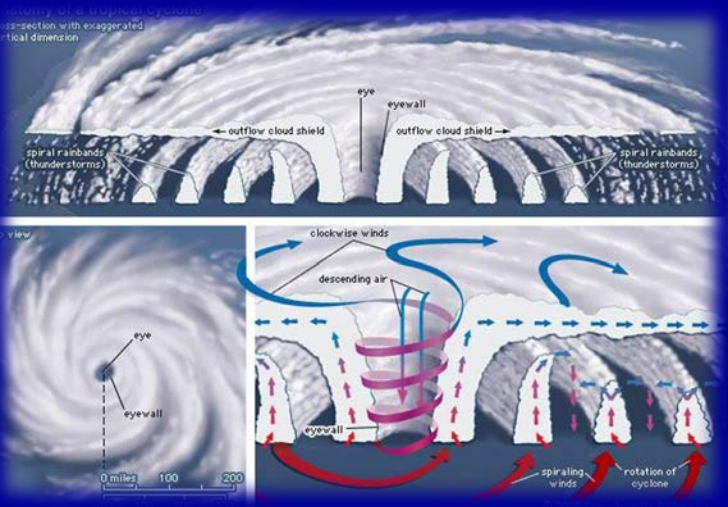
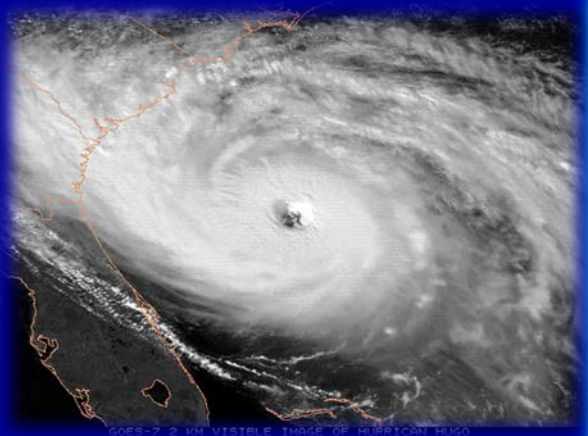
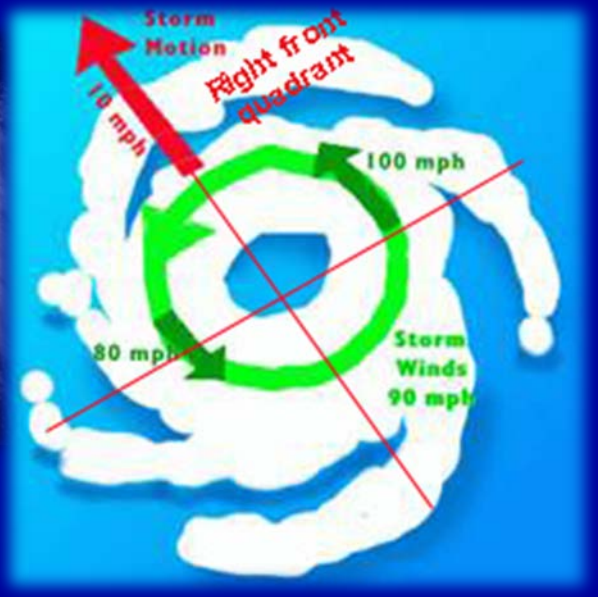
# Hurricane Structure: Theory and Application



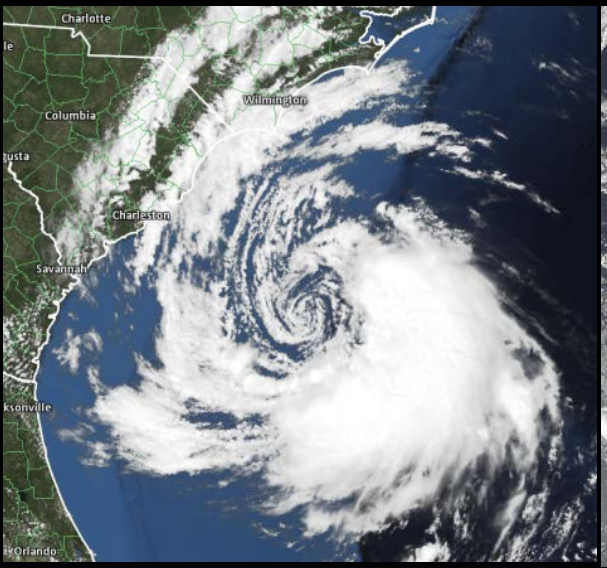

Matt Onderlinde

National Hurricane Center

Special Thanks: John Cangialosi

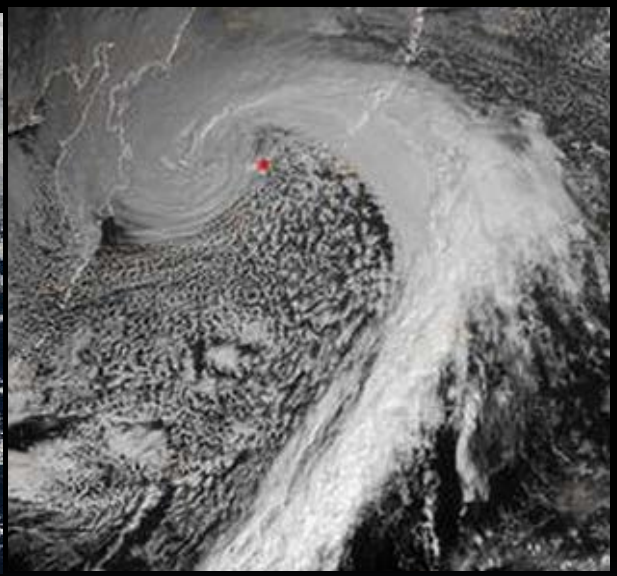
**World Meteorological Organization Workshop**

# Is this Tropical, Subtropical, or Extratropical?




Subtropical

Tropical



Extratropical

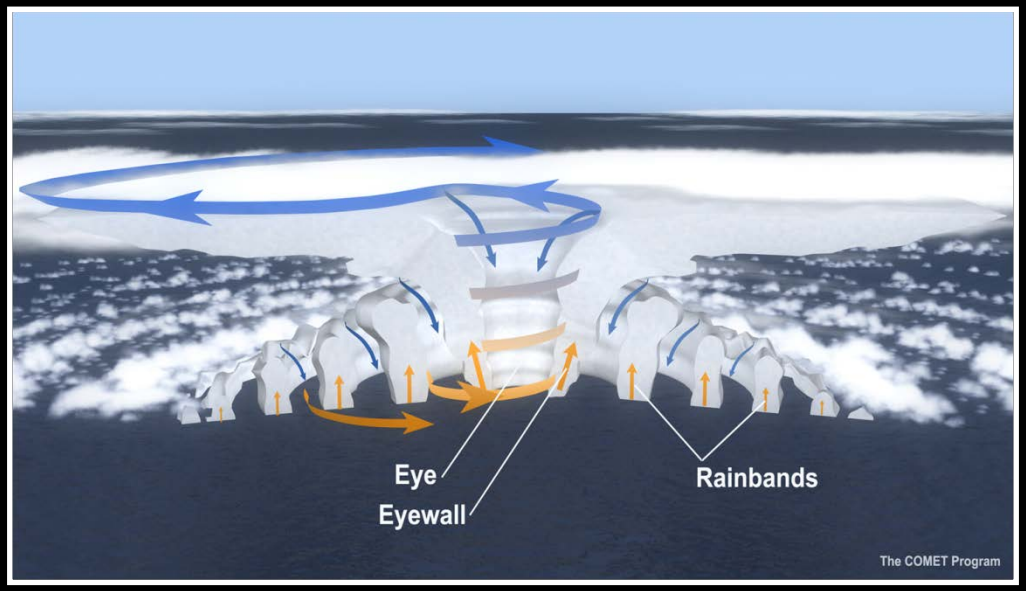
# Is this Tropical, Subtropical, or Extratropical?

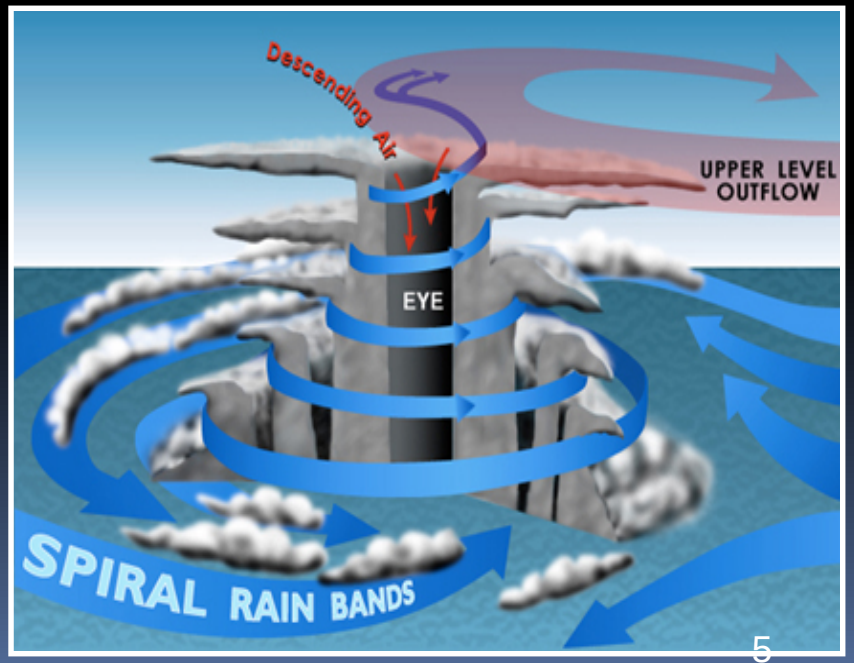

6:11 PM

# Intensity and Structure Parameters that NHC analyzes and predicts

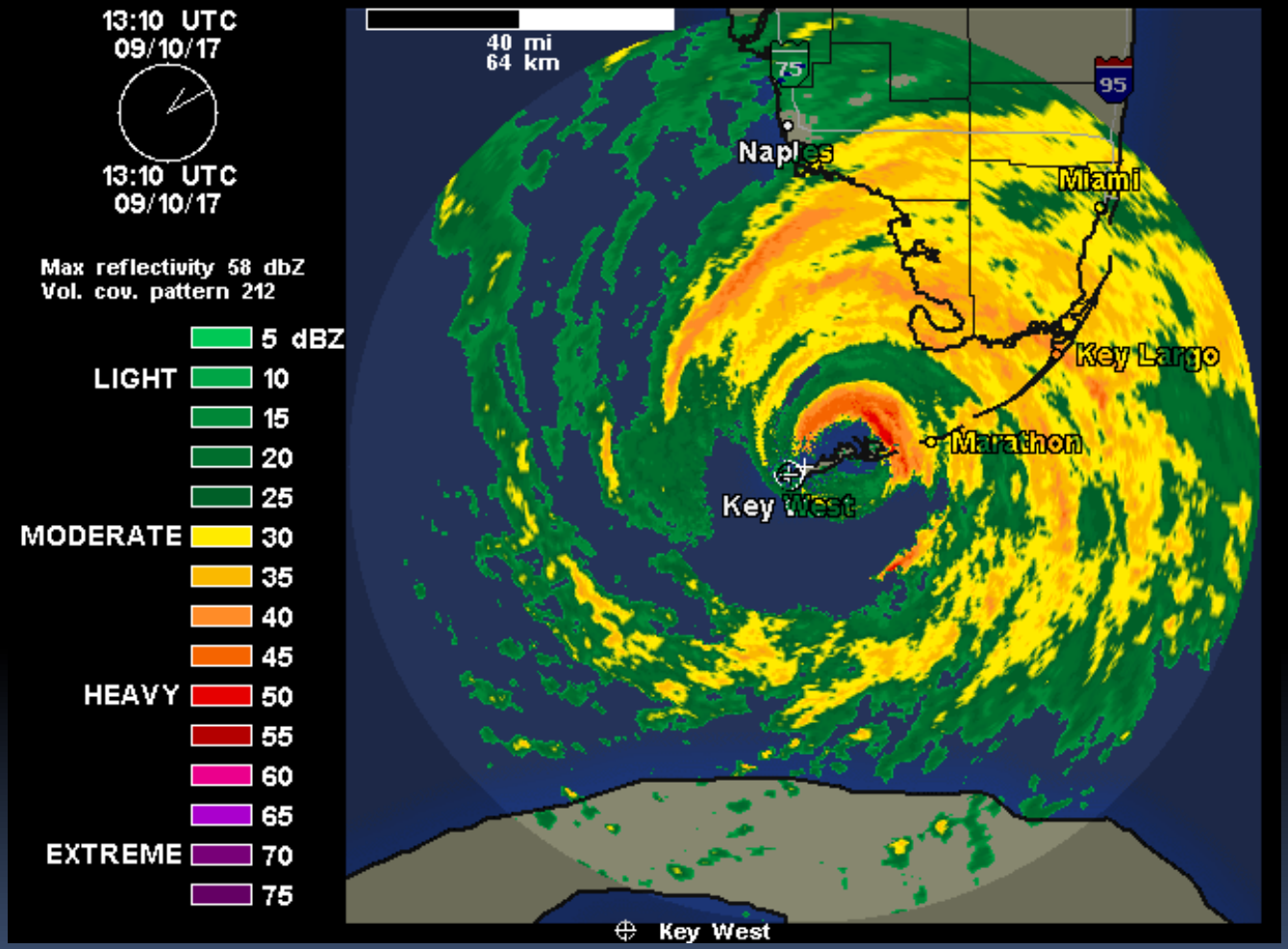
- Maximum Wind Speed
- Radius of 34-,50-,64-kt winds
- Minimum Pressure
- Radius of Maximum Wind
- Radius of the Outermost Closed Isobar

