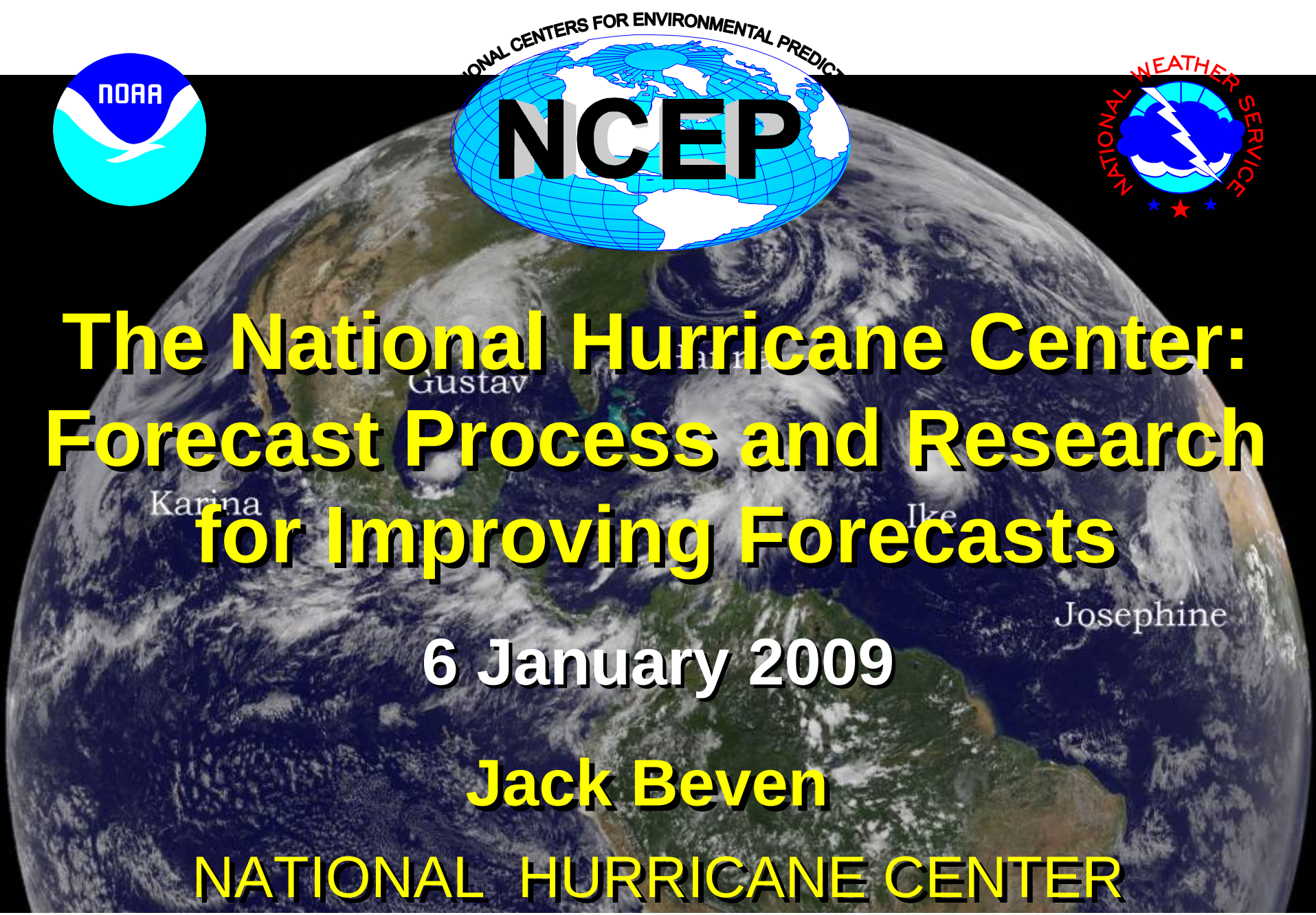


The National Hurricane Center: Forecast Process and Research for Improving Forecasts

6 January 2009

Jack Beven

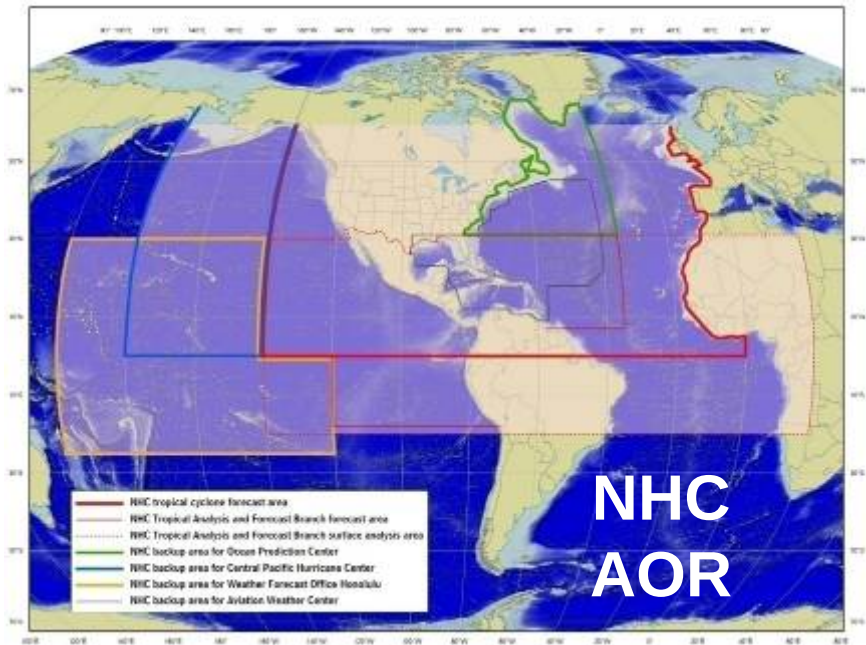
NATIONAL HURRICANE CENTER

WHERE AMERICA'S CLIMATE AND WEATHER SERVICES BEGIN

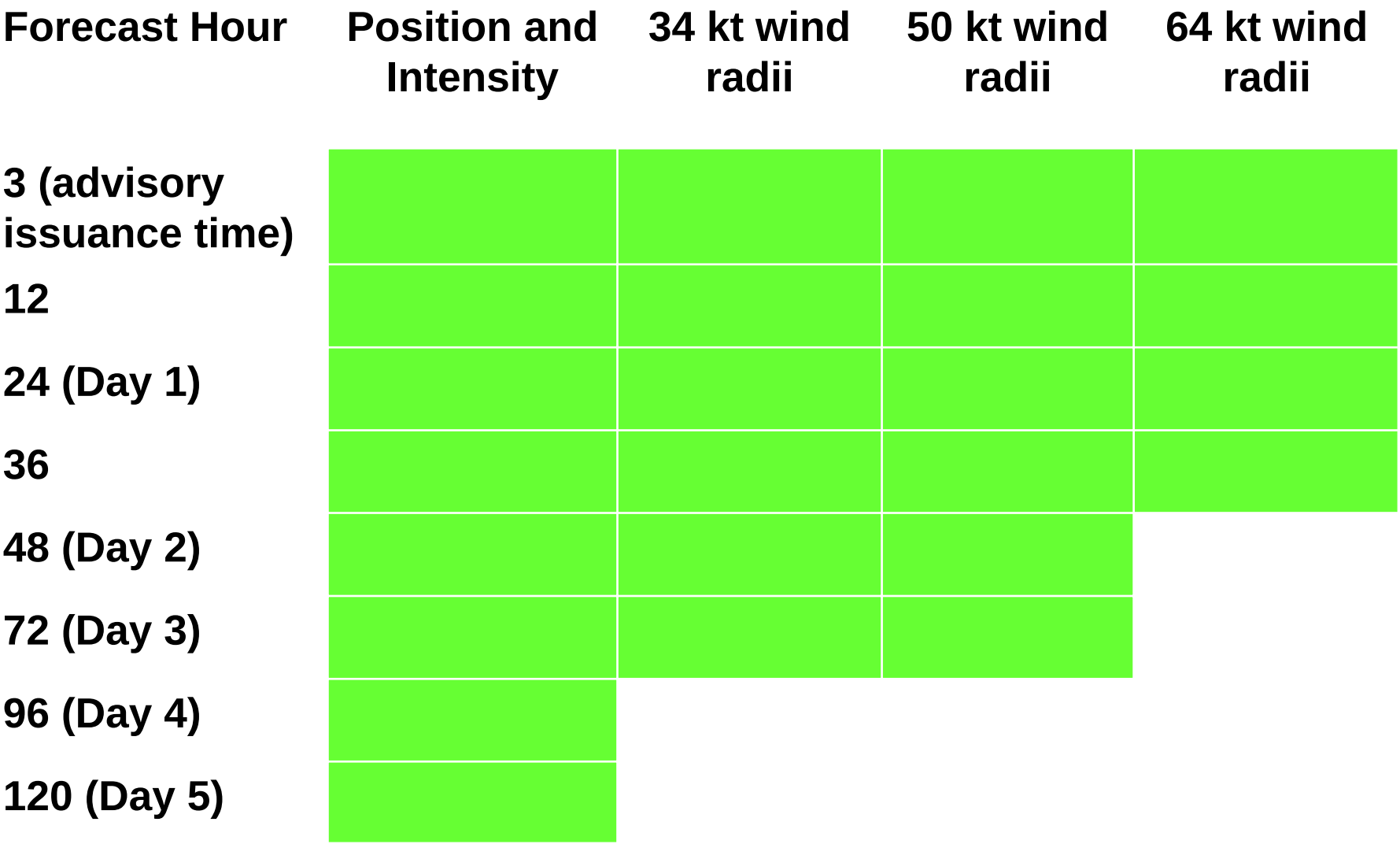
The National Hurricane Center

- WMO – RSMC (RA-IV)
- NCEP Remote Center (NWS)
- Co-located with NWS Miami WFO

- Located on FIU Campus
- Cat 5 rated structure *(designed by Herb Saffir)*
- Easy media access



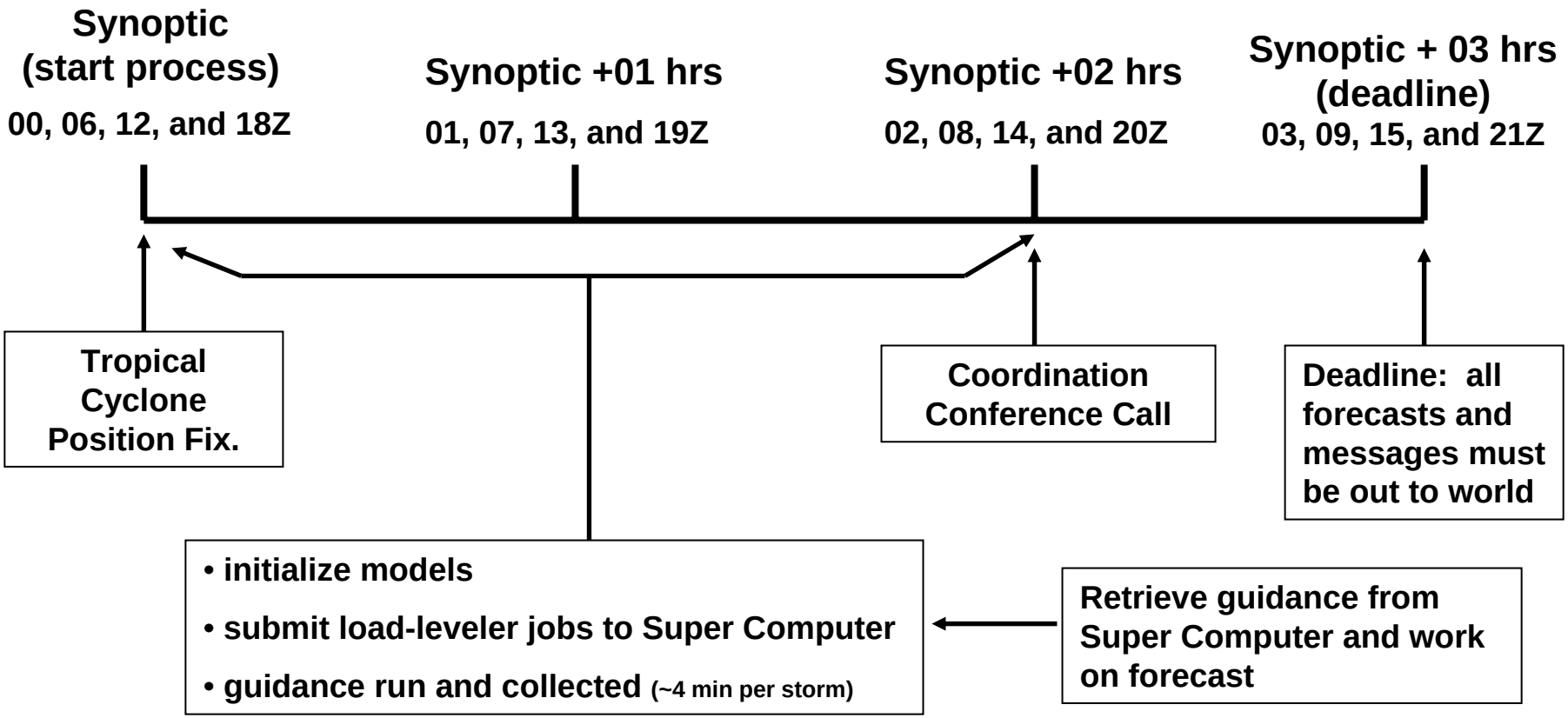
NHC Tropical Cyclone Forecast Parameters



Tropical Cyclone Forecast Timeline

Operational Forecast Centers: NHC and CPHC

Backup Forecast Center: HPC



Additional – During Hurricane watch and warning phase, intermediate forecasts are sent out every 3 or 2 hours continuously.

Advisories Products (routine and specials)

For Tropical and Sub-tropical Cyclones

BULLETIN:
HURRICANE HUMBERTO SPECIAL ADVISORY NUMBER 4
NWS TPC/NATIONAL HURRICANE CENTER MIAMI FL AL092007
1215 AM CDT THU 13 SEP 2007

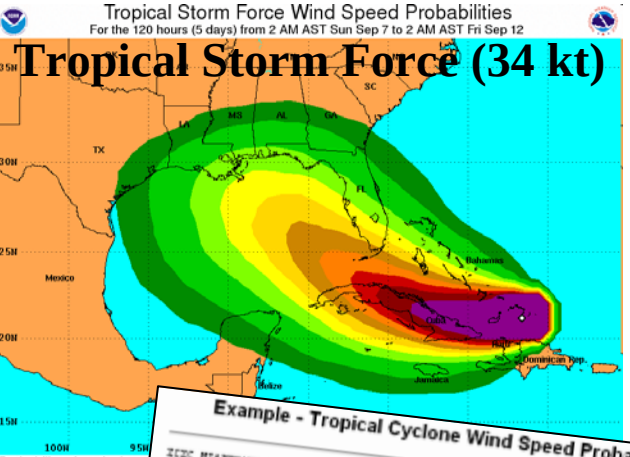
... HUMBERTO BECOMES A HURRICANE JUST BEFORE LANDFALL ...
... HURRICANE FORCE WINDS COVER SMALL AREA NORTHEAST OF CENTER ...

