Tropical Cyclone Winds

Florida Governor's Hurricane Conference

May 12, 2008

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National Hurricane Center

To be discussed…

- **Intensity Definition**
- **Estimation of Current Intensity**
- **Factors that Influence Intensity Change**
- **Official Intensity Forecasts / Models**
- **Factors of Winds over Land**
- **Decision Making Tools**

WHAT IS THE INTENSITY OF A TROPICAL CYCLONE?

It is defined as the
maximum sustained surface wind:

The maximum wind, averaged over a 1- minute interval at an altitude of 33 ft (10 m), associated with the circulation of the tropical cyclone at a given point in time

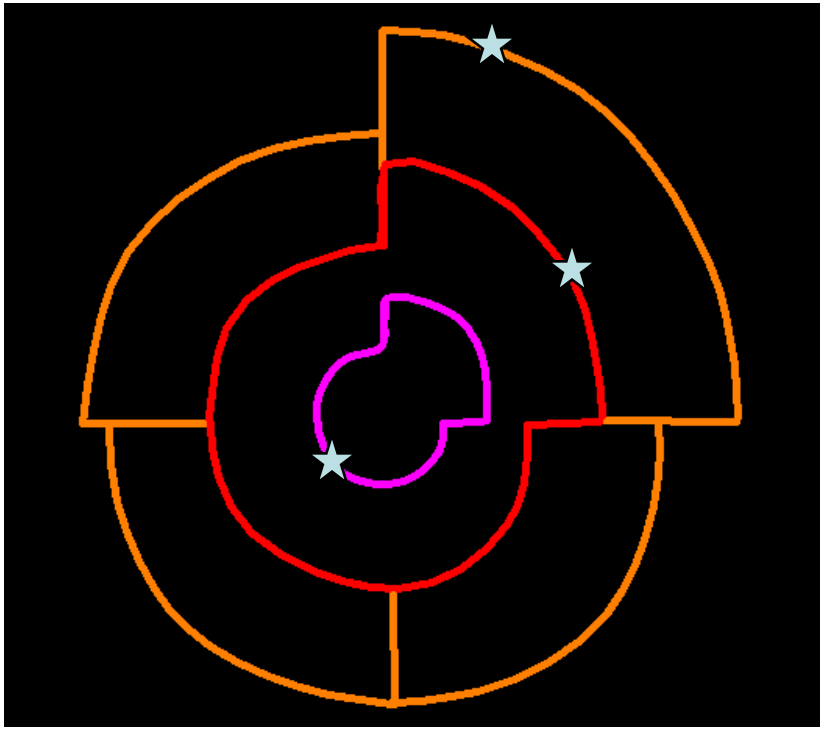
With very, very, few exceptions
direct measurements of this quantity are
not available

NHC Wind Forecasts

- Initial & forecast intensity out through 5 days
- 64/50/34 kt wind radii @ initial, 12h, 24h, 36h
  50/34 kt wind radii @ 48h and 72h
- Wind radii are roughly estimated into four quadrants:

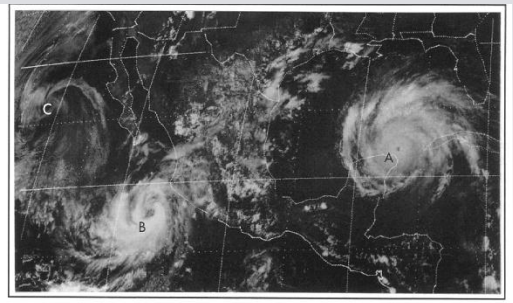
NE - SE - SW - NW

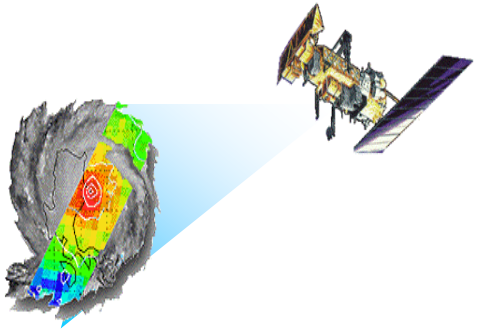
****** Only depicts the maximum extent of winds in each quadrant ******

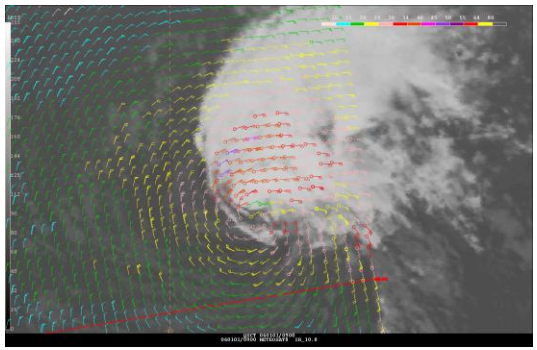


HOW DO WE ESTIMATE INTENSITY?

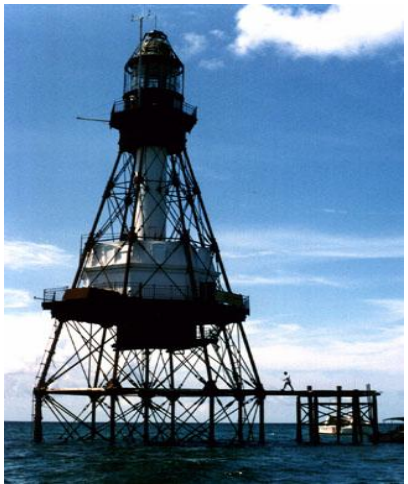
- **Satellites (primary)**
  - **Geostationary infrared & visible images (Dvorak Technique)**
  - **Microwave soundings (AMSU)**
  - **Scatterometer derived surface winds (QSCAT)**





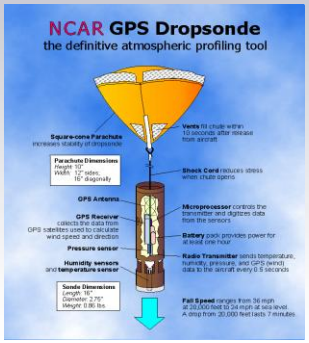


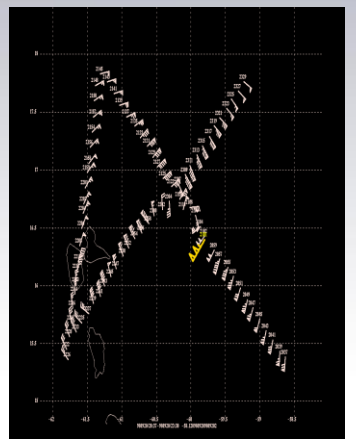
- **Surface observations**
  - **Ships, buoys, land stations (limited)**

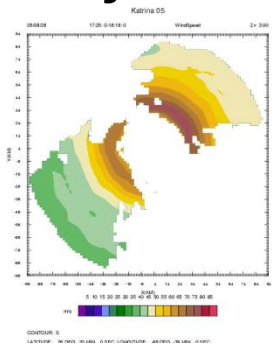


HOW DO WE ESTIMATE INTENSITY Cont. ?

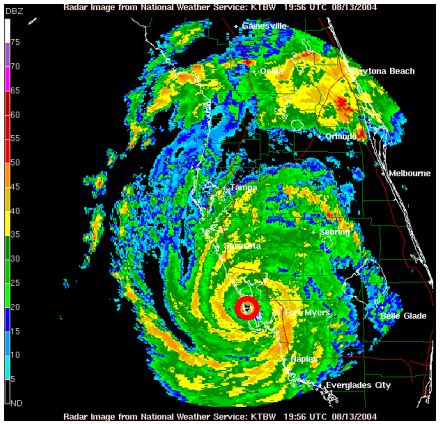
- **Aircraft Reconnaissance**
  - **Flight-level winds**
  - **GPS dropsondes**
  - **Stepped-Frequency Microwave Radiometer (SFMR)**

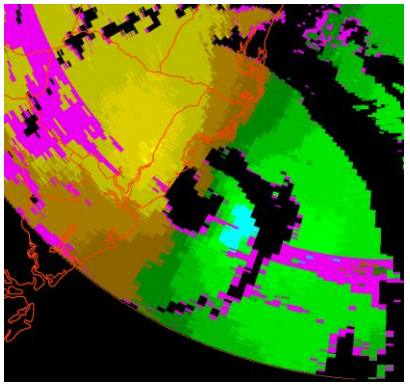






- **Doppler radar**
  - **Land-based (WSR-88D)**
  - **Airborne**

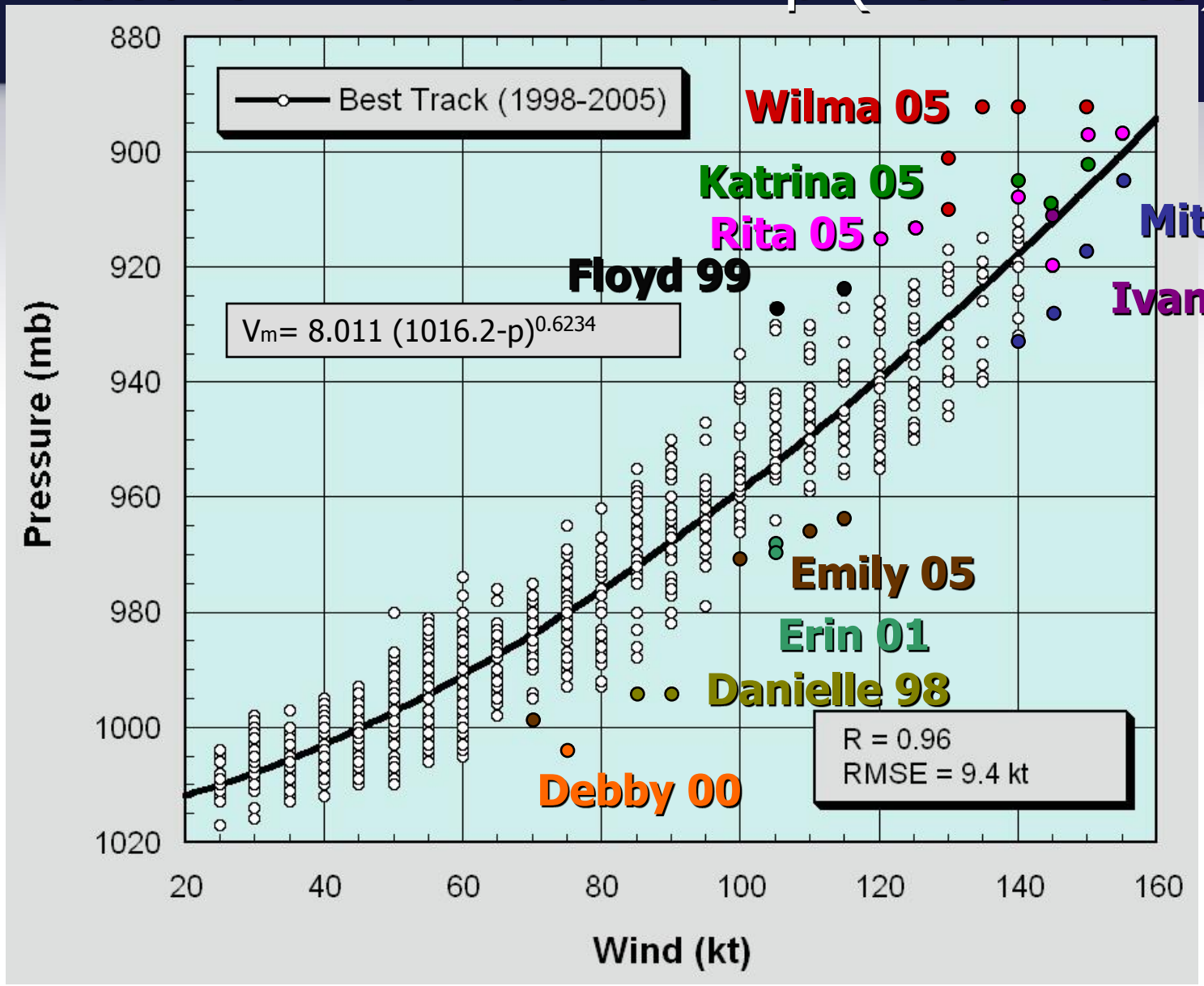




Can we use central pressure to estimate TC intensity ?

Pressure / Wind Relationships

Reconnaissance Based "Best Track" Pressure-Wind Relationship (1998-2005)



Ranges in MSLP by TC Category

Weak TS (<50 kt)	**993-1013 mb**	**(20 mb spread)**
Strong TS (50-63 kt)	**974-1010 mb**	**(36 mb)**
Category 1 Hurricane	**962-1004 mb**	**(42 mb)**
Category 2 Hurricane	**947-994 mb**	**(47 mb)**
Category 3 Hurricane	**927-971 mb**	**(44 mb)**
Category 4 Hurricane	**892-964 mb**	**(72 mb)**
Category 5 Hurricane	**892-933 mb**	**(41 mb)**

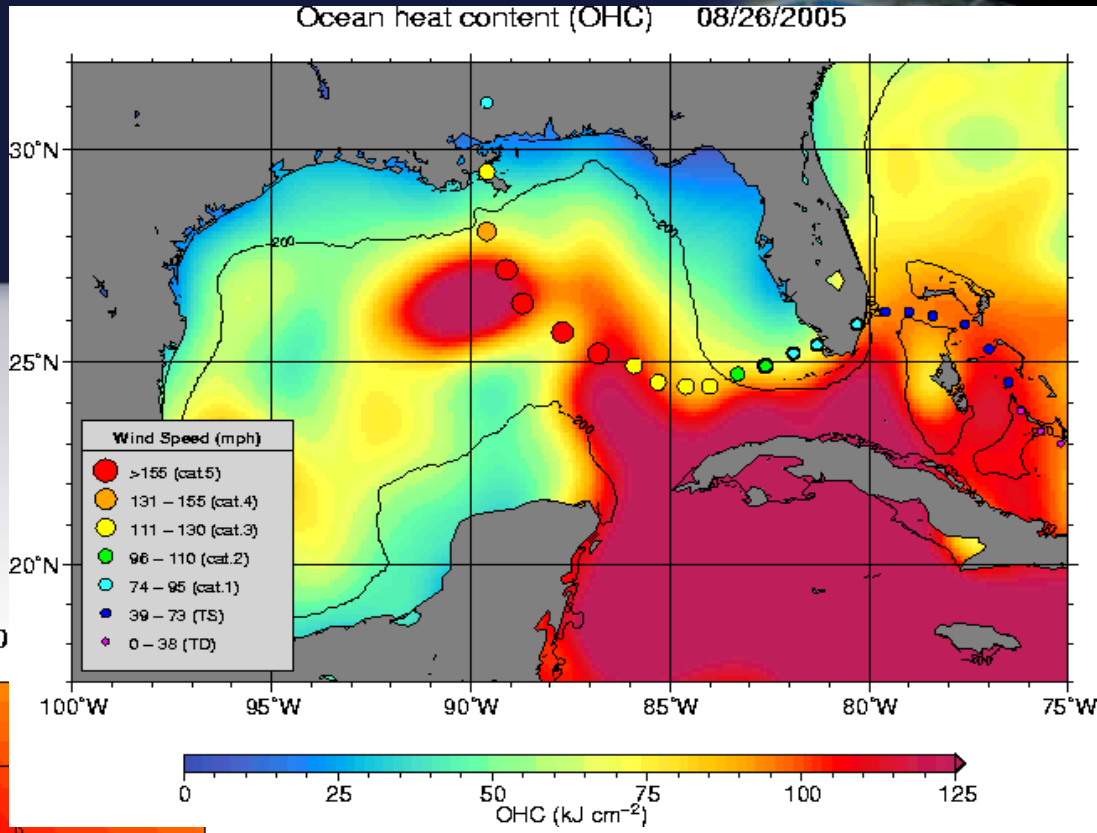
FACTORS AFFECTING TC INTENSITY

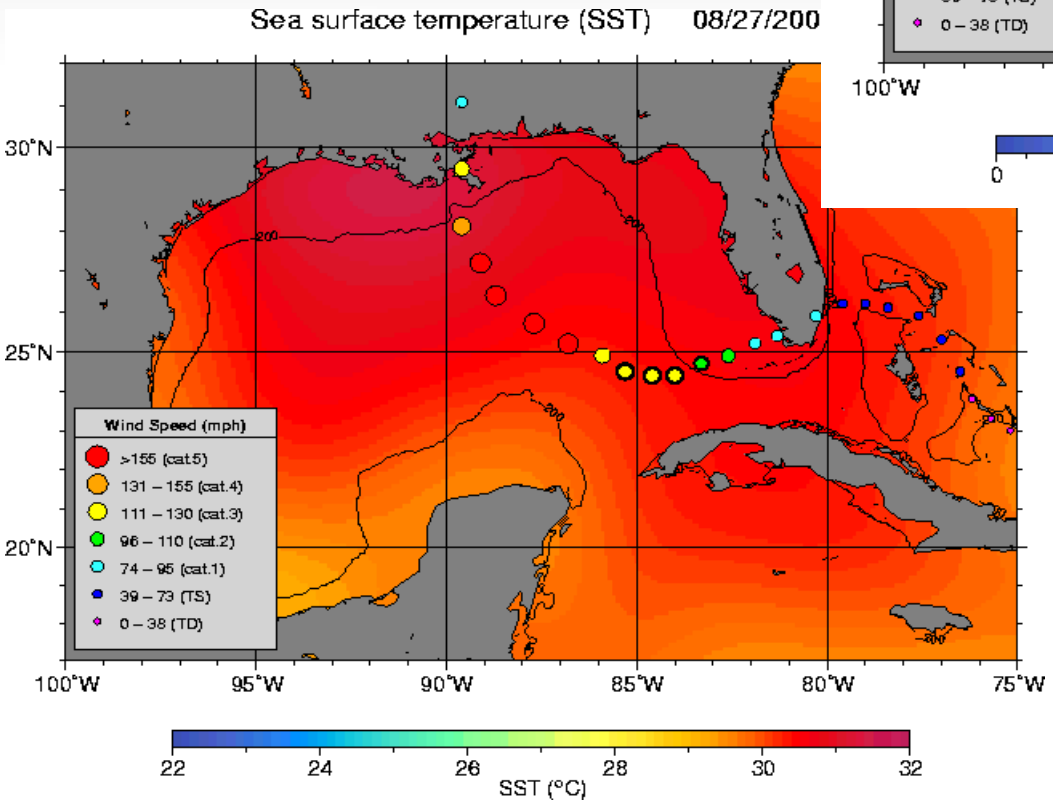
- **Sea surface temperature / upper ocean heat content.**
- **Environmental winds, esp. vertical wind shear.**
- **Trough interactions.**
- **Temperature and moisture patterns in the storm environment.**
- **Internal effects (e.g. eyewall replacement cycles).**
- **Interaction with land.**

