Advanced Hurricane Modeling at EMC: The HWRF

Naomi Surgi

and HWRF Team

NCEP/Environmental Modeling Center

WHERE AMERICA'S CLIMATE AND WEATHER SERVICES BEGIN

HWRF TEAM

Qingfu L., Vejay T., Young K.,

Bob T., Bill O'C

Janna O'C, Zack Z. (new members)

Also, thanks to Isaac G., Morris B……

Overview

- **HWRF ’07 implementation strategy, initial HWRF config, T&E requirements**
- **2007 HWRF**
- **The Advanced HWRF**

HWRF Development

- CONDUCTED 27 EXPERIMENTS since 2002 , ie: 27 versions of the HWRF
- Tested each upgrade (numerics, physics, coupling) for clean comparisons - comprehensive testing (>200 runs)
- FINALIZED HWRF FOR '07
- PERFORMED EXTENSIVE COMPARISONS BETWEEN GFDL AND HWRF FOR MULTIPLE SEASONS AND STORMS - THREE SEASONS ('04, '05, '06) for both ATL and EPAC basins

  Note: HWRF, 1745 runs; GFDL 900 runs; HWRF ran 4X/day, GFDL 2X/day. Ran homogeneous comparison between HWRF and GFDL for 0Z and 12Z runs

- NO TUNING OF HWRF (tuning has a lot of impact on track and intensity skill)
- NO OCEAN COUPLING IN EPAC

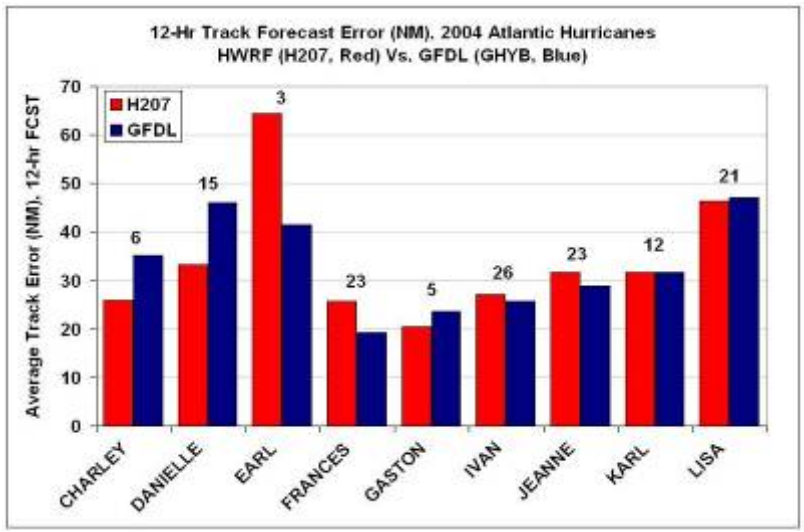
Hurricane Forecast System Requirements Document for T20

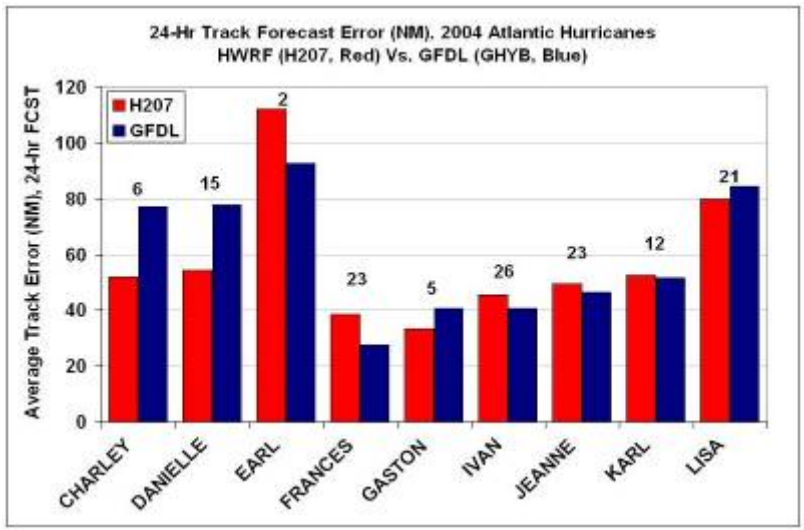
Requirements document co-written between EMC and TPC for transition to NCEP operations of a new candidate hurricane model…or for annual or periodic upgrades to an existing operational hurricane model for transition to NCEP operations.

Sets standards for:

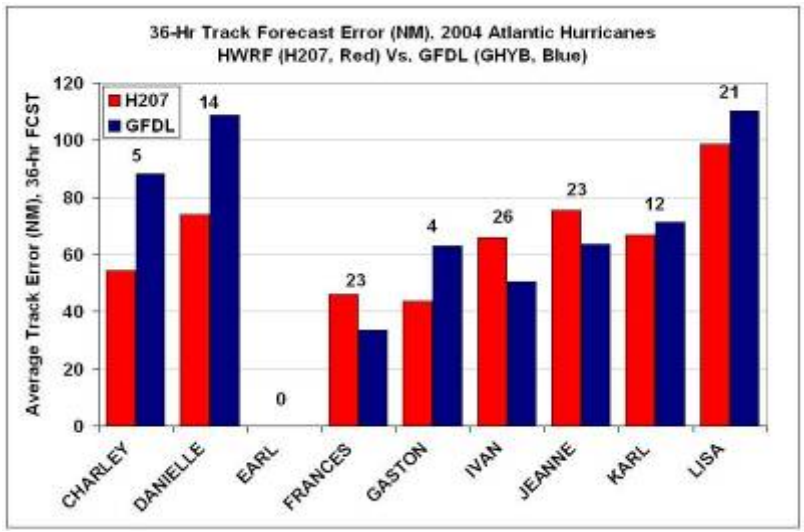
- **Performance testing – case load, eval criteria**
- **System functionality – initialization, coupling**
- **Computational performance**