# Structure of a Hurricane

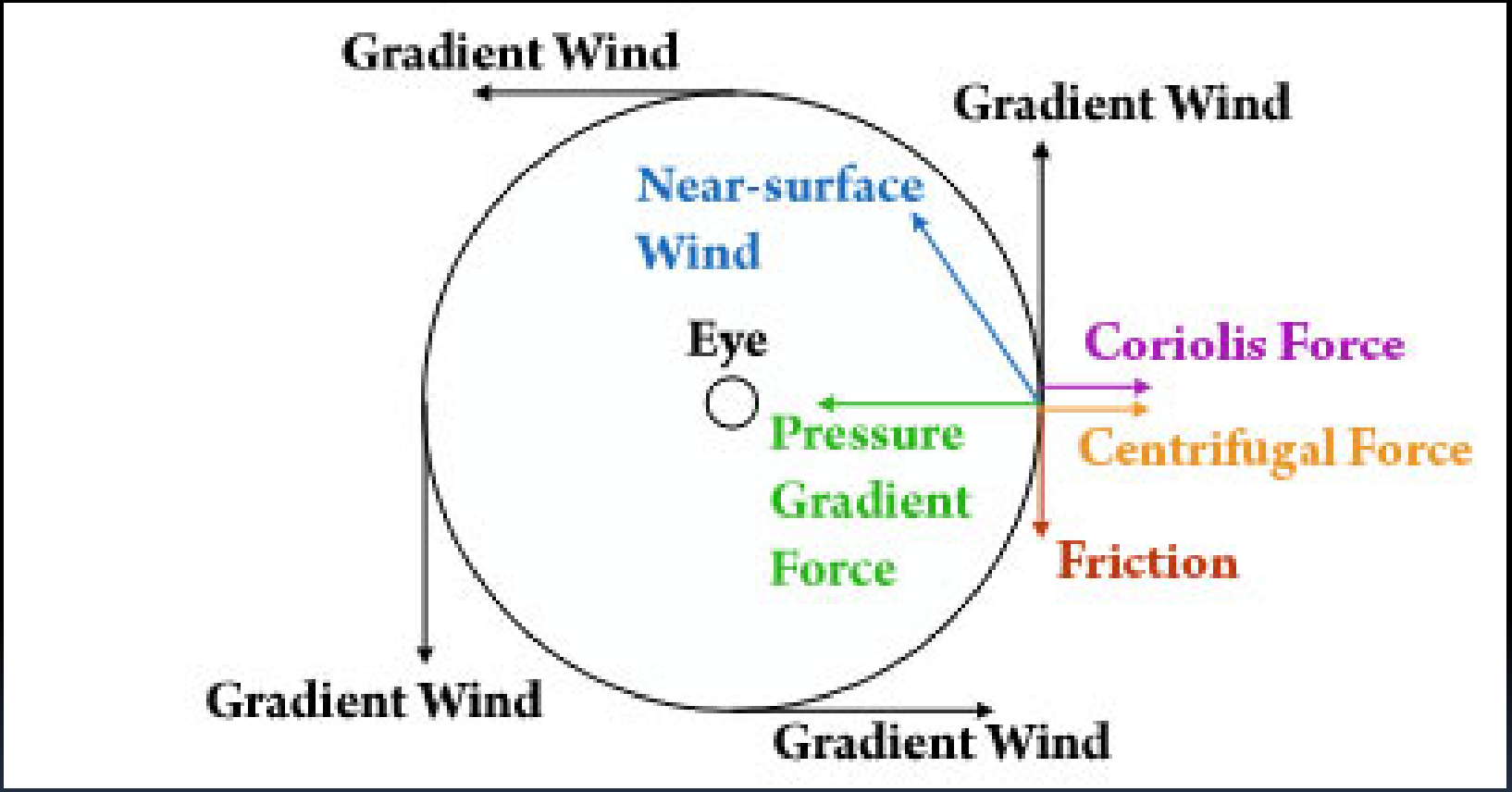


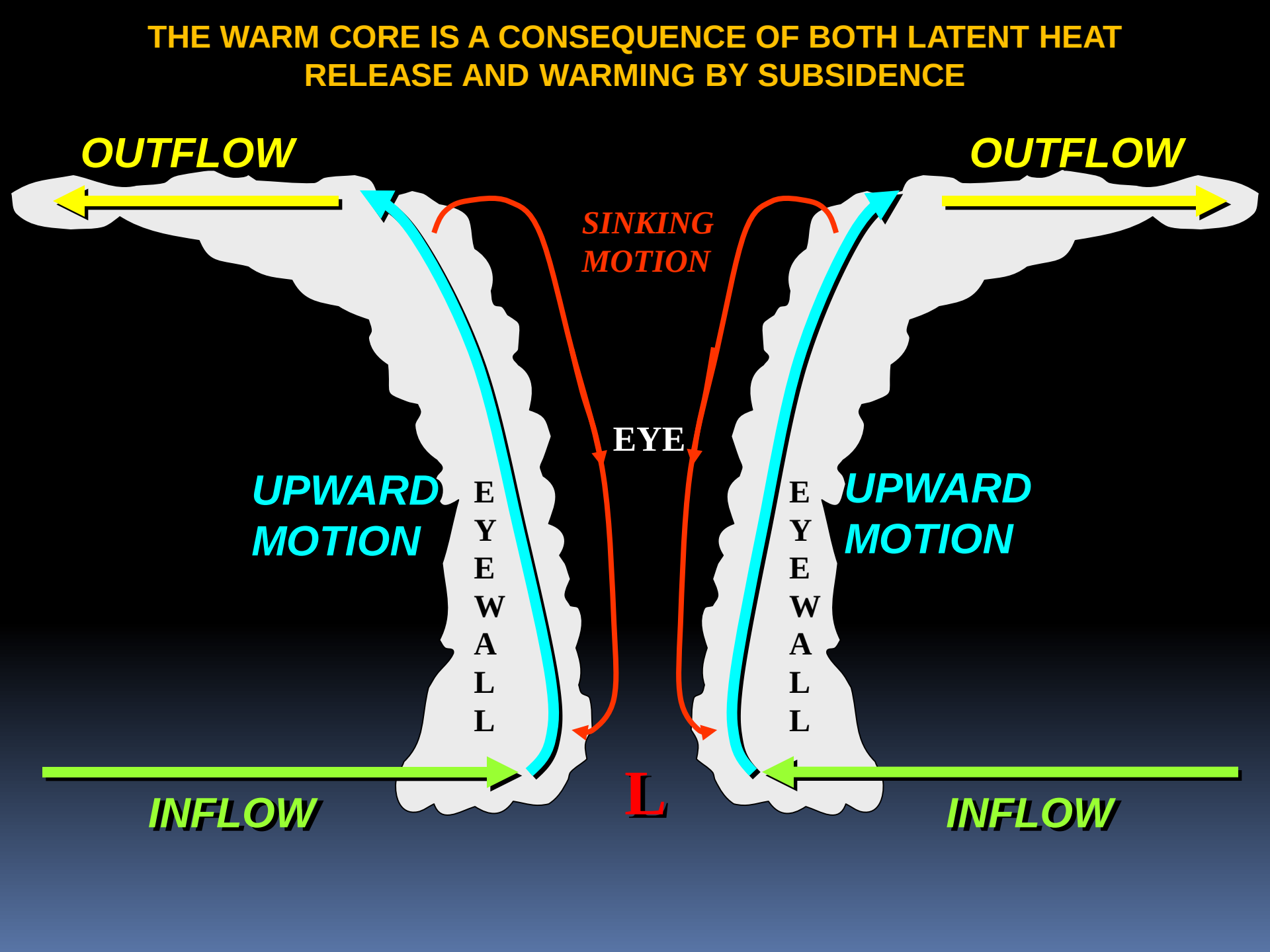
# Hurricane Structure

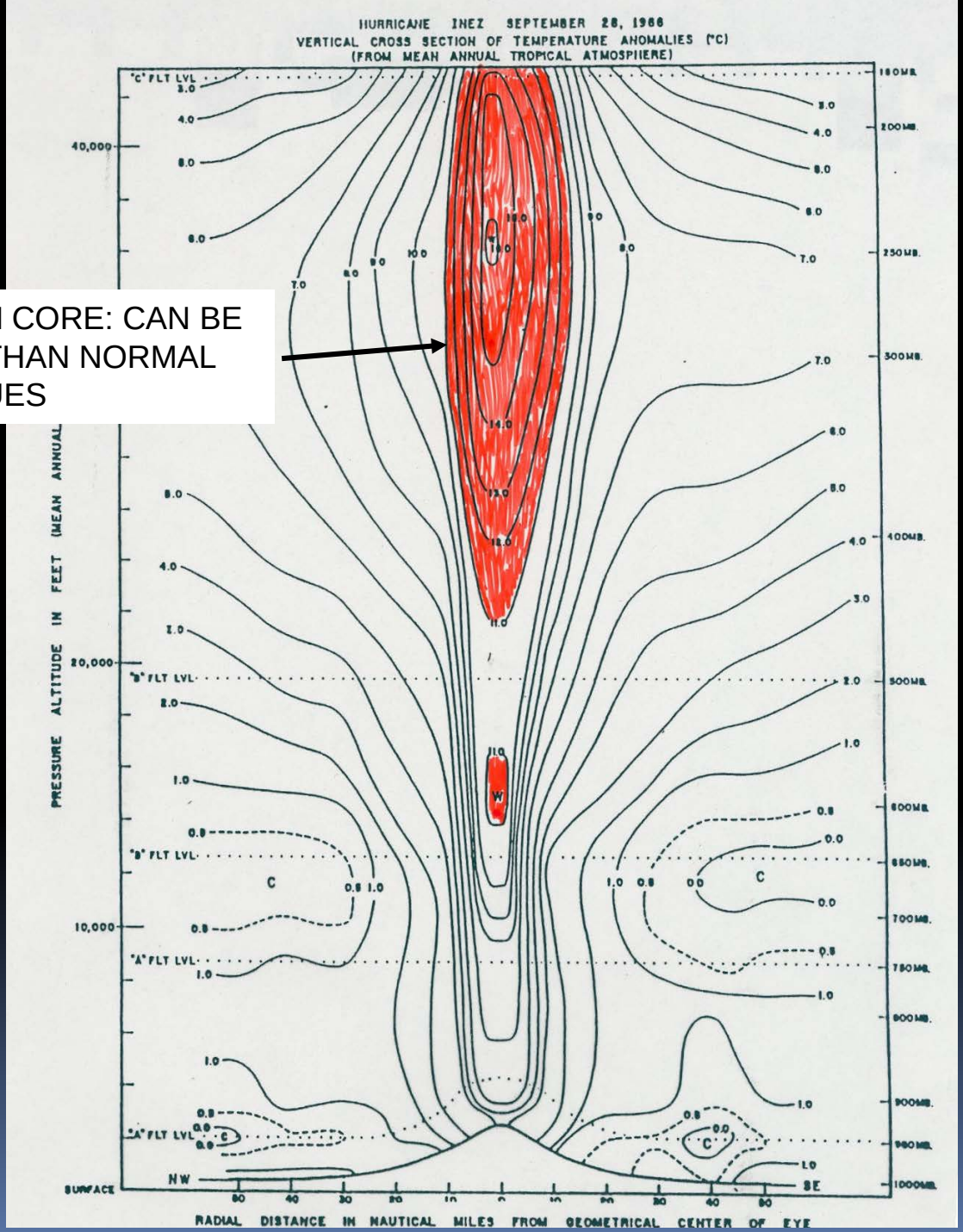


# Primary Circulation



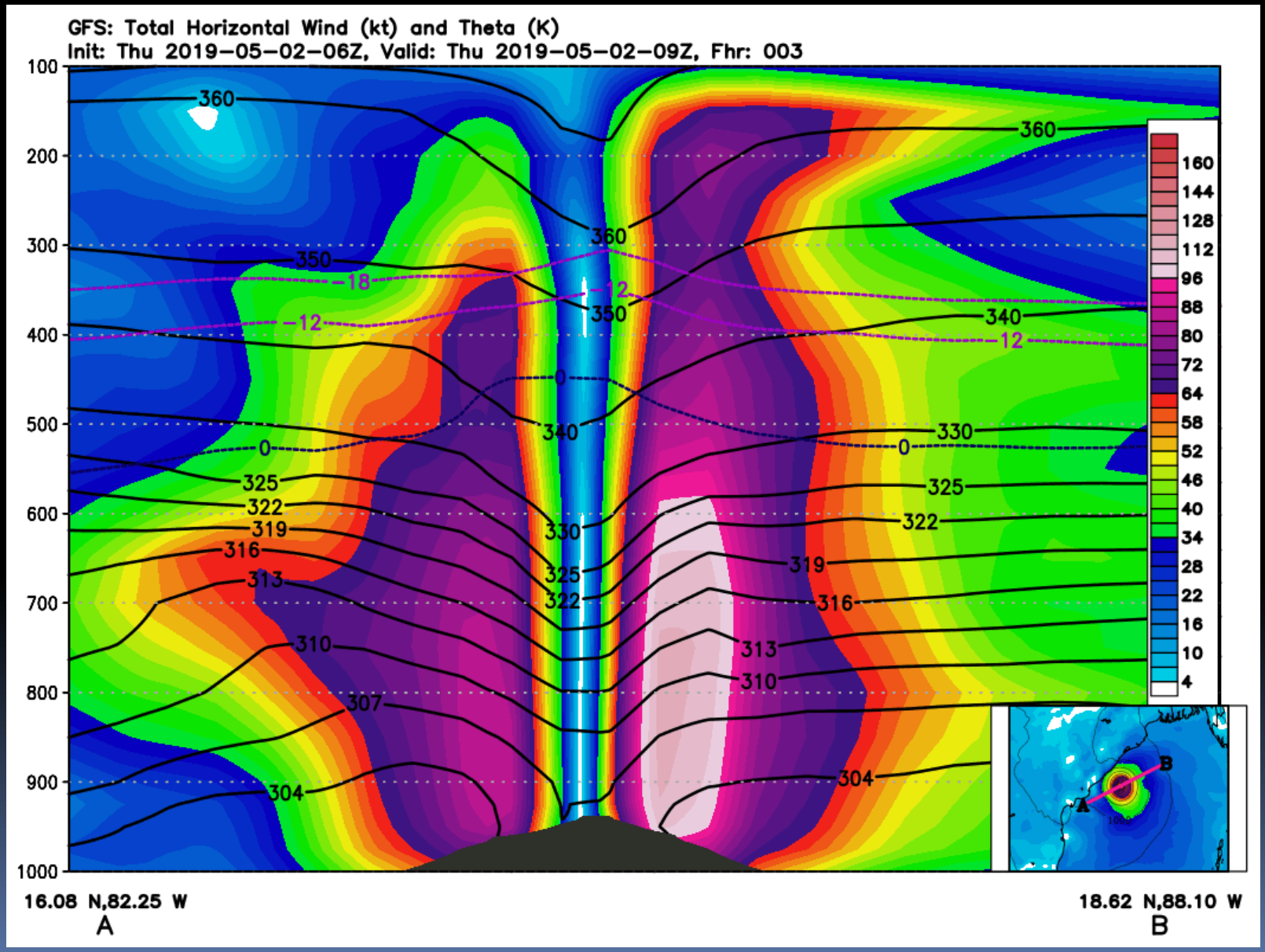
# THE WARM CORE IS A CONSEQUENCE OF BOTH LATENT HEAT RELEASE AND WARMING BY SUBSIDENCE

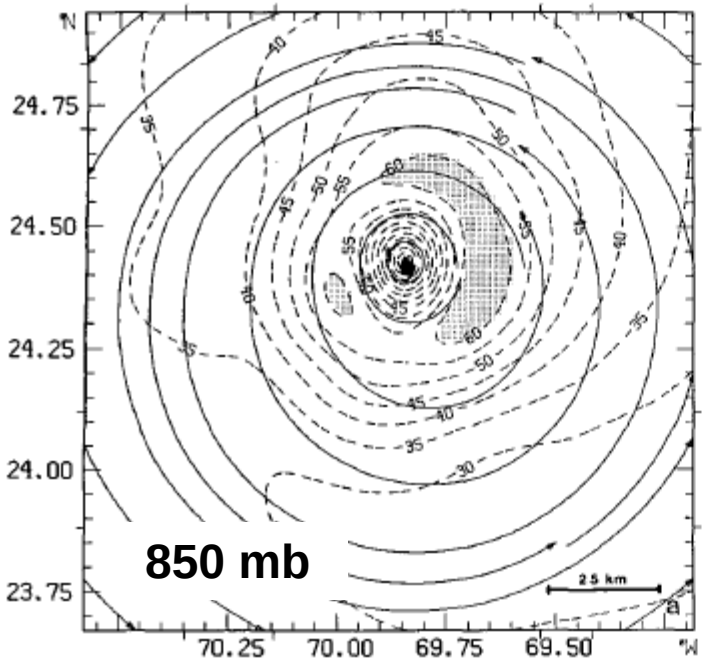


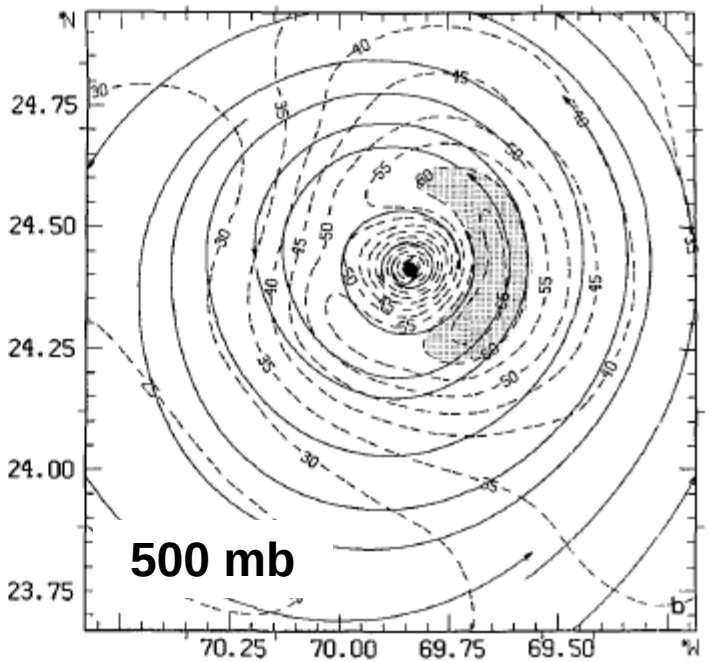


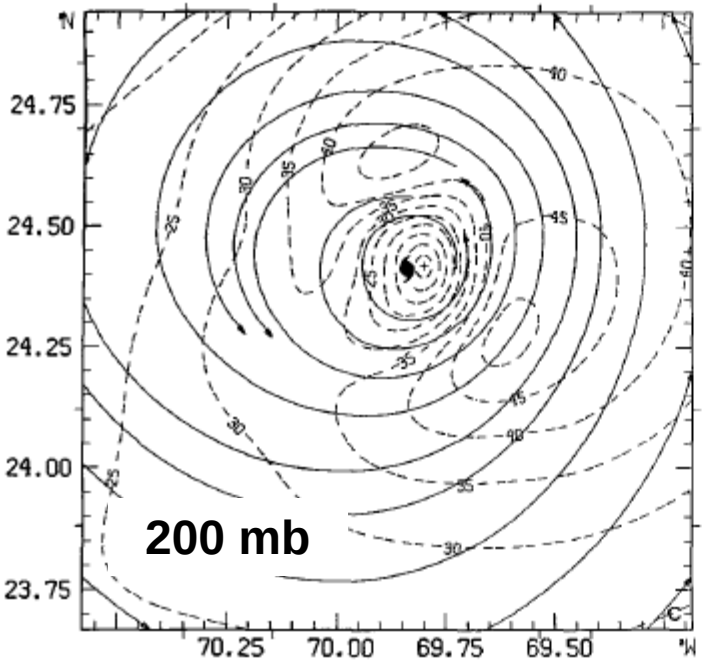

INTENSE WARM CORE: CAN BE 16 K WARMER THAN NORMAL TROPICAL VALUES

# DEEP-LAYER CYCLONIC CIRCULATION



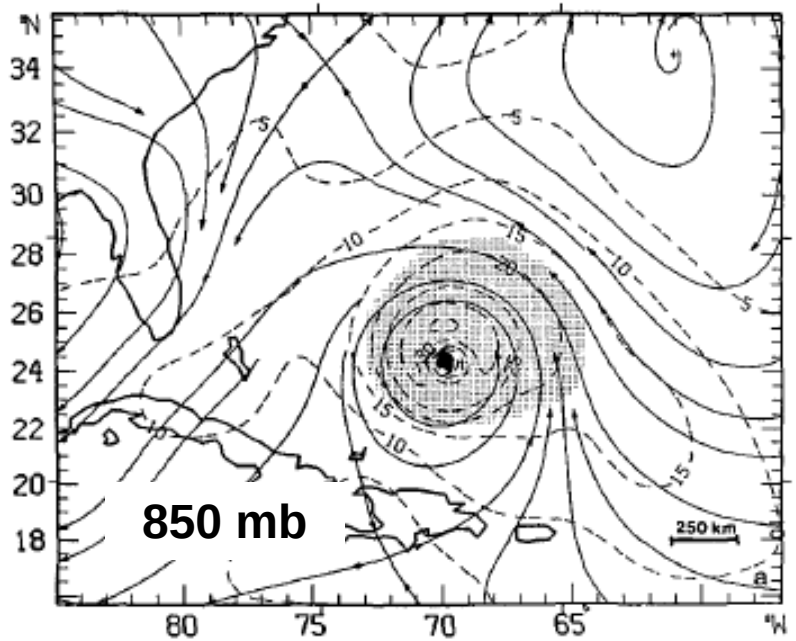


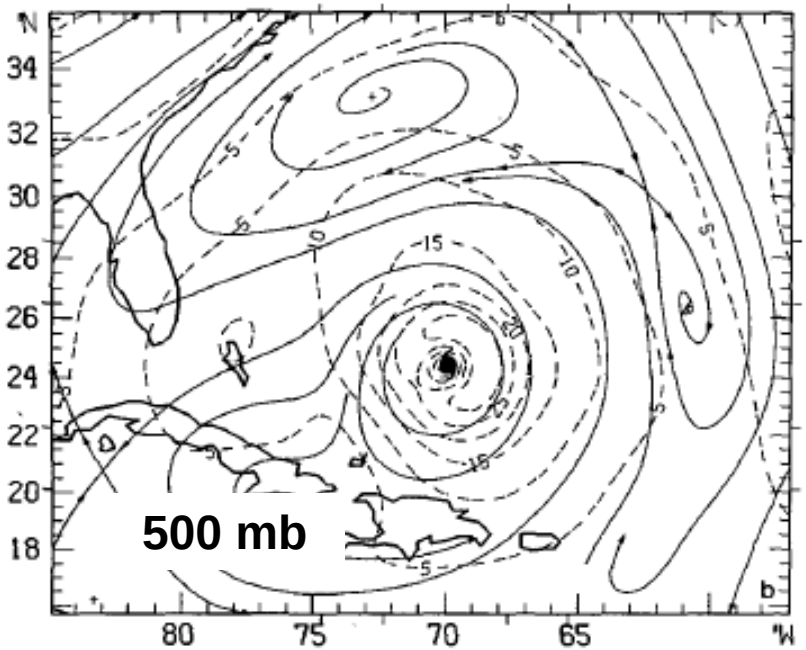



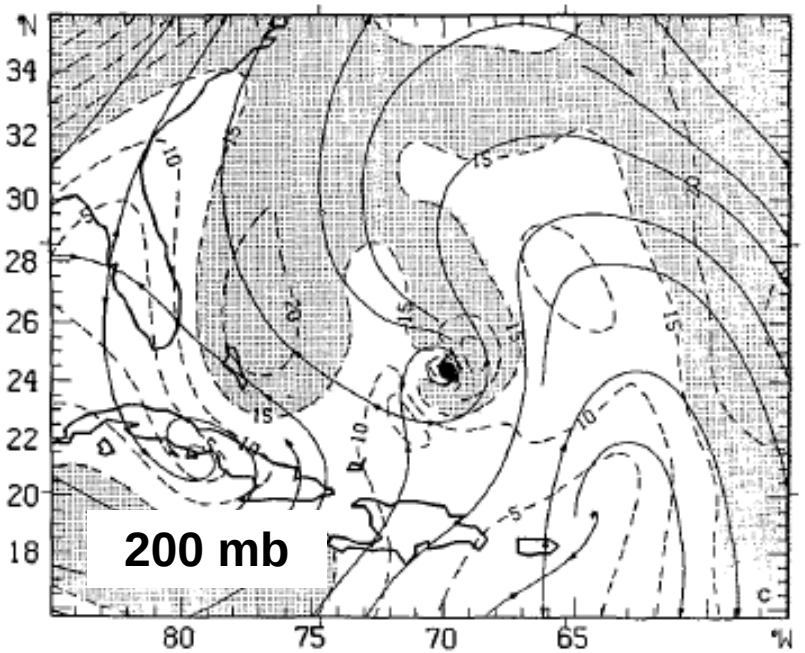




**NOTE: CYCLONIC CIRCULATION AT UPPER-TROPOSPHERIC LEVEL, WITHIN A FEW DEGREES RADIUS OF THE CENTER!**

FIG. 4. Analysis of wind (streamlines and isotachs) on meshes 1–3 for (a) 850, (b) 500, and (c) 200 mb. Isotachs are at 5 m $s^{-1}$ intervals. Shading indicates wind speeds greater than 60 m $s^{-1}$.



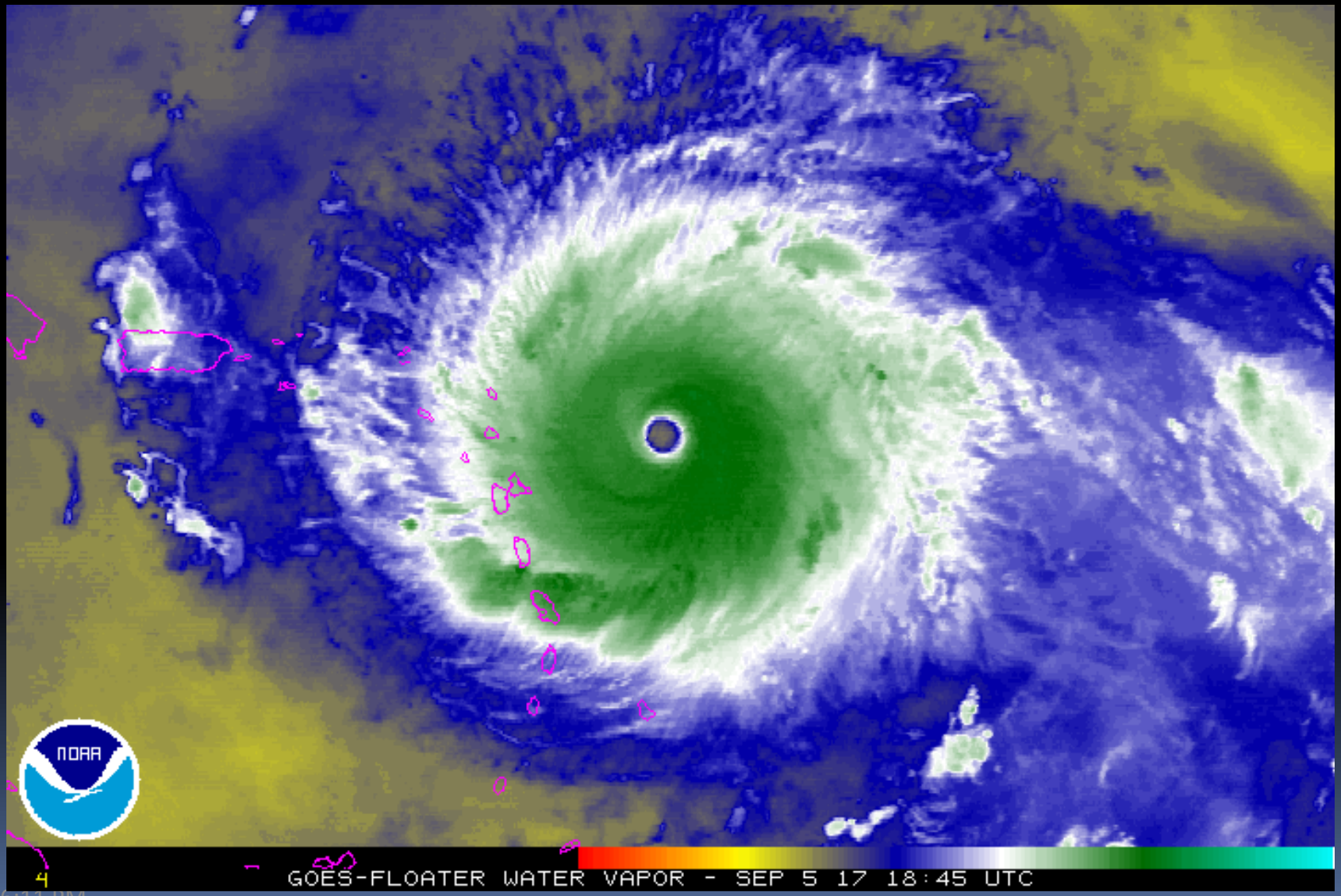




**BEYOND A FEW DEGREES RADIUS FROM THE CENTER, THE UPPER-TROPOSPHERIC FLOW TURNS ANTICYCLONIC**

FIG. 5. Analysis of wind (streamlines and isotachs) for meshes 6–7 for (a) 850, (b) 500, and (c) 200 mb. Isotachs are at 5 m $s^{-1}$ intervals. Shading in (a) indicates area of tropical storm force winds (17.5 m $s^{-1}$), and in (c) areas with winds greater than 15 m $s^{-1}$.

