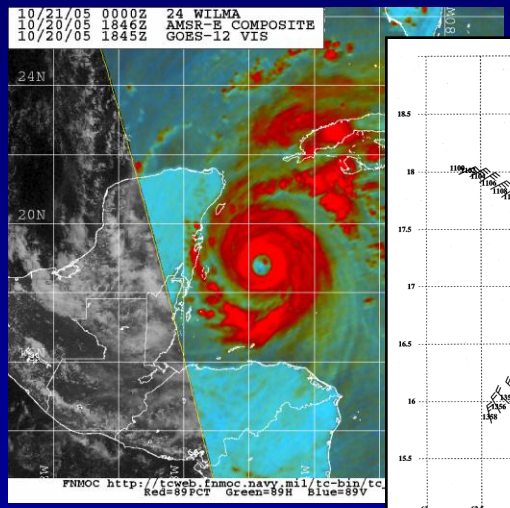
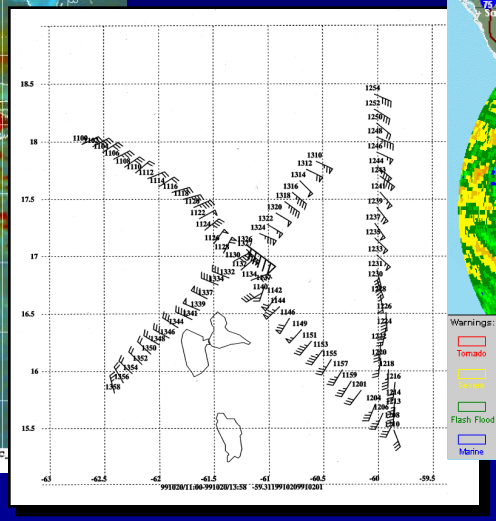
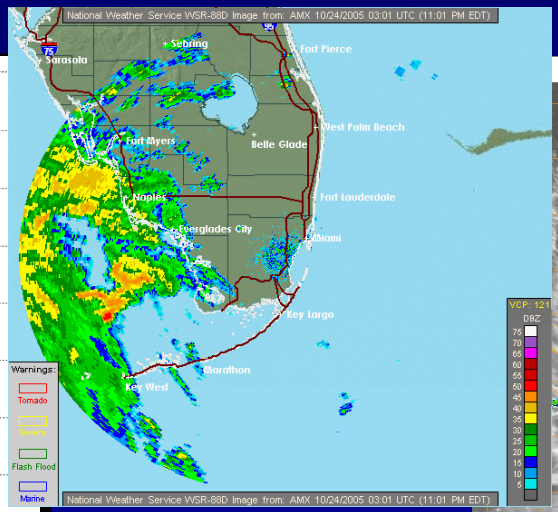
NATIONAL HURRICANE CENTER

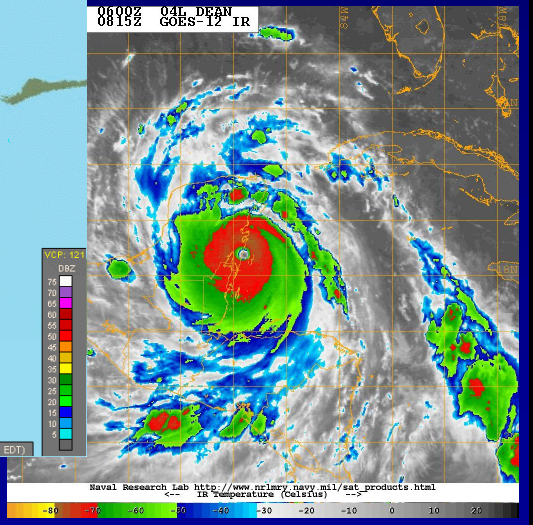
Miami, Florida

Tropical Meteorology 101: Data Sources and Limitations









Daniel Brown
NATIONAL HURRICANE CENTER

NATIONAL HURRICANE CENTER

Miami, Florida

The National Hurricane Center forecasts…

- 72-hour forecast of track positions, intensity, and wind speed radii
- 96- and 120-hour track positions and intensities.

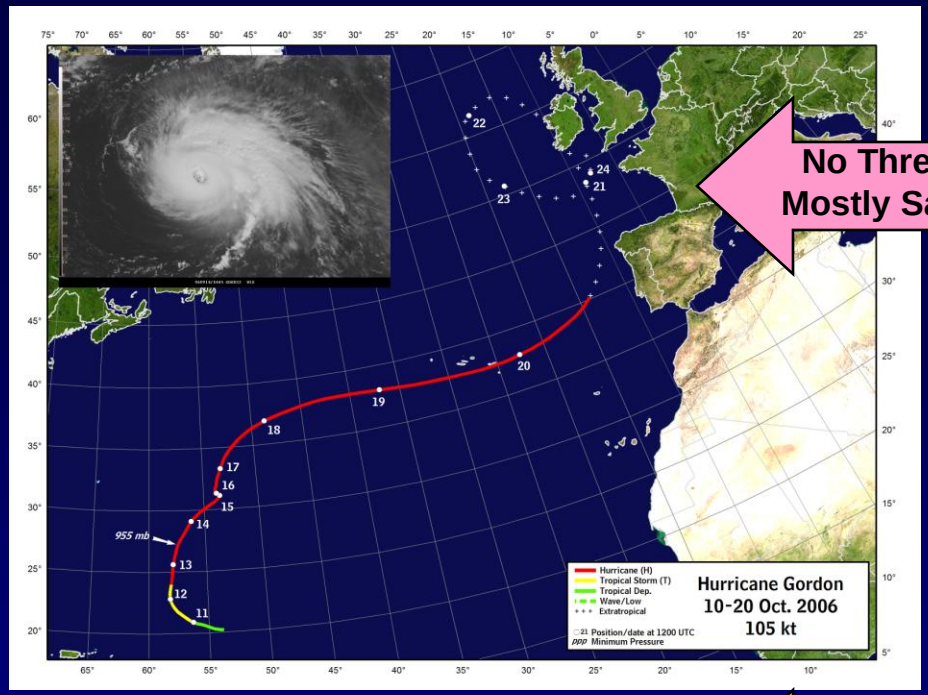
Also included are

- watches and warnings
- brief storm surge, tornado, and rainfall statements

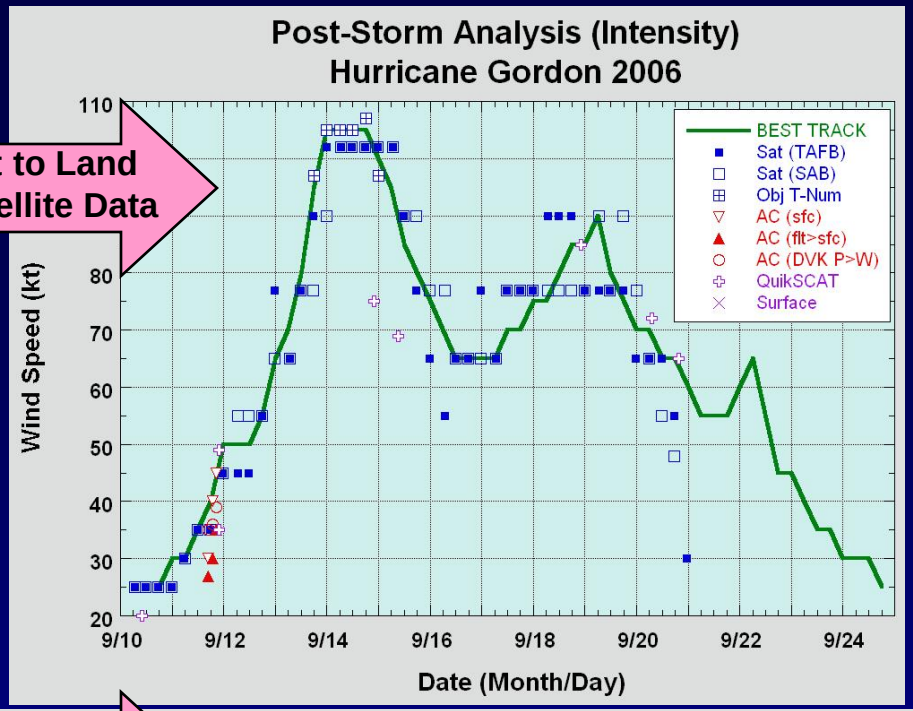
Forecast Hour (Day)	Position and Intensity	34 kt wind radii	50 kt wind radii	64 kt wind radii
3 (adv time)				
12				
24 (1)				
36				
48 (2)				
72 (3)				
96 (4)				
120 (5)				

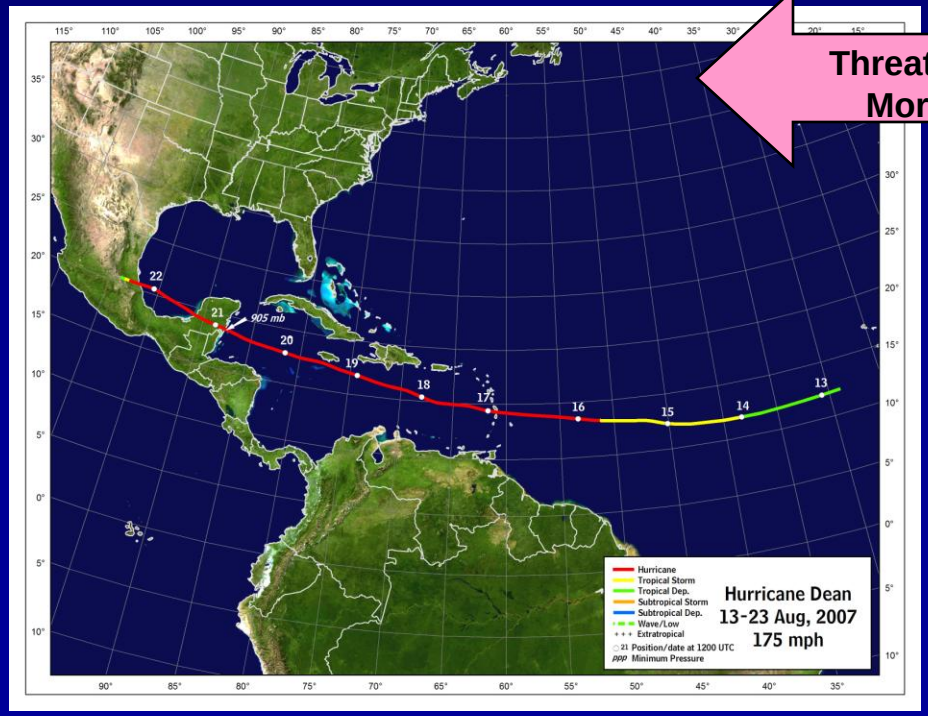
NHC Observational Tools

Availability of different data sources depend on the storm location and/or if the storm is threatening land

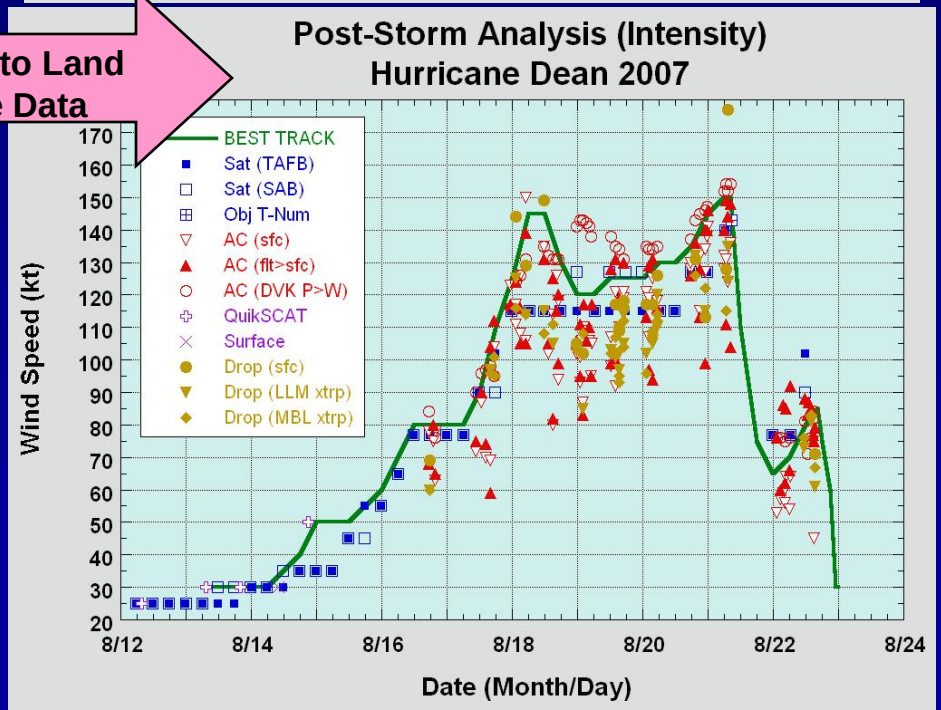


No Threat to Land
Mostly Satellite Data



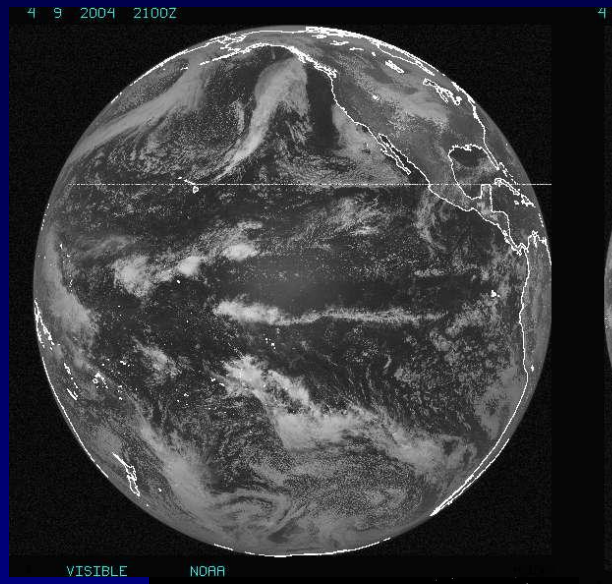


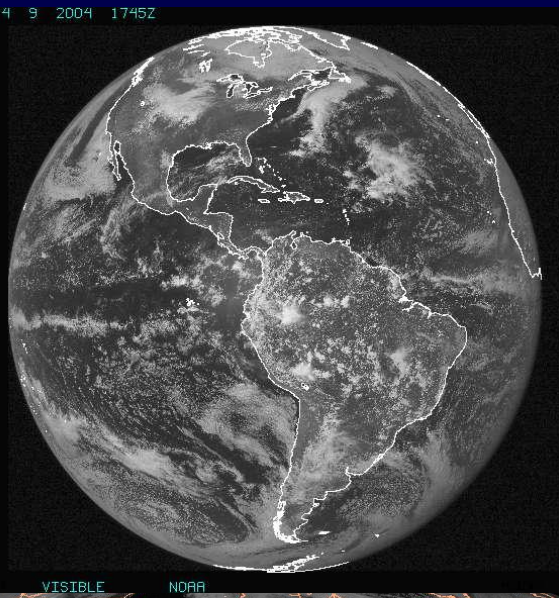
Threat to Land
More Data

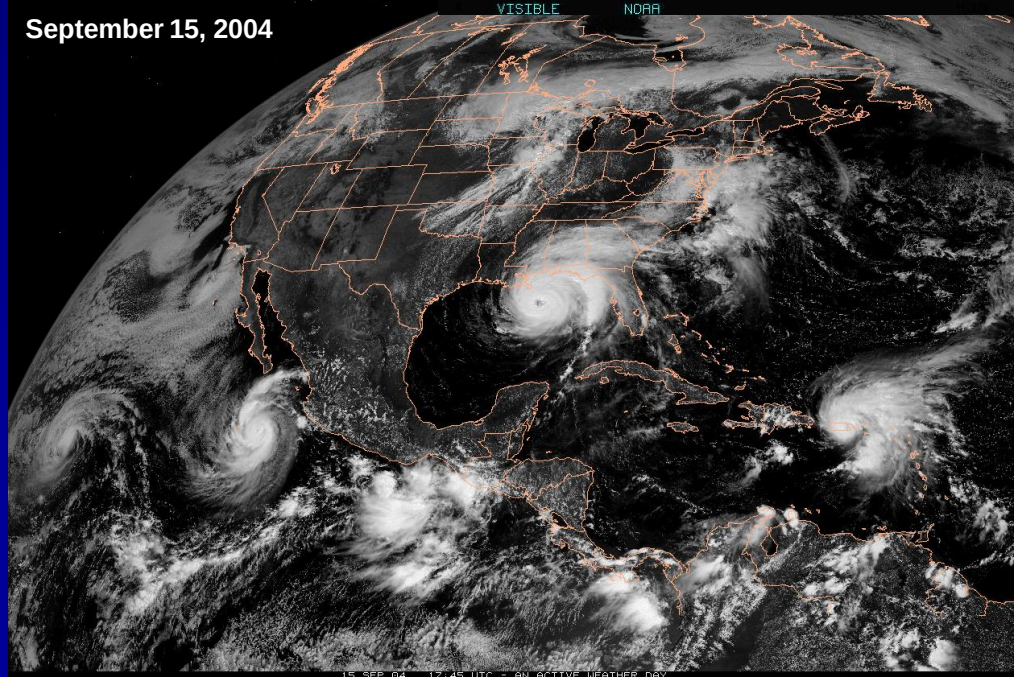


Geostationary Satellites

- Satellite does not move with respect to the Earth's surface
- Located 22,000 miles (35,000 km) above the Earth's Equator
- Provide imagery every 15-30 min
- Best source to monitor the tropics on a daily basis

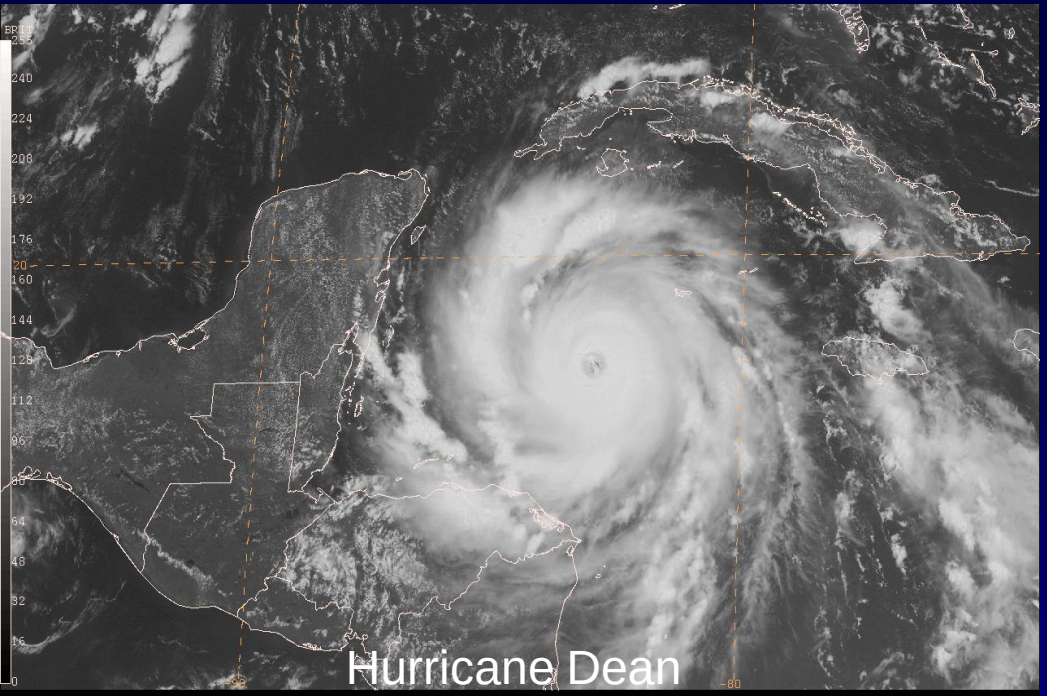


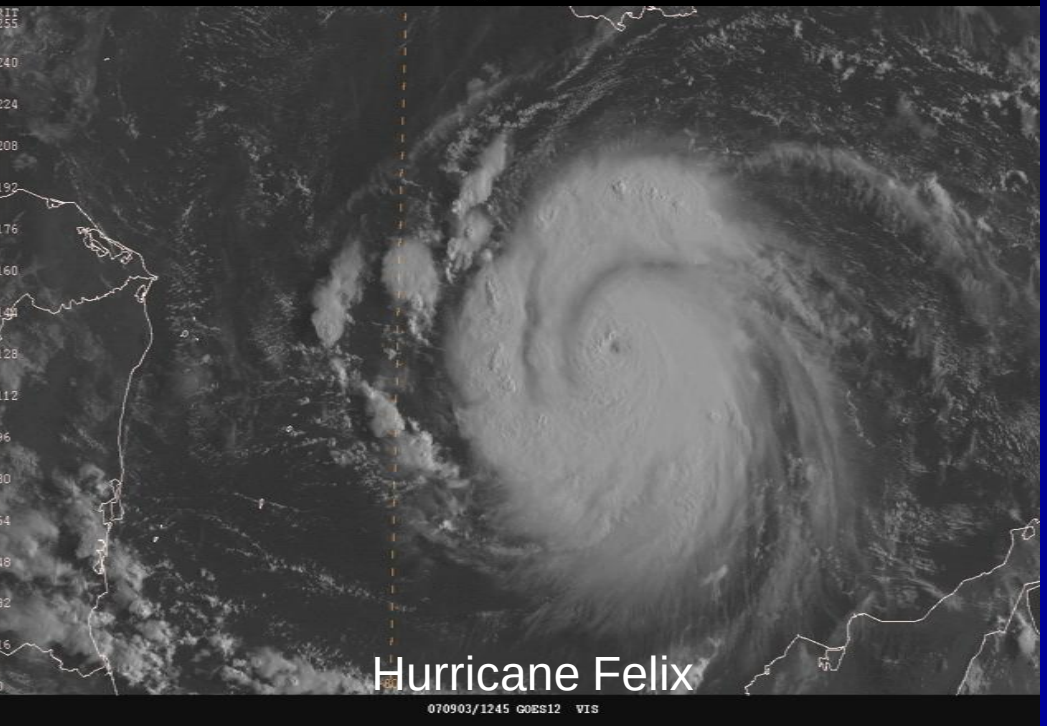


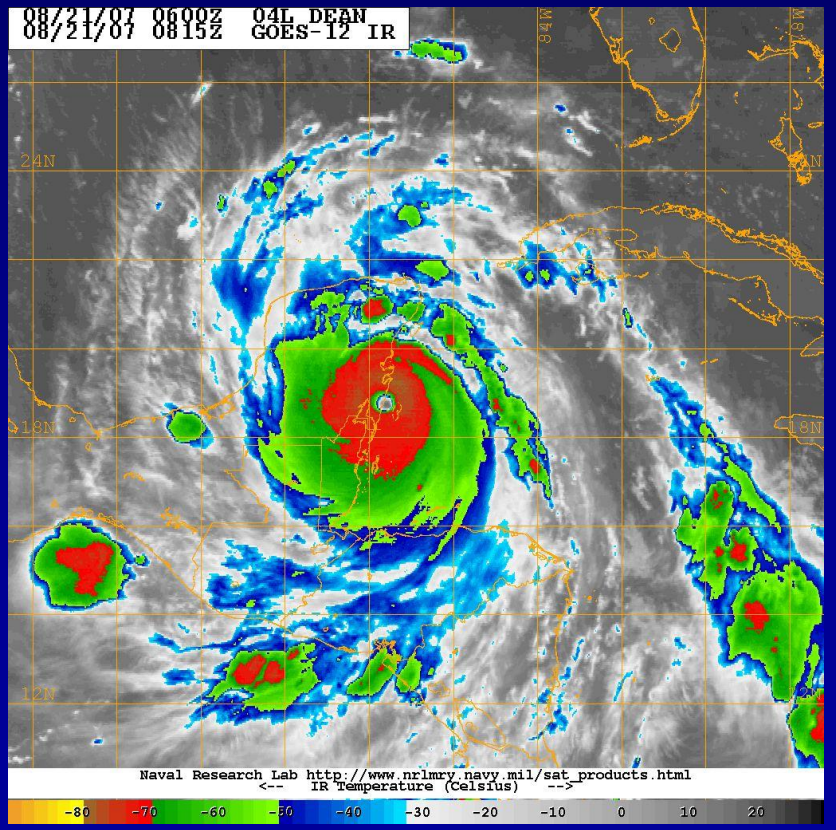


Geostationary Satellite Imagery

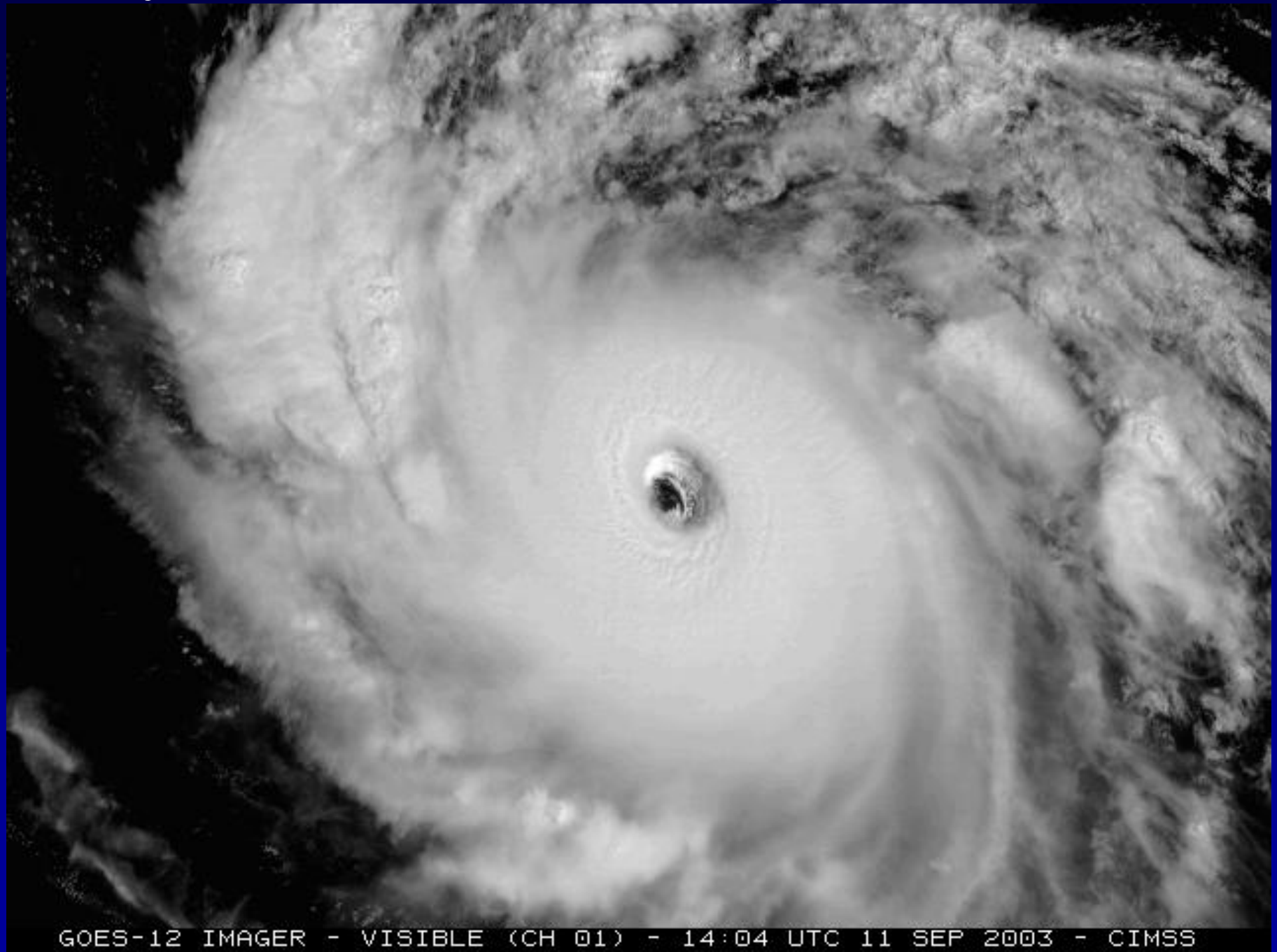
- Used to location the cyclone center and estimate intensity