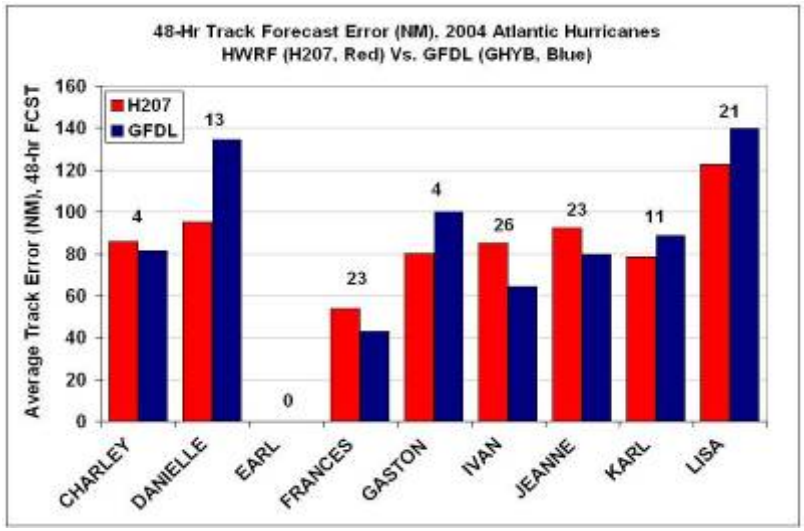
12 & 24hr. 2004 ATL



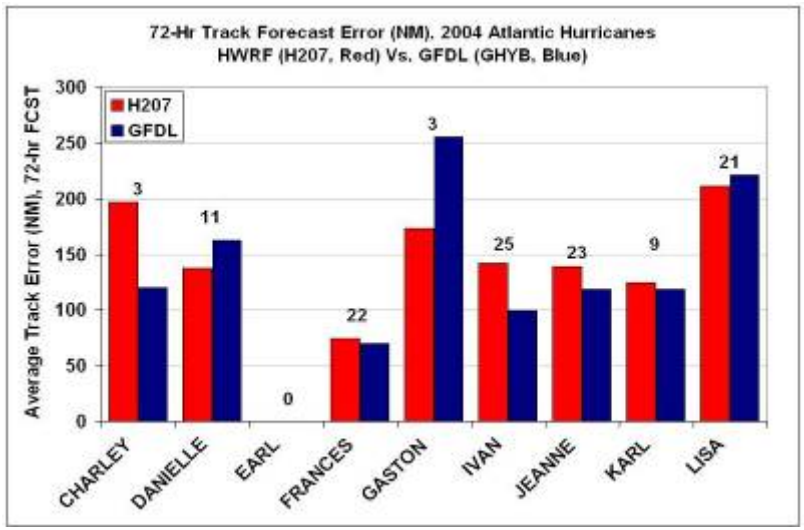


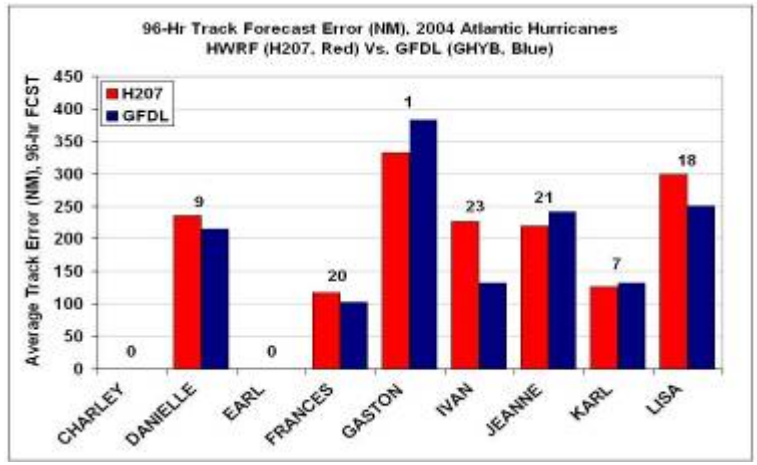
36 & 48hr. 2004 ATL

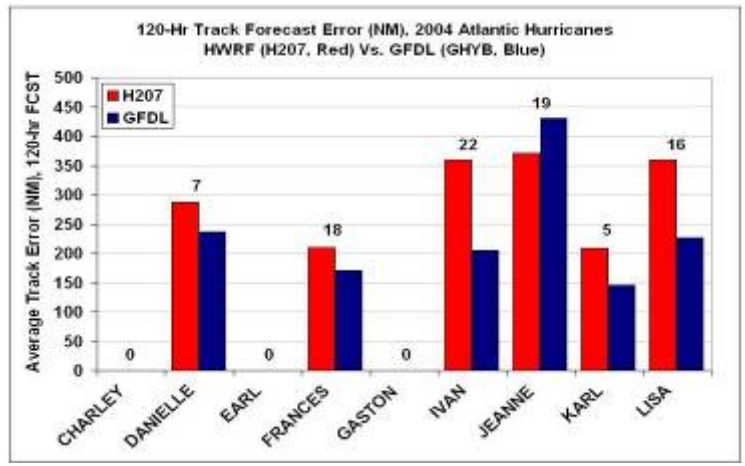




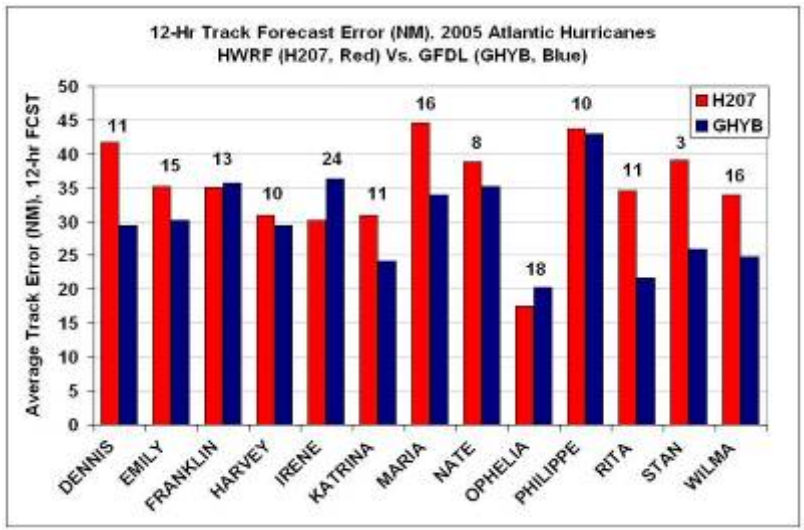
72, 96, 120hr. 2004 ATL

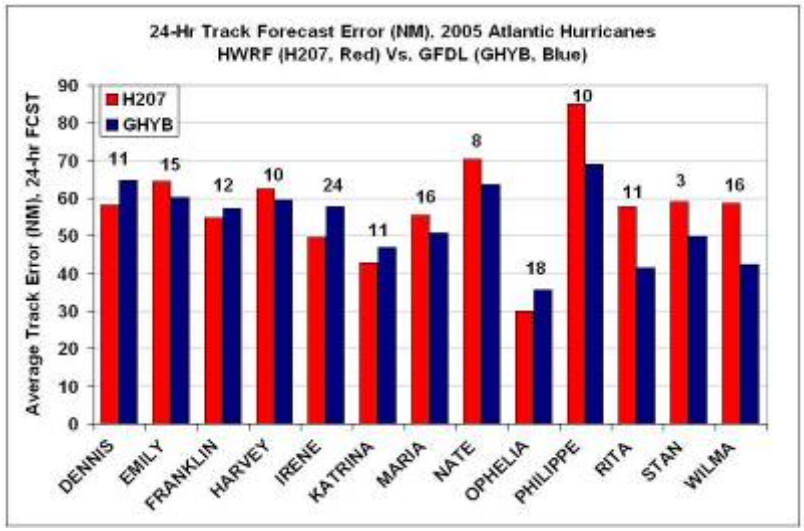




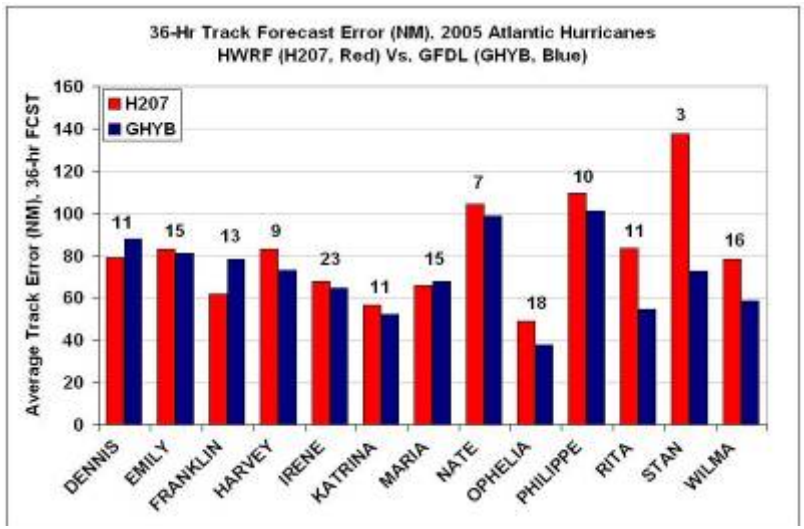


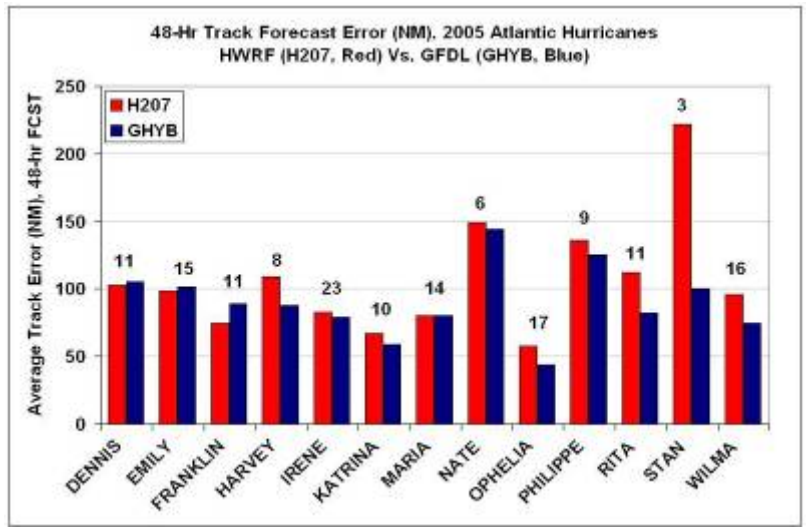
12 & 24hr. 2005 ATL





36 & 48hr 2005 ATL





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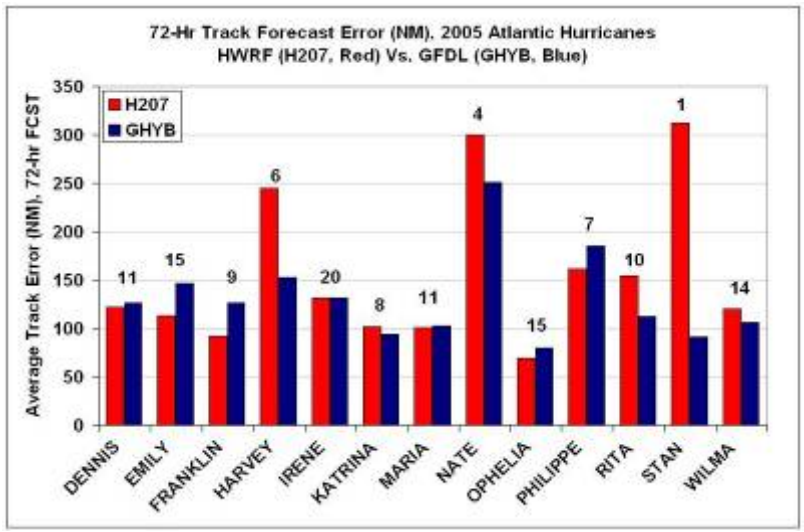
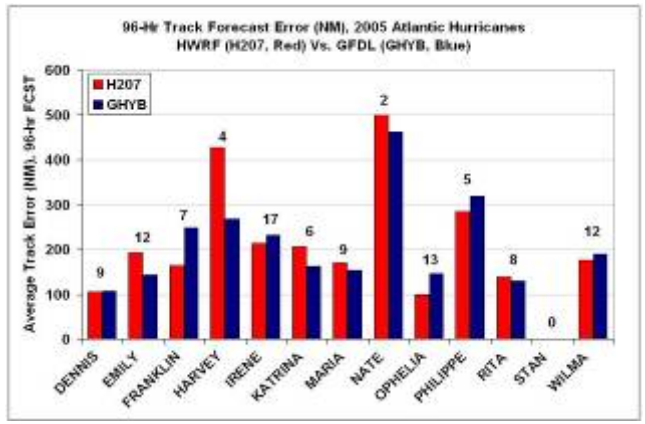
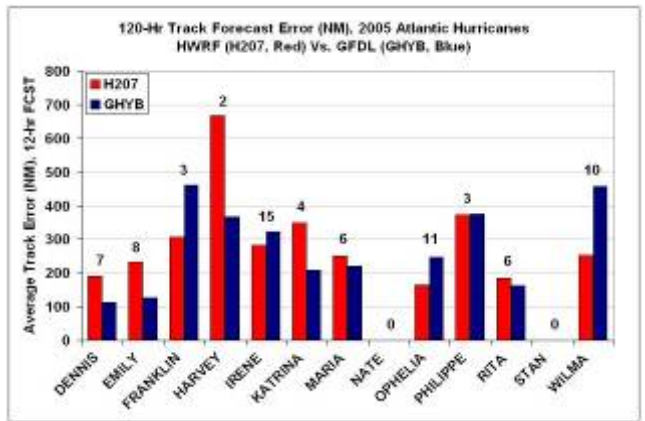
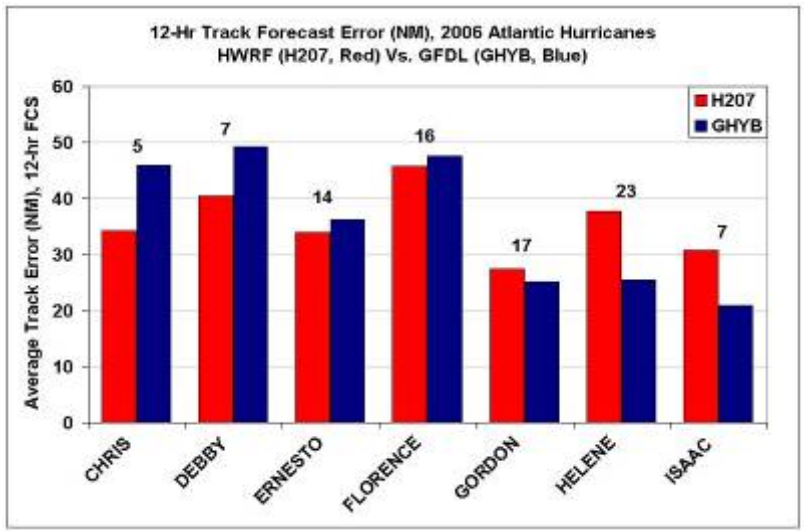
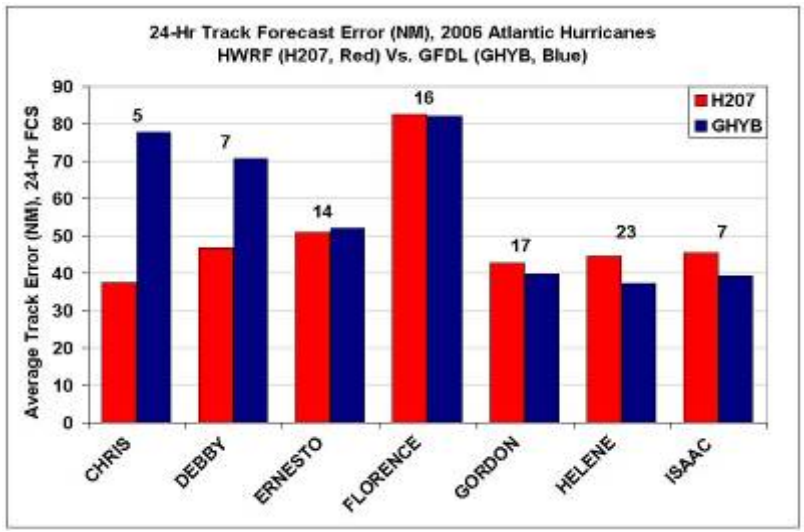






