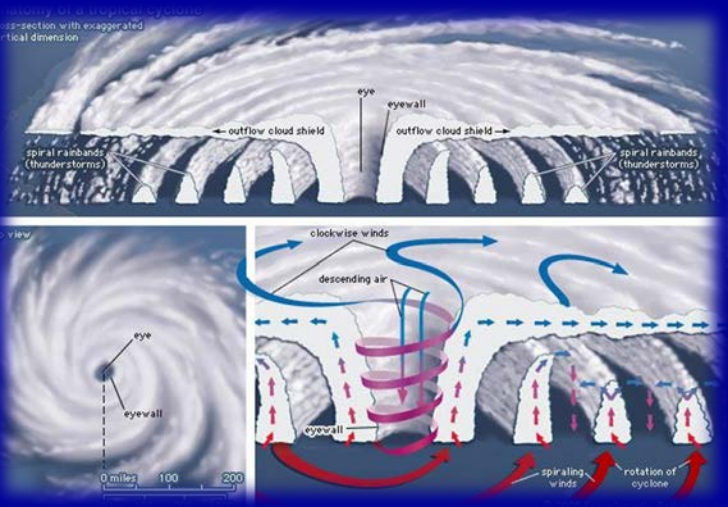
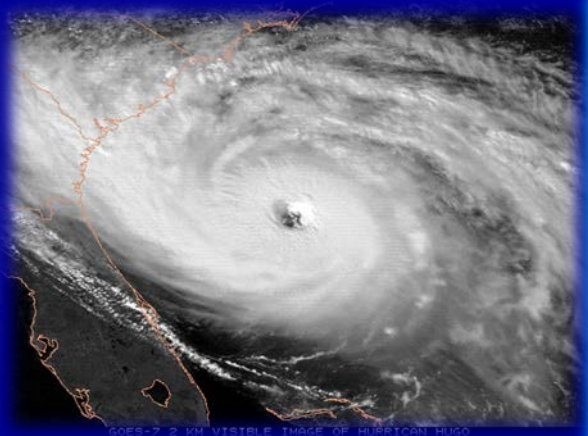
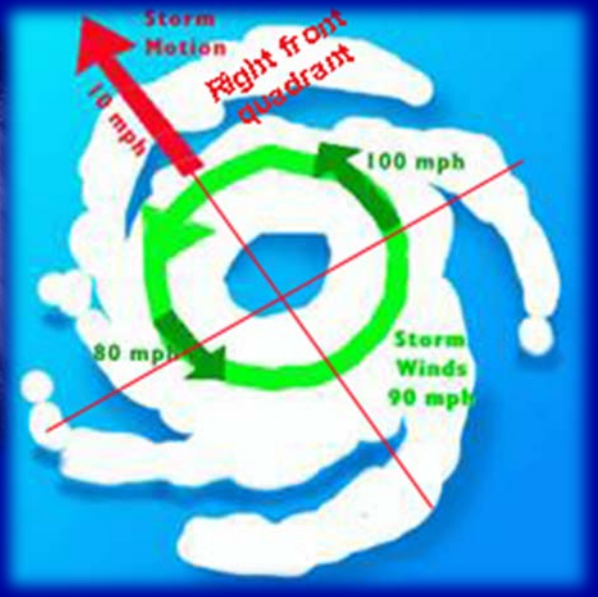
Tropical Cyclone Structure: Theory and Application







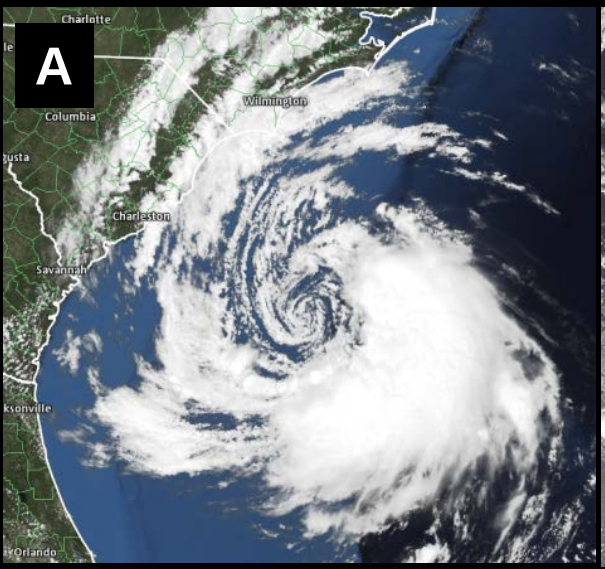
Philippe Papin

National Hurricane Center

Special Thanks: John Cangialosi & Matt Onderlinde

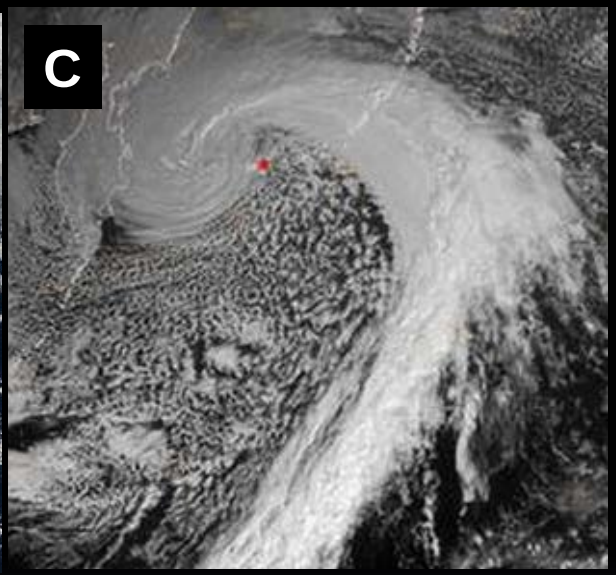
World Meteorological Organization Workshop

Is this Tropical, Subtropical, or Extratropical?



Subtropical

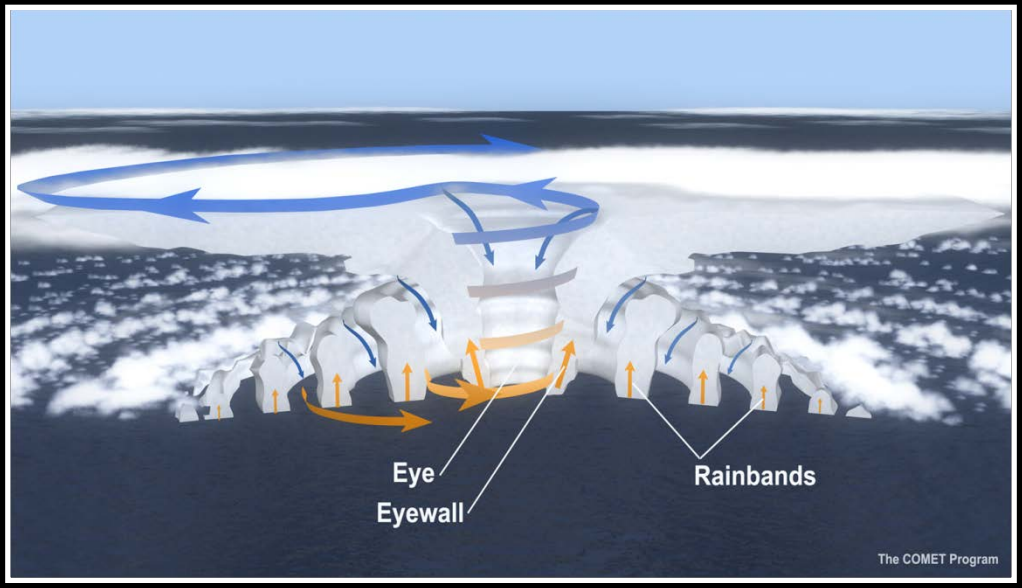
Tropical

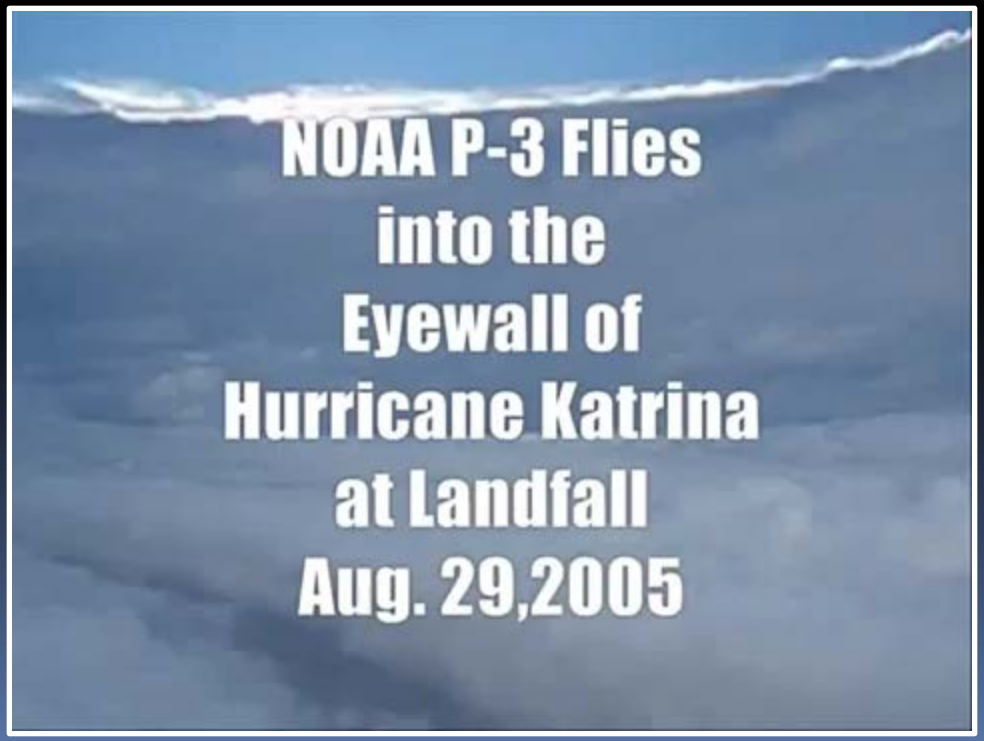


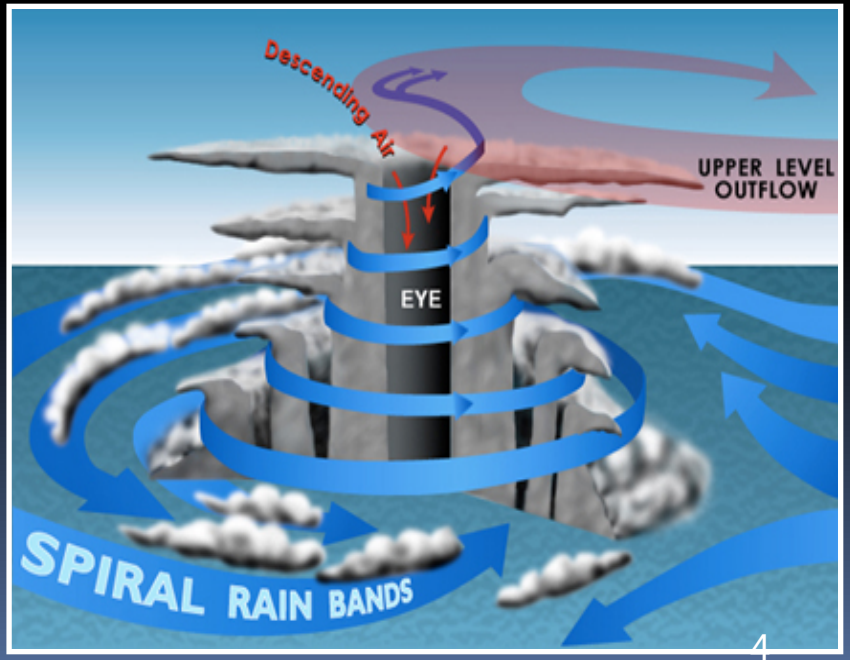
Extratropical

Is this Tropical, Subtropical, or Extratropical?

