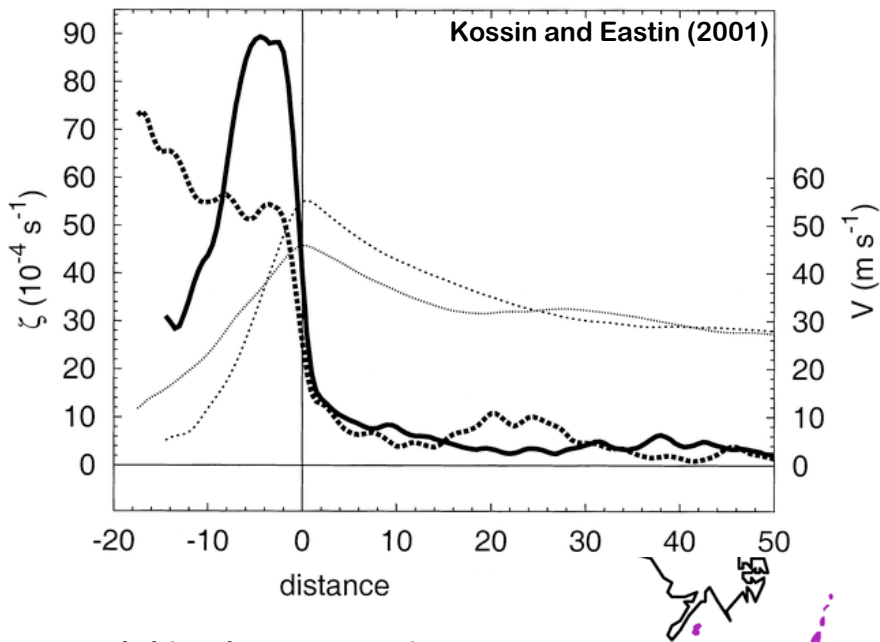


Each vorticity maximum (mesovortex) acts to mix air between the eye and the eyewall

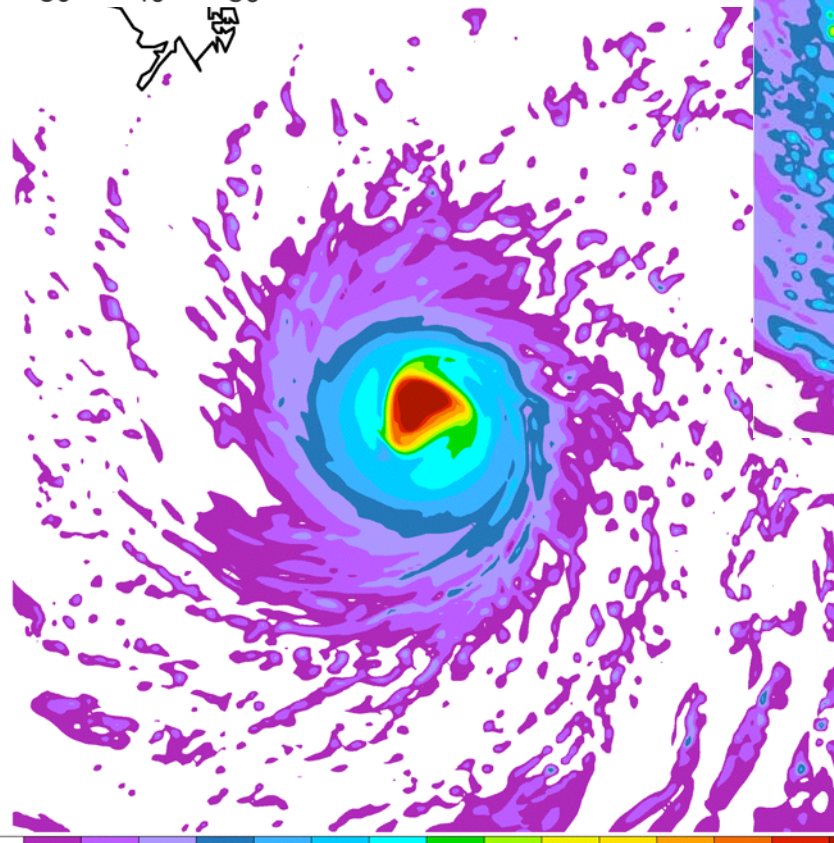
900 hPa relative vorticity



Vorticity mixing spins down the winds in the eyewall and spins up the winds in the eye, reducing TC intensity, **BUT...**