12 & 24hr 2006 ATL





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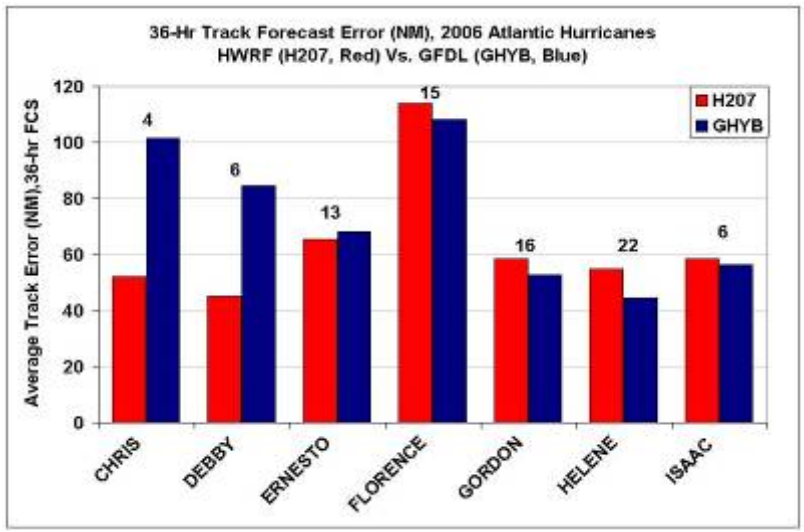

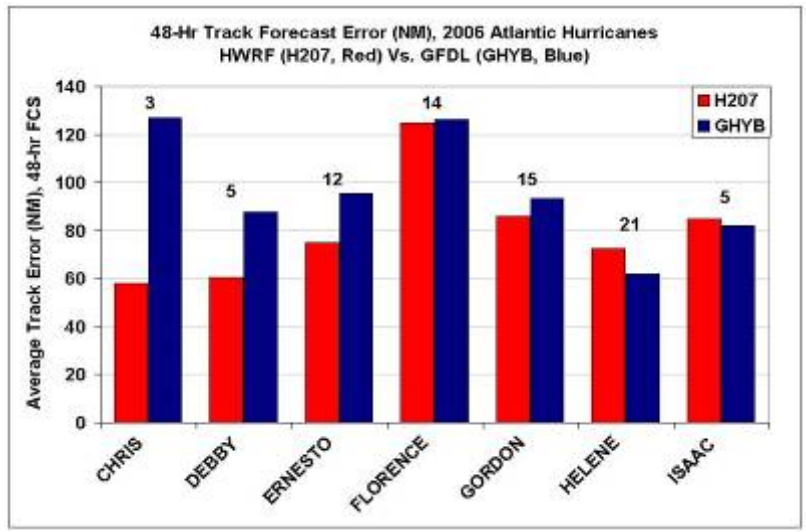

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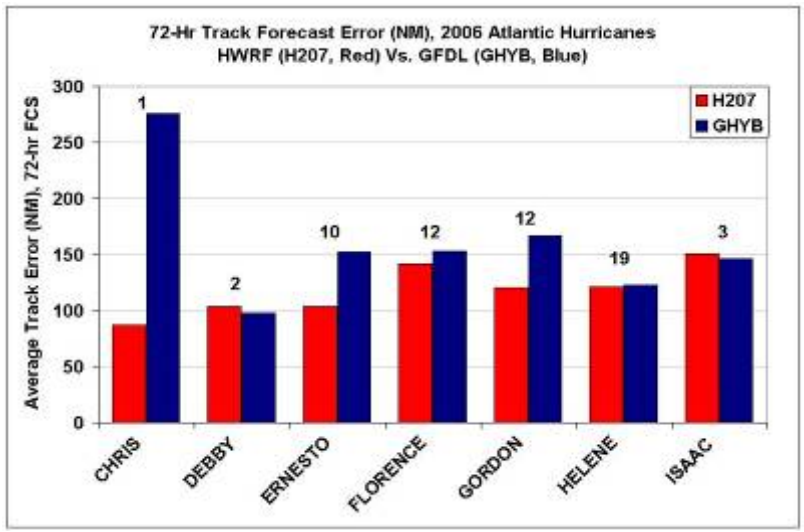
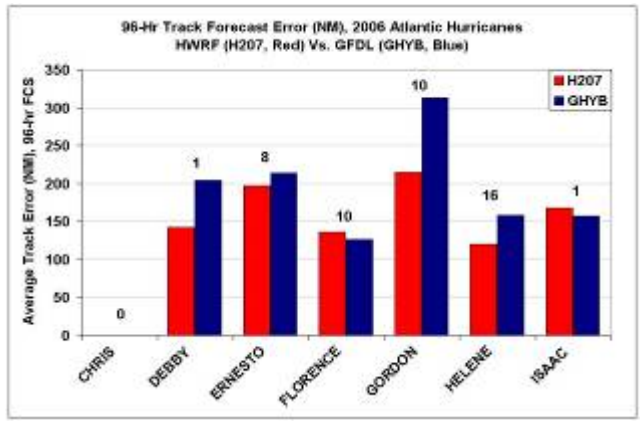
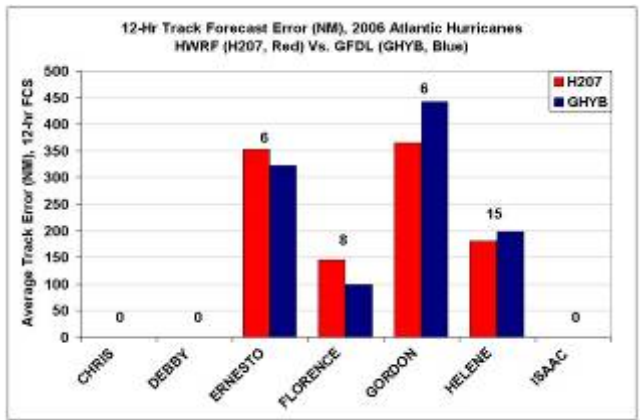
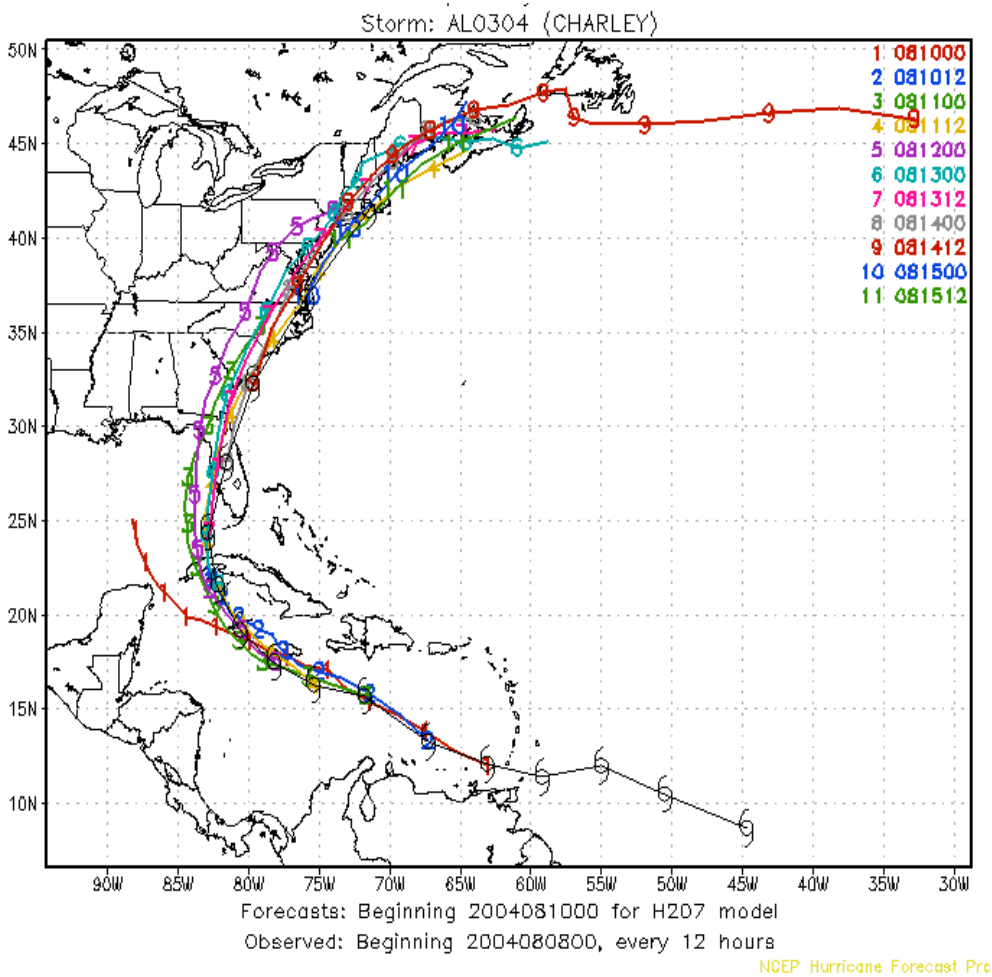