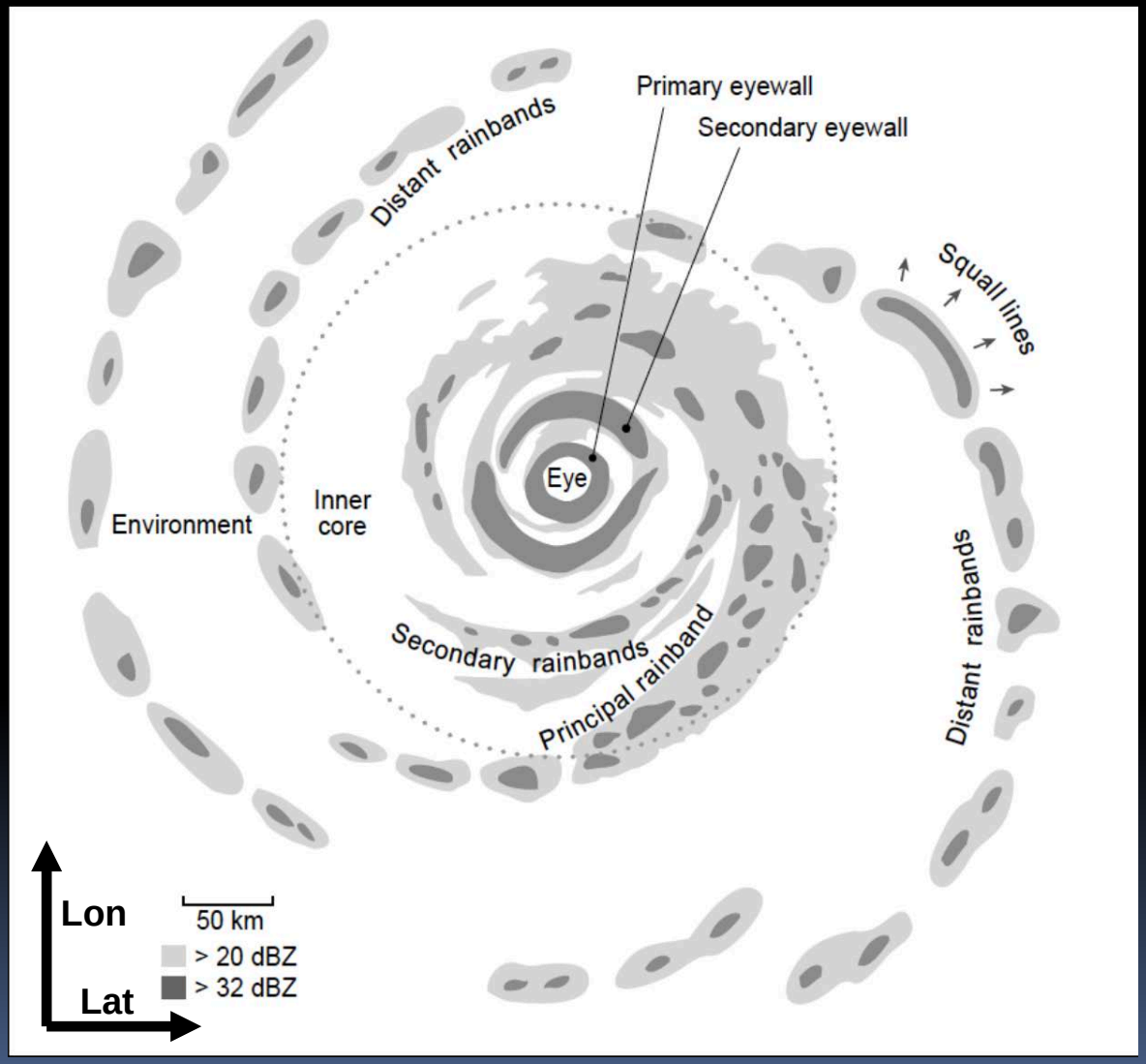
Typical Structure of a Hurricane





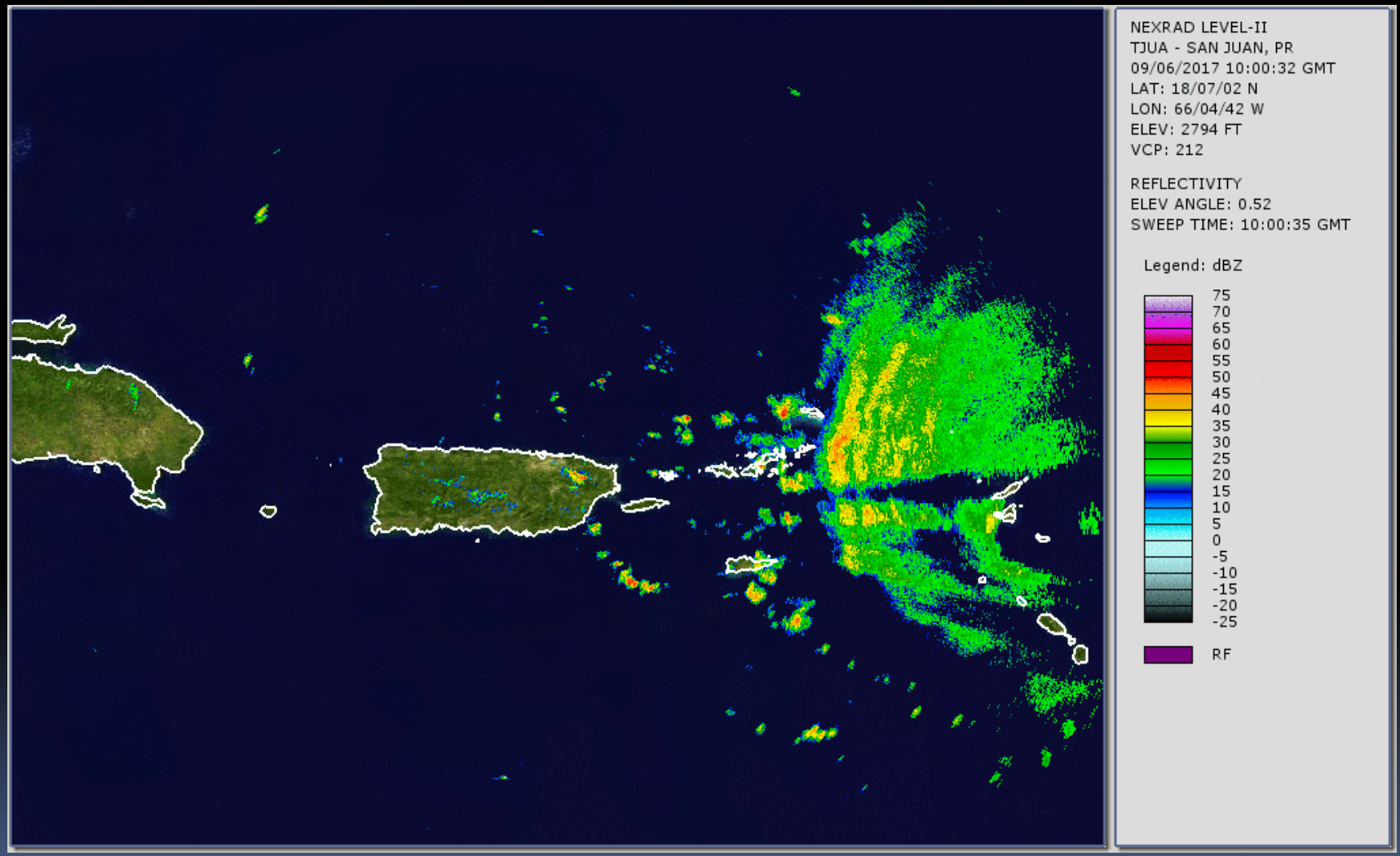


2D Idealized Hurricane Structure

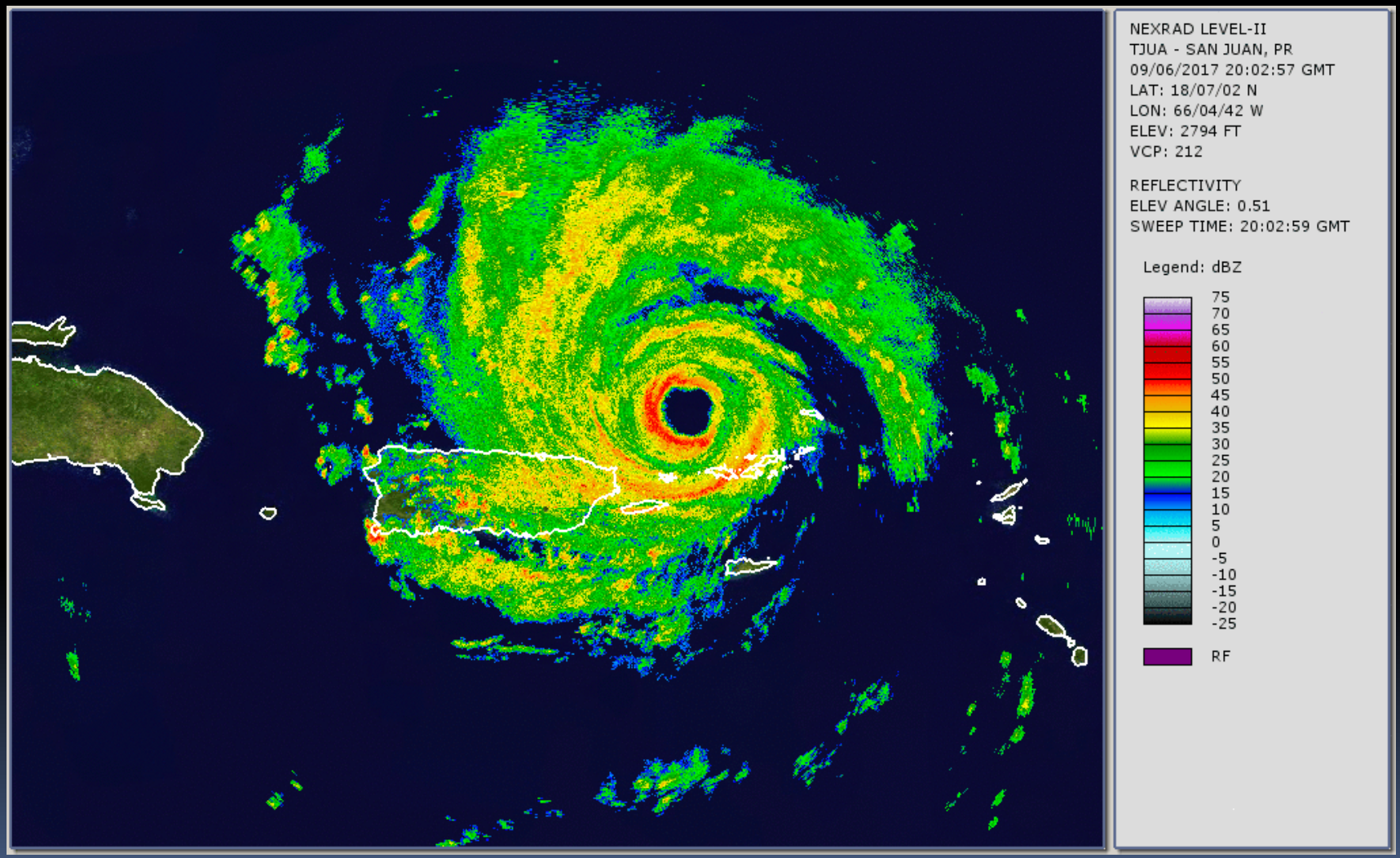


Houze (2010) – Review: Clouds in Tropical Cyclones

Hurricane Structure - Irma



Hurricane Structure - Irma



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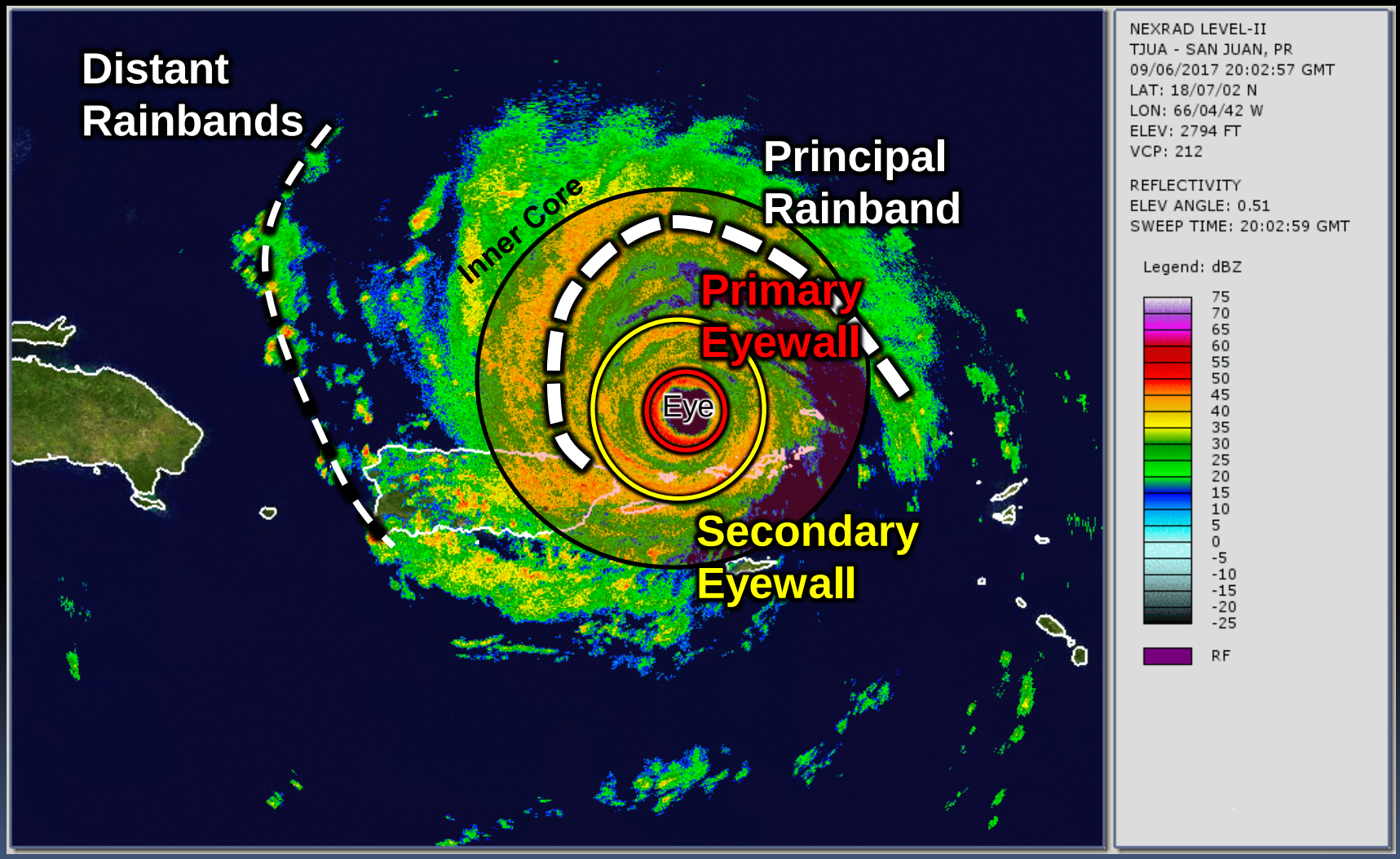
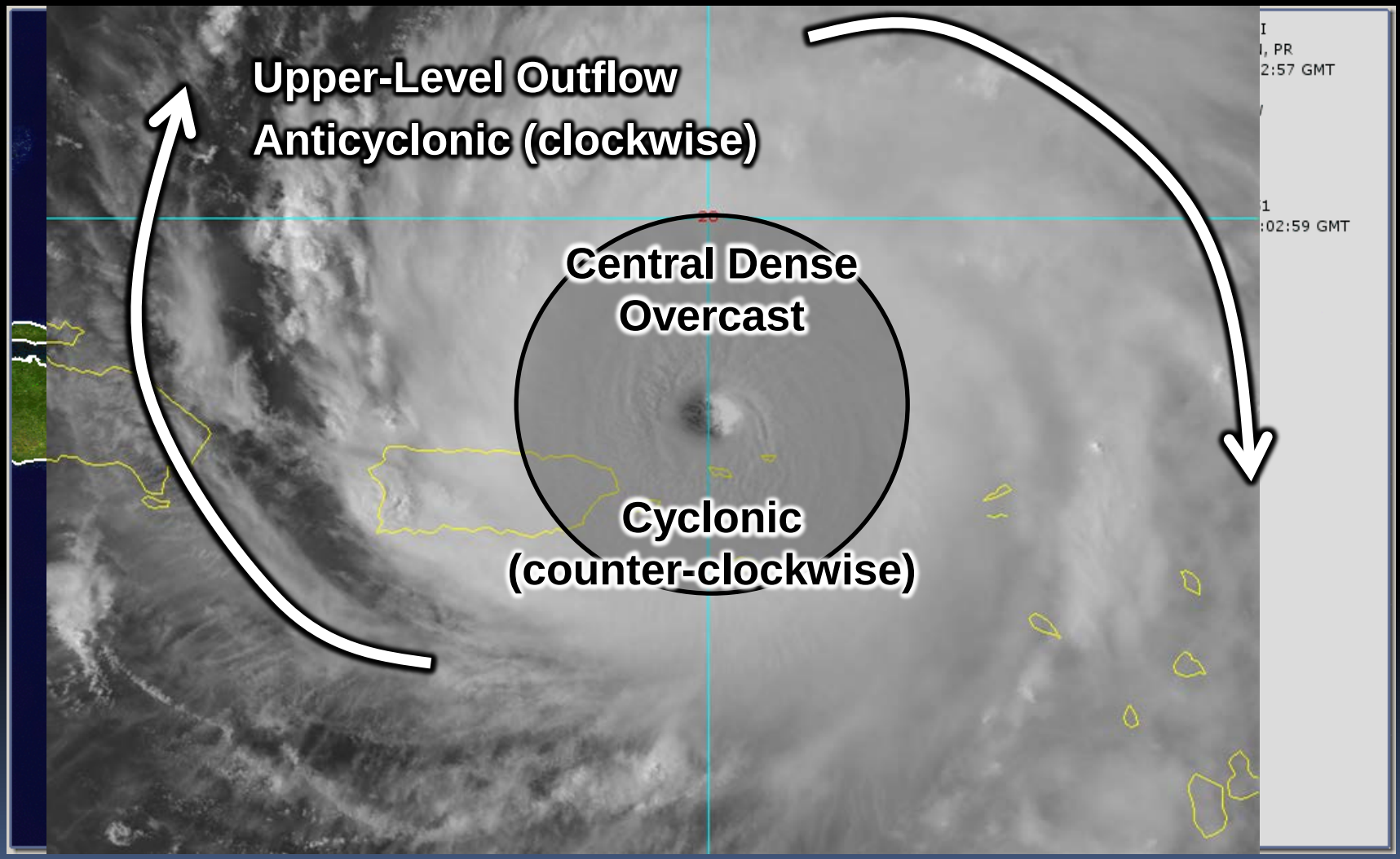
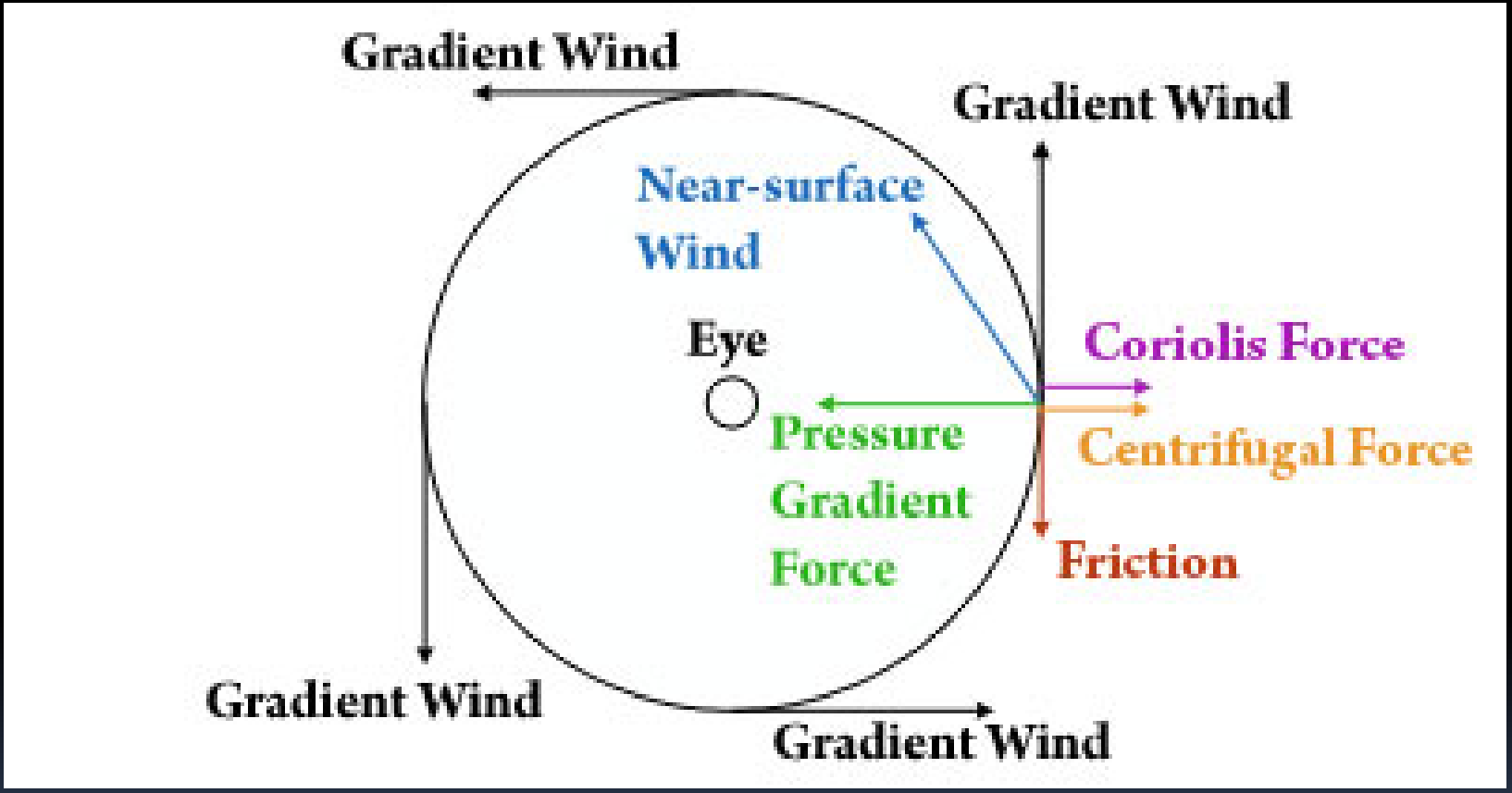
Hurricane Structure - Irma



Hurricane Structure - Irma

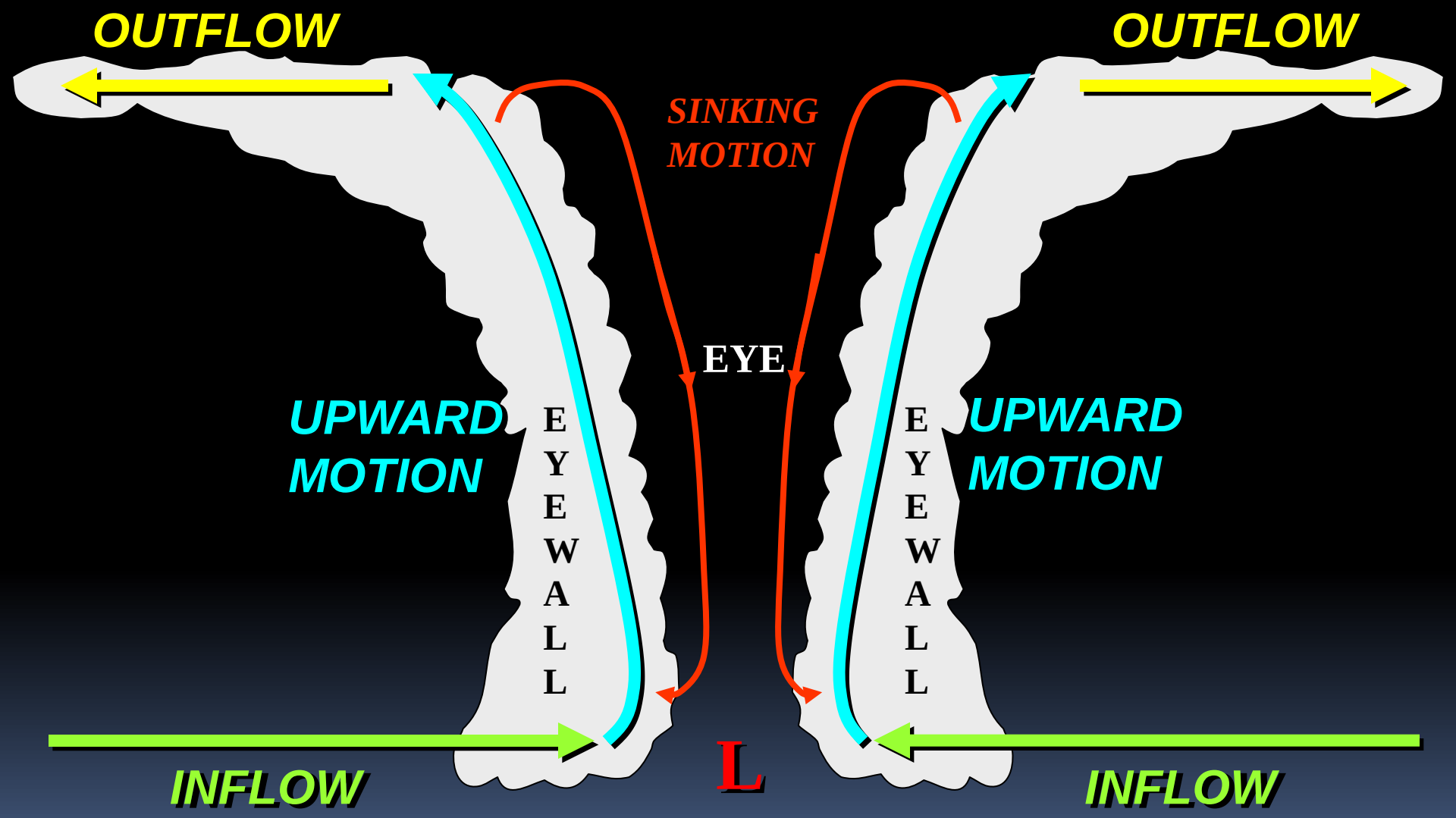


Primary Circulation



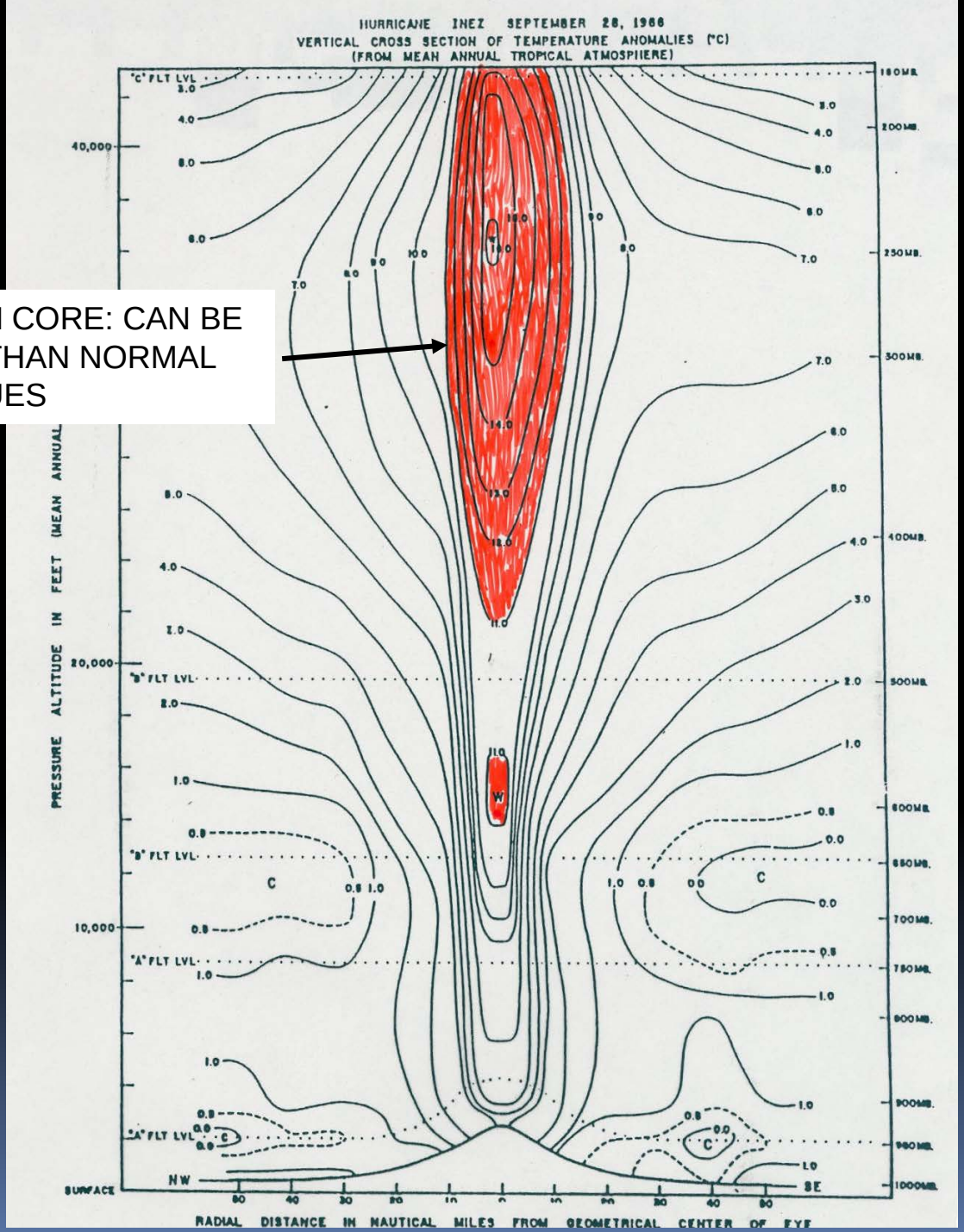
Low-Level Horizonal Circulation in Gradient Wind Balance