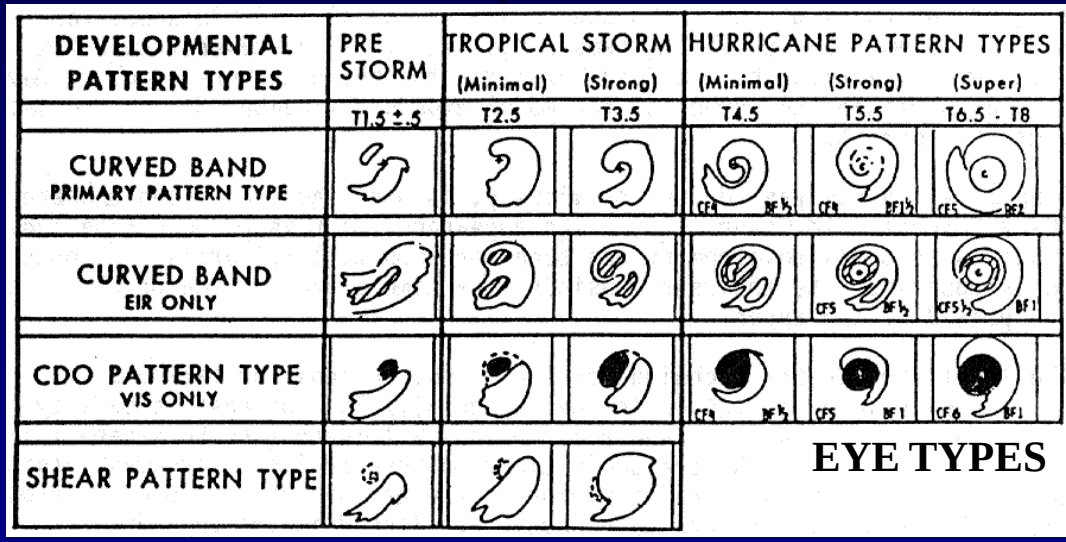
Eye Of Hurricane Isabel on September 11, 2003



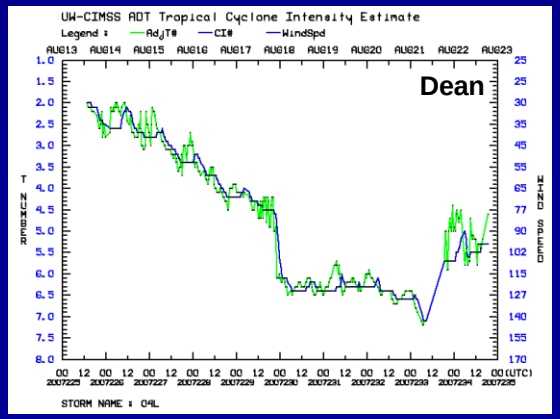
The Dvorak Technique

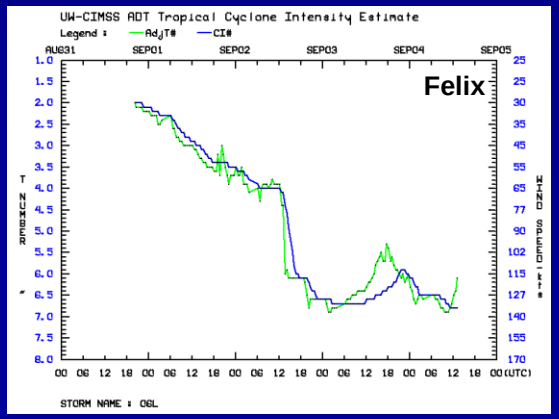
- A statistical method for estimating the intensity of tropical cyclones from satellite imagery
- Uses Infrared and Visible imagery
- Uses "measurement" of the cyclone cloud pattern and a set of rules
- Comes in manual and automated versions
- Related technique for subtropical cyclones

Dvorak Technique Cloud Patterns



Automated Dvorak Technique

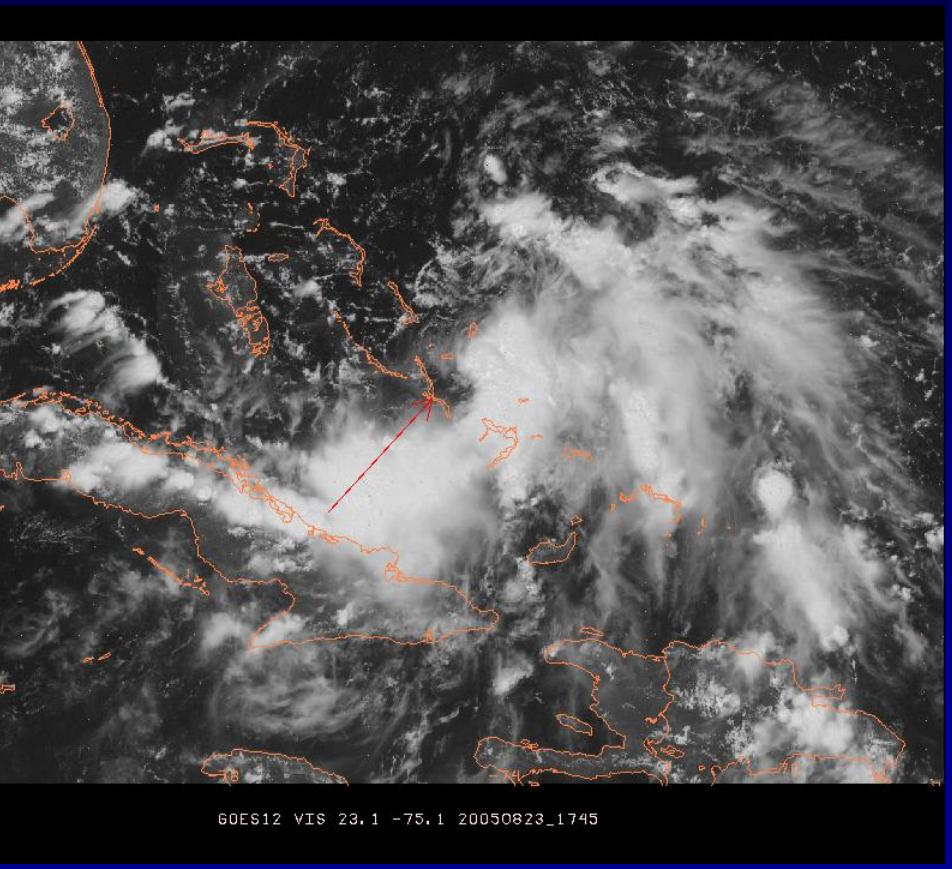




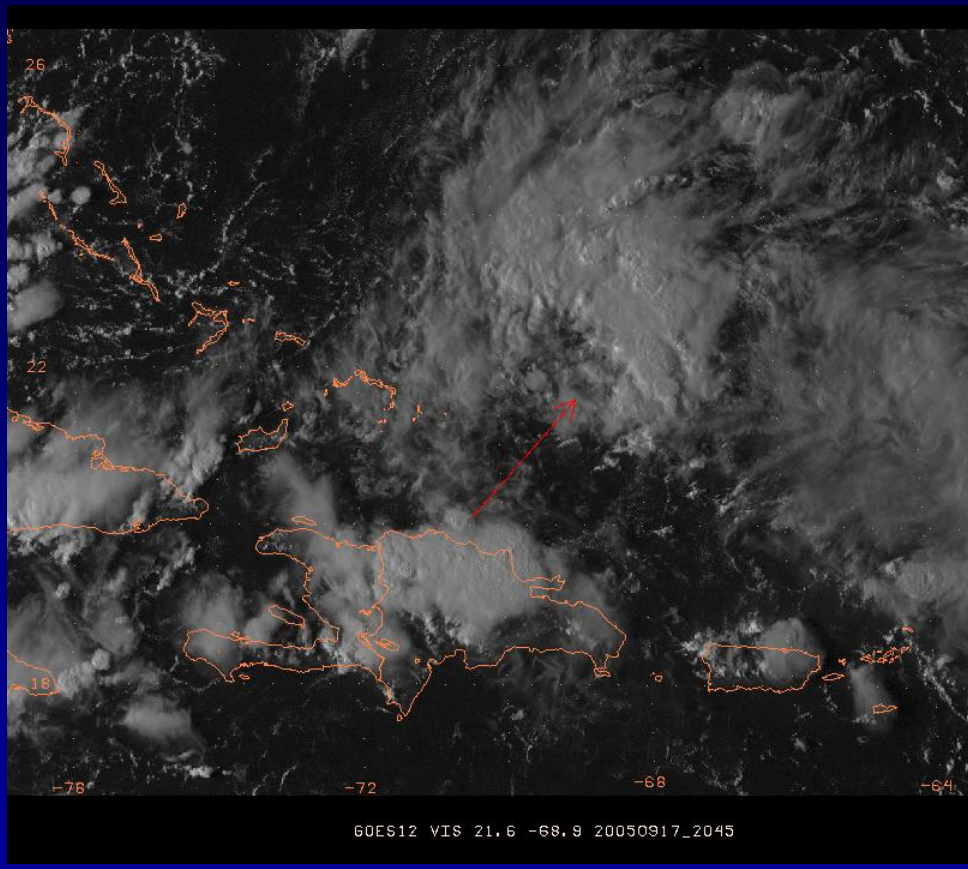
Dvorak Technique Output

CI Number	MWS (kt)	MSLP (Atlantic)	MSLP (NW Pacific)
1.0	25		
1.5	25		
2.0	30	1009 mb	1000 mb
2.5	35	1005 mb	997 mb
3.0	45	1000 mb	991 mb
3.5	55	994 mb	984 mb
4.0	65	987 mb	976 mb
4.5	77	979 mb	966 mb
5.0	90	970 mb	954 mb
5.5	102	960 mb	941 mb
6.0	115	948 mb	927 mb
6.5	127	935 mb	914 mb
7.0	140	921 mb	898 mb
7.5	155	906 mb	879 mb
8.0	170	890 mb	858 mb