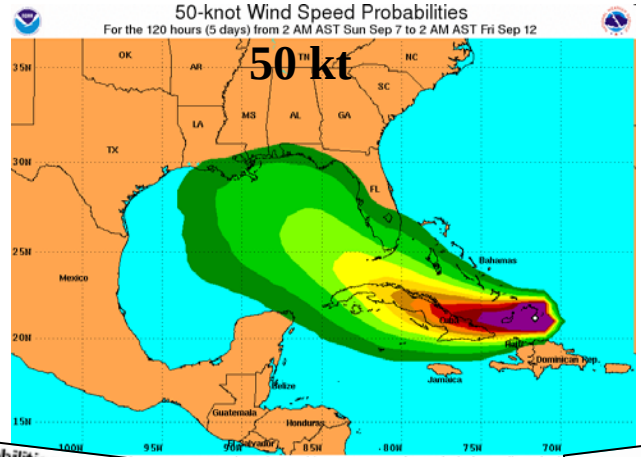
AT 1215 AM CDT ... 0515Z ... A HURRICANE WARNING HAS BEEN ISSUED FROM EAST OF HIGH ISLAND TEXAS TO CAMERON LOUISIANA. THE HURRICANE WARNING FOR HUMBERTO MEANS THAT HURRICANE CONDITIONS ARE EXPECTED WITHIN THE WARNING AREA WITHIN THE NEXT FEW HOURS.

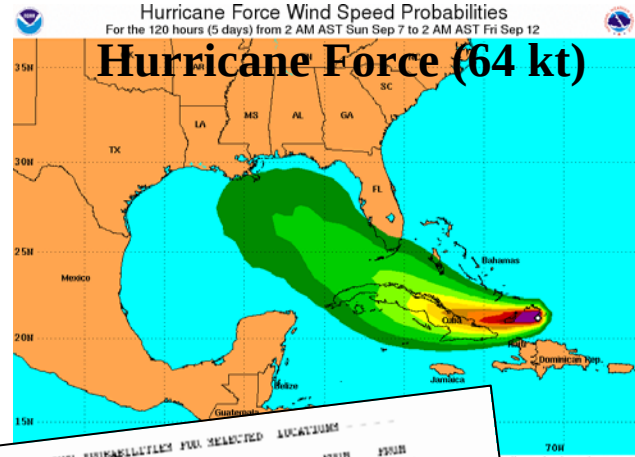
A TROPICAL STORM WARNING REMAINS IN EFFECT FROM EAST OF SARGENT TEXAS TO HIGH ISLAND TEXAS ... AND FROM EAST OF CAMERON LOUISIANA TO INTRACOASTAL CITY LOUISIANA.

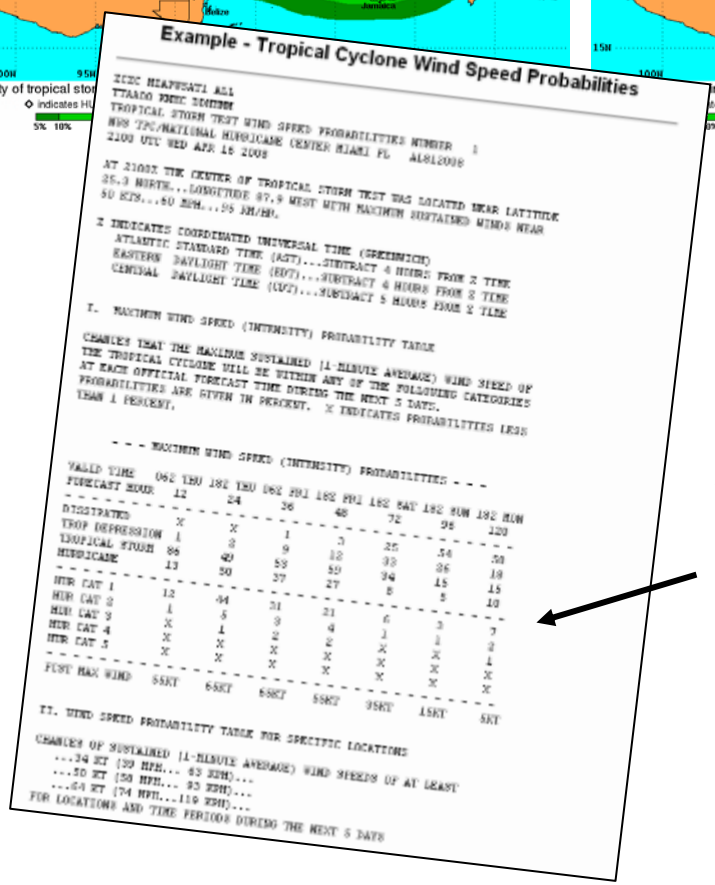
- **Forecast/Advisories**
- **Public Advisories**
- **Discussion - forecaster**
- **ICAO Aviation Warning**
- **Wind probabilities**
- **TC Update**
- **TC Position estimate**

Wind Speed Probability Products









Example - Tropical Cyclone Wind Speed Probabilities

ZCZC MIAPWSAT1 ALL
TTAA00 KNHC 201500
TROPICAL STORM TEST WIND SPEED PROBABILITIES NUMBER 1
NWS TPC/NATIONAL HURRICANE CENTER MIAMI FL AL012008
2100 UTC WED APR 16 2008

AT 21000Z THE CENTER OF TROPICAL STORM TEST WAS LOCATED NEAR LATITUDE
25.3 NORTH...LONGITUDE 87.9 WEST WITH MAXIMUM SUSTAINED WINDS NEAR
50 KTS...60 MPH...95 KM/HR.

Z INDICATES COORDINATED UNIVERSAL TIME (GREENWICH)
ATLANTIC STANDARD TIME (AST)...SUBTRACT 4 HOURS FROM Z TIME
EASTERN DAYLIGHT TIME (EDT)...SUBTRACT 4 HOURS FROM Z TIME
CENTRAL DAYLIGHT TIME (CDT)...SUBTRACT 5 HOURS FROM Z TIME

I. MAXIMUM WIND SPEED (INTENSITY) PROBABILITY TABLE

CHANCES THAT THE MAXIMUM SUSTAINED (1-MINUTE AVERAGE) WIND SPEED OF
THE TROPICAL CYCLONE WILL BE WITHIN ANY OF THE FOLLOWING CATEGORIES
AT EACH OFFICIAL FORECAST TIME DURING THE NEXT 5 DAYS.
PROBABILITIES ARE GIVEN IN PERCENT. X INDICATES PROBABILITIES LESS
THAN 1 PERCENT.

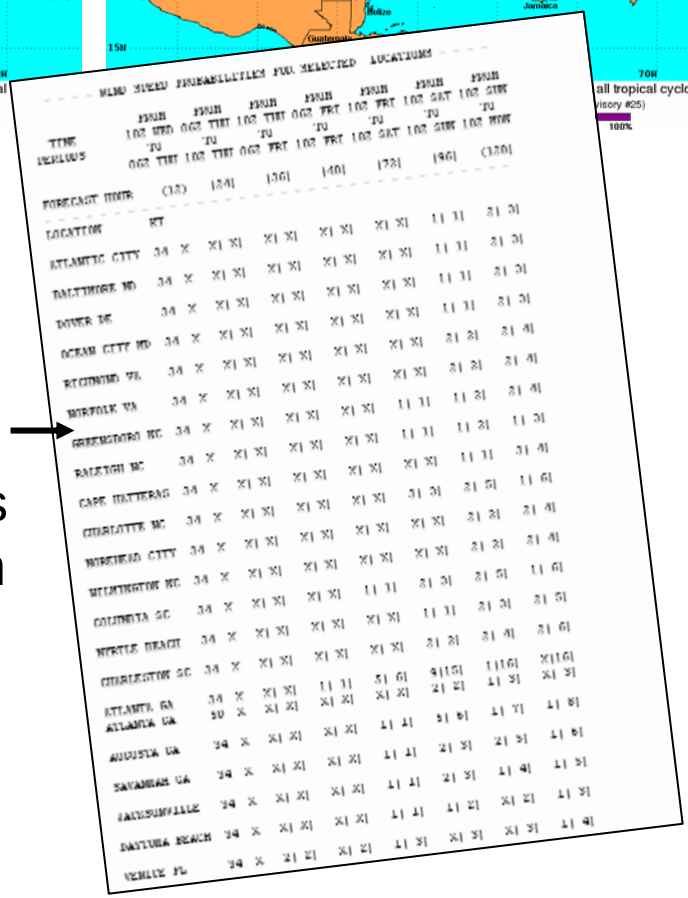
- - - MAXIMUM WIND SPEED (INTENSITY) PROBABILITIES - - -

VALID TIME	062 1200	182 1200	062 FRI	182 FRI	182 SAT	182 SUN	182 MON
FORECAST HOUR	12	24	36	48	72	96	120
DISSIPATED	X	X					
TROP DEPRESSION	1	2	1	3	25		
TROPICAL STORM	86	49	58	12	33	56	50
HURRICANE	13	50	37	59	34	36	18
				27	8	15	15
						5	10
HUR CAT 1	12	44	31	21			
HUR CAT 2	1	5	5	9	6	3	3
HUR CAT 3	X	1	2	4	1	1	2
HUR CAT 4	X	X	X	2	X	X	1
HUR CAT 5	X	X	X	X	X	X	X
				X	X	X	X
FCST MAX WIND	55KT	65KT	55KT	55KT	35KT	15KT	5KT

II. WIND SPEED PROBABILITY TABLE FOR SPECIFIC LOCATIONS

CHANCES OF SUSTAINED (1-MINUTE AVERAGE) WIND SPEEDS OF AT LEAST
...34 KT (39 MPH... 63 KMH)...
...50 KT (58 MPH... 93 KMH)...
...64 KT (74 MPH...119 KMH)...
FOR LOCATIONS AND TIME PERIODS DURING THE NEXT 5 DAYS

Text Product Includes Location Specific Wind Probabilities and the Maximum Wind Speed Probability Table

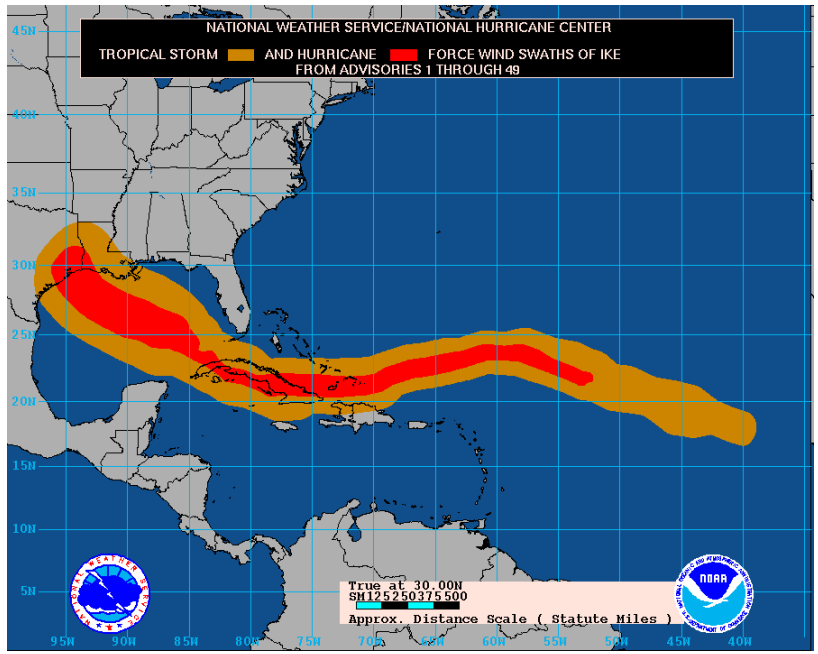


WIND SPEED PROBABILITIES FOR SELECTED LOCATIONS

TIME (HOURS)	FROM 1200 WED TO 0600 THU	FROM 0600 THU TO 1800 THU	FROM 1800 THU TO 0600 FRI	FROM 0600 FRI TO 1800 FRI	FROM 1800 FRI TO 0600 SAT	FROM 0600 SAT TO 1800 SAT	FROM 1800 SUN TO 1800 MON
FORECAST HOUR	(12)	(24)	(36)	(48)	(72)	(96)	(120)
LOCATION	KT						
ATLANTIC CITY	34	X	X	X	X	1	3
BALTIMORE MD	34	X	X	X	X	1	3
DOVER DE	34	X	X	X	X	1	3
OCEAN CITY MD	34	X	X	X	X	3	4
RICHMOND VA	34	X	X	X	X	3	4
NORFOLK VA	34	X	X	X	X	1	3
GREENSBORO NC	34	X	X	X	1	1	3
RALEIGH NC	34	X	X	X	X	1	4
CAPE HATTERAS	34	X	X	X	X	3	6
CHARLOTTE NC	34	X	X	X	X	3	4
MOREHEAD CITY	34	X	X	X	X	3	4
WILMINGTON NC	34	X	X	X	1	3	6
COLUMBIA SC	34	X	X	X	1	3	5
MYRTLE BEACH	34	X	X	X	X	3	6
CHARLESTON SC	34	X	X	X	X	3	6
ATLANTA GA	34	X	X	1	1	6	16
ATLANTA GA	50	X	X	X	X	2	5
AUGUSTA GA	34	X	X	X	1	2	6
SAVANNAH GA	34	X	X	X	1	2	5
JACKSONVILLE	34	X	X	X	1	2	4
DAYTONA BEACH	34	X	X	X	1	1	3
VENICE FL	34	X	2	2	1	1	3

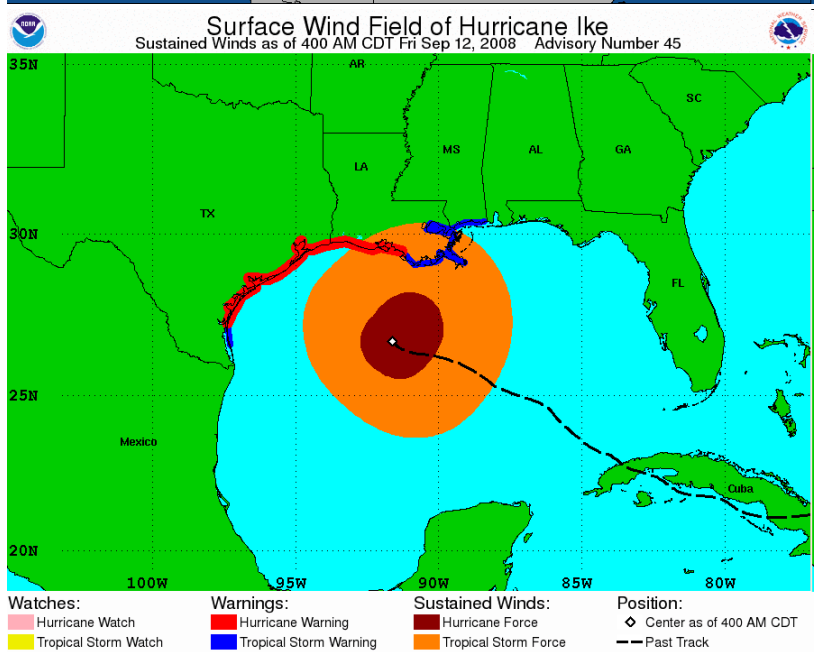
NHC Graphical Advisory Products

1. **Wind speed probabilities**
2. **Forecast track and threat area**
3. **Intensity forecast table**
4. **Cyclone size graphic**
5. **Wind swath graphic**