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

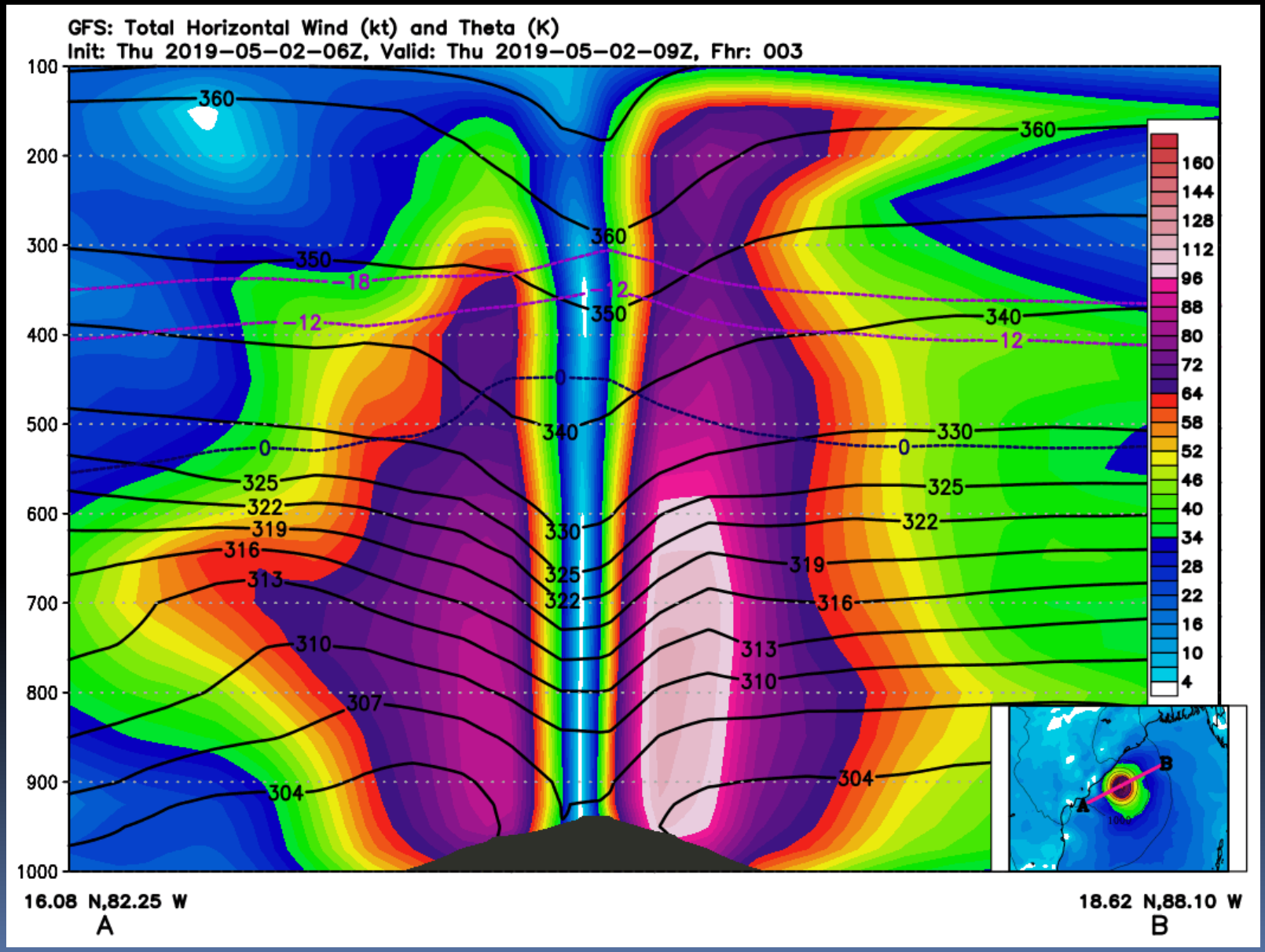


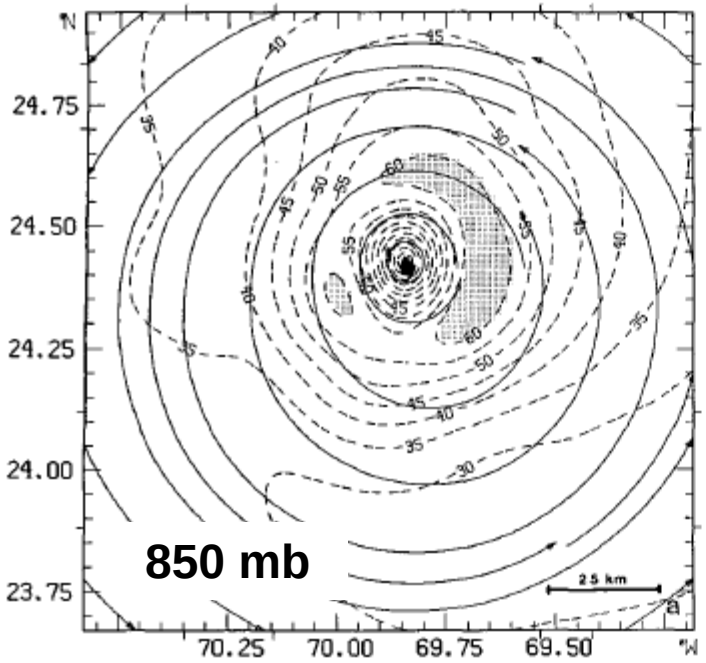
Vertical Circulation – In, Up, and Out

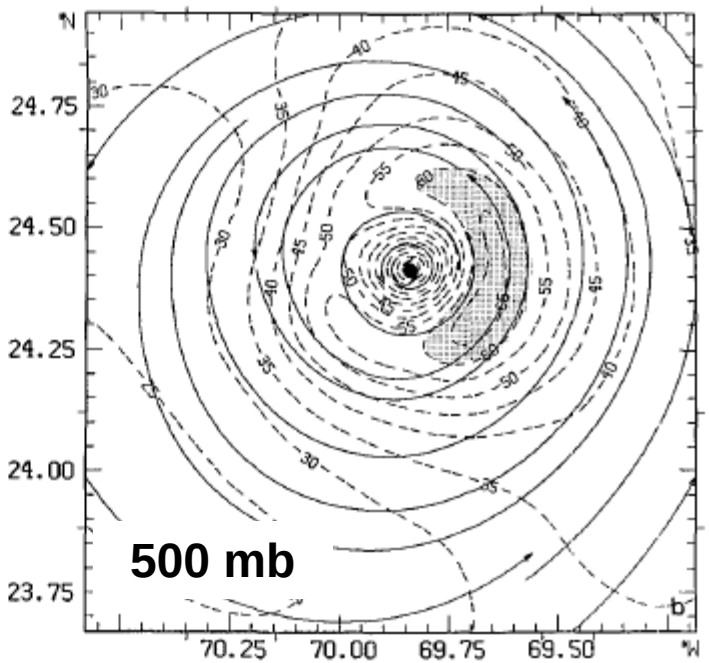
INTENSE WARM CORE: CAN BE 16 K WARMER THAN NORMAL TROPICAL VALUES

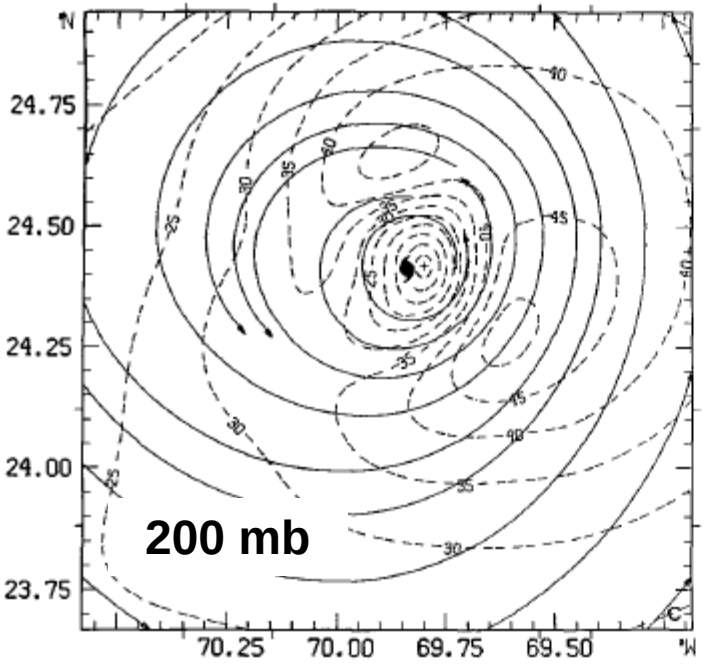


DEEP-LAYER CYCLONIC CIRCULATION



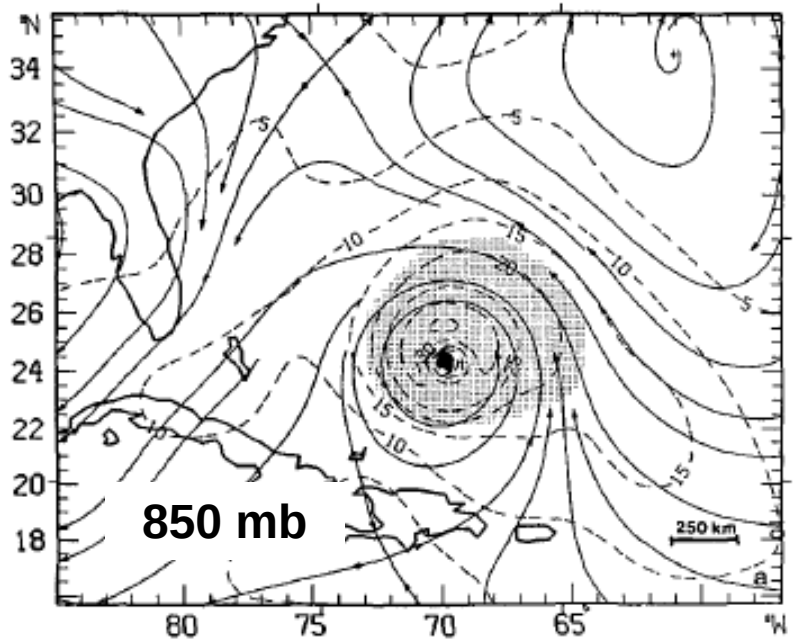


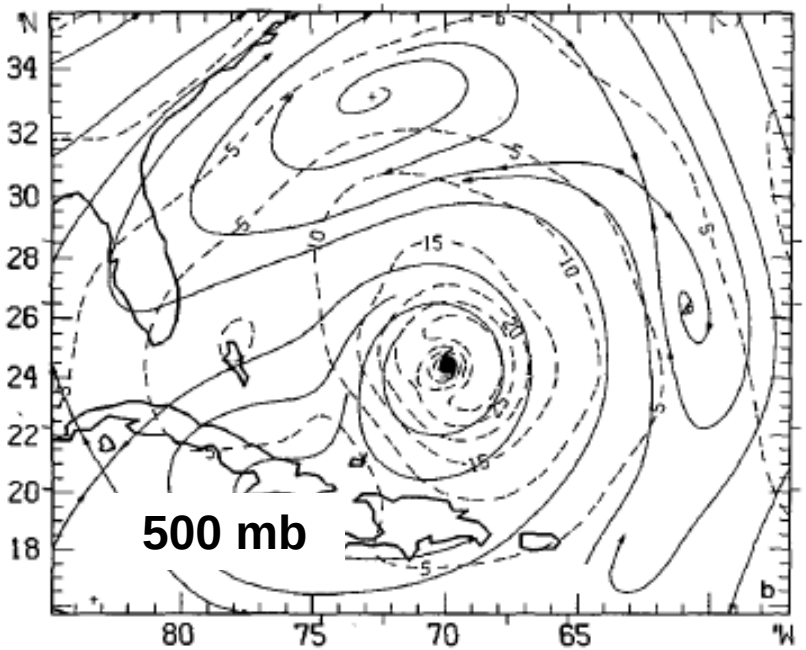


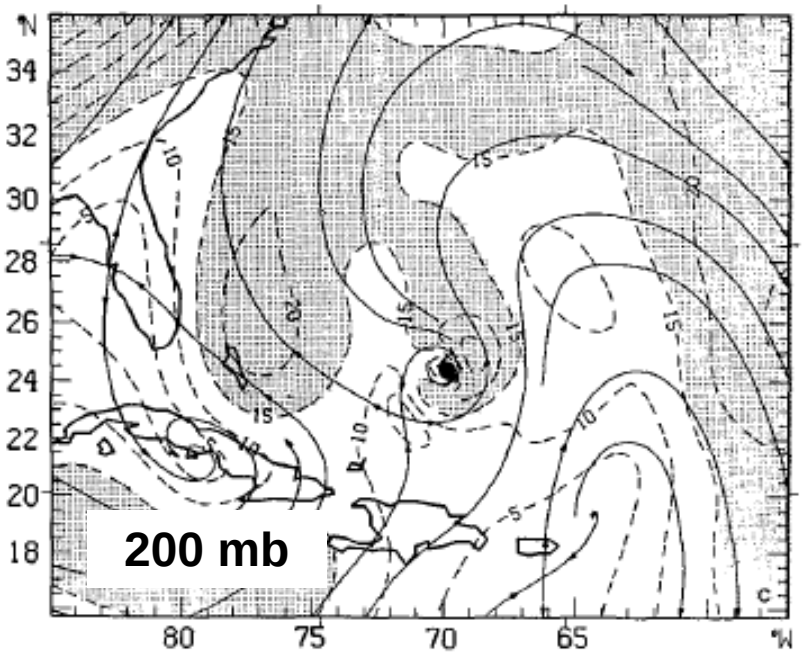


NOTE: CYCLONIC CIRCULATION AT UPPER-TROPOSPHERIC LEVEL, WITHIN A FEW DEGREES RADIUS OF THE CENTER!

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}.



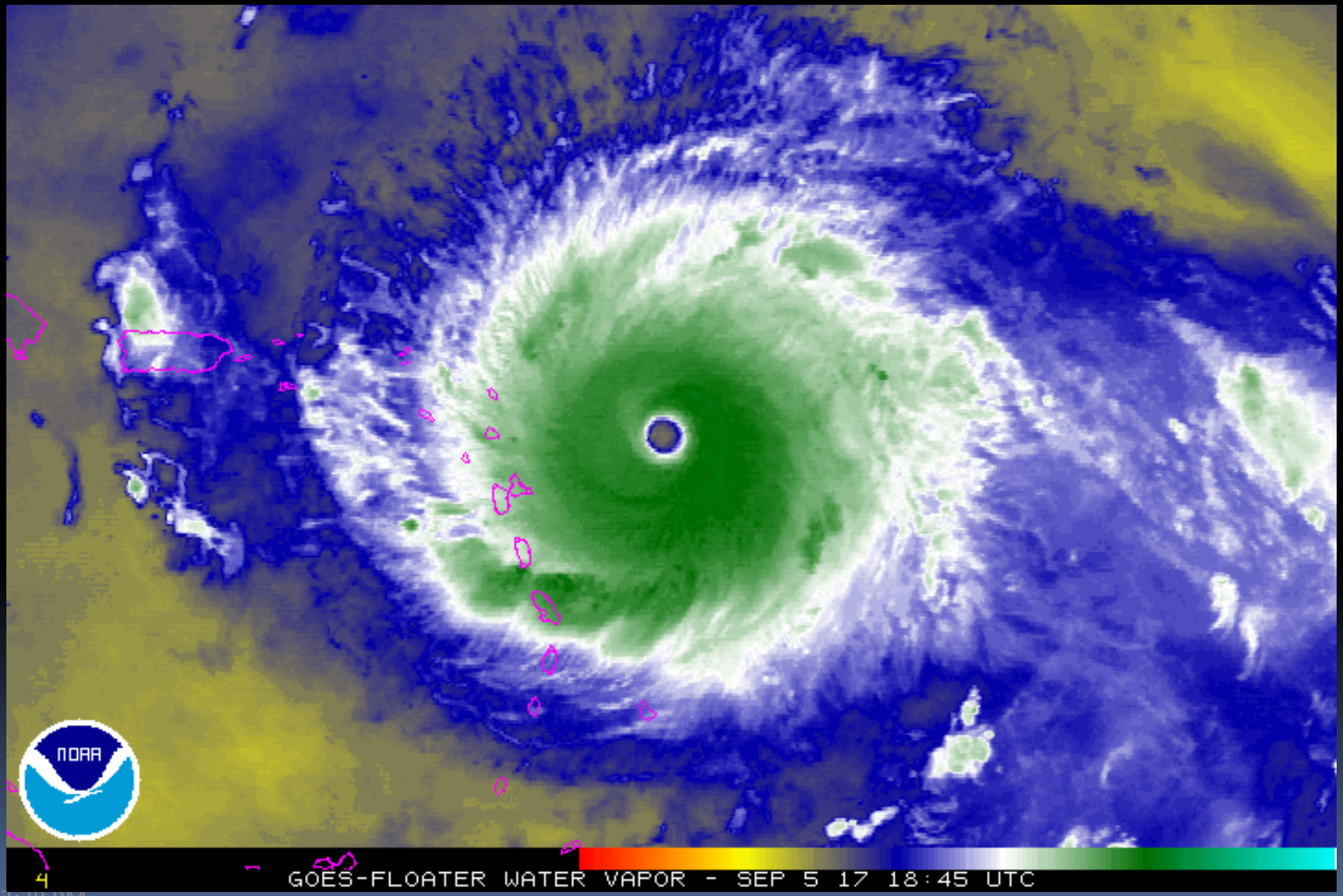




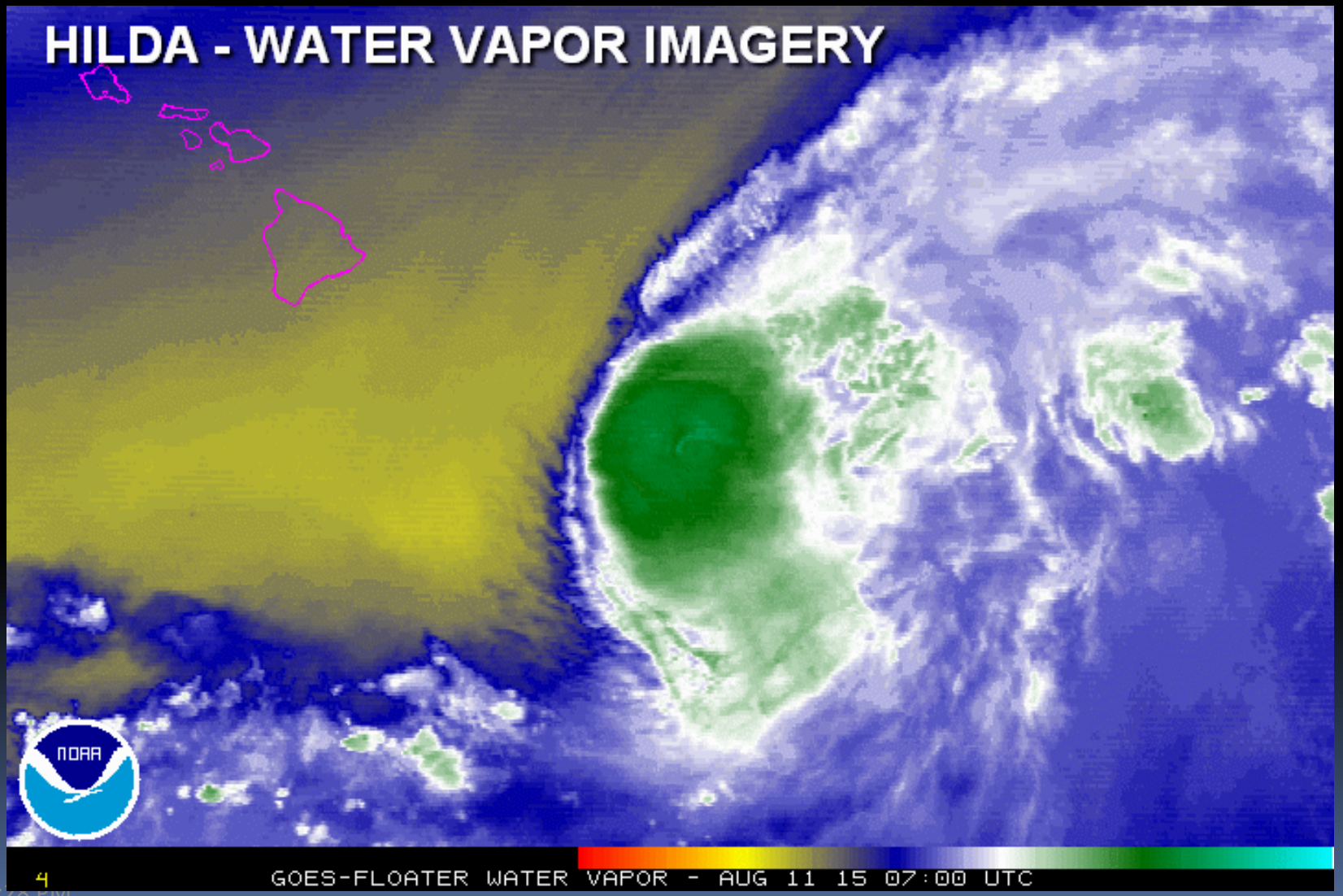
BEYOND A FEW DEGREES RADIUS FROM THE CENTER, THE UPPER-TROPOSPHERIC FLOW TURNS ANTICYCLONIC

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



Restricted outflow



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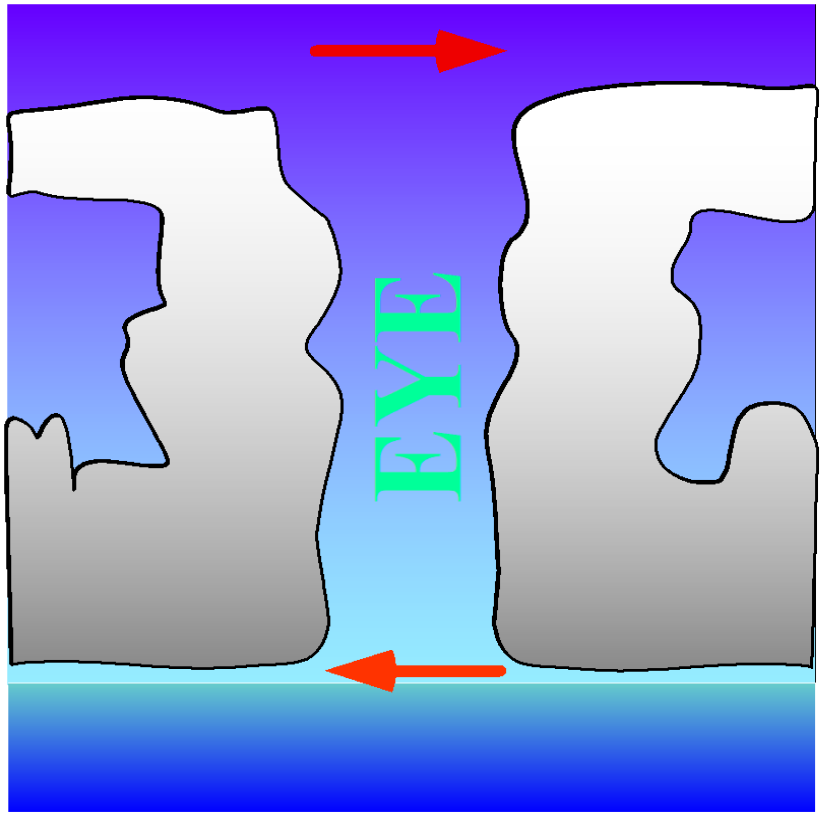
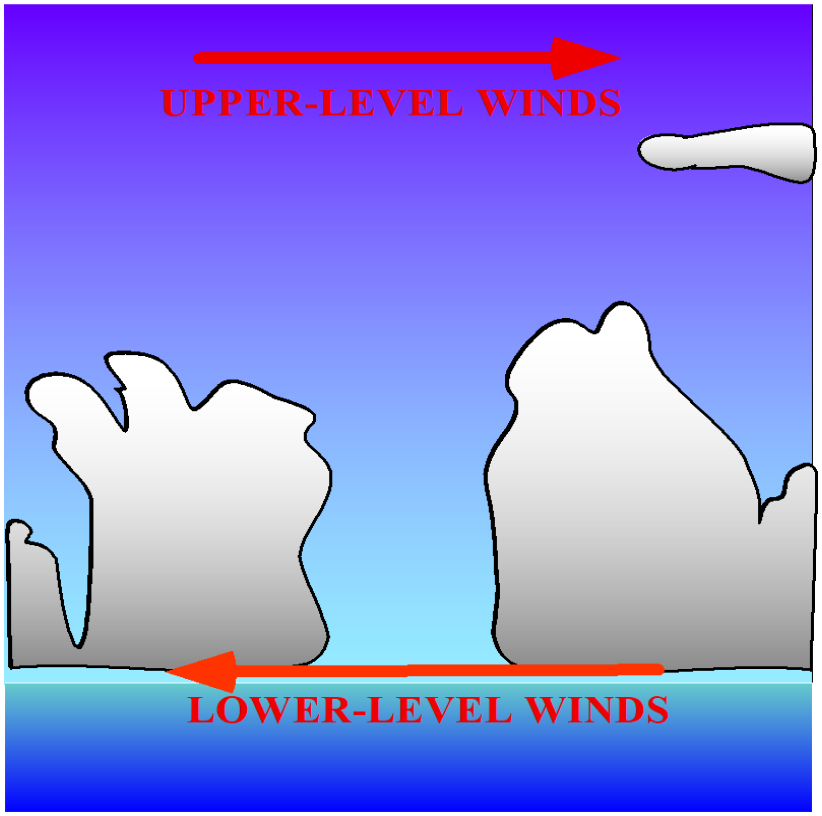
The Effects of Wind Shear