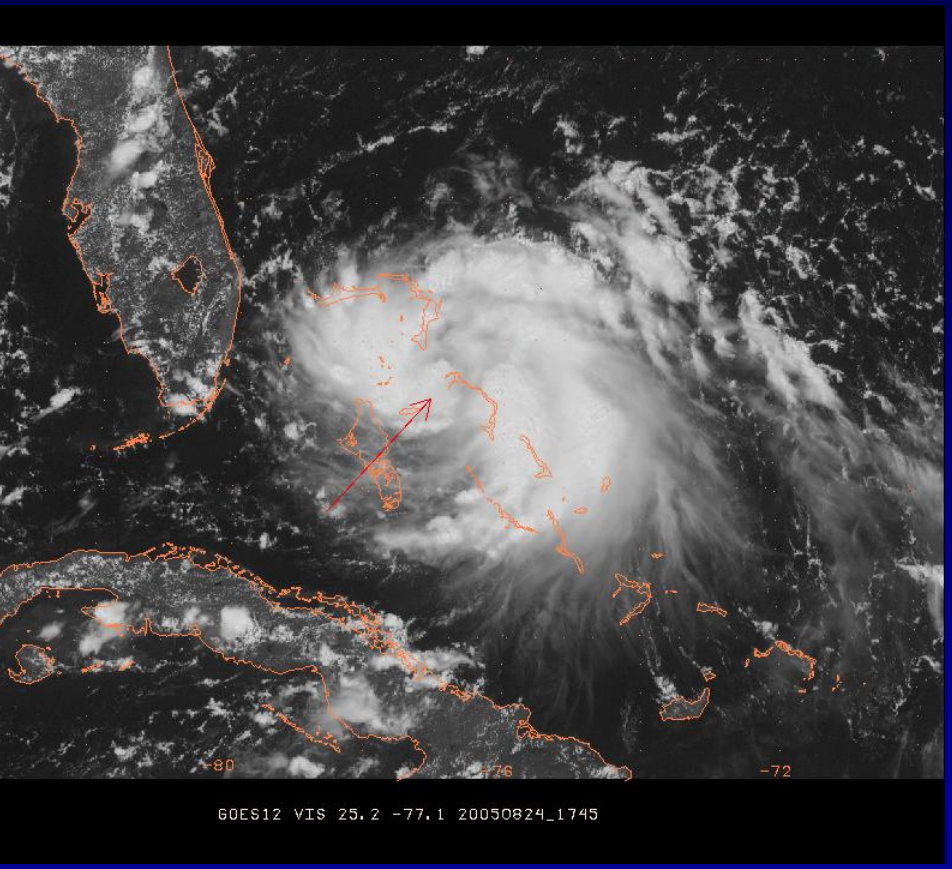
Katrina August 23



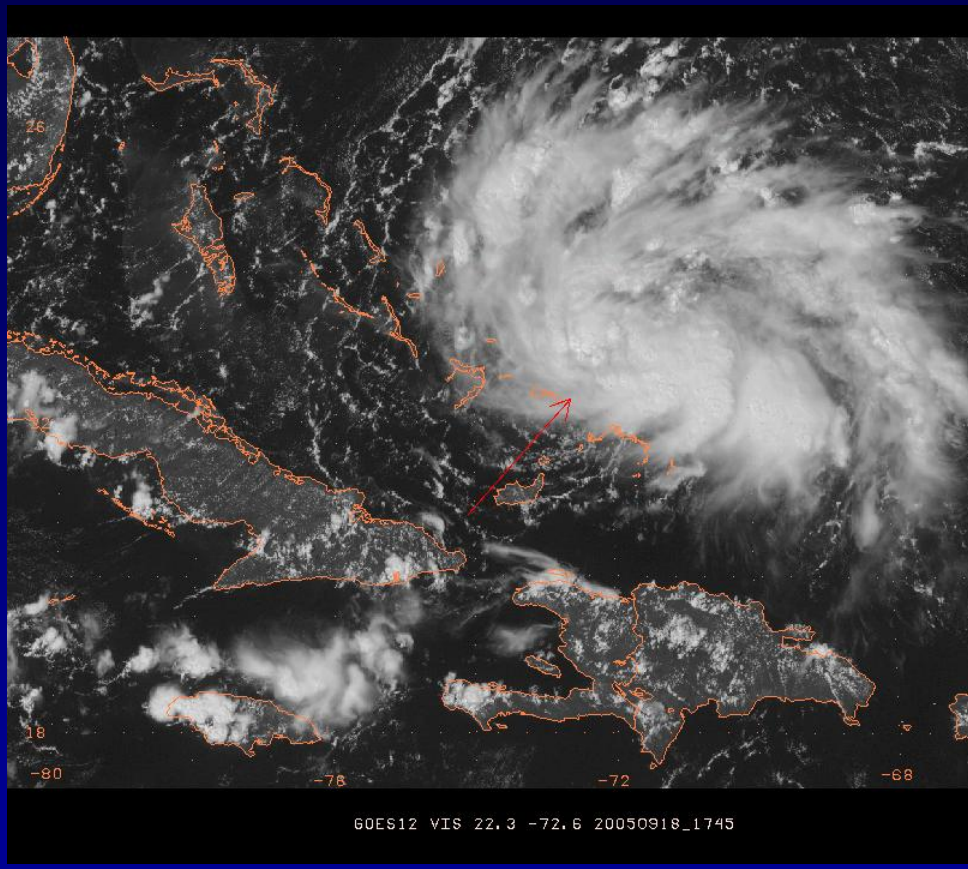
Rita September 17



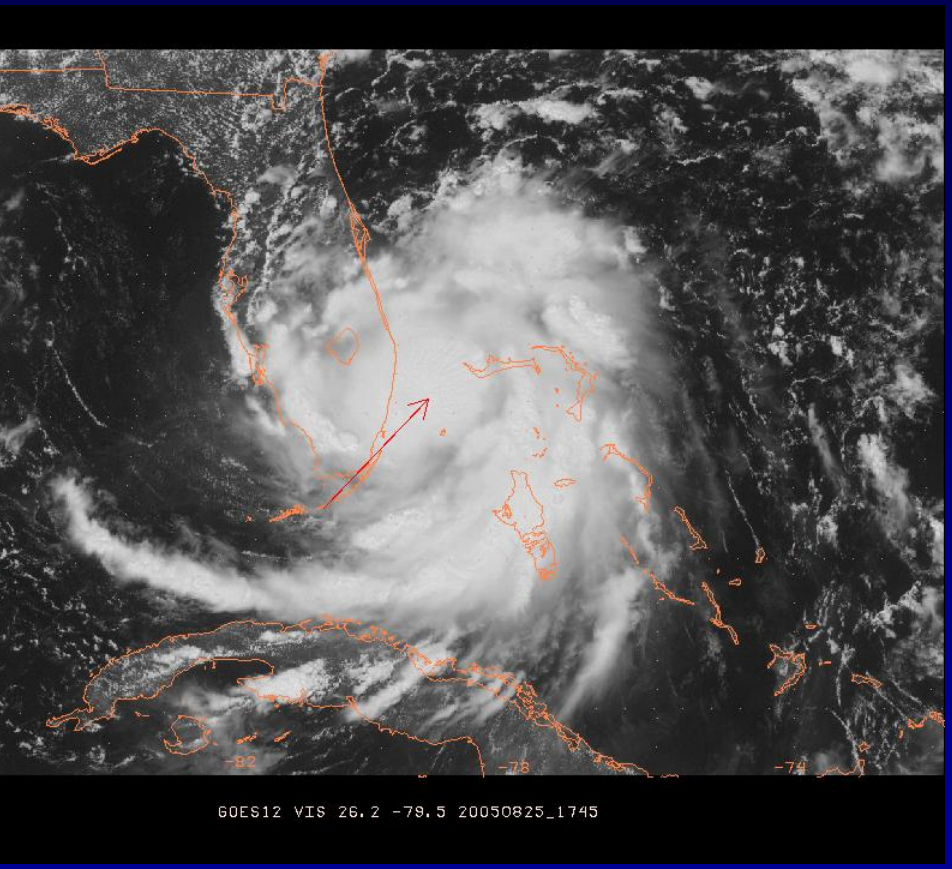
Katrina August 24



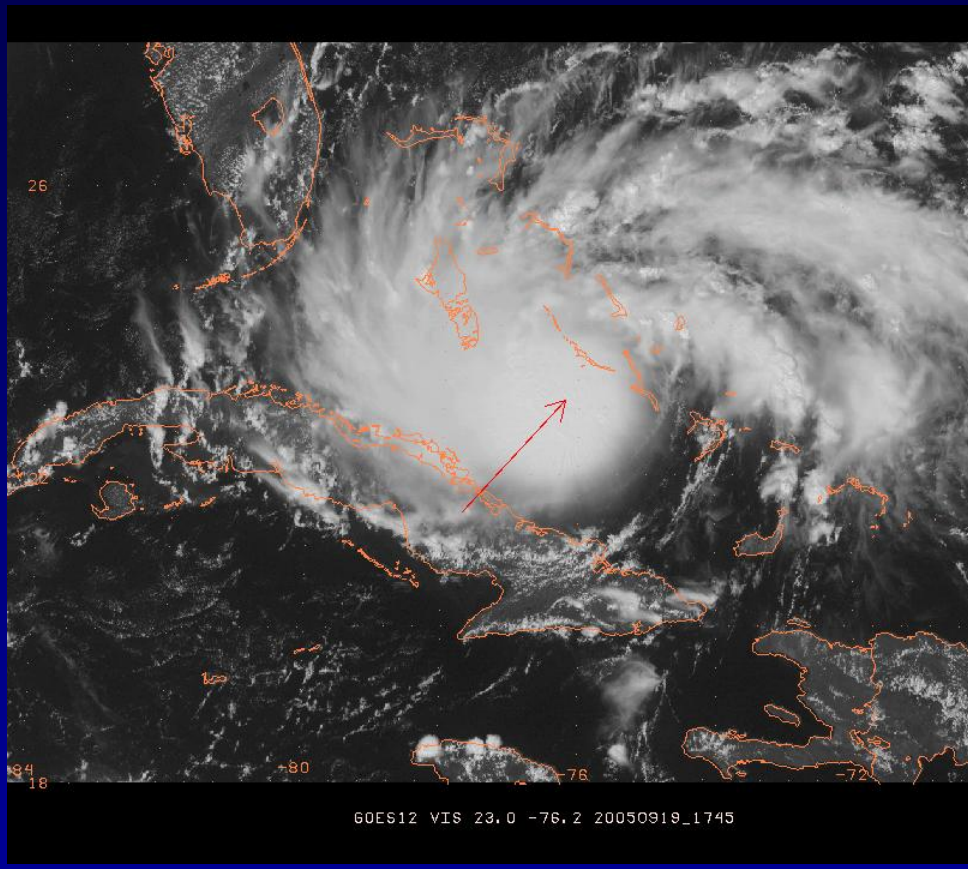
Rita September 18



Katrina August 25

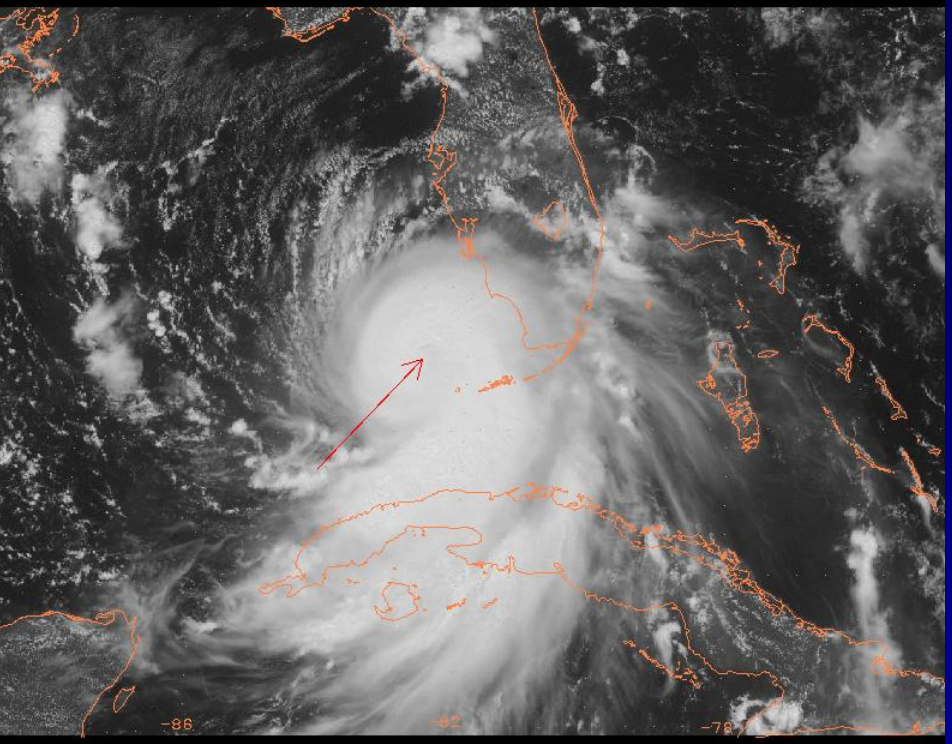


Rita September 19

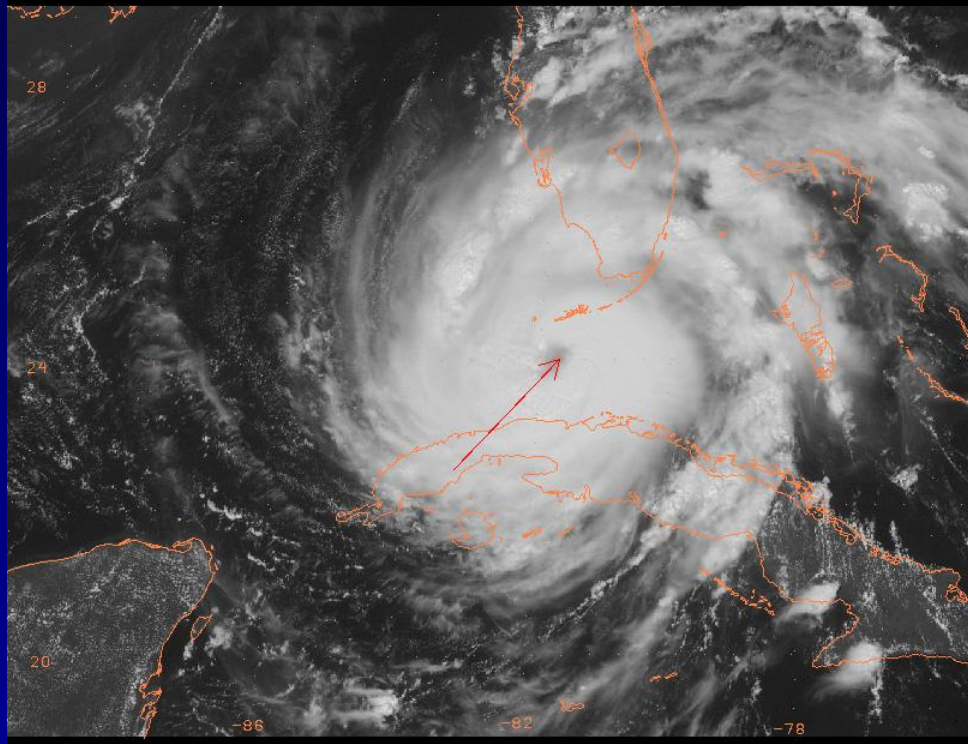


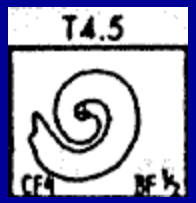
T3.5

Katrina August 26

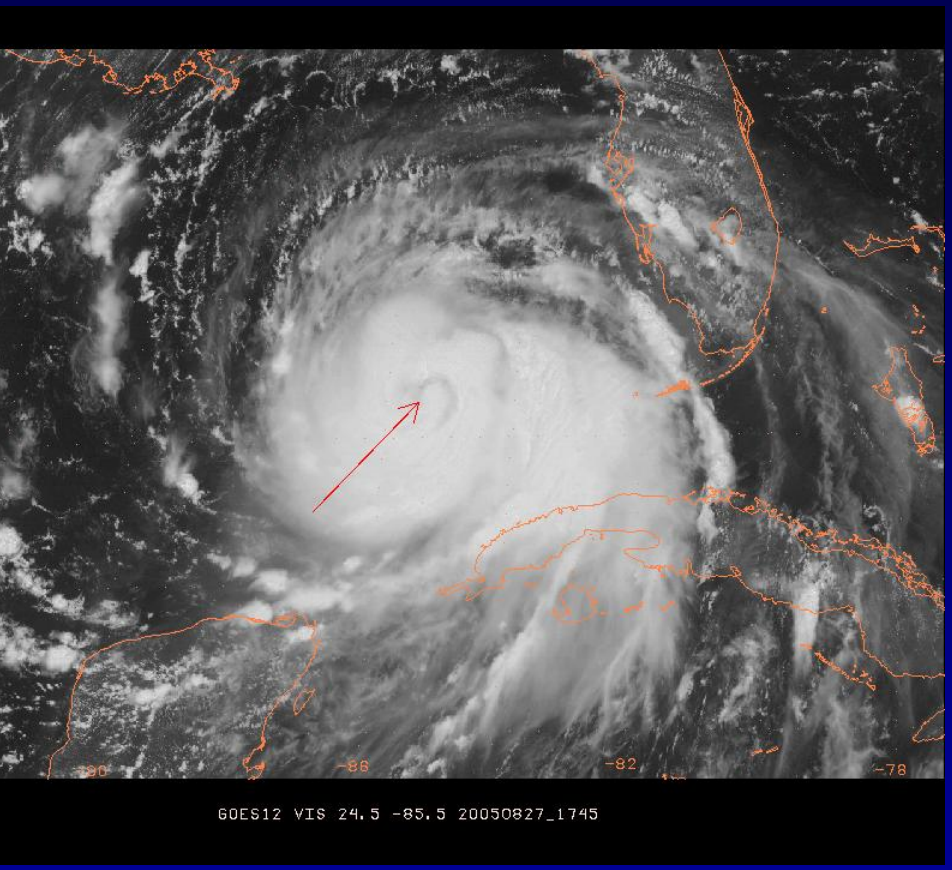


Rita September 20

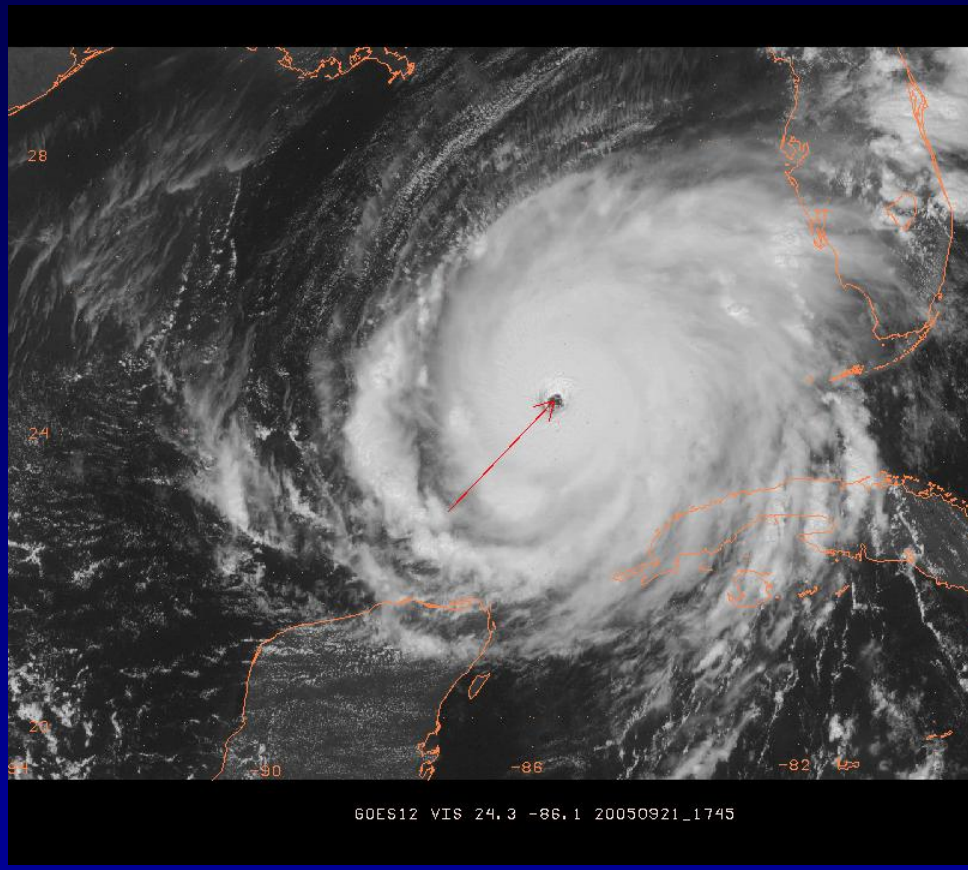


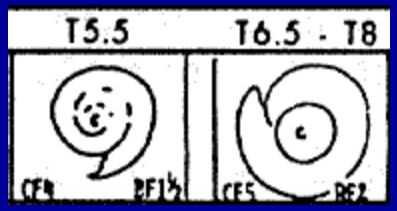


Katrina August 27

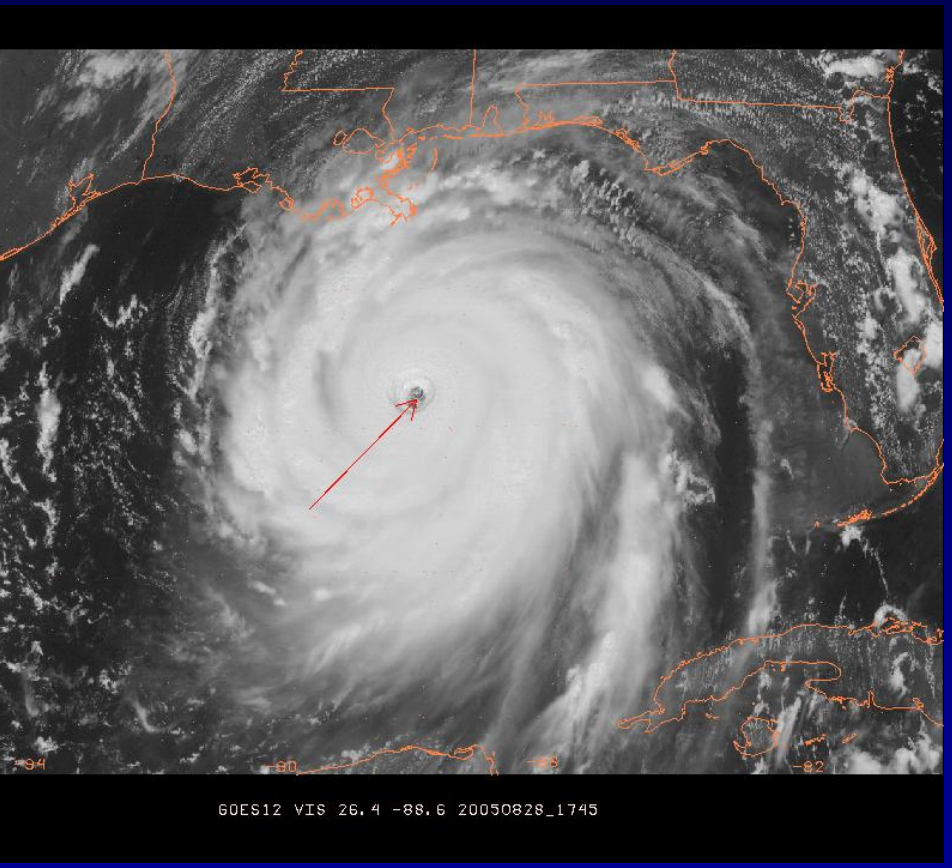


Rita September 21

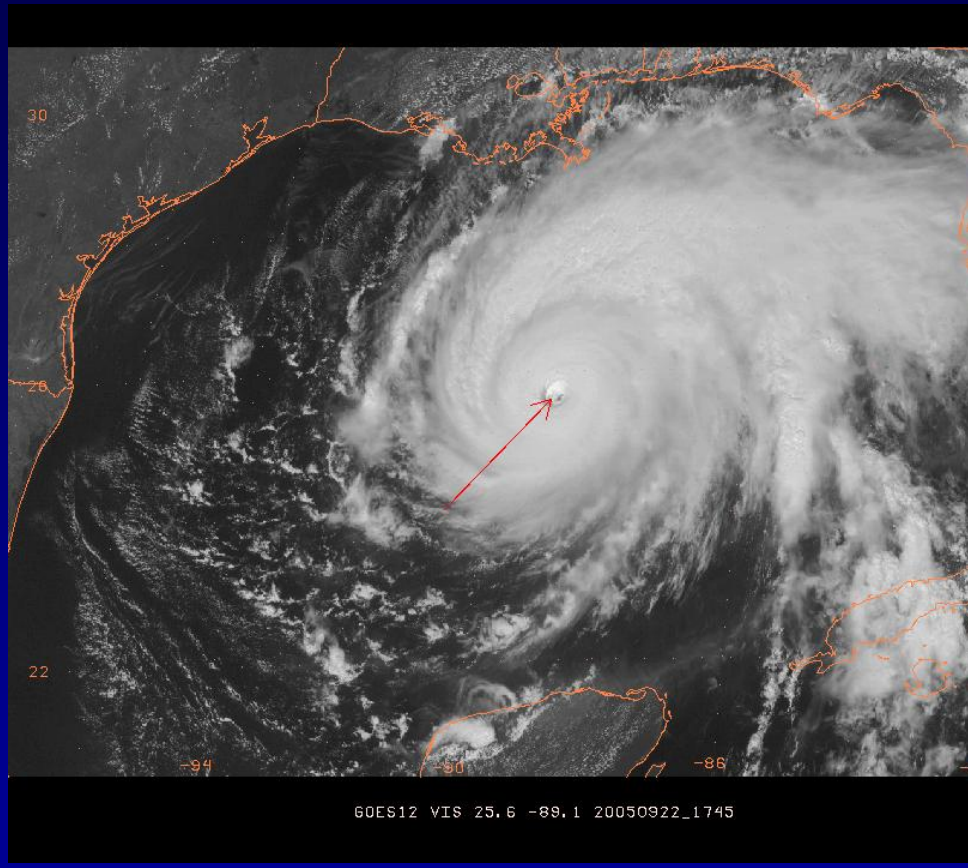


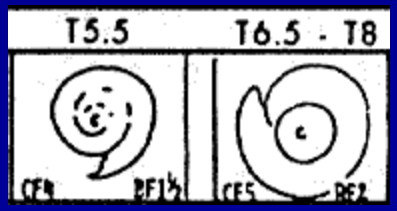


Katrina August 28

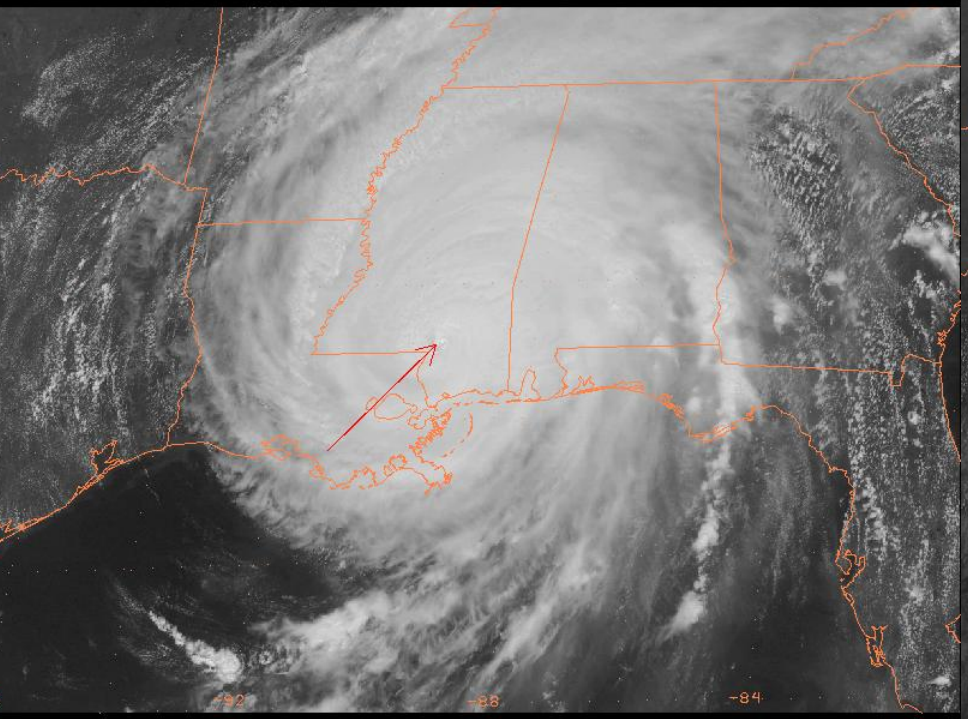


Rita September 22



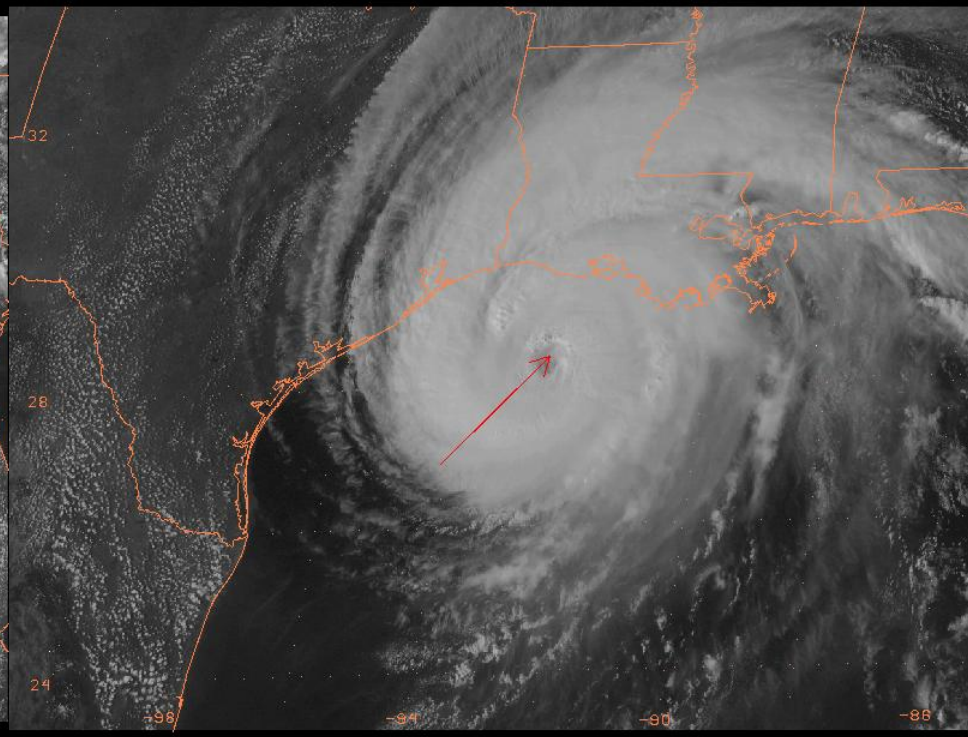


Katrina August 29



GOES12 VIS 31.1 -89.6 20050829_1745

Rita September 23



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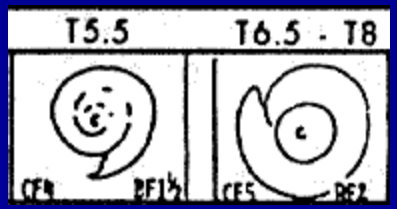
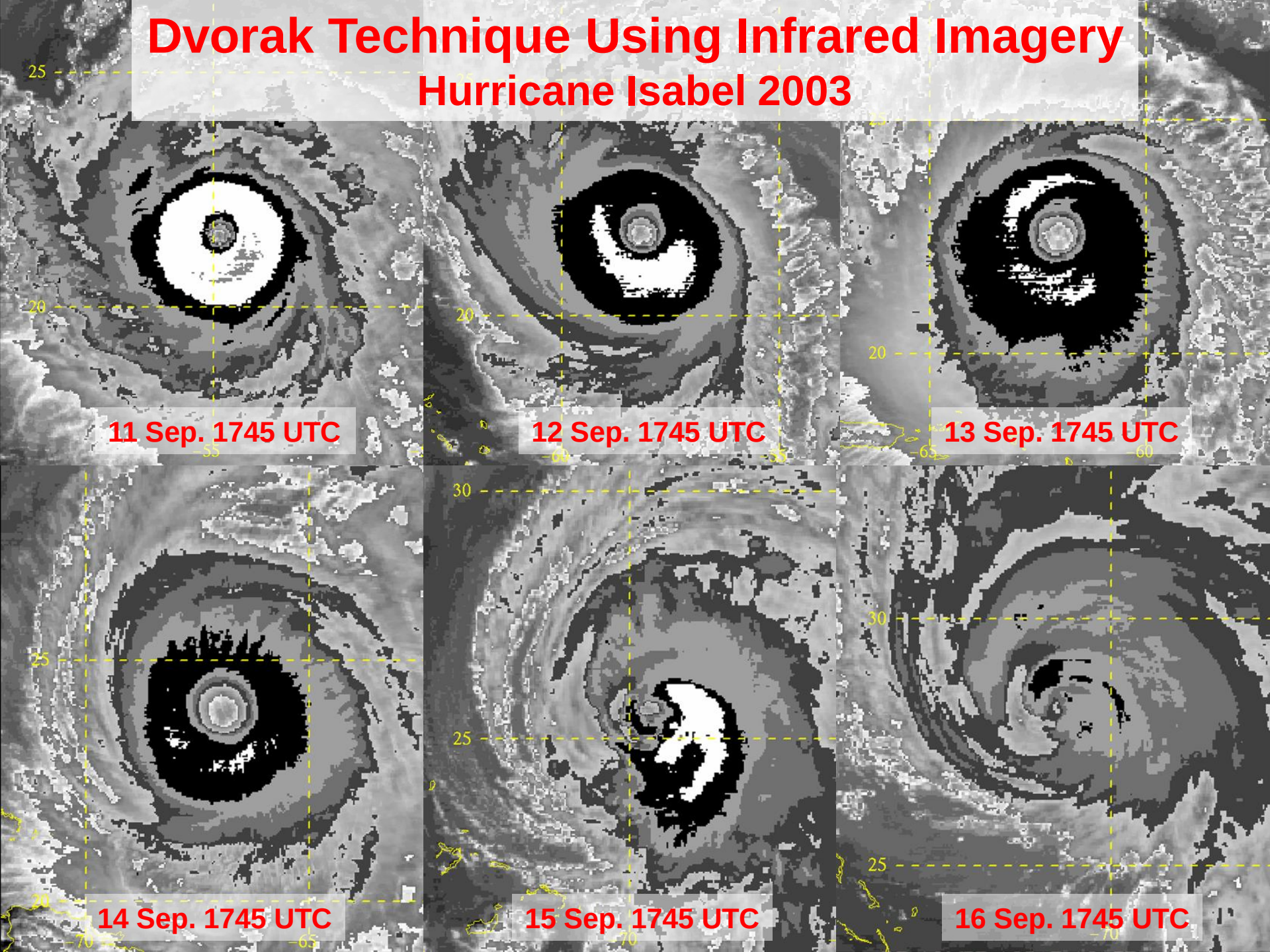


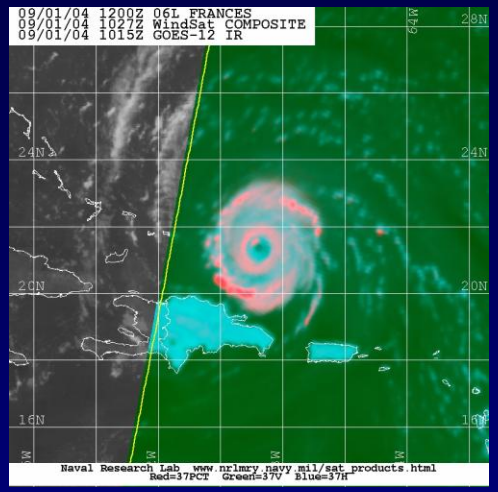
Dvorak Technique Using Infrared Imagery

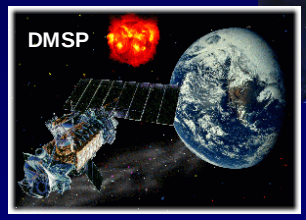
Hurricane Isabel 2003



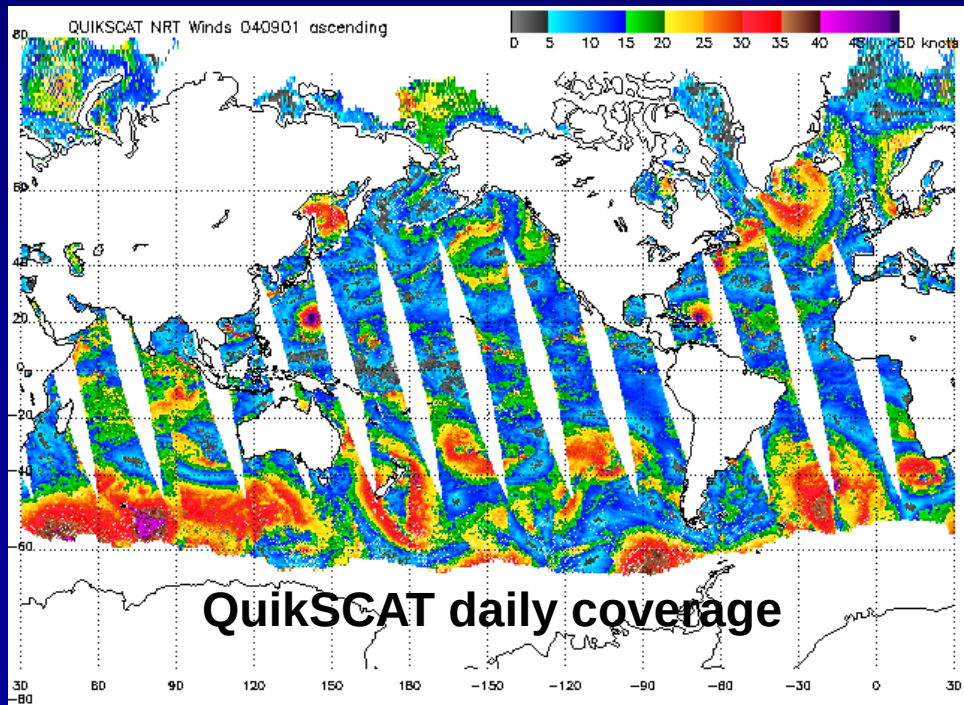
Low Earth-Orbit Satellites

- Typically fly between 300-800 miles above the Earth's surface
- Most commonly fly from pole to pole (polar orbiting)
- Carry high spatial resolution instruments, including microwave imagers and sounders
- Can have gaps in instrument coverage between orbits, which causes infrequent sampling of cyclones