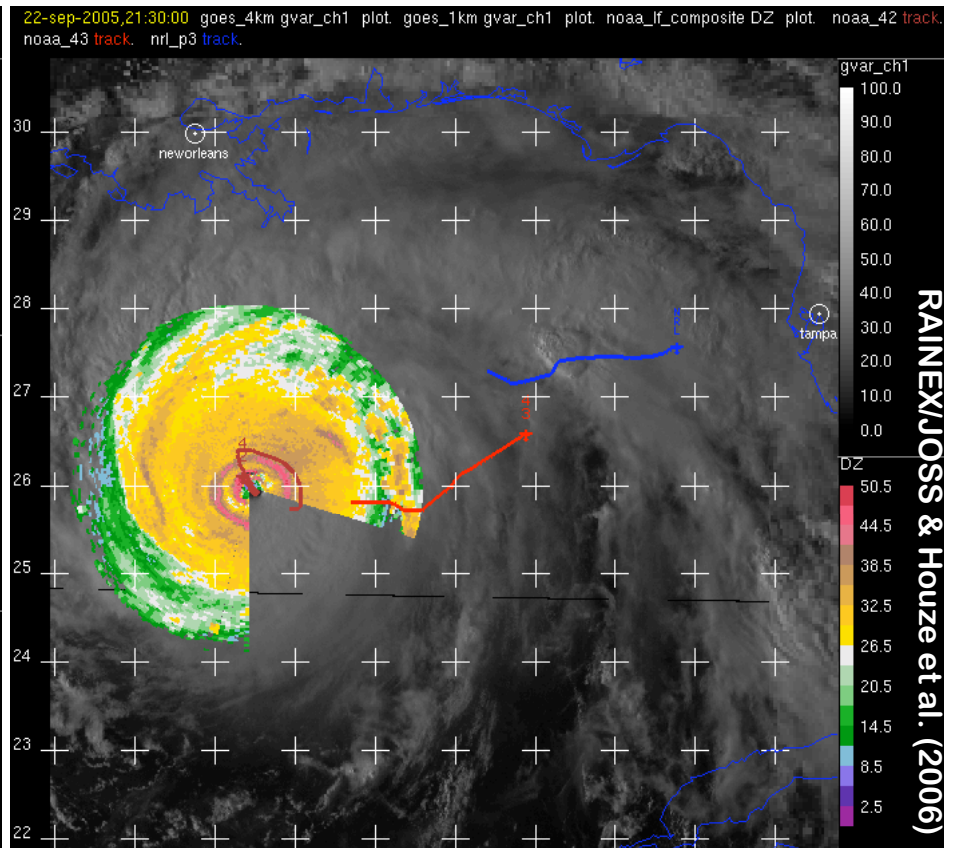
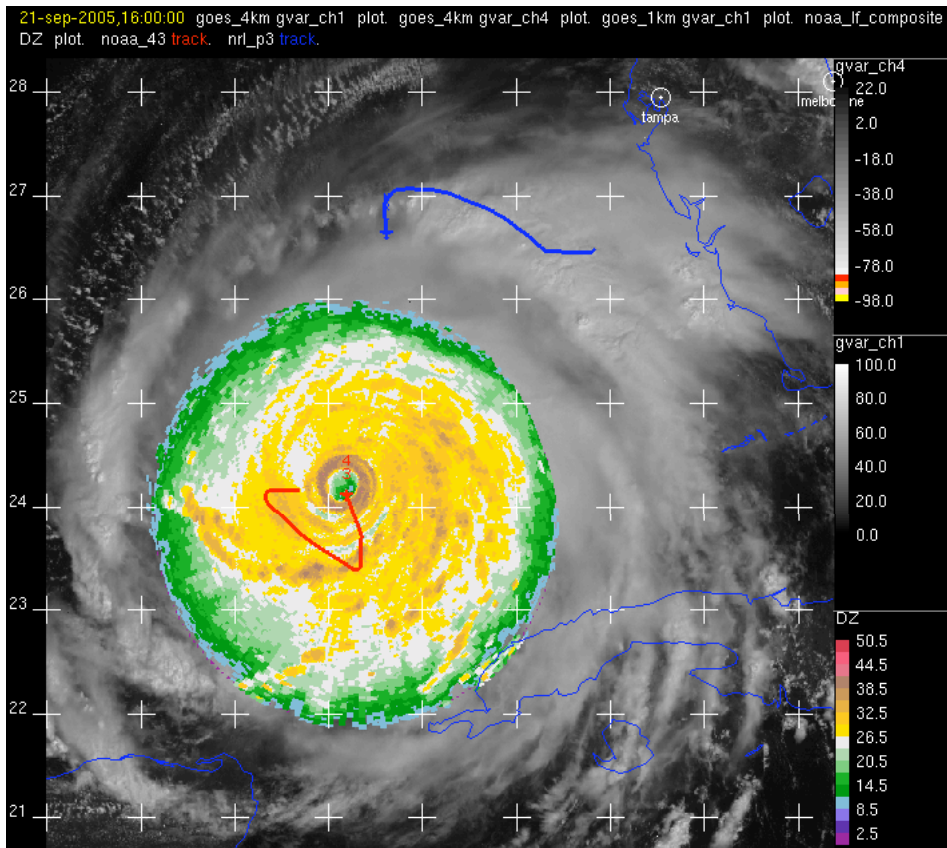
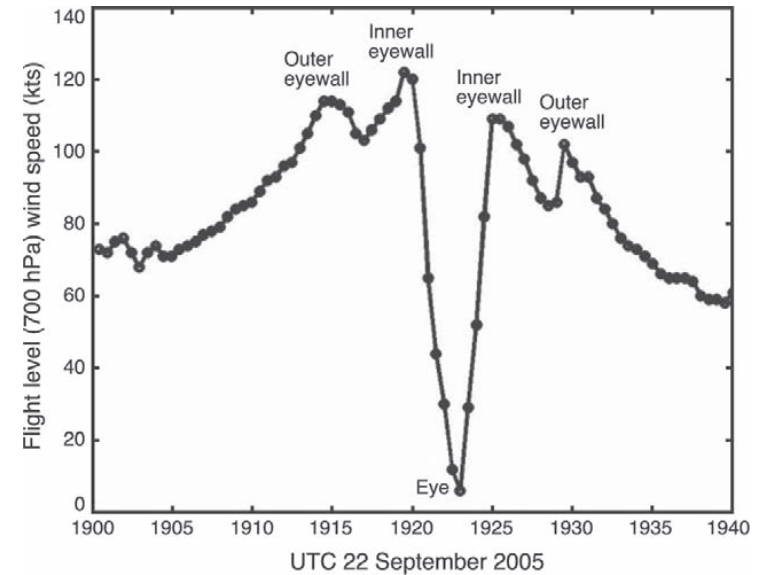
High Θ_e air (warm, juicy) is also mixed out of the eye, into the eyewall, feeding deep convection which can increase TC intensity