Ocean Heat Content

estimates the amount of heat available over a depth of warm water.

the greater the depth the more available heat that can be potentially converted to energy

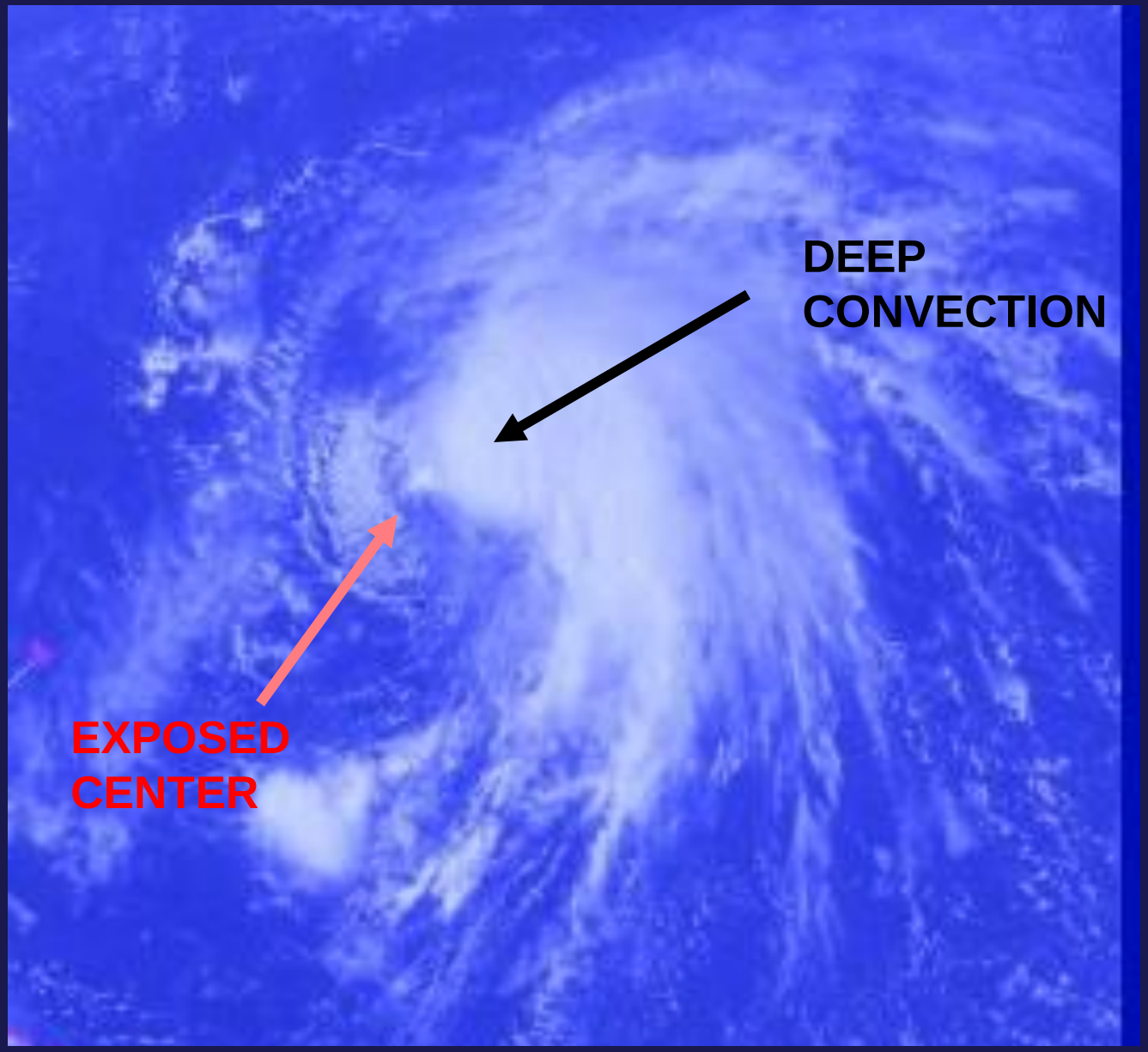




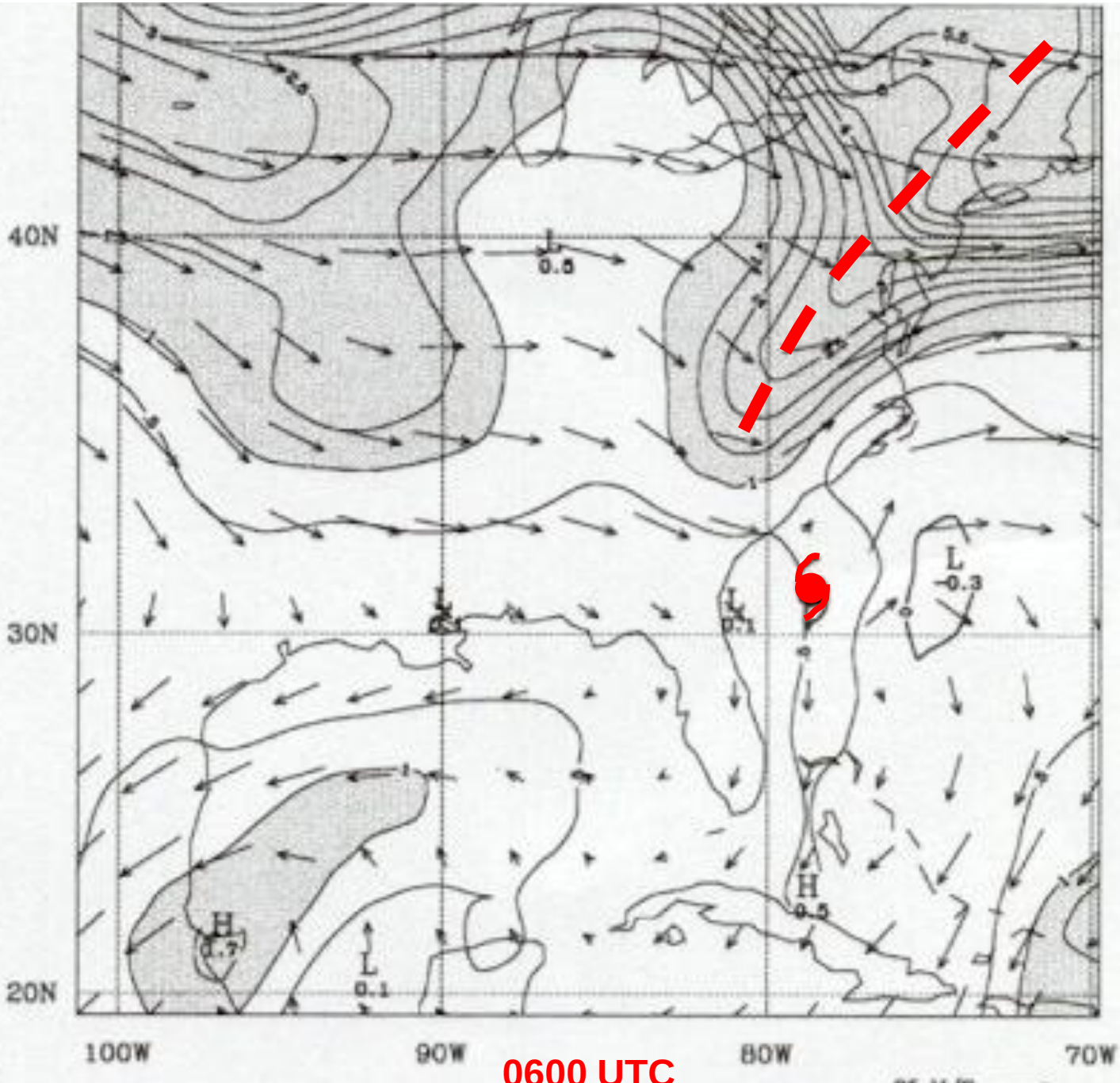
Sea Surface Temperatures

only provide a view of the very top layer of the ocean.

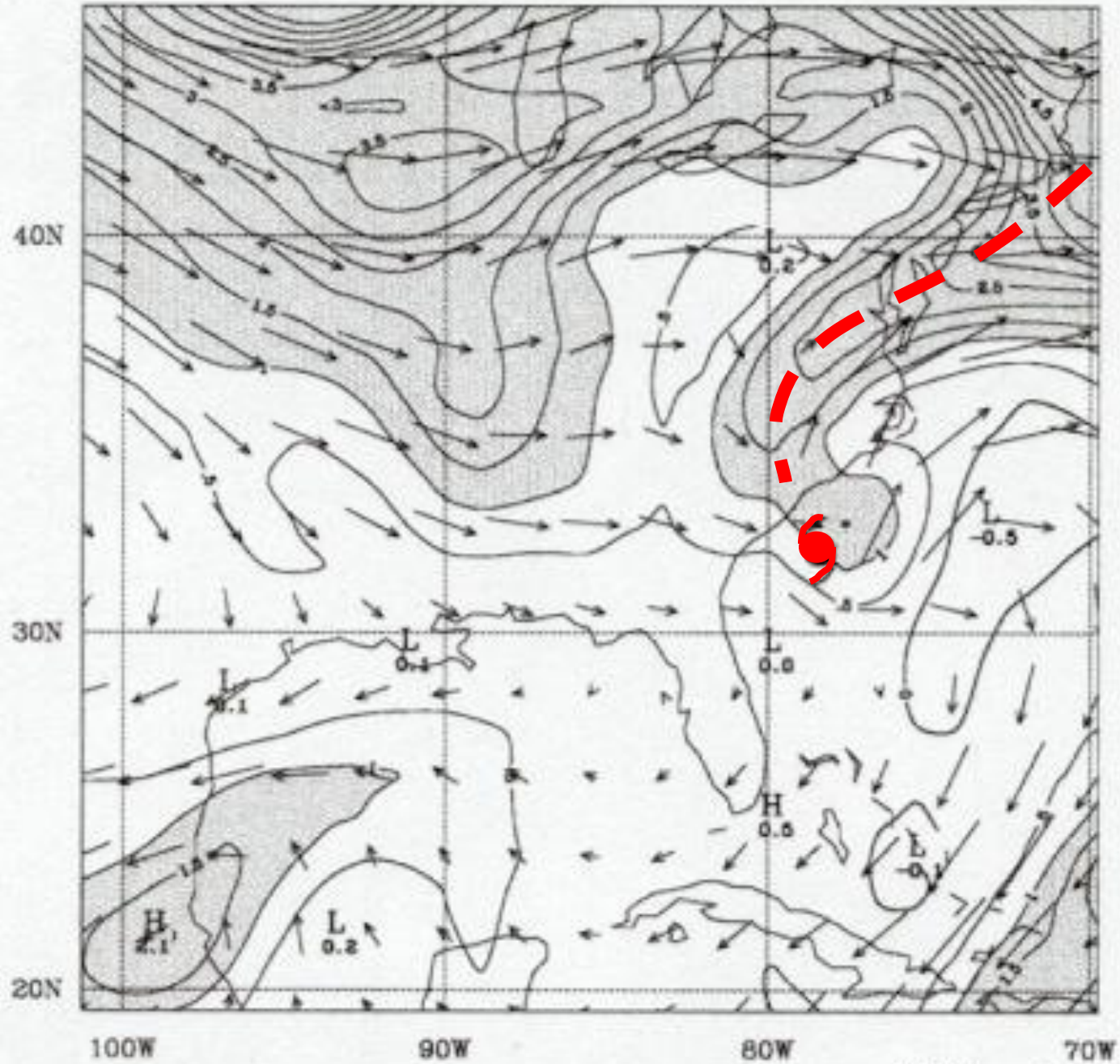
VERTICAL WIND SHEAR



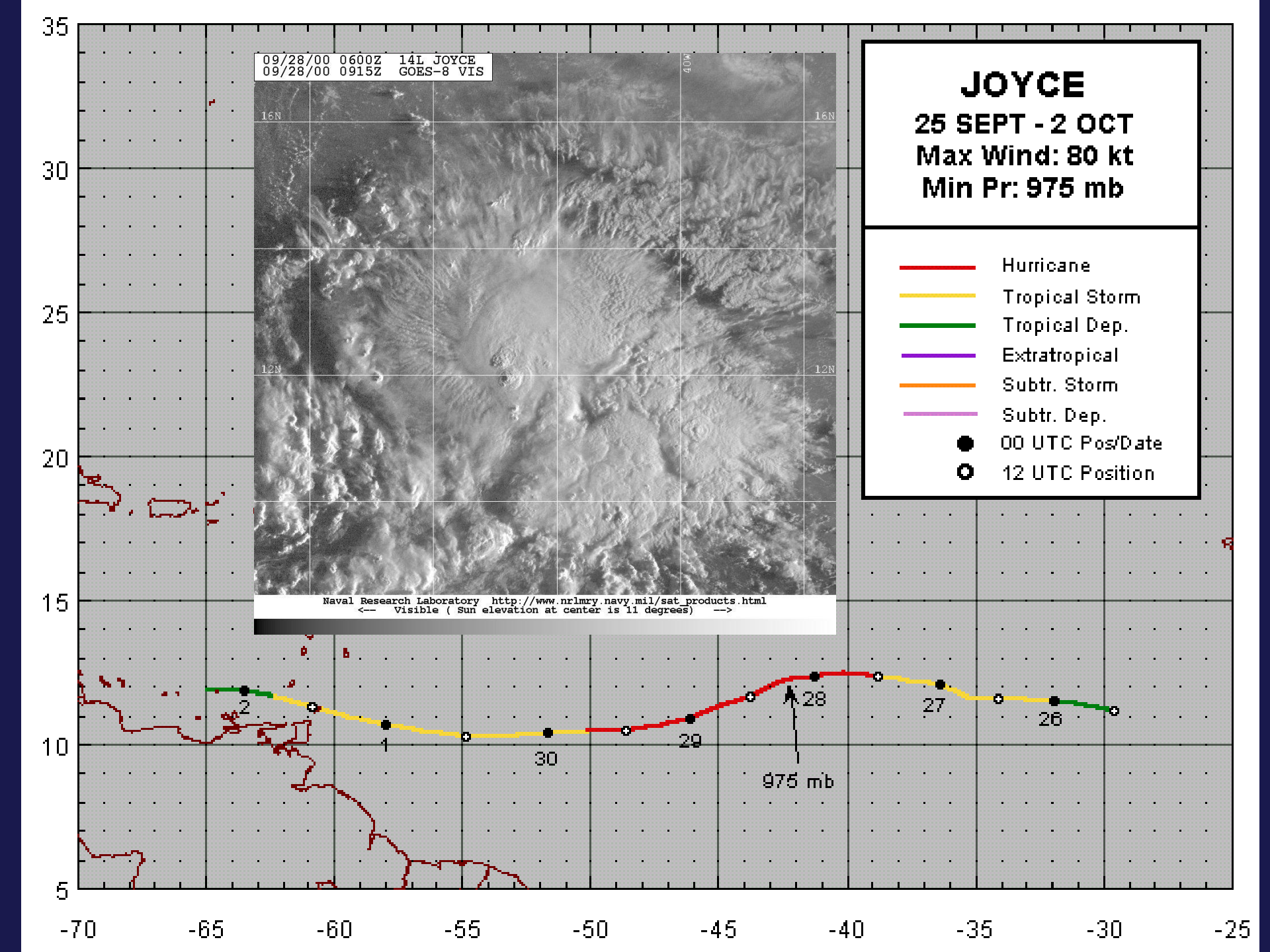
TROUGH INTERACTION: HURRICANE BERTHA, JULY 12 1996