Microwave location, structure, intensity, rainfall



QuikSCAT daily coverage

Geostationary vs. Polar-Orbiting Satellites Altitude Comparison

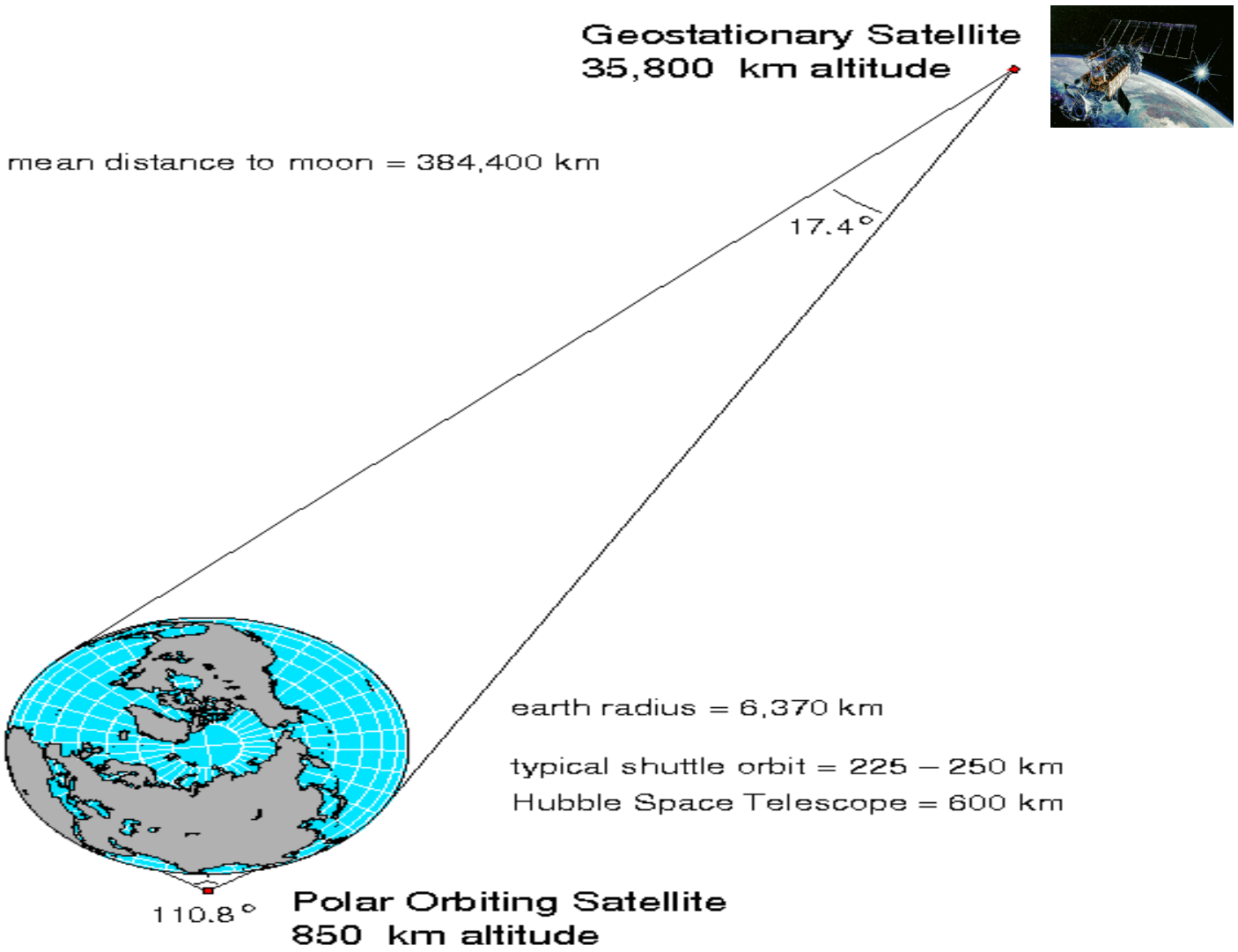


Image courtesy of http://www.nrlmry.navy.mil

Sun-synchronous Daily Orbital Path

Slightly more than 14 orbits per day

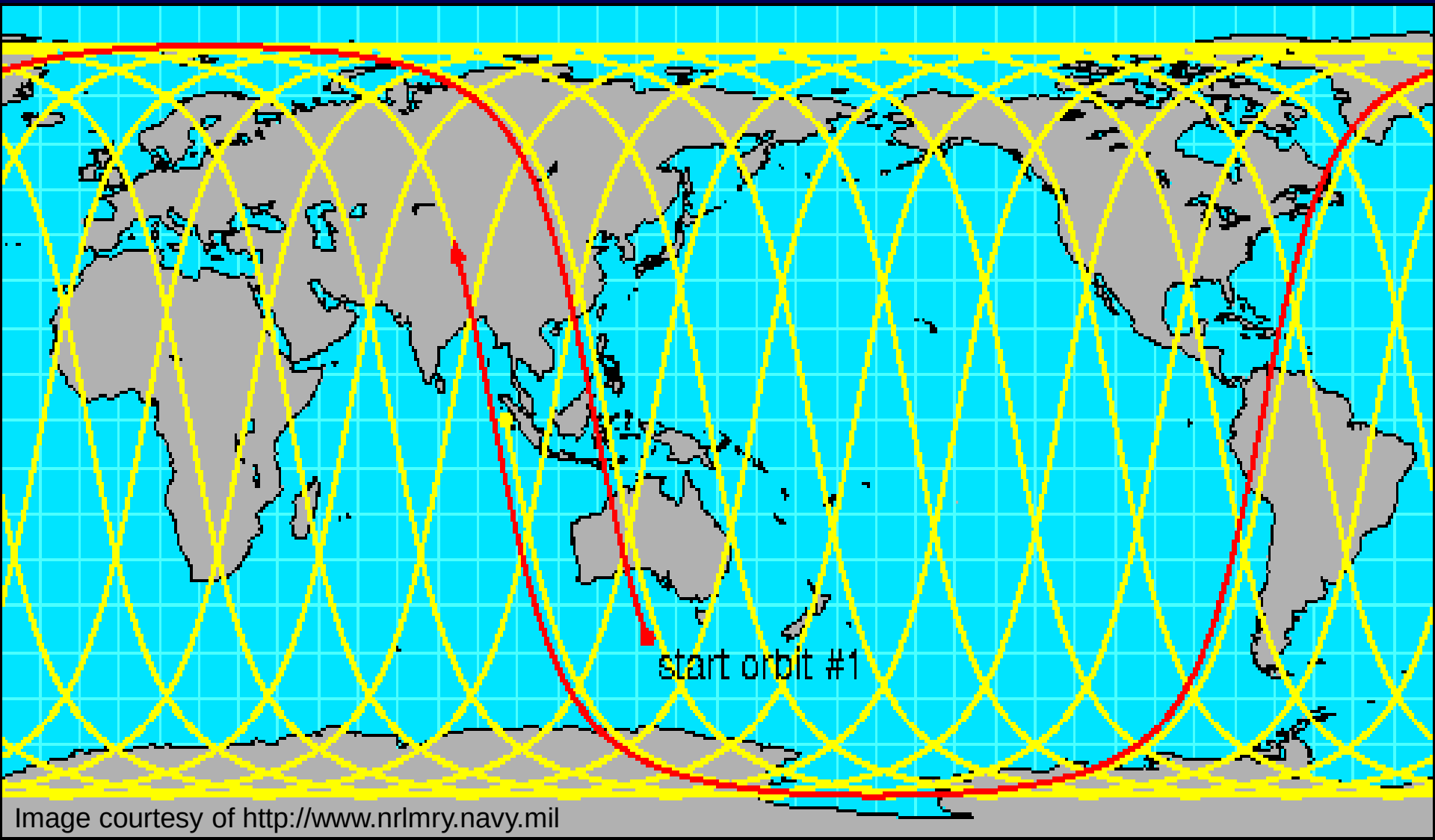
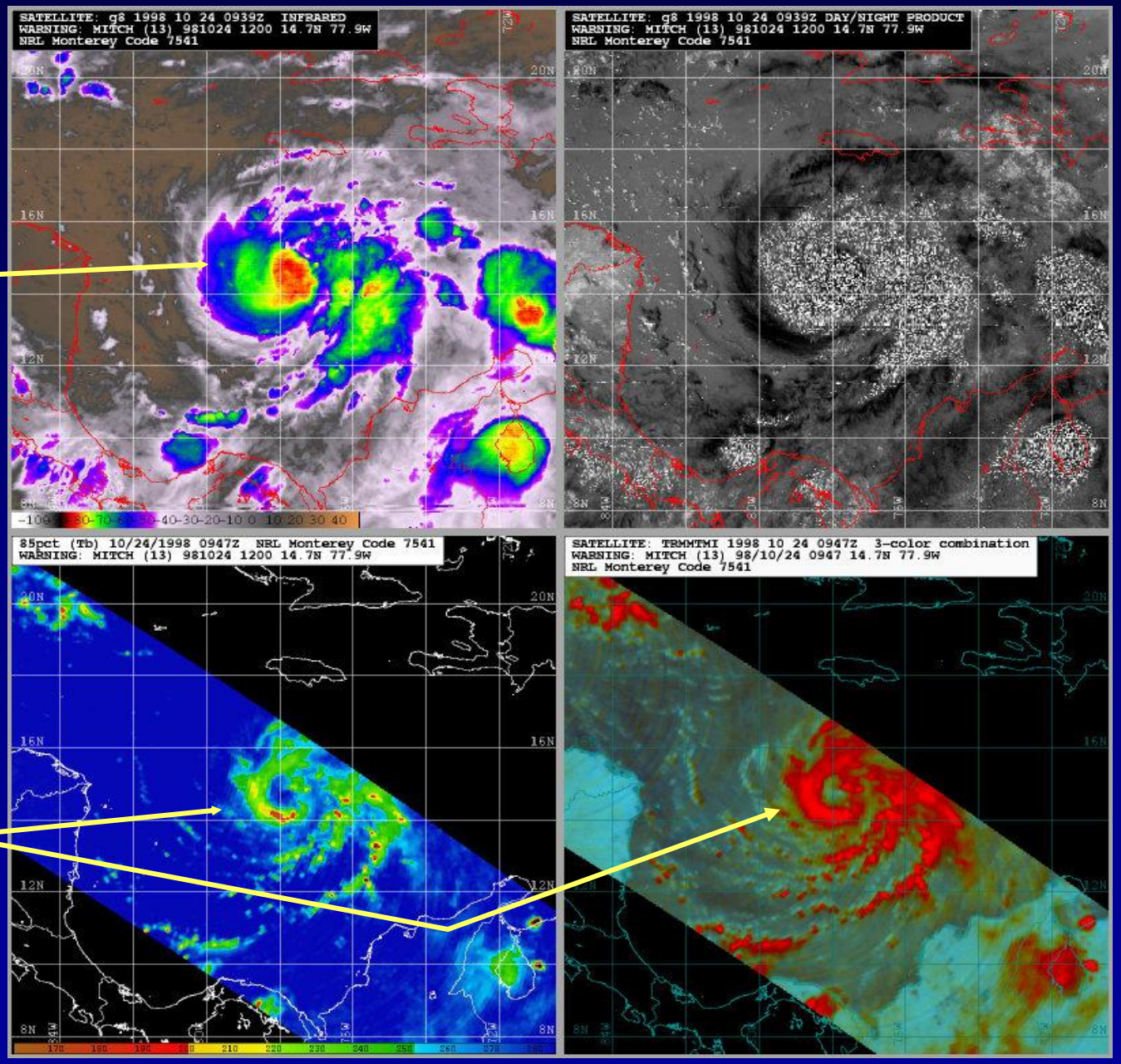


Image courtesy of http://www.nrlmry.navy.mil

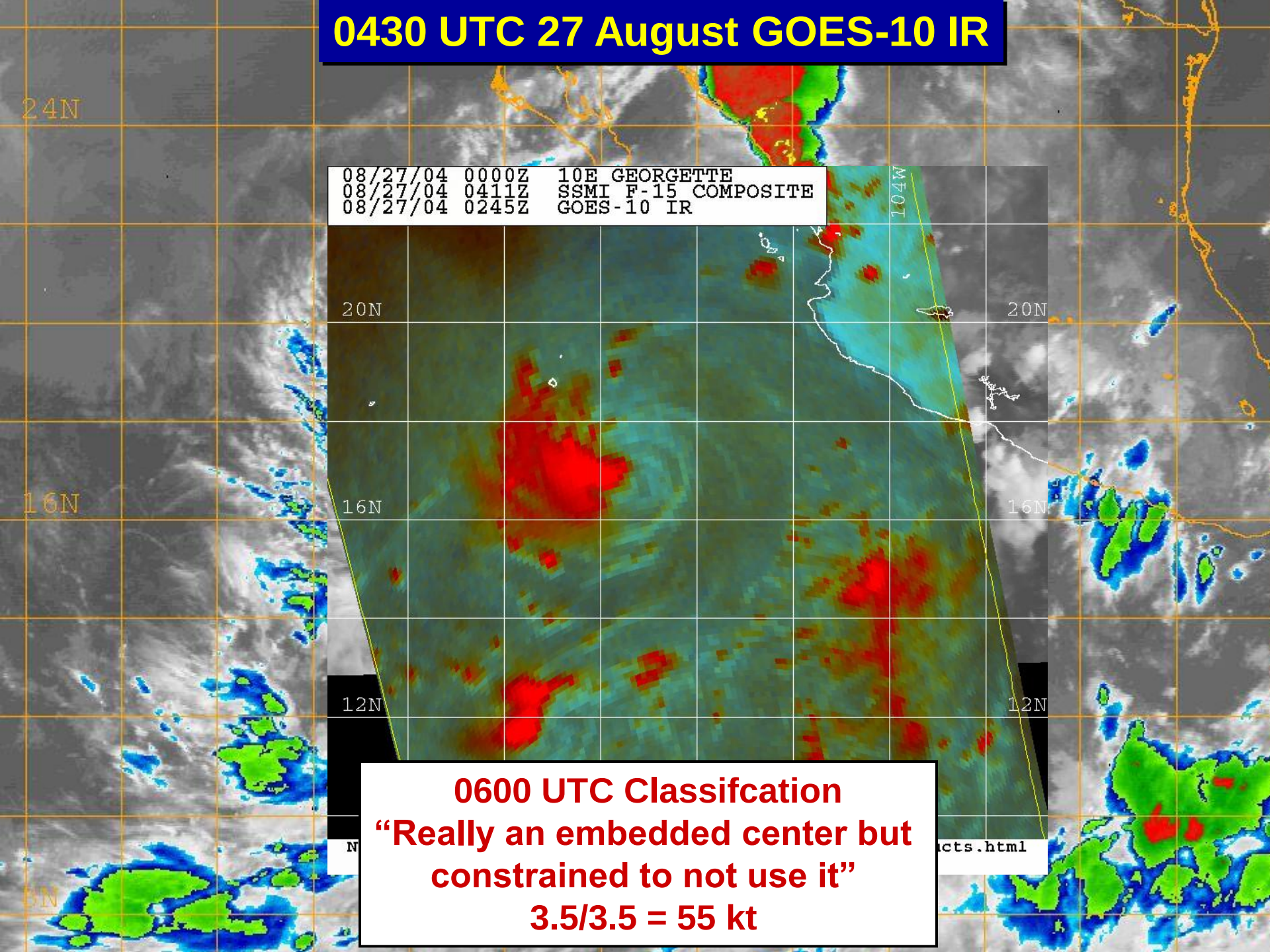
Microwave Satellite Imagery Fixes

Center is difficult to locate in conventional IR imagery...

…but is easy to locate in microwave imagery that even depicts an eye

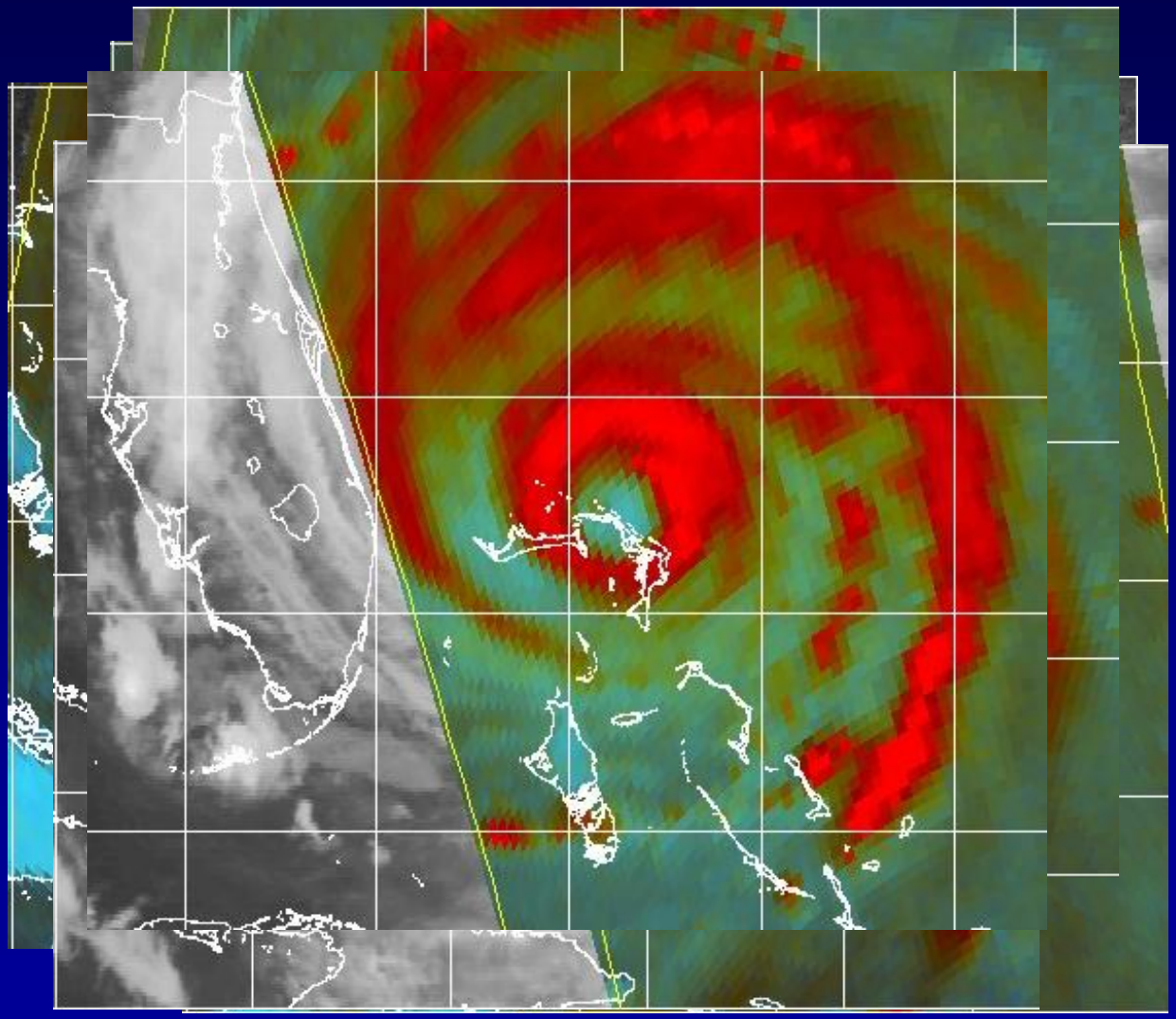


0430 UTC 27 August GOES-10 IR



0600 UTC Classifcation
"Really an embedded center but constrained to not use it"
3.5/3.5 = 55 kt

Concentric Eyewall Cycle
Hurricane Floyd (1999)



13 / 0116Z

13 / 1122Z

13 / 1347Z

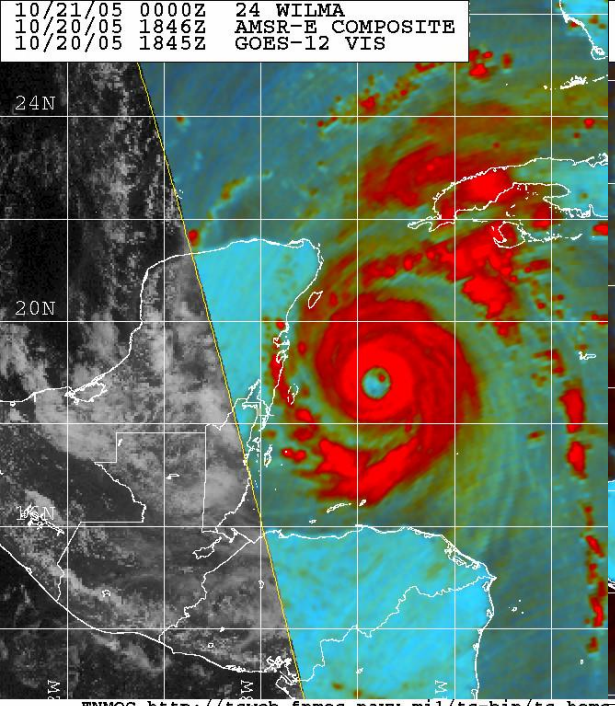
13 / 2240Z

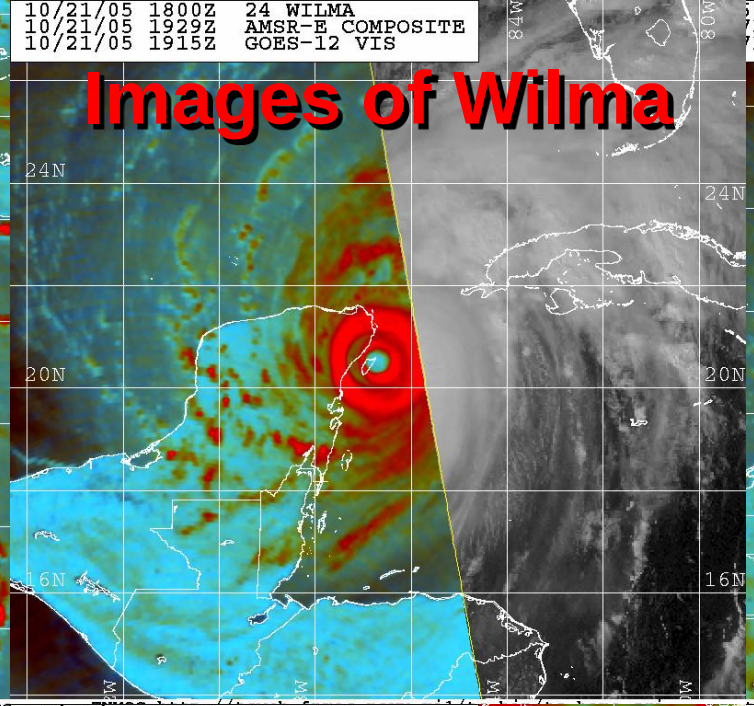
14 / 0104Z

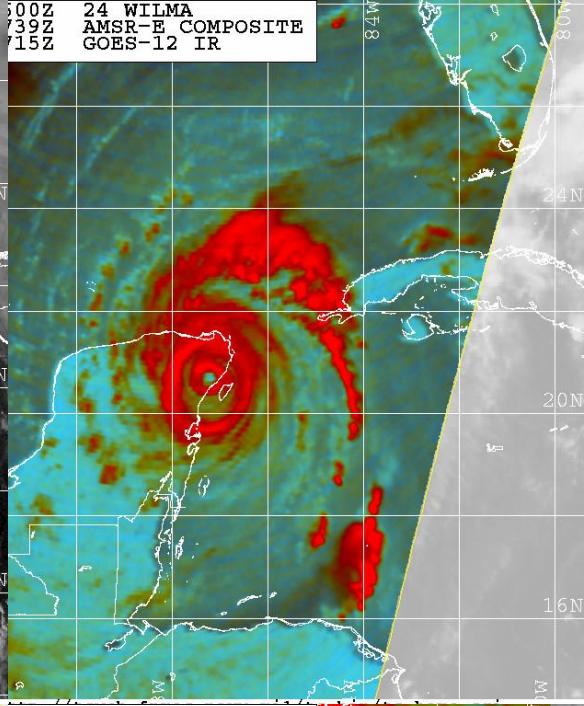
14 / 1110Z

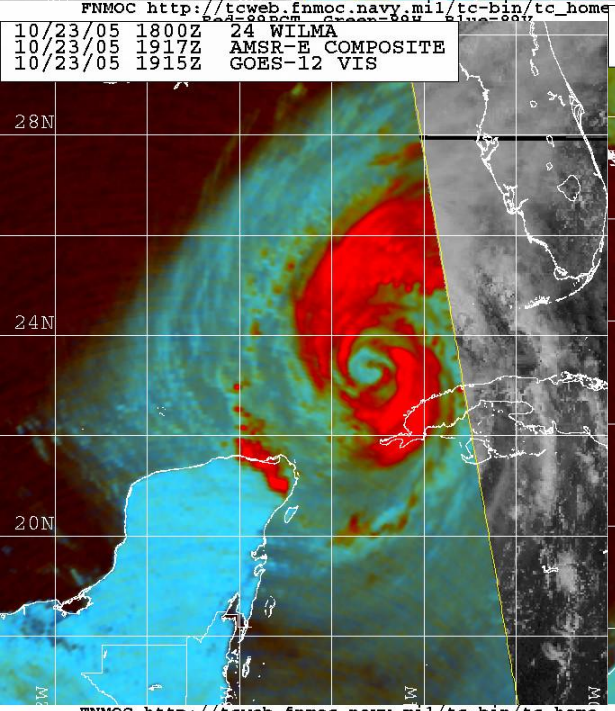
14 / 2228Z

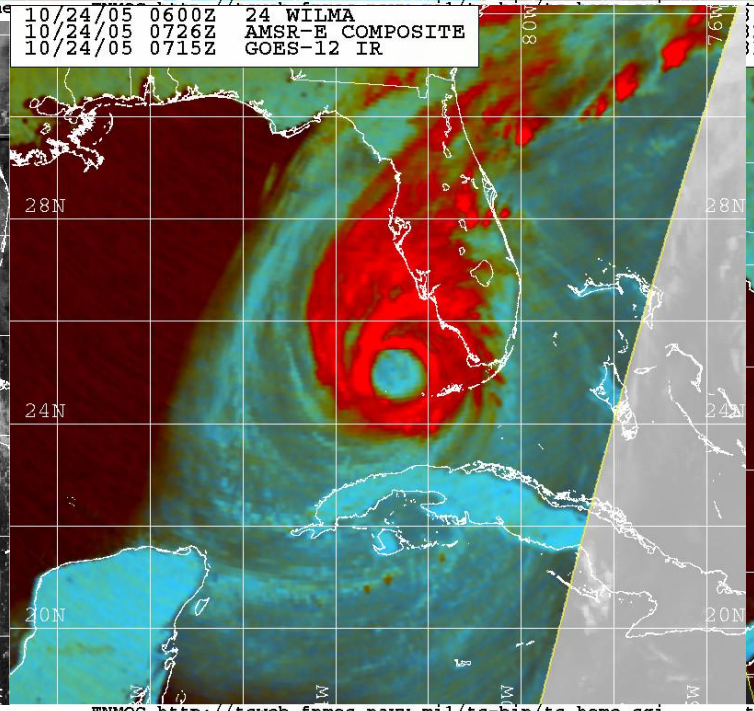
Images of Wilma

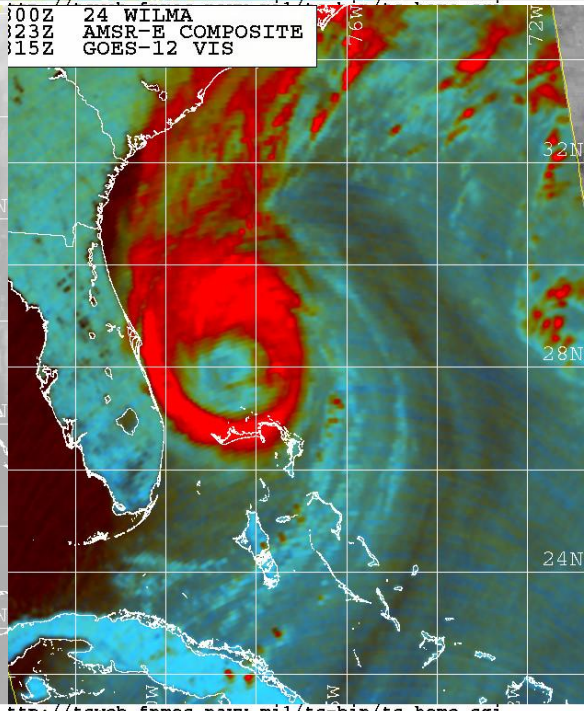












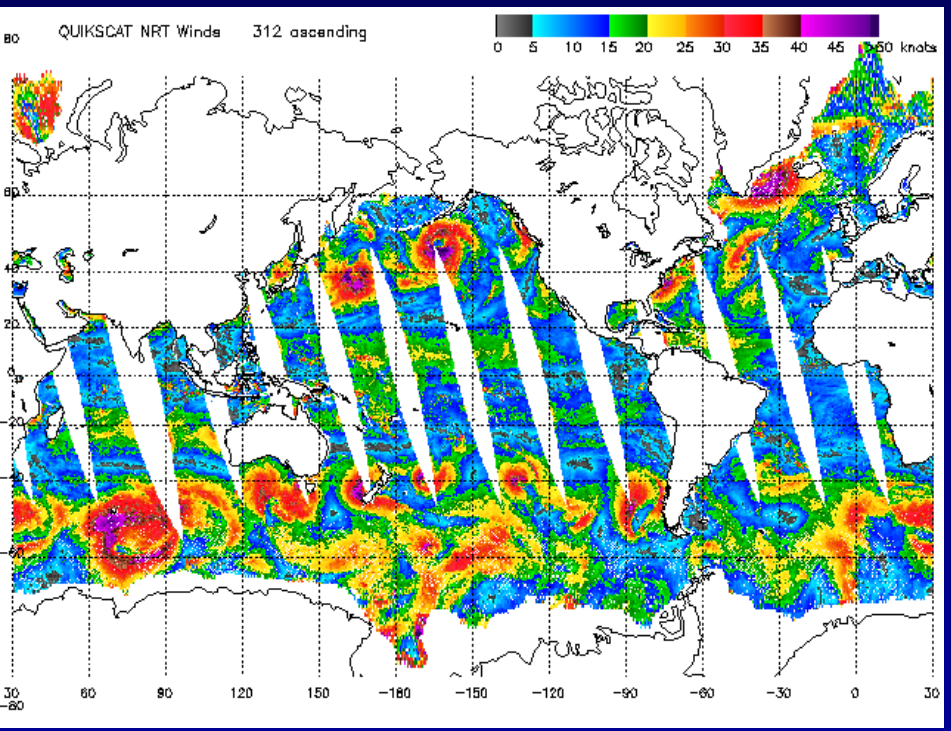
QuikSCAT

- NASA research satellite launched in 1999
- A microwave scanning radar (scatterometer)
- Capable of estimating ocean surface wind speed and direction
- Accurate wind retrievals up to about 90 knots *outside of rain areas*
- Retrievals impacted by moderate to heavy rain and require careful human interpretation
- Wind retrieval spatial resolution of 12.5 km to within 30 km of the coastline

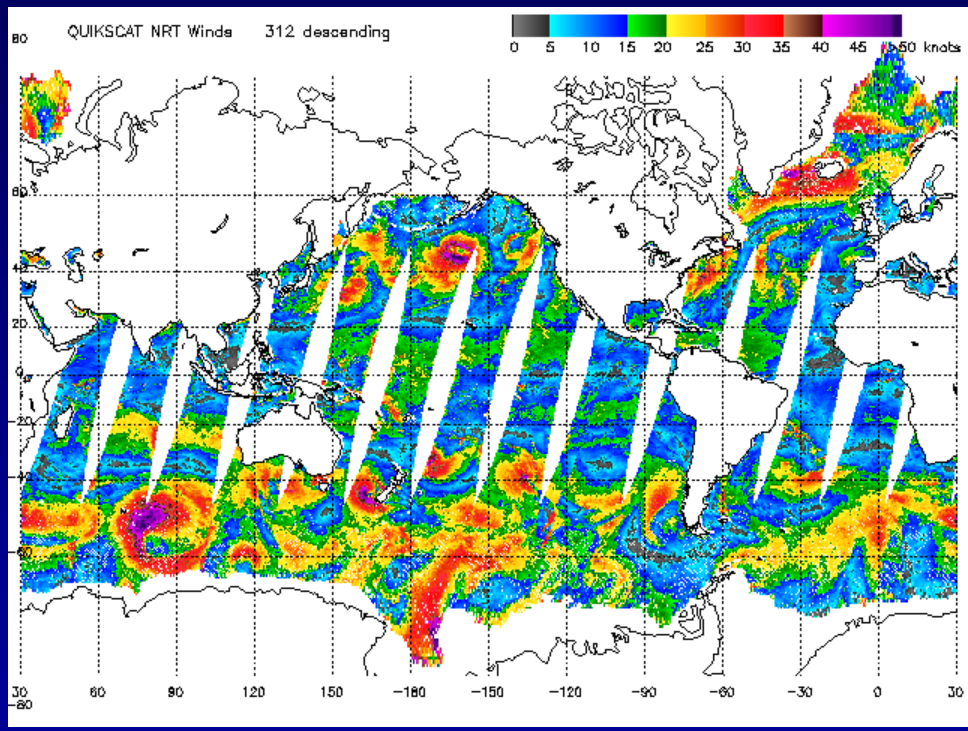
- Past its planned service life, but continues to produce good quality data