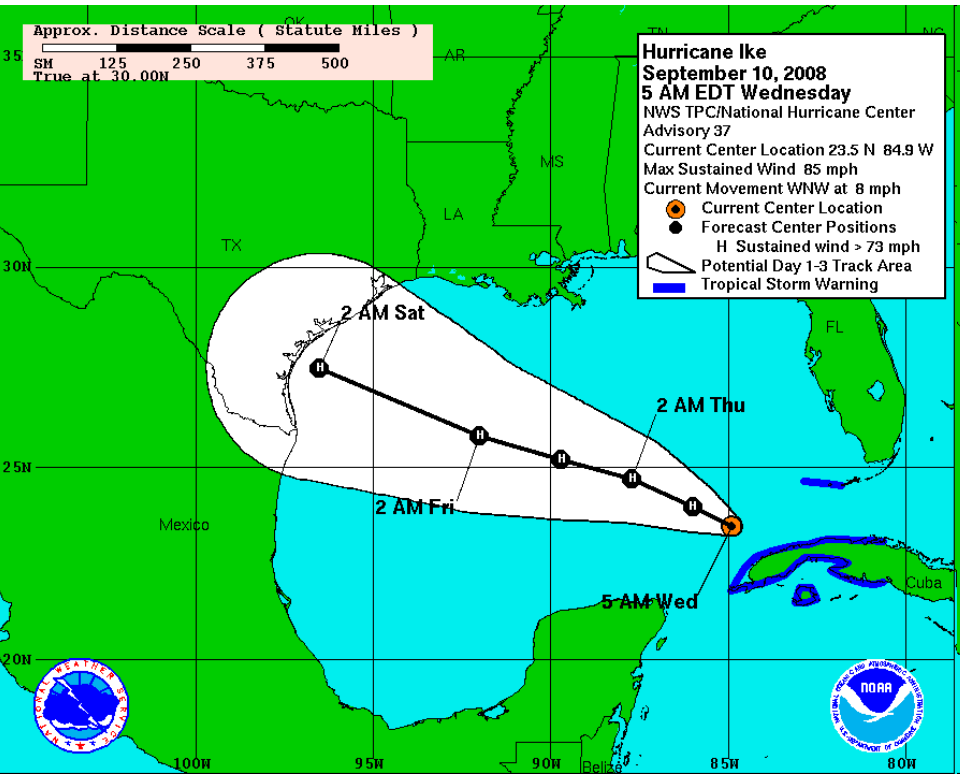


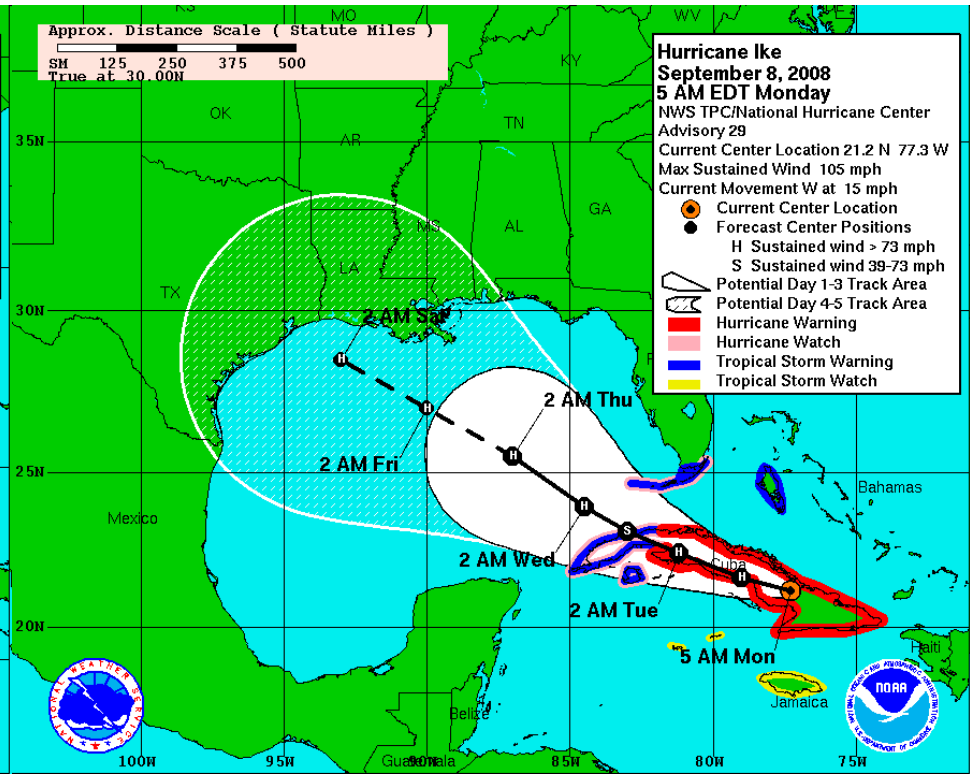
Intensity (Maximum Wind Speed) Probability Table
Hurricane Ike Advisory Number 29
5:00 AM EDT Sep 8 2008

Wind Range (mph)	Forecast Time: 12 hour for 2 PM Mon	24 hour for 2 AM Tue	36 hour for 2 PM Tue	48 hour for 2 AM Wed	72 hour for 2 AM Thu	96 hour for 2 AM Fri	120 hour for 2 AM Sat
Dissipated	<1%	<1%	3%	3%	4%	12%	27%
Tropical Depression (<39)	<1%	2%	12%	4%	3%	8%	13%
Tropical Storm (39-73)	11%	57%	60%	35%	20%	15%	20%
Hurricane (all categories)	89%	42%	25%	59%	74%	65%	40%
-- Category 1 (74-95)	79%	37%	21%	37%	30%	18%	13%
-- Category 2 (96-110)	9%	4%	3%	14%	21%	17%	11%
-- Category 3 (111-130)	1%	1%	1%	5%	17%	20%	10%
-- Category 4 (131-155)	1%	1%	<1%	2%	5%	10%	6%
-- Category 5 (>155)	<1%	<1%	<1%	<1%	1%	1%	1%
Forecast Maximum Wind	85 mph	75 mph	70 mph	85 mph	105 mph	115 mph	115 mph



Forecast Track/Threat Area



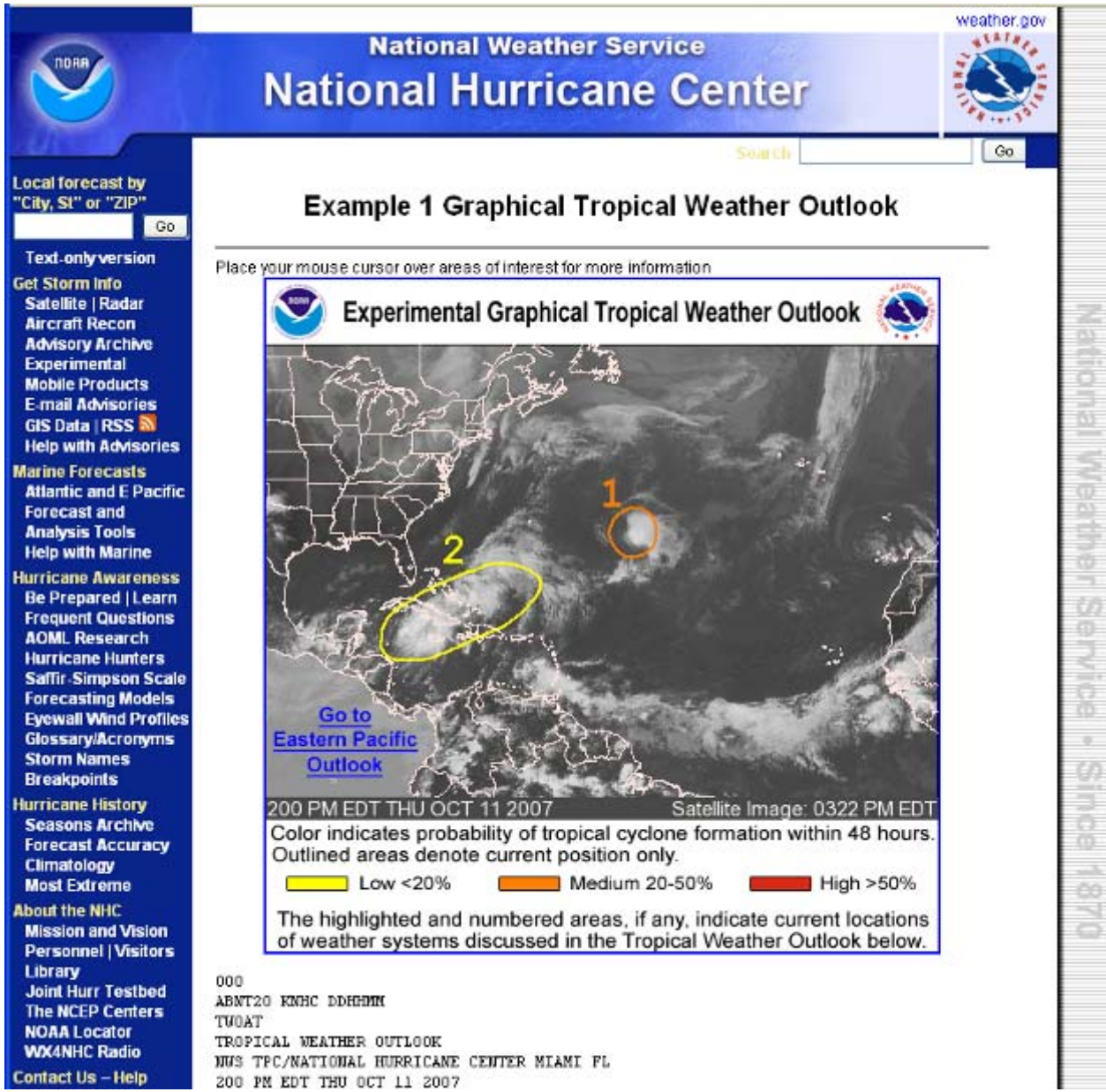


3-day **5-day**

The cone is formed by enclosing the area swept out by a set of circles along the forecast track, with the size of each circle set so that two-thirds of historical official forecast errors over a 5-year sample fall within the circle.

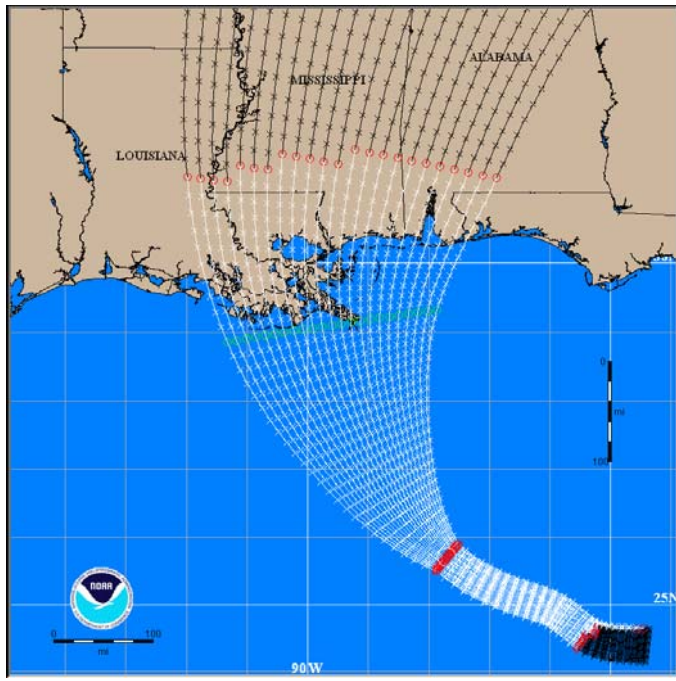
Other NHC Products

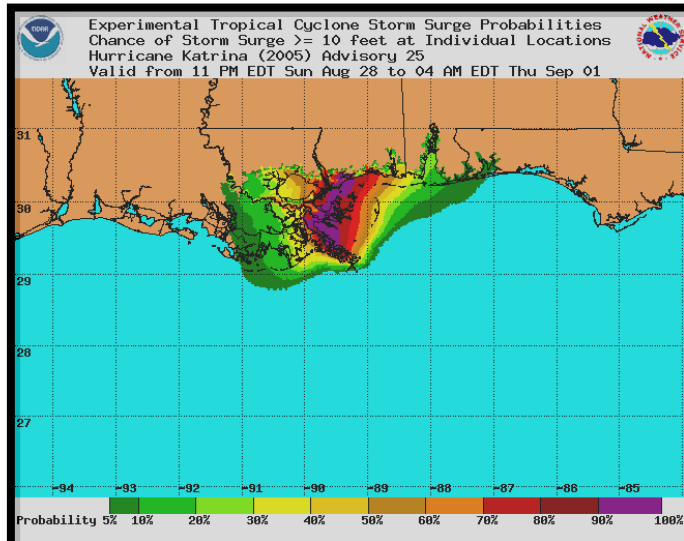
- **Tropical Cyclone Position Estimate (as needed)**
- **Tropical Cyclone Update (as needed)**
- **Tropical Weather Outlook (graphical and text products, including regularly scheduled and special versions)**



Changes for 2009

- **Extend lead time for watches to 48 hours and lead time for warnings to 36 hours**
- **Graphical tropical weather outlook (TWO) becomes operational**
  - **Text TWO to include three-tiered categorical genesis forecast**
  - **“Special” TWOs to be issued instead of the Special Tropical Disturbance Statements**
- **Probabilistic storm surge graphic becomes operational**
- **Development of storm surge inundation products**
- **Tropical cyclone wind field graphic becomes operational**