HWRF



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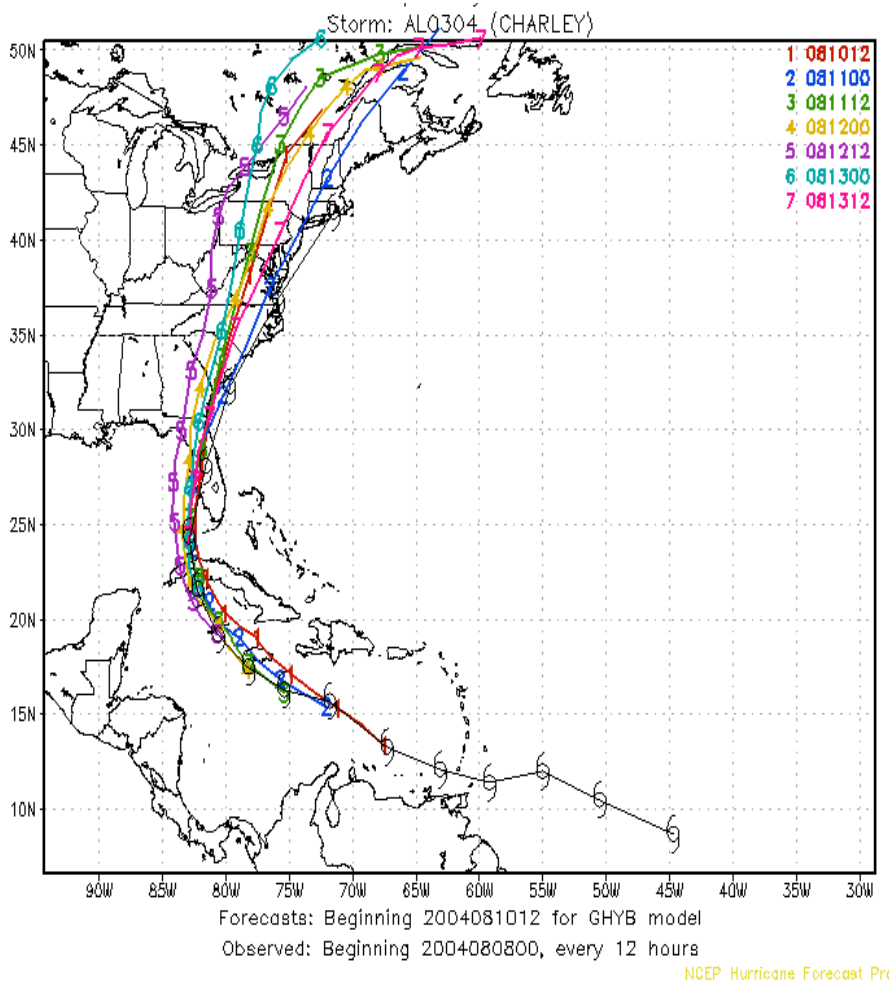
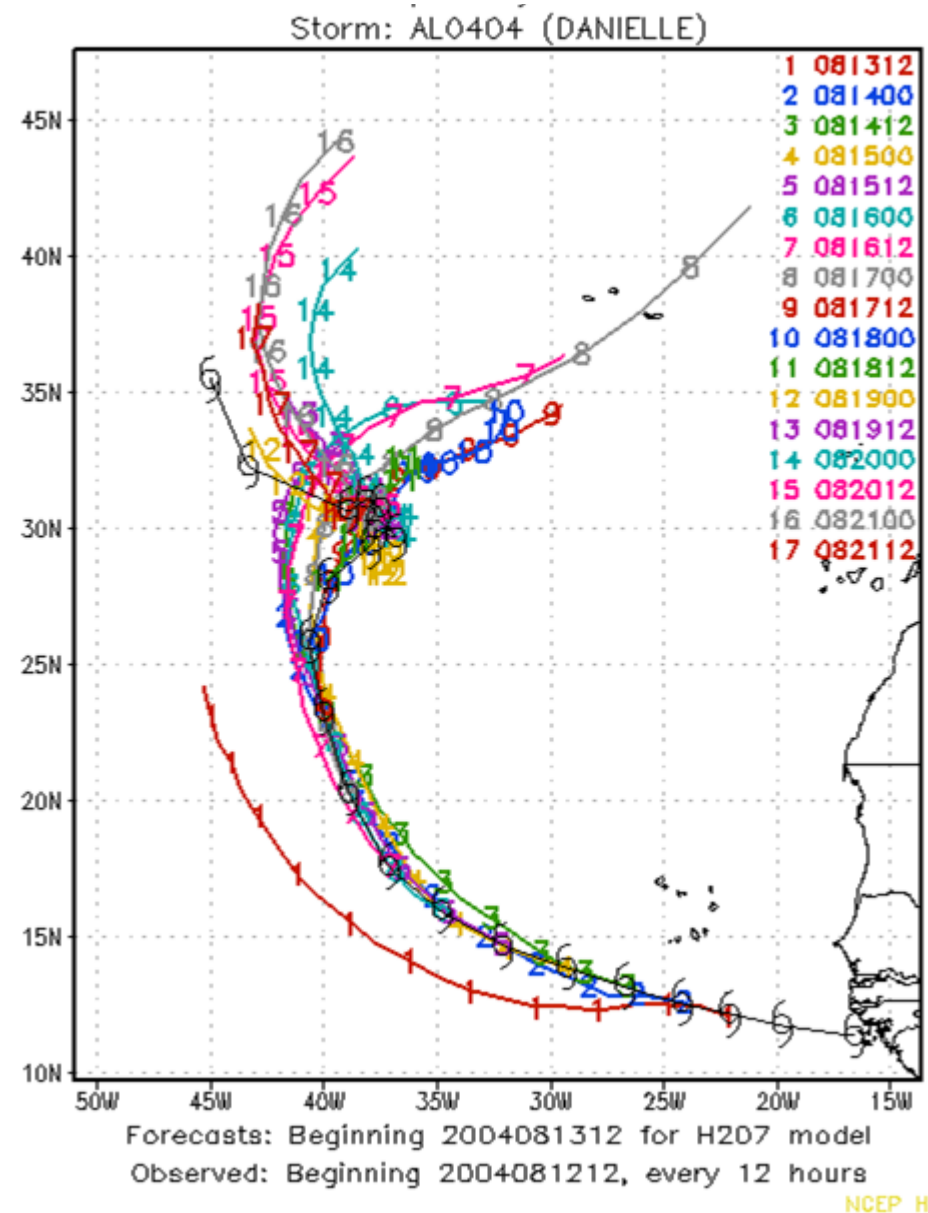


Tracks for CHARLEY, 2004

HWRF



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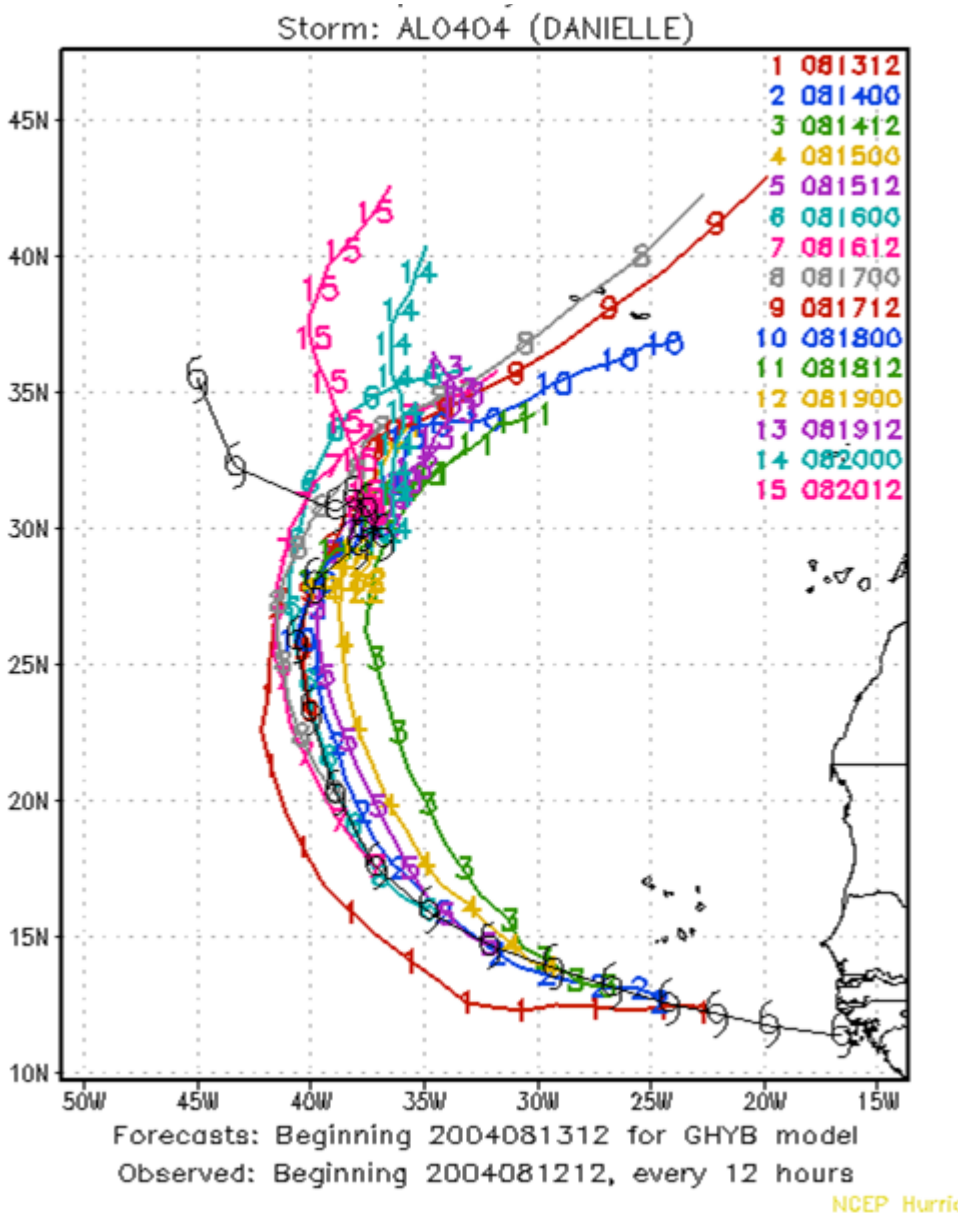