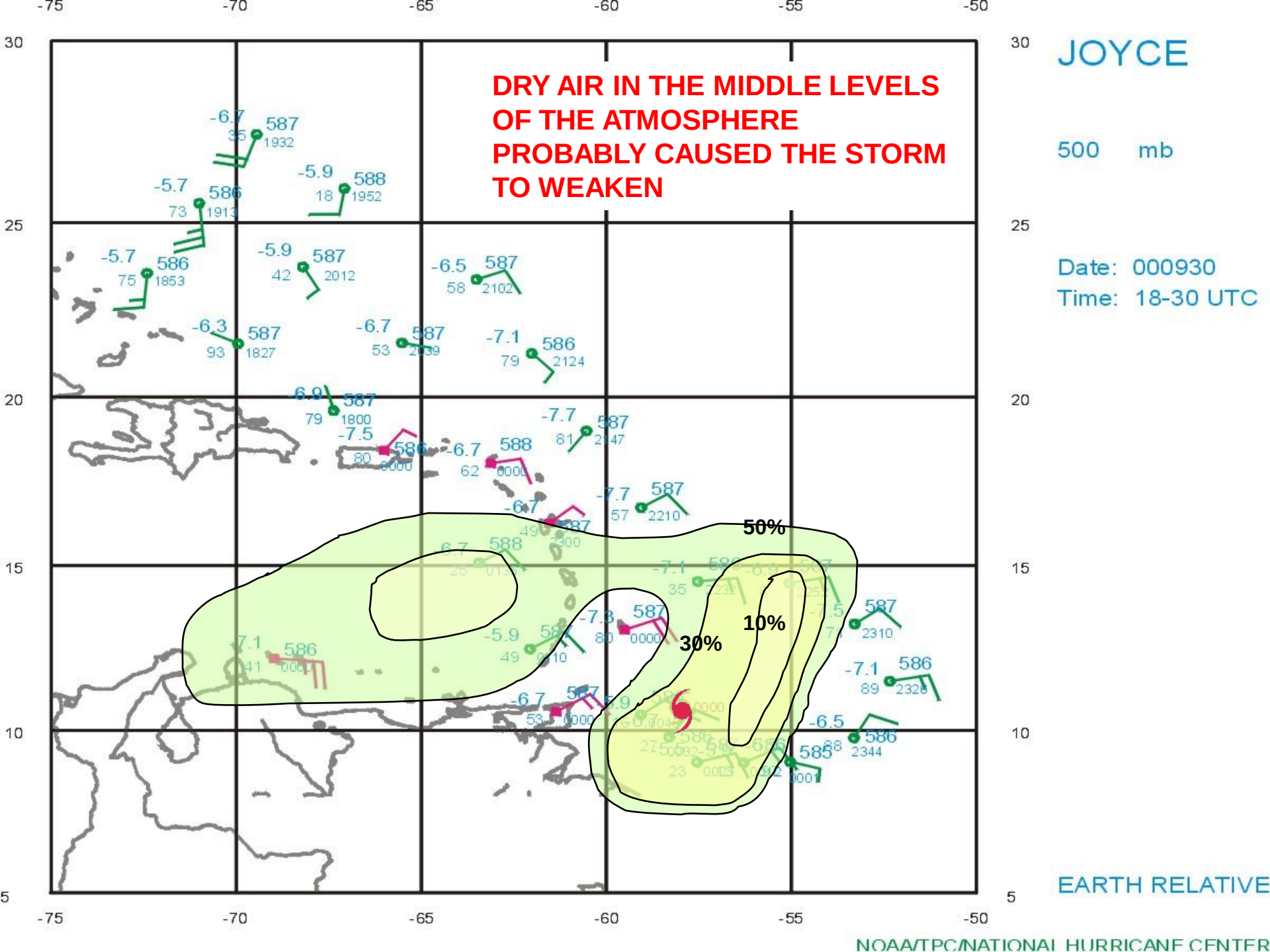


BERTHA RE-STRENGTHENED JUST BEFORE LANDFALL



1200 UTC


09/28/00 0600Z 14L JOYCE
09/28/00 0915Z GOES-8 VIS
16N
12N
40W
Naval Research Laboratory http://www.nrlmry.navy.mil/sat_products.html
<-- Visible (Sun elevation at center is 11 degrees) -->
JOYCE
25 SEPT - 2 OCT
Max Wind: 80 kt
Min Pr: 975 mb
Hurricane
Tropical Storm
Tropical Dep.
Extratropical
Subtr. Storm
Subtr. Dep.
00 UTC Pos/Date
12 UTC Position
2
1
30
29
28
975 mb
27
26
35
30
25
20
15
10
5
-70
-65
-60
-55
-50
-45
-40
-35
-30
-25


DRY AIR IN THE MIDDLE LEVELS
OF THE ATMOSPHERE
PROBABLY CAUSED THE STORM
TO WEAKEN
JOYCE
500 mb
Date: 000930
Time: 18-30 UTC
50%
30%
10%
EARTH RELATIVE
NOAA/TPC/NATIONAL HURRICANE CENTER

Eyewall Replacement Cycles

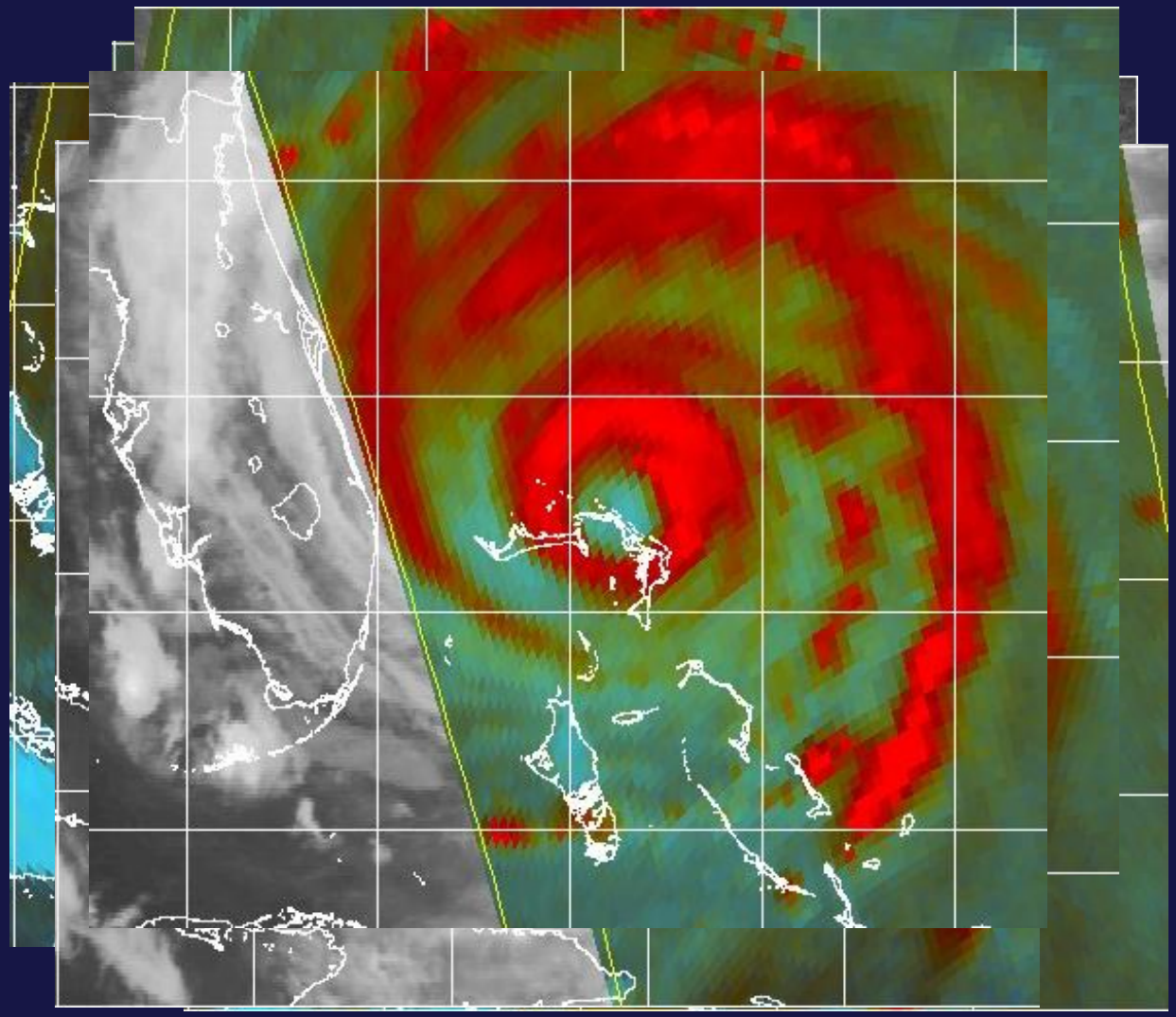
In addition to large-scale environmental influences, tropical cyclone intensity change can be caused by inner-core processes, such as eyewall replacement cycles:

In stronger hurricanes, we often see a concentric eyewall develop at a larger distance from the center than the radius of the original eyewall.

When this outer eyewall becomes dominant, some weakening usually occurs.

However, this outer eyewall could contract, in which case the hurricane would re-intensify.

CONCENTRIC EYEWALL CYCLE
HURRICANE FLOYD



13 / 0116Z

13 / 1122Z

13 / 1347Z

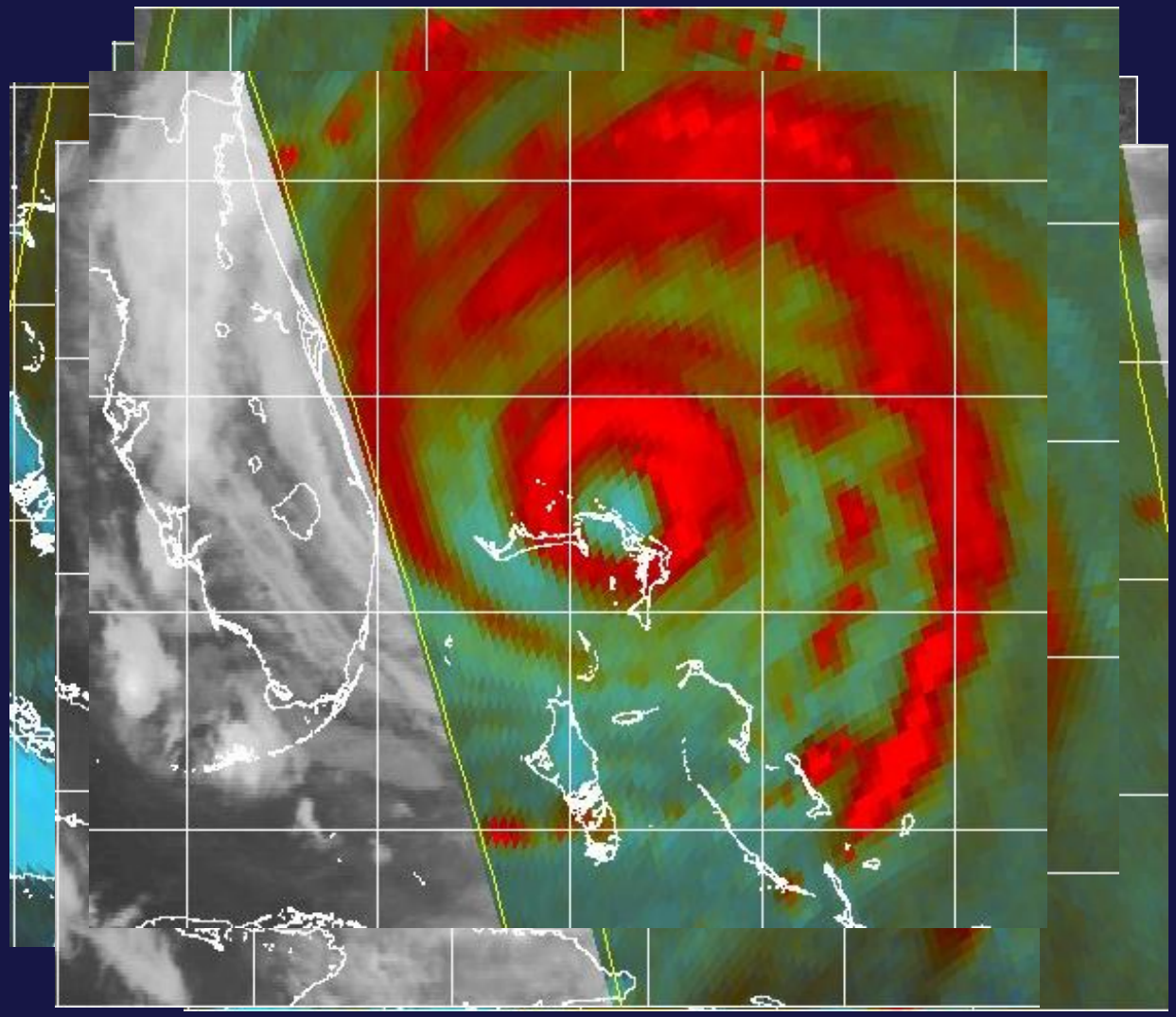
13 / 2240Z

14 / 0104Z

14 / 1110Z

14 / 2228Z

CONCENTRIC EYEWALL CYCLE
HURRICANE FLOYD



13 / 0116Z

13 / 1122Z

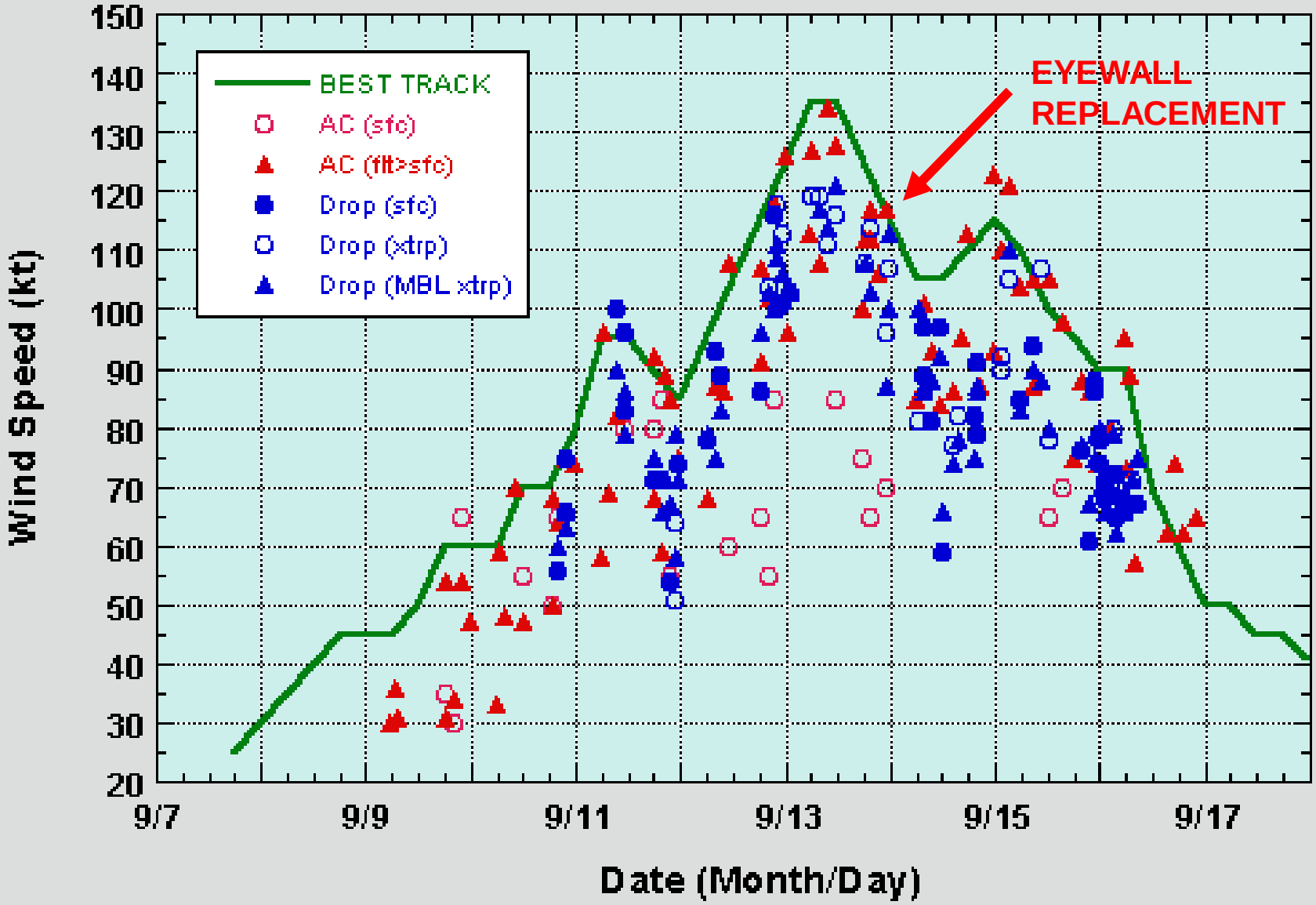
13 / 1347Z

13 / 2240Z

14 / 0104Z

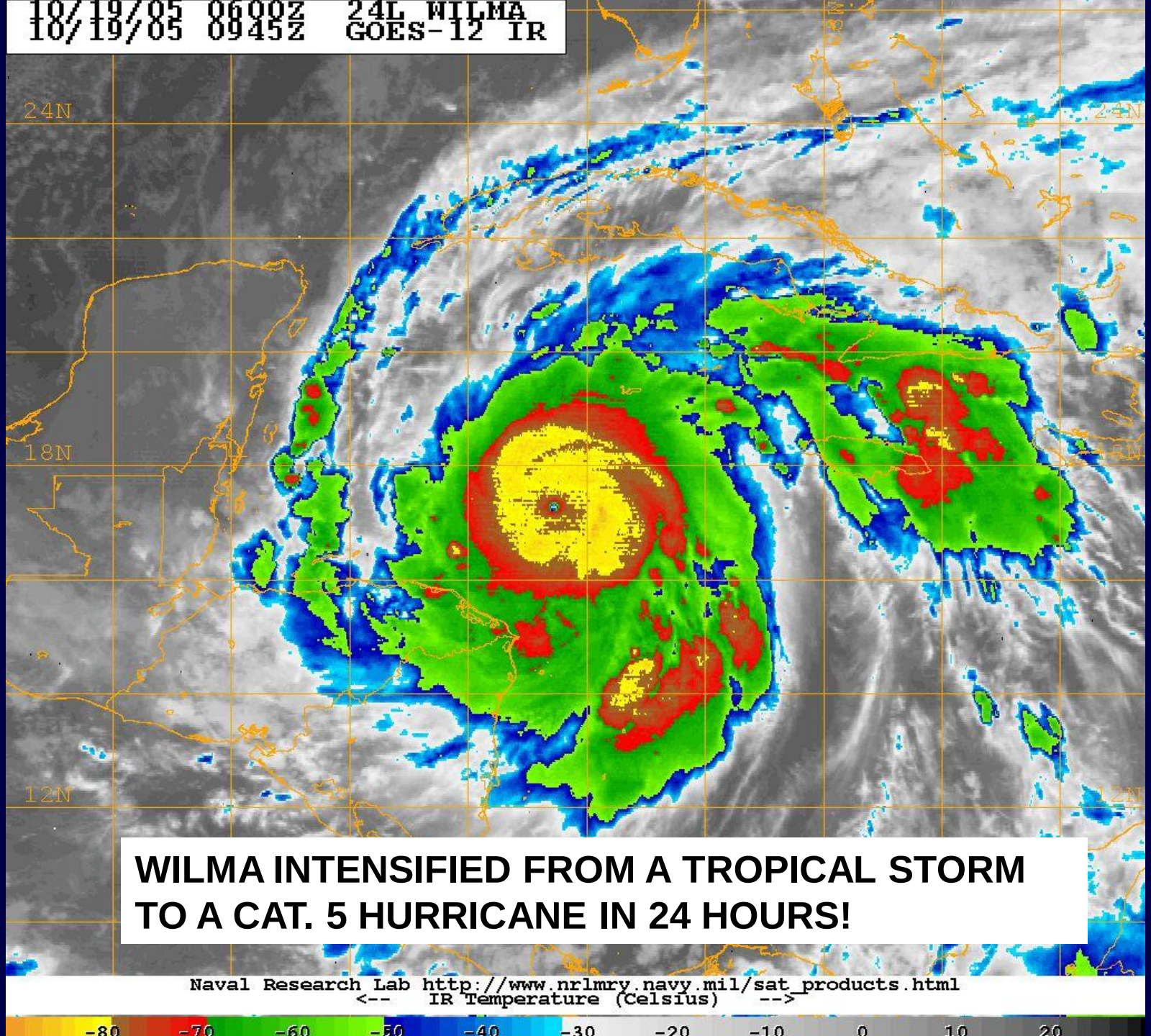
14 / 1110Z

14 / 2228Z


Best Track Intensity - Hurricane Floyd
September 1999
BEST TRACK
AC (sfc)
AC (flt>sfc)
Drop (sfc)
Drop (xtrp)
Drop (MBL xtrp)
EYEWALL
REPLACEMENT
Wind Speed (kt)
150
140
130
120
110
100
90
80
70
60
50
40
30
20
9/7
9/9
9/11
9/13
9/15
9/17
Date (Month/Day)