# Well-established outflow

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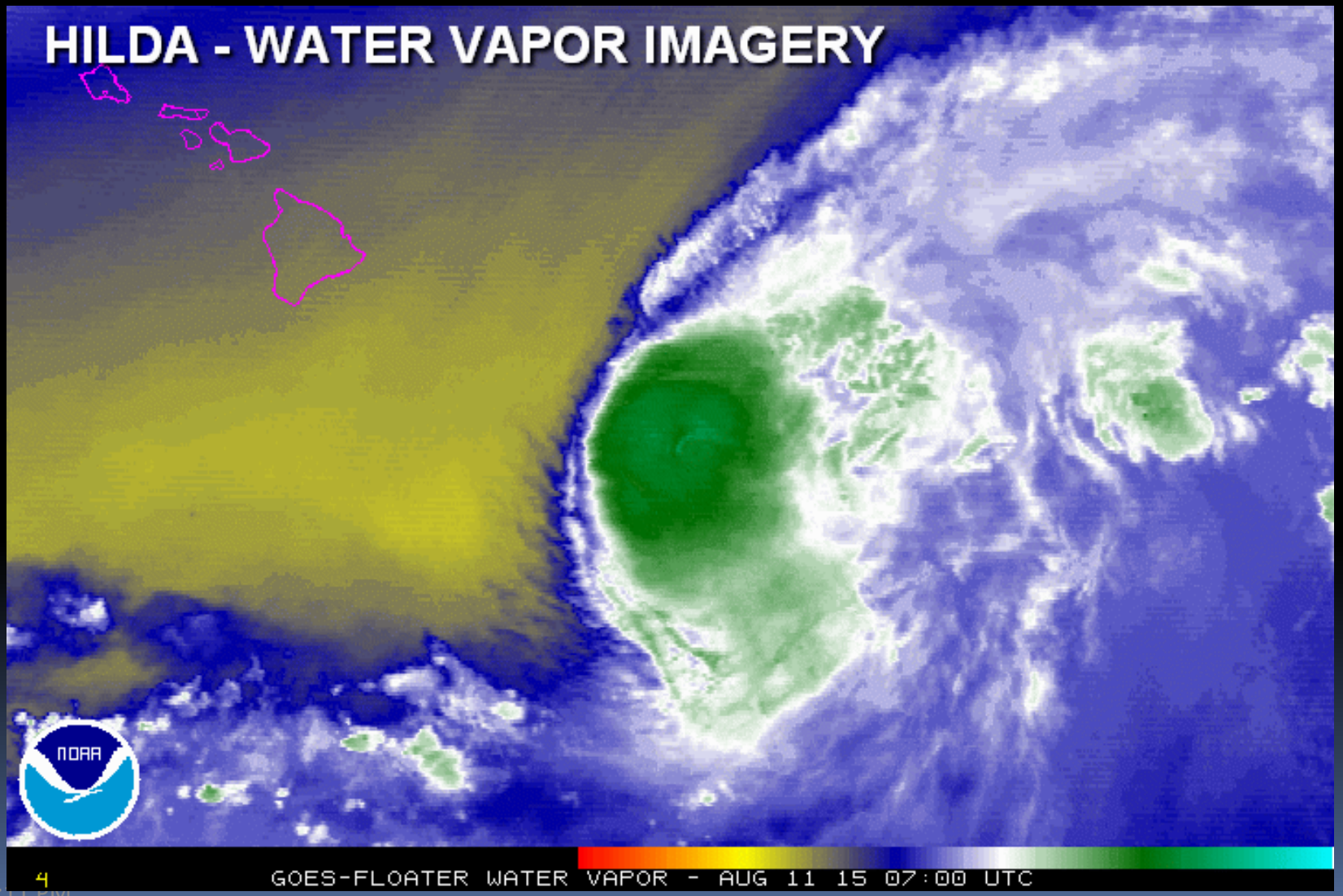
# Restricted outflow

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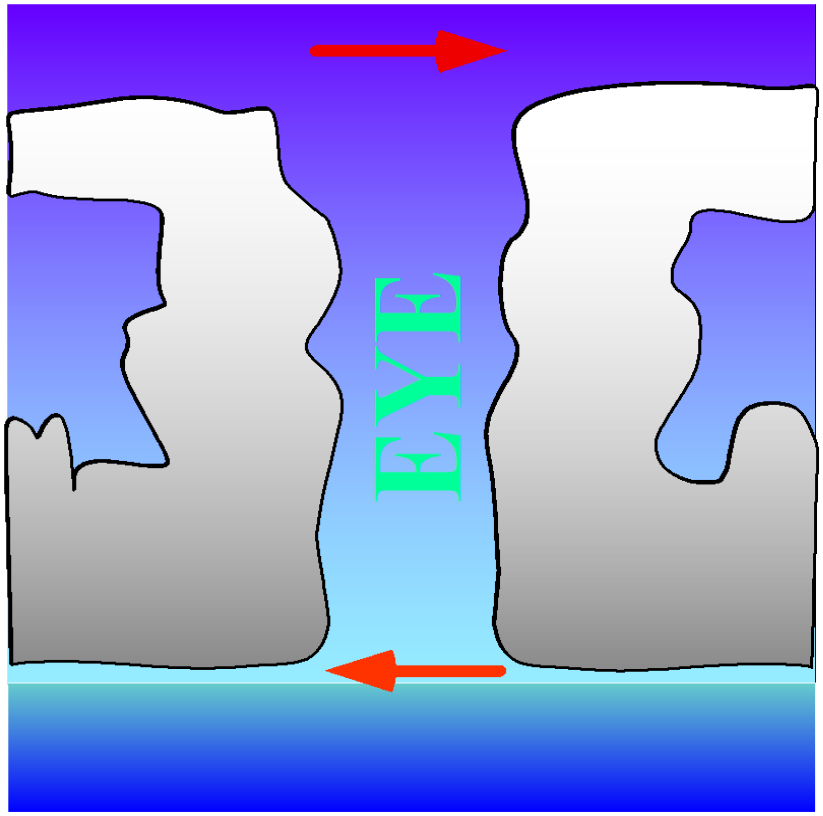
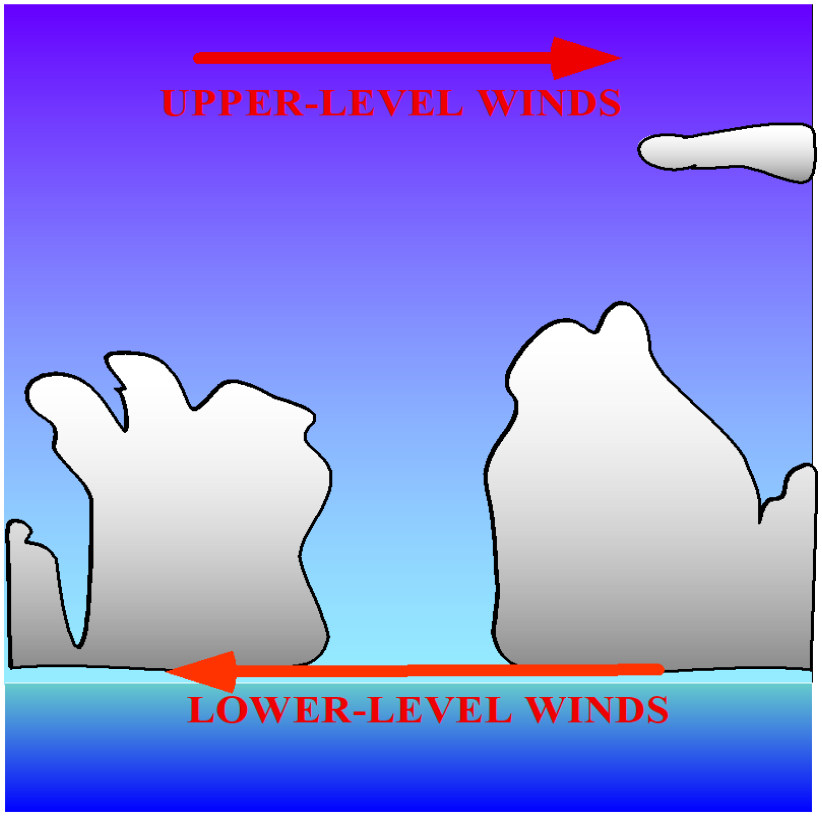
# Intensifying vs. Non-Intensifying

# The Effects of Wind Shear

## Effects of Vertical Wind Shear ($V_z$) on Tropical Cyclones

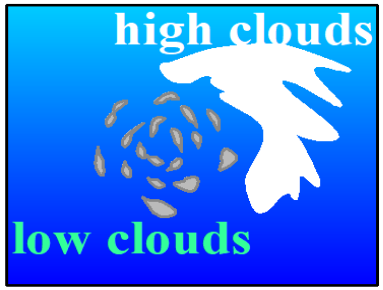



Neal Dorst/Stan Goldenberg
Hurricane Research Division
AOML/NOAA

***WEAK* SHEAR = FAVORABLE**

***STRONG* SHEAR = *UN*FAVORABLE**



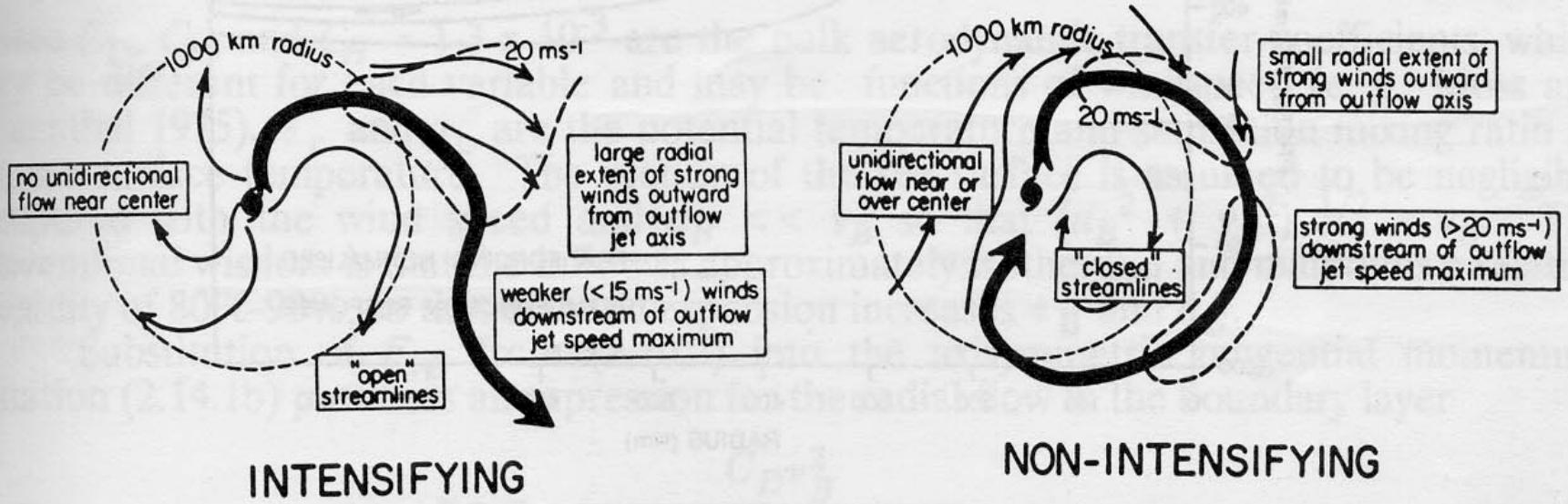
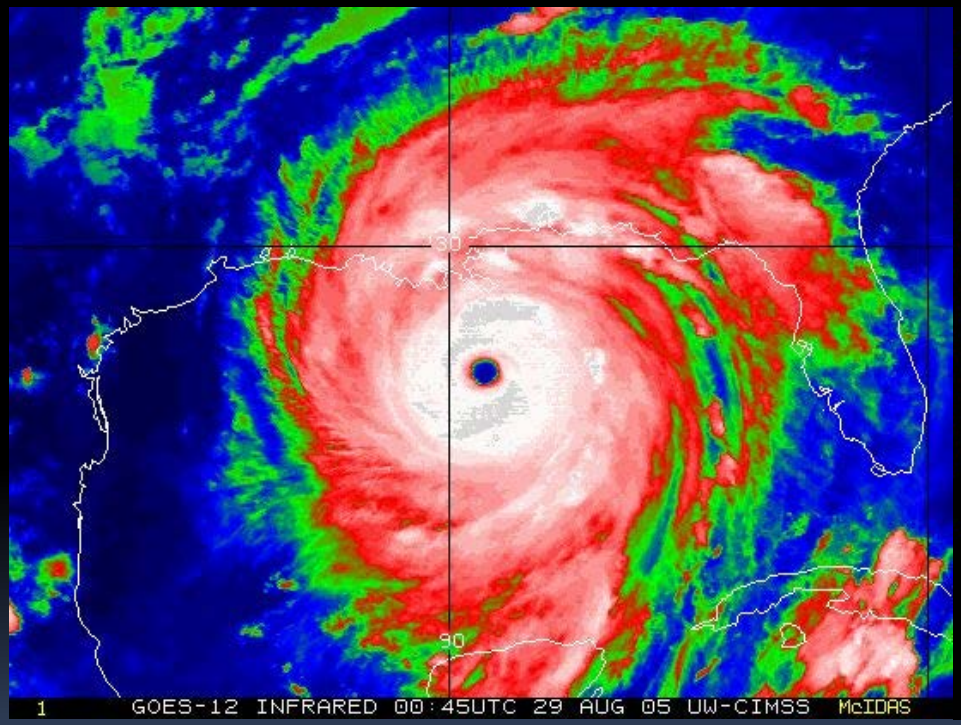
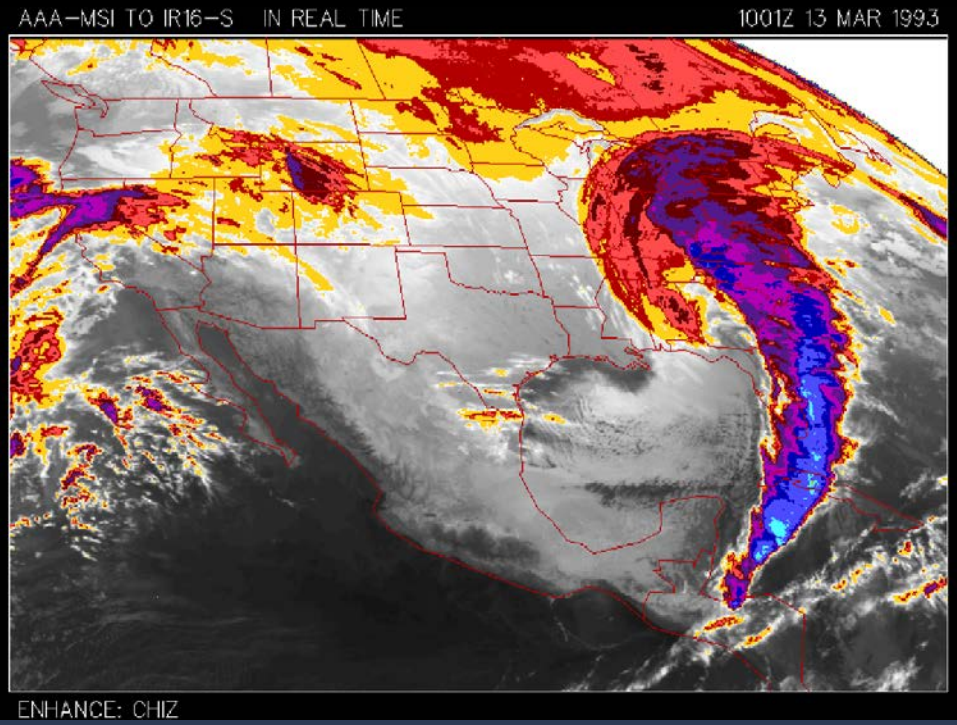



Fig. 2.17 Differences between the outflow and upper-level asymmetries of intensifying and nonintensifying hurricanes (Merrill 1988b).

# The Extremes:
# Tropical vs. Extratropical Cyclones

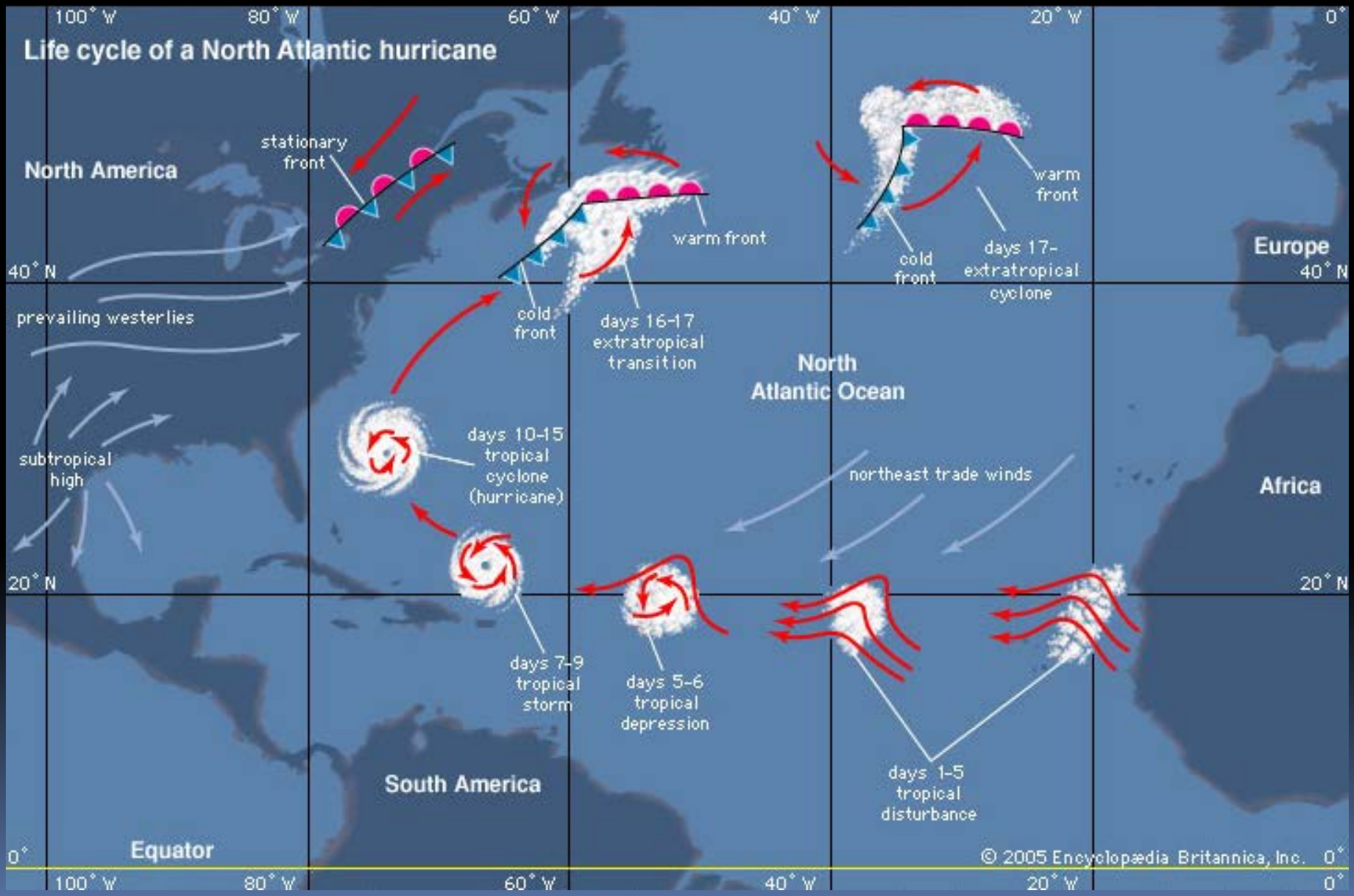



Hurricane Katrina (2005)