QuikSCAT (SeaWinds) Daily Coverage from sun-synchronous orbit (90% coverage of global oceans per day)

Ascending Pass



Descending Pass

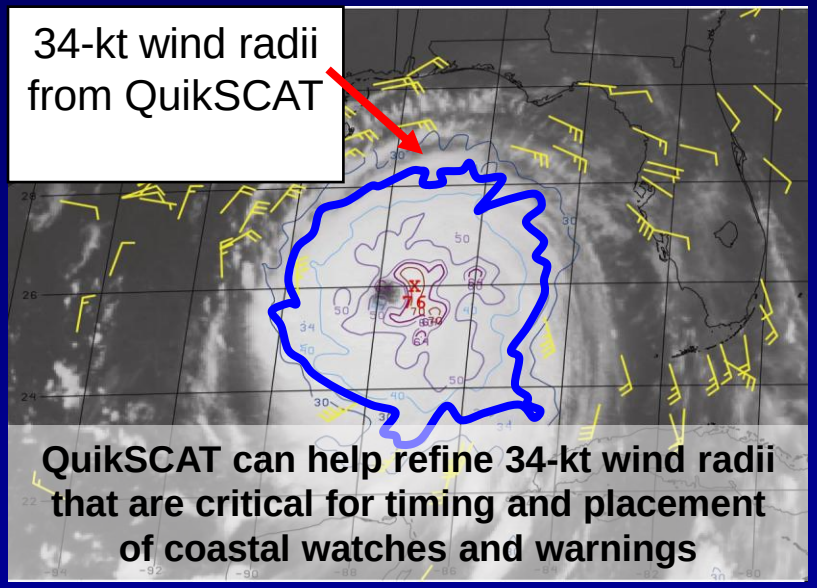


Each swath is about 1800 km wide

Impact of QuikSCAT on Tropical Cyclone Forecasts and Warnings

QuikSCAT is the only tool for providing large-scale measurements of TC surface winds. Wide data swath can sample entire circulation of TC. QuikSCAT winds are used to:

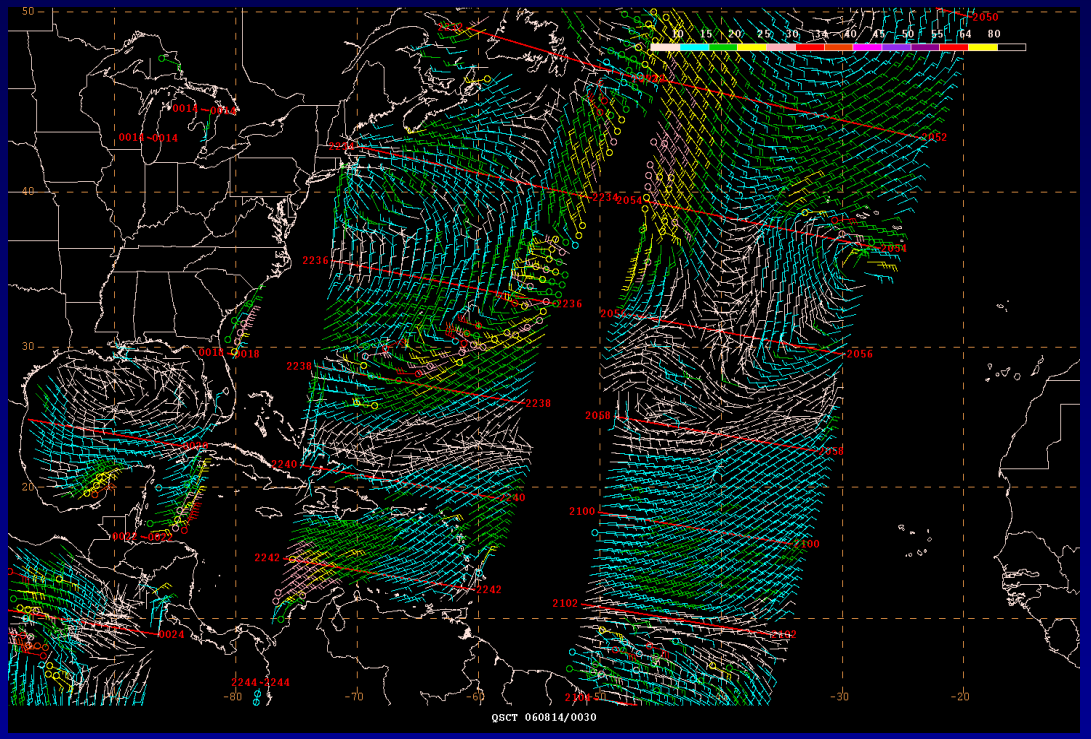
- **Estimate intensity (maximum sustained surface wind)**, especially for tropical storms, but not for most hurricanes
- **Improve analysis of 34 kt and 50 kt wind radii** of tropical cyclones to refine ship avoidance and coastal warning areas
- **Detect and locate surface circulation centers** in tropical cyclones
- How QuikSCAT was used in cases when it was mentioned in NHC Tropical Cyclone Discussion products during 2003-06:
  - Intensity estimation (62% of these cases)
  - Estimating center location (21%)
  - Wind radii estimation (17%)



QuikSCAT can help refine 34-kt wind radii that are critical for timing and placement of coastal watches and warnings

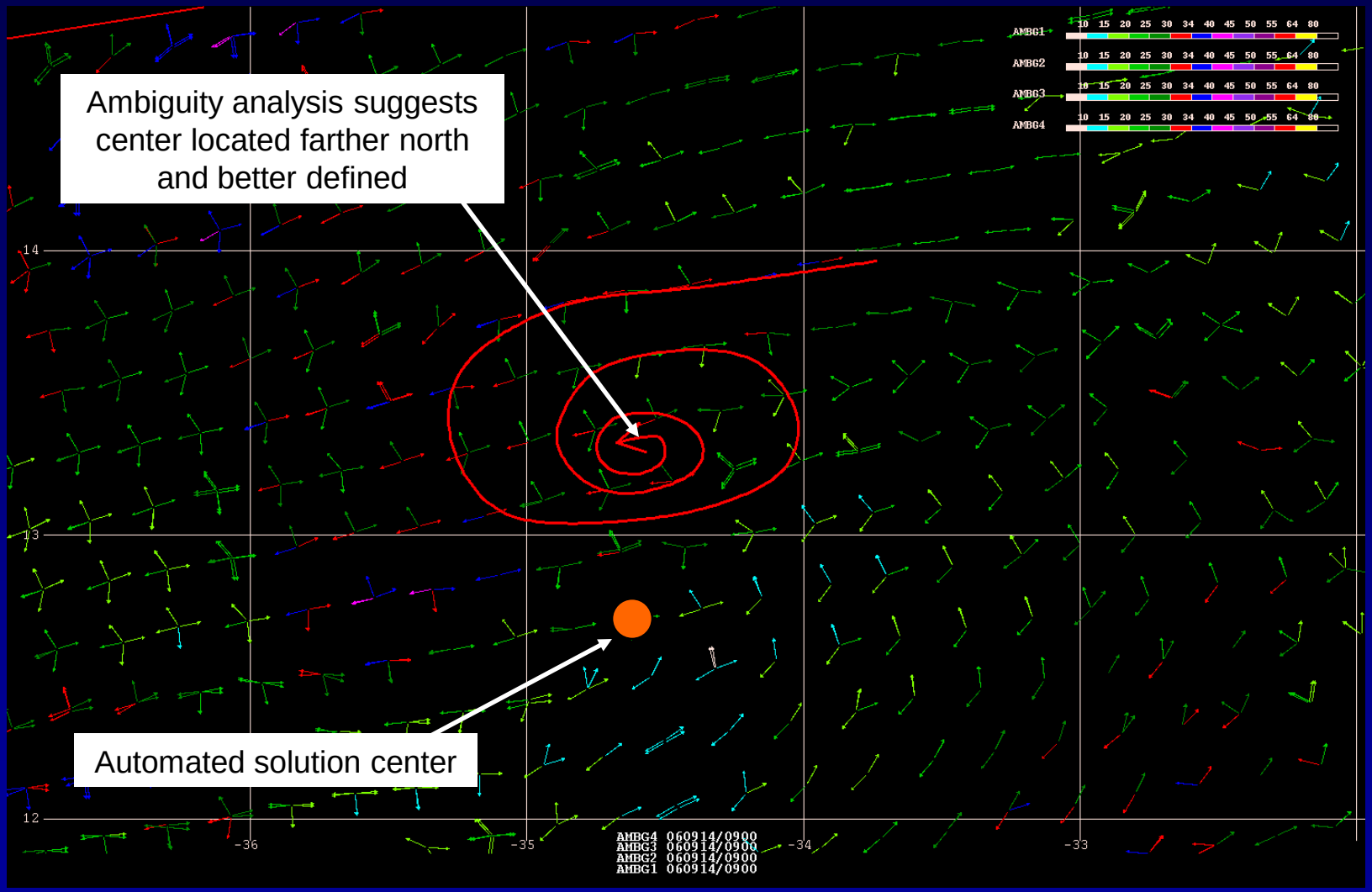
QuikSCAT Limitations

- At most two passes a day at low and mid-latitudes
- Gaps between swaths approach 1000 km in deep Tropics
- Sensitive to rain → problem in TCs and elsewhere
- Can't measure maximum wind in major hurricanes
  - Resolution, instrument design, rain effects
- Directional uncertainty limits ability to identify or locate TC centers
  - Subjective analysis of "ambiguities" by forecaster required
- The unavailability of data near shore

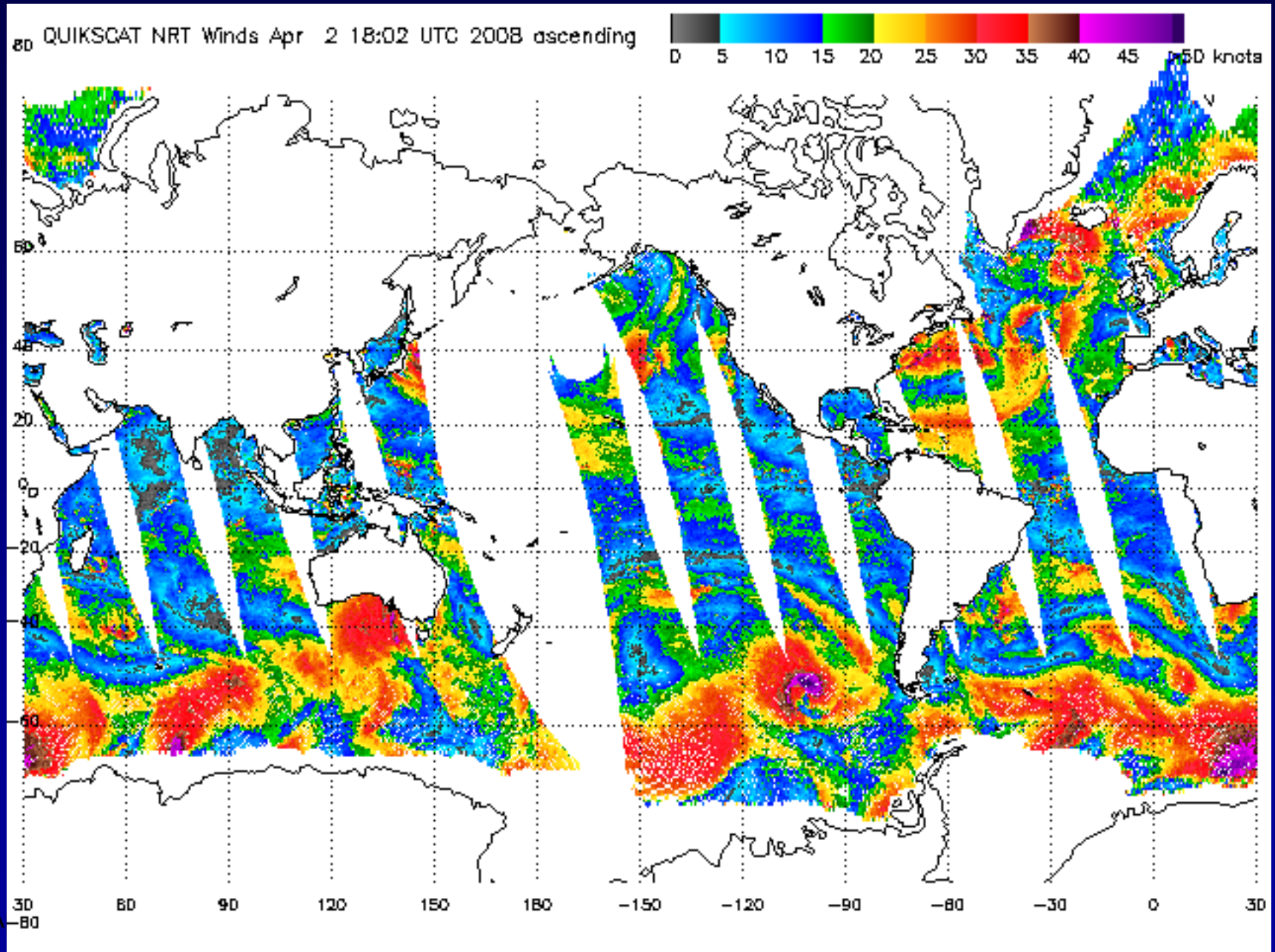


Ambiguity Analysis

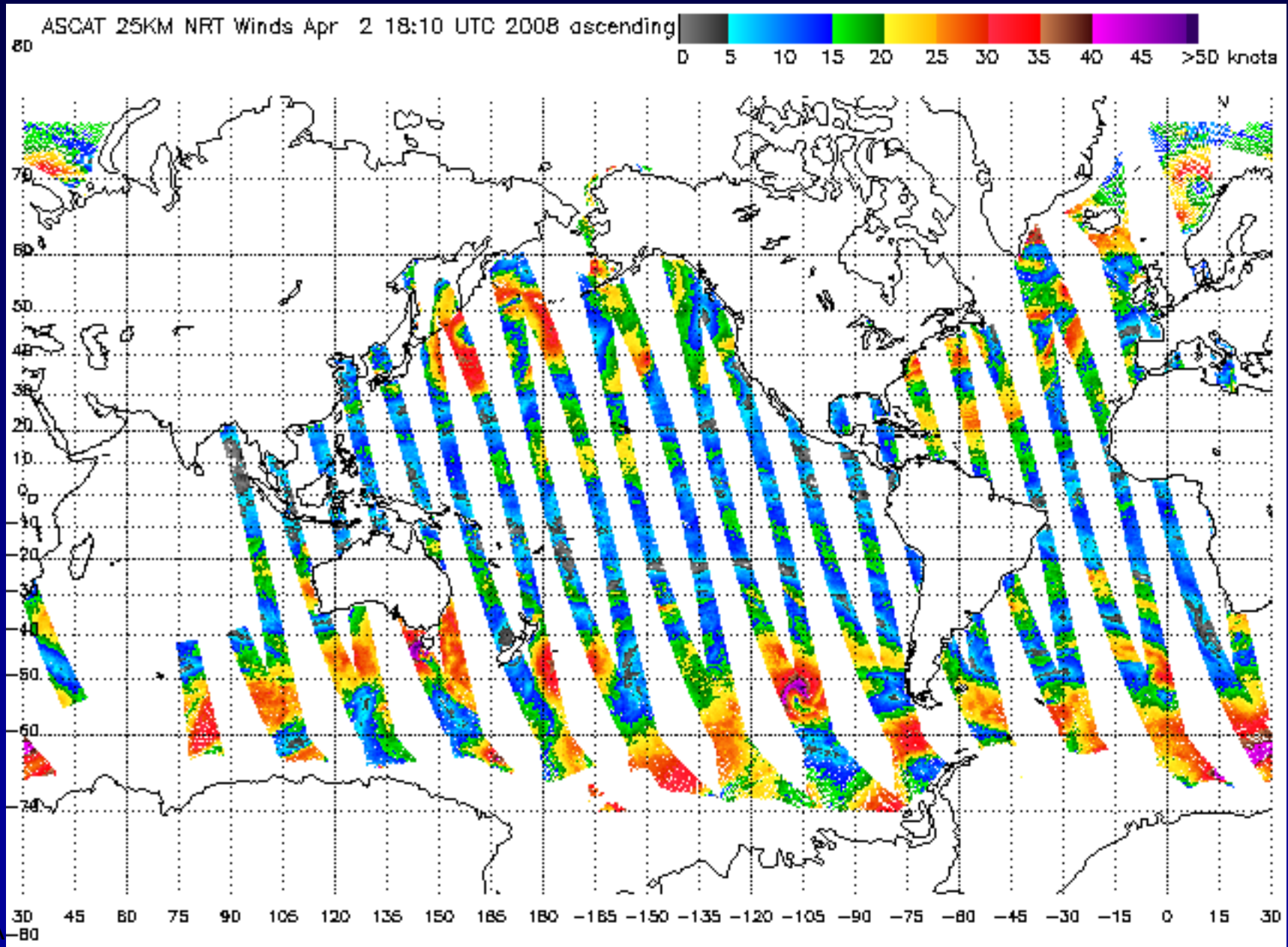
TS Helene 14 Sep. 2006



QuikSCAT Coverage

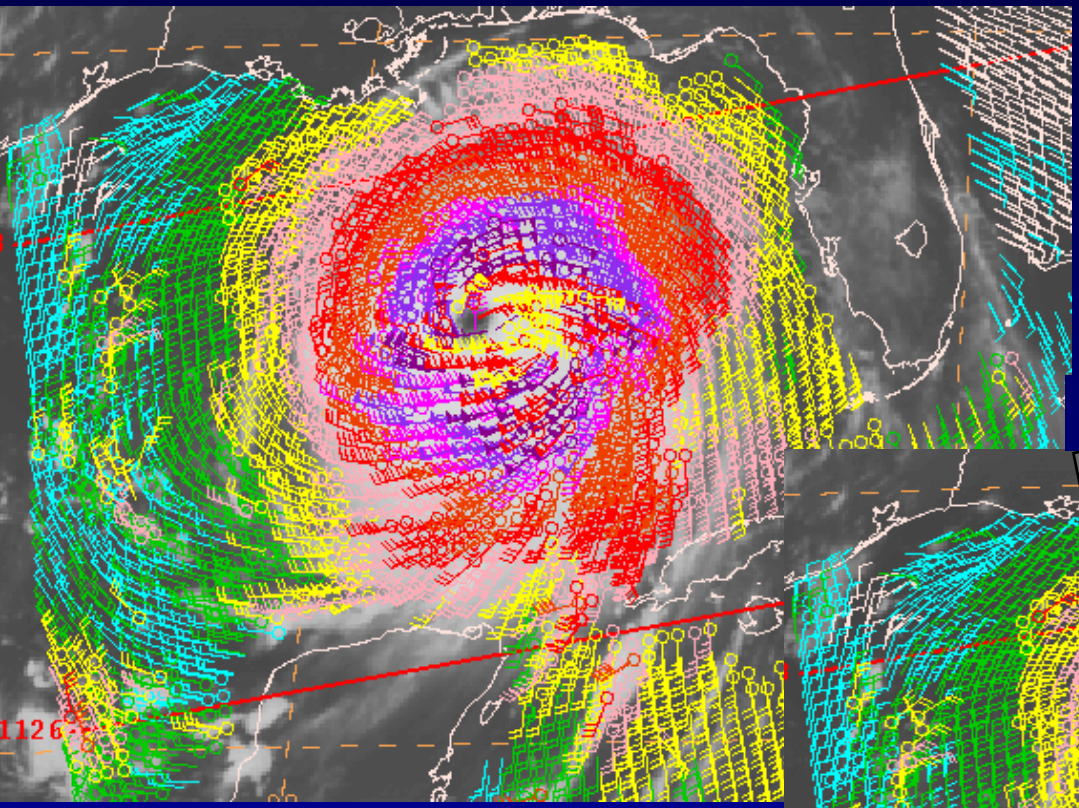


ASCAT Coverage



ASCAT vs QuikSCAT Coverage

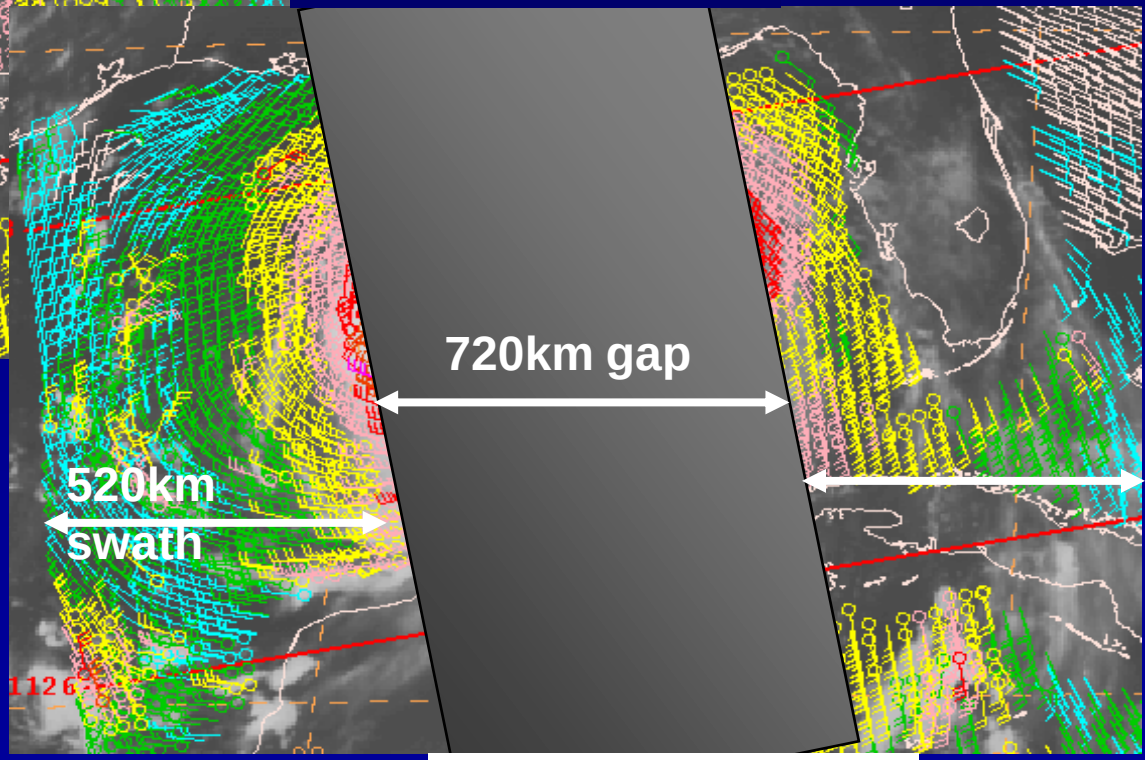
Hurricane Katrina (2005)



Actual QuikSCAT pass

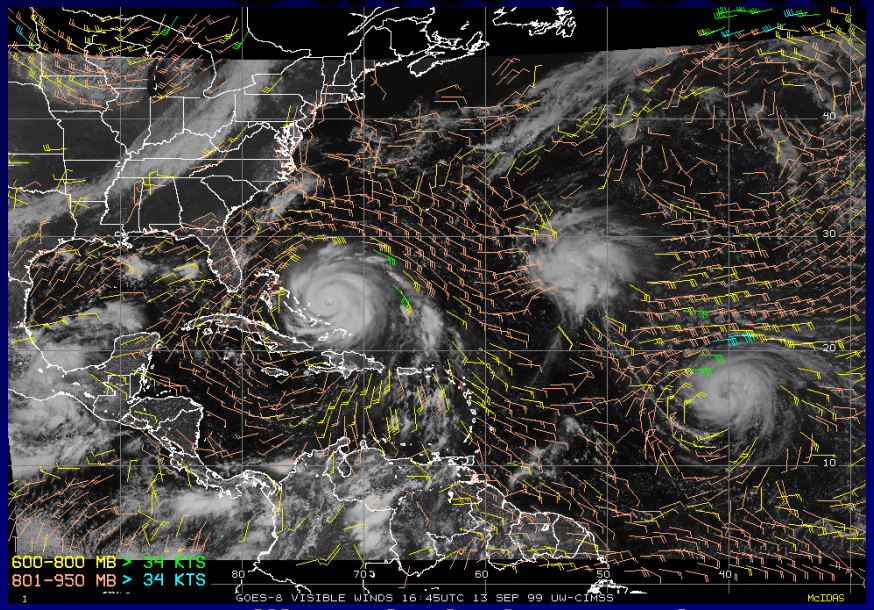
What ASCAT coverage would look like

Simulated Coverage of ASCAT pass

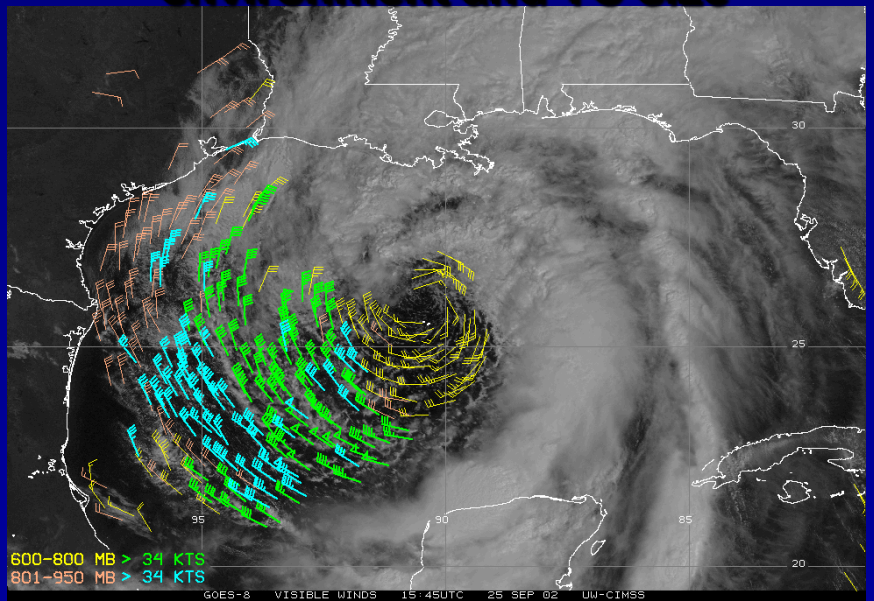


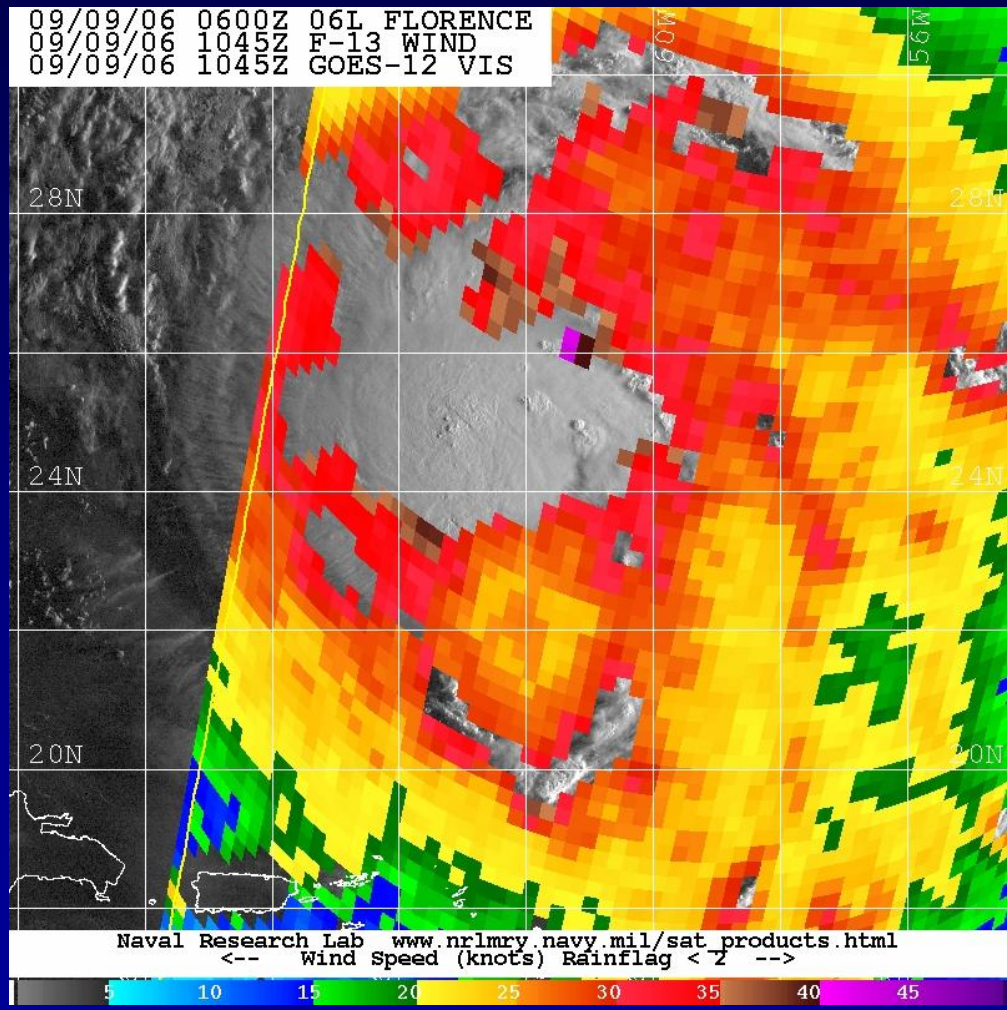
18 April 2007

Other useful satellite data



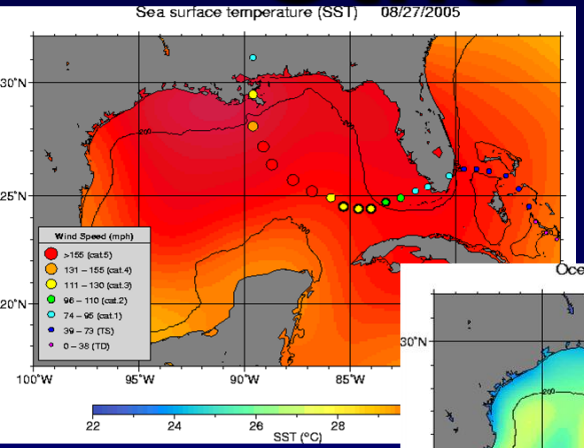
Satellite winds for nearby environment and TC size