Effects of Vertical Wind Shear (V_z) on Tropical Cyclones

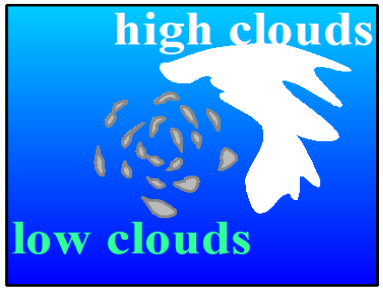




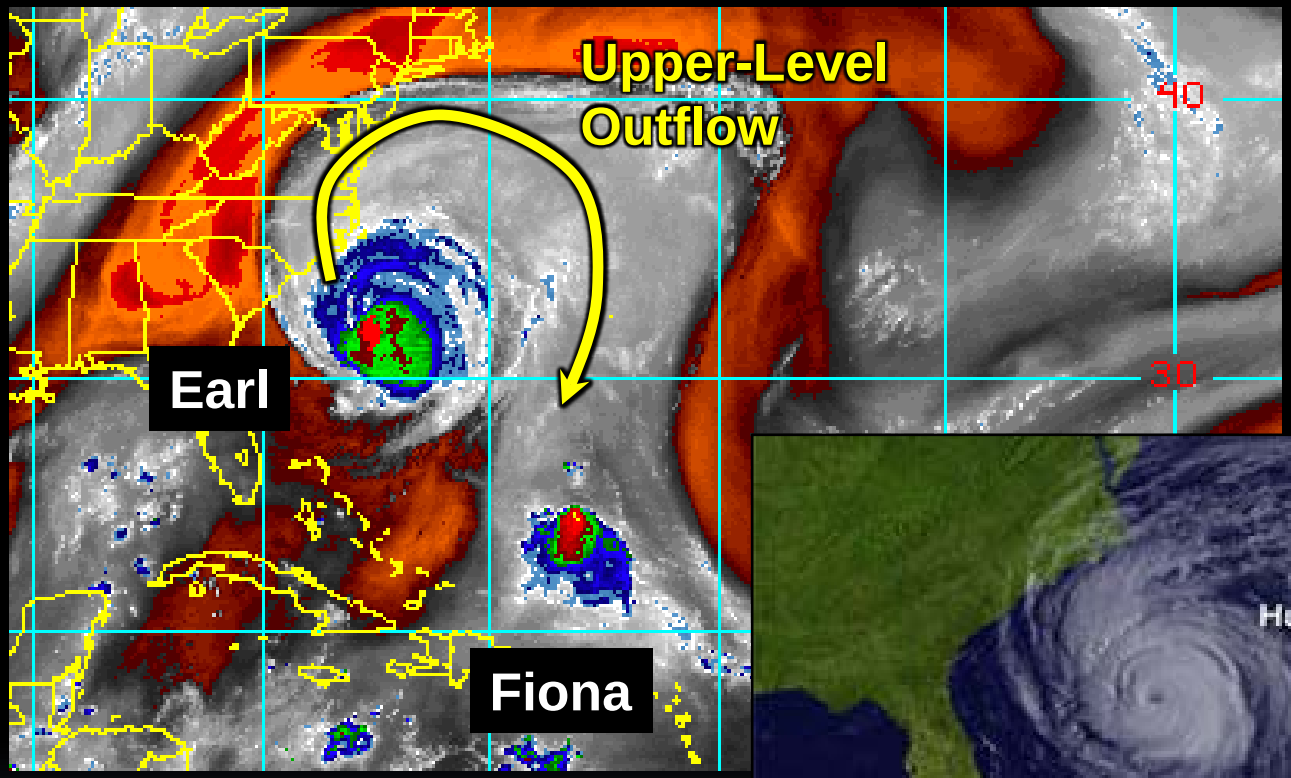
Neal Dorst/Stan Goldenberg
Hurricane Research Division
AOML/NOAA

***WEAK* SHEAR = FAVORABLE**

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



Intensifying vs. Non-Intensifying



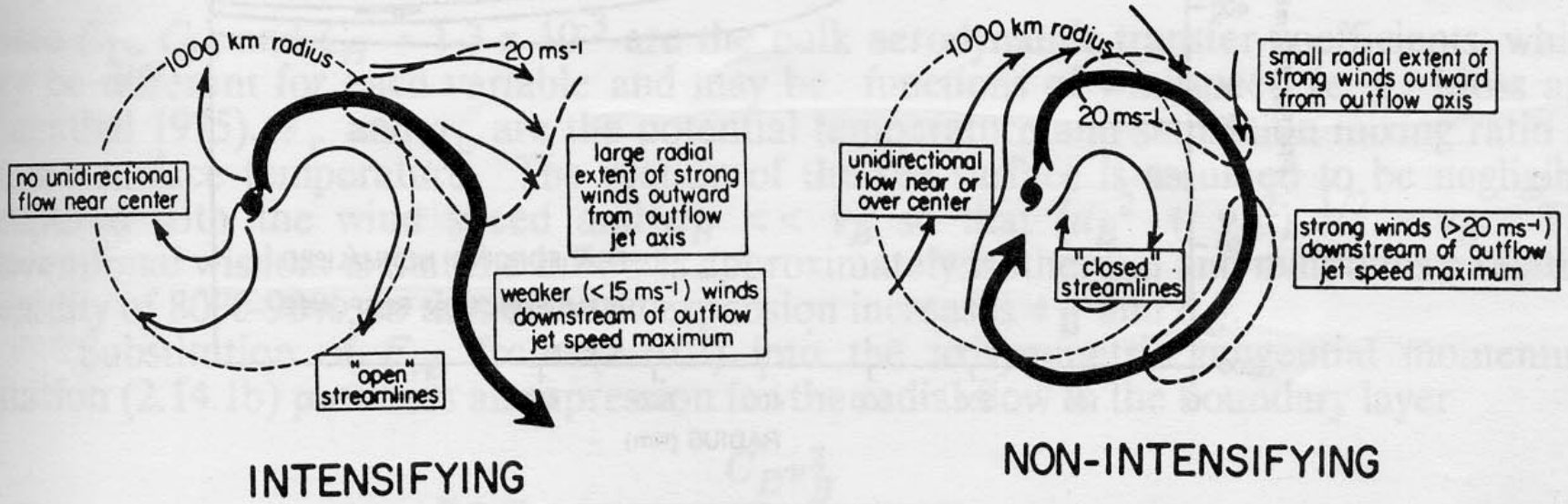
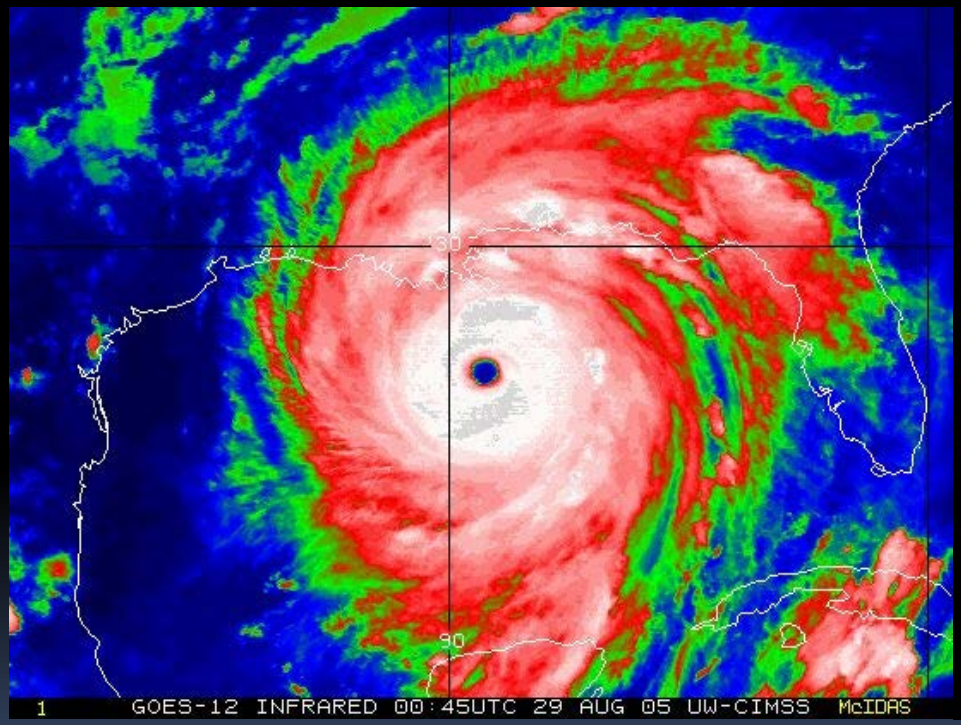
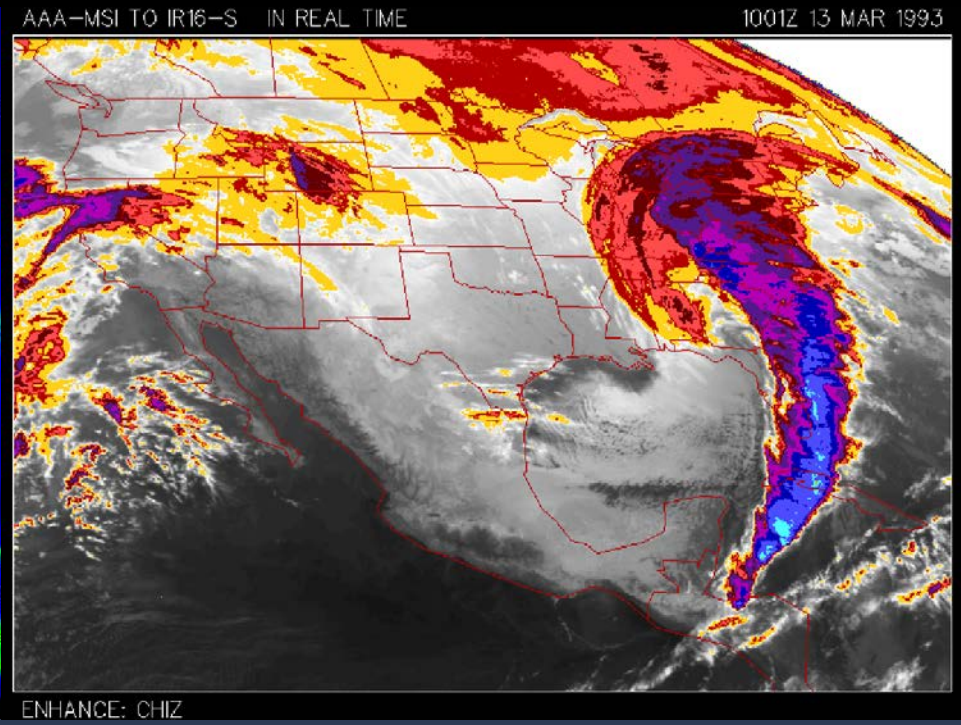


Fig. 2.17 Differences between the outflow and upper-level asymmetries of intensifying and nonintensifying hurricanes (Merrill 1988b).

The Extremes: Tropical vs. Extratropical Cyclones

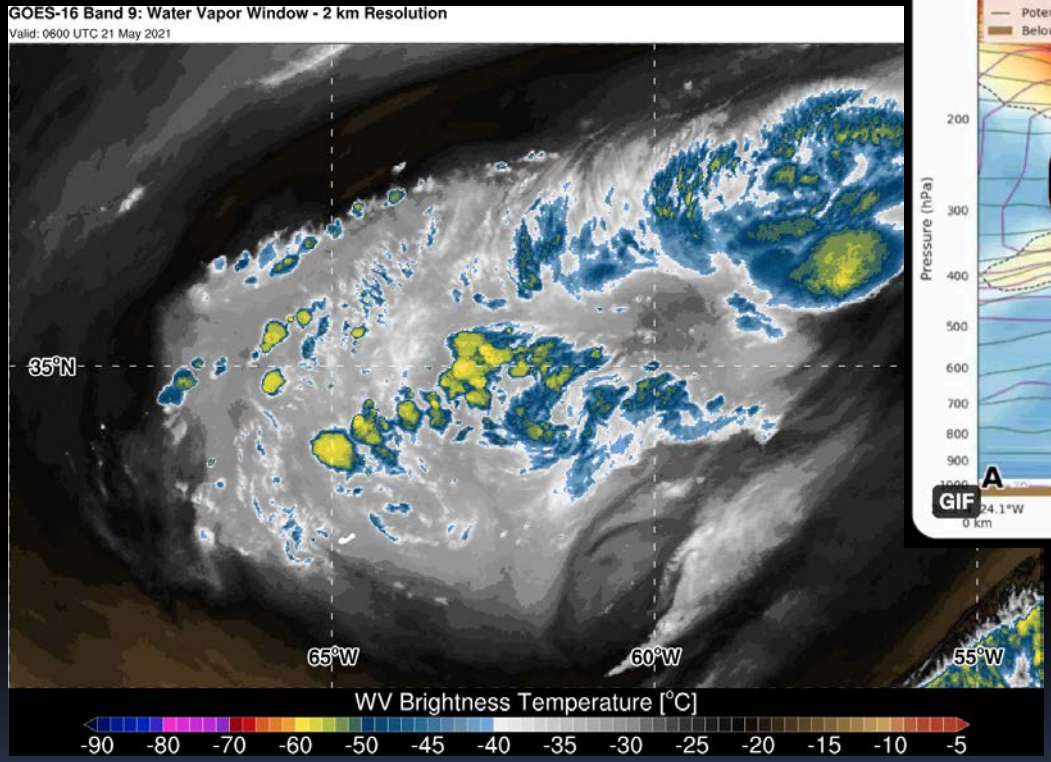


Hurricane Katrina (2005)

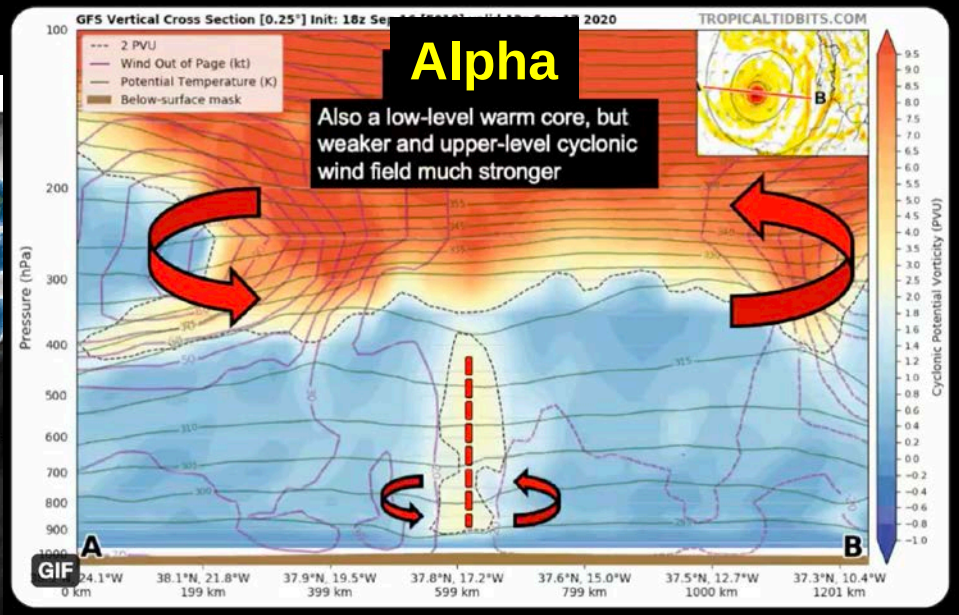


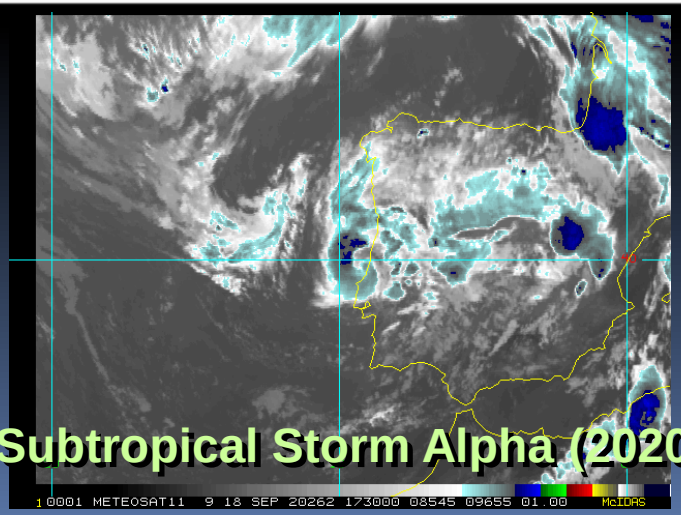
Superstorm Blizzard of March 1993

And The In Between: Subtropical Cyclones



Ana (2021) When it was a Subtropical Storm





Subtropical Storm Alpha (2020)