Tracks for DANIELLE, 2004

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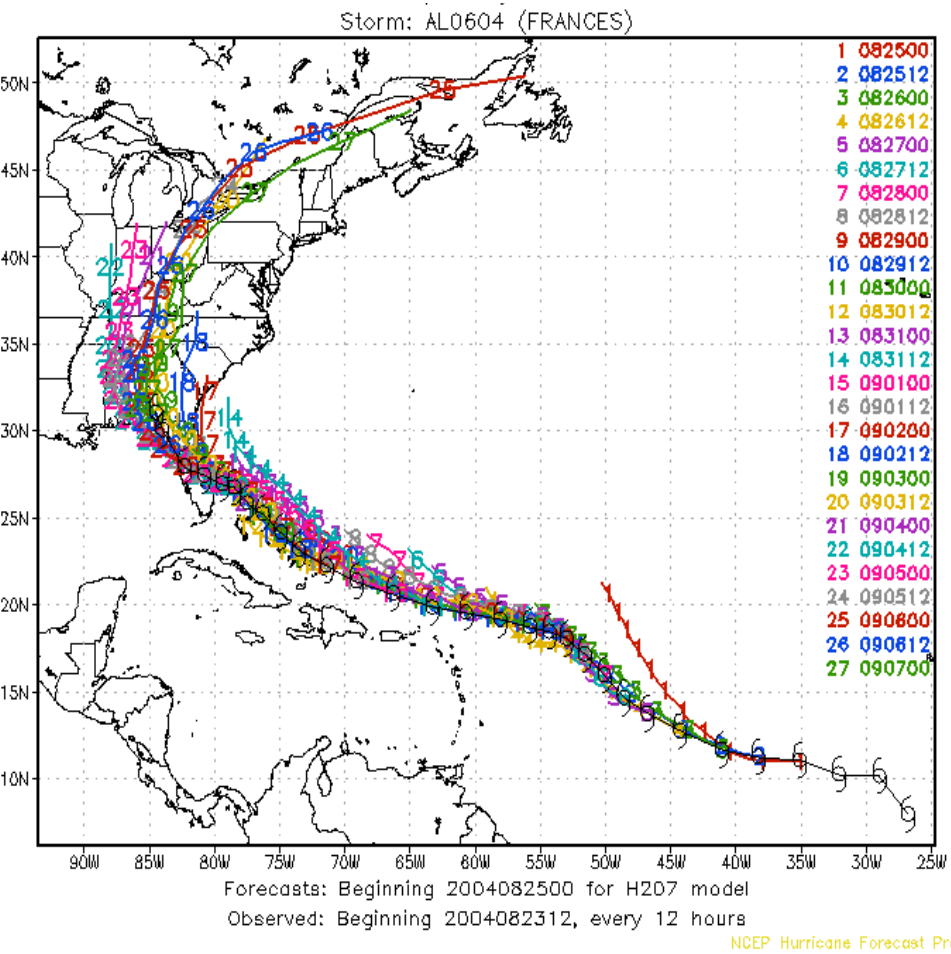

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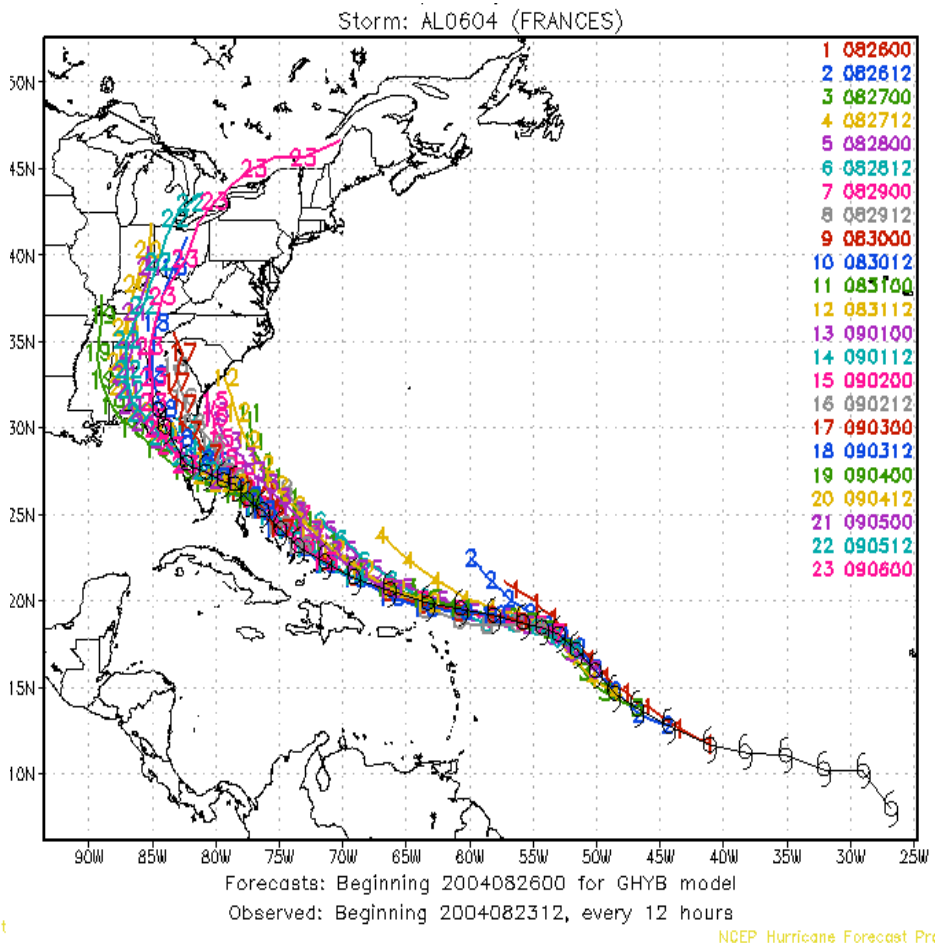
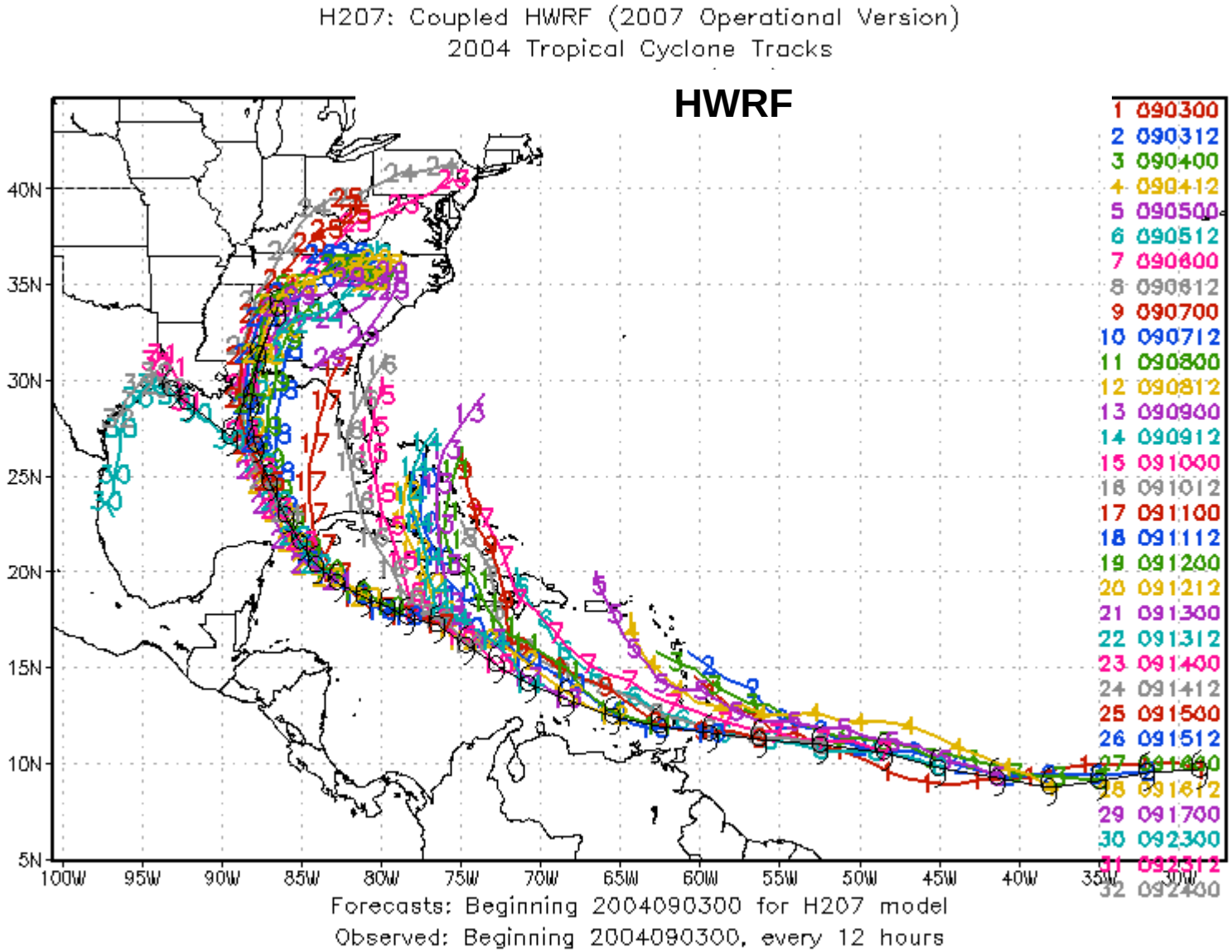


Tracks for FRANCES, 2004



Tracks for IVAN, 2004

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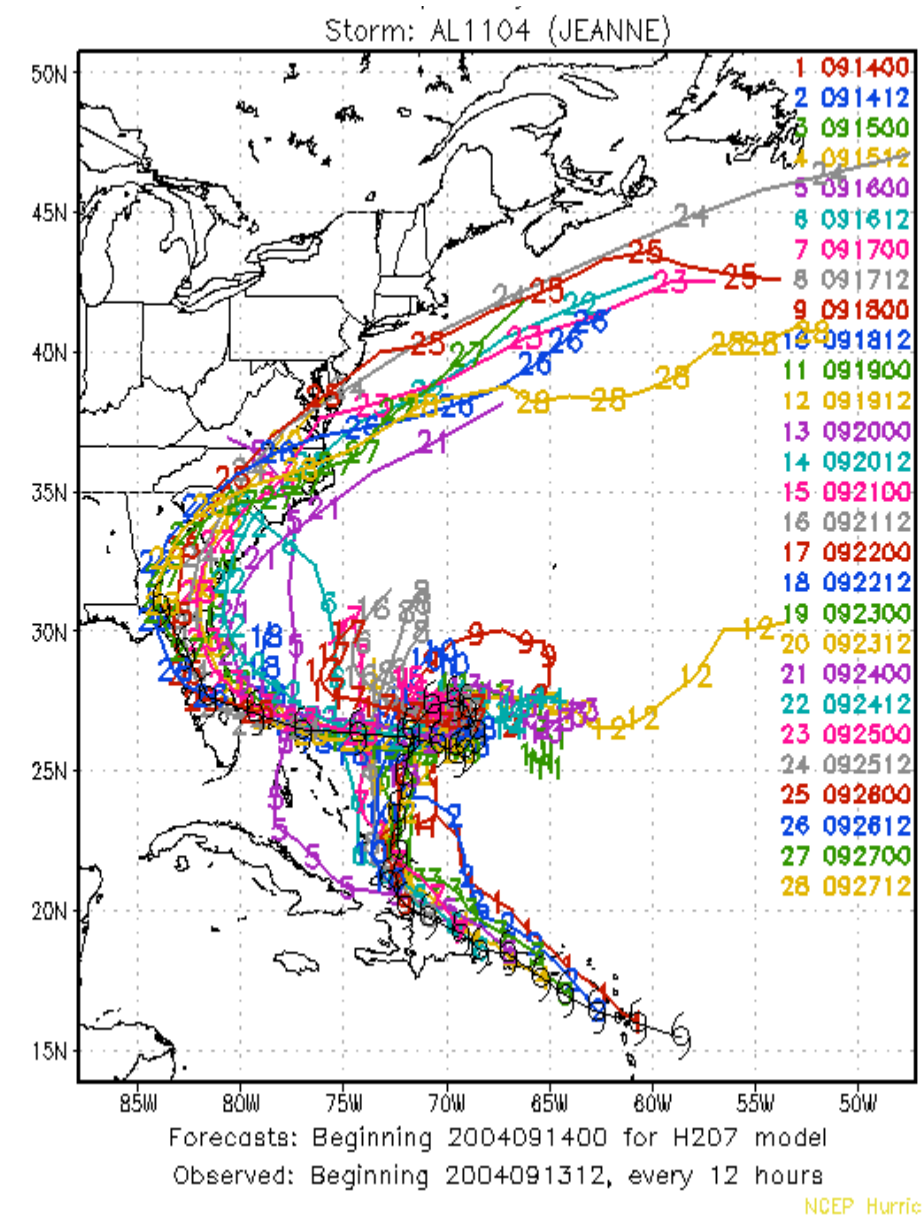