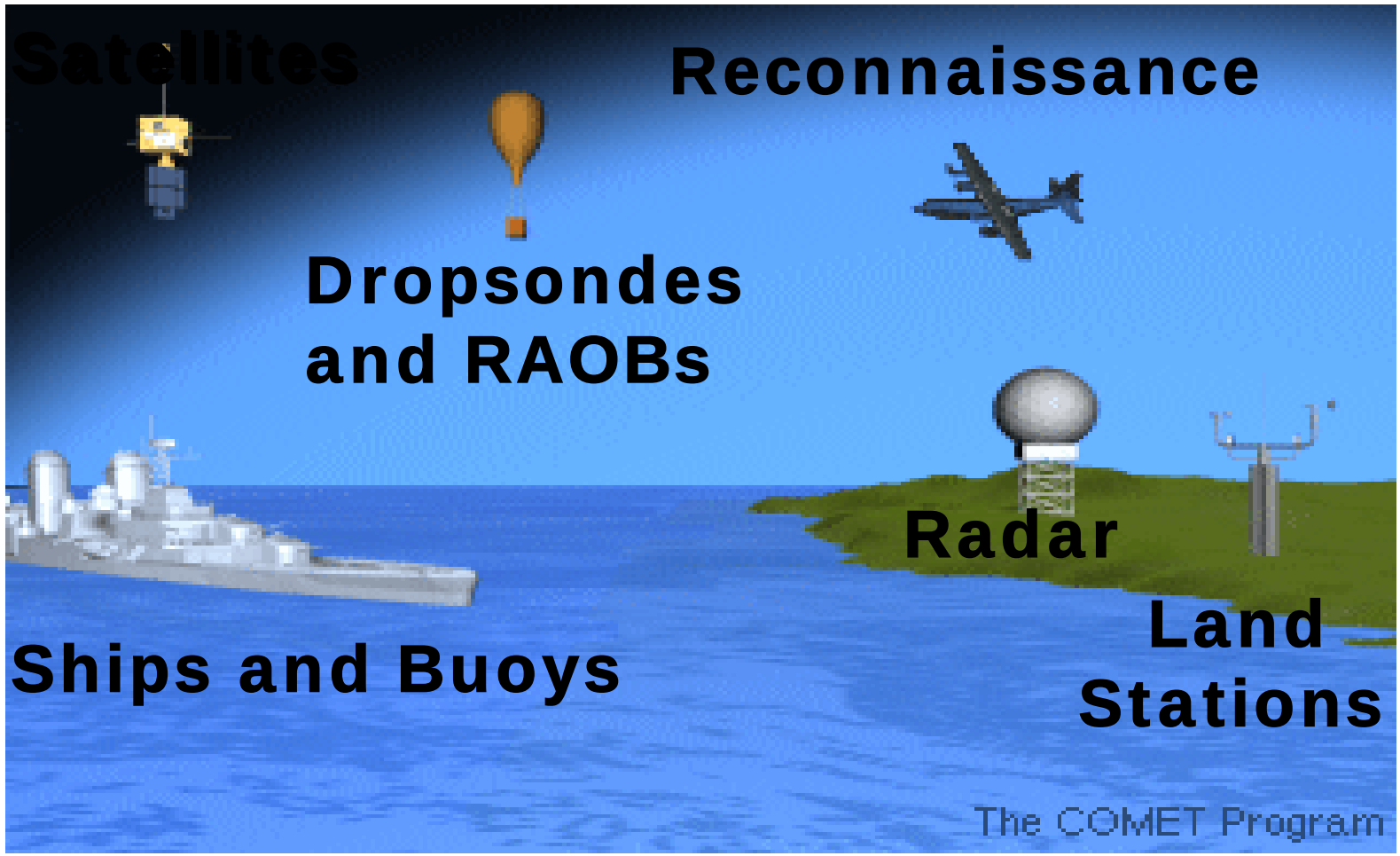




Tracking and Forecasting of Hurricanes

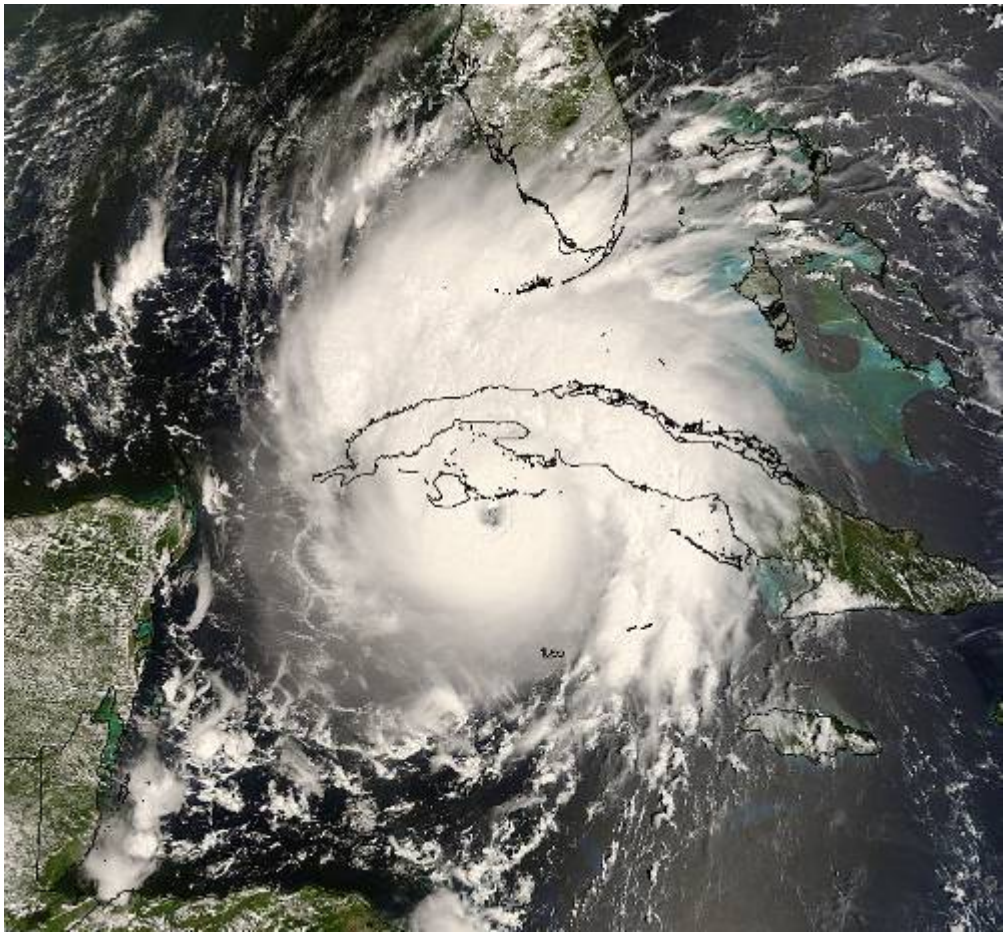
- Technology for tracking the initial motion, intensity, and size
- Forecast guidance models for track, intensity, and wind radii
- Constructing forecast of track, intensity, and wind radii – the buck stops with the hurricane specialist!
- Coordinate forecasts and warnings before the advisory goes public

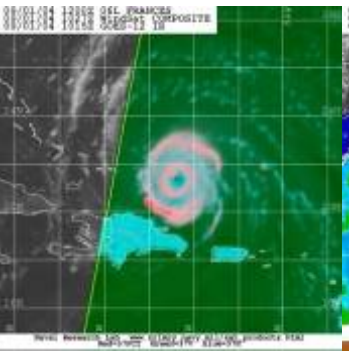
NHC Observational Tools

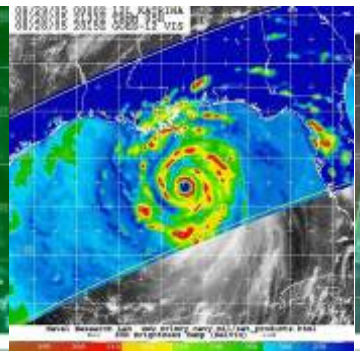


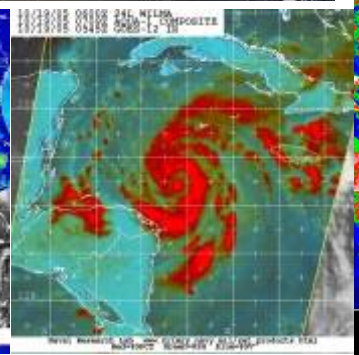
Availability of different data sources depend on the storm location and/or if the storm is threatening land

NHC Satellite Resources

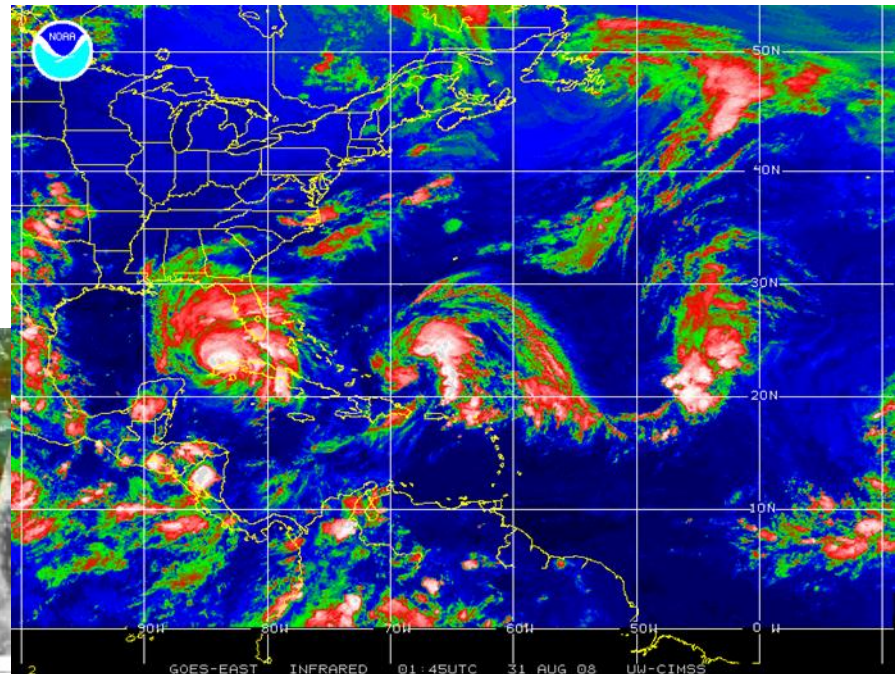






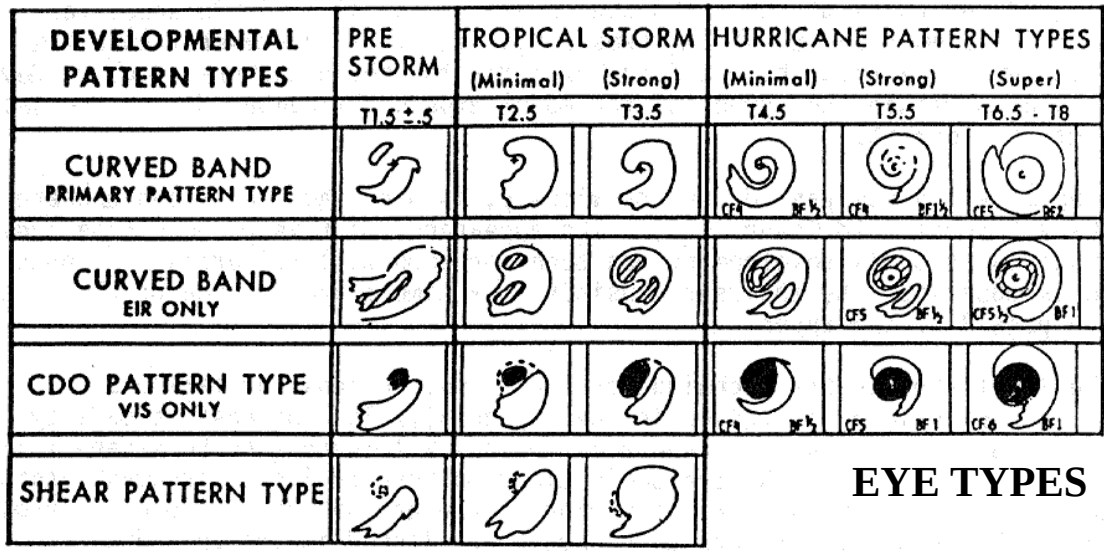


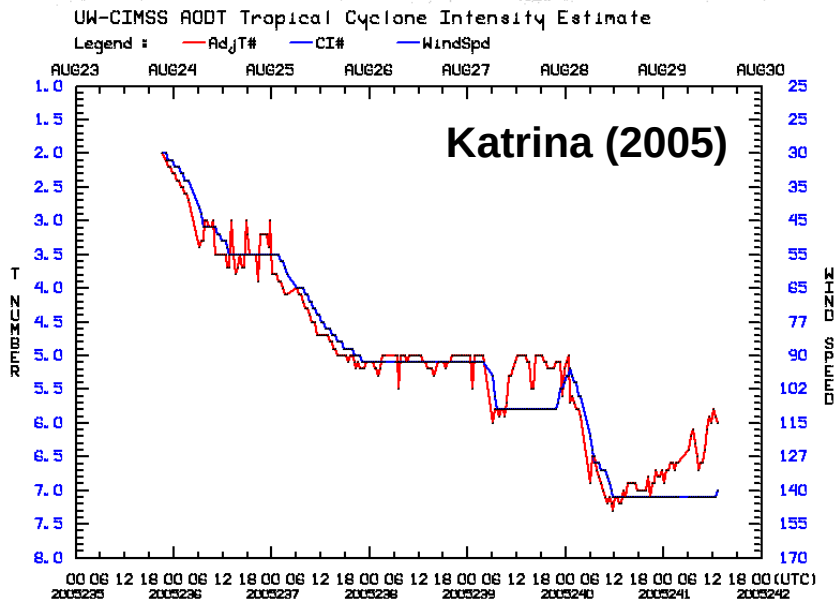
- **Geostationary GOES-11, GOES-12, and METEOSAT-9 (VIS, IR, WV every 15-30 min)**
- **Additional data from NOAA polar orbiters, DMSP polar orbiters, NASA TRMM, METOP, NASA QuikSCAT, NASA Aqua, and Coriolis/Windsat**



Satellite-Based TC Intensity Estimates: The Dvorak Technique

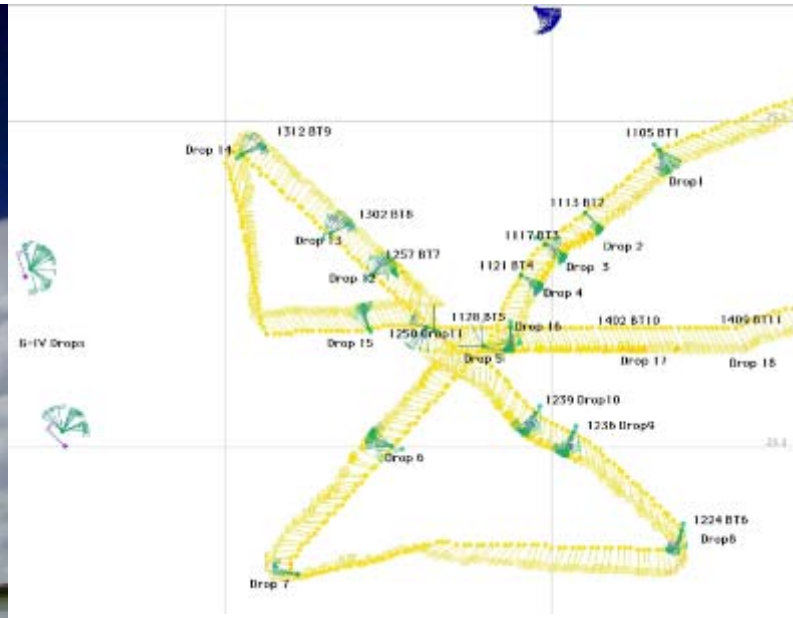
- Empirical technique relating cloud patterns to TC intensity by a set of ‘measurements’ and rules (Dvorak 1984)
- Often uses IR window brightness temperatures as a proxy for convective strength
- Comes in manual and automated versions
- Generally works well despite subjectivity, ambiguity, and imperfect relationships between TC intensity and cloud patterns