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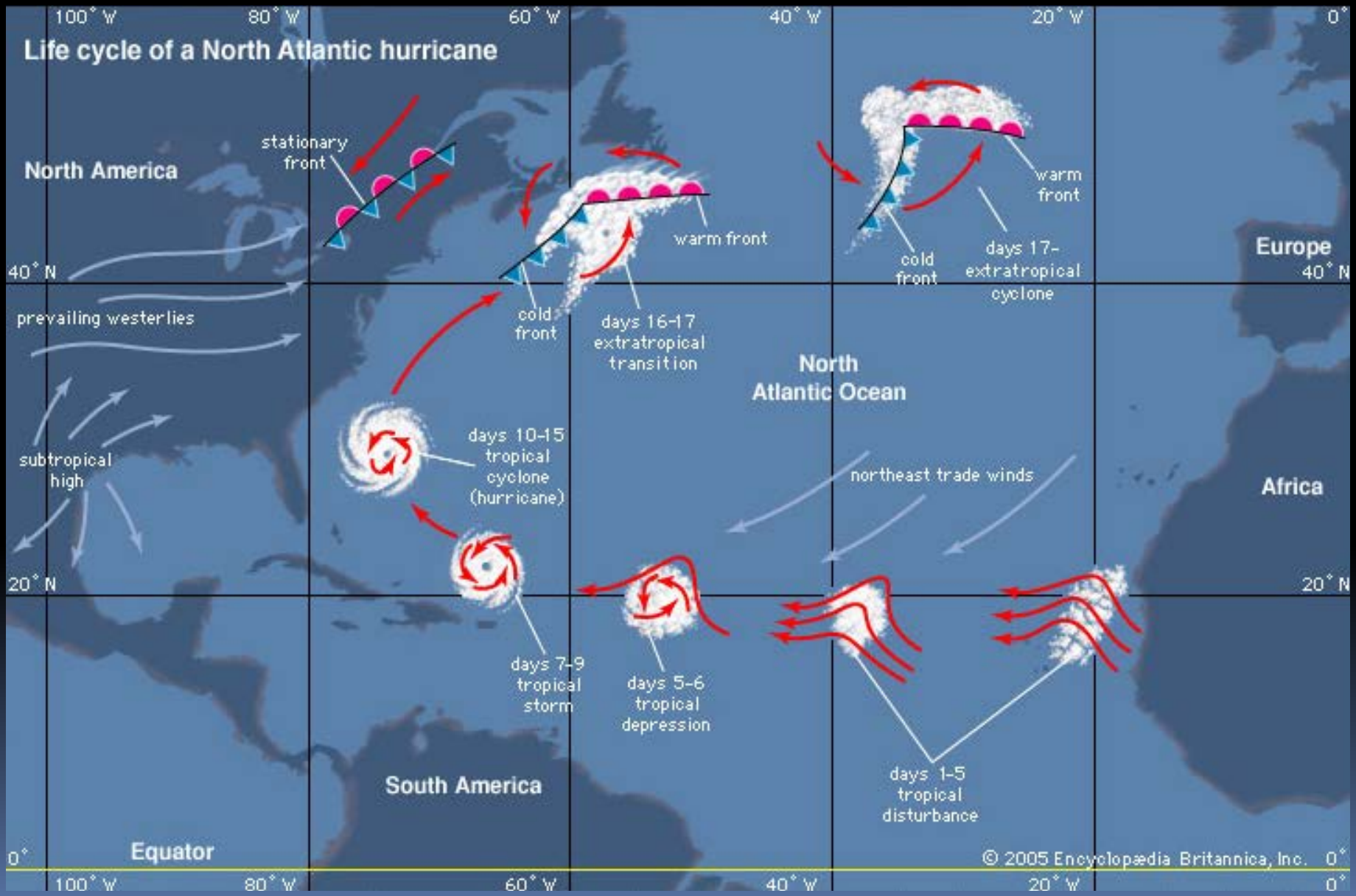
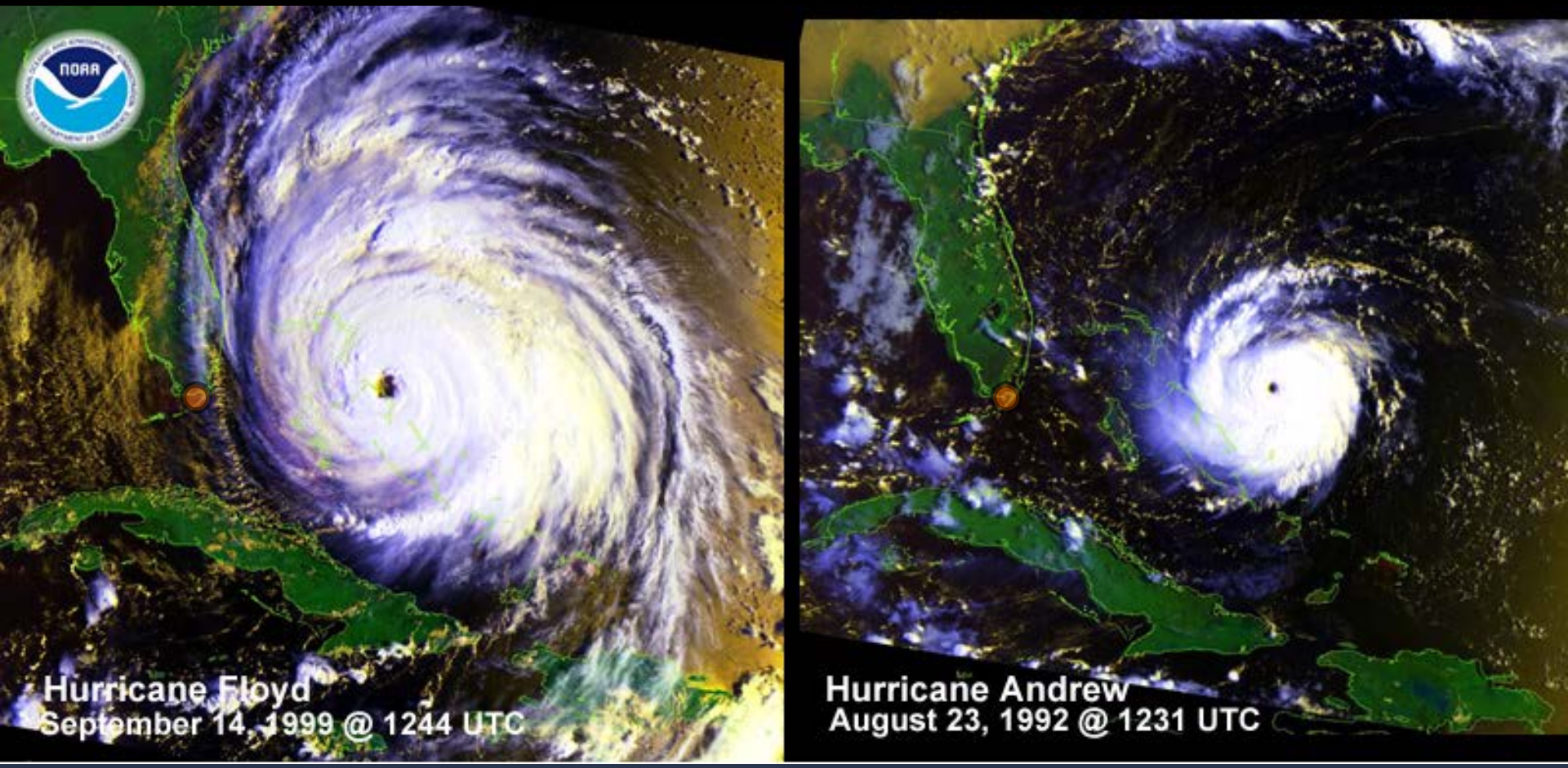
Life Cycle of a Cape Verde Hurricane

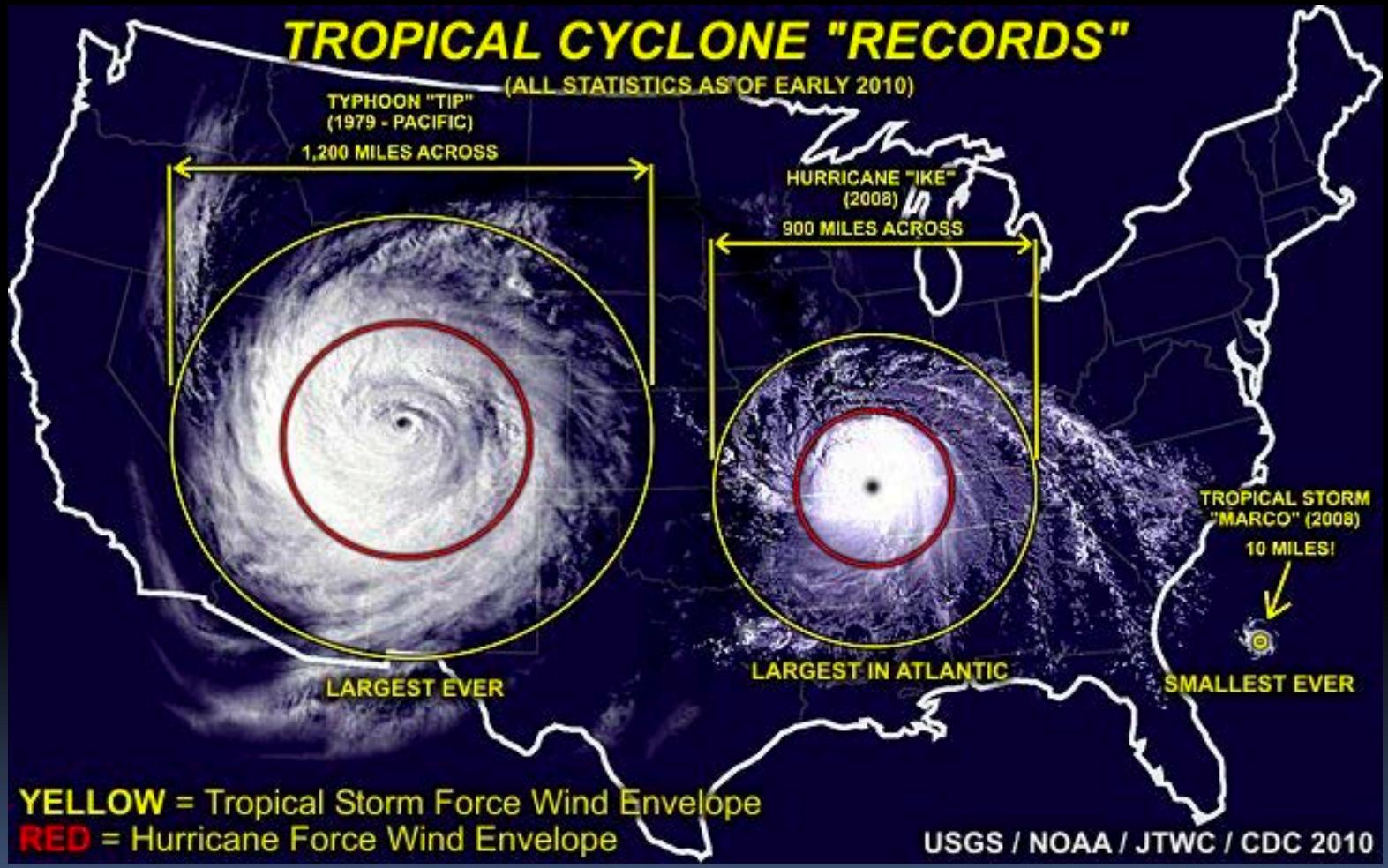


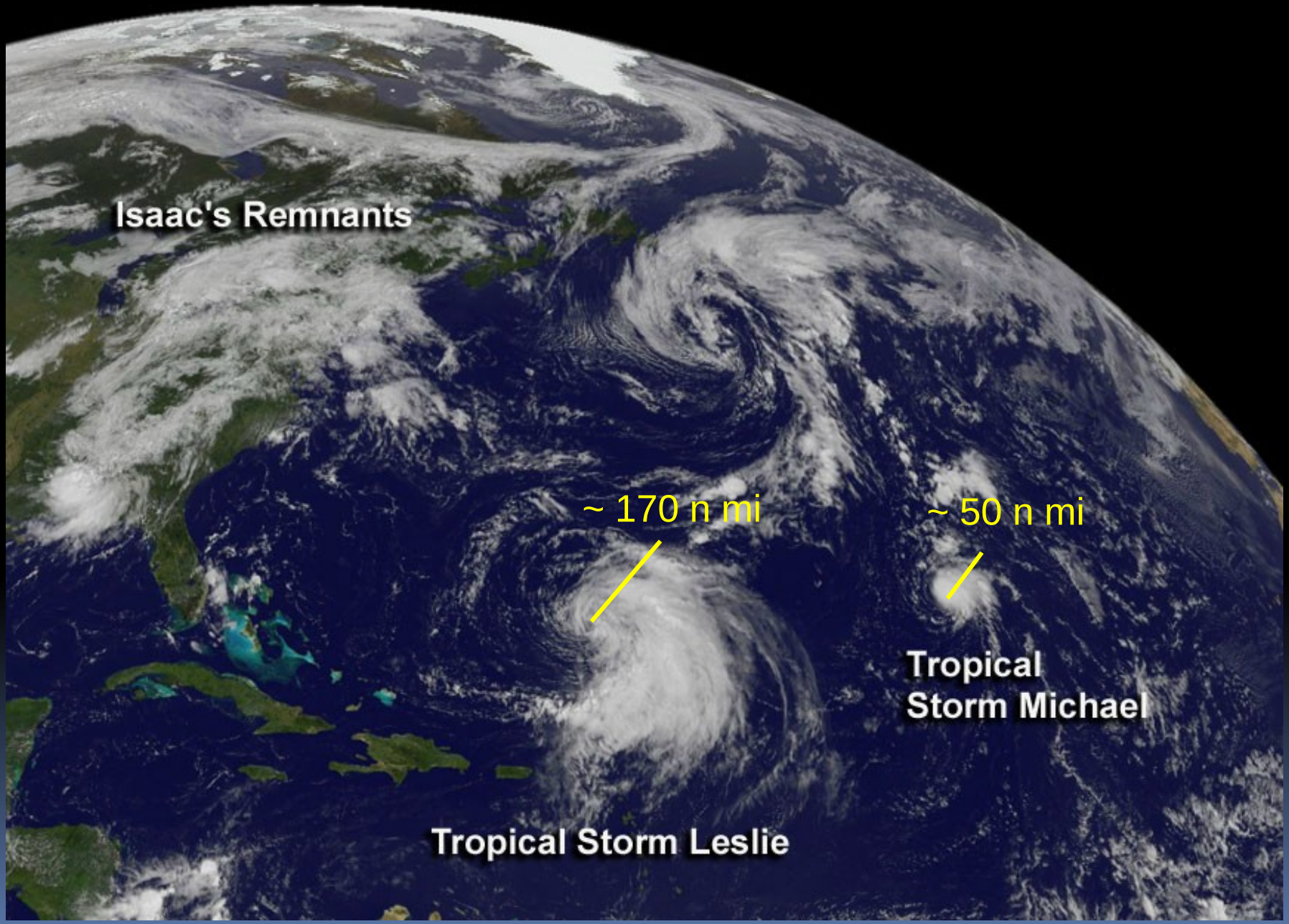
Hurricane Size Variability



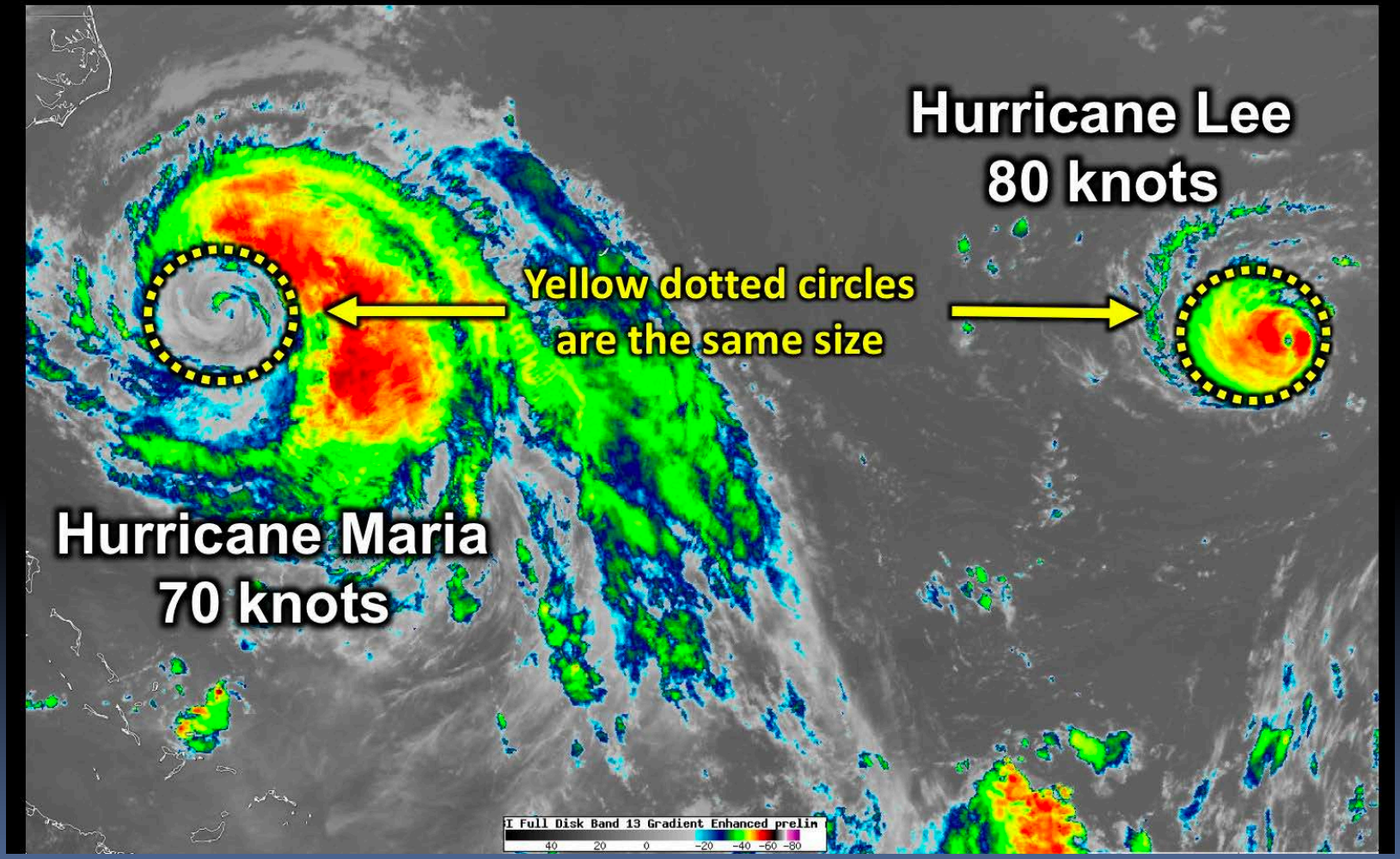
Size Matters!

The Extremes: Tip vs. Marco

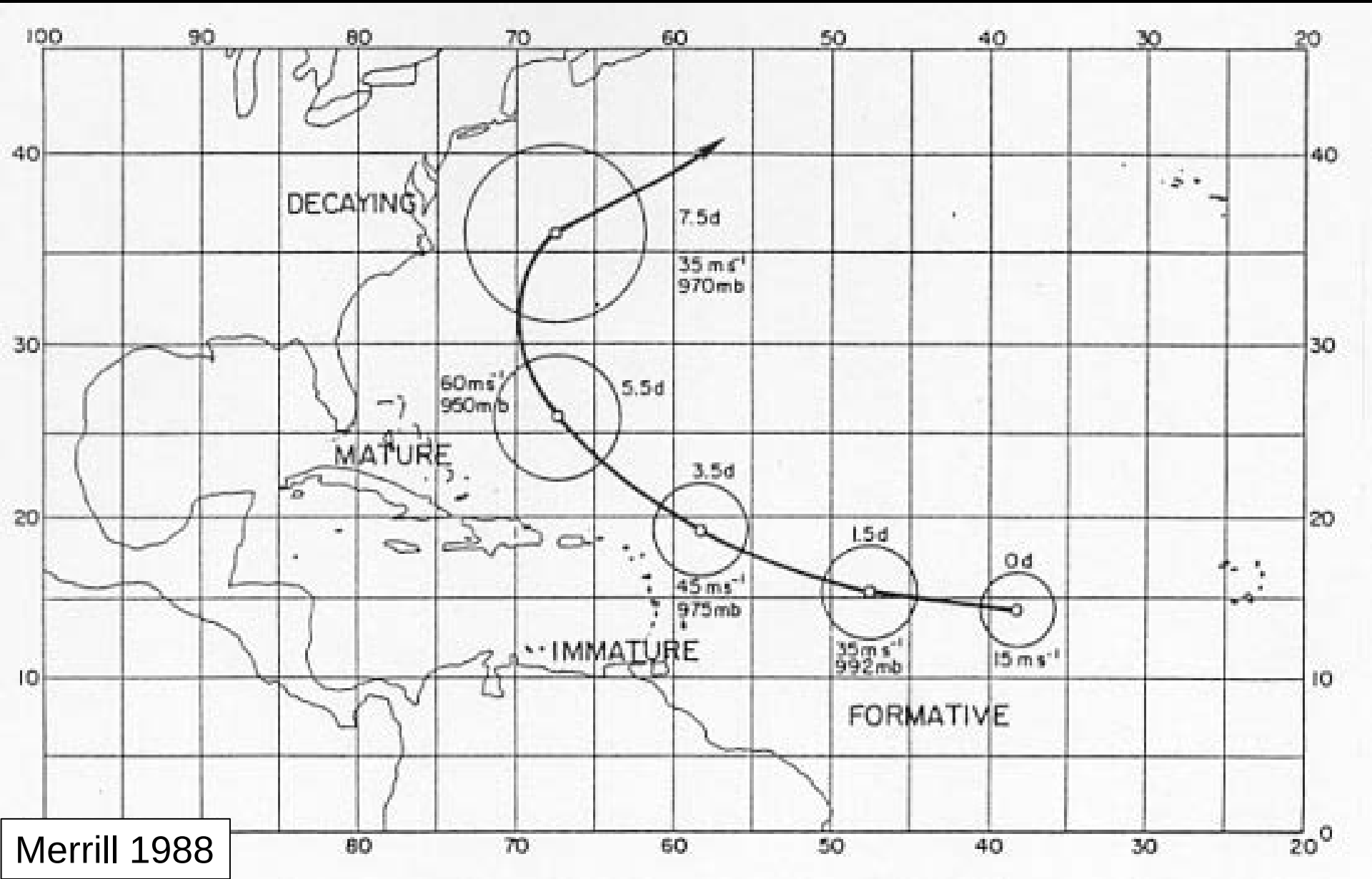



Isaac's Remnants
~ 170 n mi
~ 50 n mi
Tropical
Storm Michael
Tropical Storm Leslie