TROPICAL CYCLONE INTENSITY FORECAST MODELS

- **Statistical Models:**
  - **Decay SHIFOR** (Statistical Hurricane Intensity FORecast with inland decay).
    - Based on historical information - climatology and persistence (uses CLIPER track).
    - Measure of skill of intensity forecasts
- **Statistical/Dynamical Models:**
  - **SHIPS** (Statistical Hurricane Intensity Prediction Scheme):
    - Based on climatology, persistence, and statistical relationships to current and forecast environmental conditions.
  - **DSHIPS** (Decay SHIPS):
    - Same as SHIPS except when track forecast points are over land – when a decrease in intensity following an inland decay model is included.
  - **LGEM** (Logistics Growth Equation Model – from SHIPS)
    - Uses the same predictors as SHIPS but uses them in a different way – similar to population growth where there is a limiting capacity to grow
- **Dynamical Models:**
  - **HWRF, GFDL, GFDN, GFS, UKMET, NOGAPS.**
    - Based on the present and the future by solving the governing equations for the atmosphere (and ocean).


10/19/05 0600Z 24L WILMA
10/19/05 0945Z GOES-12 IR
24N
18N
12N
WILMA INTENSIFIED FROM A TROPICAL STORM
TO A CAT. 5 HURRICANE IN 24 HOURS!
Naval Research Lab http://www.nrlmry.navy.mil/sat_products.html
<-- IR Temperature (Celsius) -->
-80 -70 -60 -50 -40 -30 -20 -10 0 10 20

A STATISTICAL TECHNIQUE TO AID IN THE FORECAST OF RI :

The 7 predictors used to estimate the probability of Rapid Intensification (defined as an increase in maxwind speed of at least 25 kt over 24 h):

Predictor	Definition
PER	Previous 12 h intensity change
SHR	850-200 mb vertical shear
D200	200 mb divergence
POT	Maximum Potential Intensity (a function of SST) minus Current Intensity
RHLO	850-700 mb relative humidity
STDIR	Standard deviation of IR brightness temperature
PIX	Percentage of GOES pixels colder than -30 C

VERIFYING: 160 KNOTS

```
*    ATLANTIC SHIPS INTENSITY FORECAST        *
*         GOES/OHC INPUT INCLUDED             *

                    WILMA  10/18/05  18 UTC

TIME (HR)          0     6    12    18    24    36    48    60    72    84    96   108   120
V (KT) NO LAND    70    75    81    86    92   100   105   108   109   106   101    92    80
V (KT) LAND       70    75    81    86    92   100   105   108   109   106   101    67    61
```

```
** 2005 ATLANTIC RAPID INTENSITY INDEX **
( 25 KT OR MORE MAX WIND INCREASE IN NEXT 24 HR)

                    WILMA     10/18/05     18 UTC

 12 HR PERSISTENCE (KT): Value:  10.0 Range: -20.0 to  25.0 Scaled value:  0.90
 850-200 MB SHEAR (KT) : Value:   8.1 Range:  42.5 to   2.5 Scaled value:  0.86
 SST (C)               : Value:  29.3 Range:  24.3 to  30.4 Scaled value:  0.82
 POT = MPI-VMAX (KT)   : Value:  92.0 Range:  27.1 to 136.4 Scaled value:  0.59
 850-700 MB REL HUM (%): Value:  81.6 Range:  57.0 to  88.0 Scaled value:  0.79
 % area w/pixels <-30 C: Value:  98.0 Range:  17.0 to 100.0 Scaled value:  0.98
 STD DEV OF IR BR TEMP : Value:  15.8 Range:  37.5 to   8.0 Scaled value:  0.74

 Scaled RI index=  5.68 Prob of RI= 59.4% is   4.9 times the sample mean(12.1%)
```

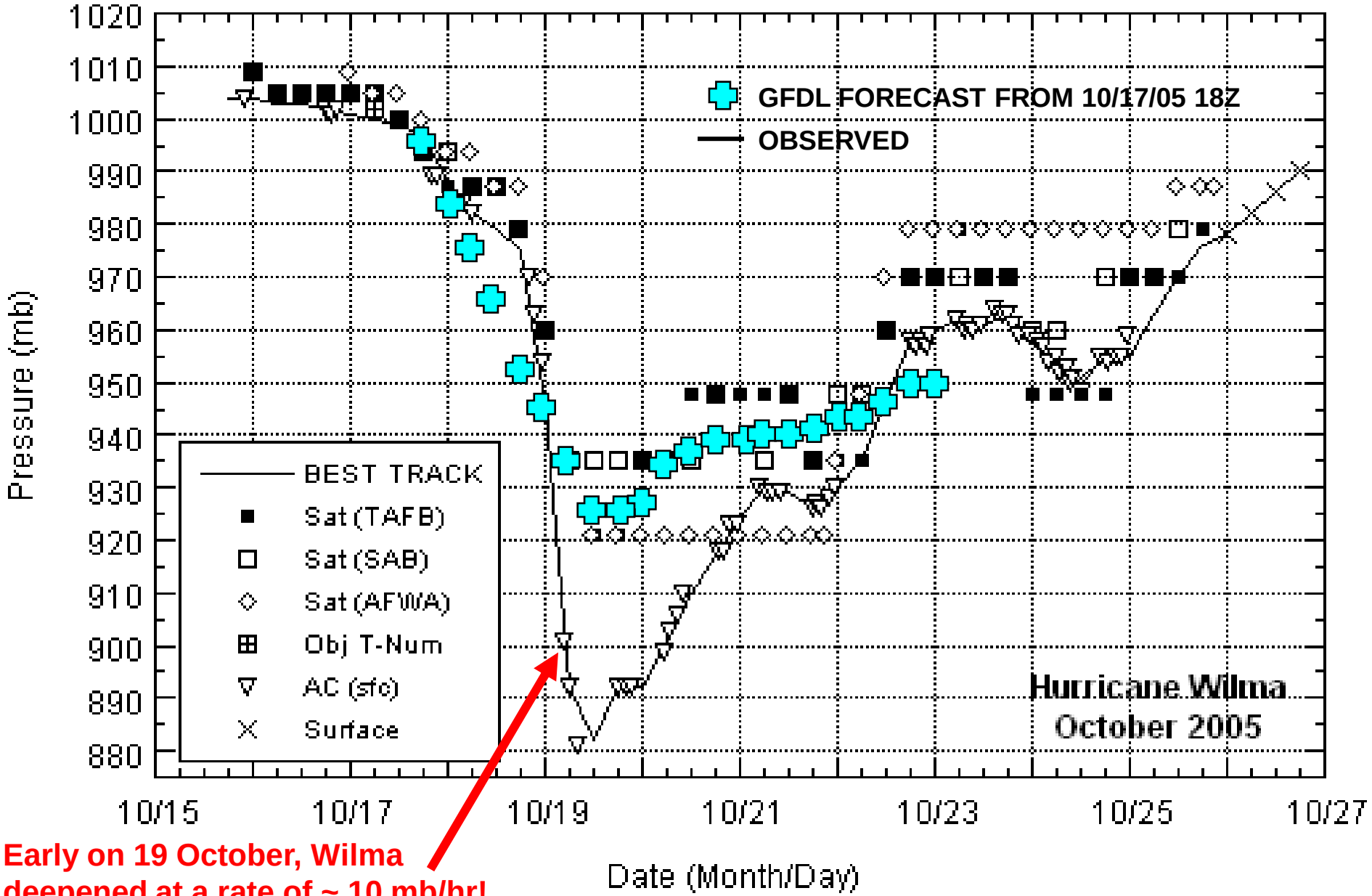
OFFICIAL FORECAST CALLED FOR 90-100 KNOTS IN 12-24 HOURS

INITIAL 18/2100Z 16.7N 81.5W 70 KT
12HR VT 19/0600Z 17.3N 82.3W 90 KT
24HR VT 19/1800Z 18.2N 83.5W 100 KT
36HR VT 20/0600Z 19.1N 84.5W 110 KT
48HR VT 20/1800Z 20.2N 85.2W 115 KT
72HR VT 21/1800Z 22.5N 85.5W 110 KT
96HR VT 22/1800Z 25.0N 82.5W 100 KT
20HR VT 23/1800Z 30.5N 75.5W 70 KT

TC INTENSITY DYNAMICAL FORECAST MODELS

- **HWRF, GFDL, NCEP Global Model (GFS), UKMET (U.K. Met Office), NOGAPS (U.S. Navy), ECMWF (European)**
- **These models are of limited use, because of…**
  - **sparse observations.**
  - **inadequate resolution (need to go down to a few km grid spacing; the HWRF and GFDL, our highest-resolution operational hurricane models, are currently about 9 km).**
  - **incomplete understanding and simulation of basic physics of intensity change.**
  - **biases in upper-level wind forecasts.**
    - **(becoming less of a problem)**

GFDL model did capture some of Wilma's rapid deepening.



Early on 19 October, Wilma deepened at a rate of ~ 10 mb/hr!

FOR TPC/NHC IN HOUSE USE ONLY!!!!!!!

ATTENTION...NATIONAL HURRICANE CENTER

NCEP COUPLED GFDL HURRICANE MODEL FORECAST MADE FOR

TROPICAL STORM PHILIPPE 17L

INITIAL TIME 18Z SEP 18

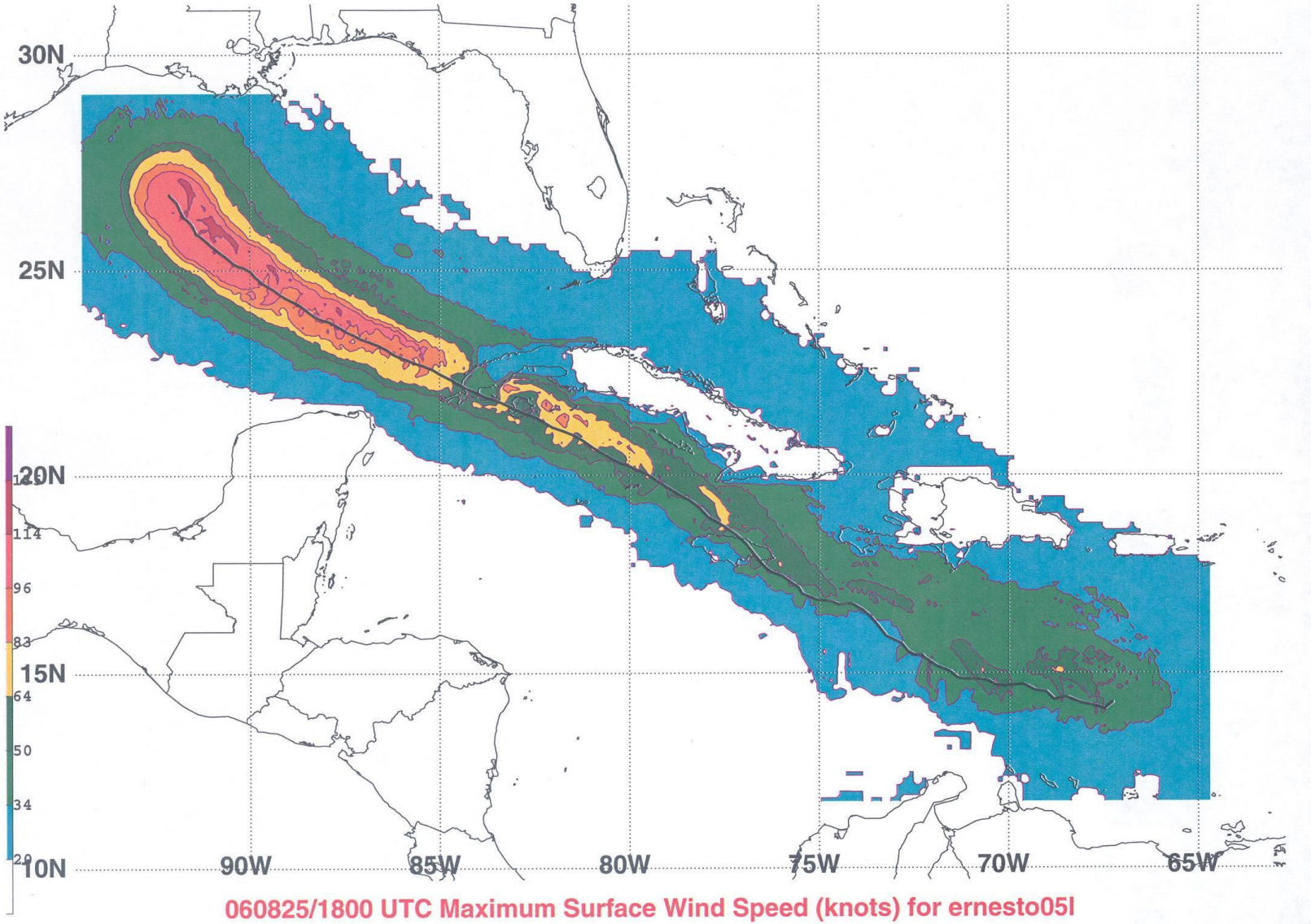
DISCLAIMER ... THIS INFORMATION IS PROVIDED AS GUIDANCE. IT REQUIRES INTERPRETATION BY HURRICANE SPECIALISTS AND SHOULD NOT BE CONSIDERED AS A FINAL PRODUCT. PLEASE SEE THE TPC/NHC OFFICIAL FORECAST.

FORECAST STORM POSITION

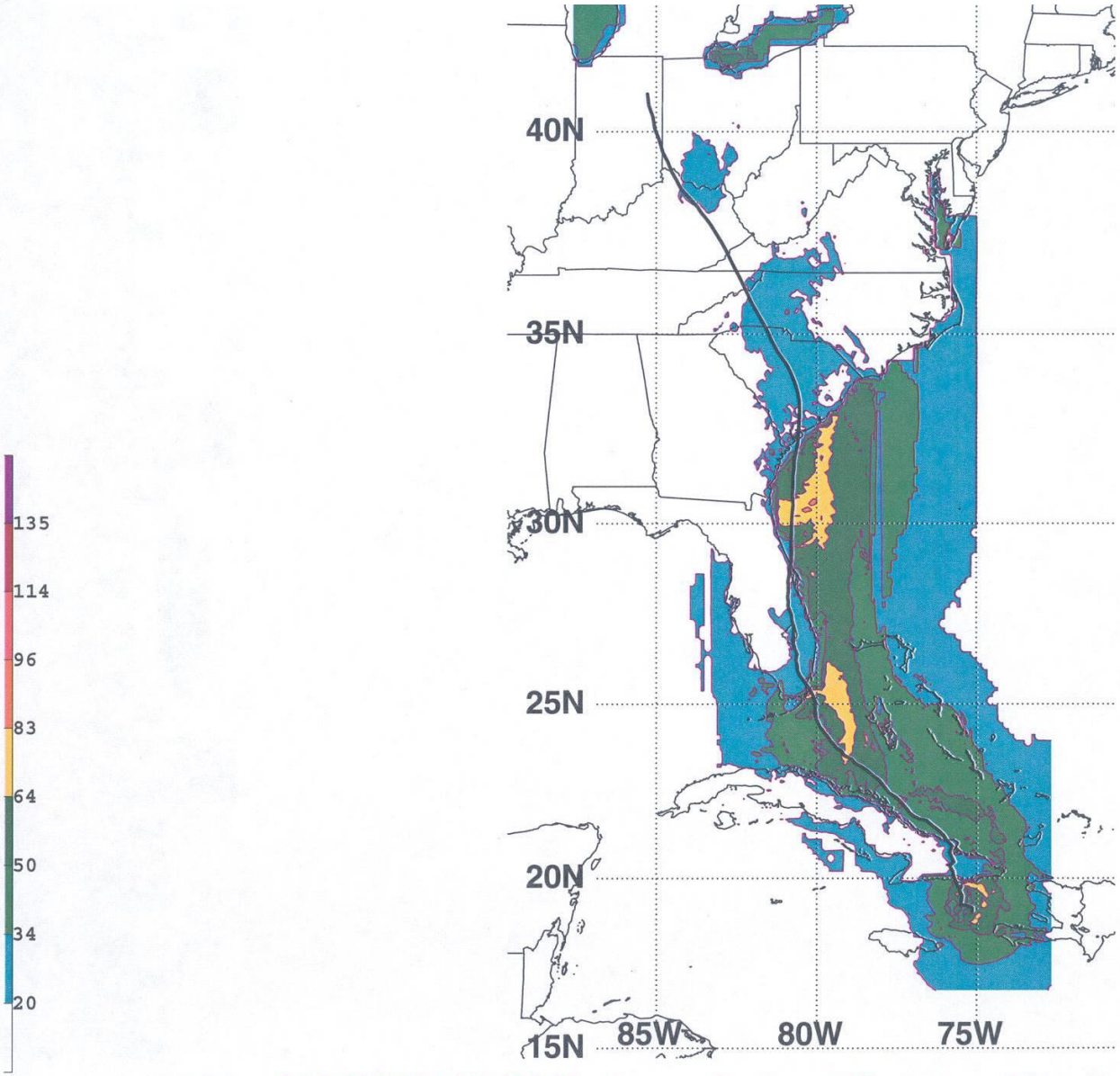
HOUR	LAT	LONG	PRES	WIND	DIR/SPD
				observed	
0	15.5	-55.8	1001	51	340/7
6	15.8	-56.1	995	59	308/4
12	16.2	-56.5	987	63	318/6
18	16.7	-57.0	974	80	316/7
24	17.0	-57.4	963	94 65	311/4
30	17.3	-57.8	963	96	307/5
36	17.8	-58.2	957	100	317/6
42	18.1	-58.5	951	100	319/4
48	18.5	-58.5	942	110 55	4/4
54	19.1	-58.4	946	111	11/6
60	19.7	-58.5	946	106	350/6
66	20.4	-58.4	943	114	6/7
72	21.2	-58.3	941	110 40	8/8
78	21.9	-58.2	940	112	2/7
84	22.7	-58.5	944	107	341/8
90	23.5	-58.8	946	103	342/8
96	24.4	-59.0	948	105	343/9
102	25.0	-59.2	950	100	348/6
108	25.7	-59.3	954	92	348/7
114	26.5	-59.3	955	93	5/8
120	27.4	-59.0	956	91 30	16/10
126	28.5	-58.4	956	92	28/12

observed: dissipated

Early GFDL forecasts for Ernesto showed a strong hurricane in the middle of the Gulf (Category 4 in this case).