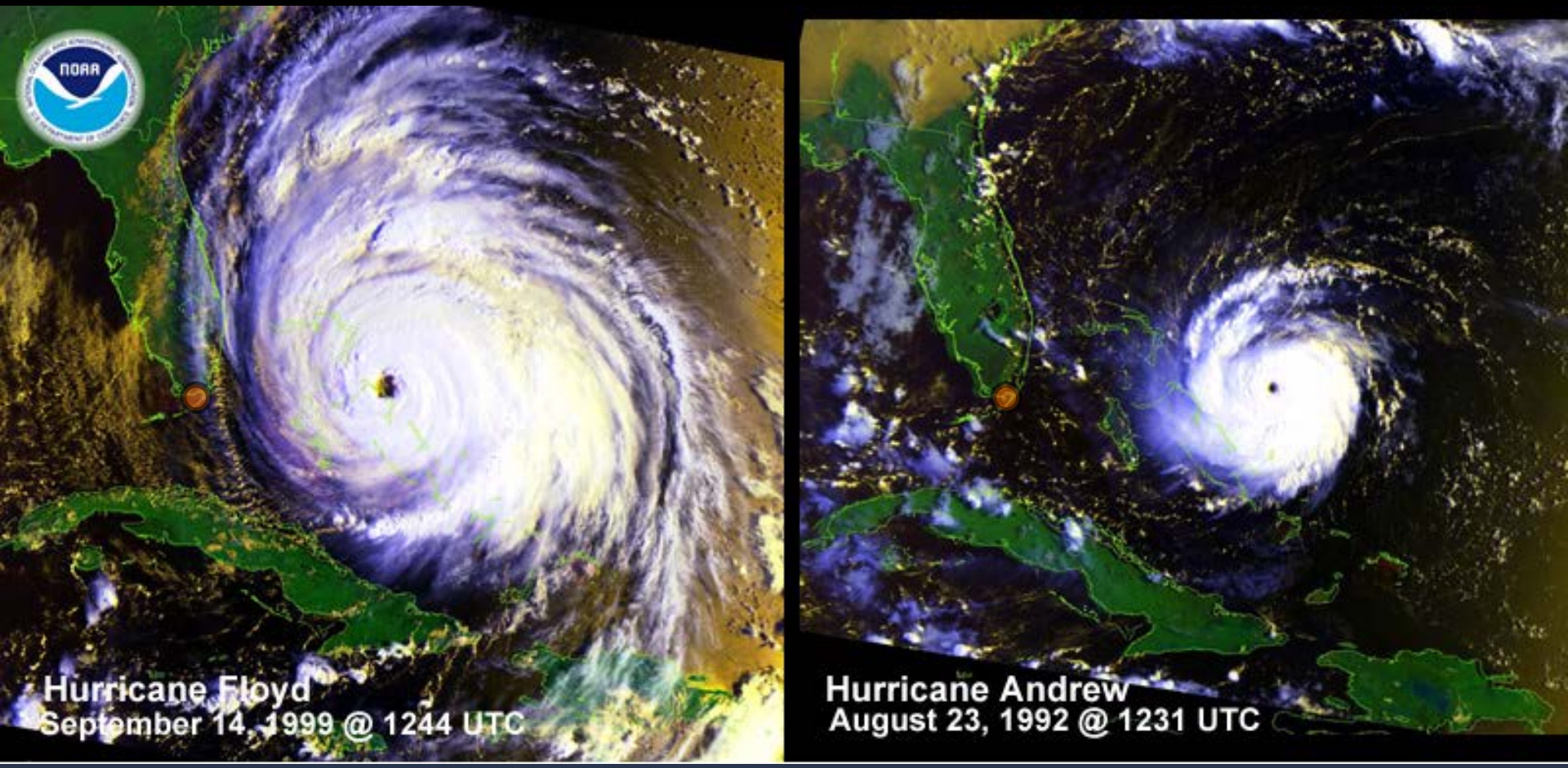



Superstorm Blizzard of March 1993

# Life Cycle of a Cape Verde Hurricane

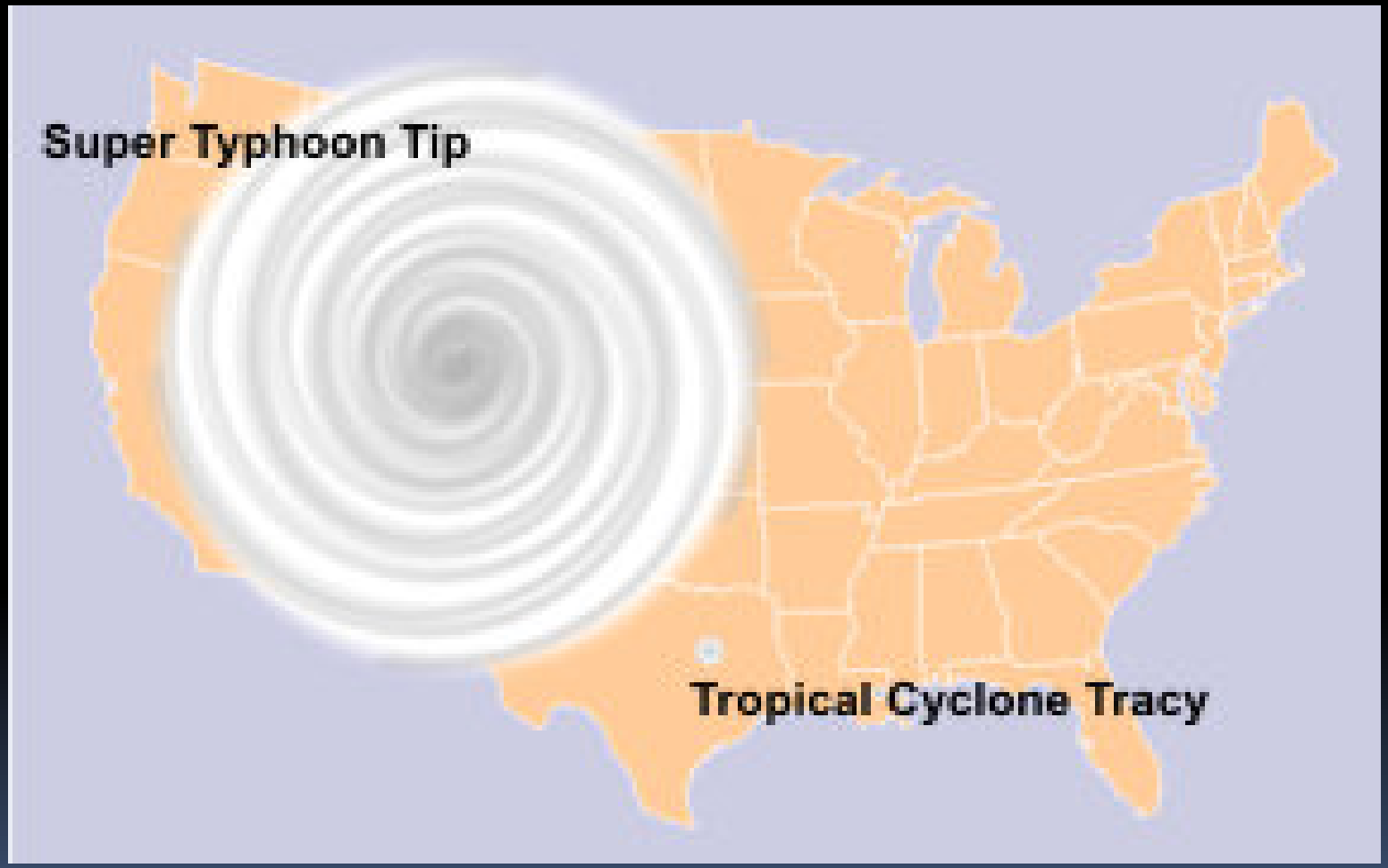


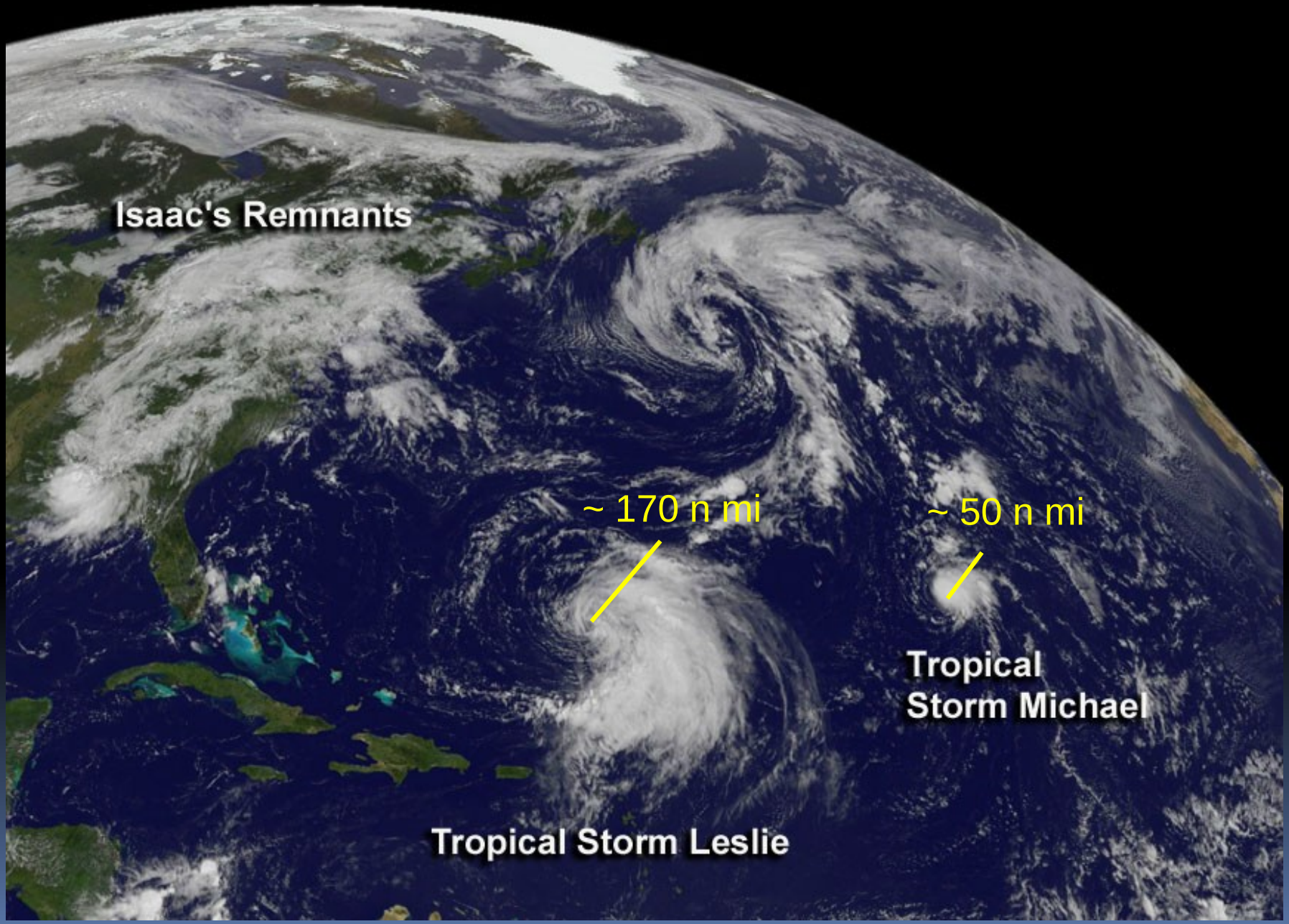
# Hurricane Size Variability



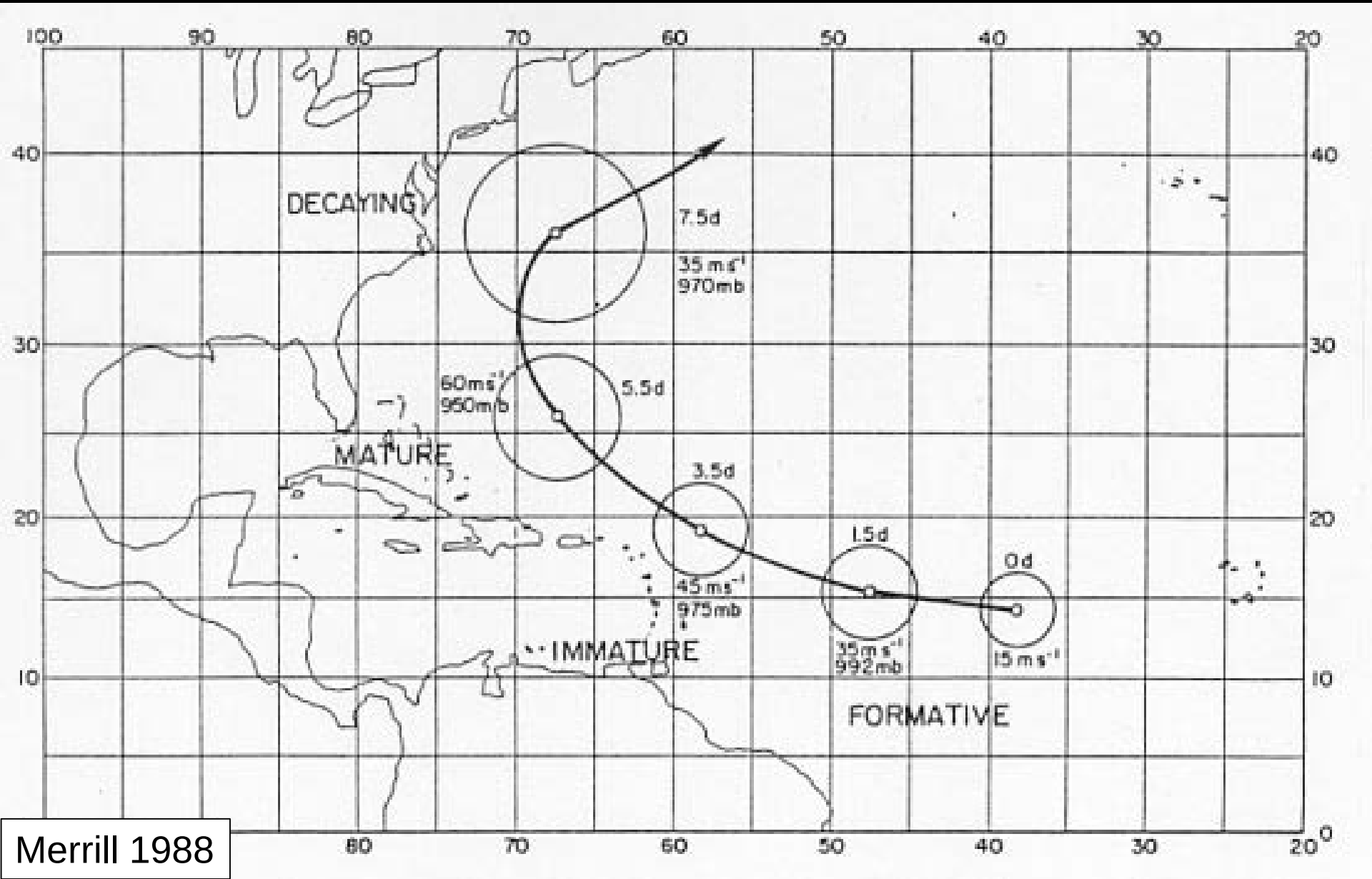

**Size Matters!**

# The Extremes: Tip vs. Tracy



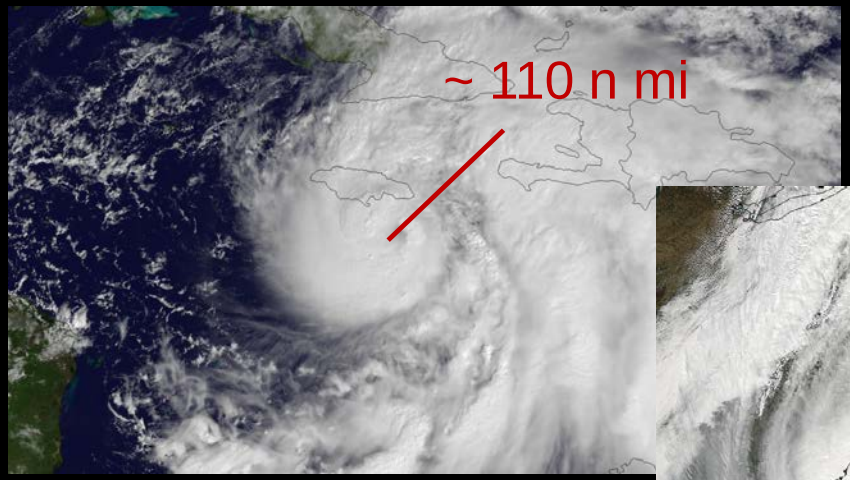

Isaac's Remnants
~ 170 n mi
~ 50 n mi
Tropical
Storm Michael
Tropical Storm Leslie