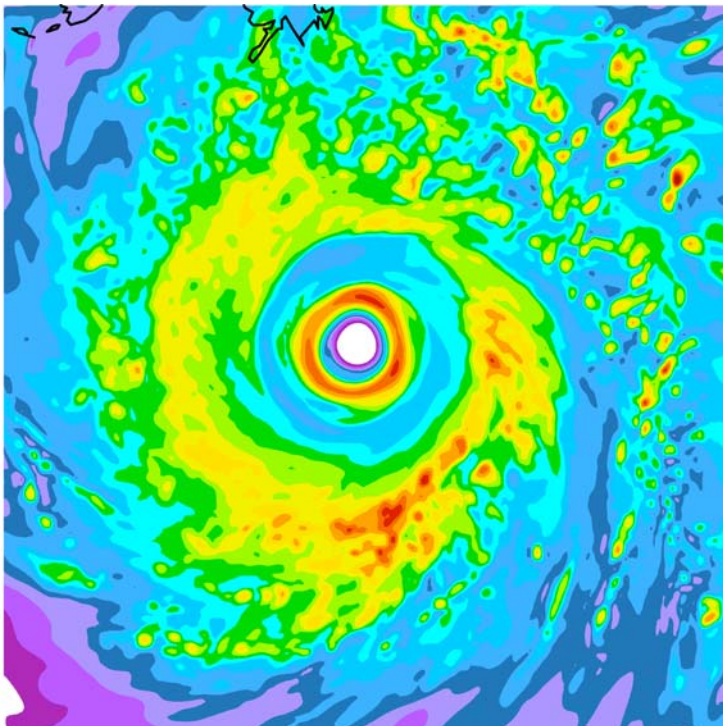
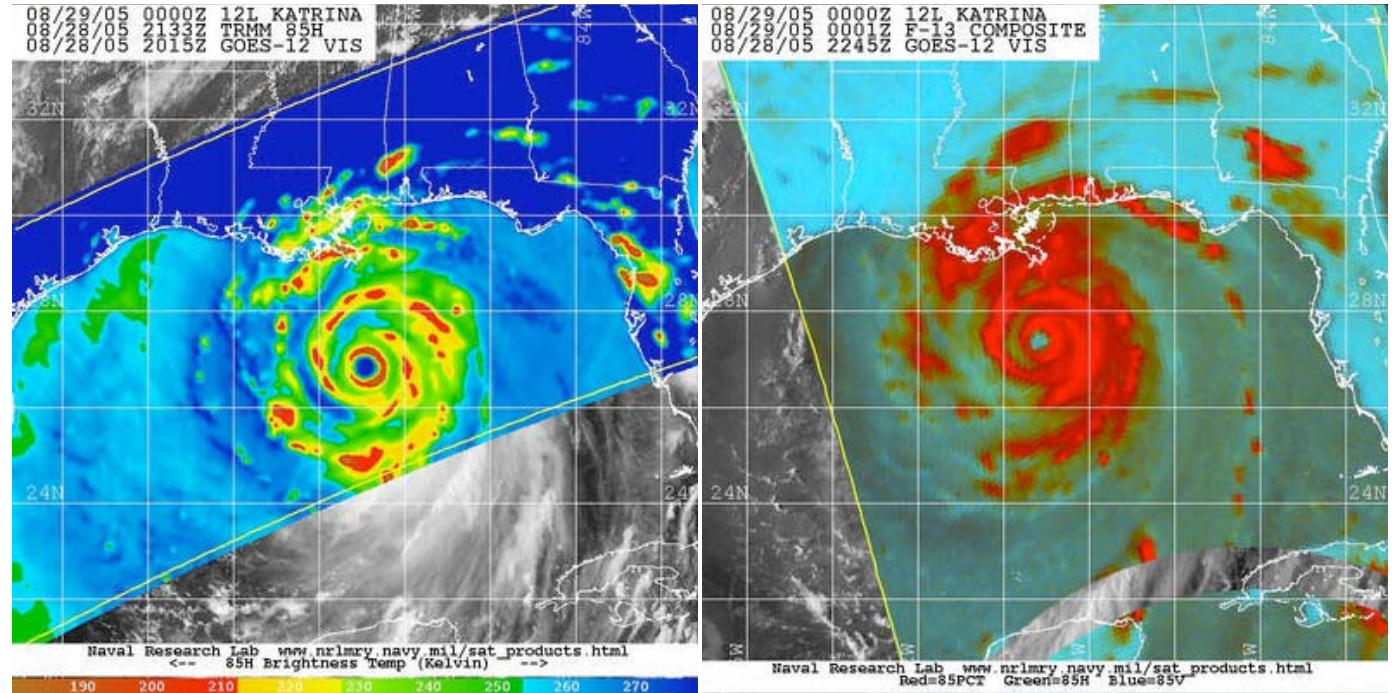
Katrina (2005) Precipitable water (top) and equivalent potential temperature (Θ_e)