Later on, the GFDL track was much better, but it depicted Ernesto reaching southeast Florida and the Carolinas as a hurricane.

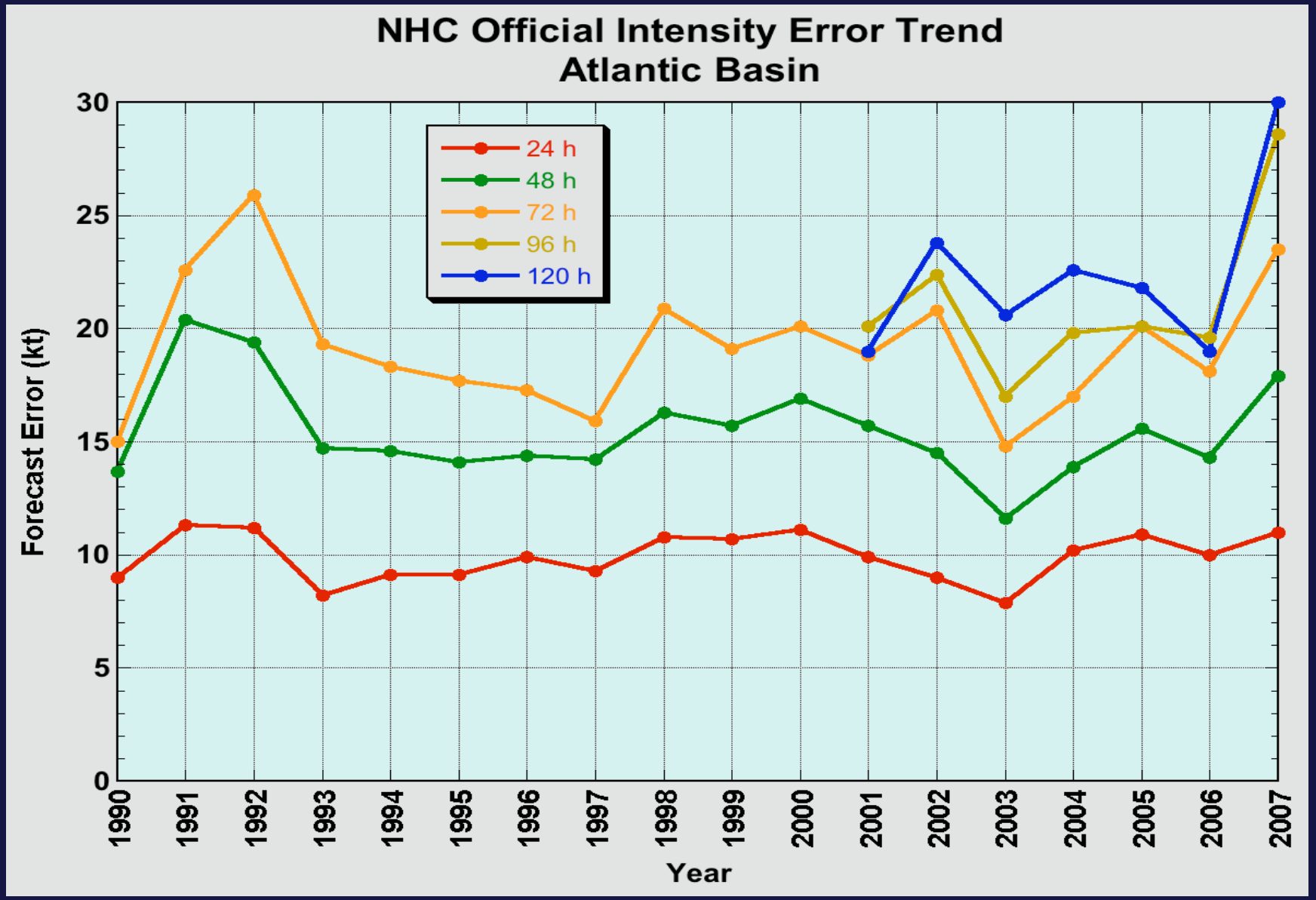


060828/0600 UTC Maximum Surface Wind Speed (knots) for ernesto05l

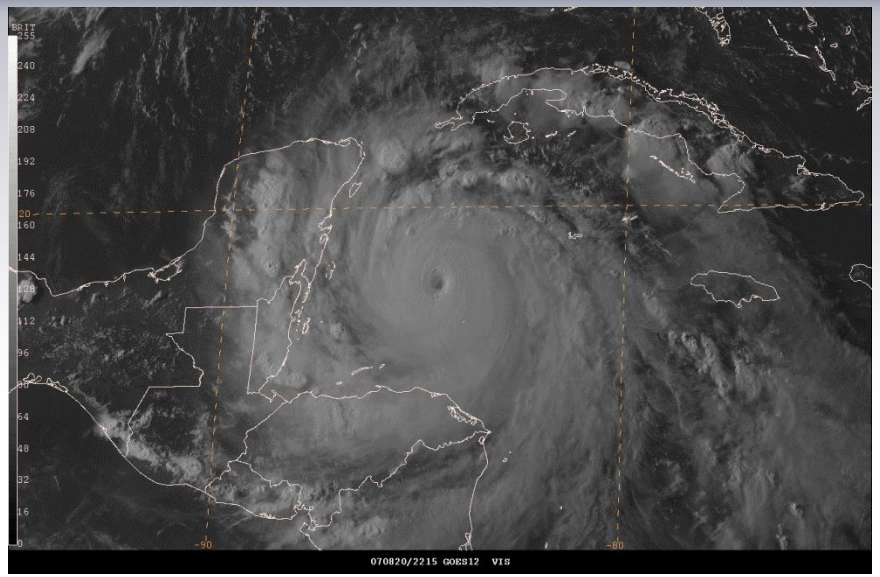
NHC OFFICIAL INTENSITY FORECAST

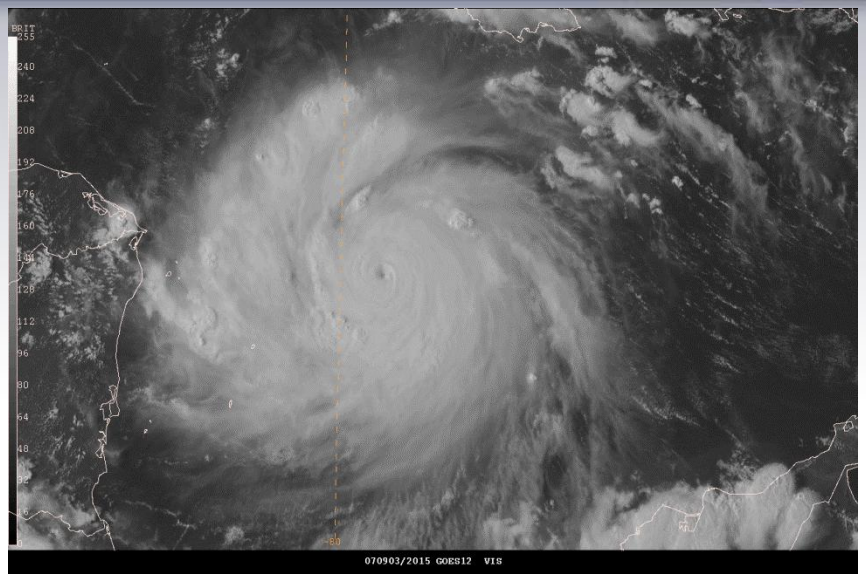
- **Based on statistical guidance from SHIPS and D-SHIFOR, qualitative guidance from dynamical models.**
- **Persistence is used quite a bit!**
- **Obvious signs in the environment, i.e. cooler waters, increasing upper-level winds, are taken into account.**
- **Generally corresponds to what is *normal* for a storm in any particular situation (e.g. the standard Dvorak development rate).**
- **Tends to be conservative; *extreme events are almost never forecast.***
- **For forecasts 24 h and beyond, the average error is roughly 1 SSHS Category (15-20 knots).**

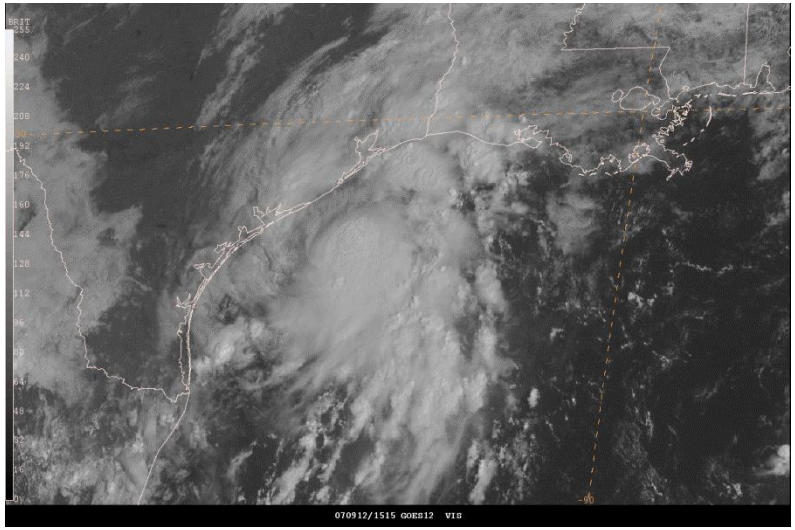
NO ~~Little~~ progress with intensity



Intensity Forecasting Guidance from 2008







Intensity forecasts for Hurricane Dean

NCEP COUPLED GFDL HURRICANE MODEL FORECAST MADE FOR HURRICANE DEAN 04L

INITIAL TIME 12Z AUG 16

HOUR	LAT	LONG	PRES	WIND	DIR/SPD
0	13.5	-53.3	990	76	275/21
6	13.9	-55.4	989	81	280/20
12	14.3	-57.3	986	85	282/19
18	14.5	-59.6	985	86	277/22
24	14.7	-61.8	987	78	273/21
30	15.2	-63.9	982	85	283/21
36	15.2	-65.8	978	80	271/18
42	15.4	-67.5	972	89	277/17
48	15.8	-69.3	964	101	283/17
54	16.2	-71.1	965	98	281/18
60	16.6	-72.9	960	99	282/18
66	17.0	-74.7	952	114	283/17
72	17.6	-76.5	945	118	289/18
78	18.2	-78.5	951	114	287/20
84	18.8	-80.1	949	118	289/16
90	19.5	-81.8	939	123	292/18
96	20.4	-83.3	925	135	301/18
102	21.4	-84.8	923	139	304/17
108	22.6	-86.2	916	142	311/17
114	23.8	-87.7	916	143	307/18
120	**25.0**	**-89.1**	**913**	**142**	**312/18**
126	26.2	-90.5	913	139	311/17

Missed 1st Intensification
130 kt oper
145 kt post

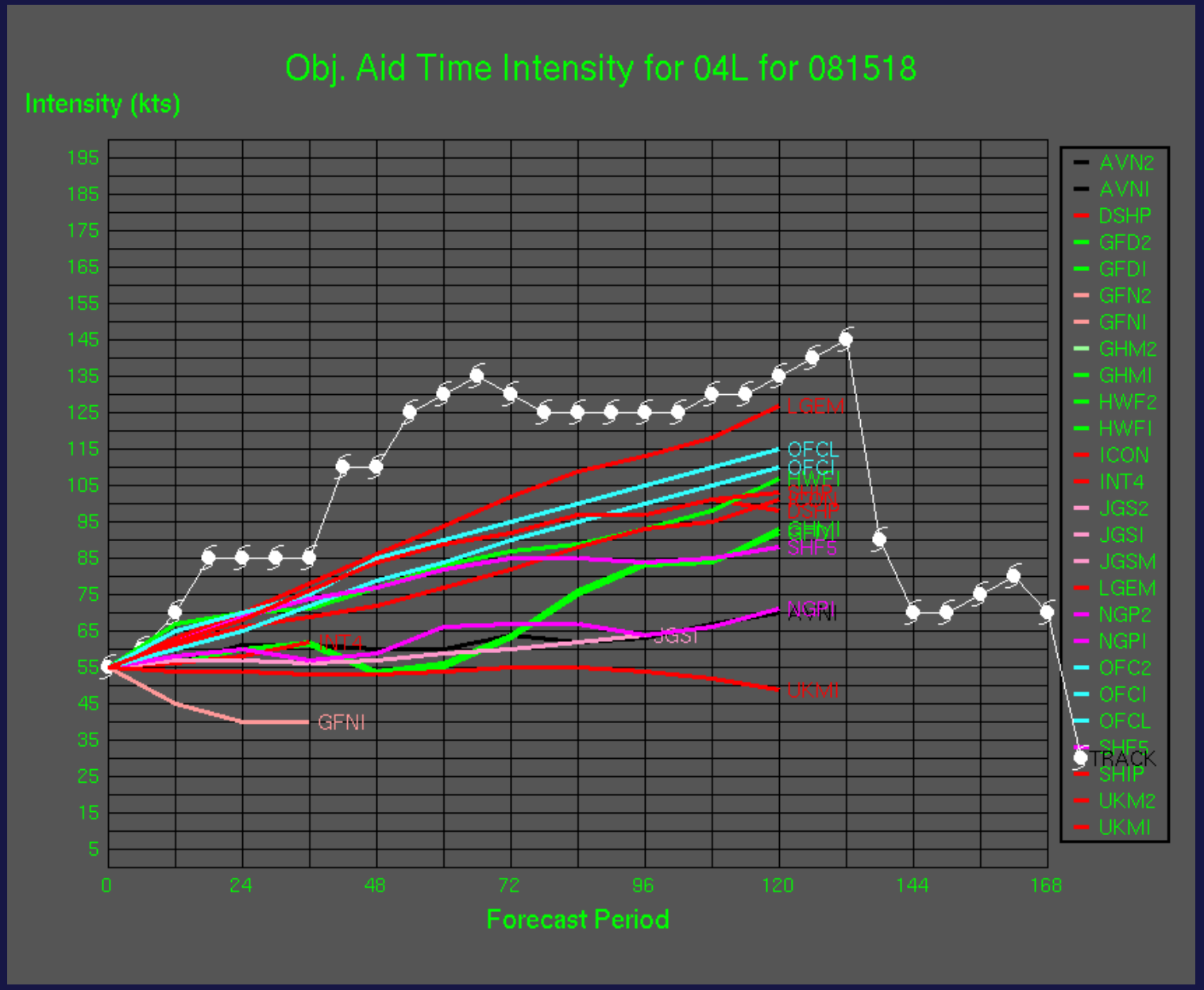
Hit 2nd Intensification
145 kt oper
150 kt post