# Tropical Cyclone Size Lifecycle

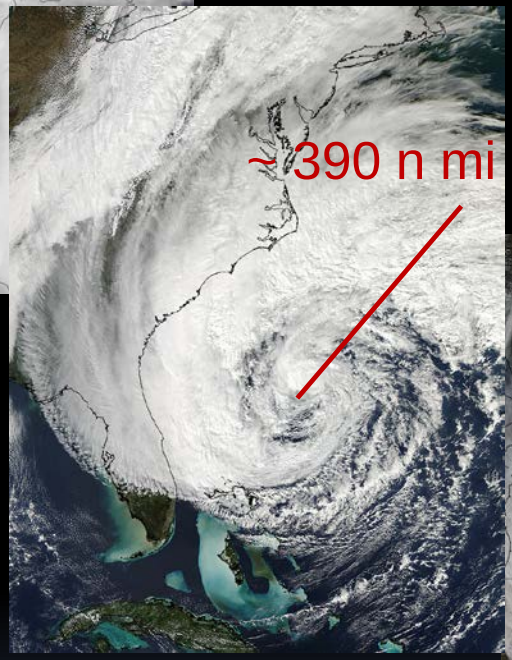



Merrill 1988

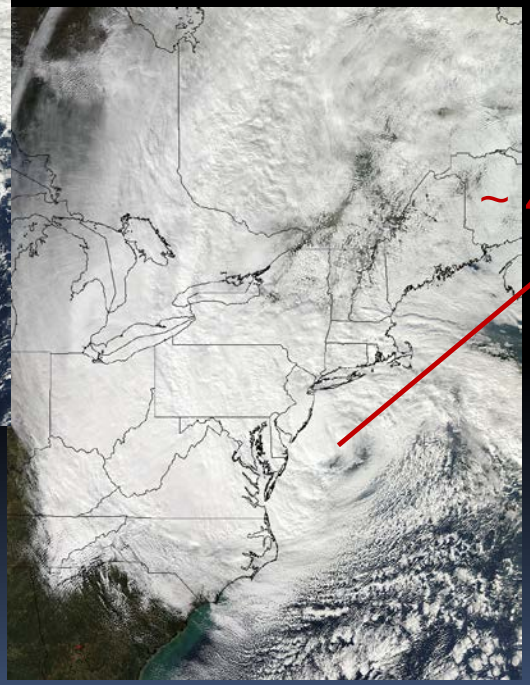
# Hurricane Sandy



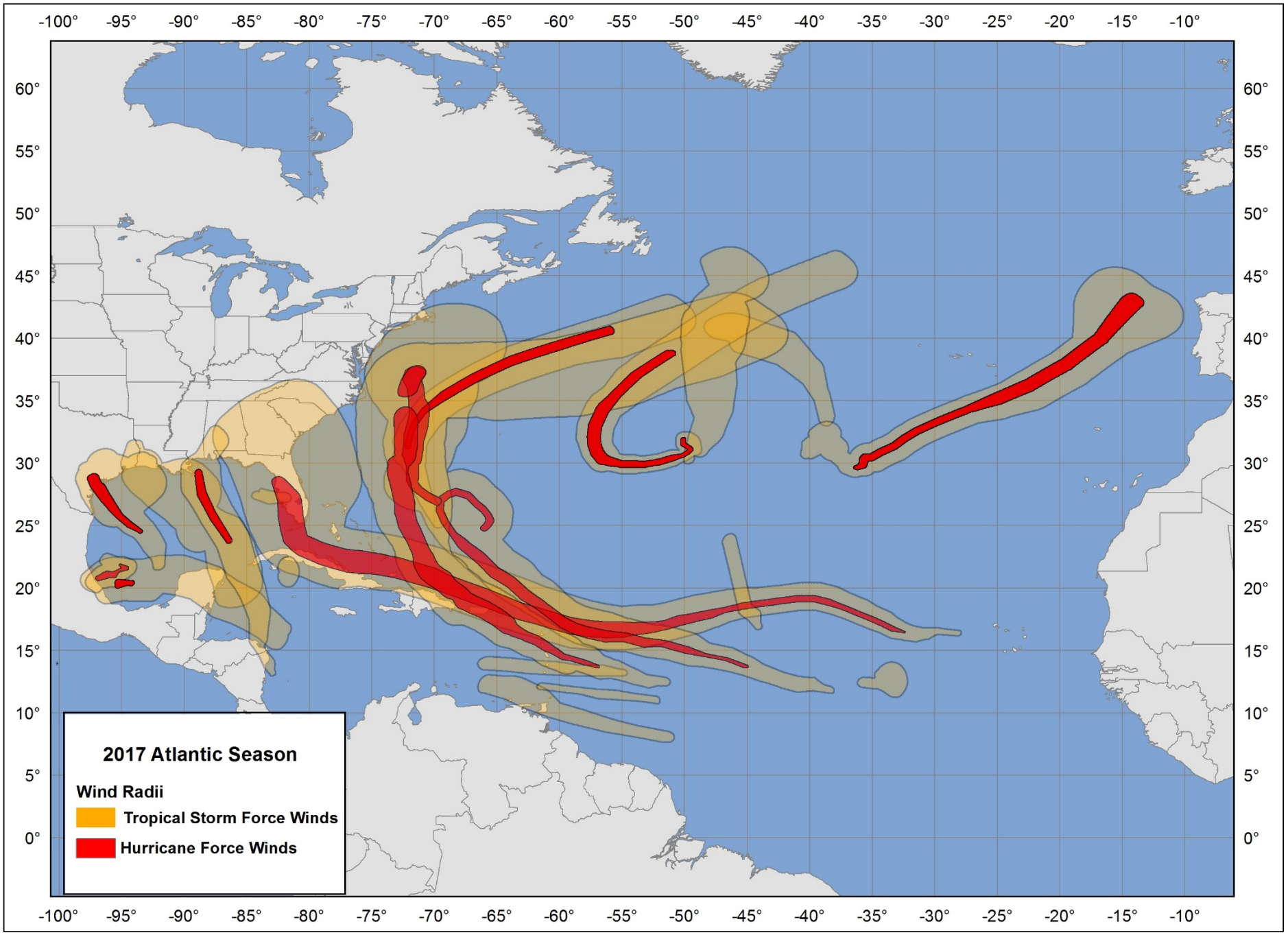

75 kt, 971 mb

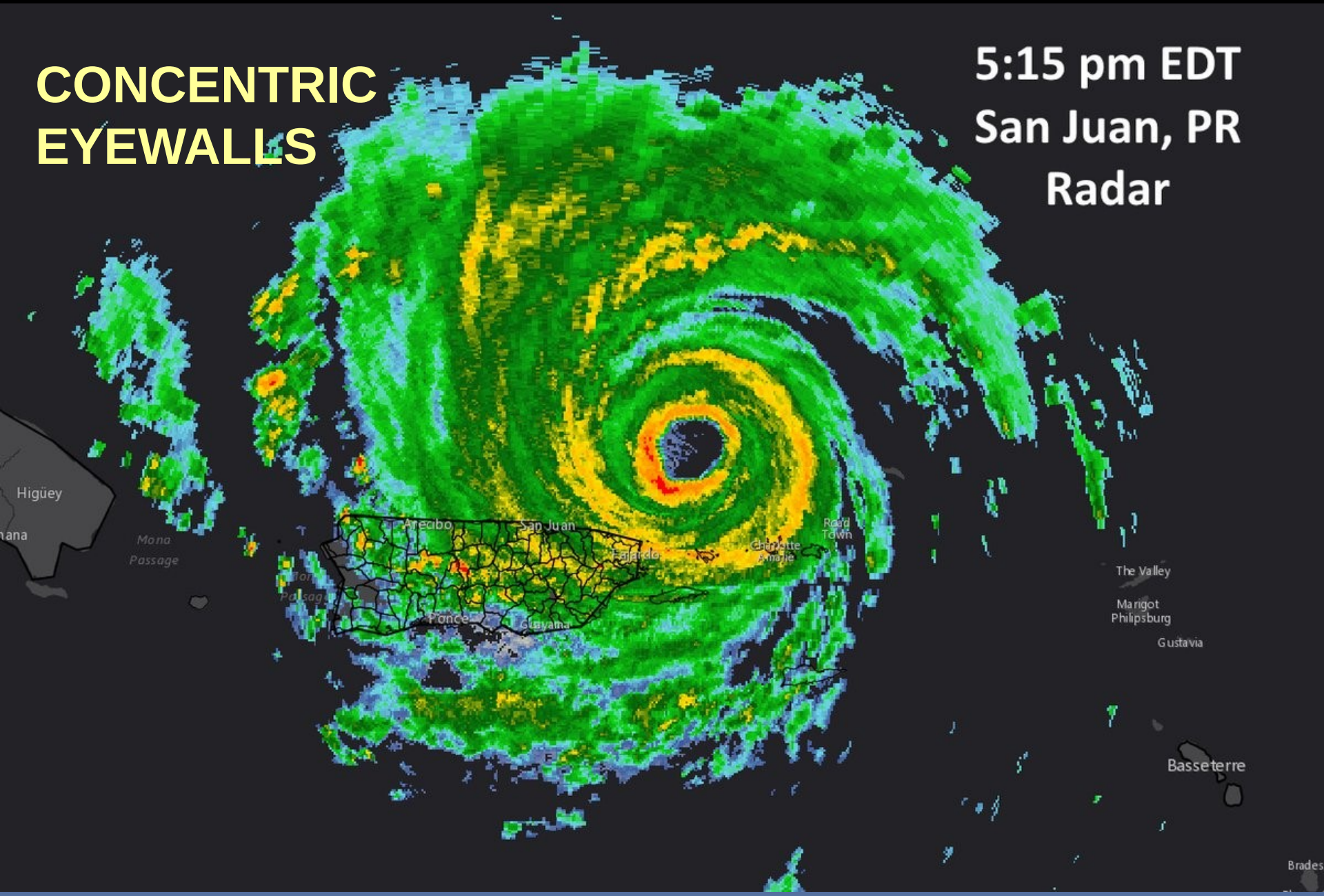



70 kt, 956 mb

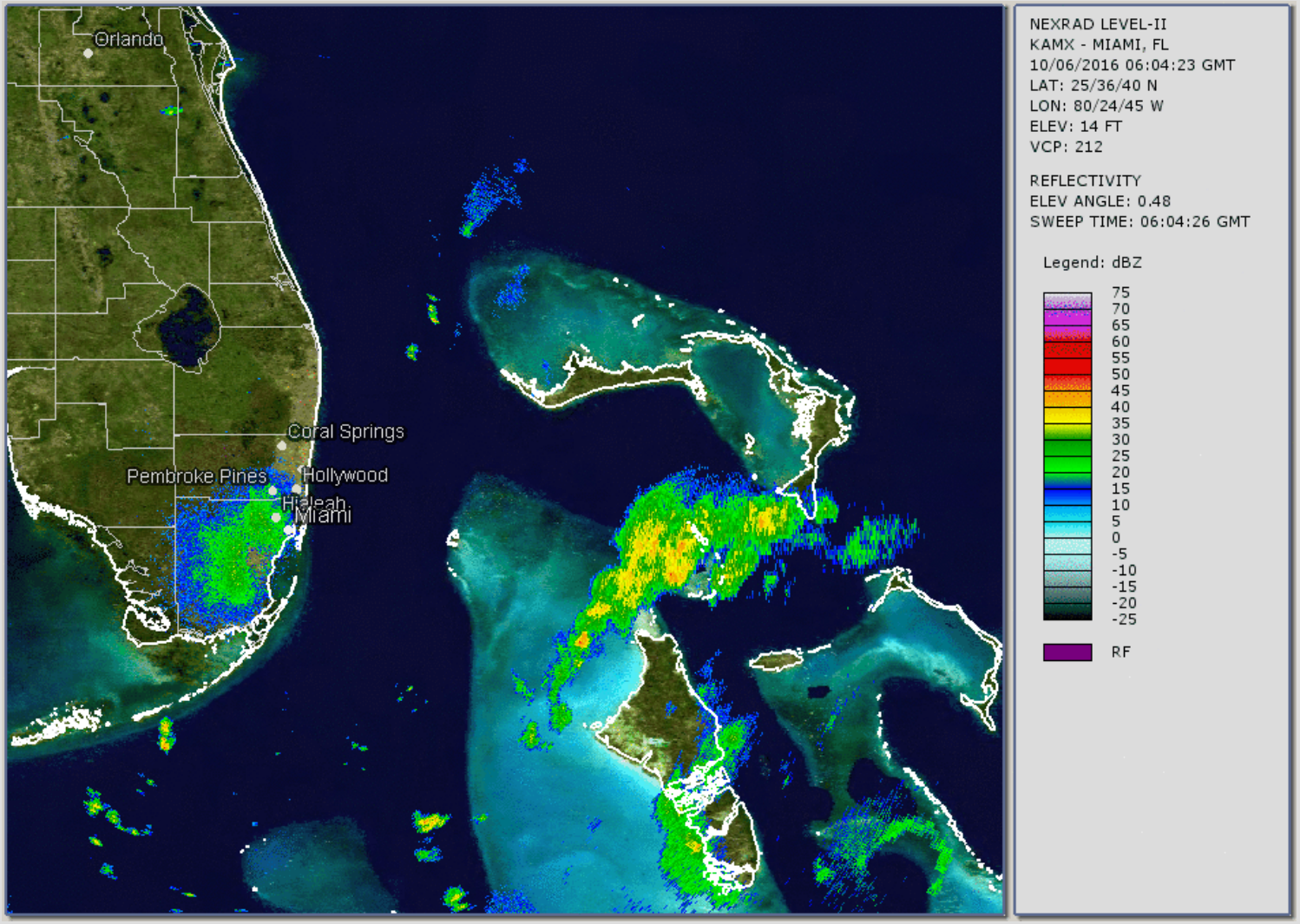



75 kt, 943 mb

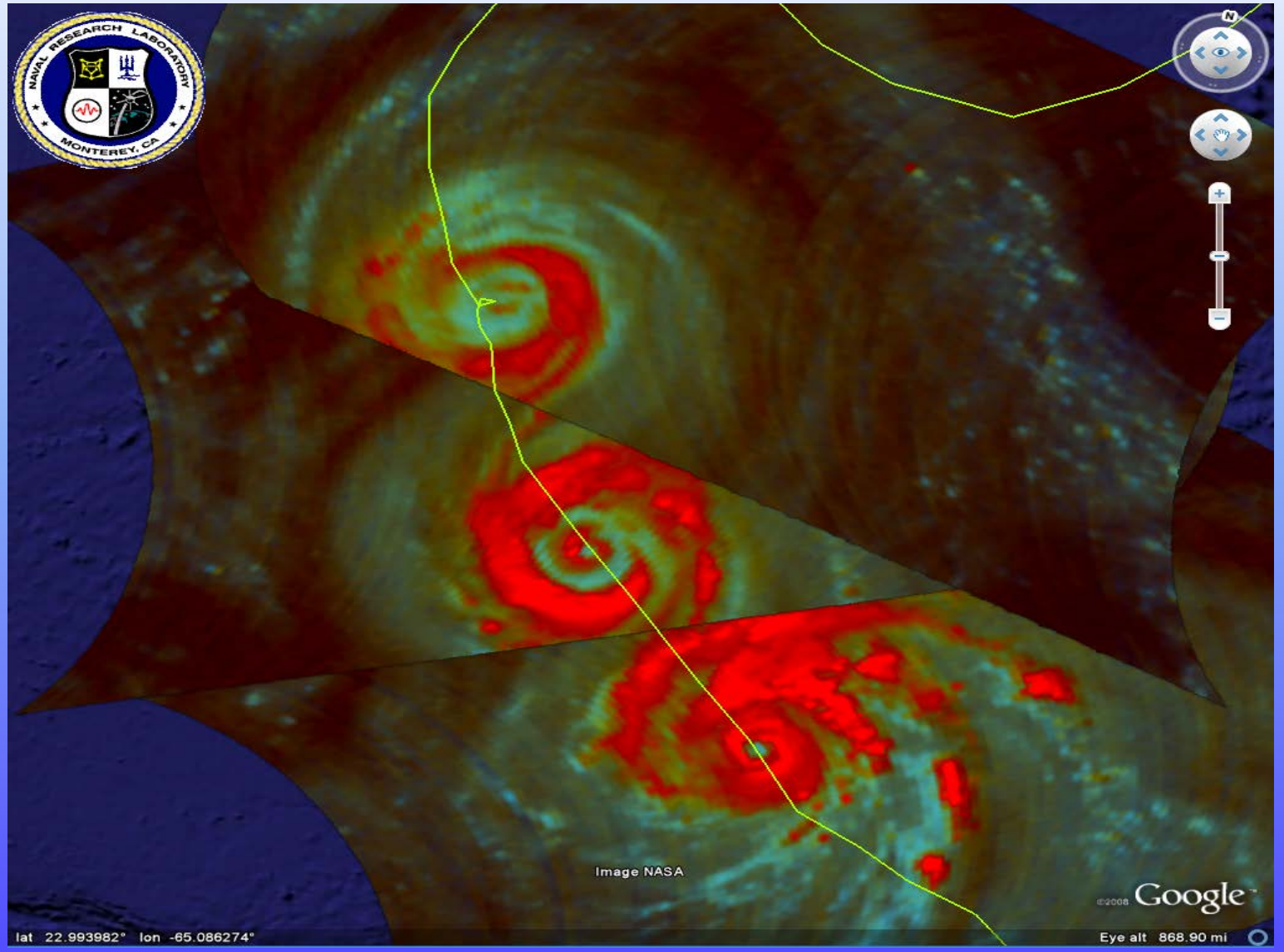

-100° -95° -90° -85° -80° -75° -70° -65° -60° -55° -50° -45° -40° -35° -30° -25° -20° -15° -10°
60° 55° 50° 45° 40° 35° 30° 25° 20° 15° 10° 5° 0°
2017 Atlantic Season
Wind Radii
Tropical Storm Force Winds
Hurricane Force Winds


CONCENTRIC EYEWALLS
5:15 pm EDT
San Juan, PR
Radar
Higüey
Mona Passage
Arecibo
San Juan
Fajardo
Ponce
Guayama
Road Town
The Valley
Marigot
Philipsburg
Gustavia
Basseterre

# Hurricane Matthew Radar Loop



# Bertha (2008) Eyewall Replacement



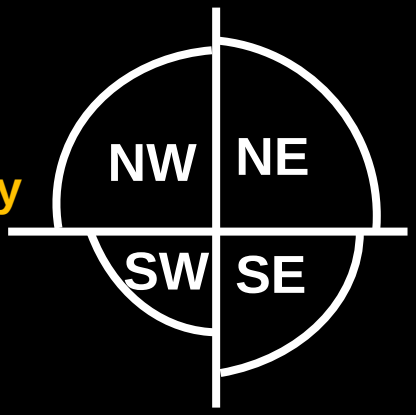
# What I know about eyewall replacement cycles

- We have a sense of when they could occur
- We can observe them
- Intensity changes are coming
- Big errors are likely going to happen too…

# Tropical Cyclone Wind Radii

NHC estimates cyclone "size" via wind radii in four quadrants

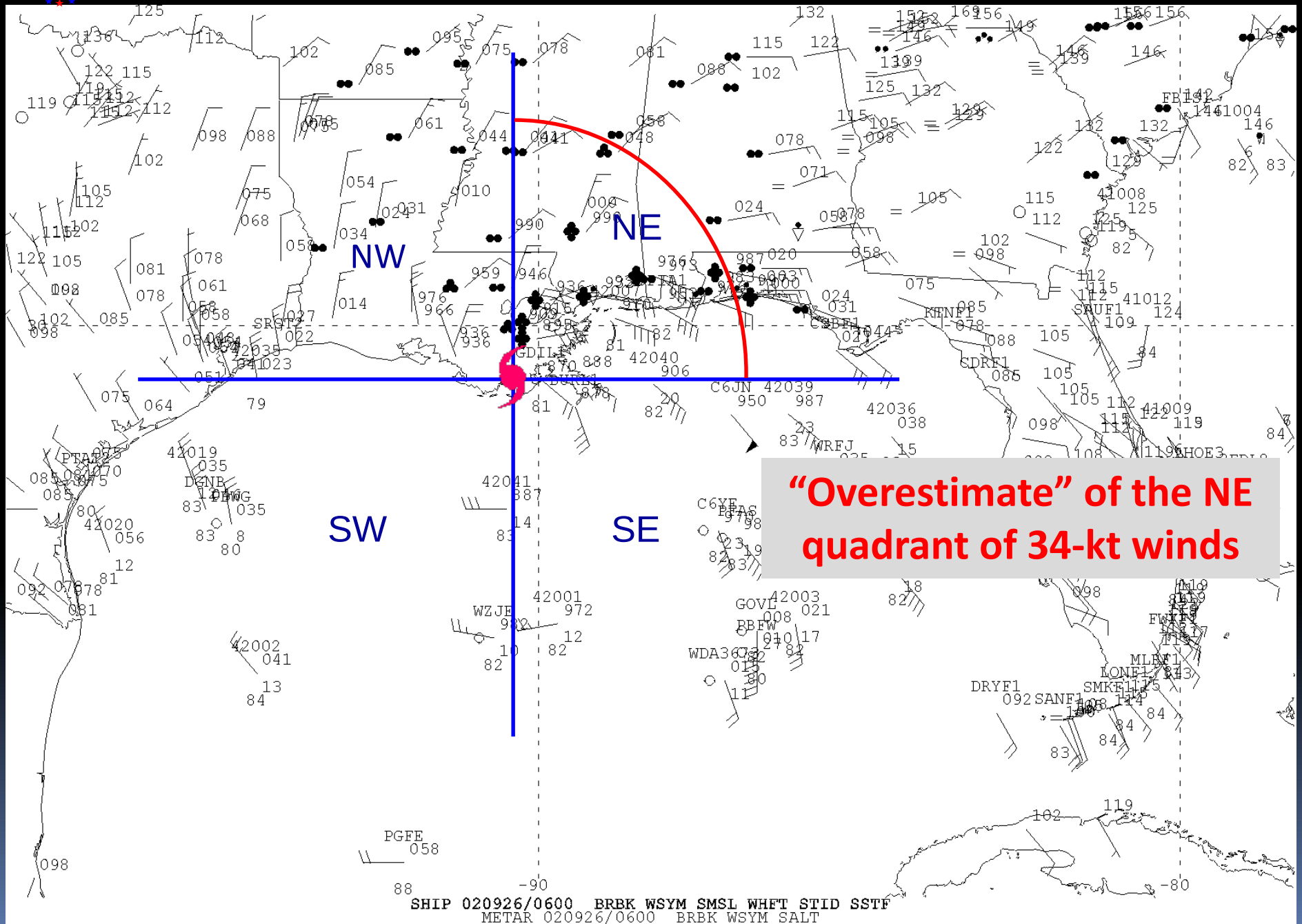
leads to an inherent over-estimate of radii, especially near land




radii represent the largest distance from center in particular quadrant

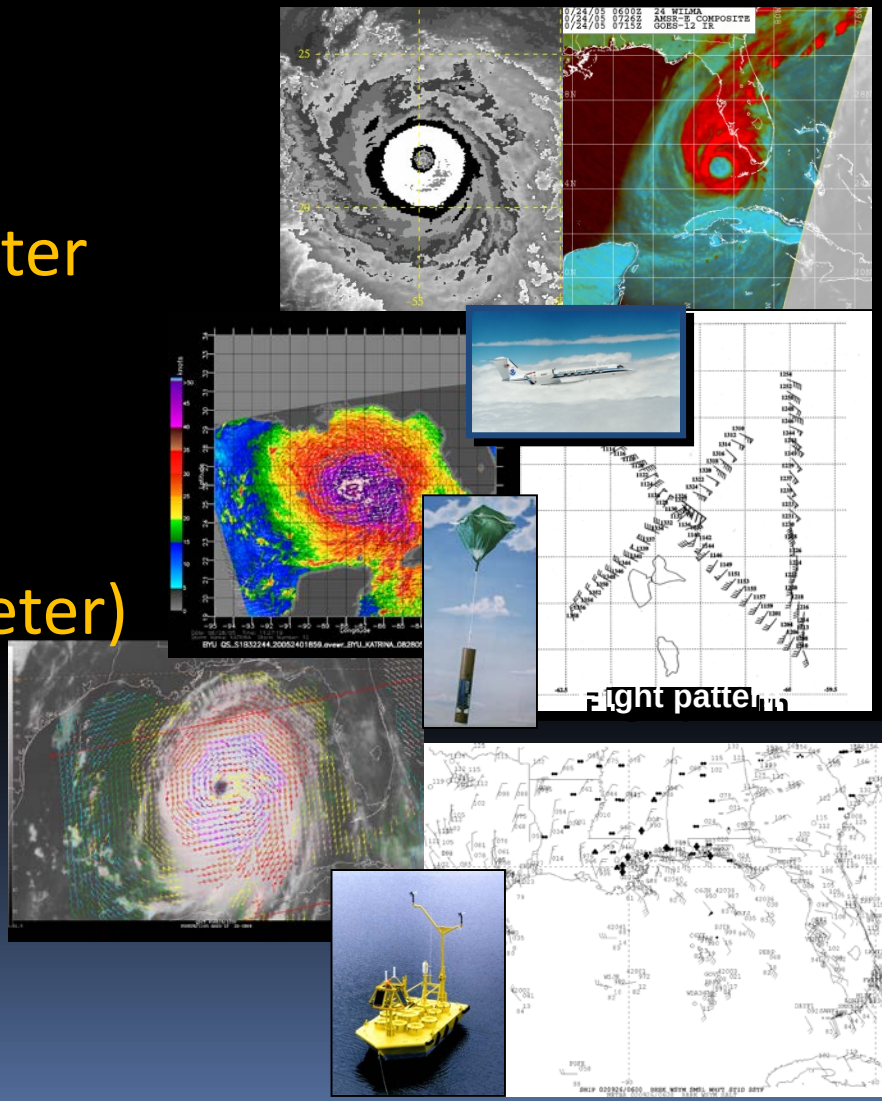
Wind radius = Largest distance from the center of the tropical cyclone of a particular sustained surface wind speed threshold (e.g., 34, 50, 64 kt) somewhere in a particular quadrant (NE, SE, SW, NW) surrounding the center and associated with the circulation at a given point in time