NHC Aircraft Resources

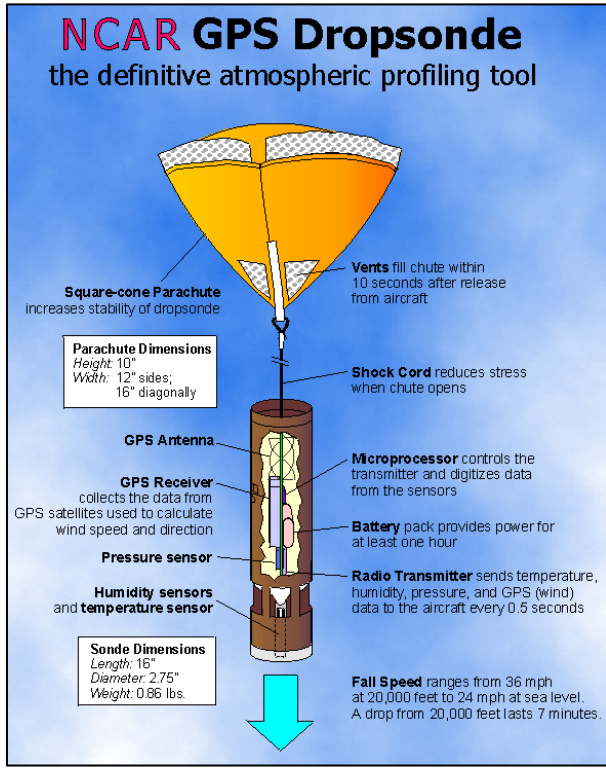
- **Ten WC-130 USAFR aircraft, two NOAA P-3 research aircraft, and one NOAA G-4 jet (synoptic surveillance missions)**
- **Aircraft usually flown in cyclones west of 55ºW <u>that threaten land</u>**
- **Aircraft provide *in situ* data on center location, intensity, size, and structure**

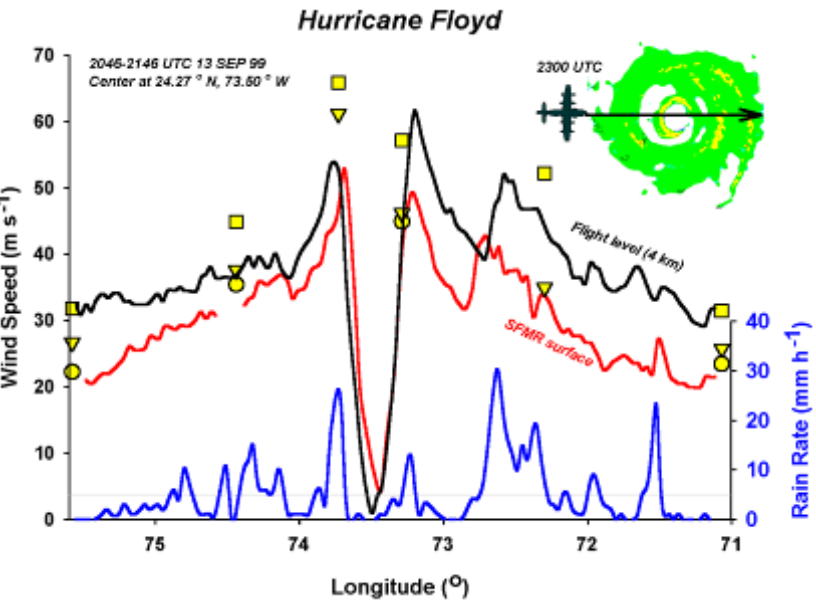


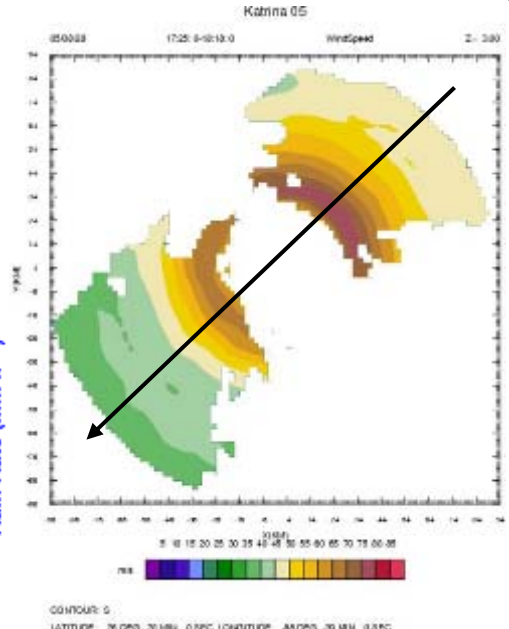
NOAA P-3 flight track in Hurricane Dolly

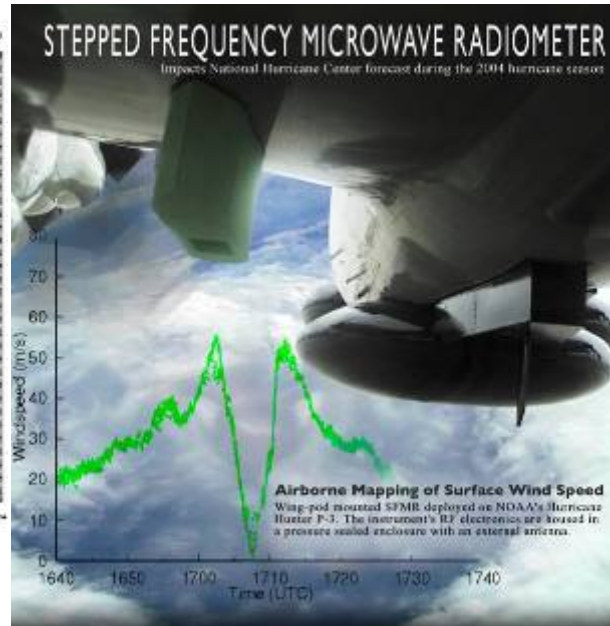
Primary Aircraft Data

- 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-3s)