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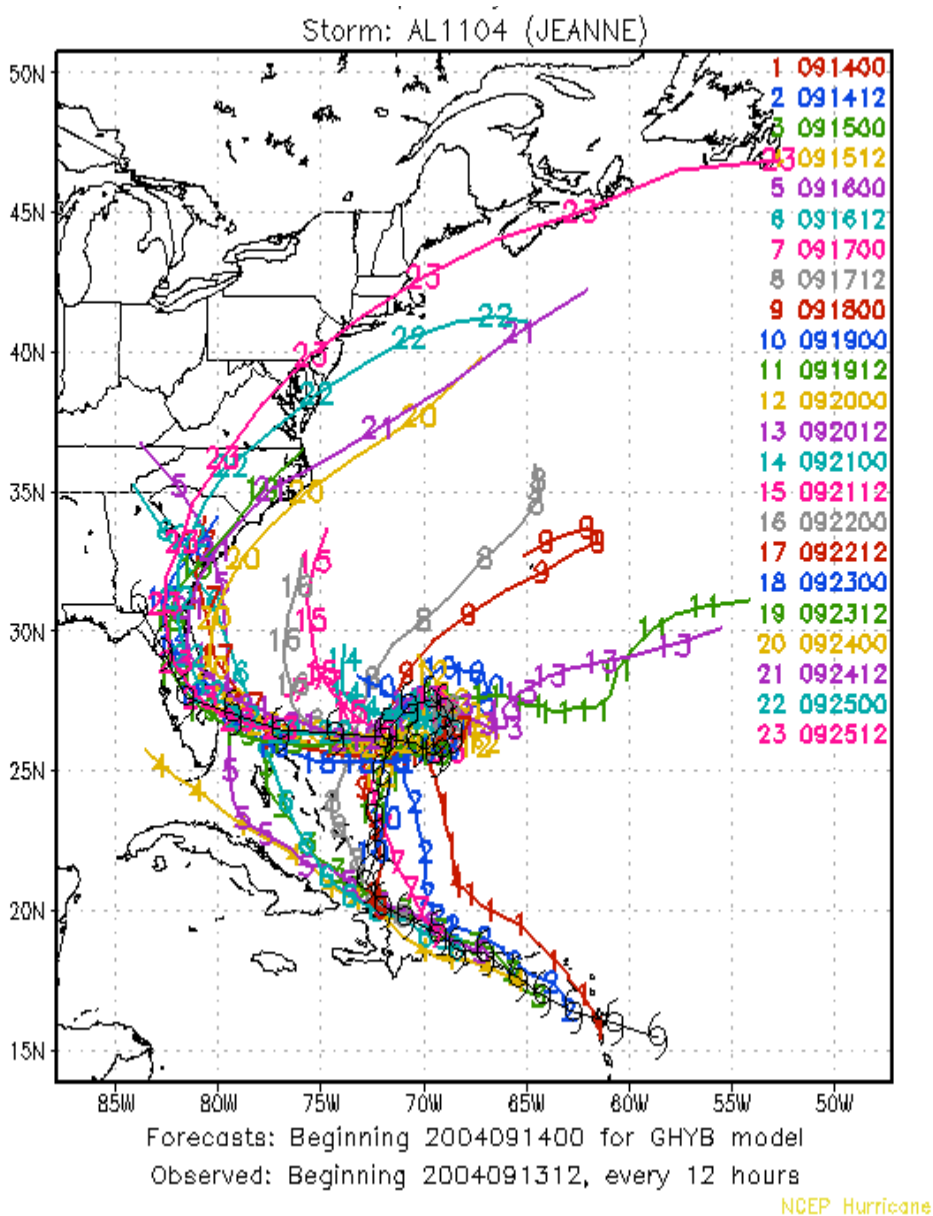

Tracks for JEANNE, 2004

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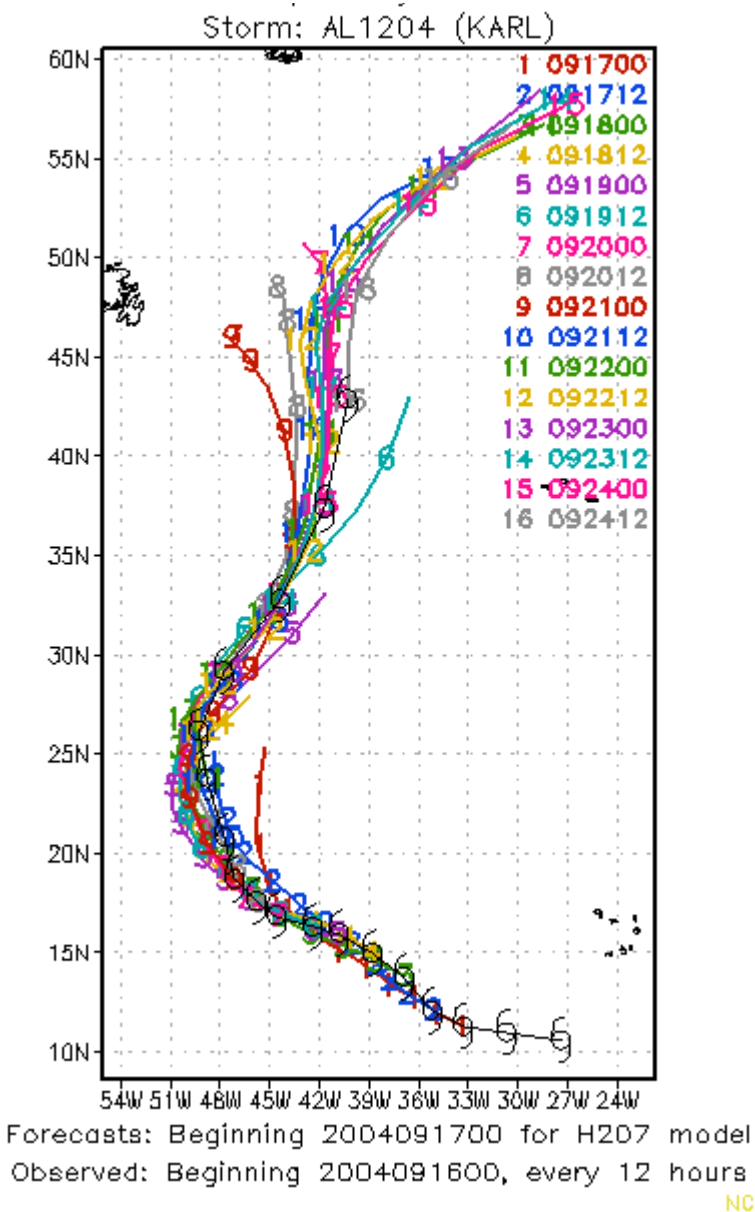

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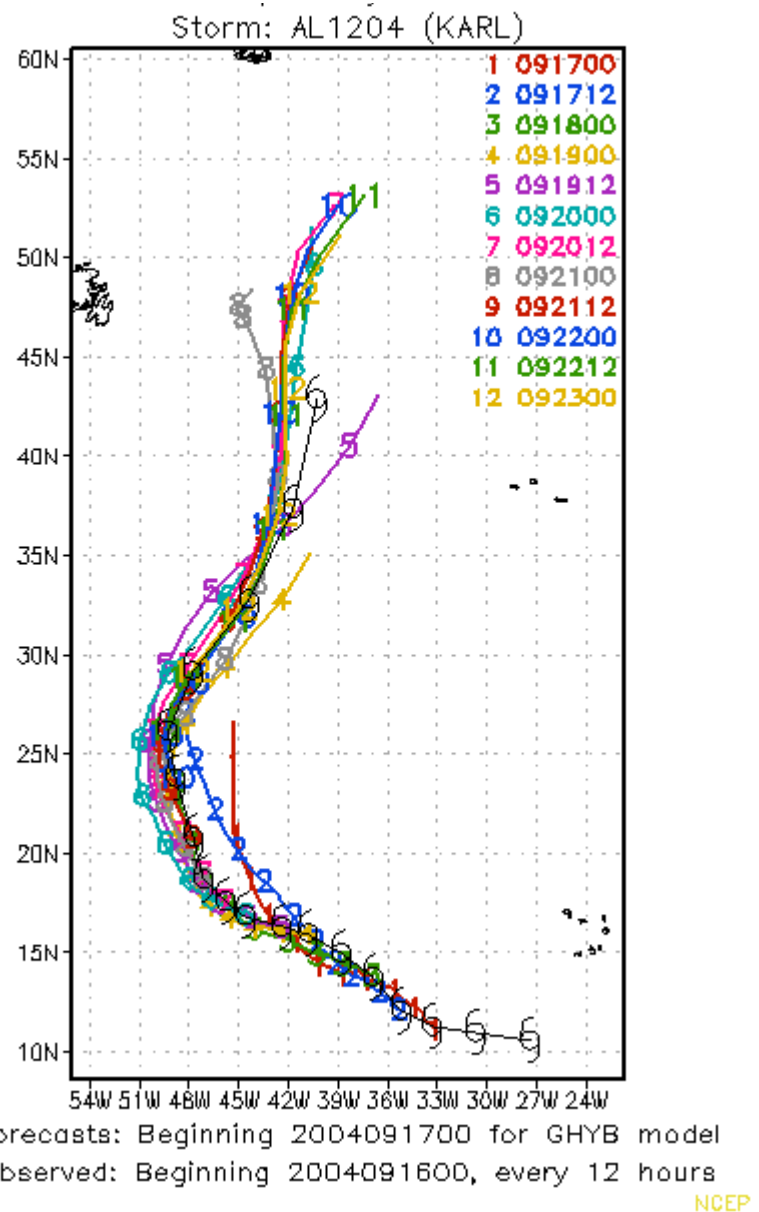