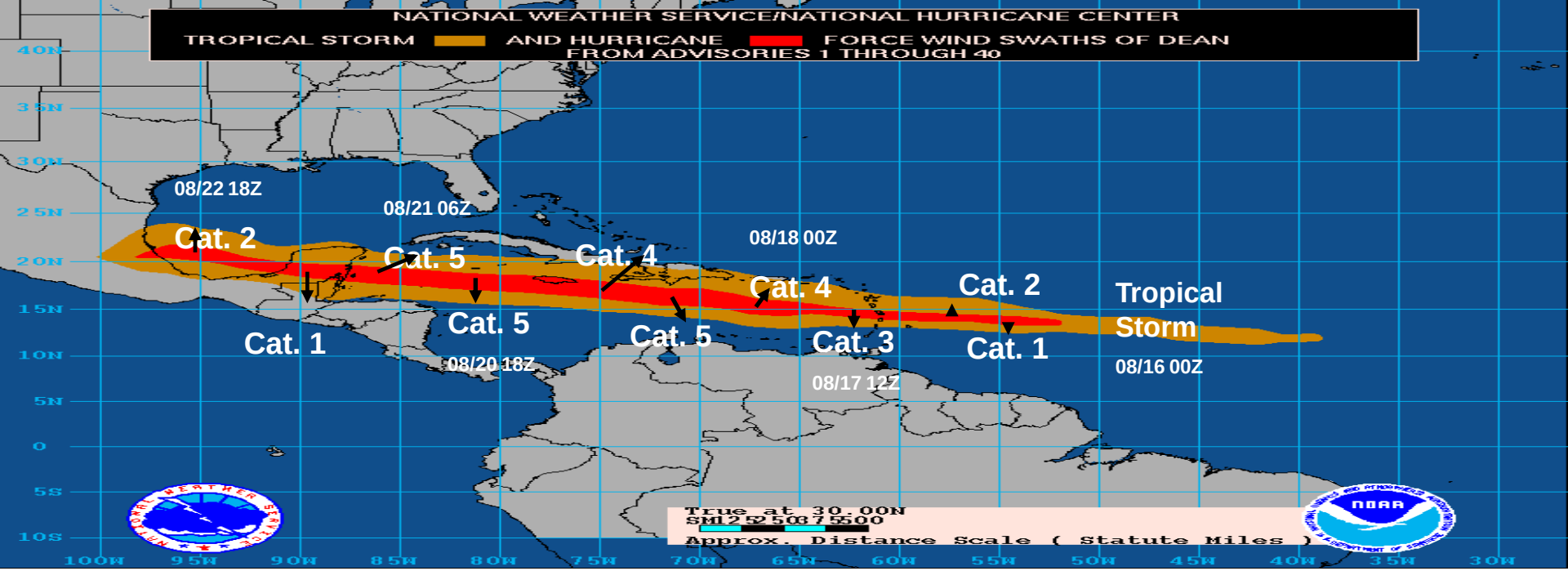
NCEP COUPLED HWRF HURRICANE MODEL FORECAST MADE FOR HURRICANE DEAN 04L

INITIAL TIME 12Z AUG 16

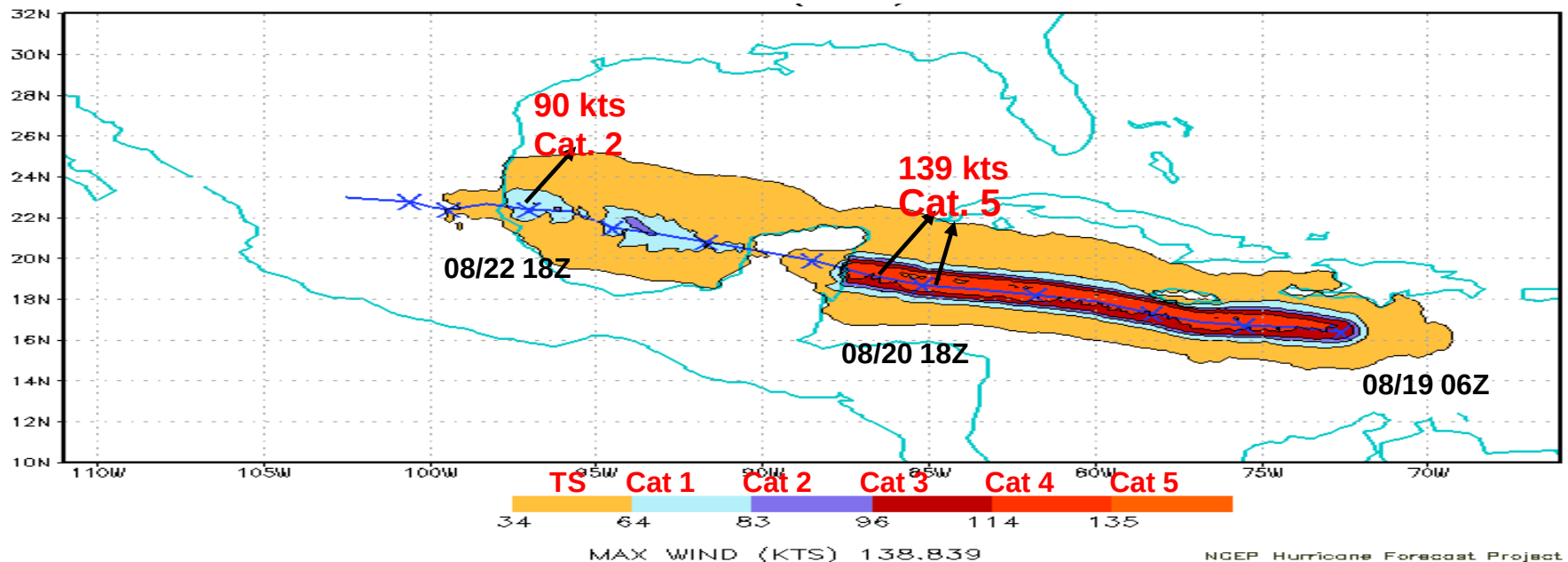
HOUR	LAT	LON	PRES	WIND	DIR/SPD
0	13.6	-53.6	982	78	275/21
6	13.8	-55.9	980	69	275/22
12	14.2	-57.9	980	78	281/20
18	14.4	-60.2	967	90	275/22
24	14.8	-62.1	962	87	282/19
30	15.1	-64.0	957	85	279/19
36	15.5	-65.8	948	93	283/18
42	15.8	-67.4	940	102	281/16
48	16.1	-68.9	933	115	281/15
54	16.4	-70.3	928	110	282/14
60	16.5	-71.5	926	114	275/12
66	16.6	-72.8	919	121	274/12
72	16.9	-74.1	921	117	283/13
78	17.5	-75.4	914	132	295/14
84	18.1	-77.0	919	118	291/16
90	18.6	-78.6	921	121	287/16
96	19.0	-80.1	905	135	285/15
102	19.4	-81.7	899	127	284/16
108	19.8	-83.0	898	132	287/13
114	20.3	-84.3	889	135	291/13
120	**21.0**	**-85.5**	**888**	**145**	**300/13**
126	21.6	-86.9	890	138	293/14

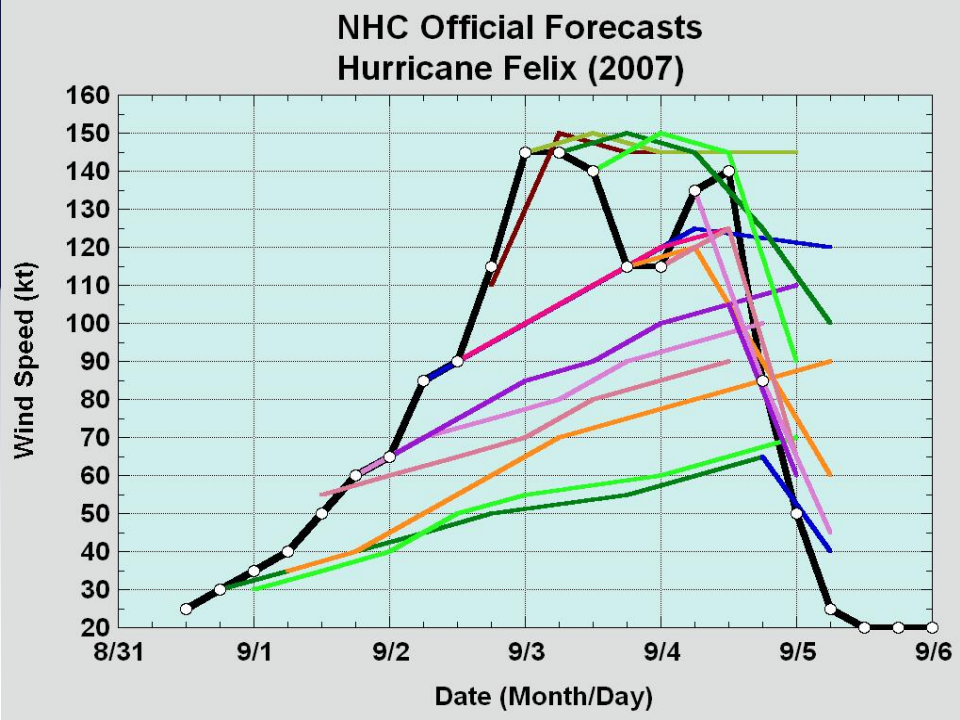
DEAN

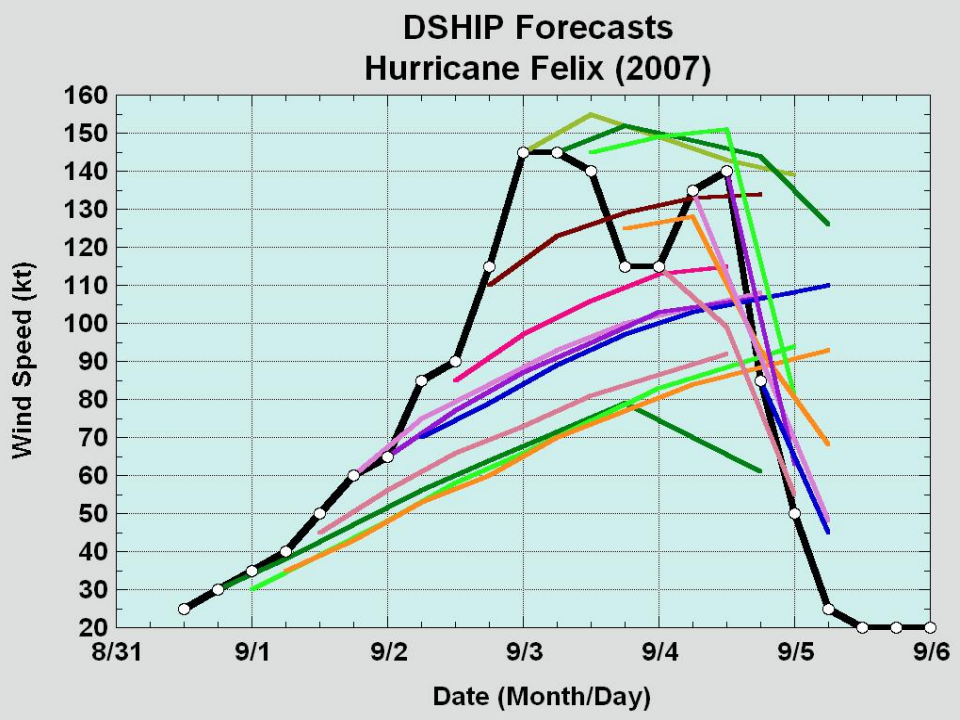

Obj. Aid Time Intensity for 04L for 081518
Intensity (kts)
195
185
175
165
155
145
135
125
115
105
95
85
75
65
55
45
35
25
15
5
0
24
48
72
96
120
144
168
Forecast Period
LGEM
OFCL
OFCI
HWFI
DSHP
GHMI
SHF5
NGPI
AVNI
JGSI
INT4
UKMI
GFNI
AVN2
AVNI
DSHP
GFD2
GFDI
GFN2
GFNI
GHM2
GHMI
HWF2
HWFI
ICON
INT4
JGS2
JGSI
JGSM
LGEM
NGP2
NGPI
OFC2
OFCI
OFCL
SHF5
SHIP
UKM2
UKMI
TRACK

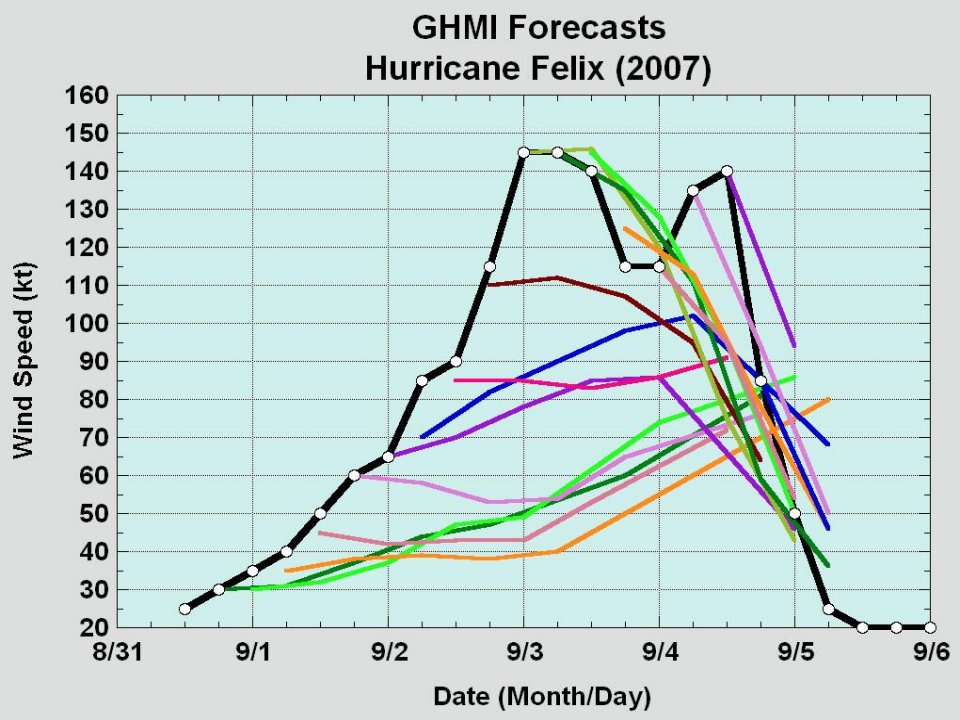


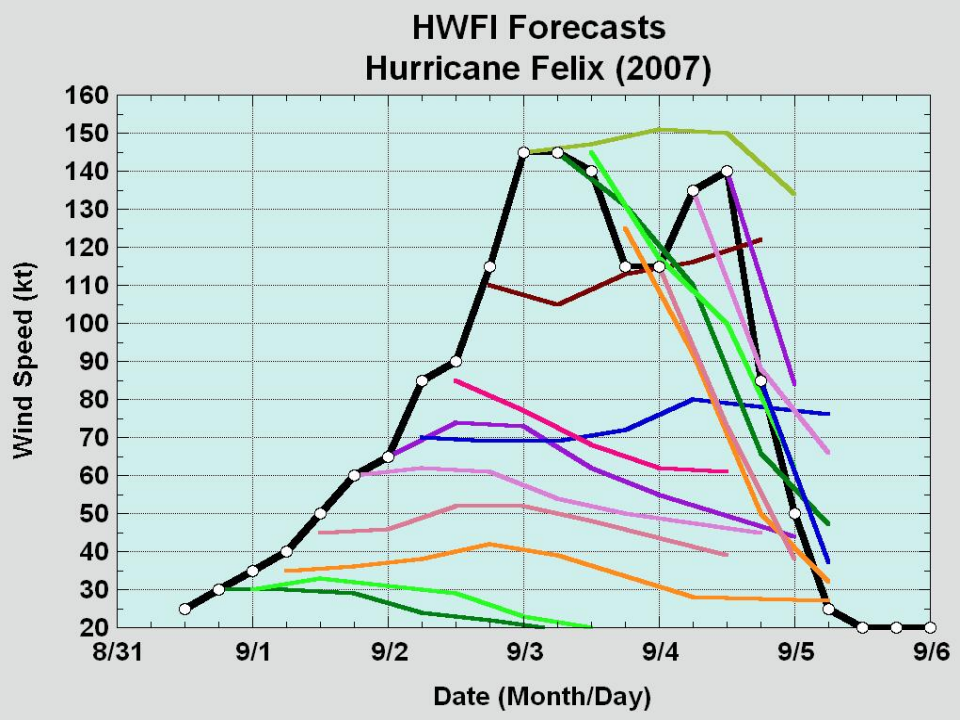
Hurricane Dean 5 day HWRF forecasts of max. winds starting from 8/19/06Z



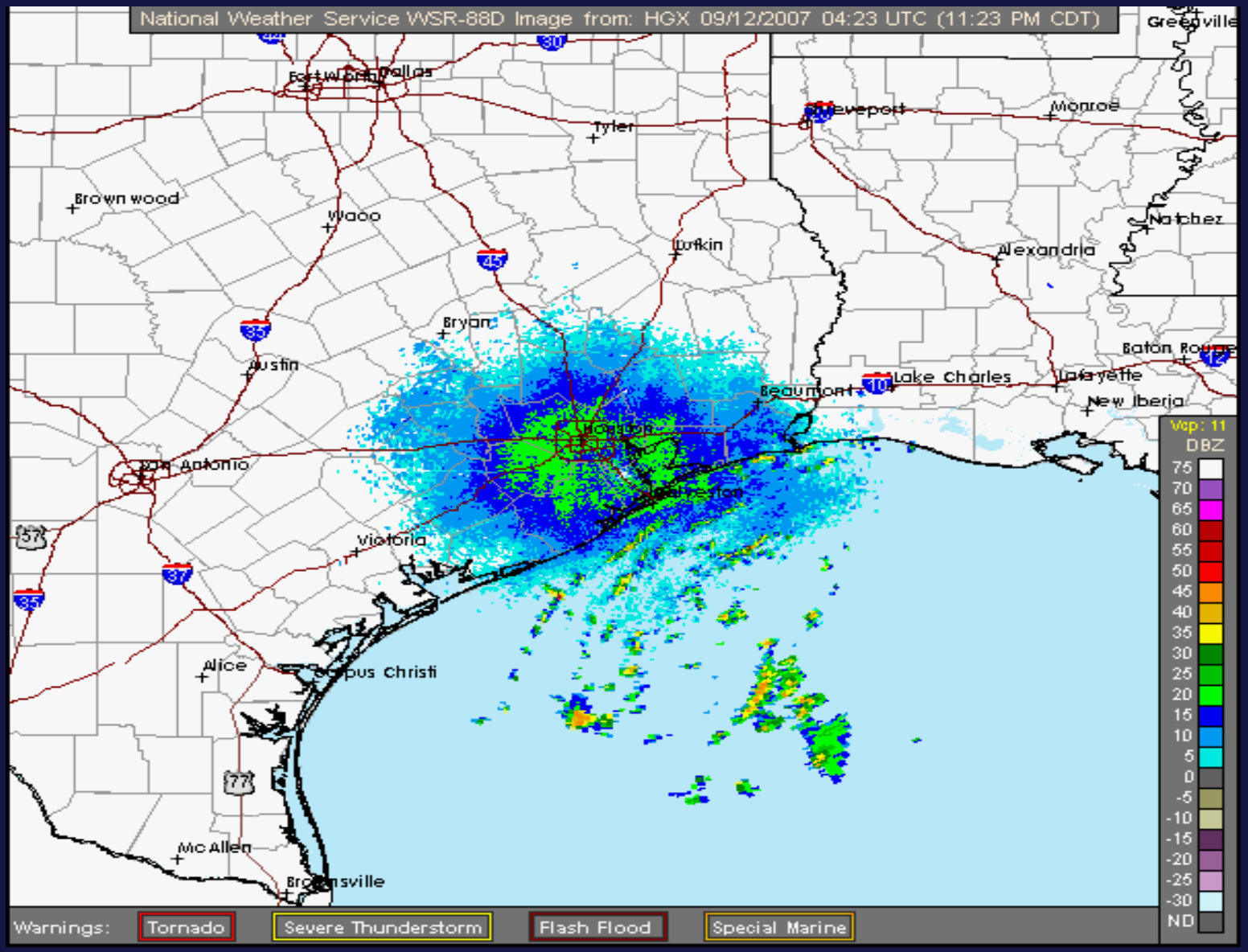

NHC Official Forecasts
Hurricane Felix (2007)
Wind Speed (kt)
Date (Month/Day)
8/31
9/1
9/2
9/3
9/4
9/5
9/6