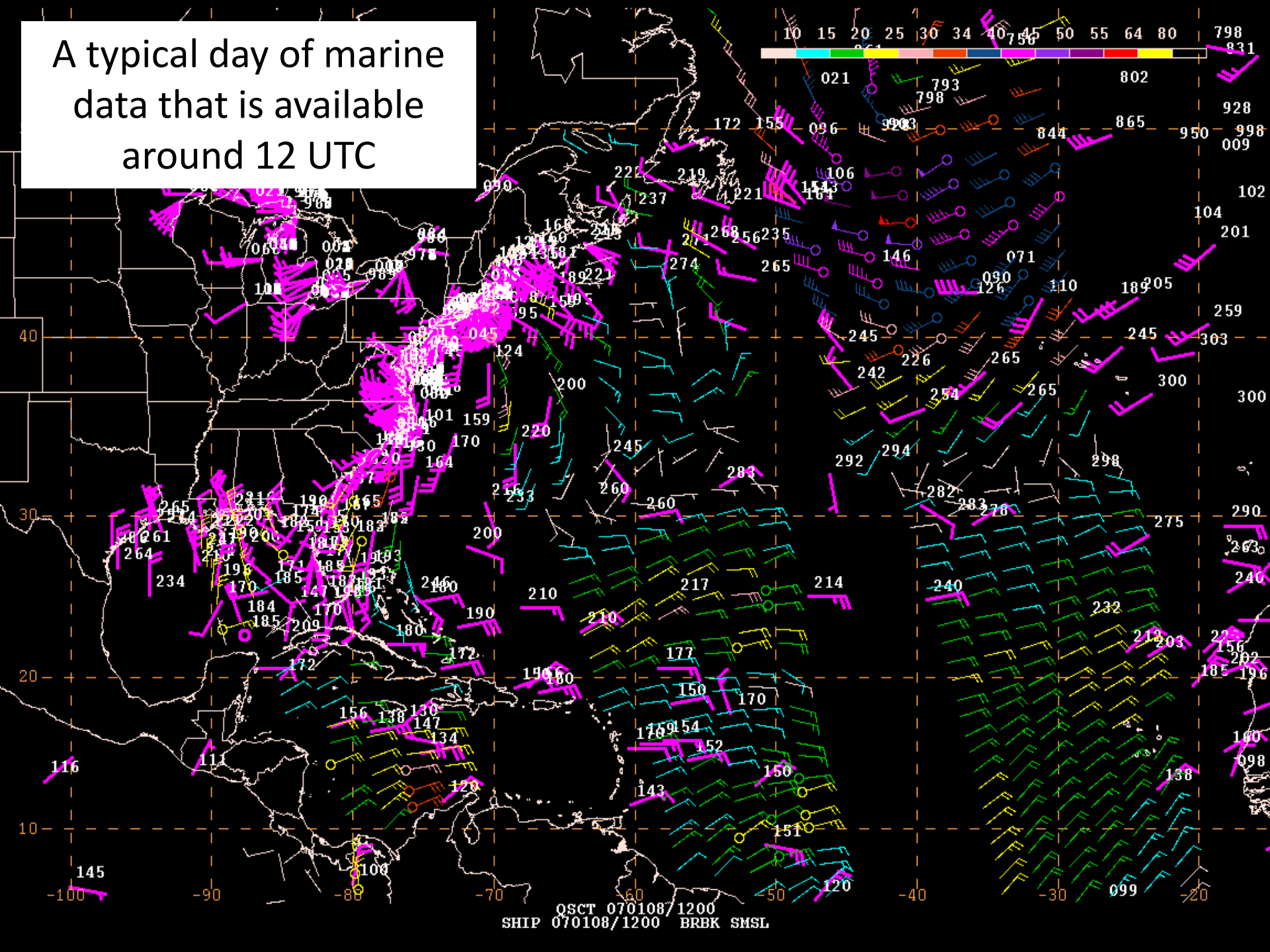
# Limitations of Four-Quadrant Radii



# Data to Determine Tropical Cyclone Size

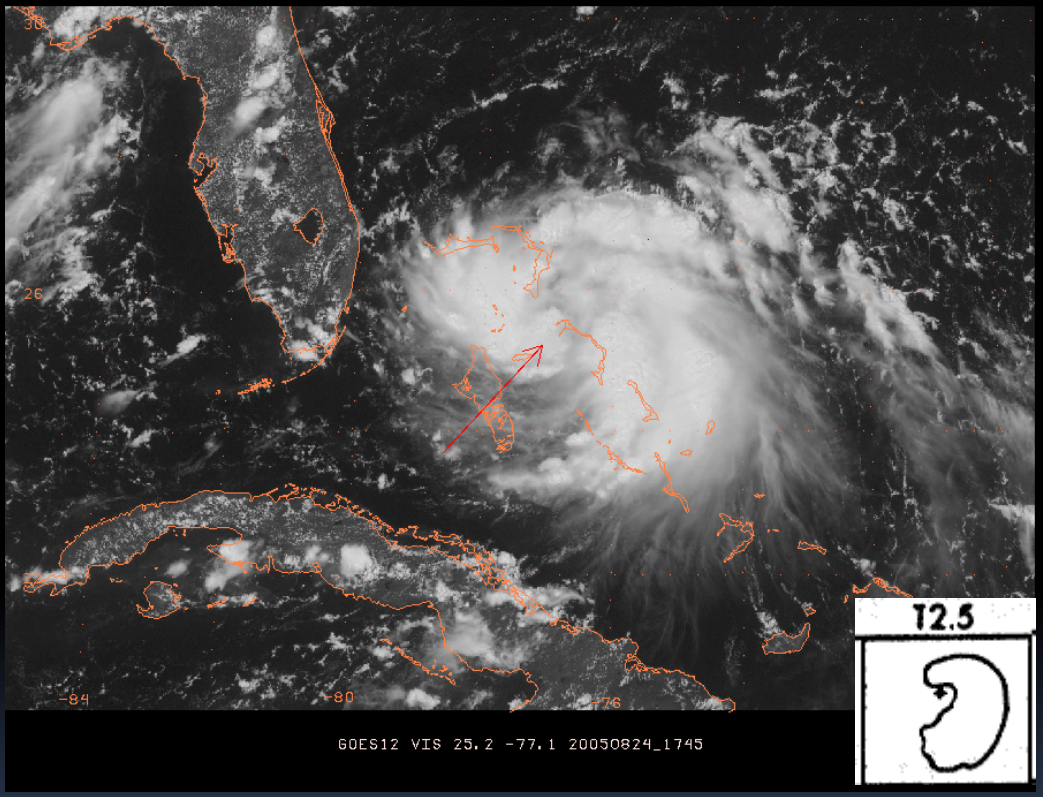
* Satellite Imagery
  - Geostationary
  - Polar Orbiting – scatterometer
* Reconnaissance Data
  - Dropsondes
  - SFMR (Stepped Frequency Microwave Radiometer)
* Surface Observations



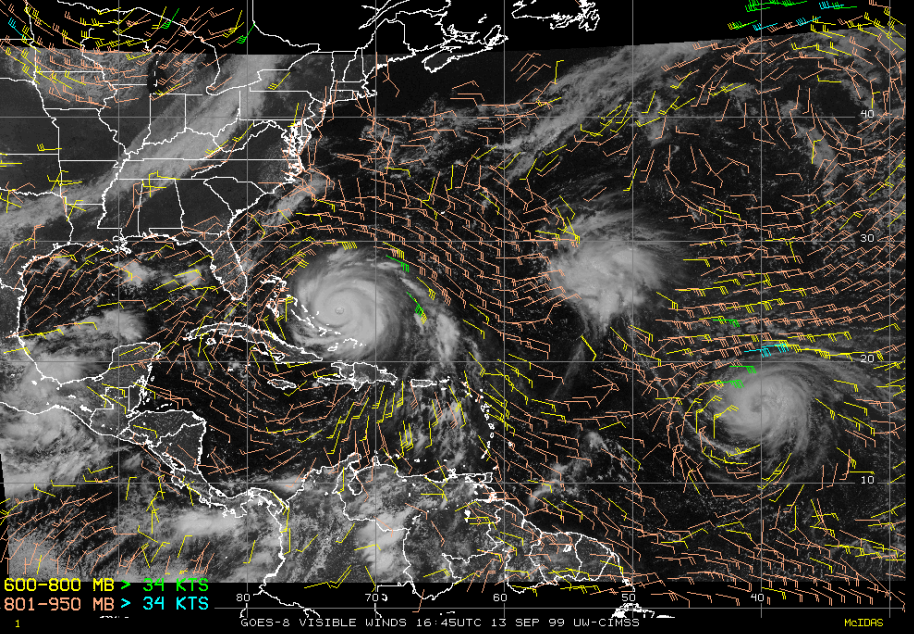

A typical day of marine data that is available around 12 UTC
10 15 20 25 30 34 40 45 50 55 64 80
40
30
20
10
-100
-90
-80
-70
-60
-50
-40
-30
-20
QSCT 070108/1200
SHIP 070108/1200 BRBK SMSL

# Analyzing and Forecasting TC Size

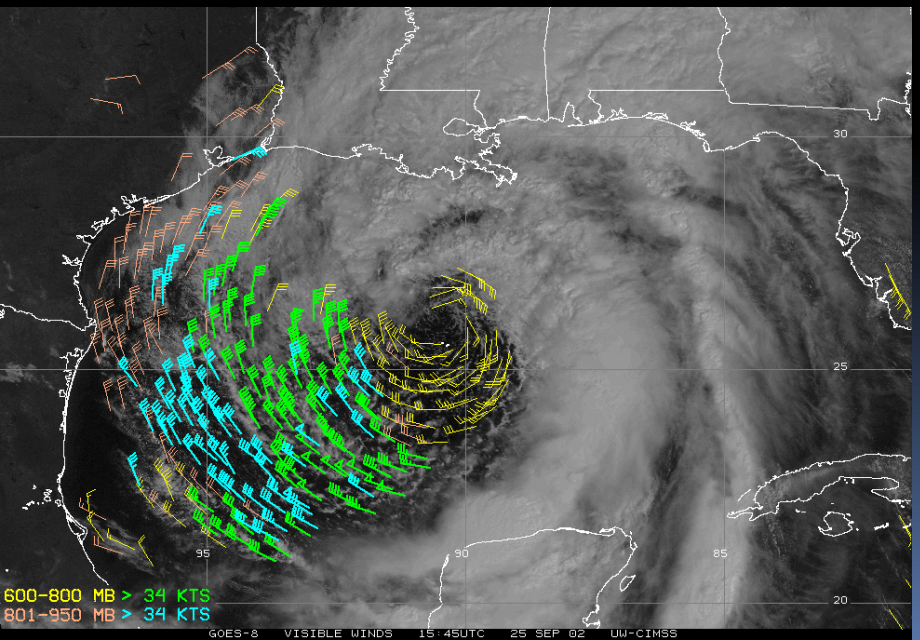
Katrina - August 24




The Dvorak Technique is very skillful at estimating intensity, but does not help with TC size



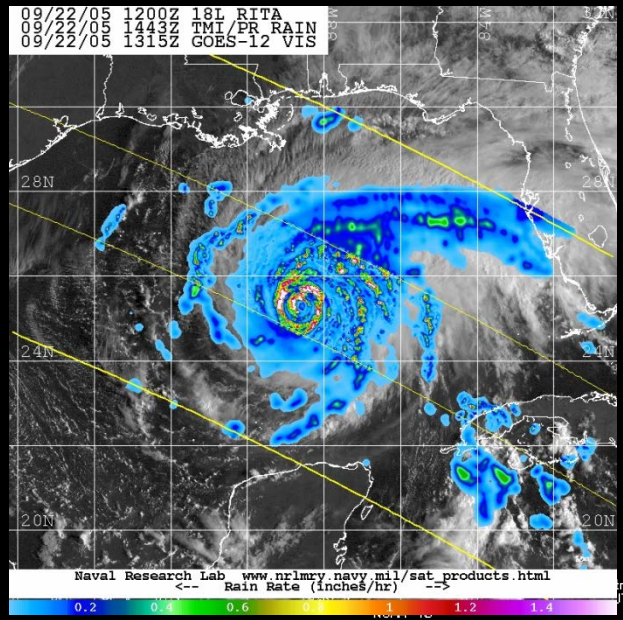

Satellite winds for nearby environment and TC size

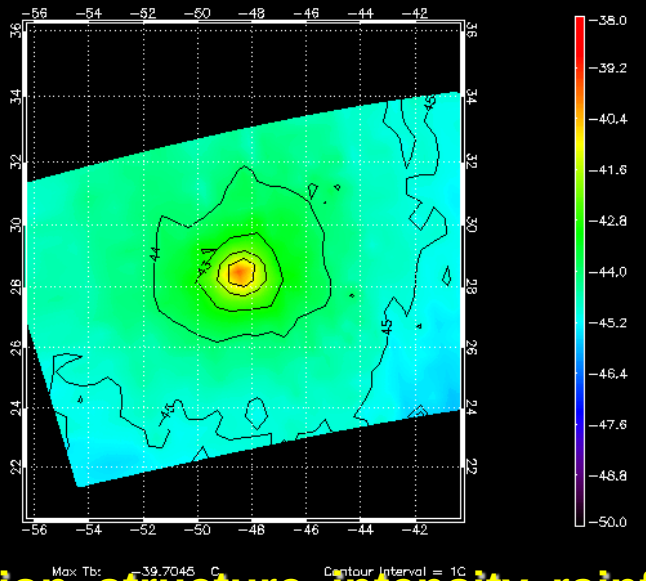



# Geostationary satellite – Low-level cloud drift winds

# Low-Earth-Orbit Satellites

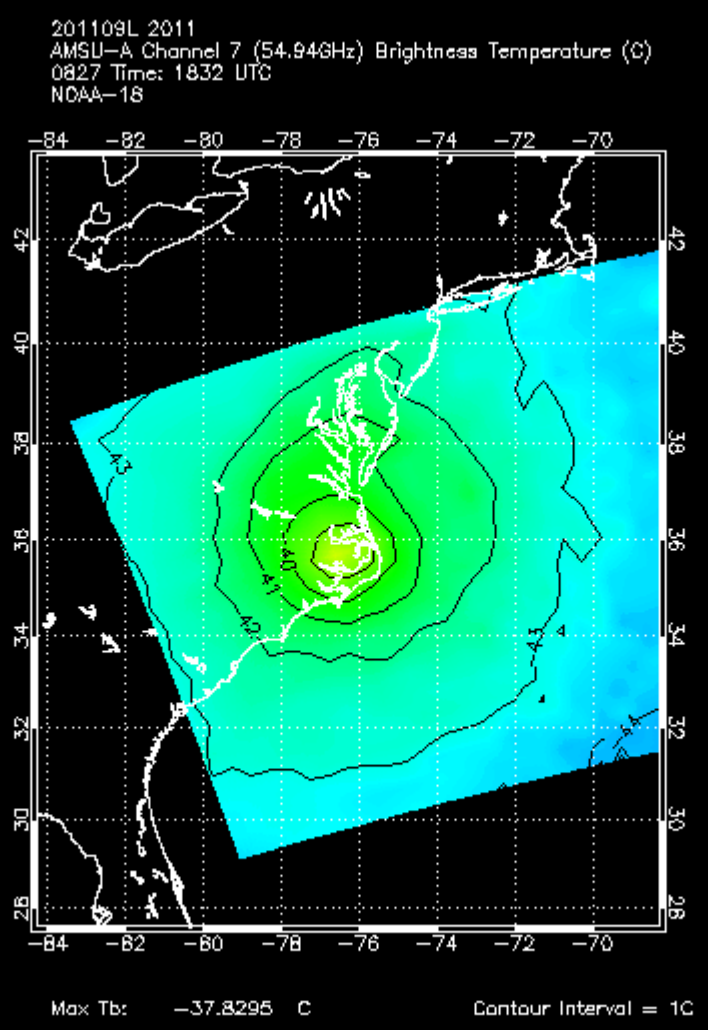
- Carry microwave imagers and sounders that can see through cloud tops and reveal the structures underneath
- Gaps in instrument coverage between orbits, which causes irregular sampling of cyclones