Tracks for KARL, 2004

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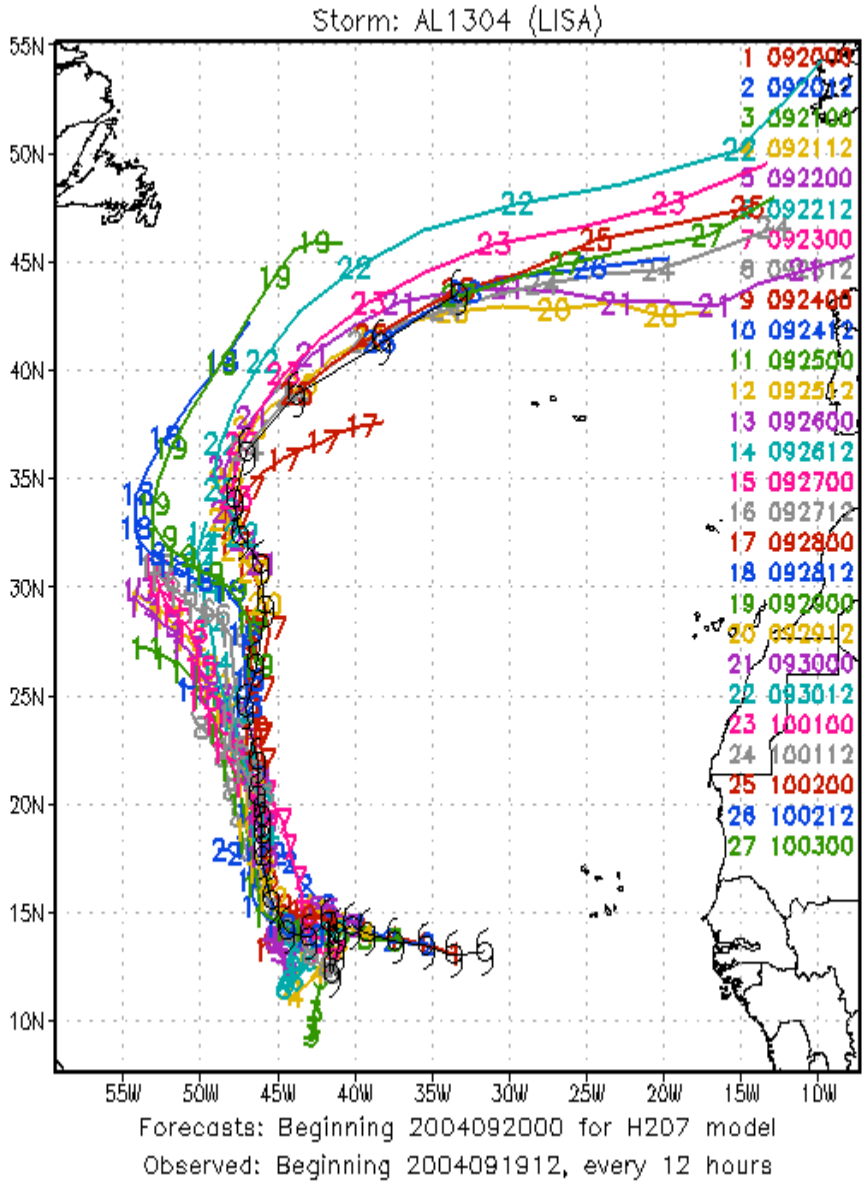

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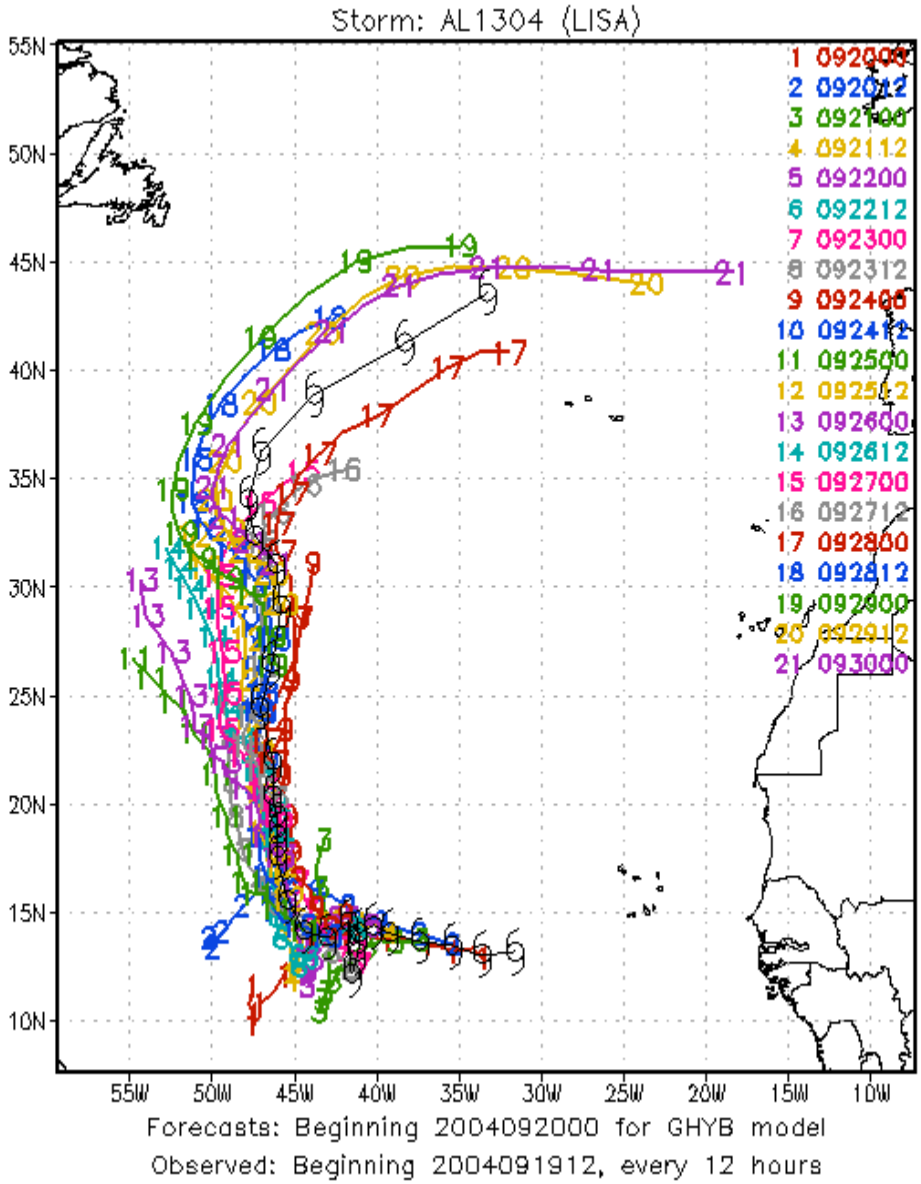

Tracks for LISA, 2004

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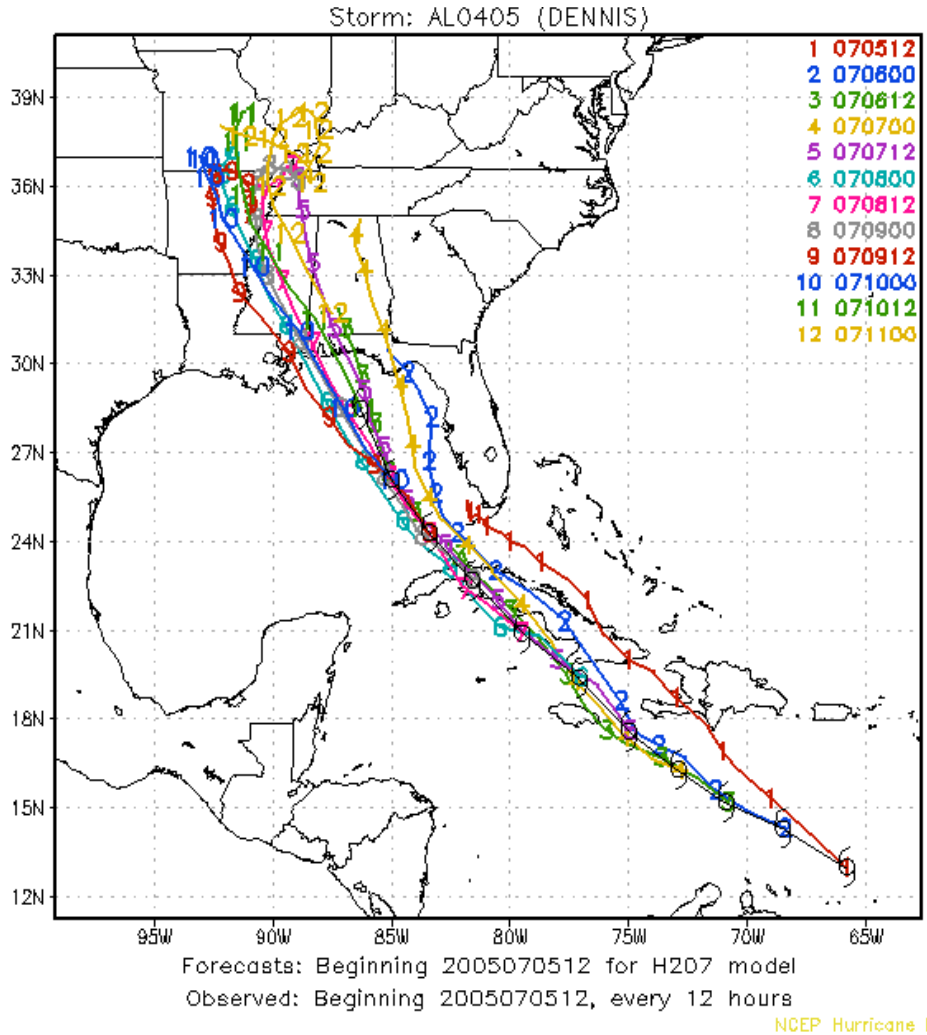