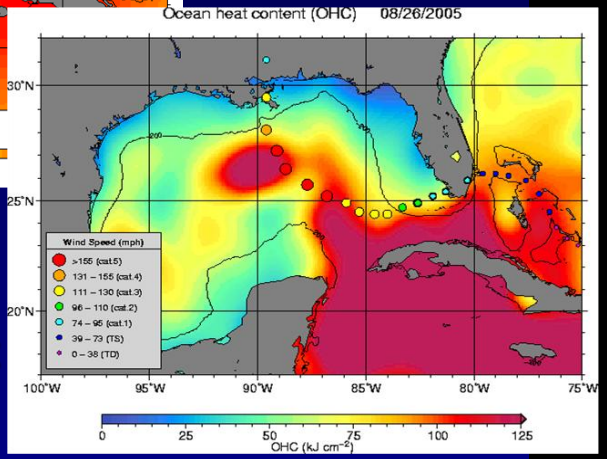




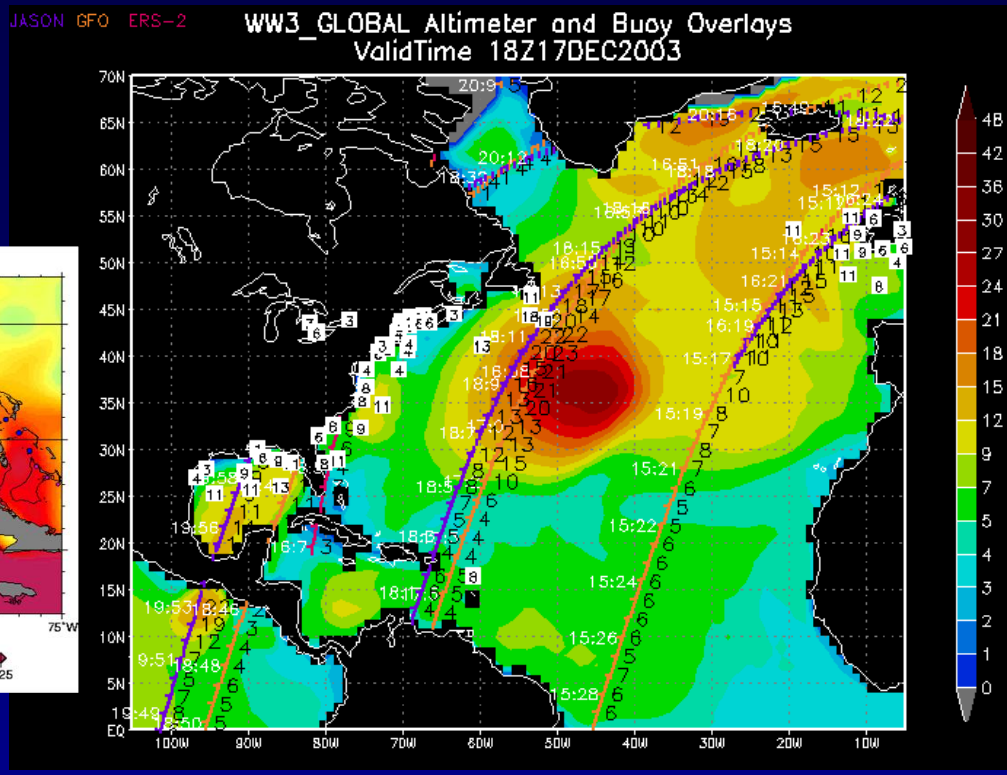
Ocean surface winds from passive microwave imagery for wind radii

Other useful satellite data

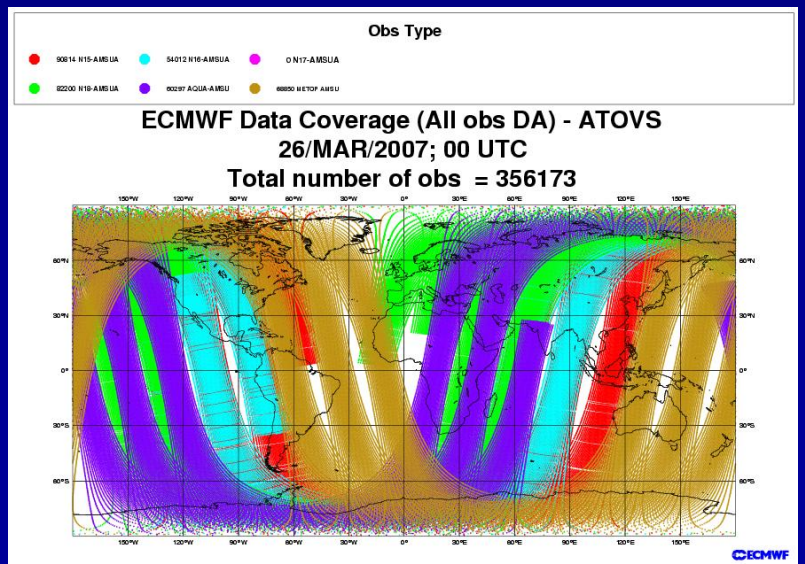




Sea surface temperatures and ocean heat content



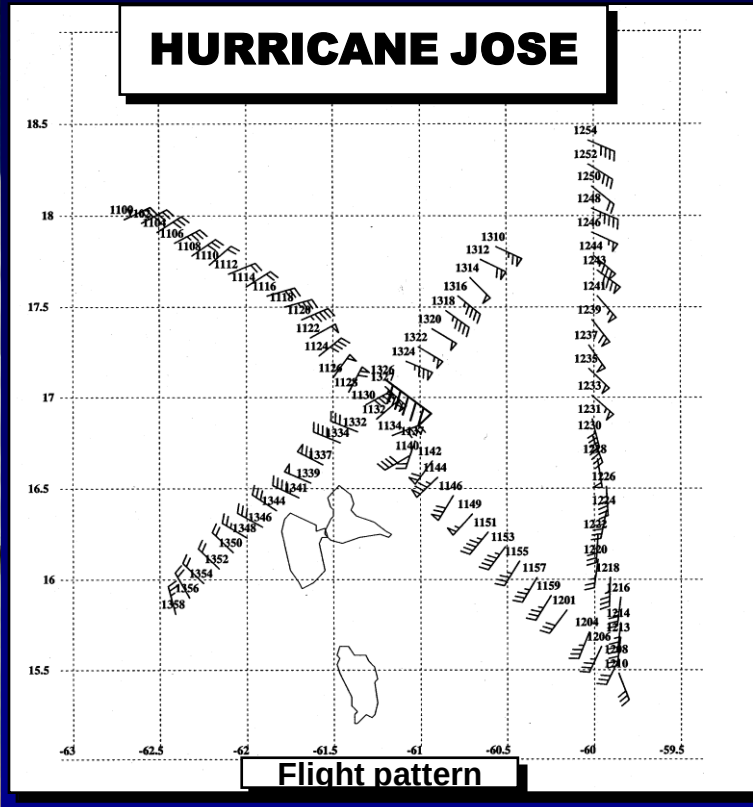
Radar altimeter- wave heights



Satellite temperature and moisture soundings for use in numerical models – not used directly at NHC but of vital importance in forecasting

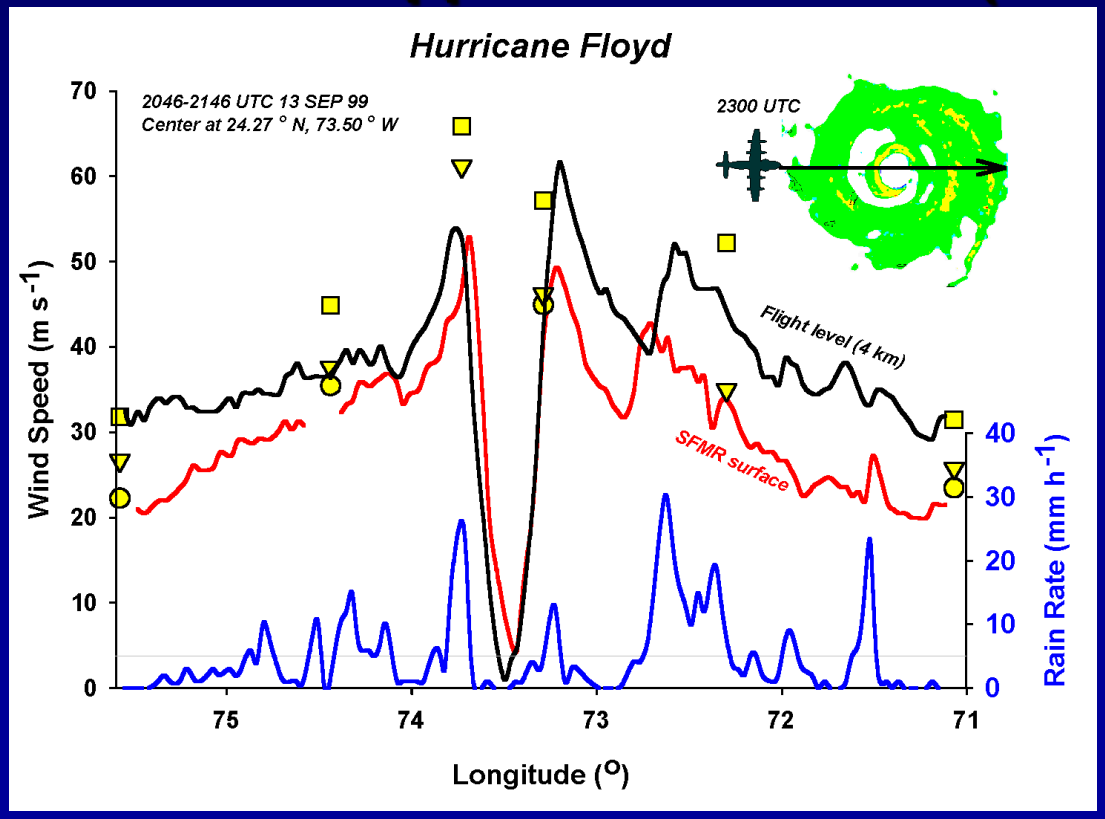
TPC Aircraft Resources

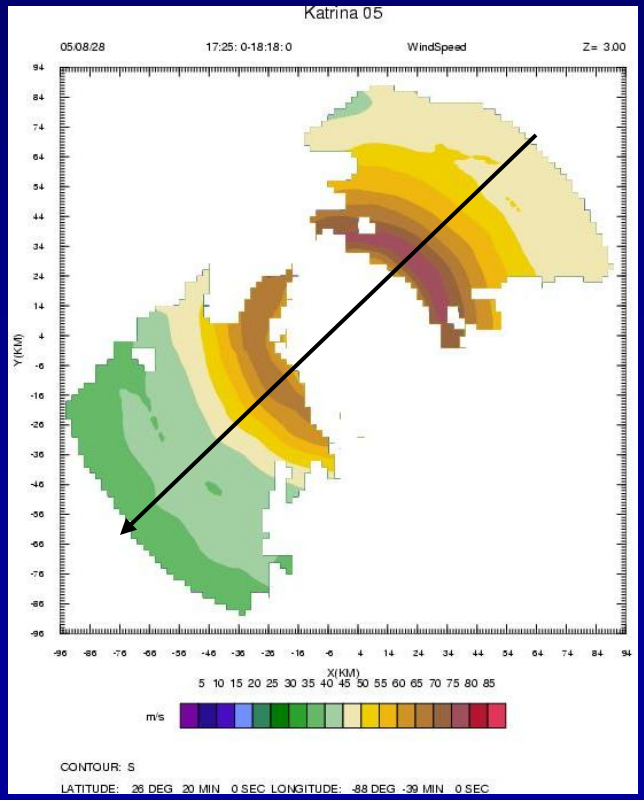
- Ten WC-130 USAFR aircraft, two NOAA P-3 research aircraft, and one NOAA G-4 jet (synoptic surveillance missions)
- Aircraft usually flown in cyclones west of 55ºW <u>that threaten land</u>
- Aircraft provide in situ data on center location, intensity, size, and structure

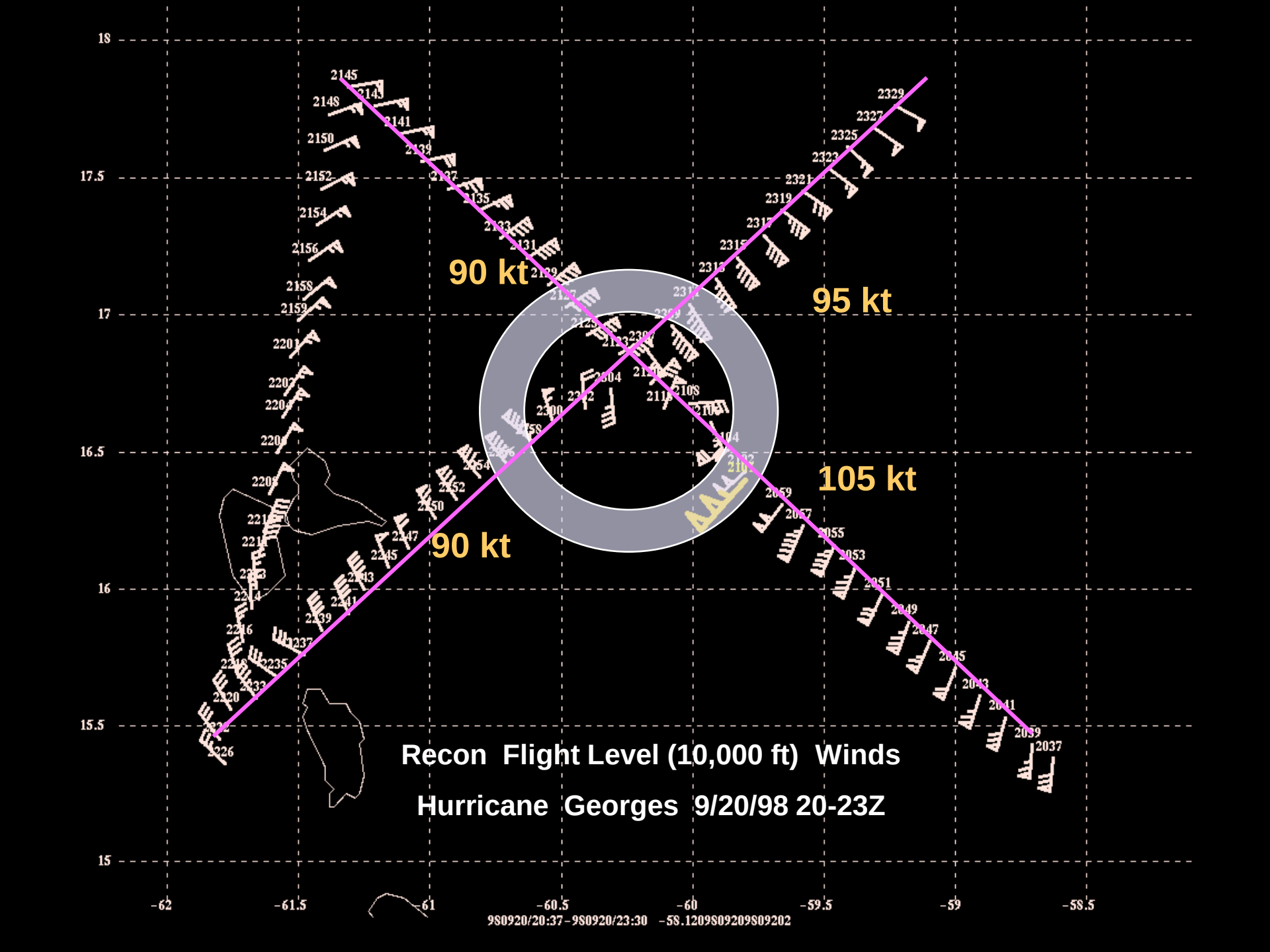


Primary Aircraft Data

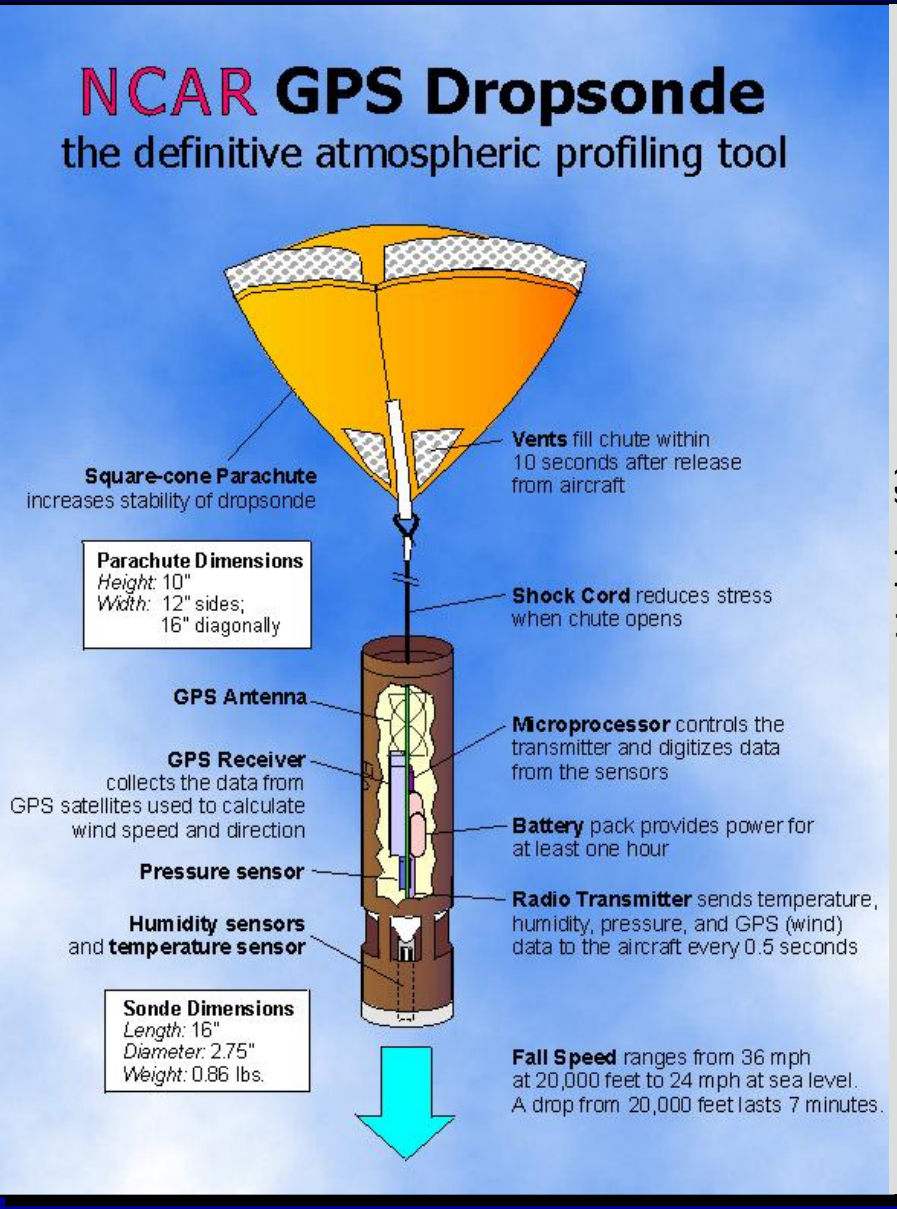
- Winds (along the aircraft track and dropsondes)
- Surface pressures (extrapolated and dropsonde)
- Surface winds from the Stepped Frequency Microwave Radiometer (<u>on all aircraft for 2008!)</u>
- Aircraft Doppler Radar winds (from the P-3's)

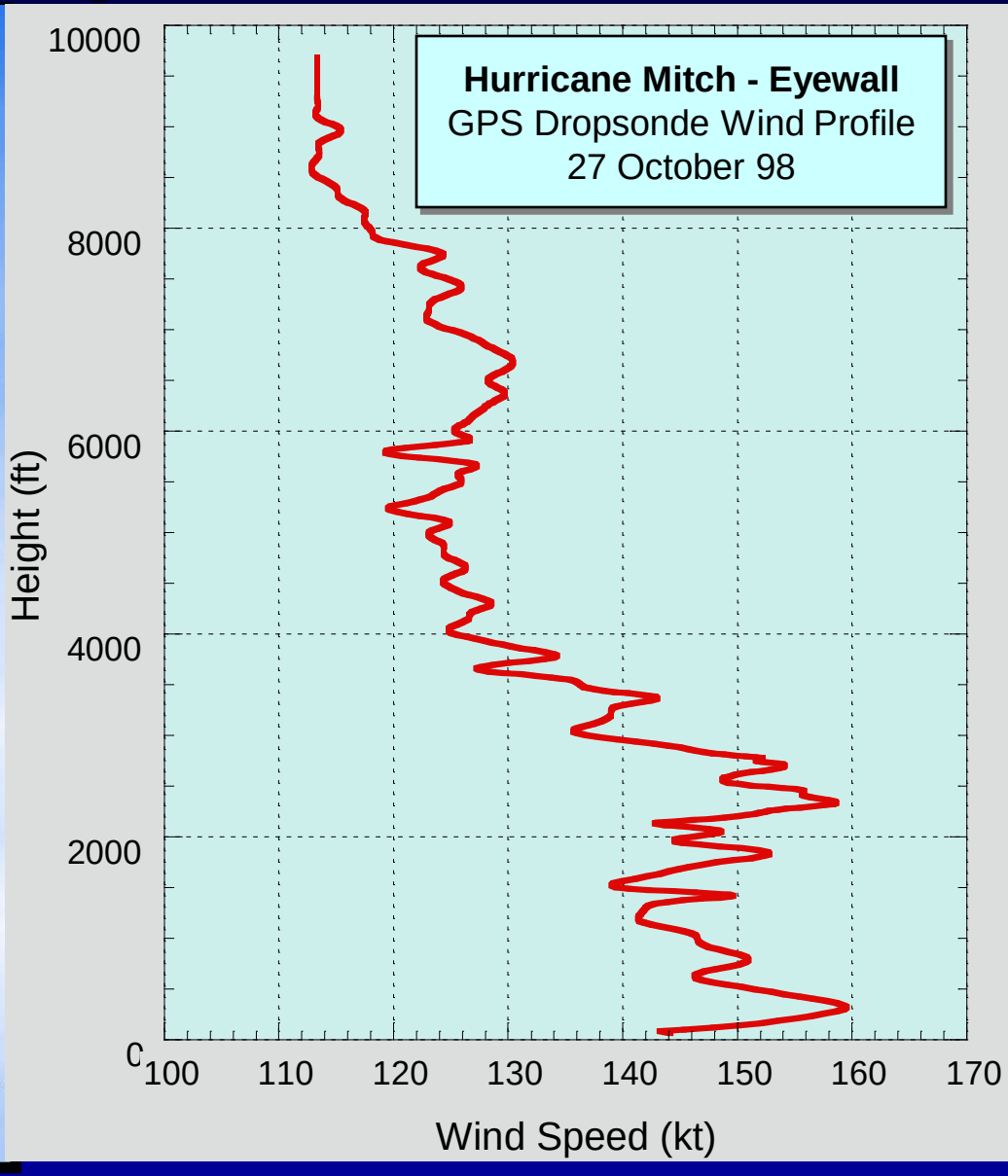




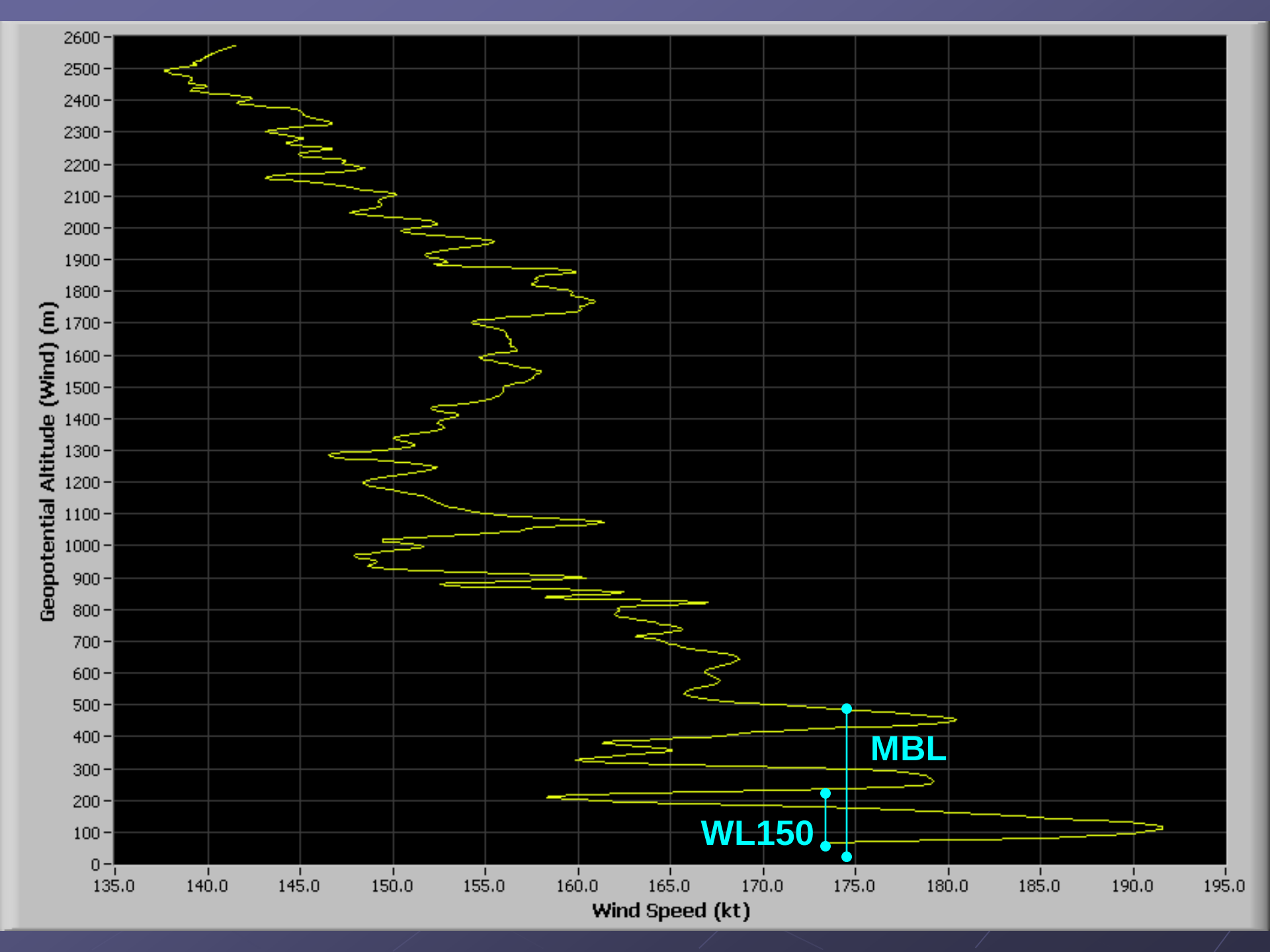

90 kt
95 kt
105 kt
90 kt
Recon Flight Level (10,000 ft) Winds
Hurricane Georges 9/20/98 20-23Z
18
17.5
17
16.5
16
15.5
15
-62
-61.5
-61
-60.5
-60
-59.5
-59
-58.5
9S0920/20:37-9S0920/23:30 -58.120980920980202