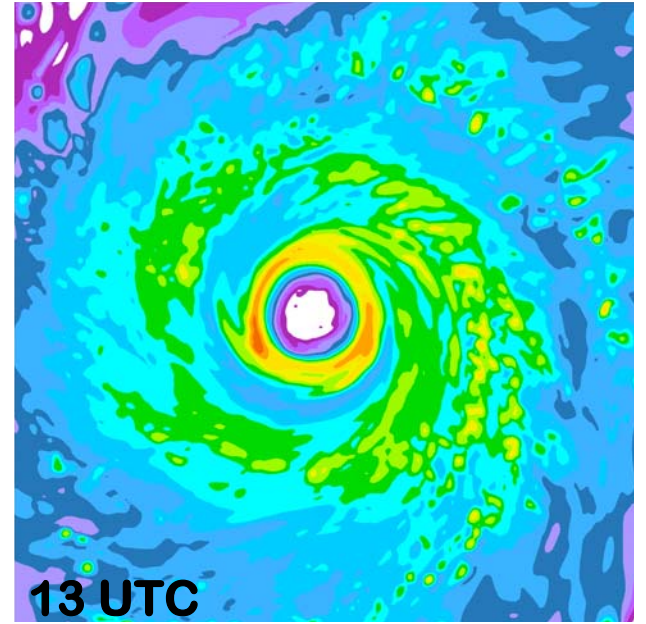
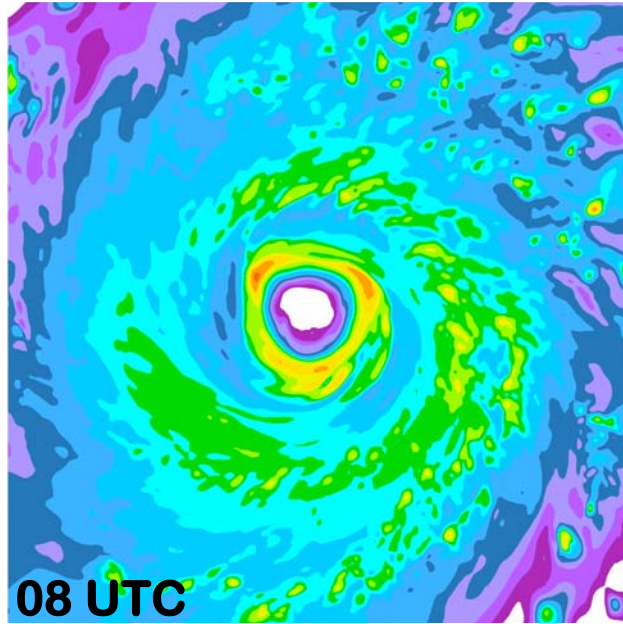
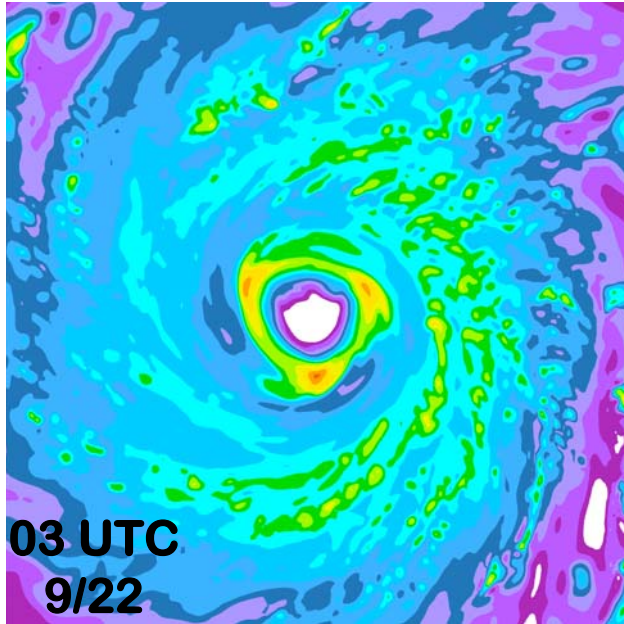
The rainbands outside the eyewalls of some (most?) intense hurricanes coalesce to form a secondary ring of high winds and reflectivity, called an outer or secondary eyewall