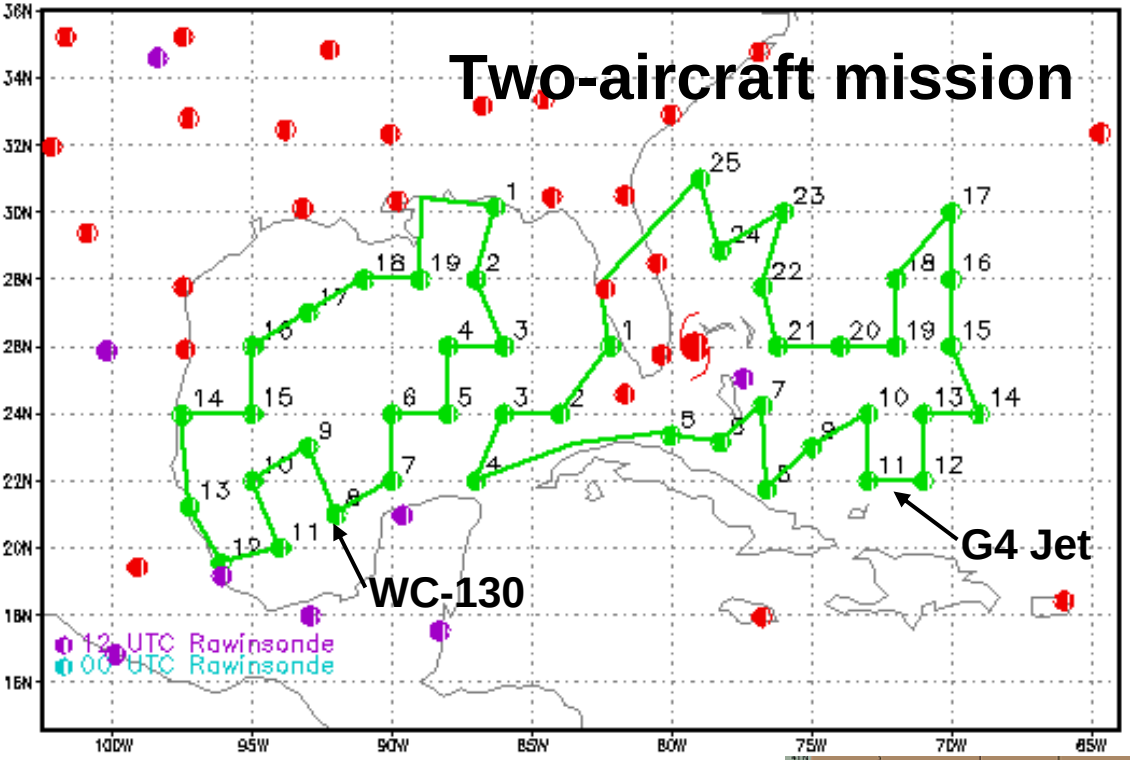


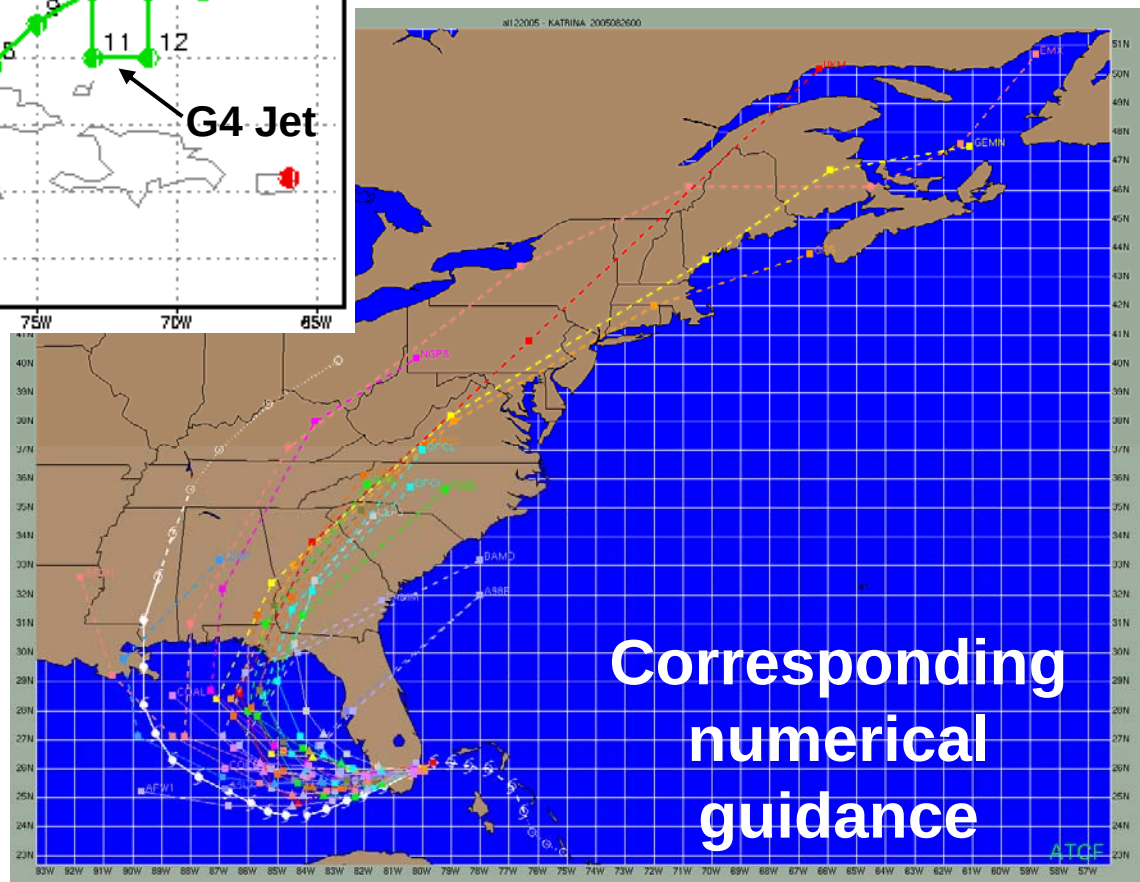




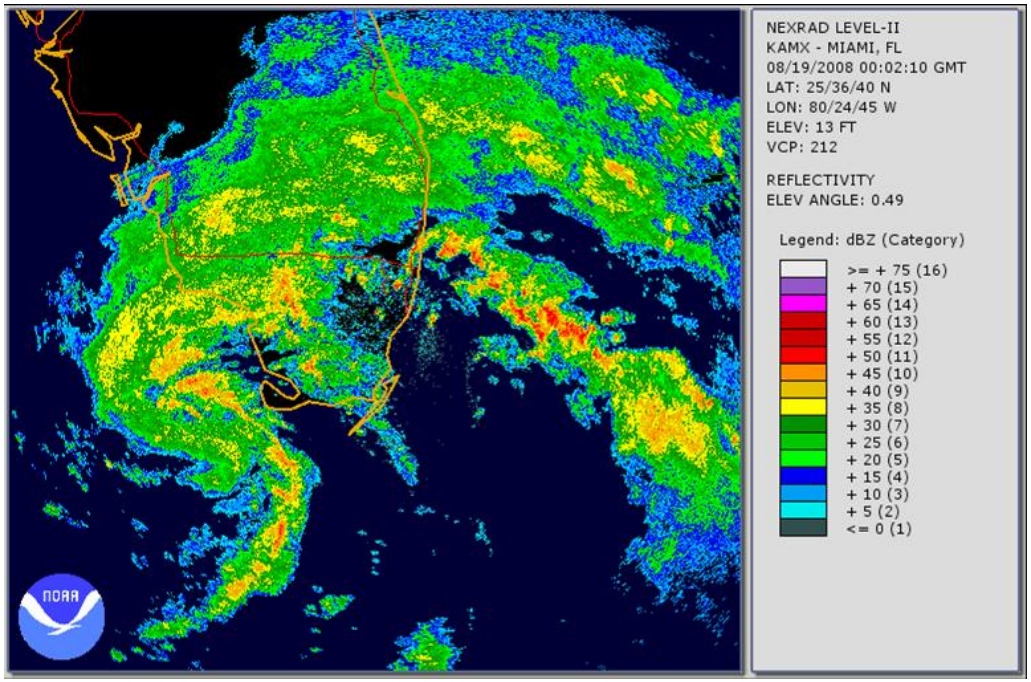


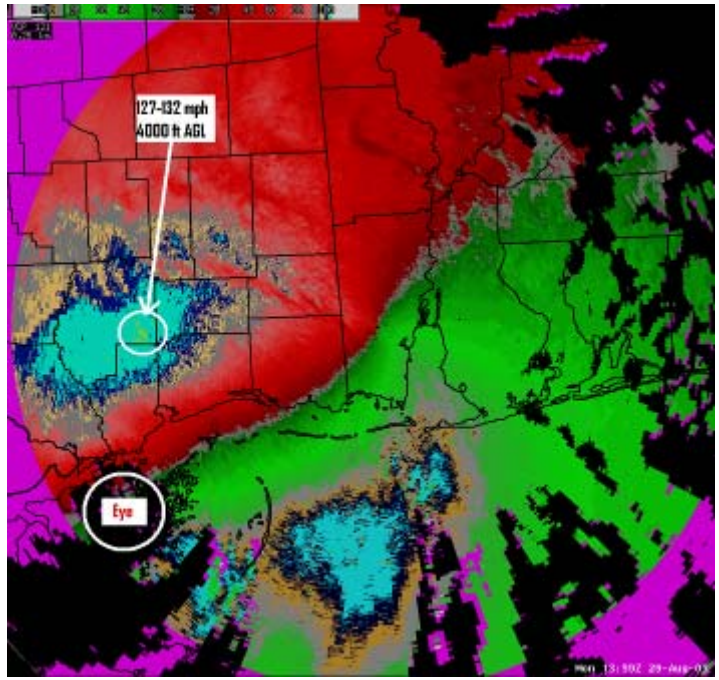
Katrina Synoptic Surveillance Missions

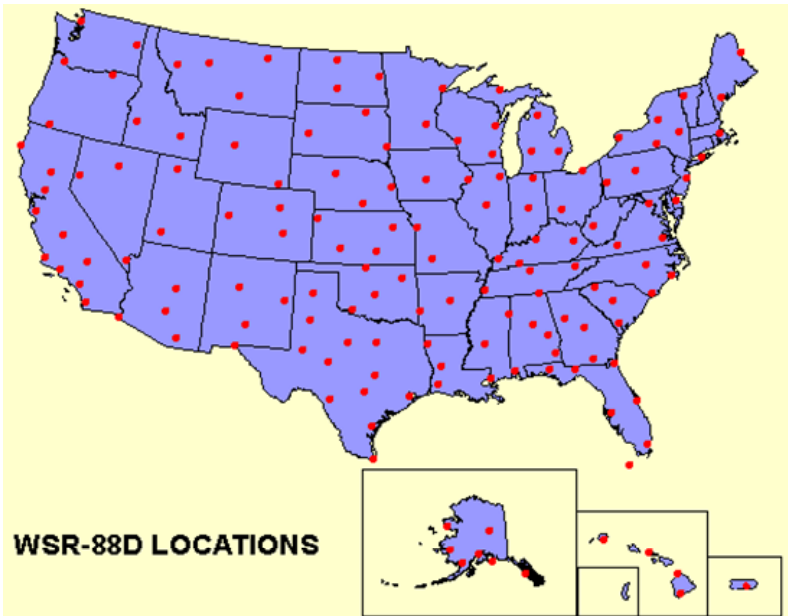




Radar Tracking of Hurricanes

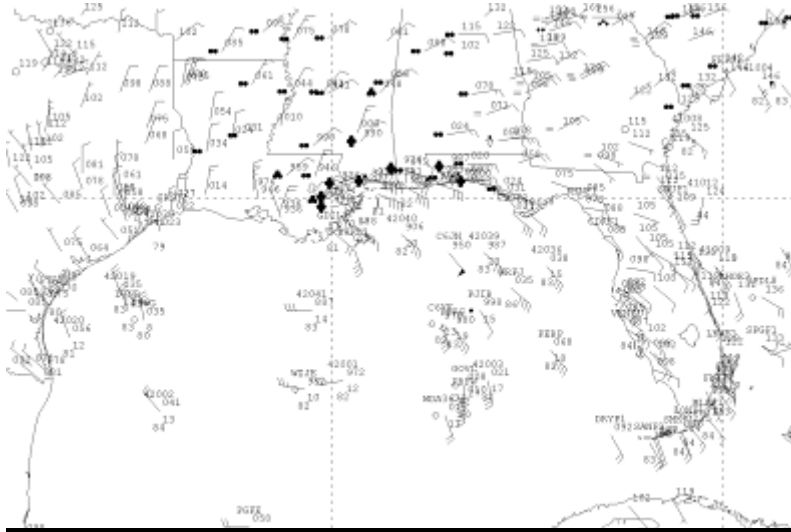


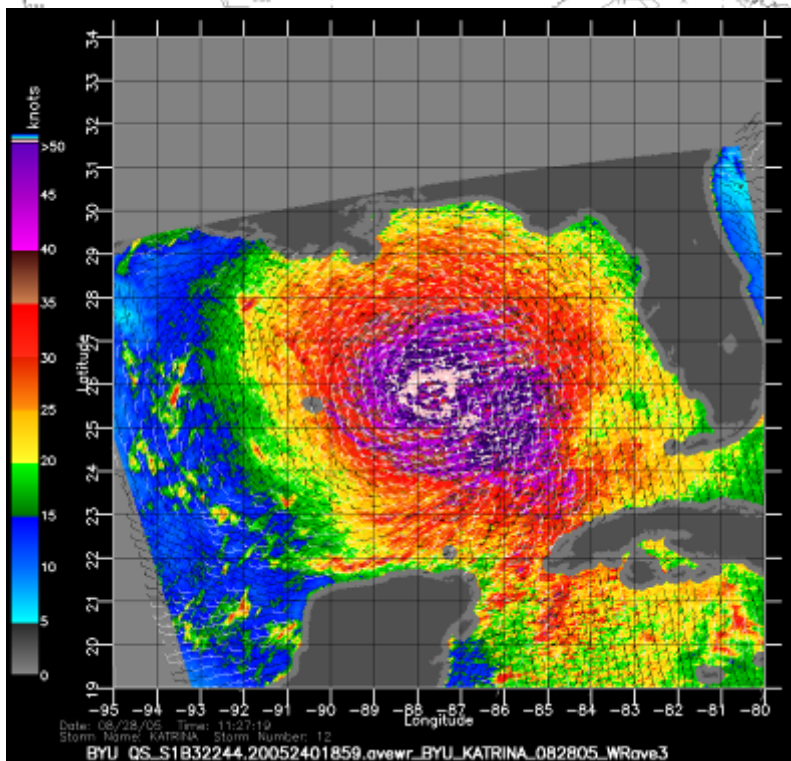




Cyclone Size Data

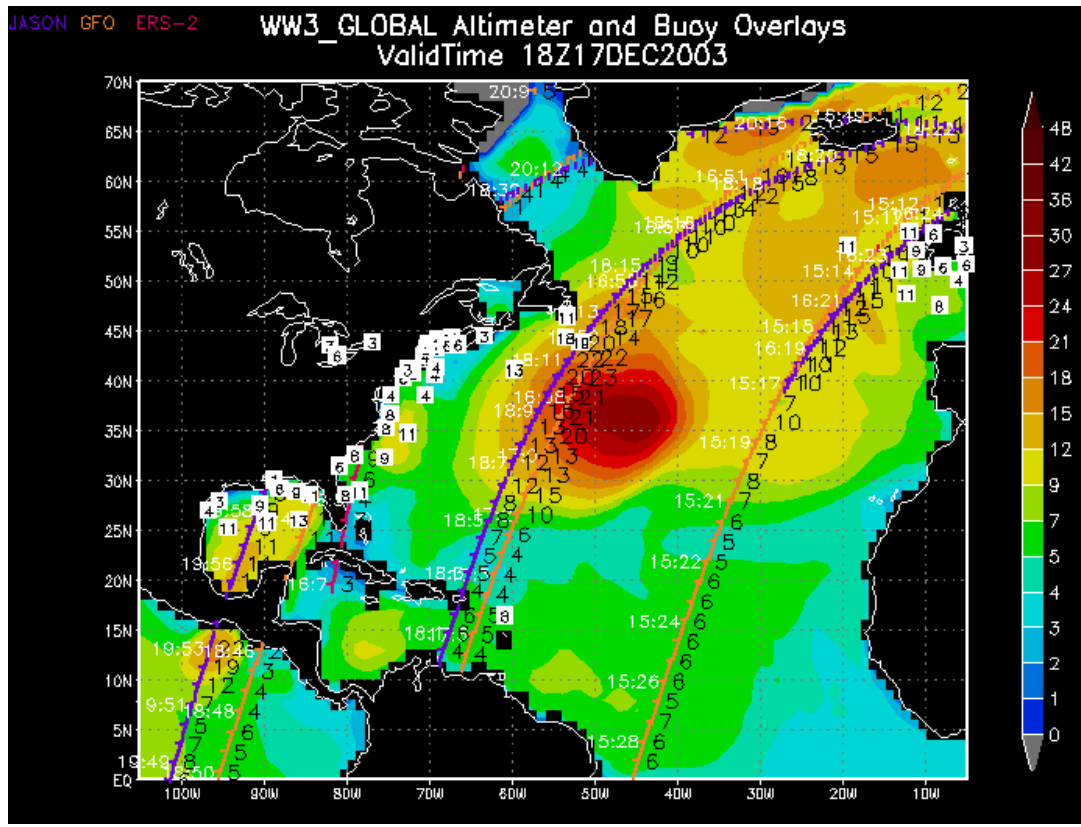
- Aircraft wind data
- Winds from ships and land stations of opportunity
- Scatterometer data (QuikSCAT, ERS-2, ASCAT)
- Passive microwave data (SSM/I, TRMM, AMSU)
- Pressure analysis from surface maps
- HRD surface wind analysis





Wave Height Data

- **TPC and the Ocean Prediction Center analyze 12 ft seas radii for the initial time of the forecast/advisory**
- **Analysis based on ships, buoys, and satellite data**