GPS Dropsondes



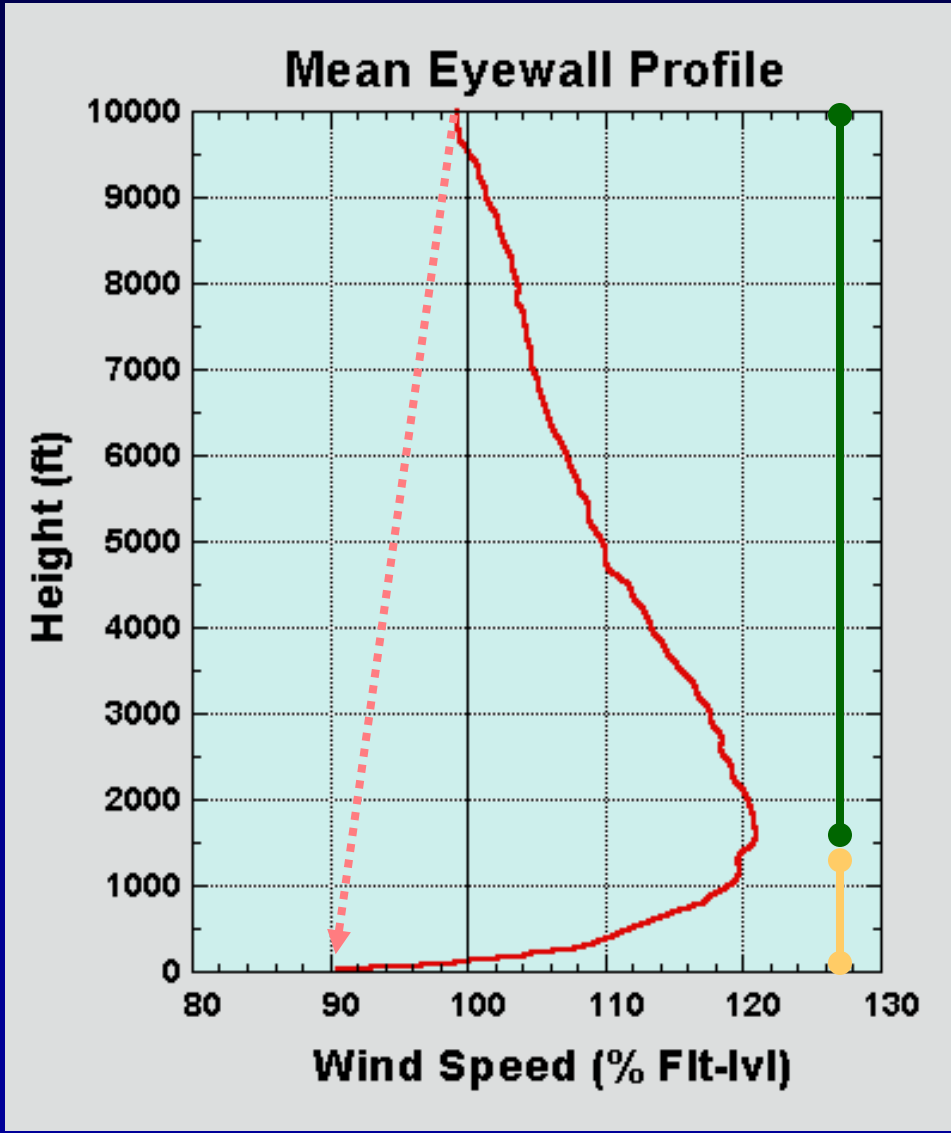


GPS sondes are used in the eyewall, elsewhere in the storm, and on G-IV missions


Geopotential Altitude (Wind) (m)
2600
2500
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
135.0
140.0
145.0
150.0
155.0
160.0
165.0
170.0
175.0
180.0
185.0
190.0
195.0
Wind Speed (kt)
MBL
WL150

Reducing Flight-Level Data to the Surface

Based on GPS Dropsonde Data

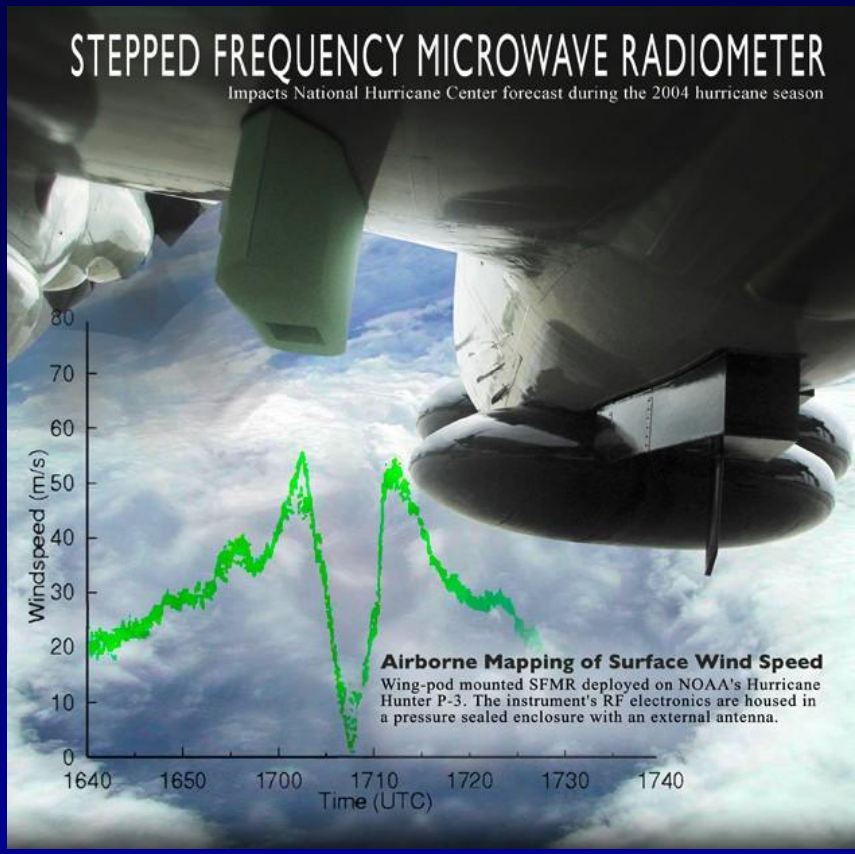


Winds increase downward from flight-level (10,000 ft) Because the hurricane is "warm-core".

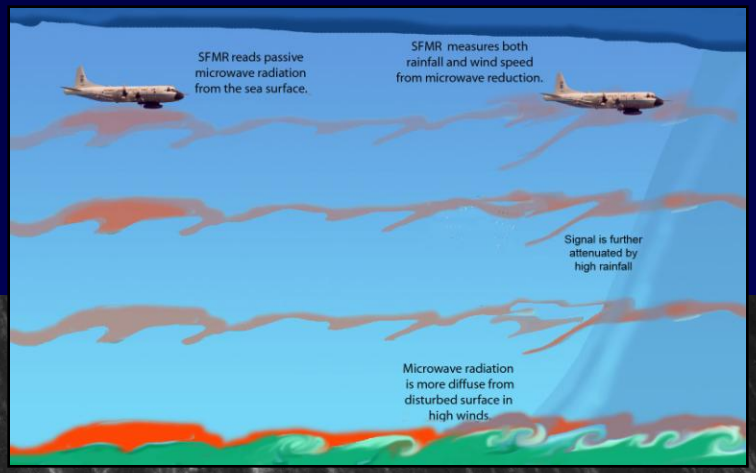
Friction decreases wind in the lowest 1500 ft of the eyewall.

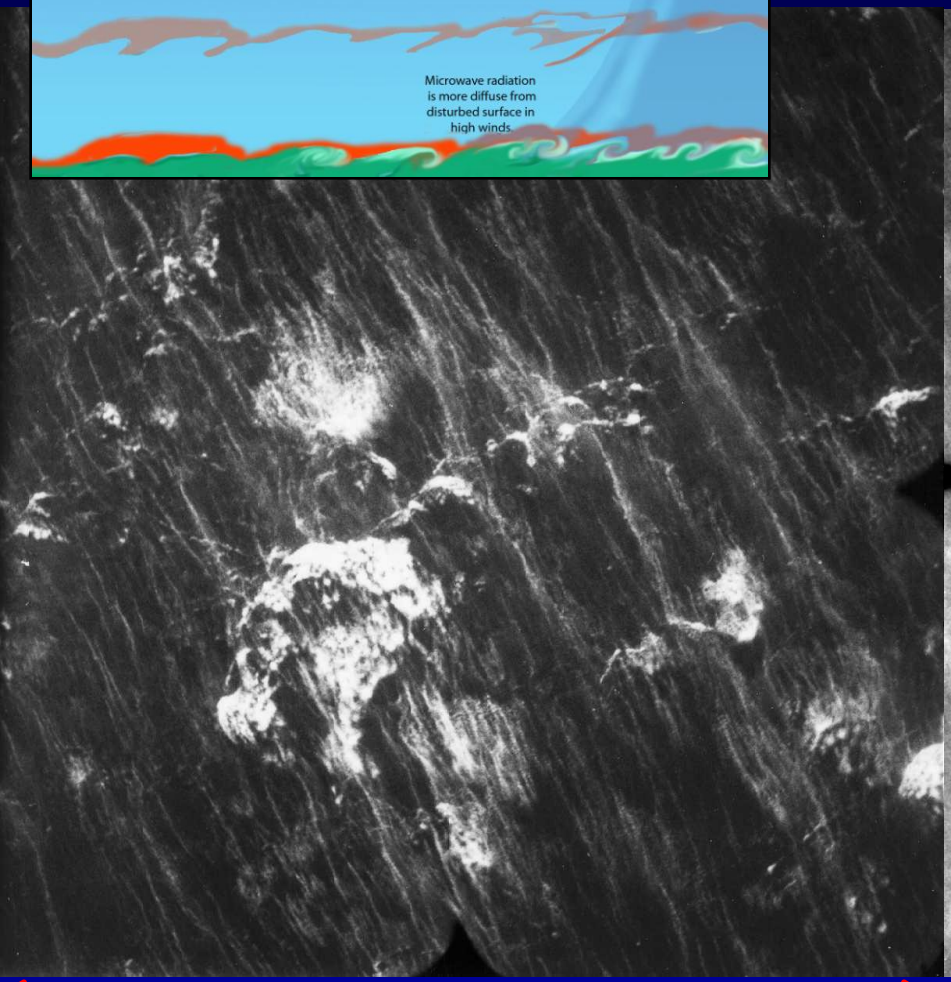
Stepped-Frequency Microwave Radiometer

- Relates microwave radiation from ocean to surface wind speed
- Can measure max surface winds in core of major hurricane
- Only provides data along line of flight
- First data from C-130s in 2007; on entire fleet in 2008

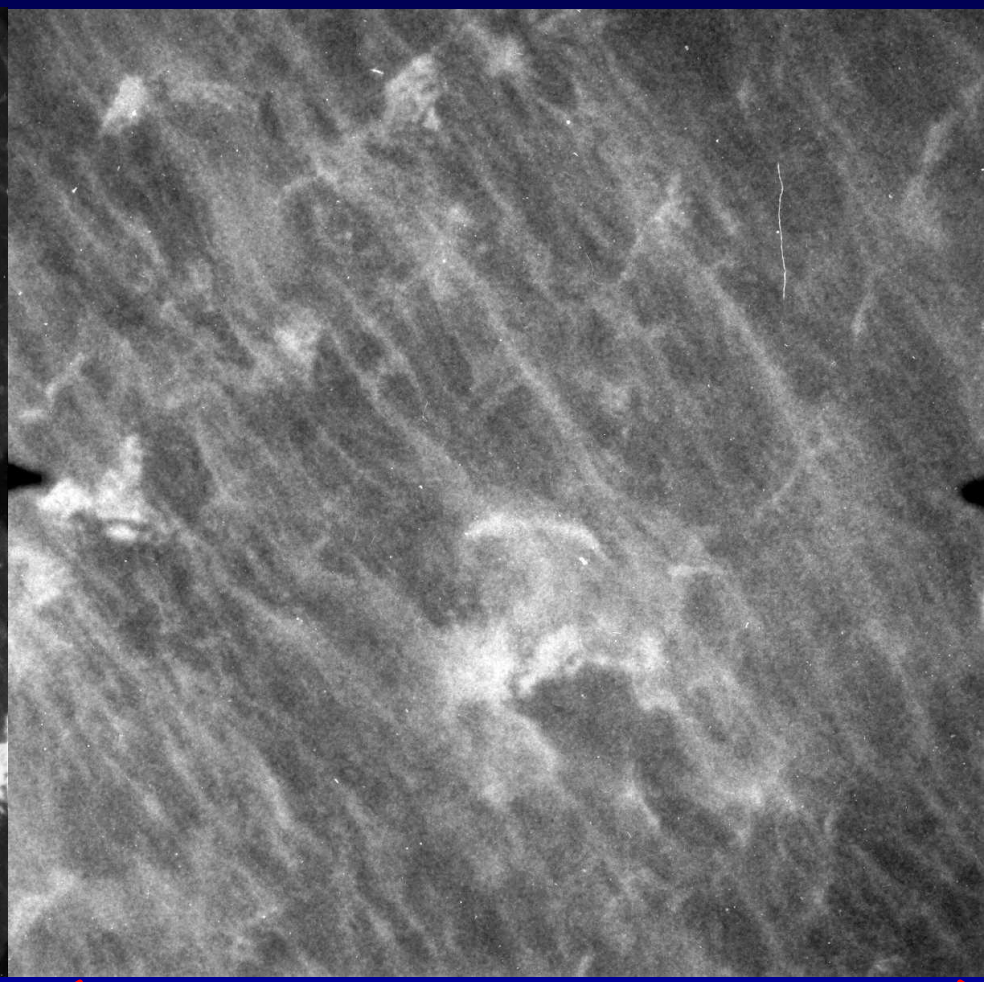


SFMR measure microwave radiation from ocean surface whitecaps and roam streaks

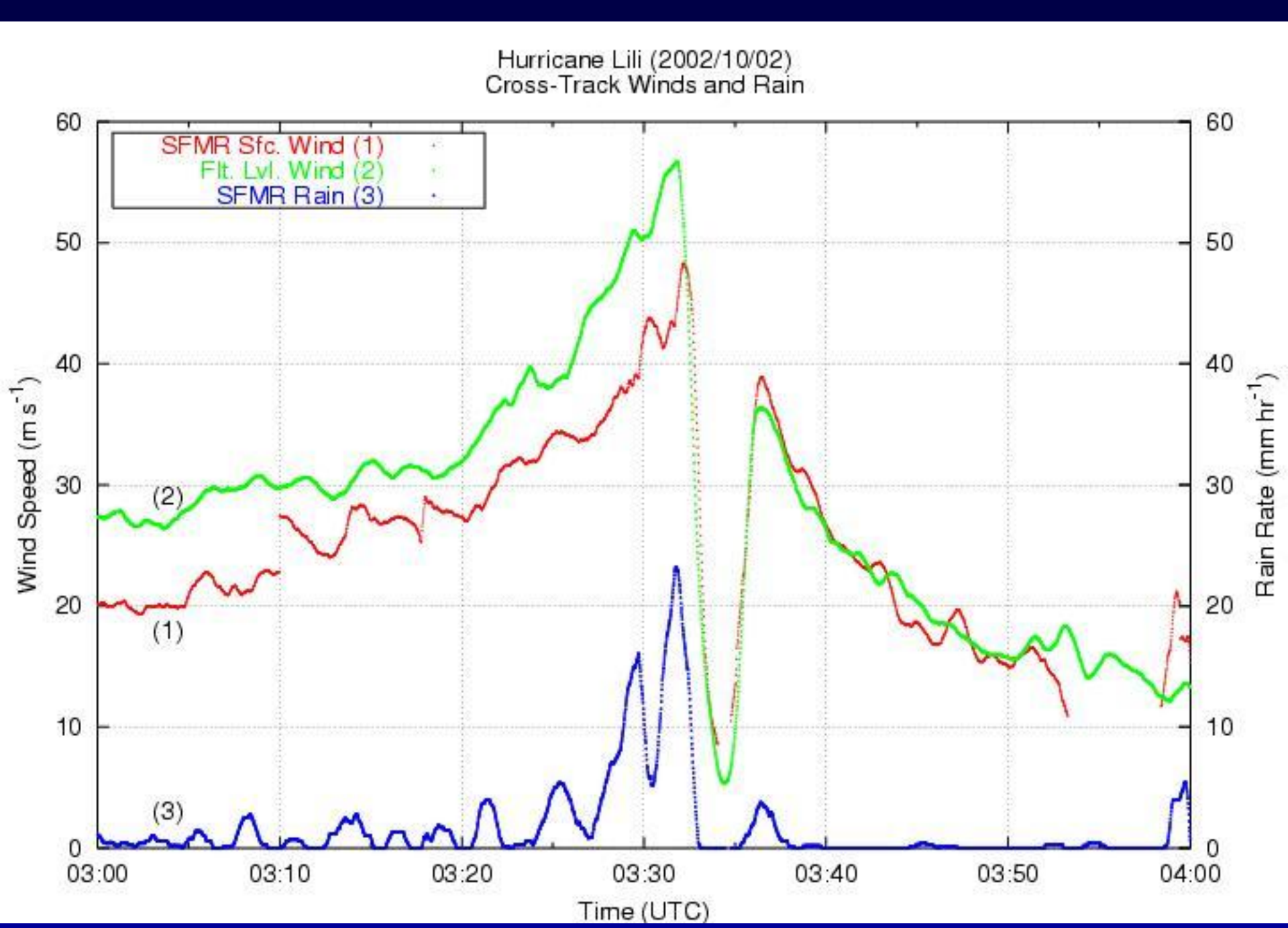




200 m
Wind speed ~ 60 mph



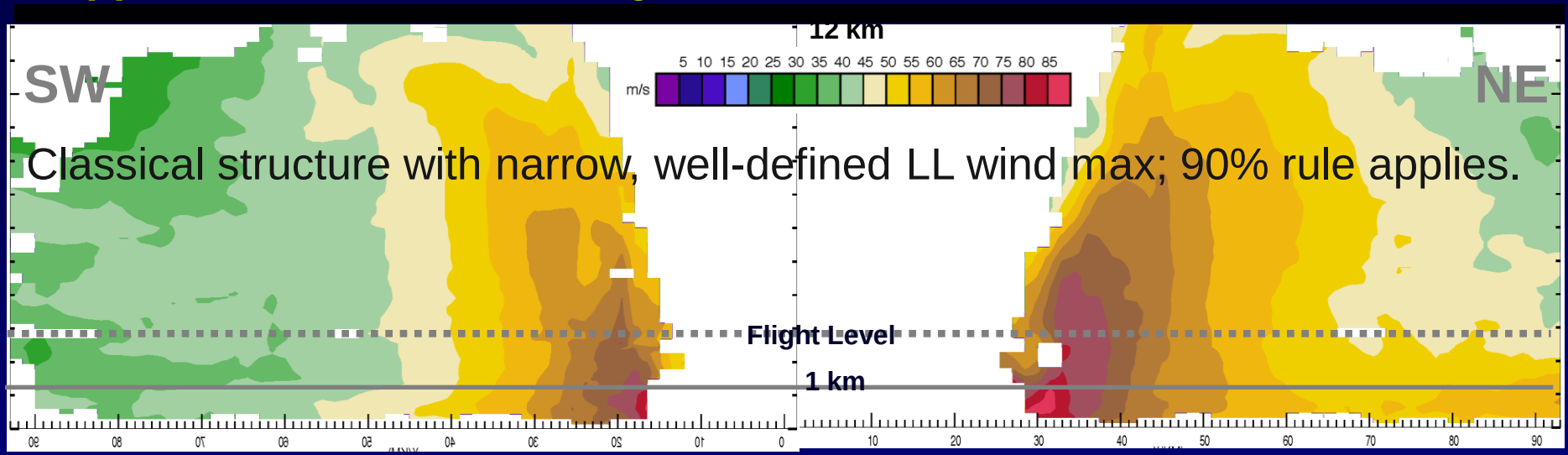
200 m
Wind Speed ~ 100 mph


Hurricane Lili (2002/10/02)
Cross-Track Winds and Rain
SFMR Sfc. Wind (1)
Flt. Lvl. Wind (2)
SFMR Rain (3)
(1)
(2)
(3)
Wind Speed (m s-1)
Rain Rate (mm hr-1)
Time (UTC)
0
10
20
30
40
50
60
03:00
03:10
03:20
03:30
03:40
03:50
04:00

SFMR issues

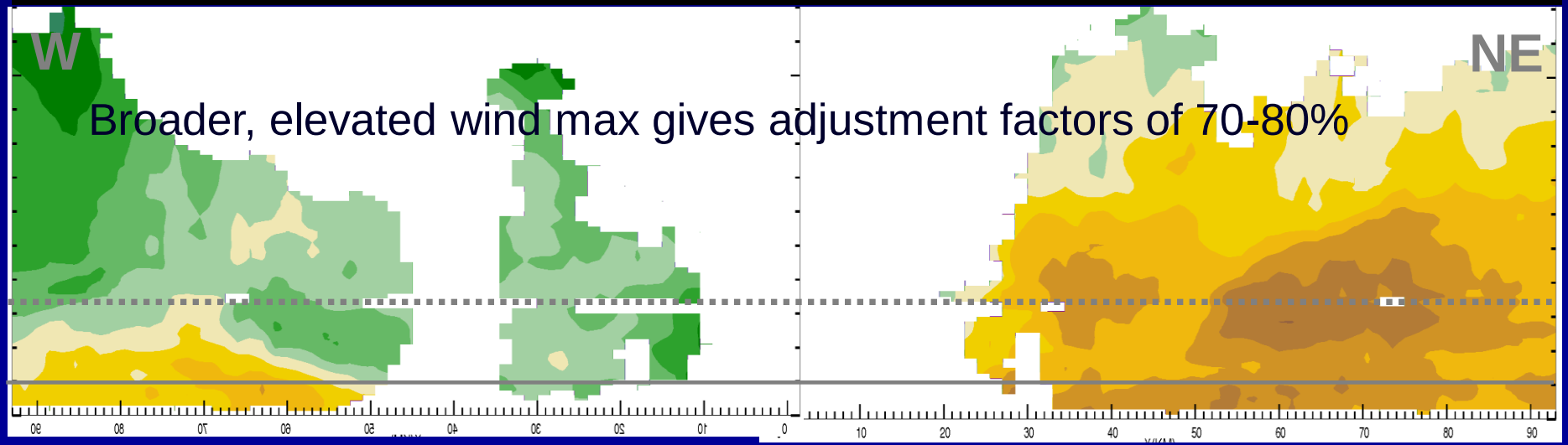
- Shoaling – breaking waves in areas of shallow water can artificially increase the SFMR retrieved wind speed
- Interaction of wind and wave field can introduce errors (~ 5 kt)
- Rain impacts not always properly accounted for (mainly < 50 kt)
- Calibration only recently completed. Algorithms still under development, and forecaster understanding of these issues is primitive.

Doppler Wind Profile - 28 Aug 1725-1820 UTC



Classical structure with narrow, well-defined LL wind max; 90% rule applies.