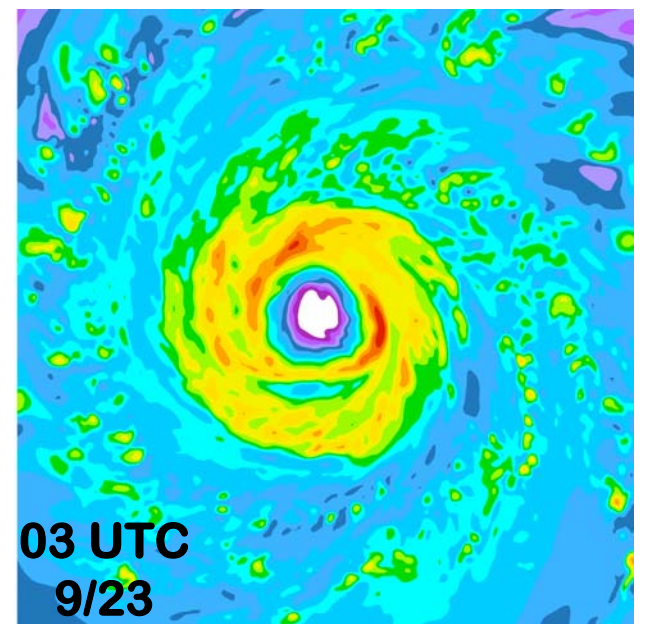
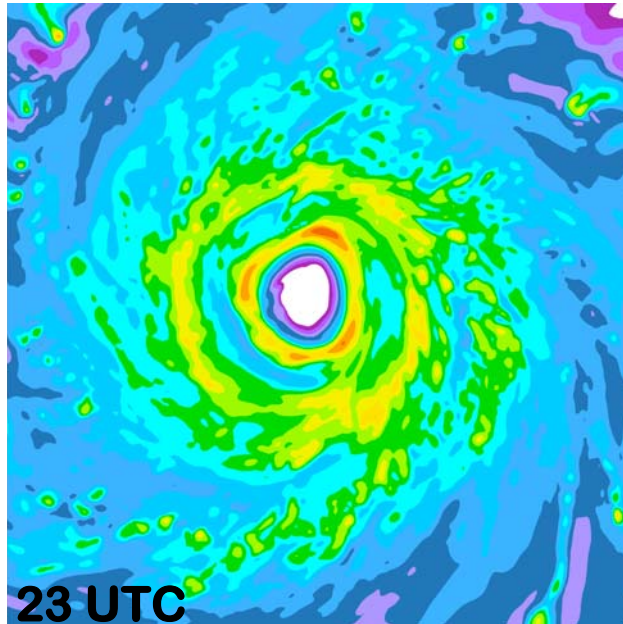
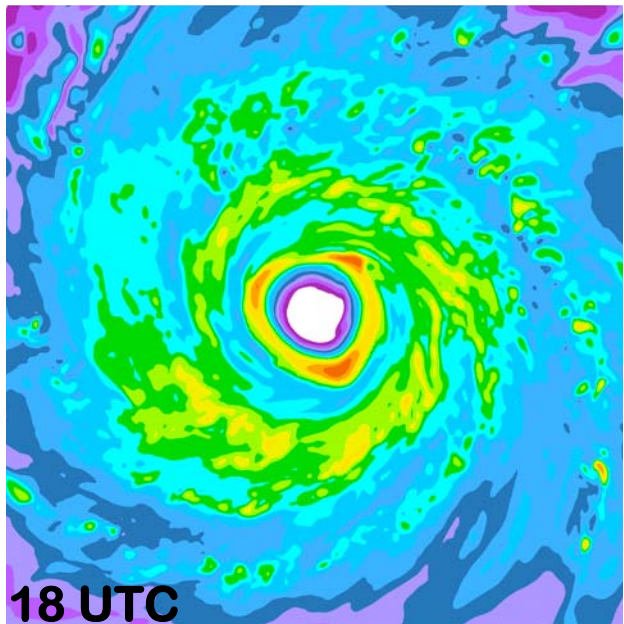
RAINEX/JOSS & Houze et al. (2006)