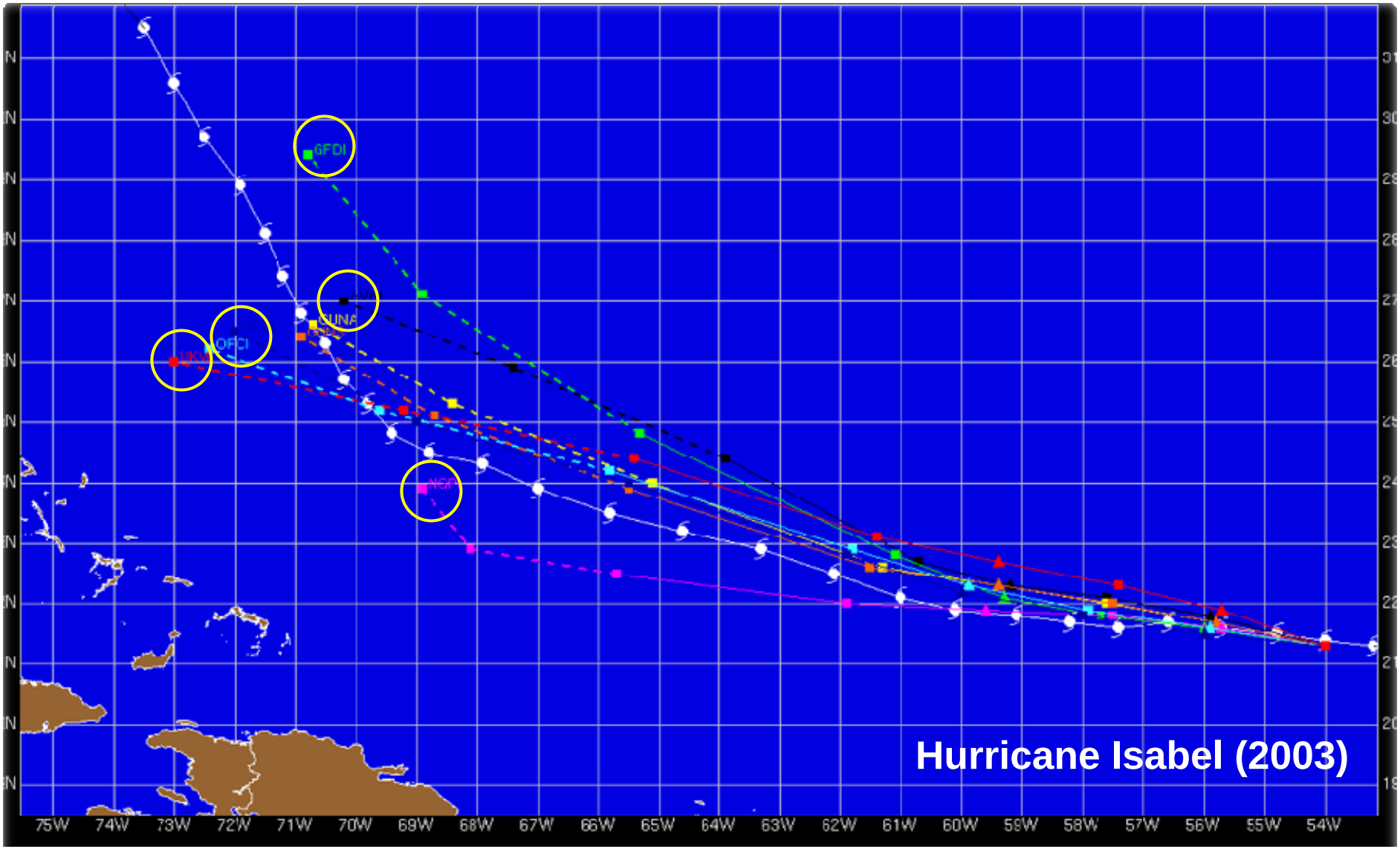


Jason-2 satellite will add to the available wave height data

Constructing the Forecast

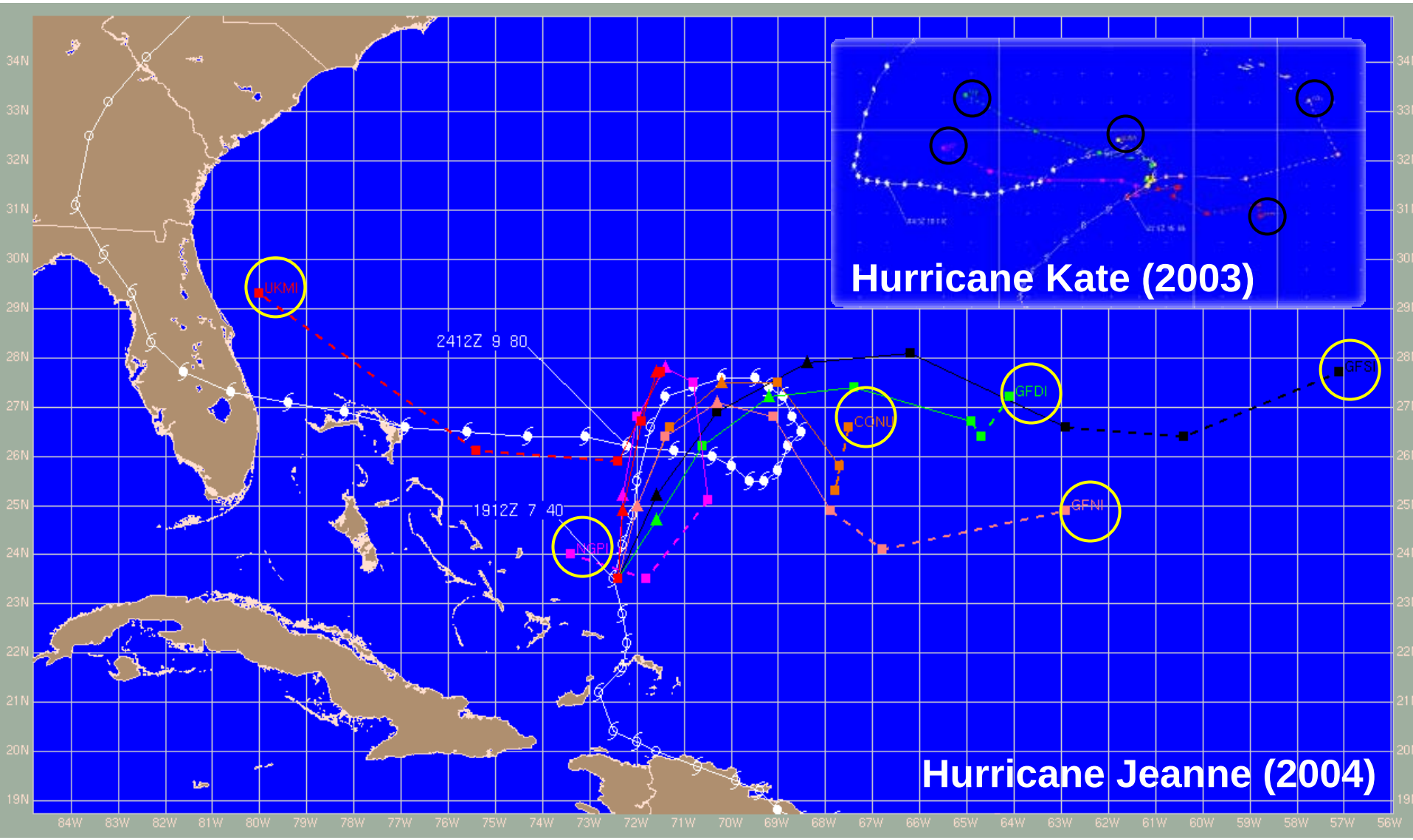
- **Based on the knowledge and experience of the forecaster combined with model guidance and all available data**
- **Important to maintain consistency with the previous forecast**
- **Also important to remember that the guidance could be wrong!**
- **Track forecast guidance has the greatest skill. Intensity guidance has less skill, while the skill of size guidance is still being evaluated.**

Utilize the Best “Guidance” Available

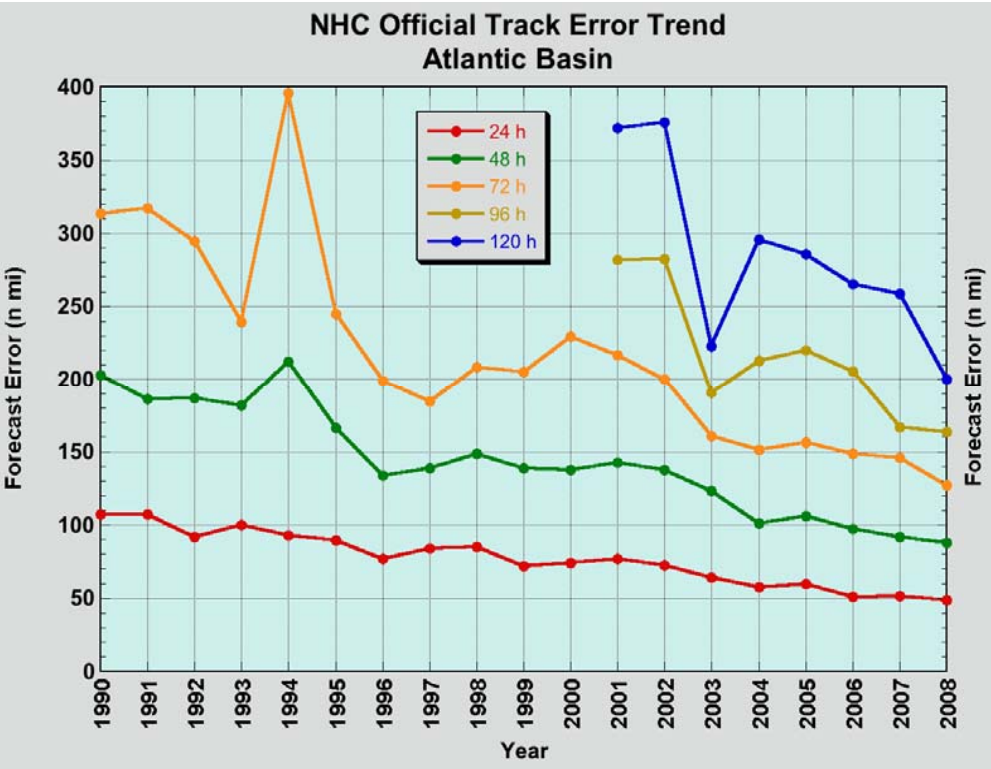


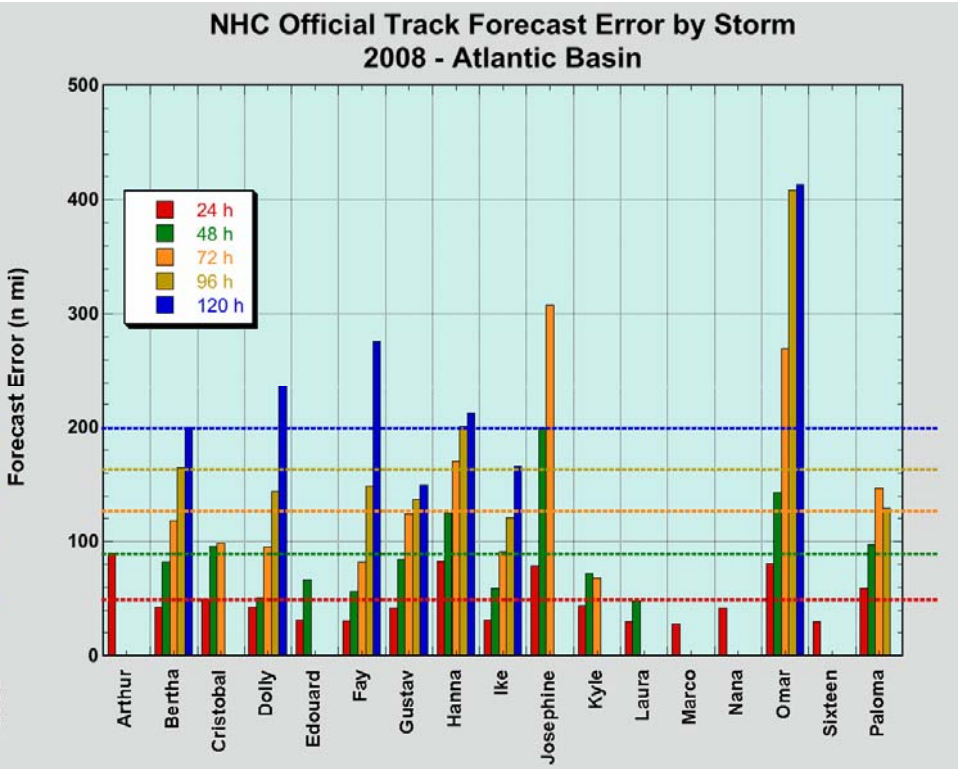
A relatively ‘easy’ forecast?

The Proverbial “Squashed Spider” Guidance



NHC Track Forecast Errors



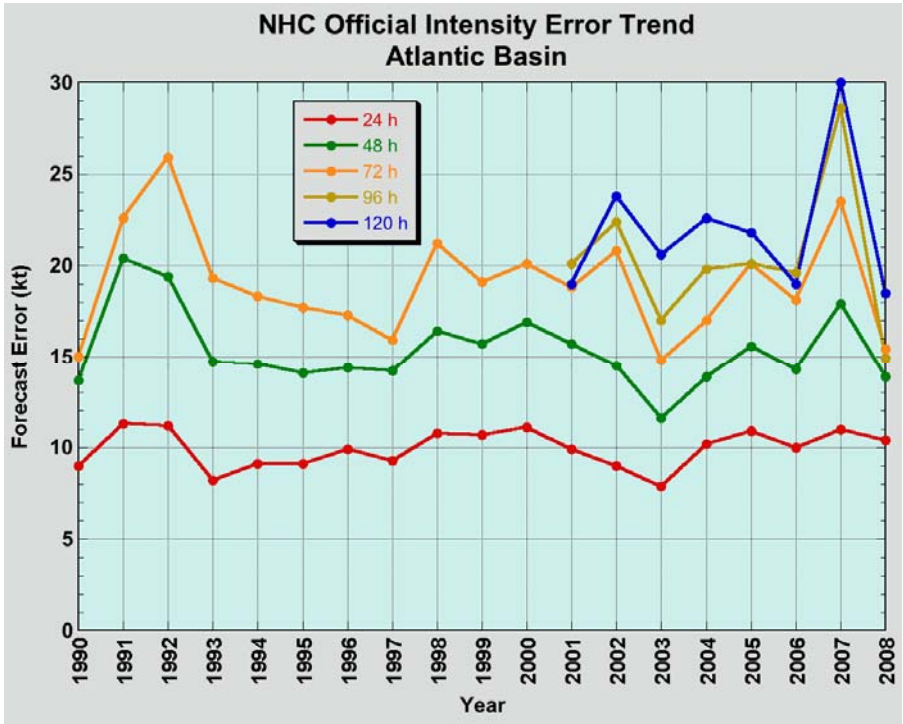


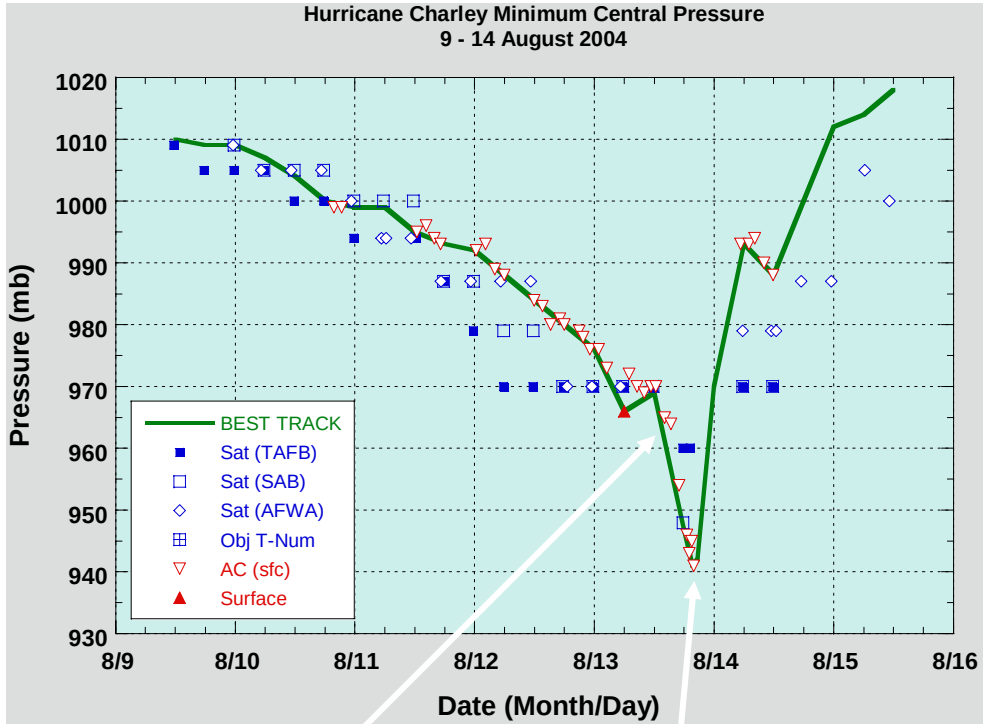
Since 1990

2008 cases

NHC Track forecasts have seen about a 50% decrease in errors since 1990. However, large errors are still possible for any given storm.

NHC Intensity Forecast Errors

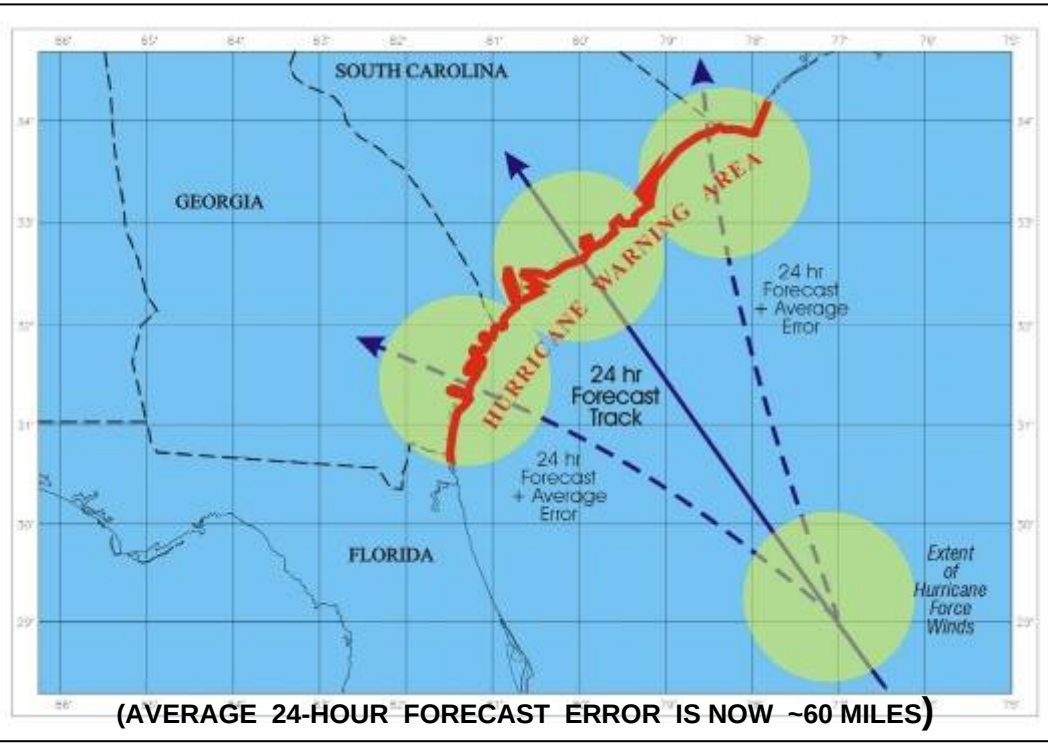




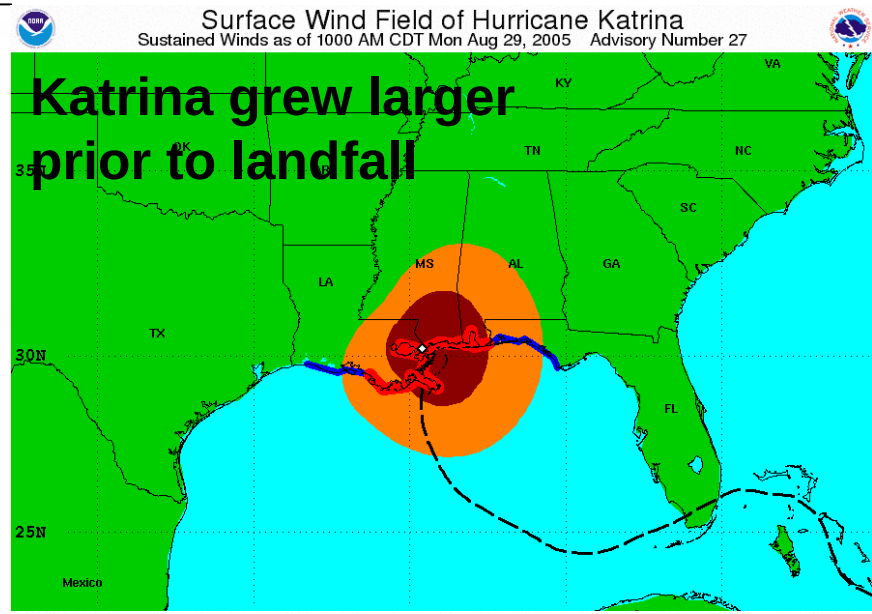
Since 1990 – little improvement noted.