DSHIP Forecasts
Hurricane Felix (2007)
Wind Speed (kt)
Date (Month/Day)
8/31
9/1
9/2
9/3
9/4
9/5
9/6

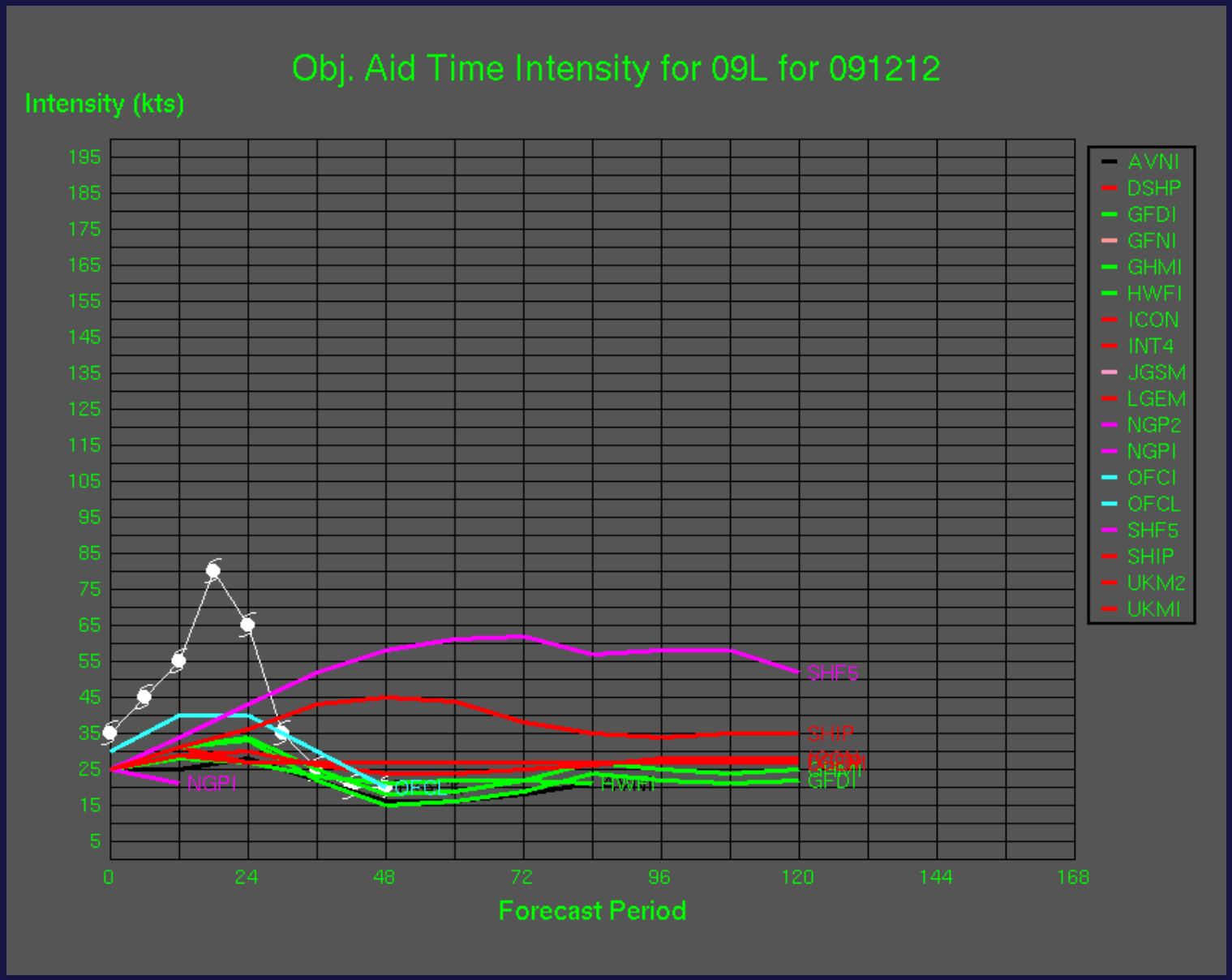

GHMI Forecasts
Hurricane Felix (2007)
Wind Speed (kt)
Date (Month/Day)
8/31
9/1
9/2
9/3
9/4
9/5
9/6


HWFI Forecasts
Hurricane Felix (2007)
Wind Speed (kt)
Date (Month/Day)
8/31
9/1
9/2
9/3
9/4
9/5
9/6

Humberto intensified from a TD to a hurricane in 18 hours!



HUMBERTO

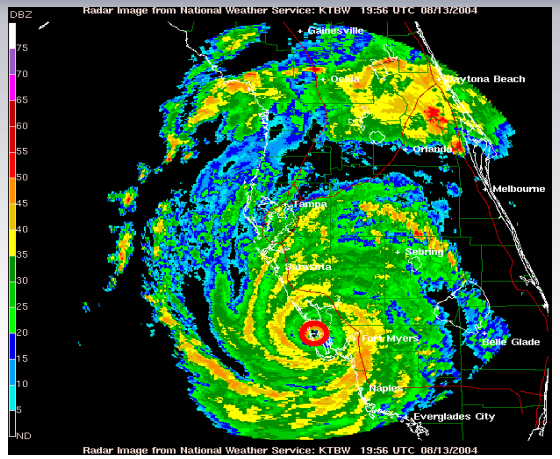

Obj. Aid Time Intensity for 09L for 091212
Intensity (kts)
195
185
175
165
155
145
135
125
115
105
95
85
75
65
55
45
35
25
15
5
0
24
48
72
96
120
144
168
Forecast Period
AVNI
DSHP
GFDI
GFNI
GHMI
HWFI
ICON
INT4
JGSM
LGEM
NGP2
NGPI
OFCI
OFCL
SHF5
SHIP
UKM2
UKMI
SHF5
SHIP
NGPI
OFCL
AVNI
GFDI

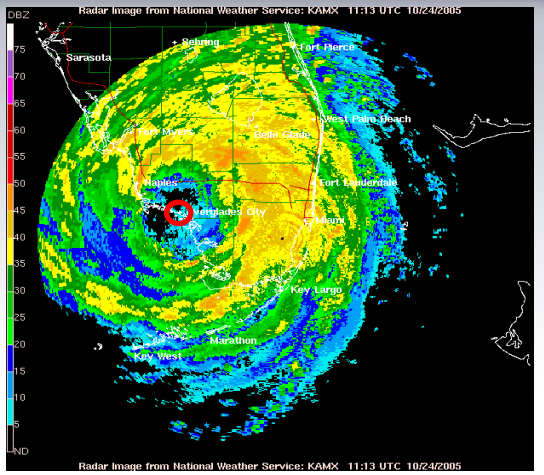
Summary of Intensity…

- **Intensity forecasting is not as advanced as track forecasting.**
- **There is less skill for intensity forecasting than there is for track forecasting.**
- **Current guidance is provided mainly by DSHIPS and GFDL, HWRF (still evaluating)**
- **We have significant difficulty in forecasting rapidly intensifying and rapidly weakening storms.**
- **The main hope for the future lies in improved dynamical models, coupled with enhanced observations and understanding of the hurricane's inner core. This is a long-term project - HFIP !**

Factors of Winds over Land

- Size of storm

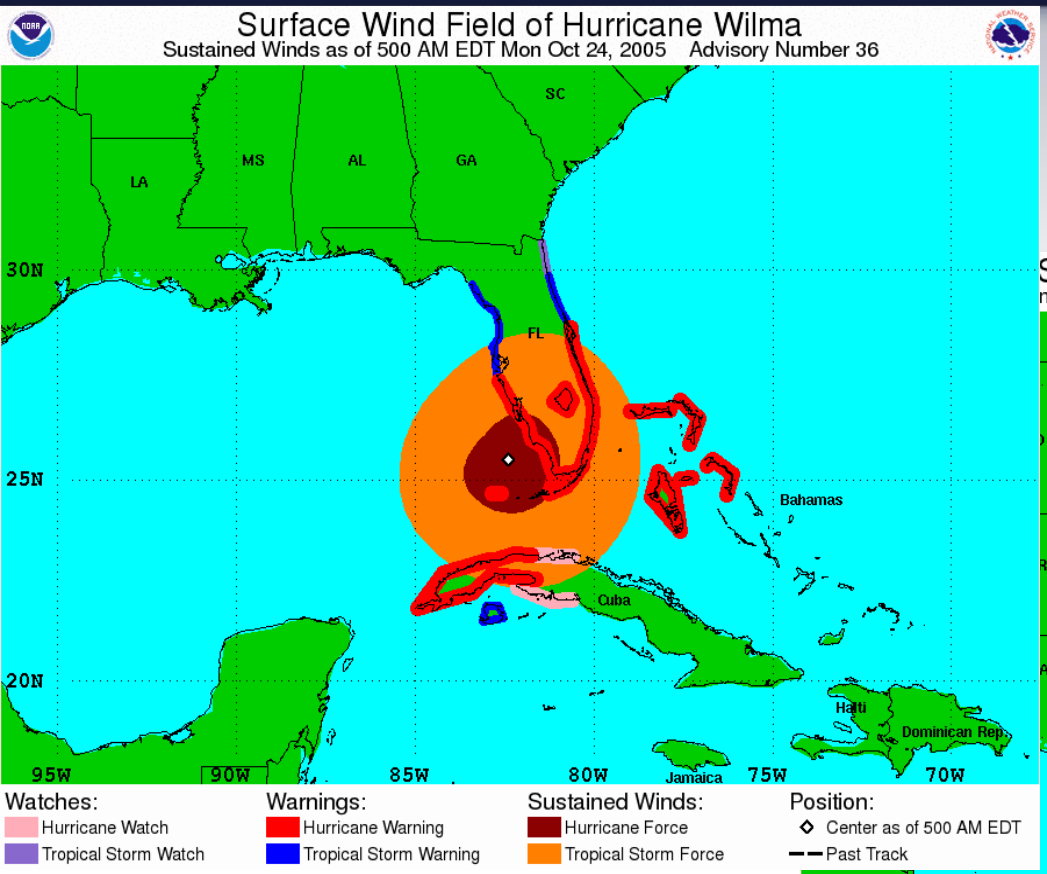


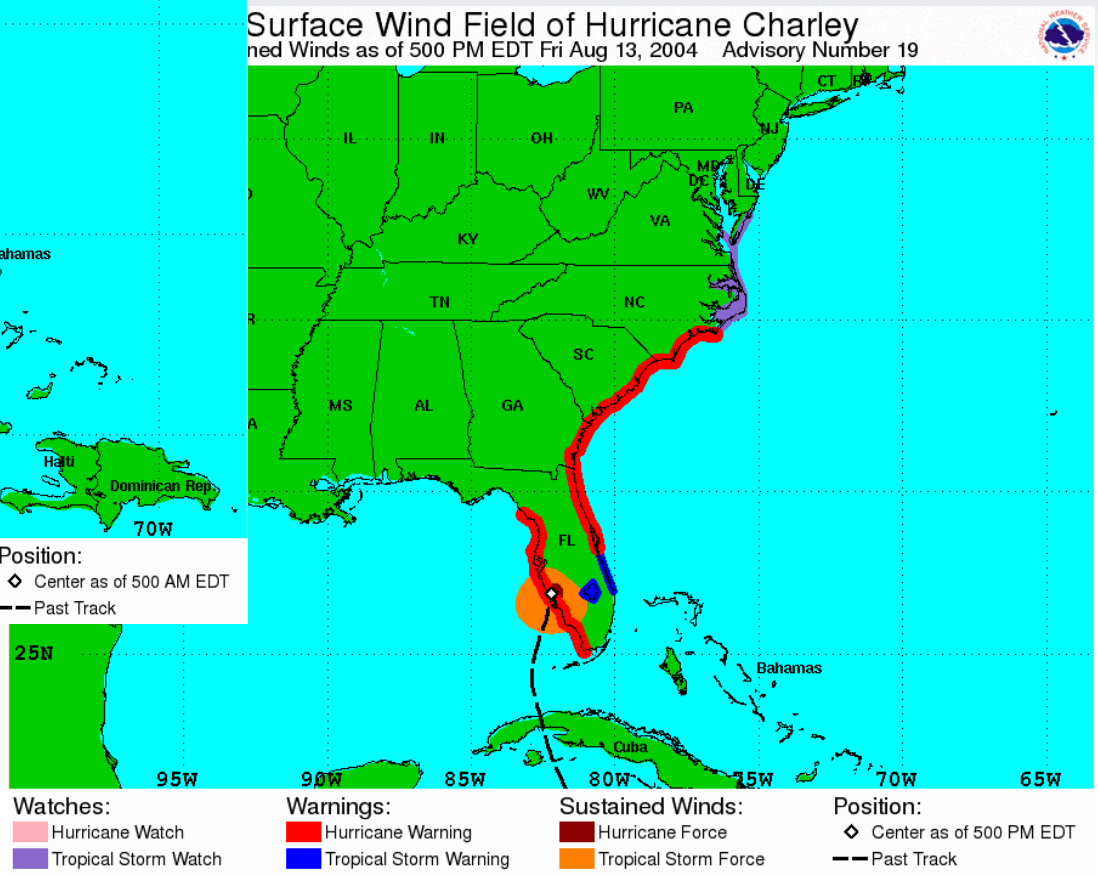


- Effects of terrain

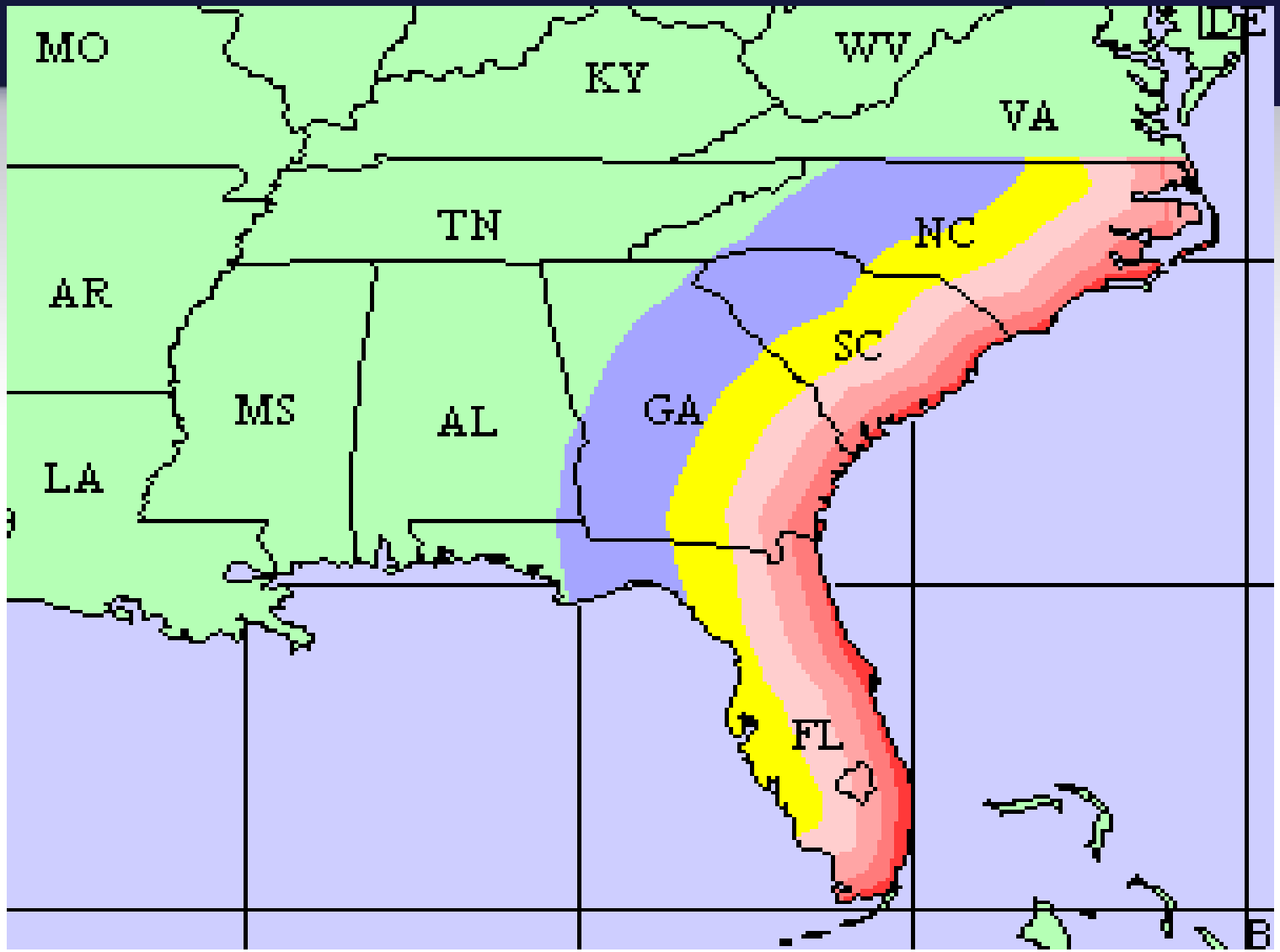
- Forward motion of the storm
  - Storm moving inland at 25 mph vs. 9 mph