GOES-16 IR Imagery – 1630 UTC 25 September 2017

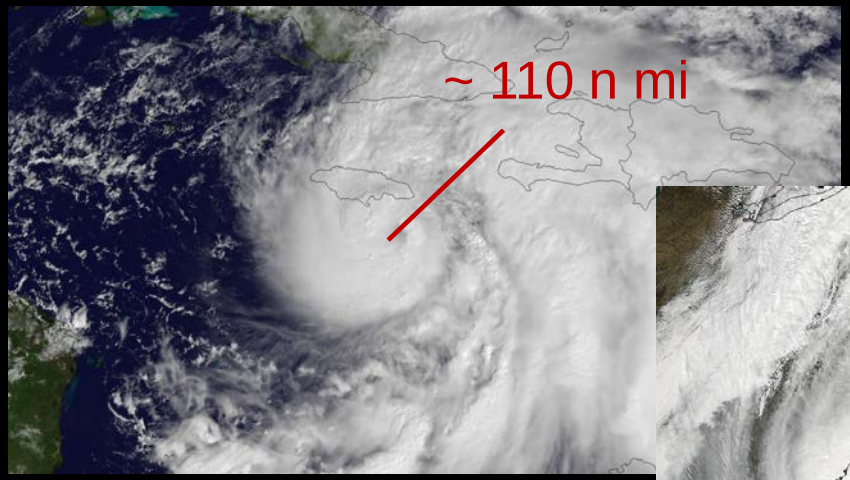


Tropical Cyclone Size Lifecycle

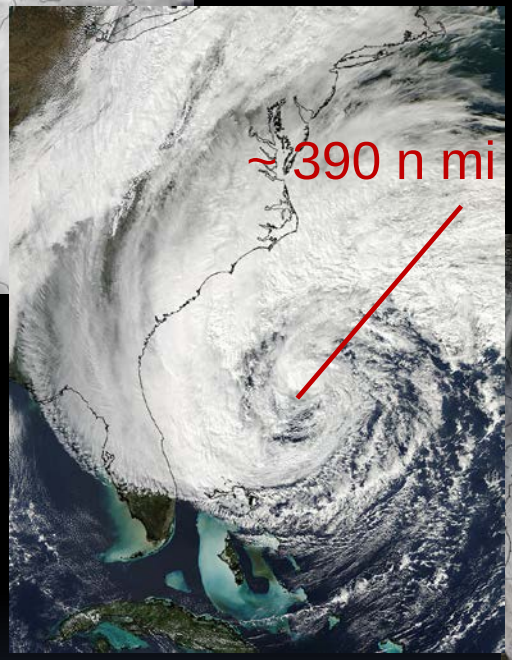


Merrill 1988

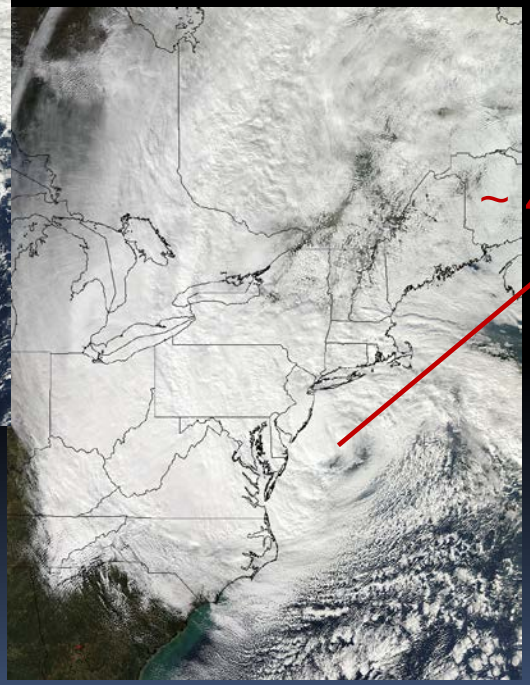
Hurricane Sandy



75 kt, 971 mb



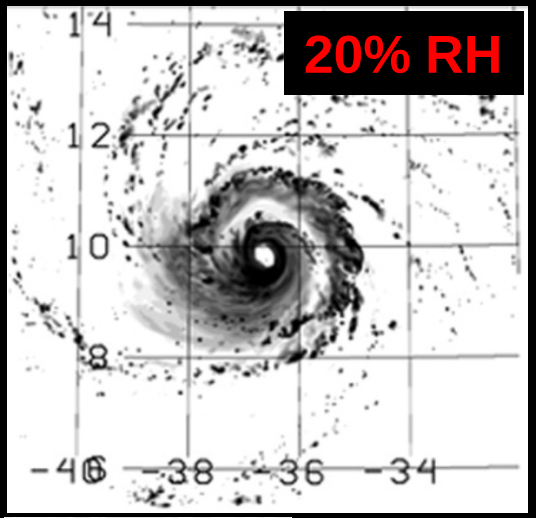
70 kt, 956 mb

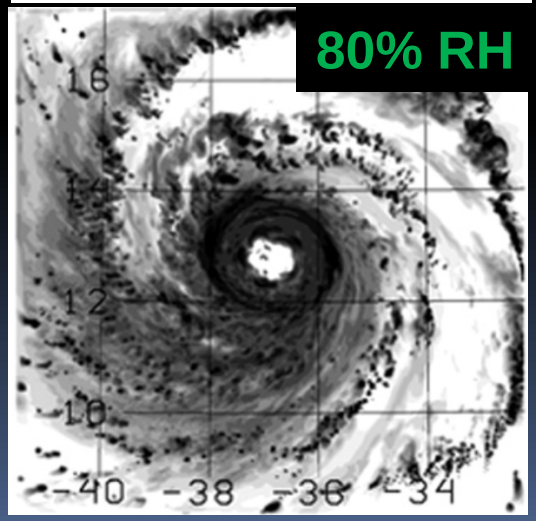


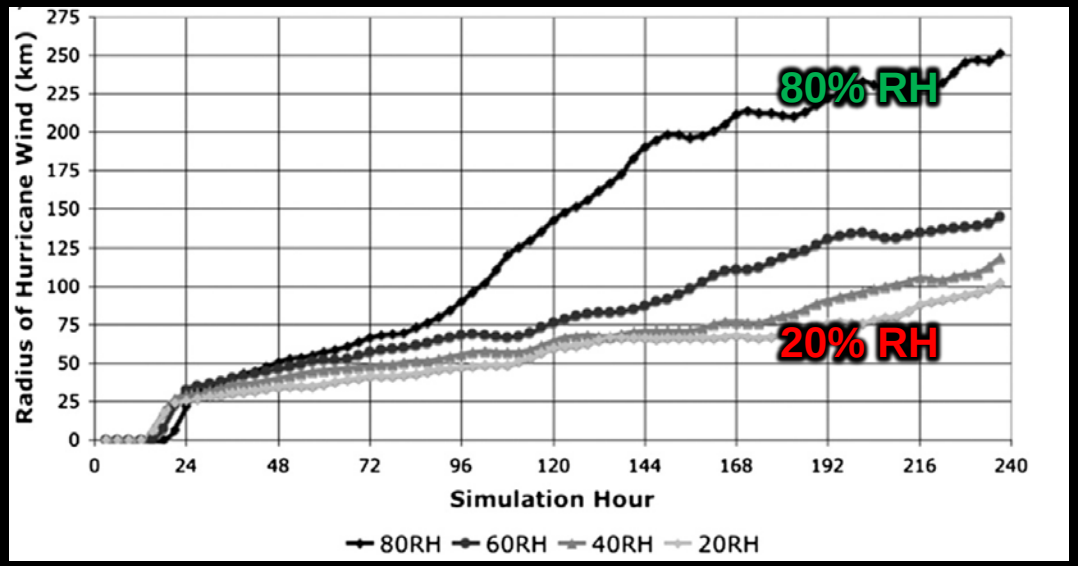
75 kt, 943 mb

Environmental Effects On Size

- Relative Humidity A Significant Factor





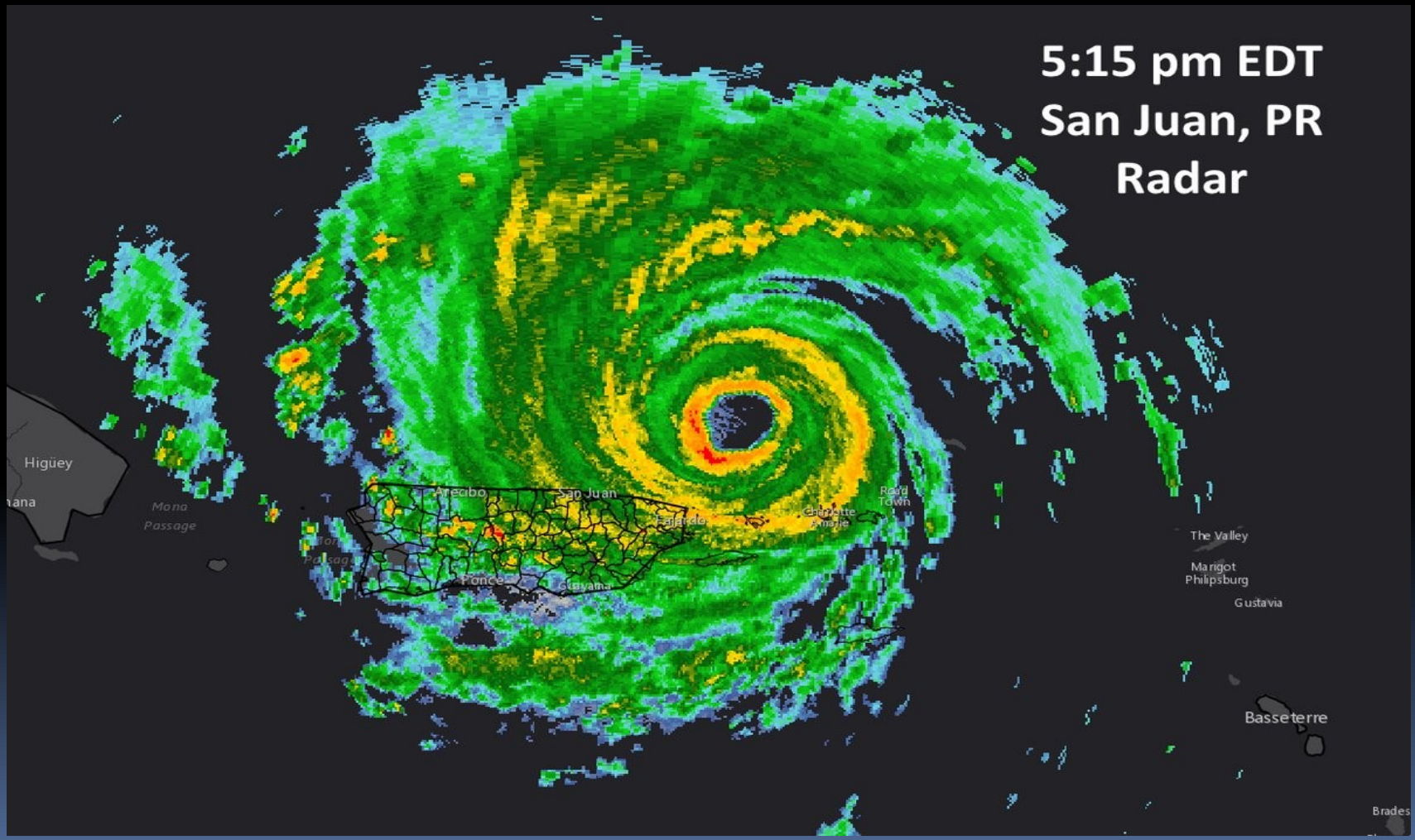


Hill and Lackmann (2009)

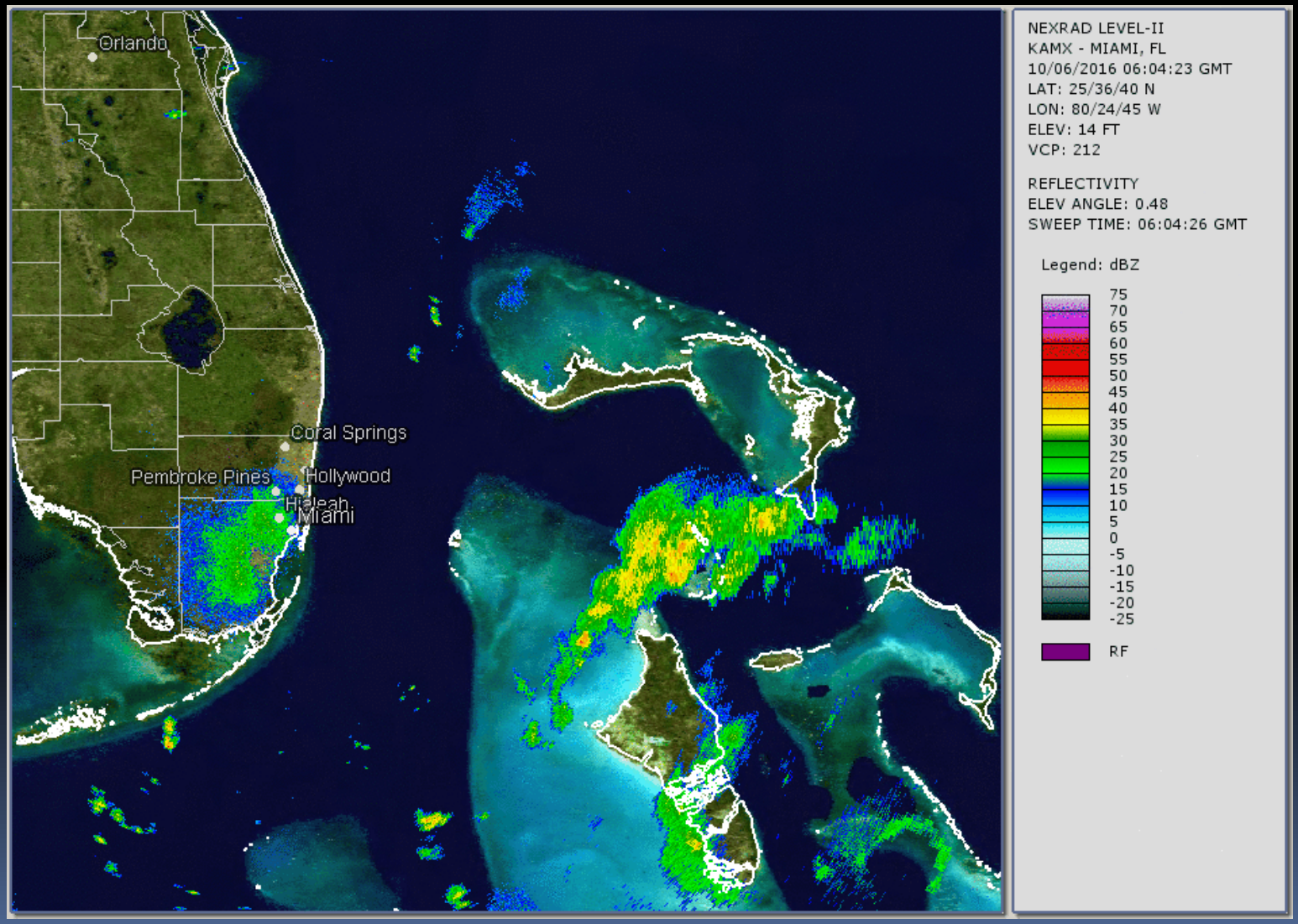
Higher environmental humidity can increase TC size over multiple days

Inner Core Structural Effects On Size

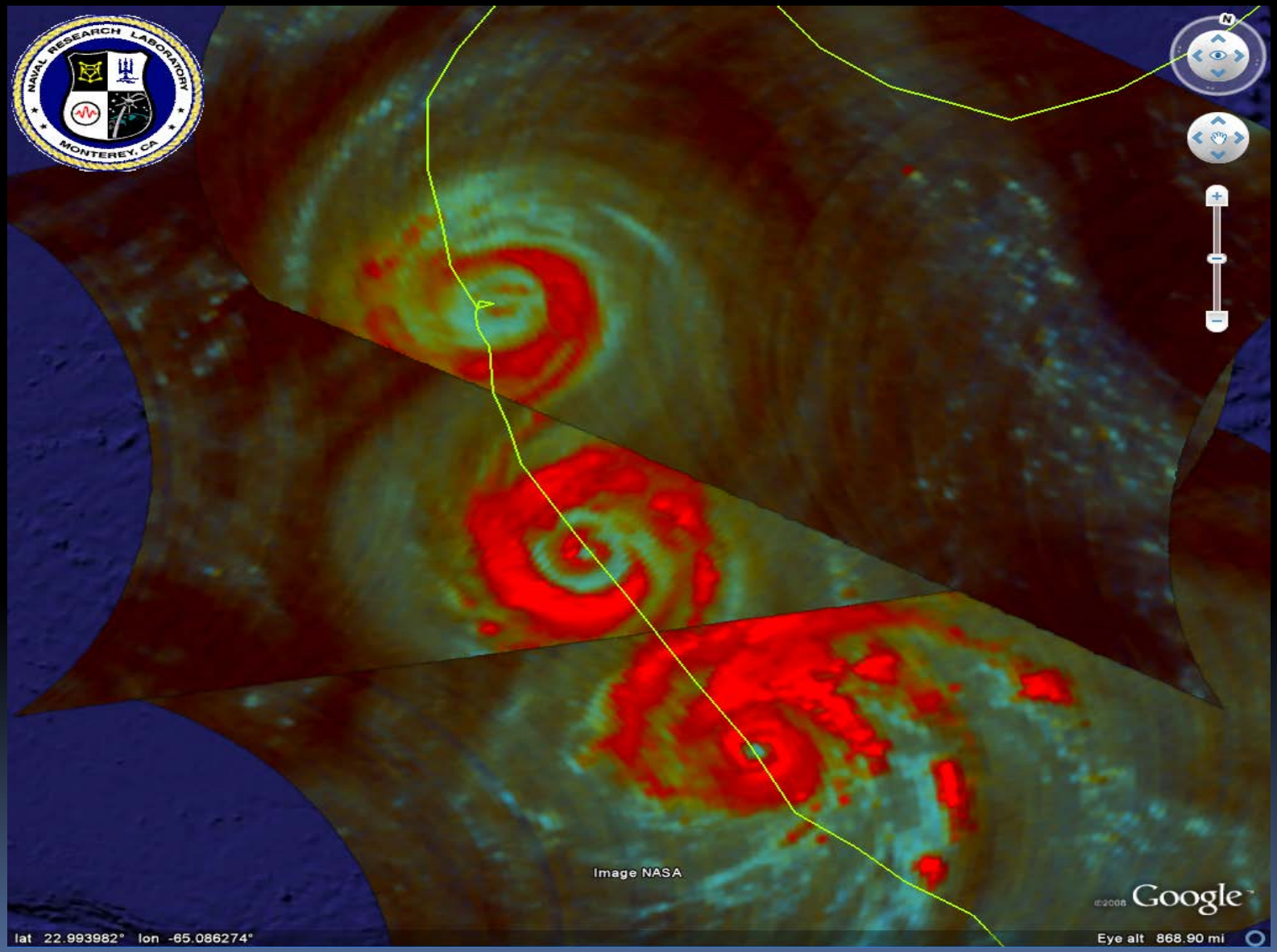
Eyewall Replacement Cycles



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 & size changes are coming
- Big errors are likely going to happen too…

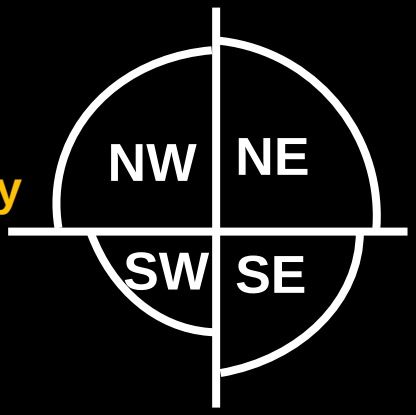
Intensity and Structure Parameters that NHC analyzes and predicts

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

Tropical Cyclone Wind Radii

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

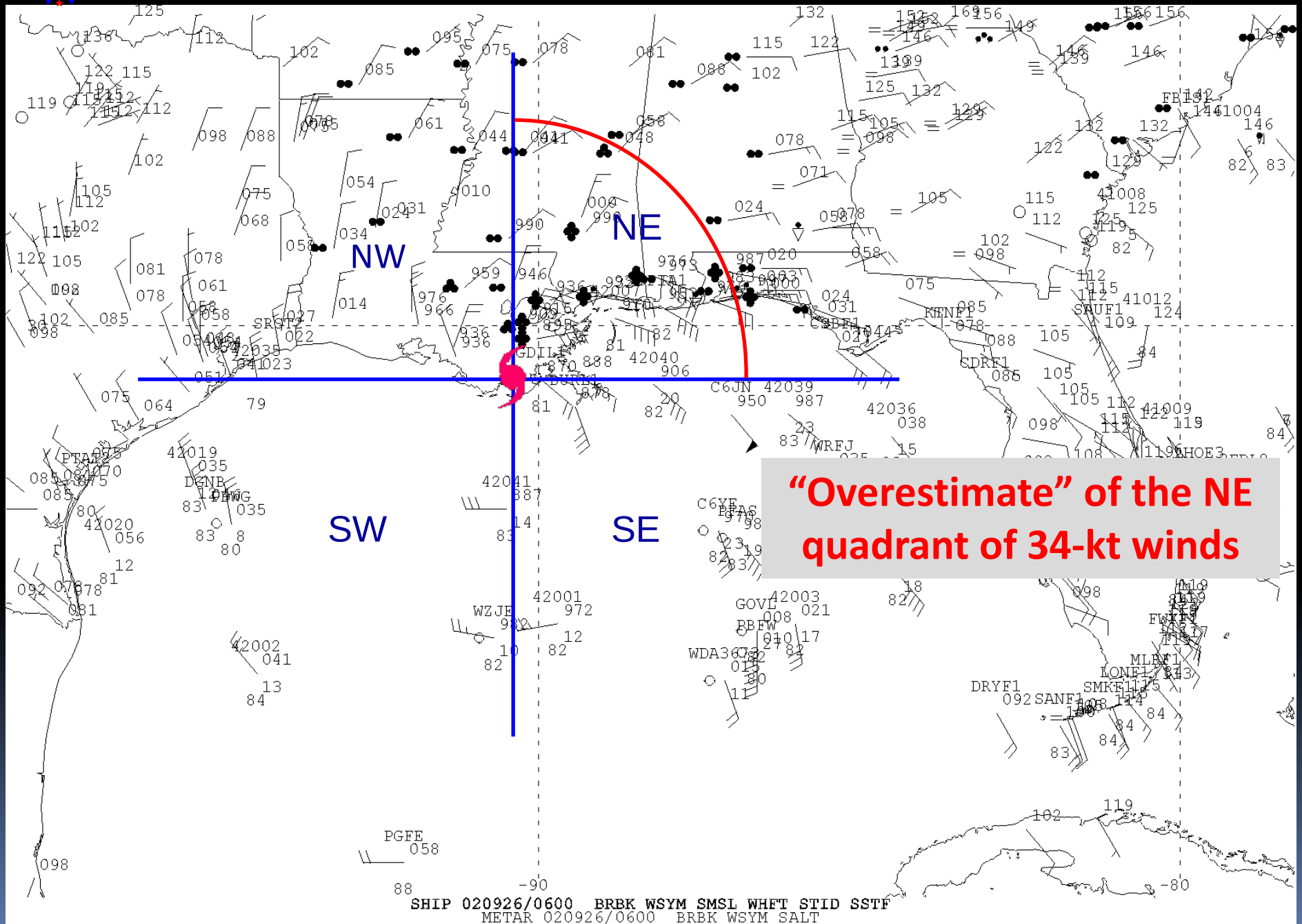
leads to an inherent over-estimate of radii, especially near land



radii represent the largest distance from center in particular quadrant

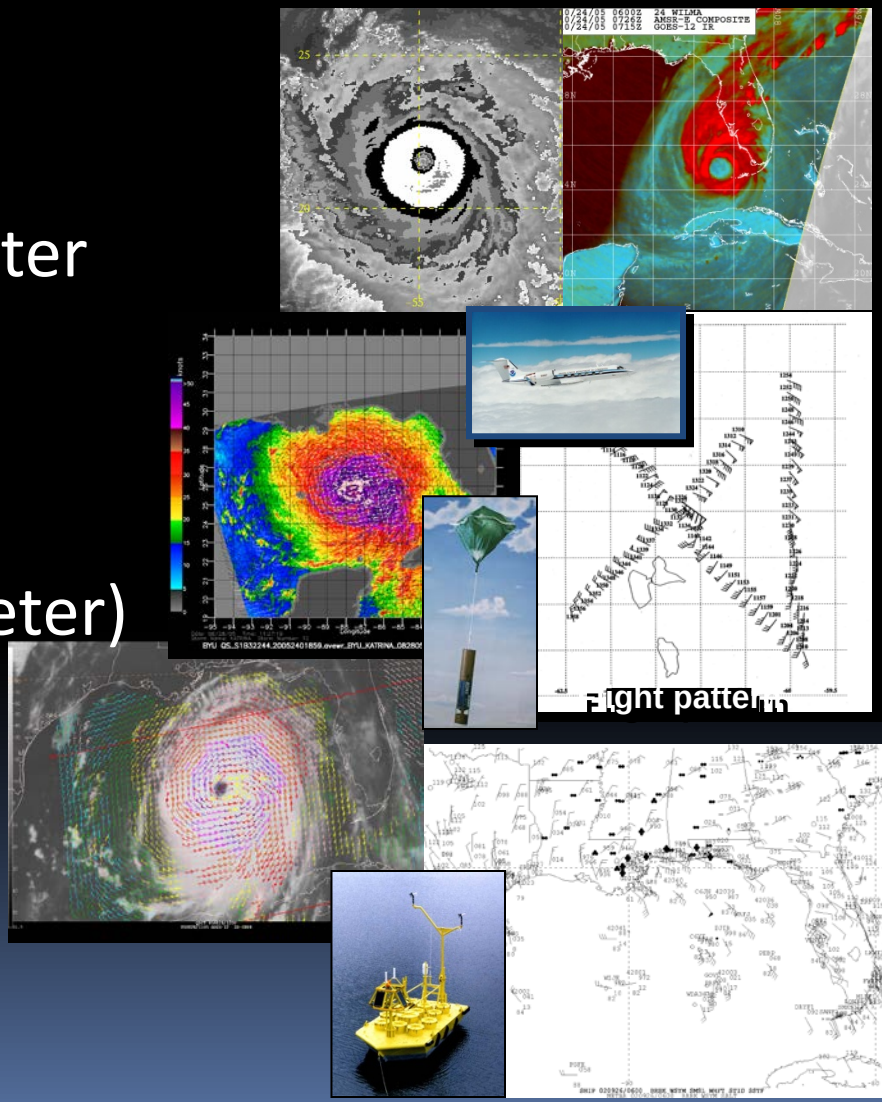
Wind radius = Largest distance from the center of the tropical cyclone of a particular sustained surface wind speed threshold (e.g., 34, 50, 64 kt) somewhere in a particular quadrant (NE, SE, SW, NW) surrounding the center and associated with the circulation at a given point in time