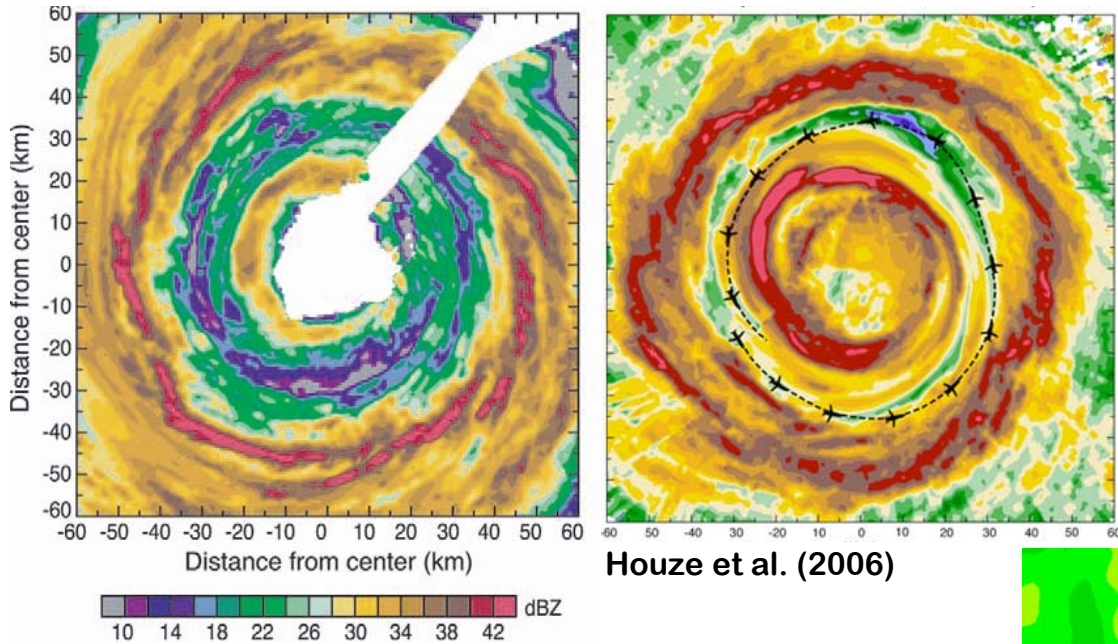


In 2005, both Hurricanes Katrina and Rita exhibited secondary eyewalls. These were captured by the RAINEX field campaign and TRMM satellite (above), and in the WRF 1.33 km forecast run of Katrina (right).