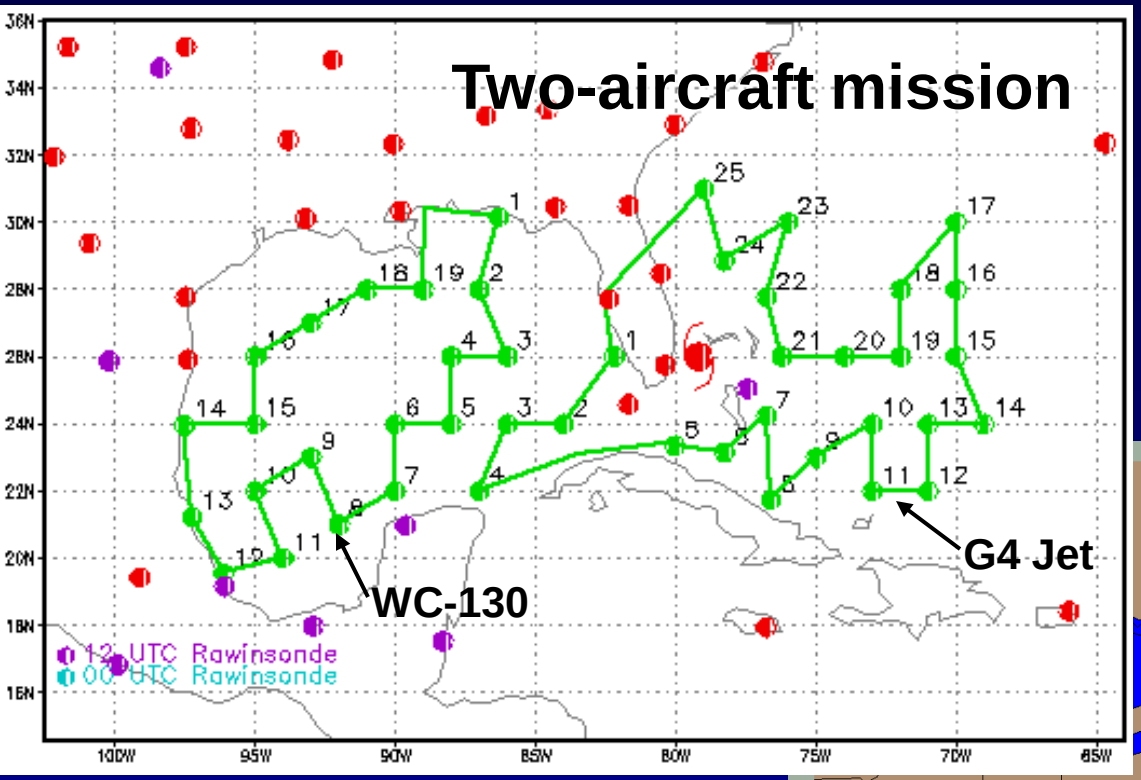
Doppler Wind Profile - 29 Aug 1000-1040 UTC

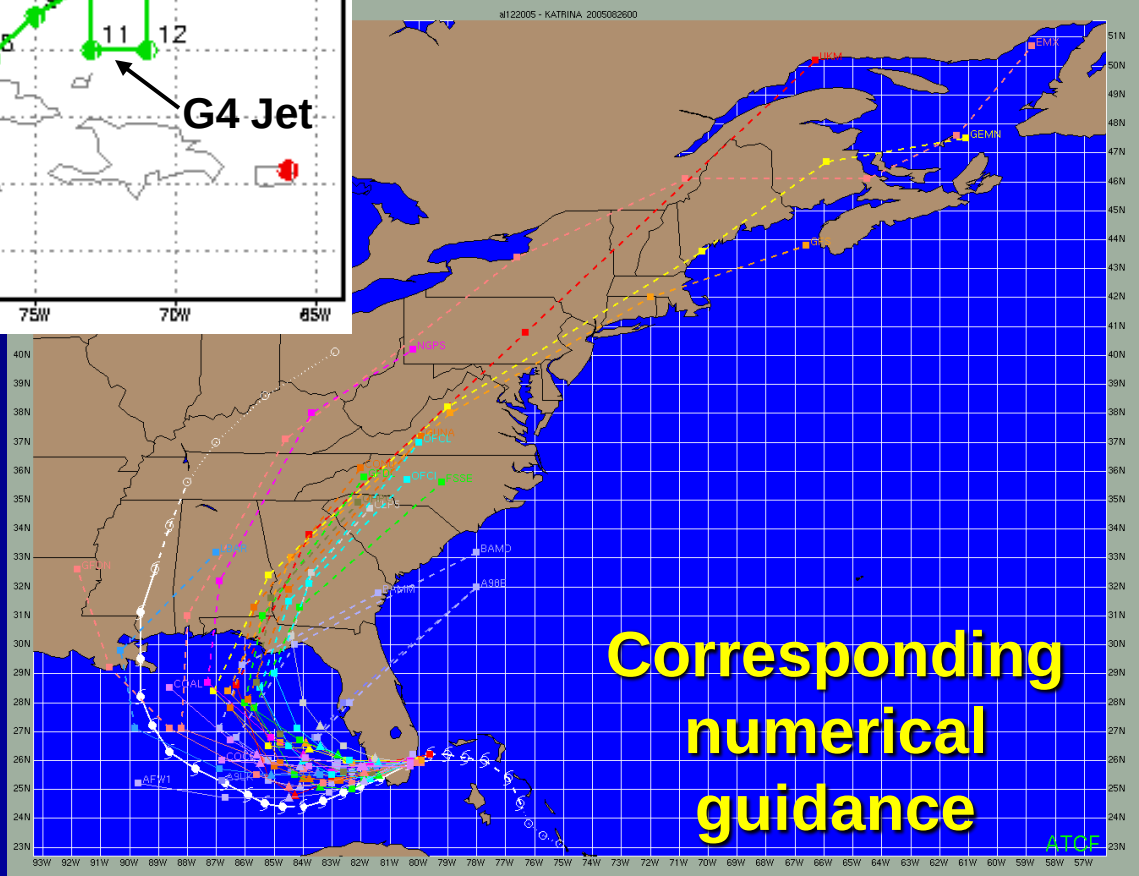


Broader, elevated wind max gives adjustment factors of 70-80%

Courtesy Pete Black, HRD

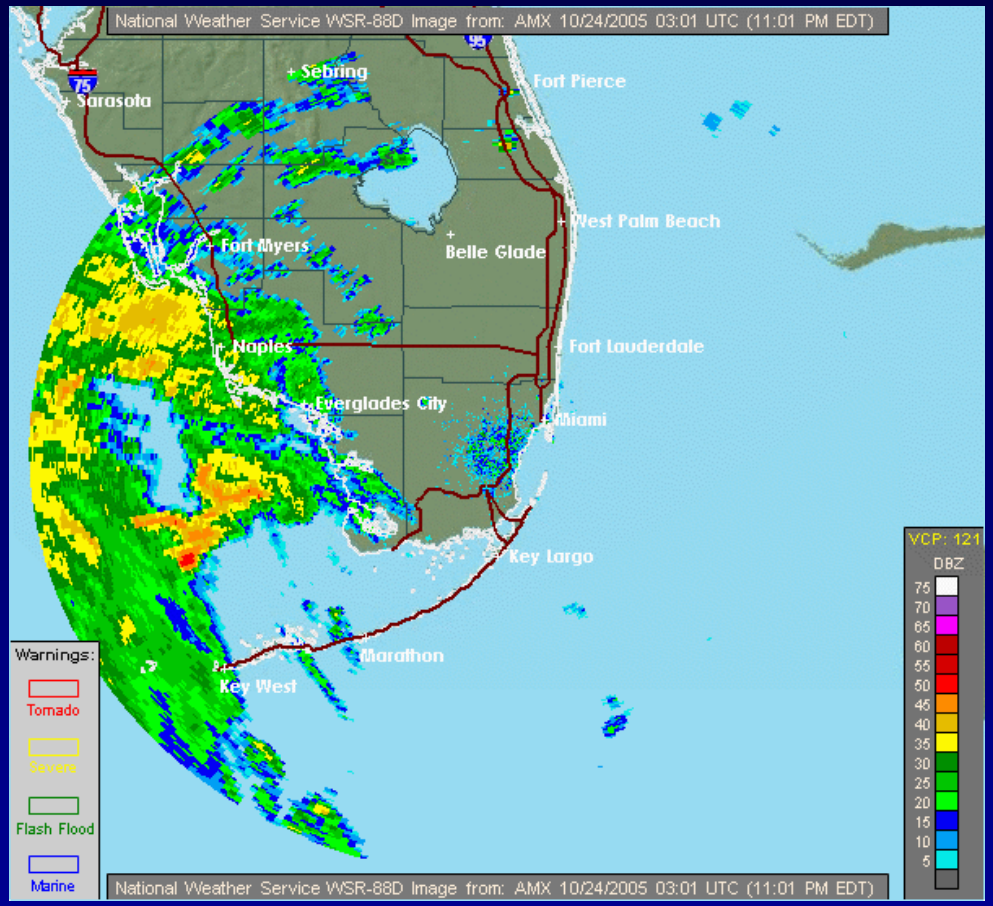
Katrina Synoptic Surveillance Missions

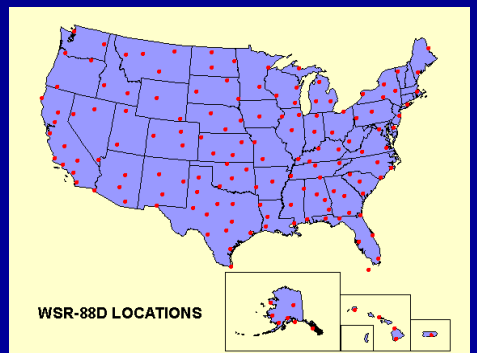




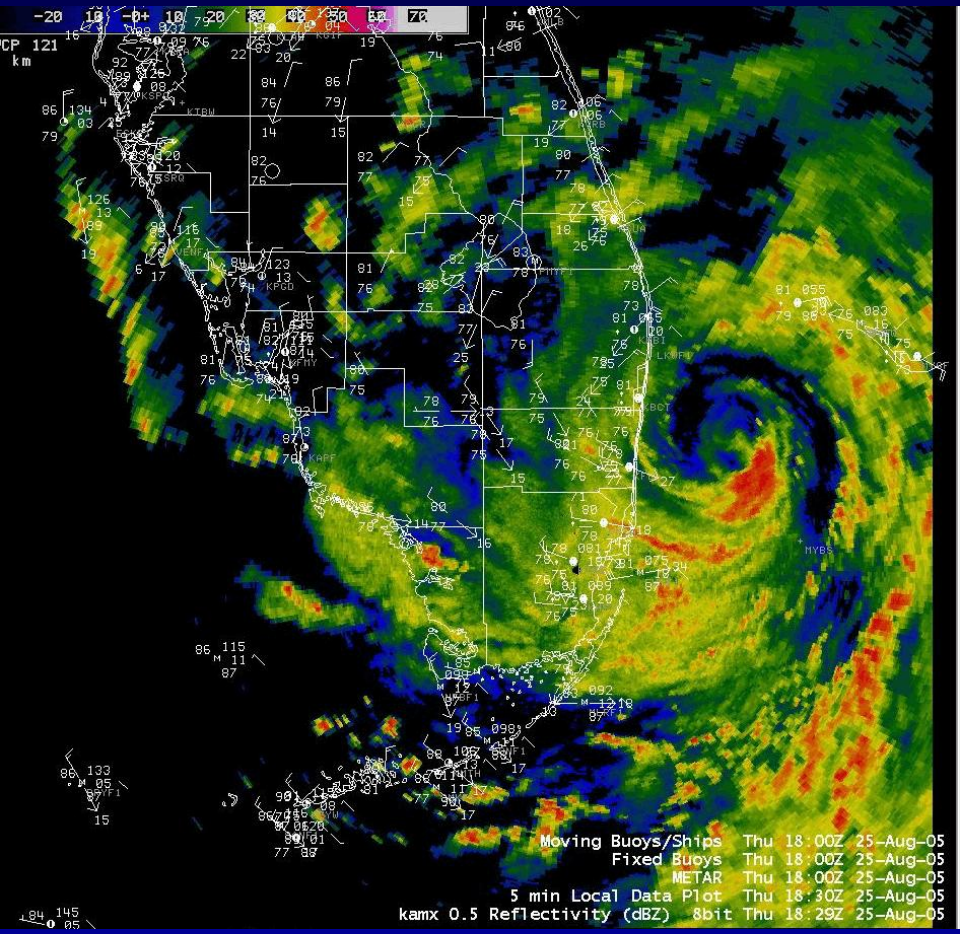
Radar Tracking of Hurricanes

- Land-based radar has a useful range of about 250 miles
- Radars report reflectivity (related to rainfall intensity), with doppler radars measuring winds blowing toward or away from the radar
- U. S. radars report data every 5-6 minutes, with less frequent data available from international radars

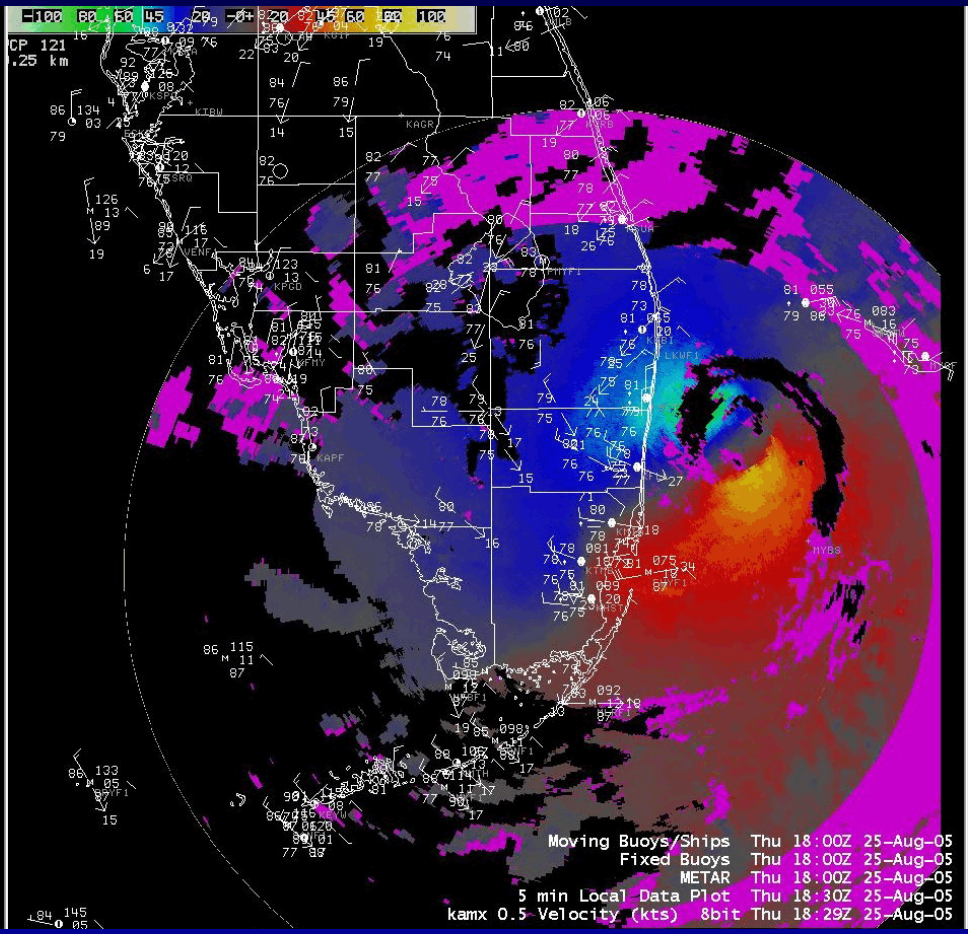




WSR-88D Animation of Katrina In Florida



Reflectivity

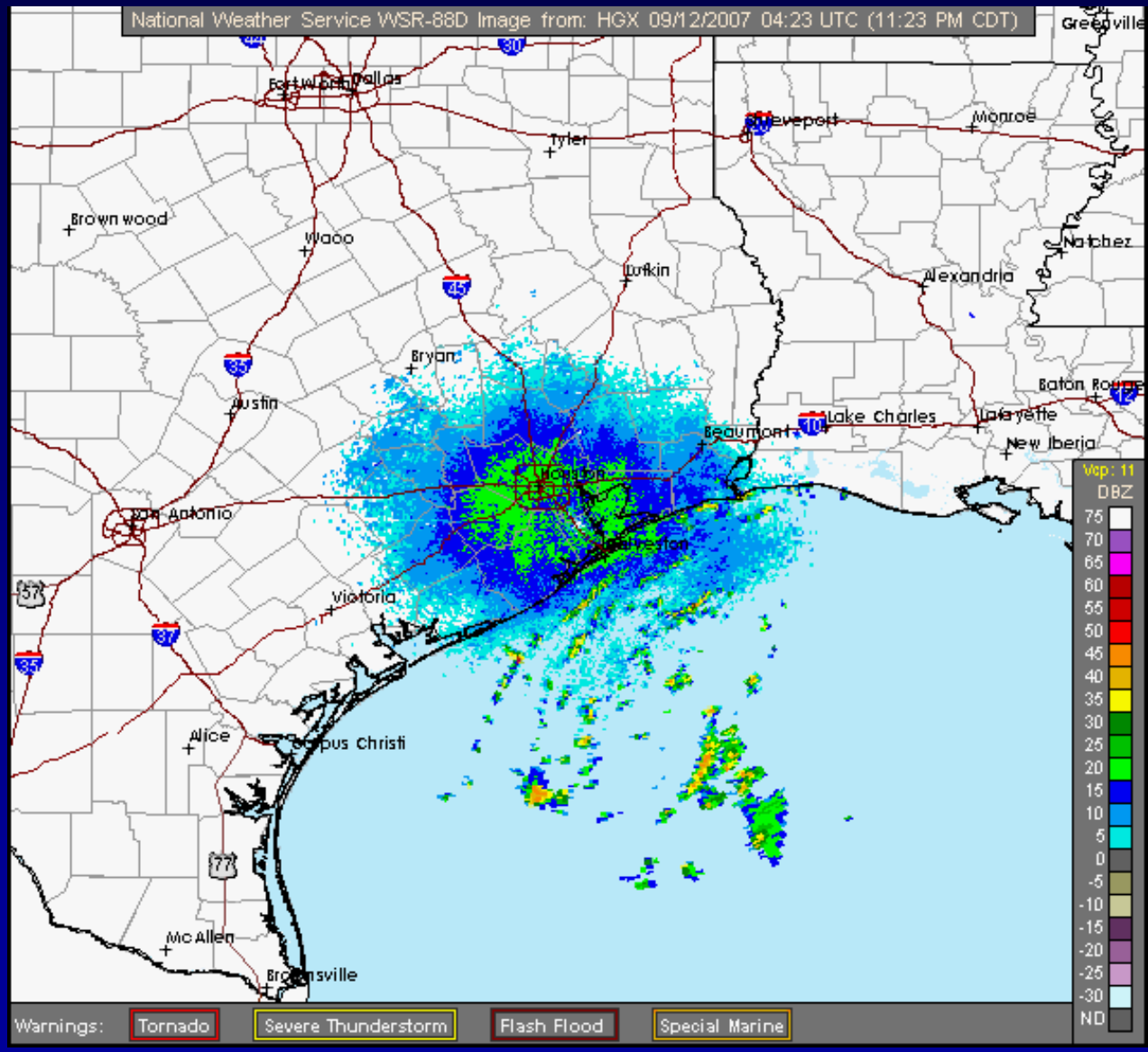


Velocity

Radar data is used for center location and structure analysis. Doppler winds provide information on intensity and size. U. S. radars also provide rainfall data.

Doppler Radar Data

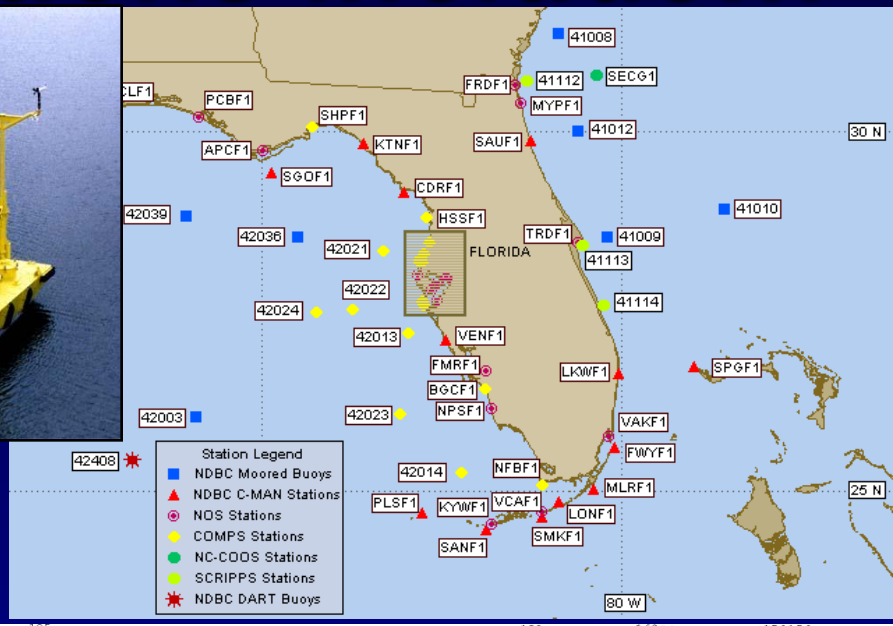
- Advantages
  - High density, high quality data
  - Available every 5-6 minutes
- Disadvantages
  - Limited use in forecasts since only available for TCs very close to land
  - Data are *not* measured at the surface
  - Data can occasionally be missing due to range obscuration



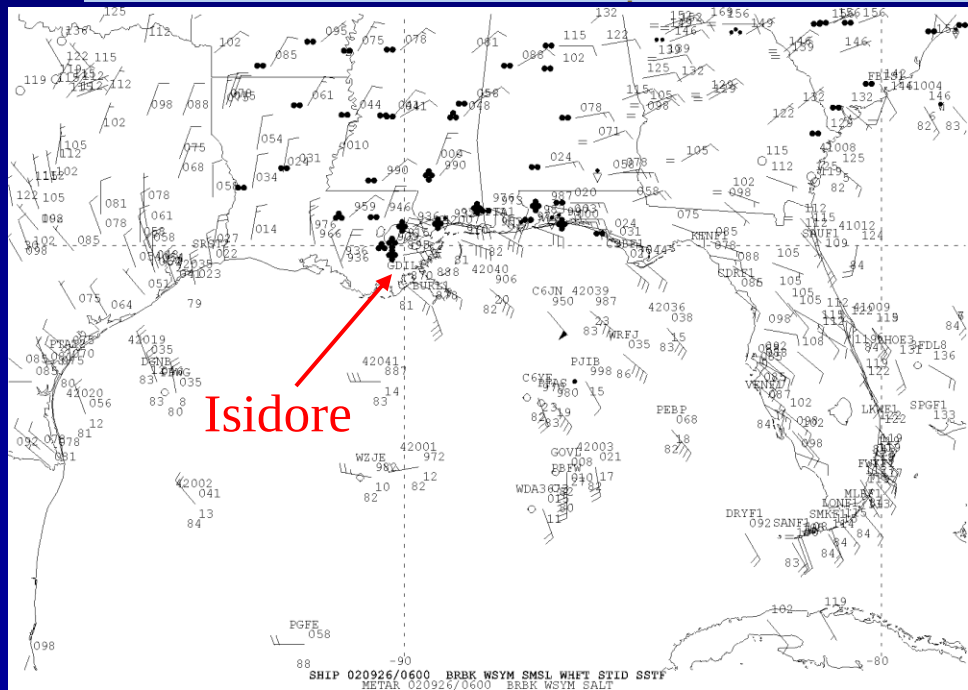
Lifecycle of Humberto (2007)

Surface Observations include…

- Ships
- Buoys and coastal automated stations
- Land stations, including ‘mesonets’

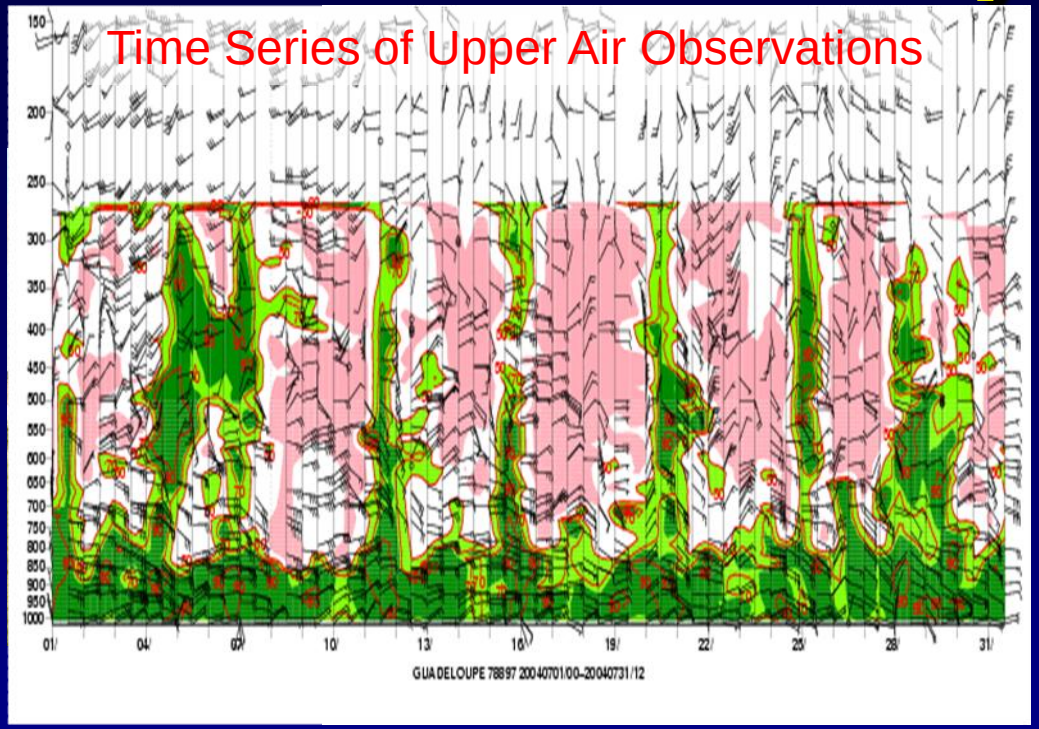


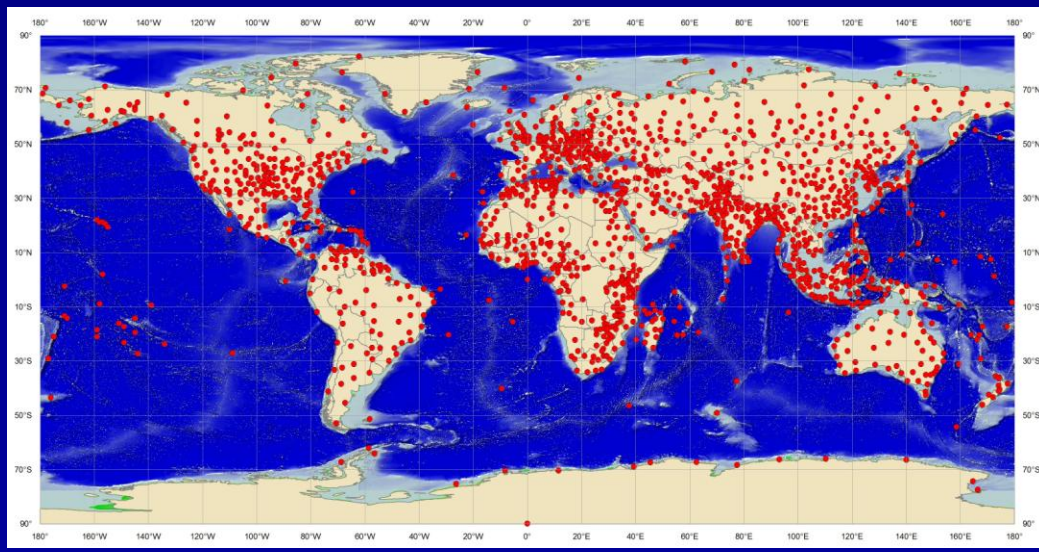
Surface stations provide wind, pressure, temperature, humidity, wave height, and sea surface temperature data. They are important not only for real-time analysis and forecasts, but for post-analysis as well.



Rawinsondes (Weather Balloons)

- Measure temperature, pressure, humidity, and wind from the surface up to 20 miles or more
- Normally launched twice per day, with some U. S. stations doing four launches per day during hurricanes
- Used to analyze the vertical structure of the atmosphere for the numerical models
- Global data is vital in the NHC forecast process





Summary

- Analyses of cyclone location, cyclone intensity, cyclone size, the near-storm atmosphere, the atmosphere away from the storm, sea surface temperatures, oceanic heat content, and wave heights are the foundation for the NHC forecasts
- If we don’t know where it is, how strong it is, and how big it is, we can’t forecast it!

Questions?