Wind Radii (size of storm) Watch-Warning Graphic

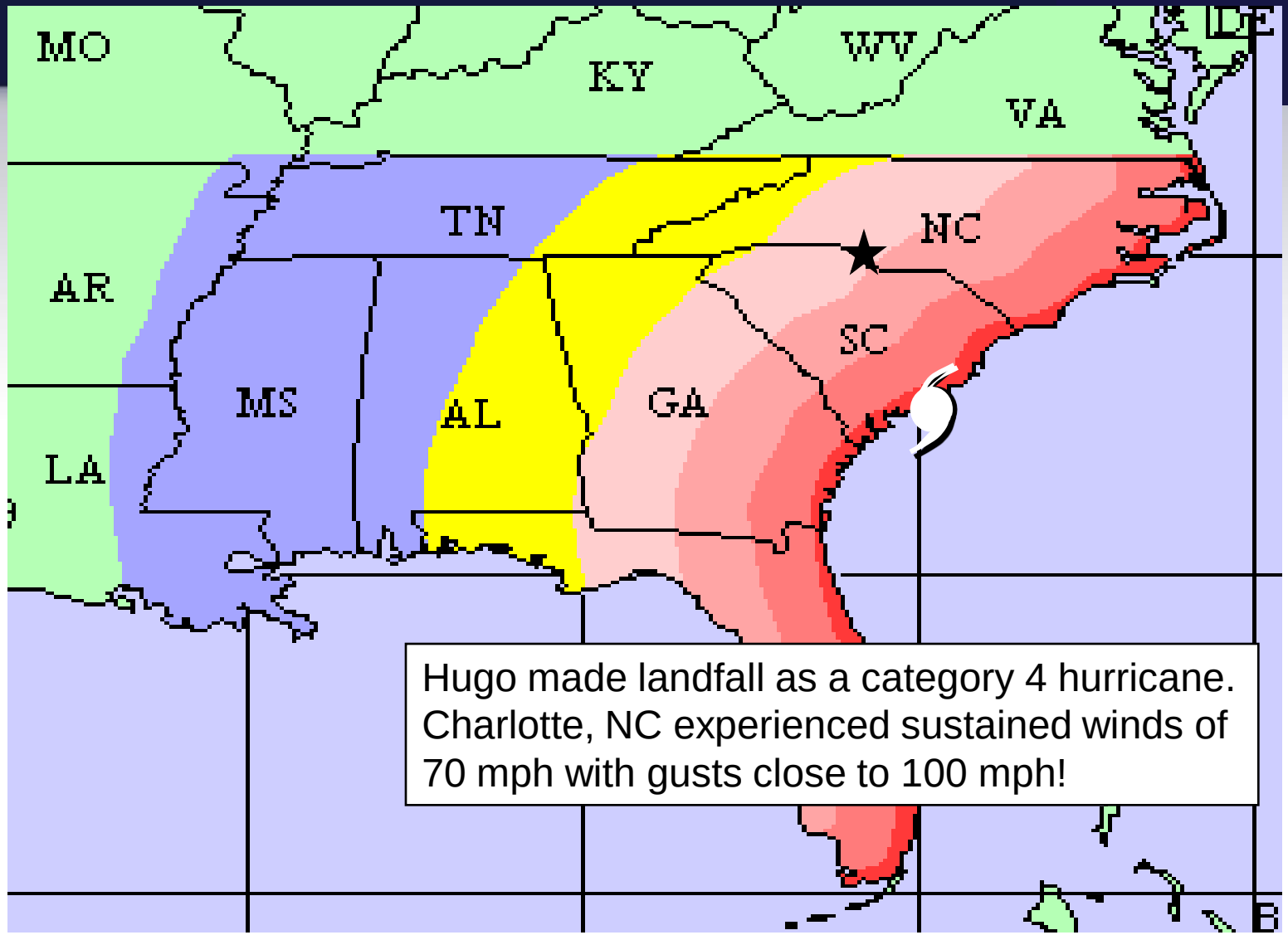




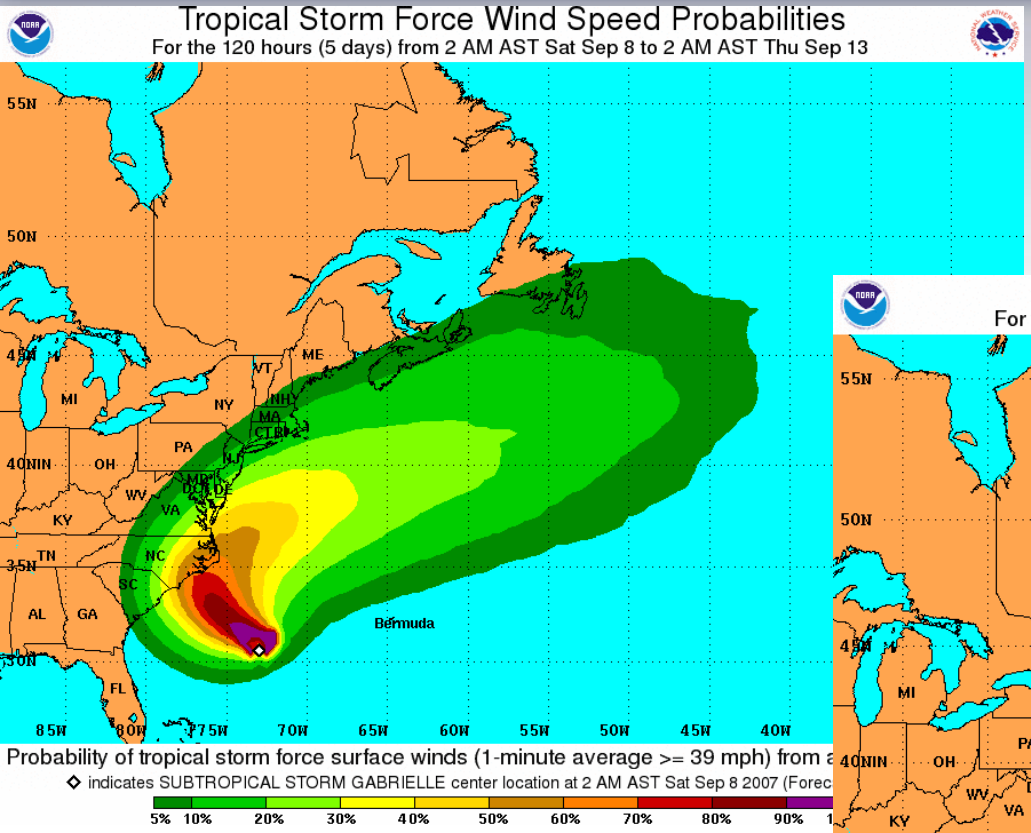
Typical Cat-4 MEOW – 9 mph

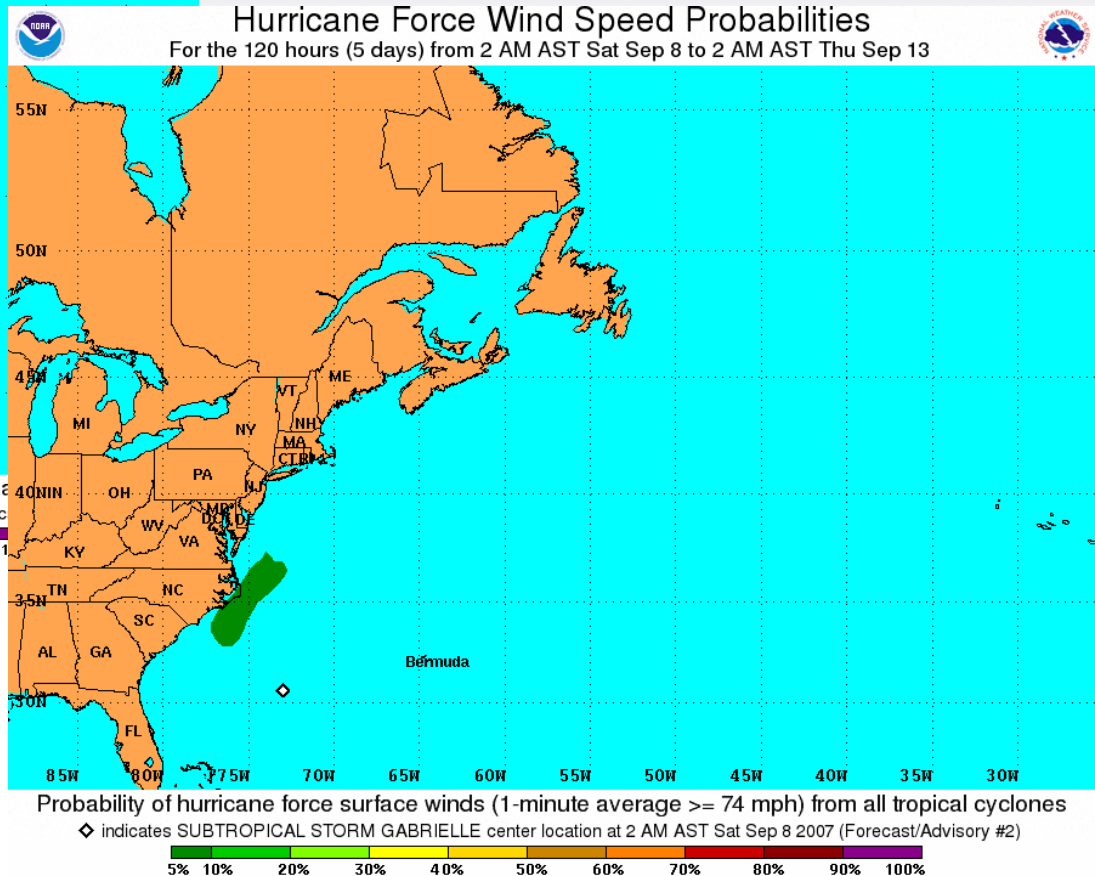


Typical Cat-4 MEOW – 25 mph



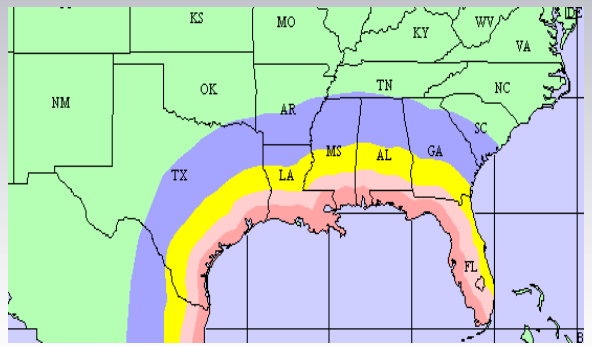
Wind Speed Probabilities



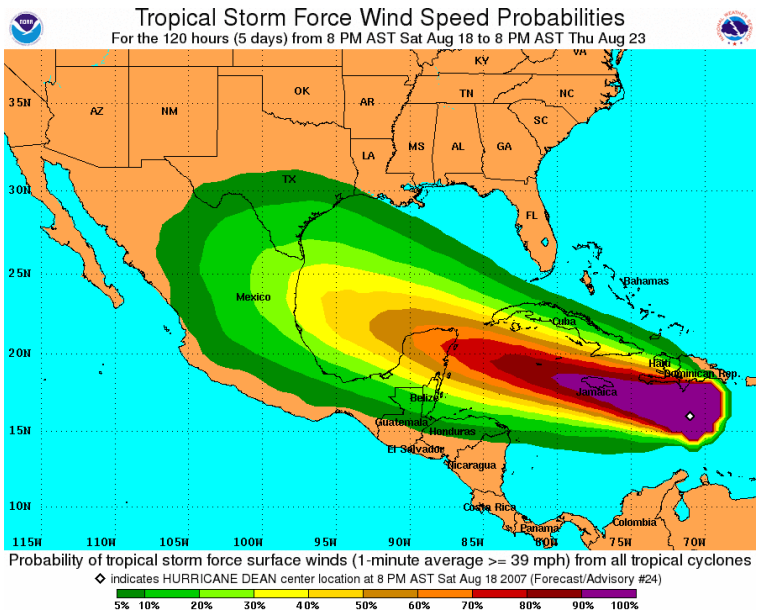


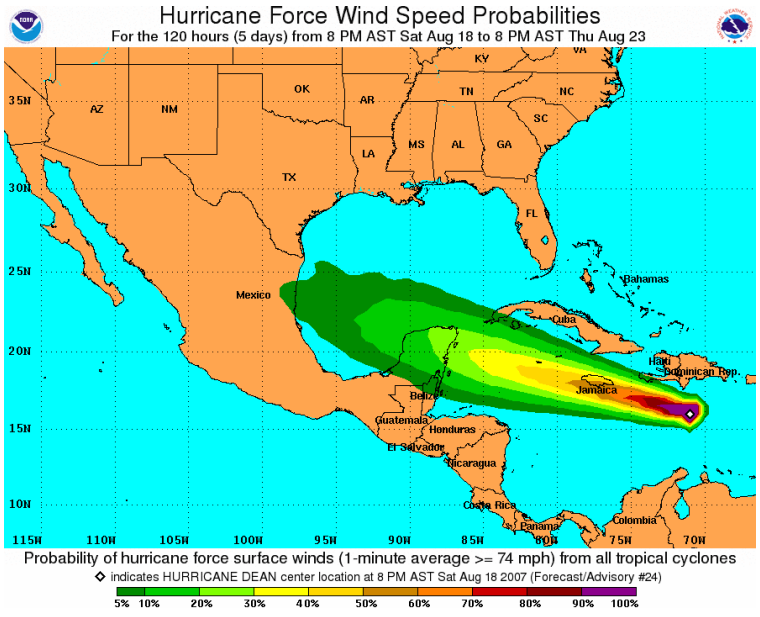
Tools you can use….

1) For <u>planning purposes</u> before the season use the MEOWs as guidance:



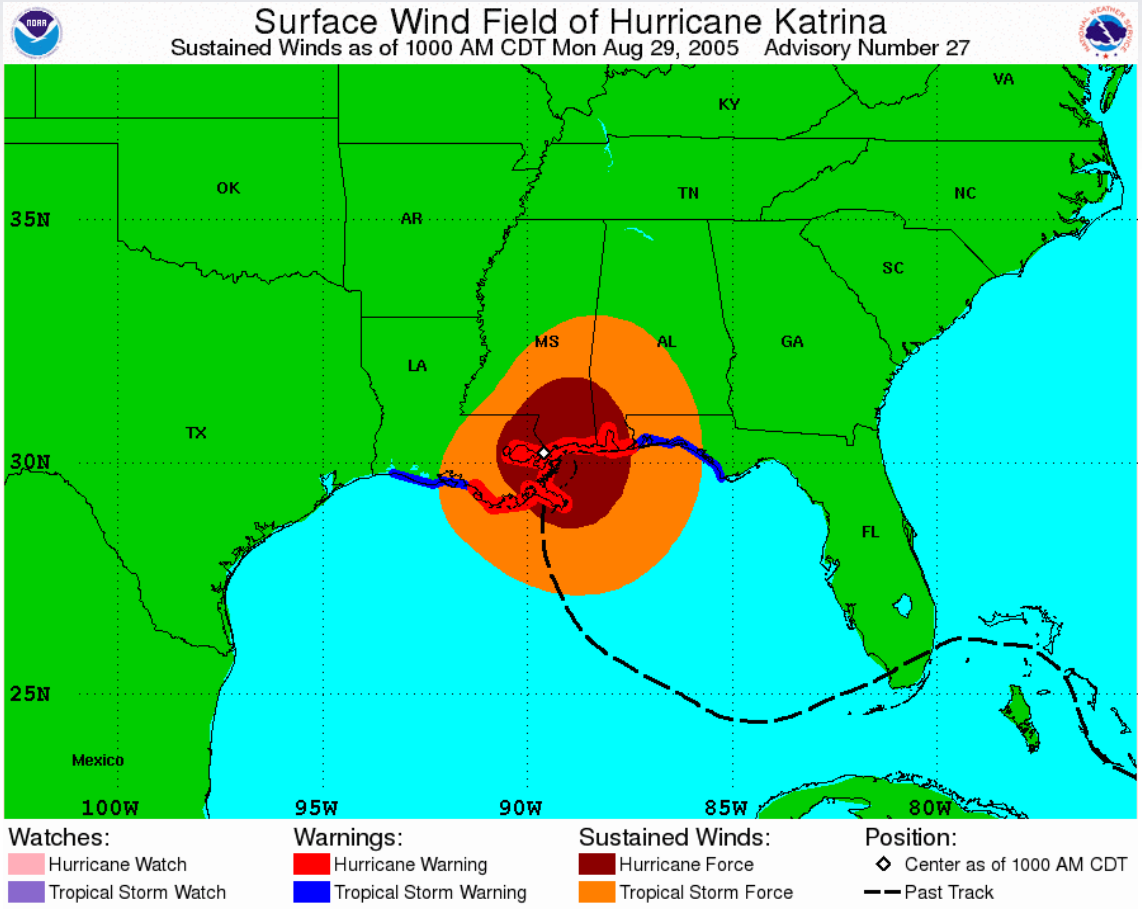
2) When a <u>storm is approaching</u>
use the wind speed probabilities to determine the potential risk for the inland extent of tropical storm and hurricane force winds





Tools you can use….

3) When the system is <u>approaching land or making landfall</u> use the initial wind radii graphic to get a picture of the current size of the storm and the potential area affected by strong winds



Thanks!