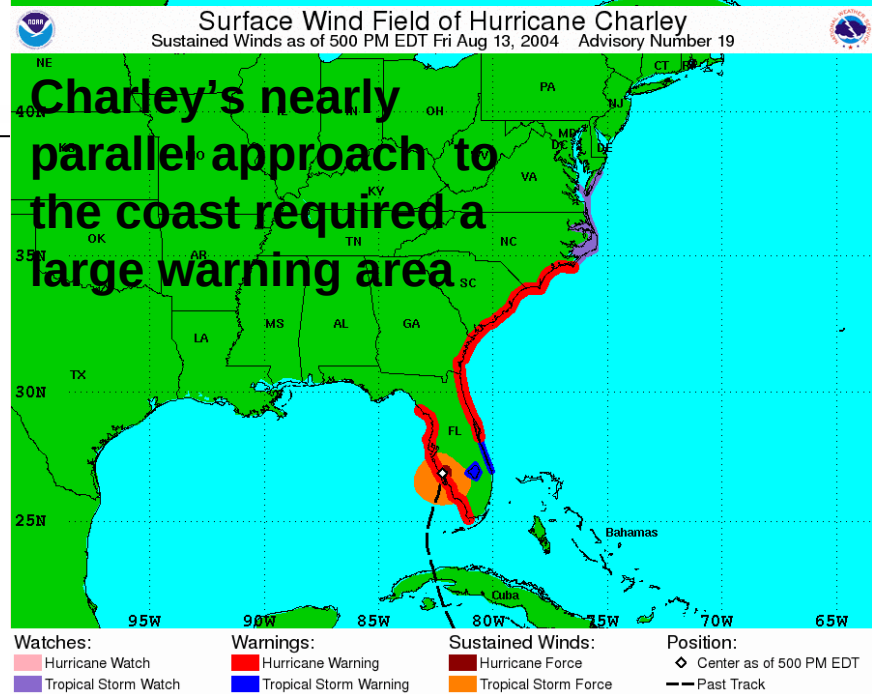
Charley deepened from 964 mb to 941 mb in 4 h 35 min near landfall – NIGHTMARE!

Issuing Warnings



(AVERAGE 24-HOUR FORECAST ERROR IS NOW ~60 MILES)





Warning Size is based on:

- Forecast track and storm size
- Known uncertainties in the forecasts
- Orientation of the forecast track with respect to the coast plays a major role in the size of the warning area
- Wind speed probabilities may become guidance for warnings

Advisory Coordination

Forecasts and warnings are coordinated with:

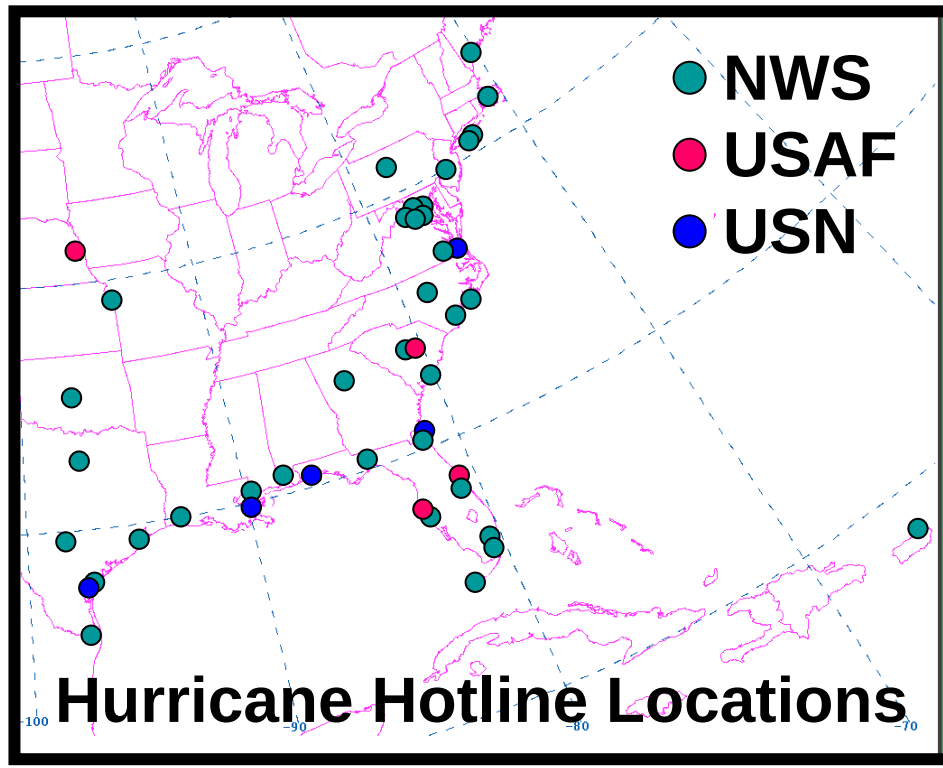
❶ The Hydrometeorological Prediction Center (HPC) and Ocean Prediction Center (OPC) in Washington, DC

❷ Local National Weather Service offices in the potentially affected area

❸ The Storm Prediction Center (SPC) in Norman, OK

❹ Department of Defense (DoD) offices

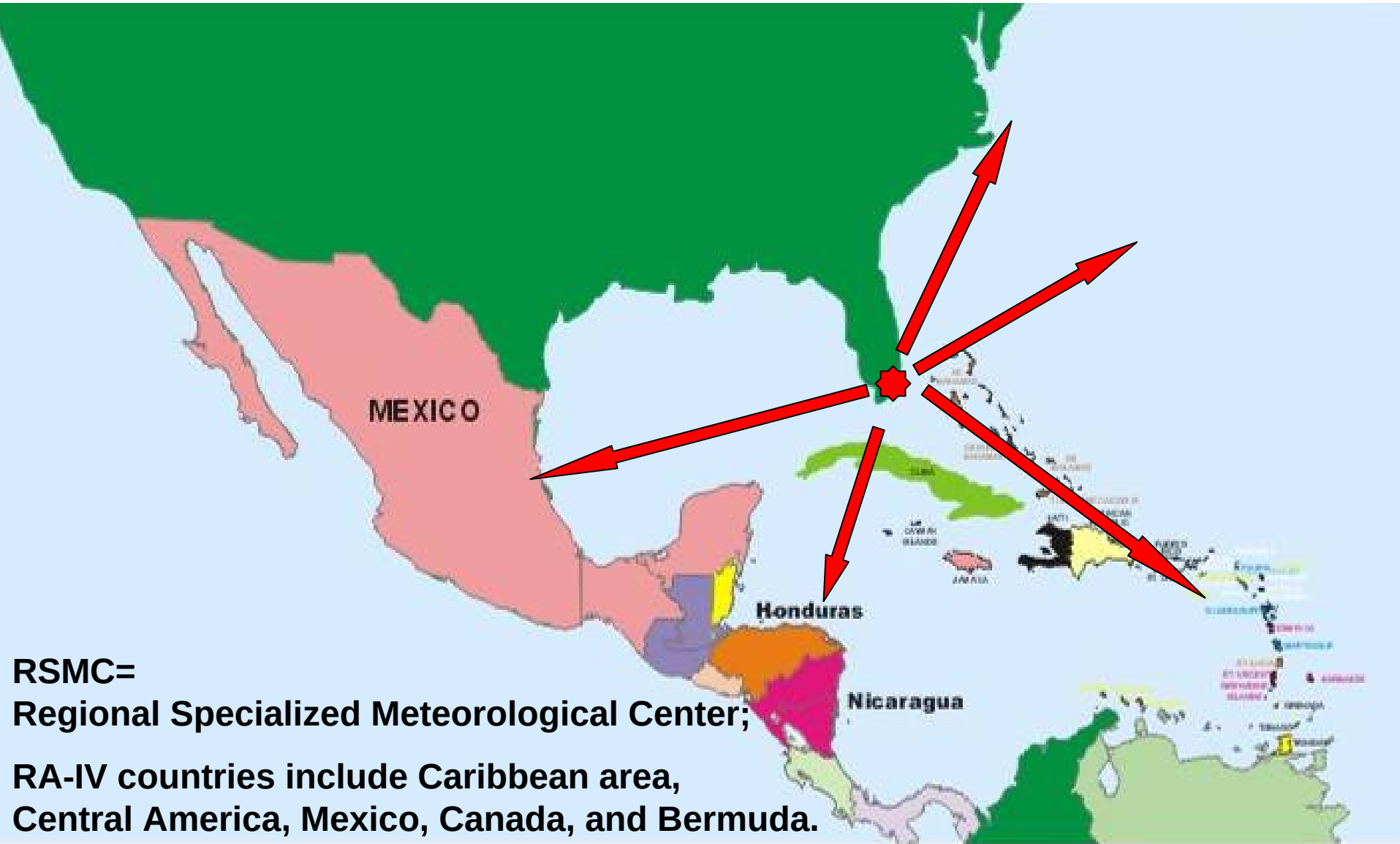
❺ International meteorological offices



(International coordination by telephone)

International Coordination

World MET. ORGANIZATION – Regional Association IV Coordination

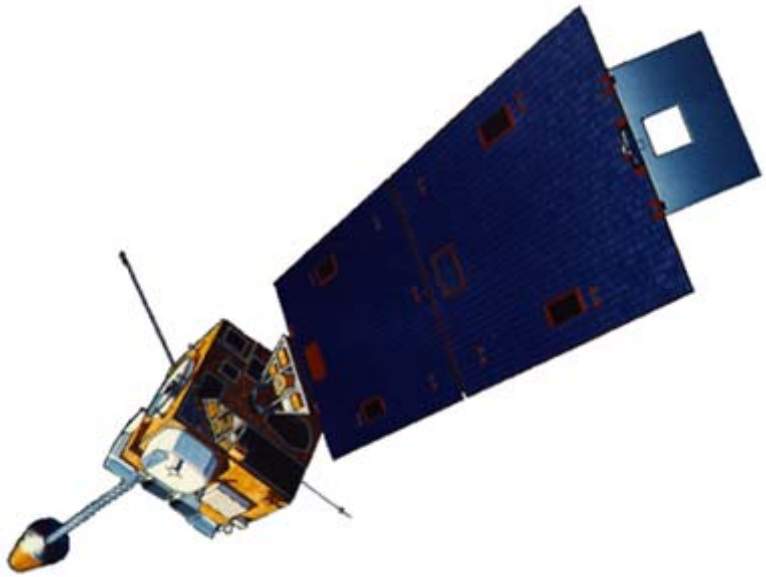


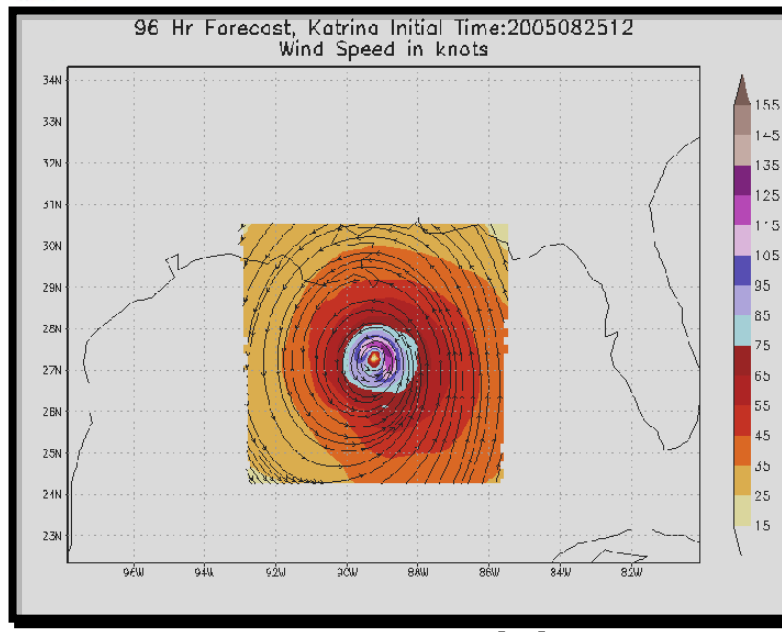
RSMC=
Regional Specialized Meteorological Center;

RA-IV countries include Caribbean area, Central America, Mexico, Canada, and Bermuda.

The Future

- **Aircraft:**
  - UAS of various types
  - Wave height altimeter
- **Satellites:**
  - GOES-R
  - NPOESS
- **Forecast Information:**
  - Wind radii / structure out to 120 HRS
  - Day 6 and Day 7 track forecasts (DHS-FEMA/DOD)
  - TC Genesis probabilities
  - Improve intensity prediction – rapid intensity problem (HFIP)
  - Issue Storm Surge watches and warnings(?)
  - Significant wave height forecasts





HWRF Model

Reference

Dvorak, V.F. 1984. Tropical cyclone intensity analysis using satellite data. NOAA Tech. Rep. NESDIS 11. 47 pp.