**Secondary eyewall formation & contraction
Hurricane Rita 1.33 km WRF**

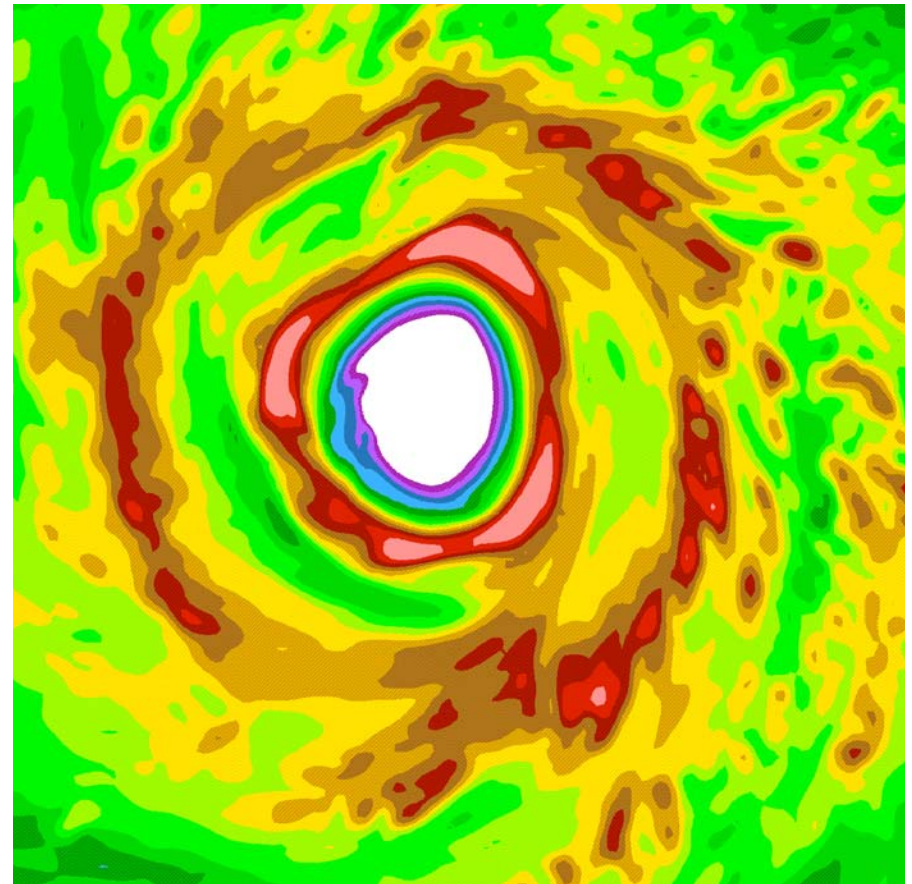




**ELDORA radar
Hurricane Rita
Eyewall replacement
cycle
17 & 18 UTC 9/22**

**1.33 km WRF simulated
Precipitable water
Hurricane Rita
23 UTC 9/22**

**But how do secondary
eyewalls form?**



Questions, Unresolved Issues and Future Work

- **Are model numerics and parameterizations playing a role in the abundance of unusually shaped eyewalls in the WRF simulations?**
- **Will 1.33 km WRF TCs always be too weak due to an abundance of eyewall asymmetries, or can mixing of high entropy air between the eye and eyewall act as an offset?**
- **What are the mechanisms by which secondary eyewalls are formed in the 1.33 km WRF simulations? Do these match observations?**
- **Many other fascinating questions waiting to be answered...**

A satellite image of a tropical cyclone, showing a central eye and concentric cloud bands. The image is overlaid with a red crosshair. The text "THANK YOU!" is written in large, bold, red capital letters across the center of the storm. A yellow outline of a landmass is visible on the left side of the image.

THANK YOU!