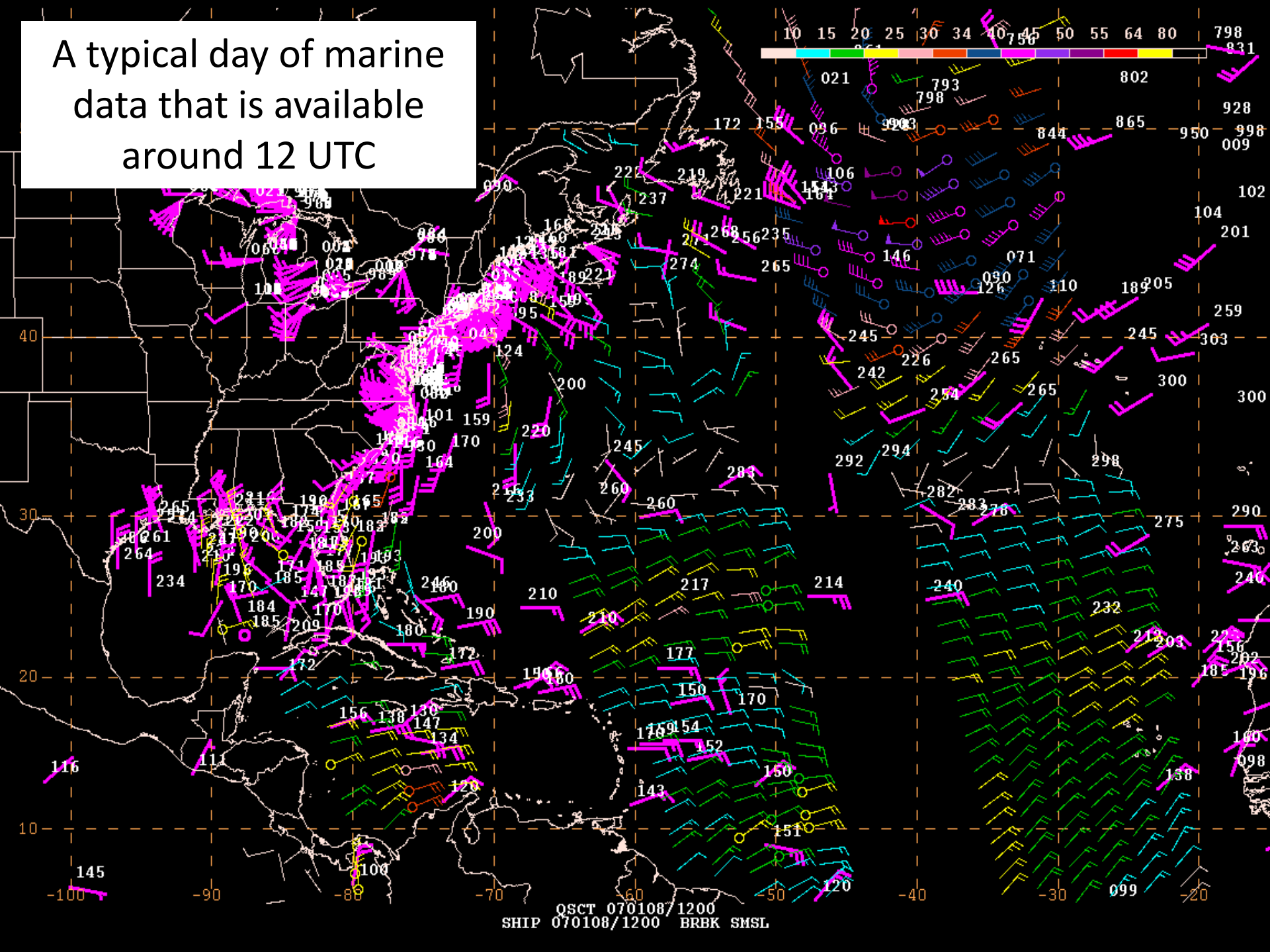
Limitations of Four-Quadrant Radii



Data to Determine Tropical Cyclone Size

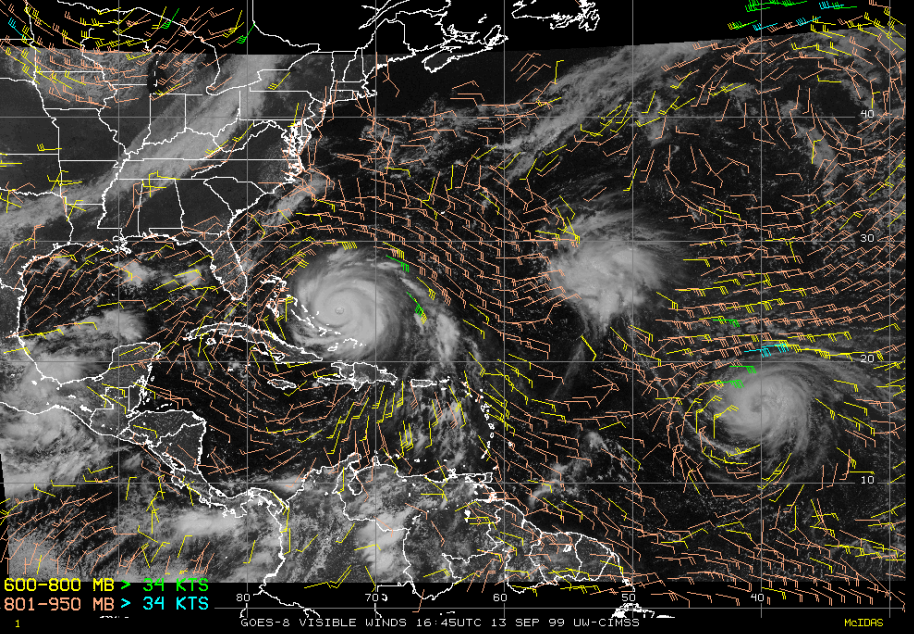
* Satellite Imagery
  - Geostationary
  - Polar Orbiting – scatterometer
* Reconnaissance Data
  - Dropsondes
  - SFMR (Stepped Frequency Microwave Radiometer)
* Surface Observations
  - Land-based
  - Marine-based
    - Ships, Buoys, Salindrones



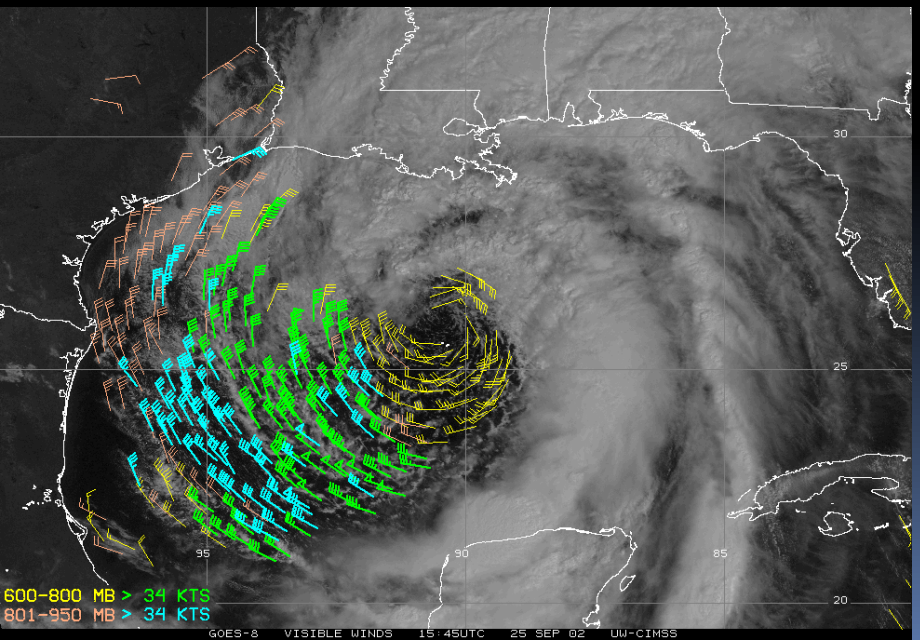

A typical day of marine data that is available around 12 UTC
10 15 20 25 30 34 40 45 50 55 64 80
40
30
20
10
-100
-90
-80
-70
-60
-50
-40
-30
-20
QSCT 070108/1200
SHIP 070108/1200 BRBK SMSL

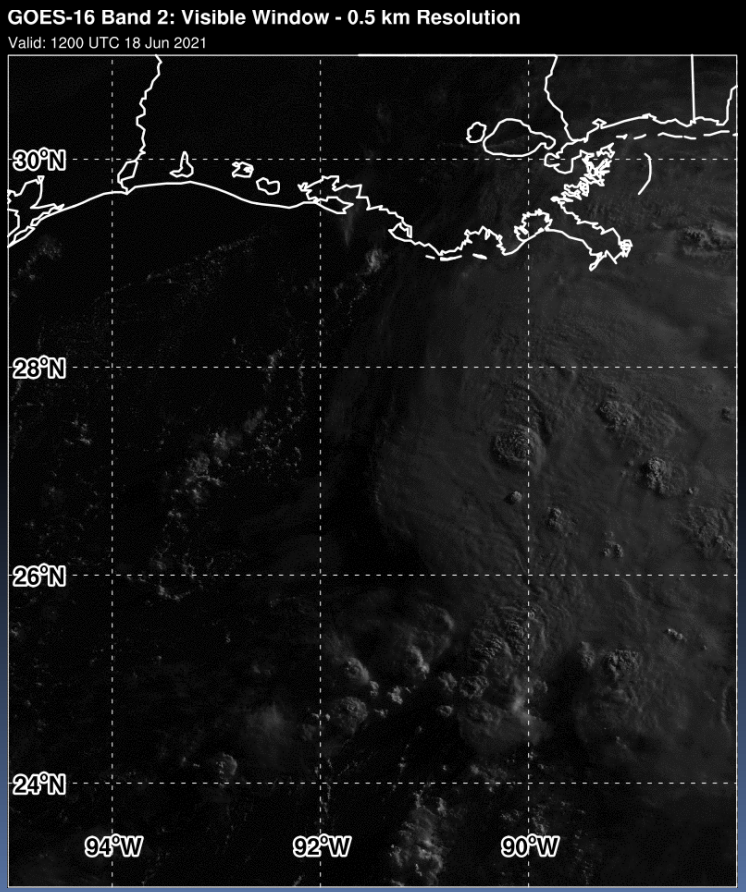
Geostationary satellite: Low-level cloud drift winds

Meso 1-min data now gives us higher temporal resolution of these observations (5-min)



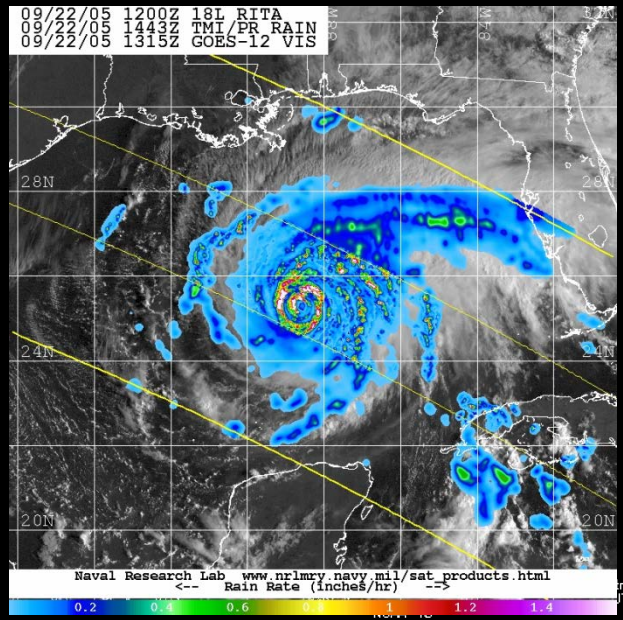
Satellite winds for nearby environment and TC size