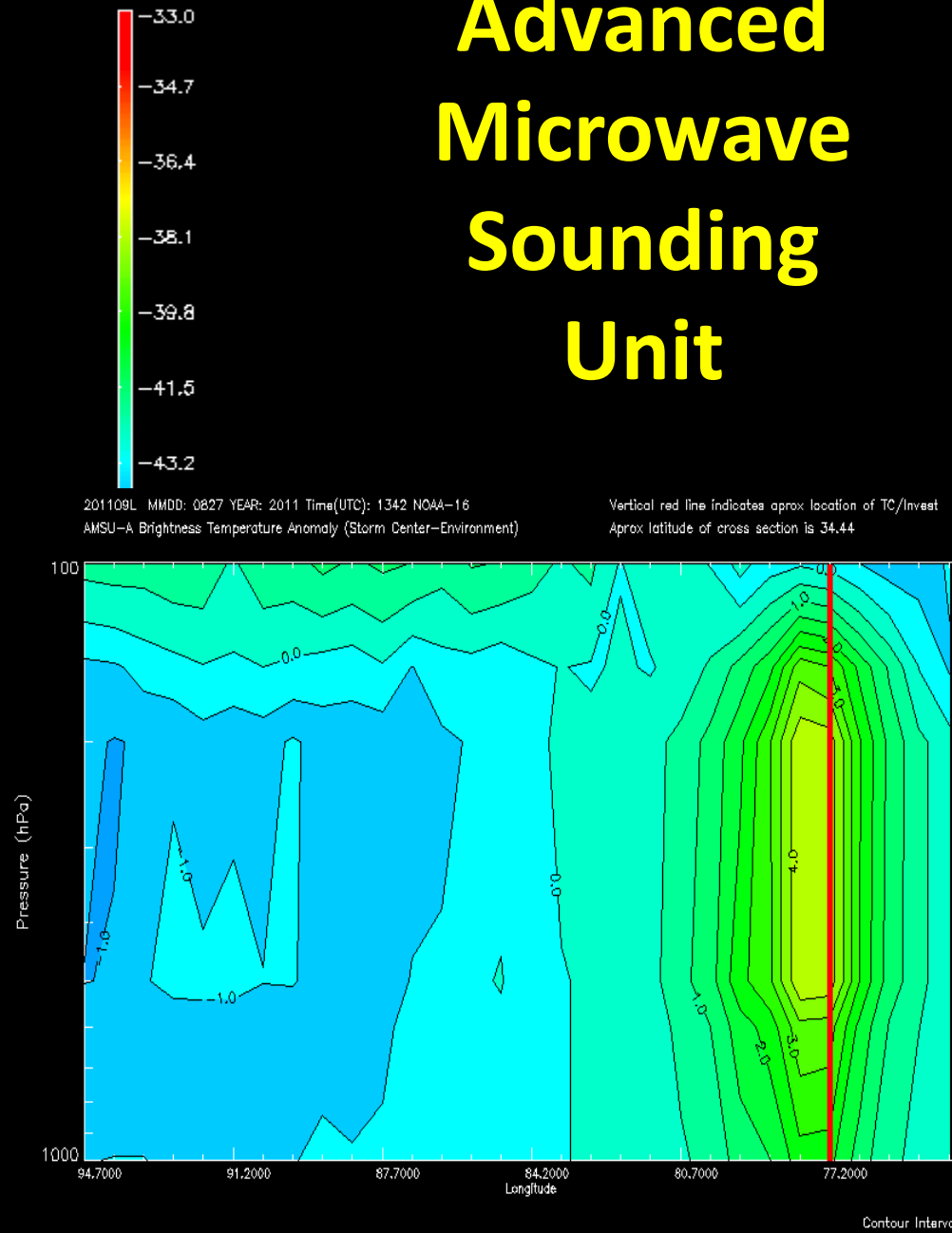


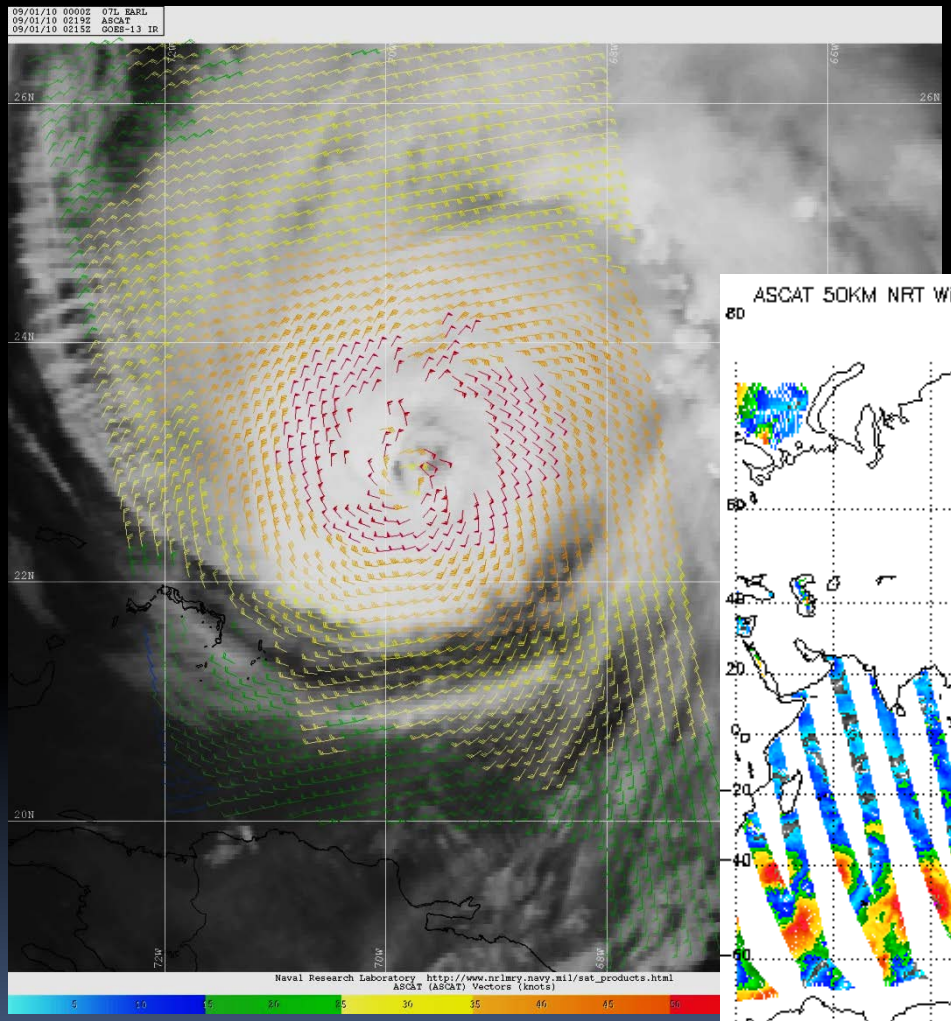

Microwave location, structure, intensity, rainfall

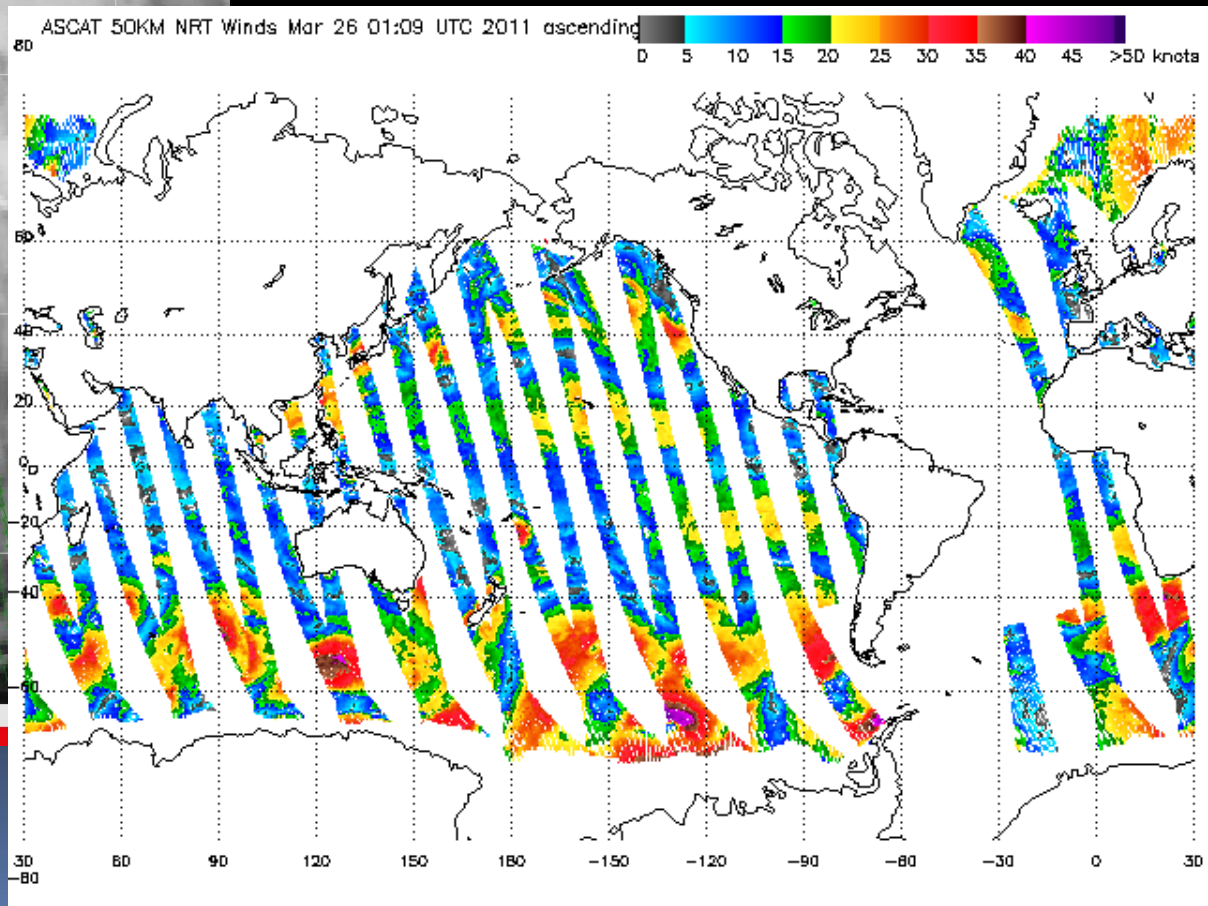
# Advanced Microwave Sounding Unit



# ASCAT (Advanced Scatterometer) – Surface Winds from a Polar-orbiting satellite

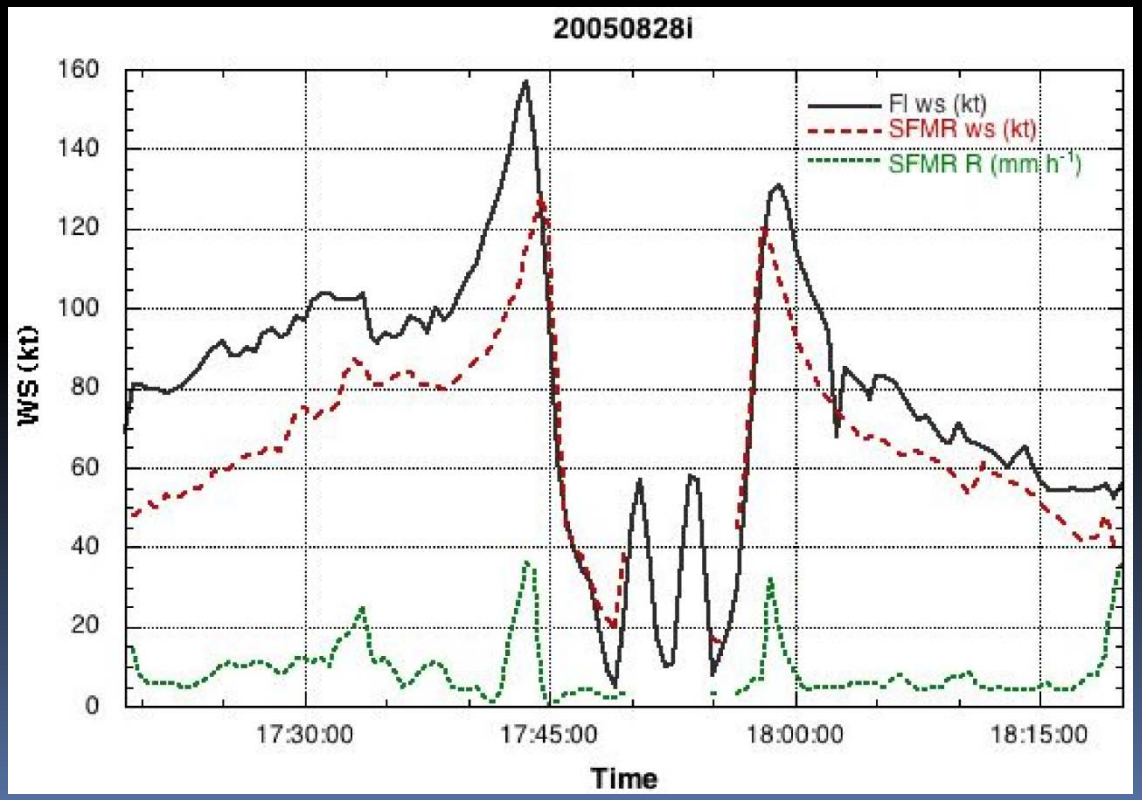


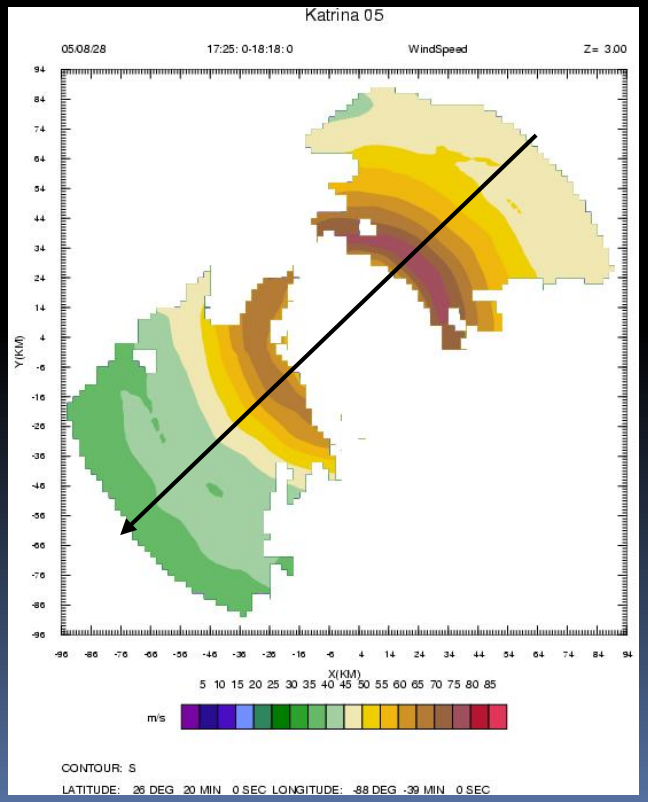



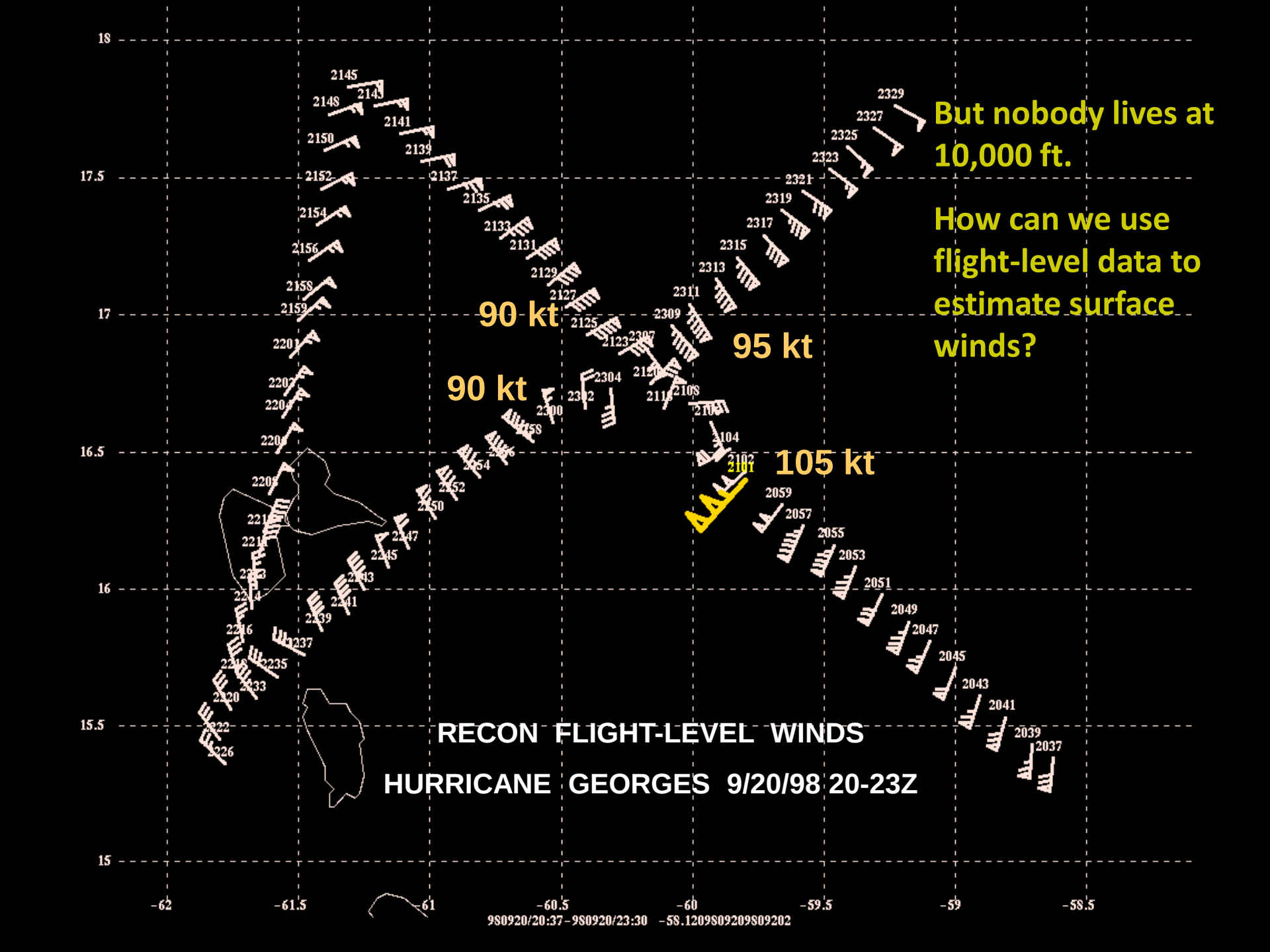
Hurricane Reconnaissance and Surveillance Aircraft (10 Air Force C-130s, 2 NOAA P3s, 1 NOAA G-IV)


# Primary Aircraft Data

- Winds (along the aircraft track and dropsondes)
- Surface pressures (extrapolated and dropsonde)
- Surface winds from the Stepped Frequency Microwave Radiometer
- Aircraft Doppler Radar winds (from the P-3's)



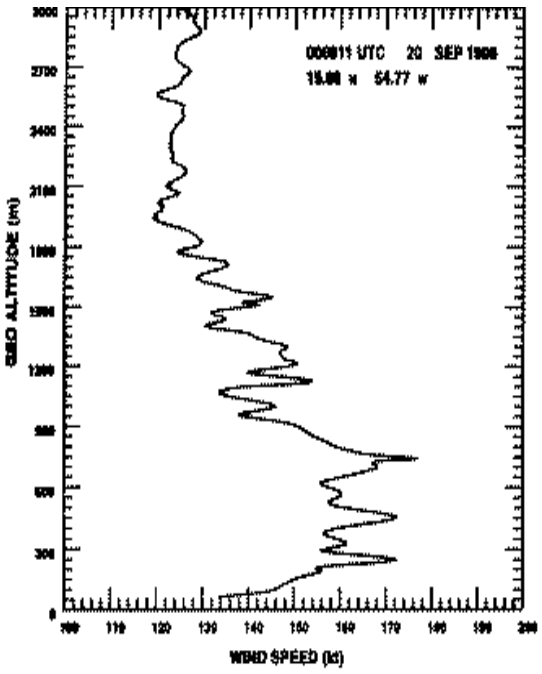




But nobody lives at 10,000 ft.
How can we use flight-level data to estimate surface winds?
90 kt
90 kt
95 kt
105 kt
RECON FLIGHT-LEVEL WINDS
HURRICANE GEORGES 9/20/98 20-23Z
18
17.5
17
16.5
16
15.5
15
-62
-61.5
-61
-60.5
-60
-59.5
-59
-58.5
9S0920/20:37-9S0920/23:30 -58.120980920980202

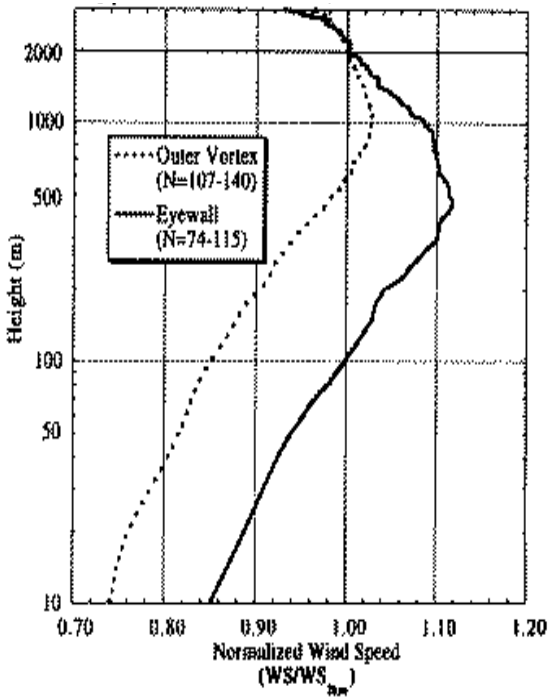
# GPS Dropsondes

Measures the wind around and in hurricanes from the aircraft to the ocean's surface

Wind in Hurricane Georges




Mean Wind Profile




Franklin and Black (1999)

# Surface wind analyses using flight level winds

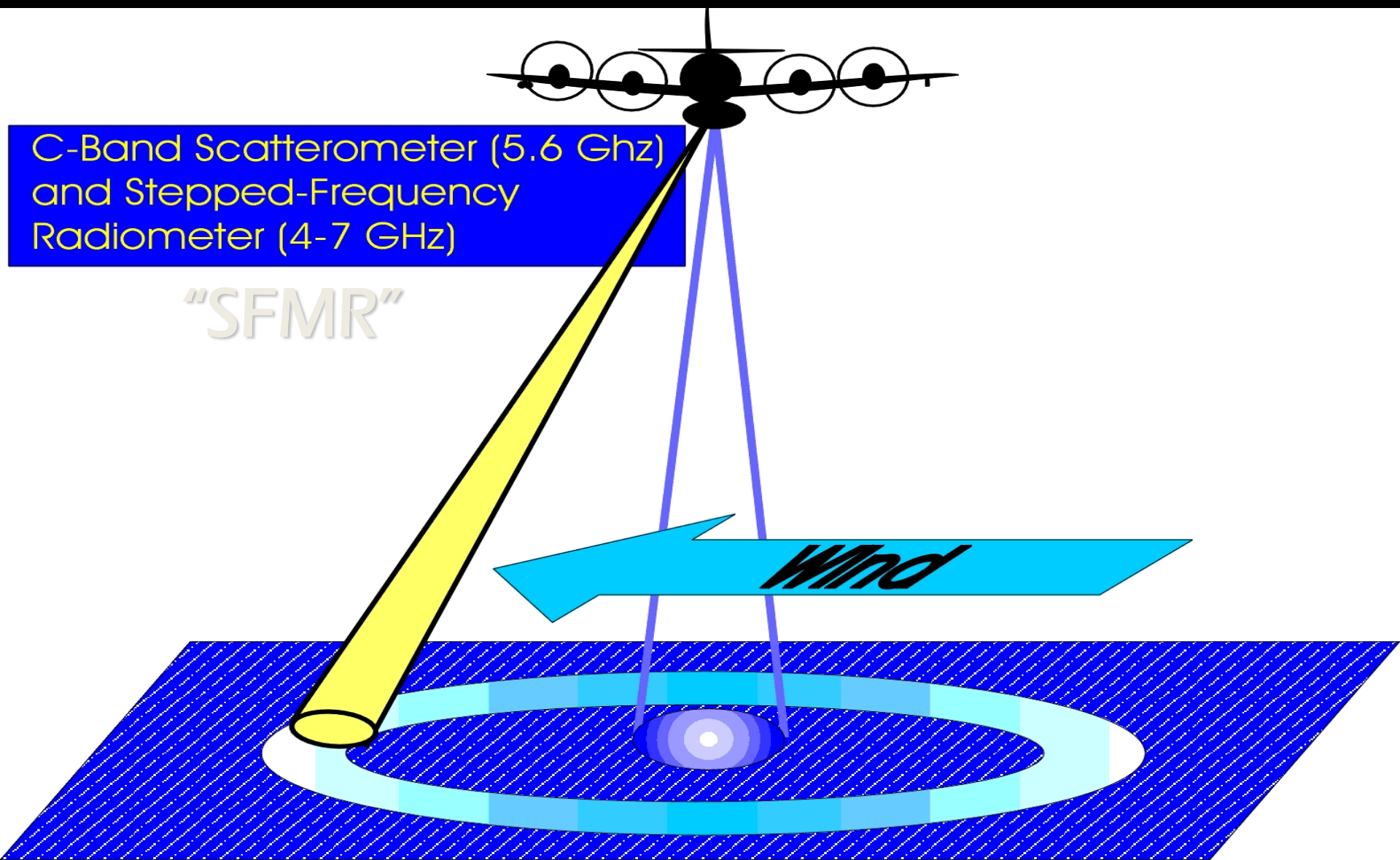
Table 2. Reduction factors and flight-level wind thresholds for determining wind radii from 700 mb data.

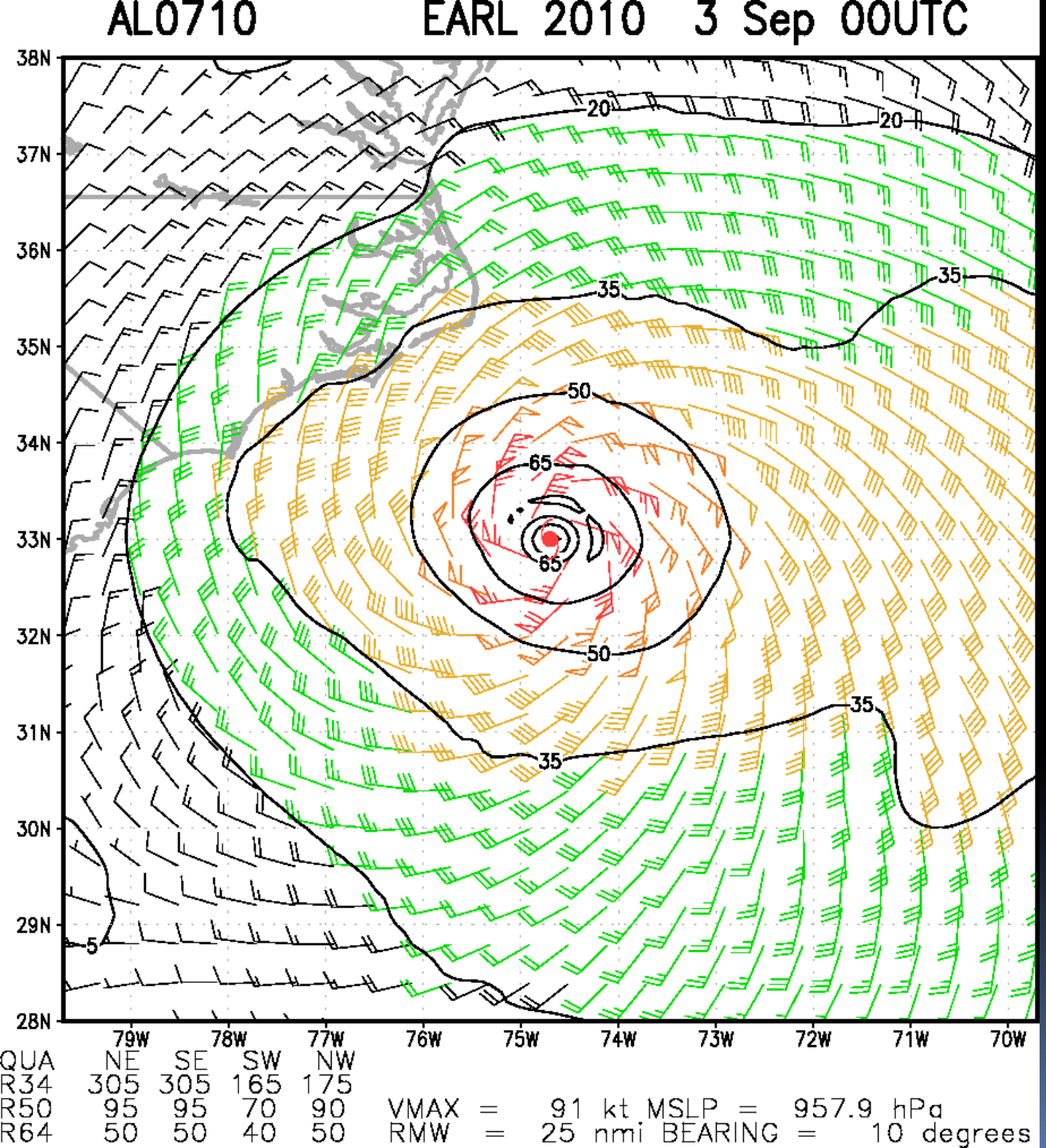
| Sample | RF10m | FLW64 (kt) | FLW50 (kt) | FLW34 (kt) |
|---|---|---|---|---|
| Eyewall | 0.90 | 70 | 55 | - |
| Outer vortex | 0.85 | 75 | 60 | 40 |
| Outer vortex / Right quad | 0.75 | 85 | 65 | 45 |
| Outer vortex / Left quad | 0.90 | 70 | 55 | 40 |

**A large sample of GPS dropsondes in the inner core of TCs provides a way to determine surface wind radii from flight level winds via the mean wind profile**

Franklin (2001)

# Remotely Sensed Surface Winds





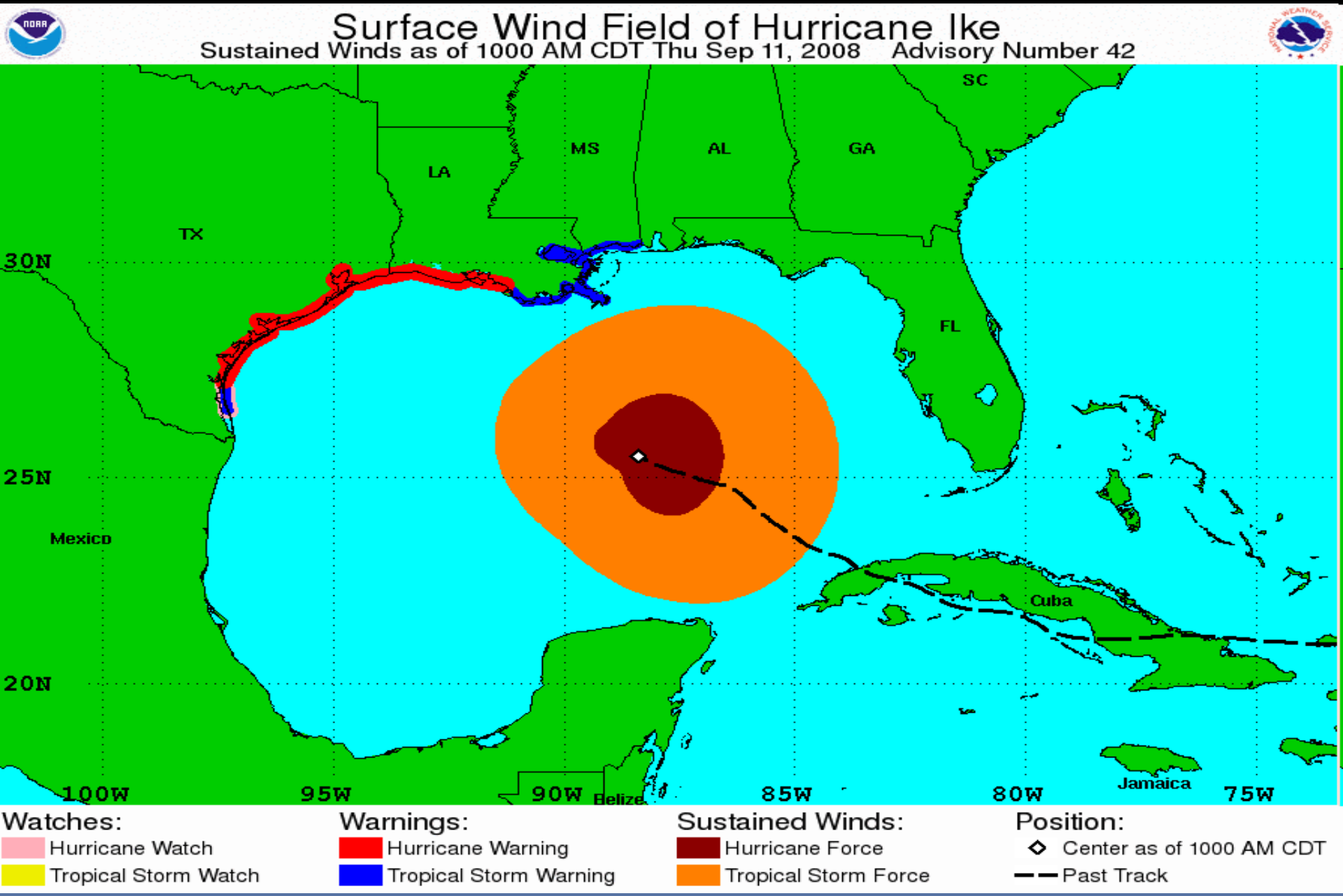

# Multiplatform Satellite Surface Wind Analysis – CIRA

Automated Surface Wind Field in Tropical Cyclones

And after using all of that data, we come up with this…

6:11 PM

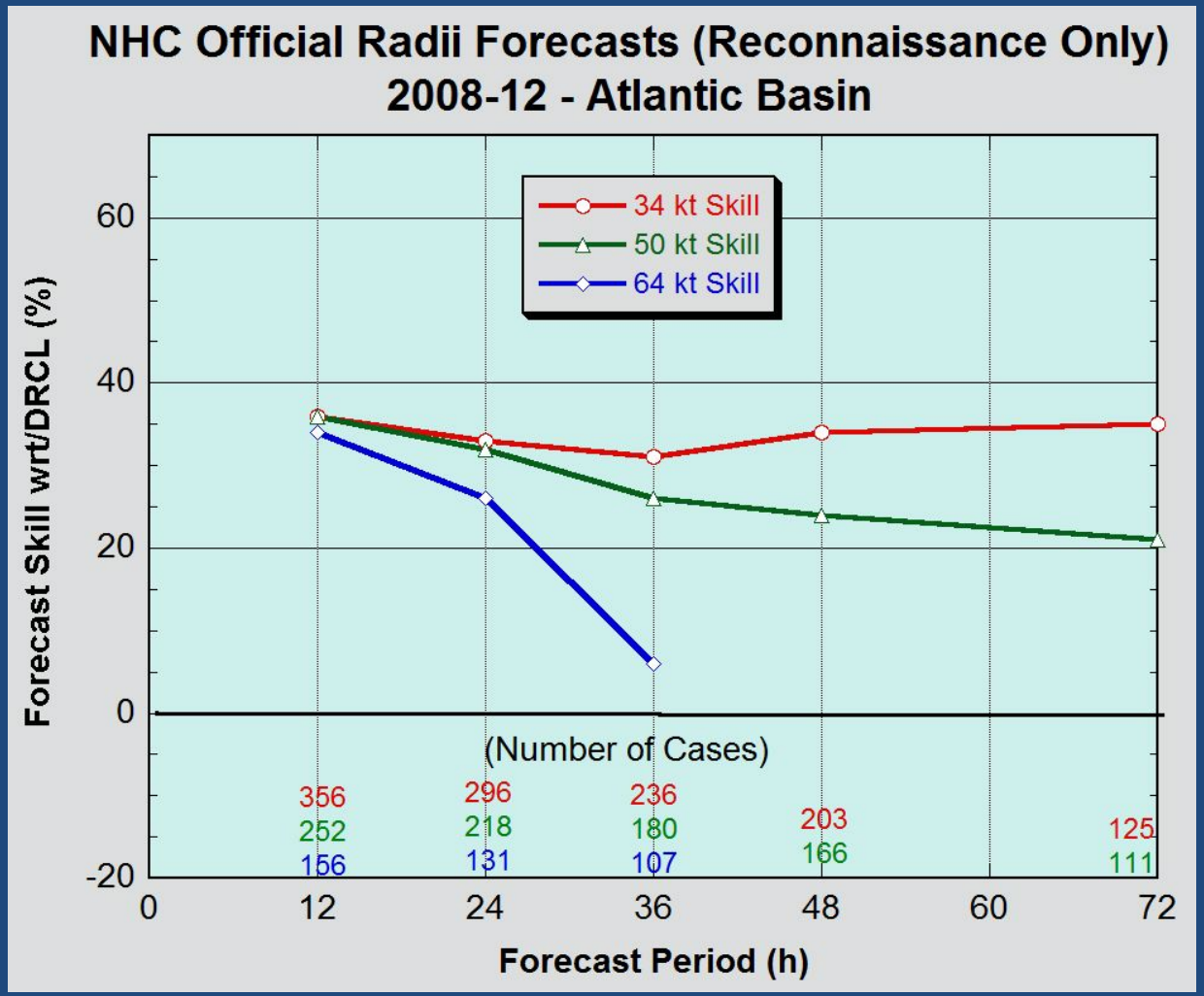
# Surface Wind Field



# Wind Radii Forecast "Guidance"

- Empirical ideas
  - Is the storm strengthening or weakening?
  - Is persistence appropriate, or are conditions changing?
  - Is the storm becoming extratropical, causing wind field to expand?
  - Will all or part of the circulation be passing over land, such that radii could decrease?
  - Is the system accelerating, such that the storm could become more asymmetric?

# NHC Forecast Skill

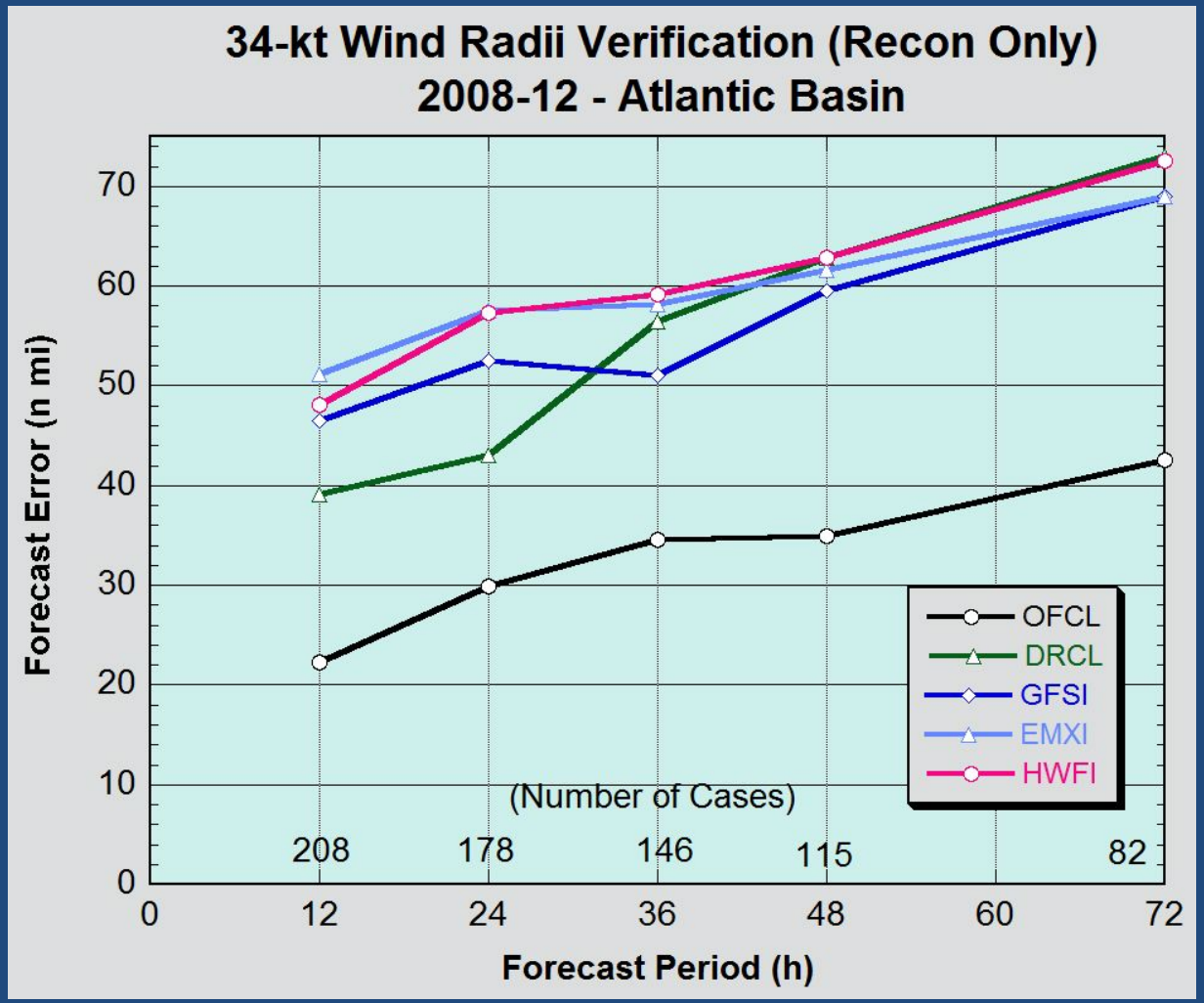



Yes, the NHC wind radii forecasts are skillful. Skill declines over time.

34 kt skill: ranges from 30-35%
50 kt skill: ranges from 20-35%
64 kt skill: ranges from 5-35%

***How good is the guidance?***

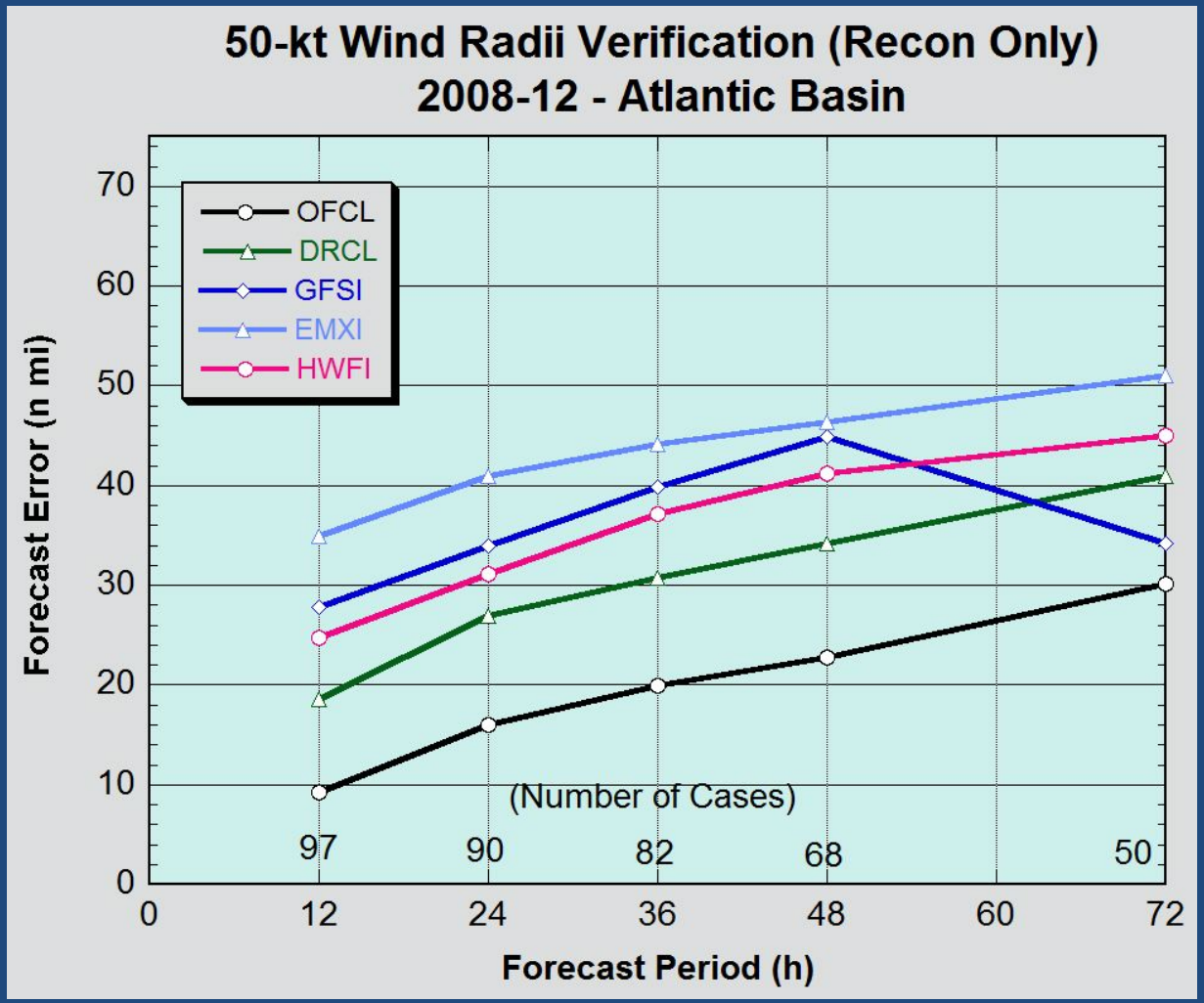
# The Models - 34 kt Verification




The guidance is not very good. OFCL is considerably better than all of the dynamical guidance shown here.

GFSI and EMXI have some skill (errors are lower than DRCL)at 48 and 72 h.

# The Models - 50 kt Verification




OFCL is considerably better than the dynamical guidance.

Among the guidance, only the GFSI had skill at 72 h.