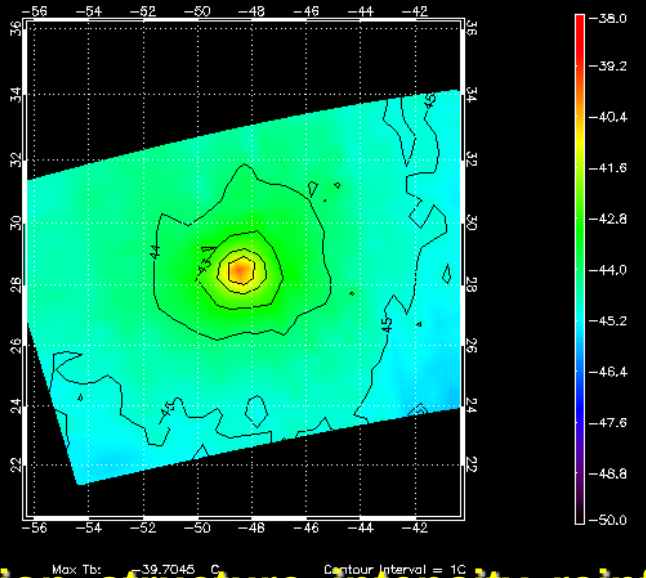


Polar-Orbiter Satellites

- 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

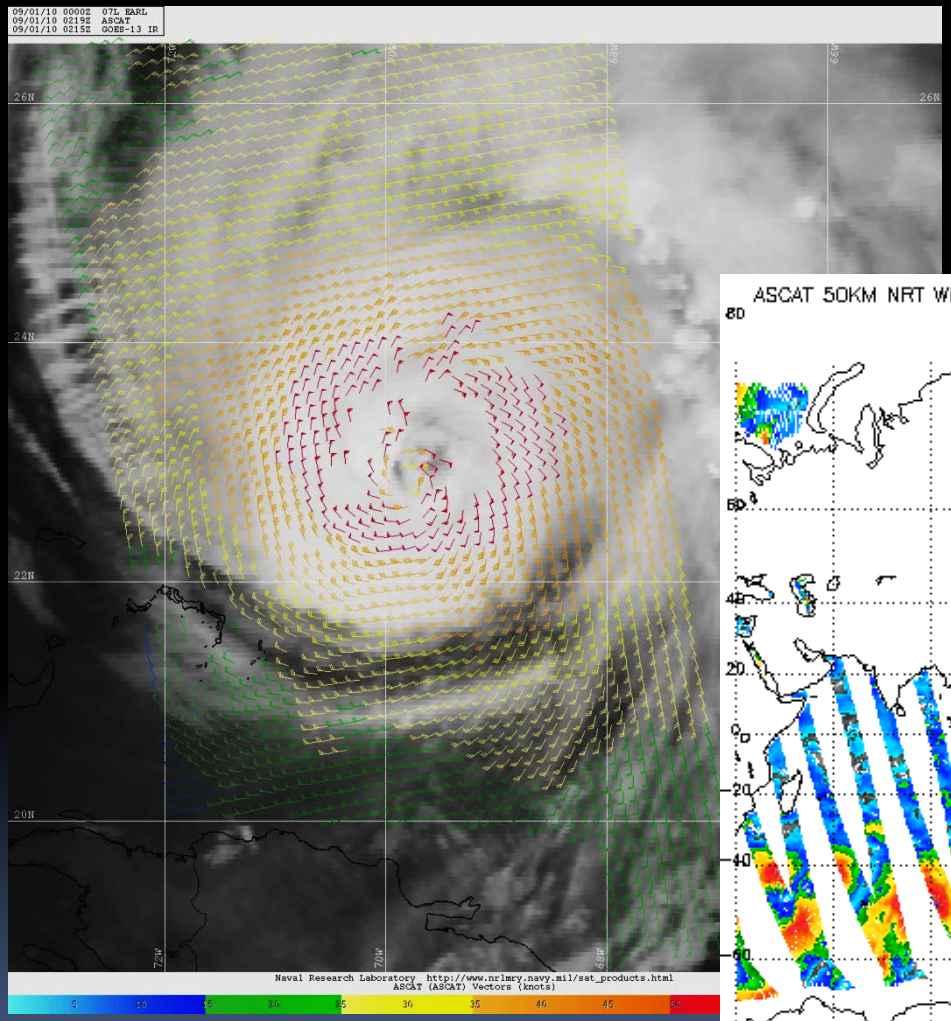


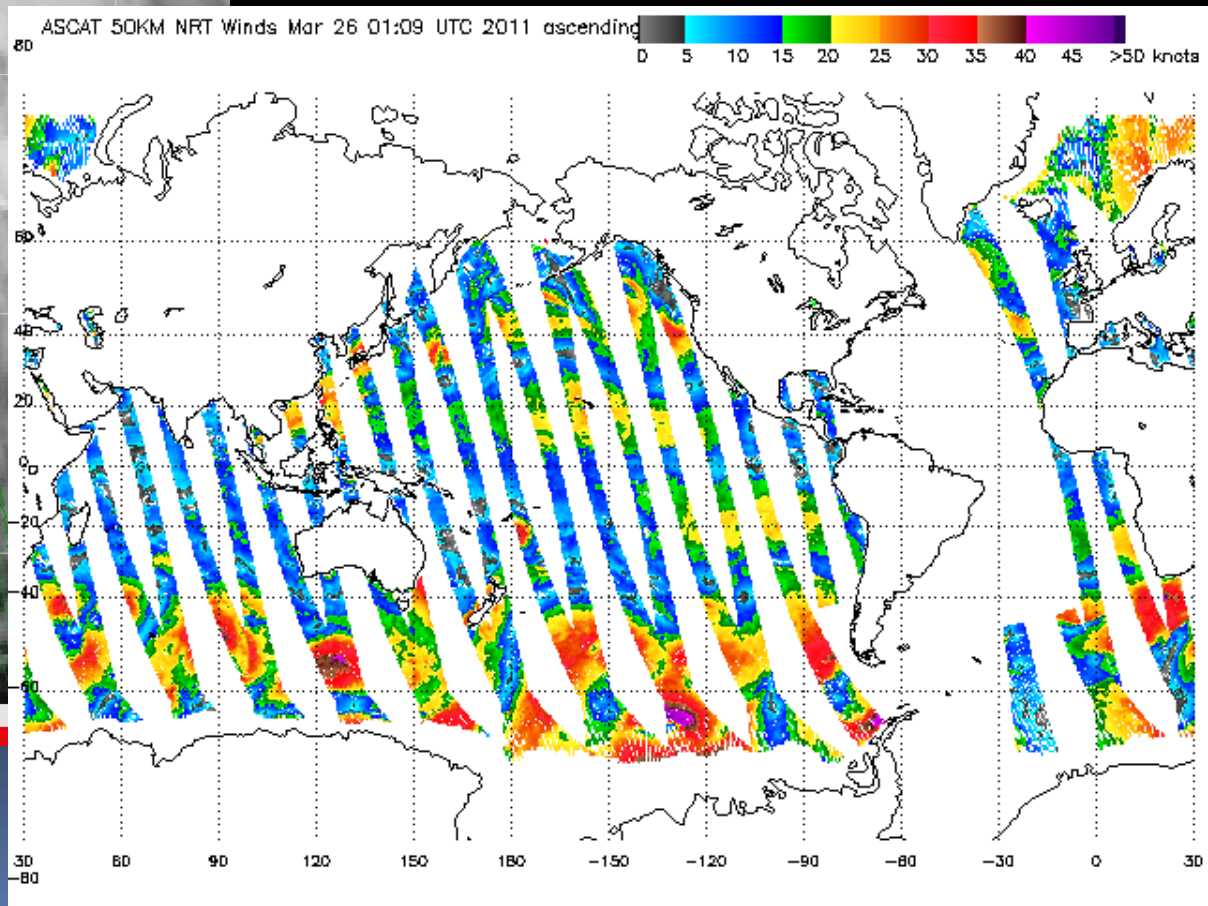
Advanced Microwave Sounding Unit



Microwave location, structure, intensity, rainfall

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

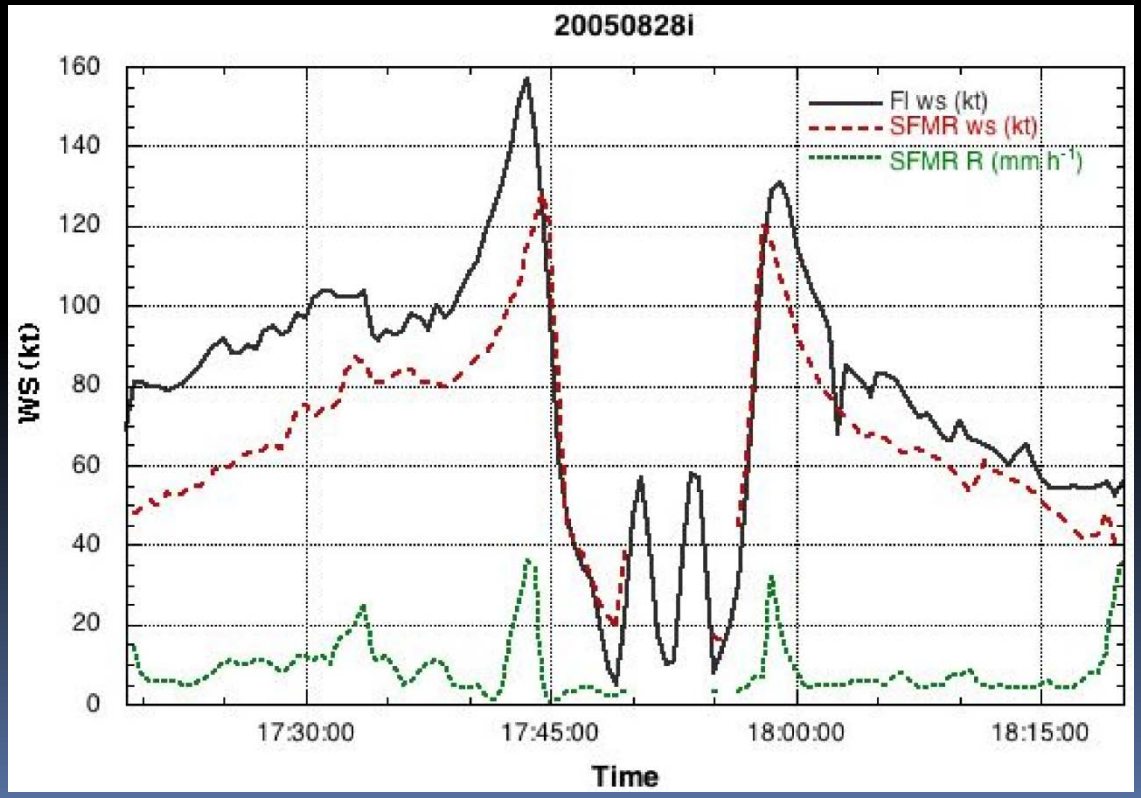




Hurricane Reconnaissance and Surveillance Aircraft (10 Air Force C-130s, 2 NOAA P3s, 1 NOAA G-IV)

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)



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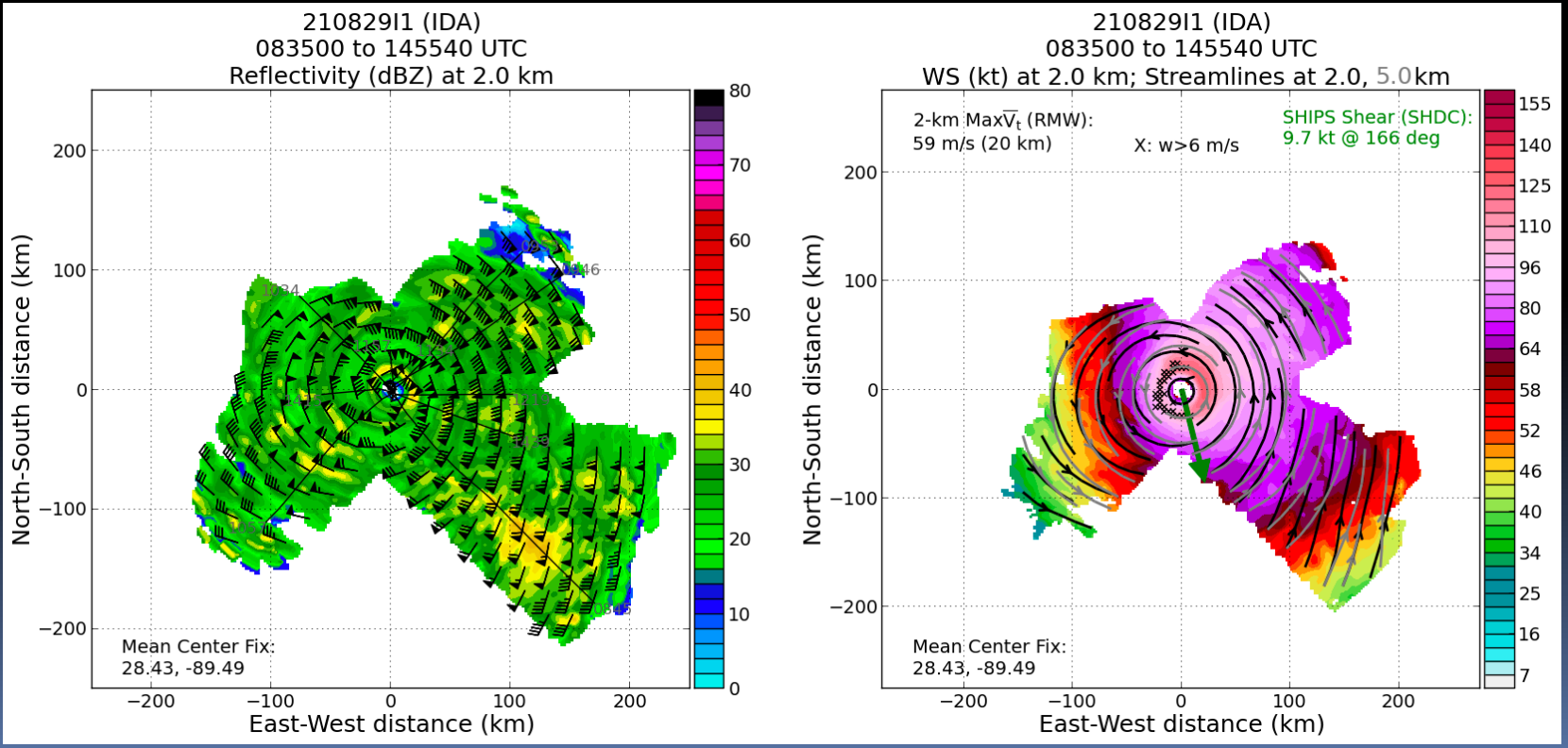
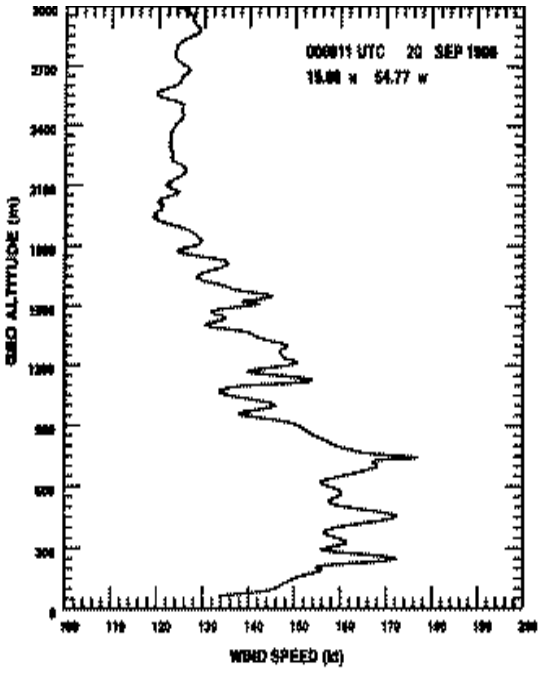


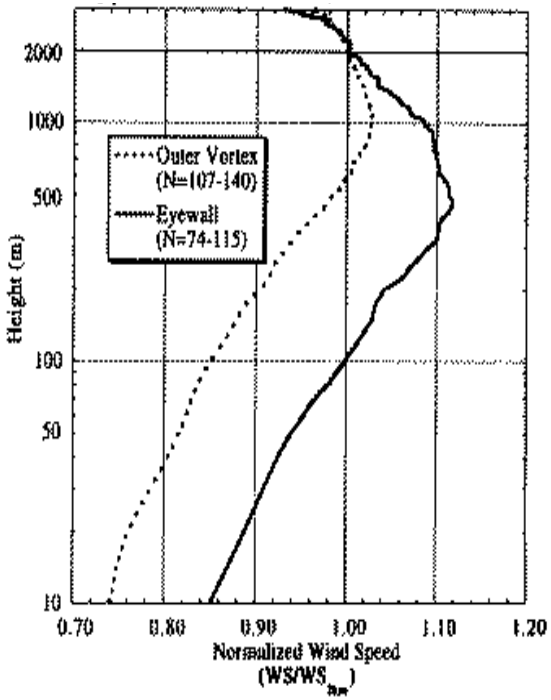
GPS Dropsondes

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

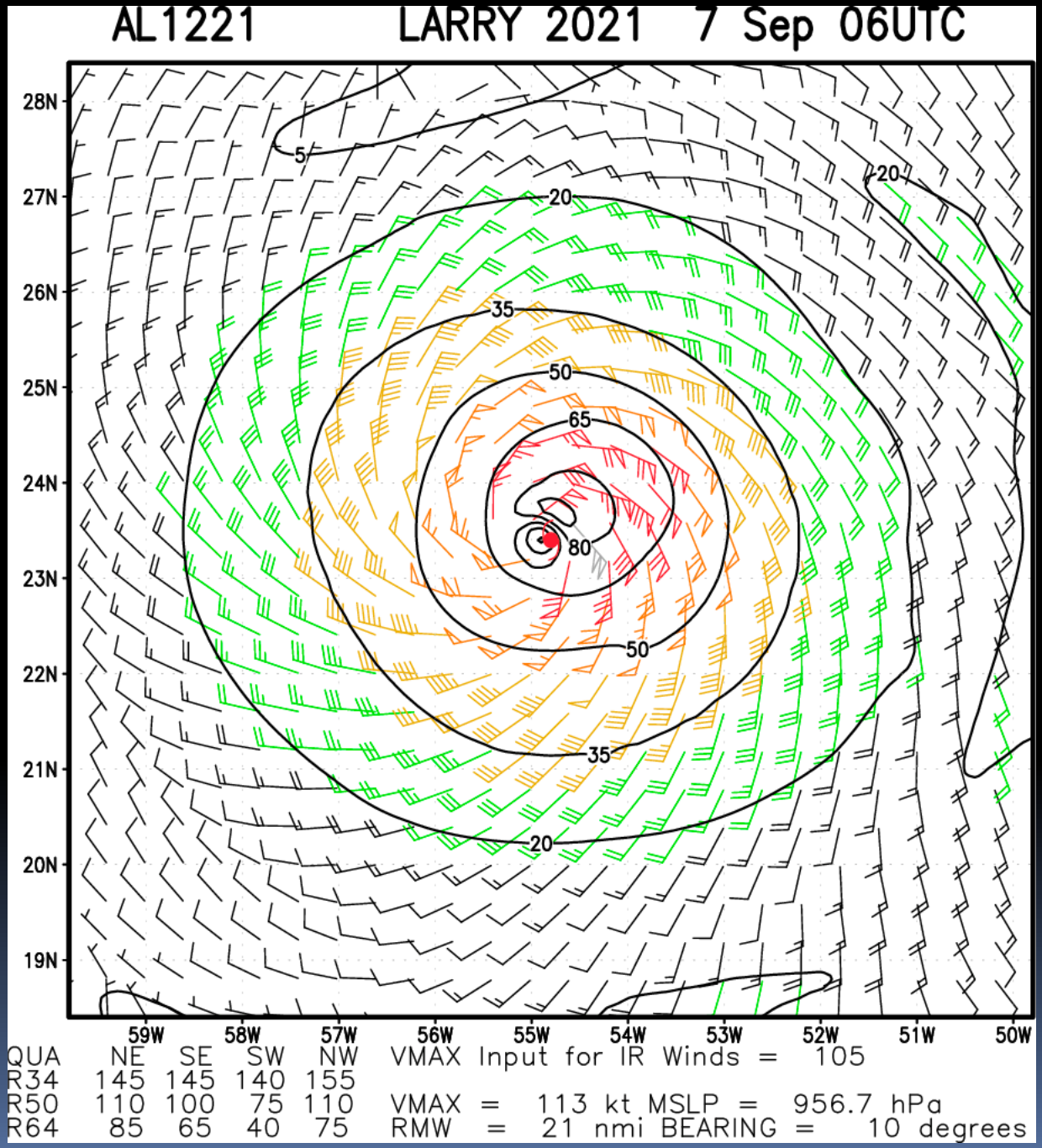
Wind in Hurricane Georges



Mean Wind Profile



Franklin and Black (1999)



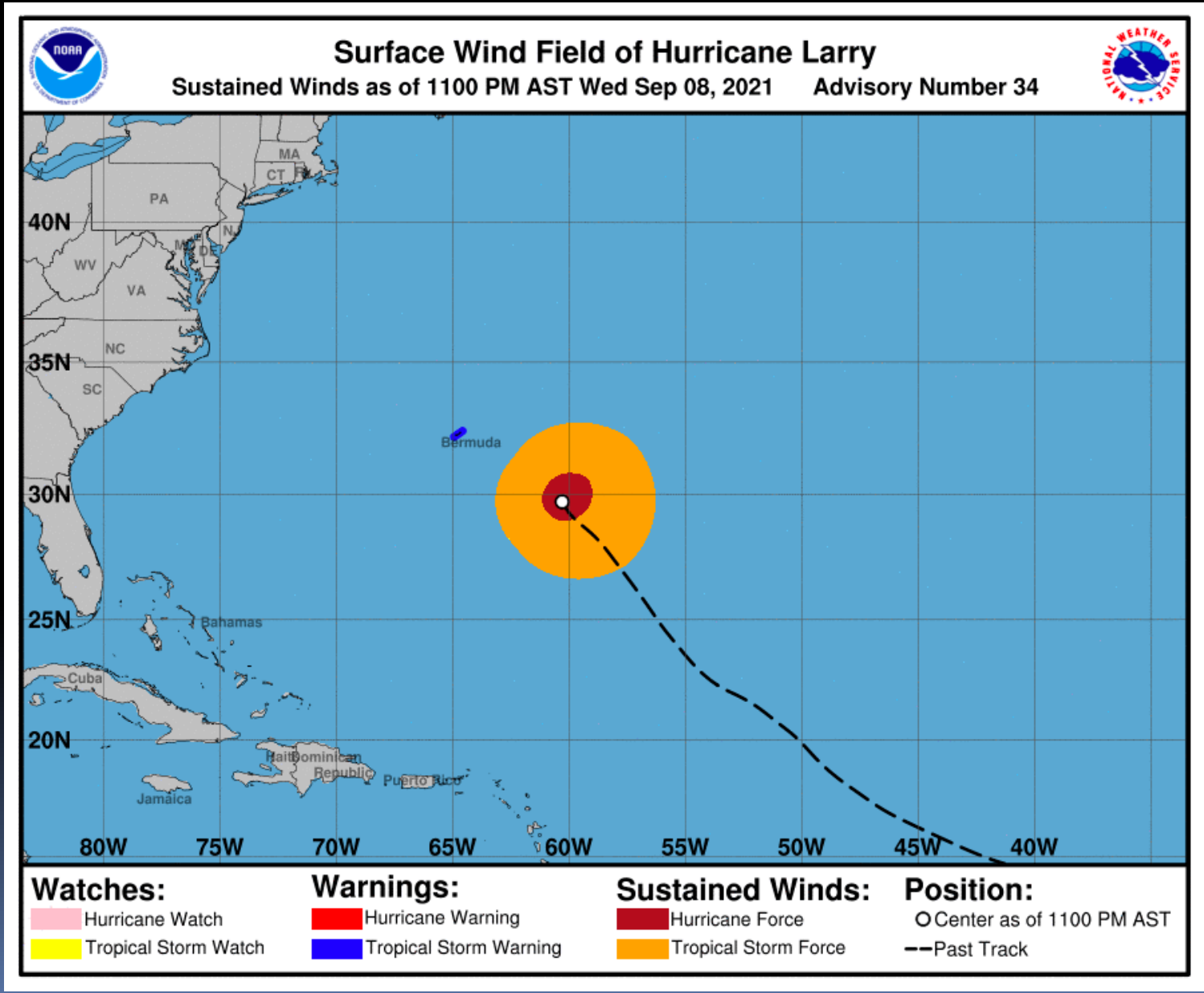
Multiplatform Satellite Surface Wind Analysis – CIRA

Automated Surface Wind Field in Tropical Cyclones

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

3:28 PM

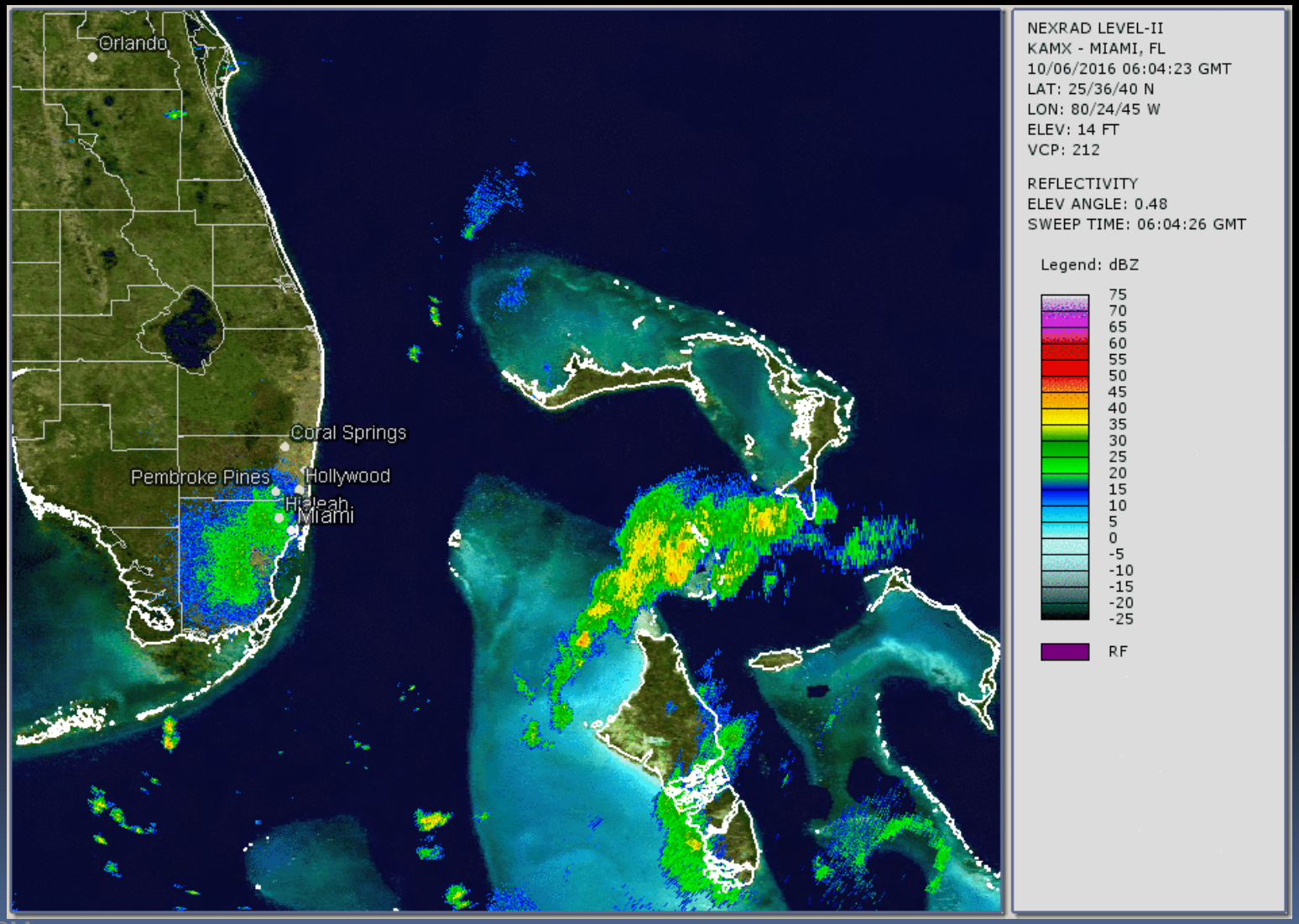
Surface Wind Field



Take Home Points

- Tropical Cyclones exist in many sizes and shapes but have these main characteristics
  - Warm core at center
  - Strong cyclonic winds that peak at low levels & decrease with height
  - Upper-level wind field outside center is anticyclonic in mature Hurricanes
- Hurricanes comprised of many other components
  - Outer, Principal and Secondary Rainbands
  - Primary and Secondary Eyewalls and Eye
- Size & Shape often determined by nearby environment and lifecycle
  - Vertical Wind Shear affects cloud pattern & RH affects Size
  - TCs tend to grow over their lifecycle and as they gain latitude
- Many tools at our arsenal to diagnose storm structure
  - Satellite (Geostationary / Polar Orbiters)
  - Aircraft Observations (Flight Level / SFMR / Dropsondes / Radar)
  - Surface Observations (Land, Buoys, Ships)

Questions?



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