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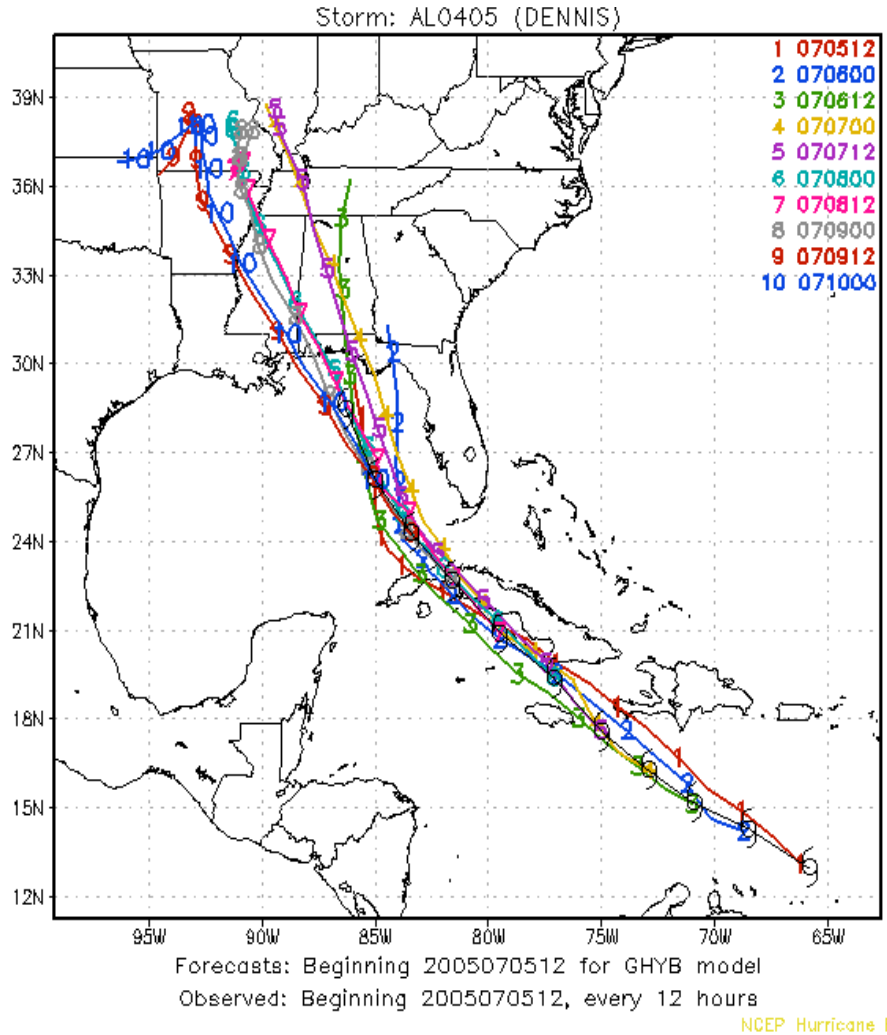
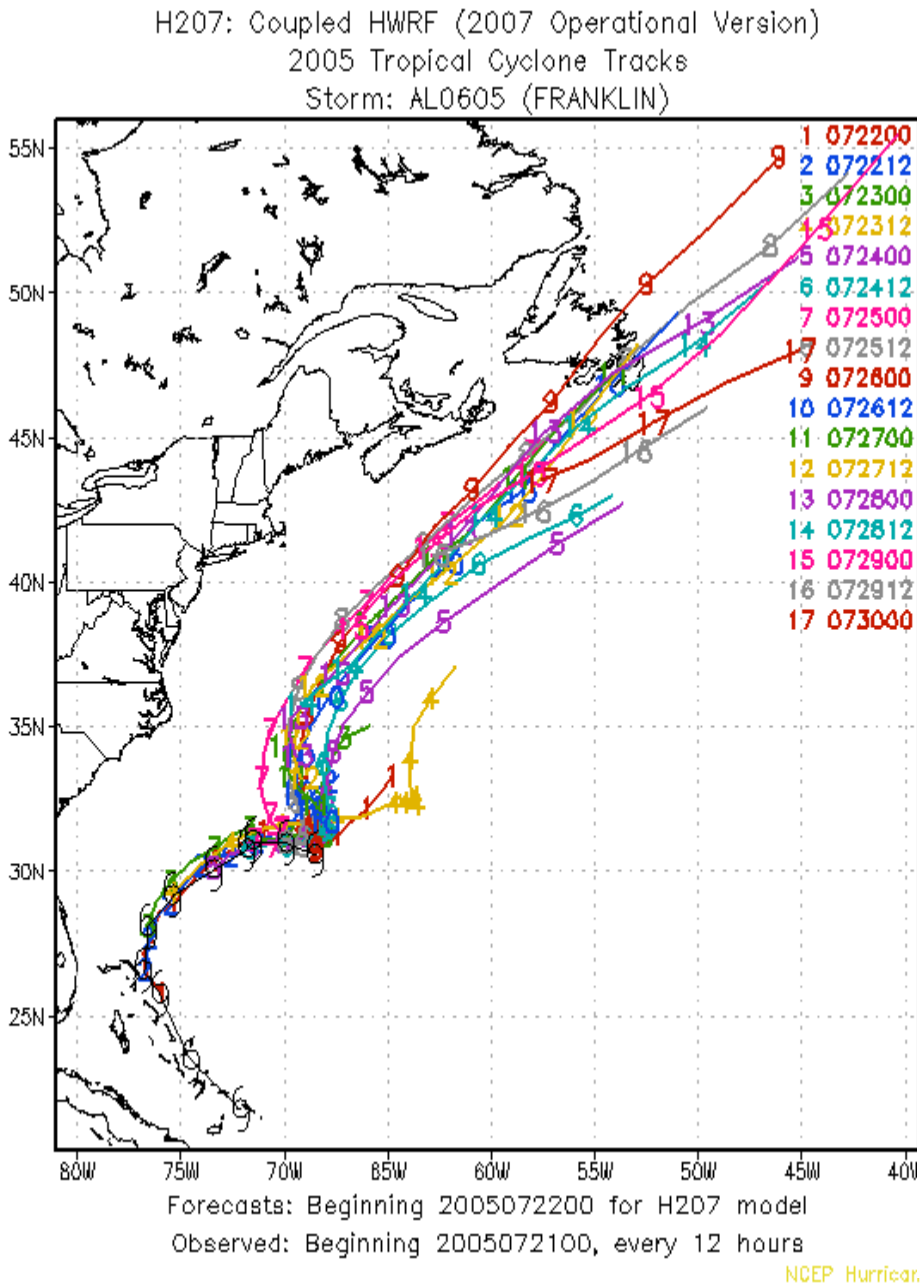
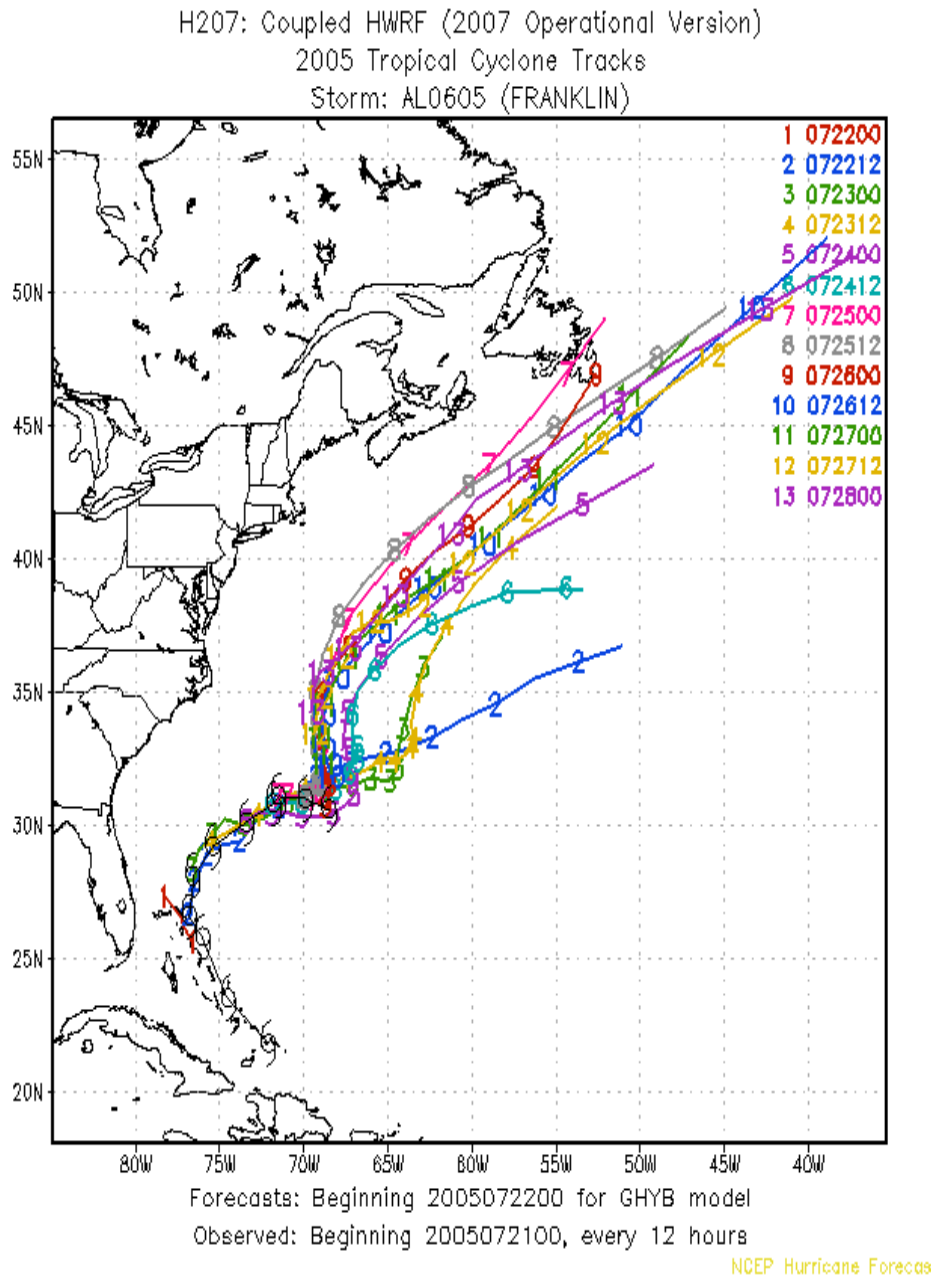


DENNIS (2005) TRACKS





FRANKLIN (2005) TRACKS

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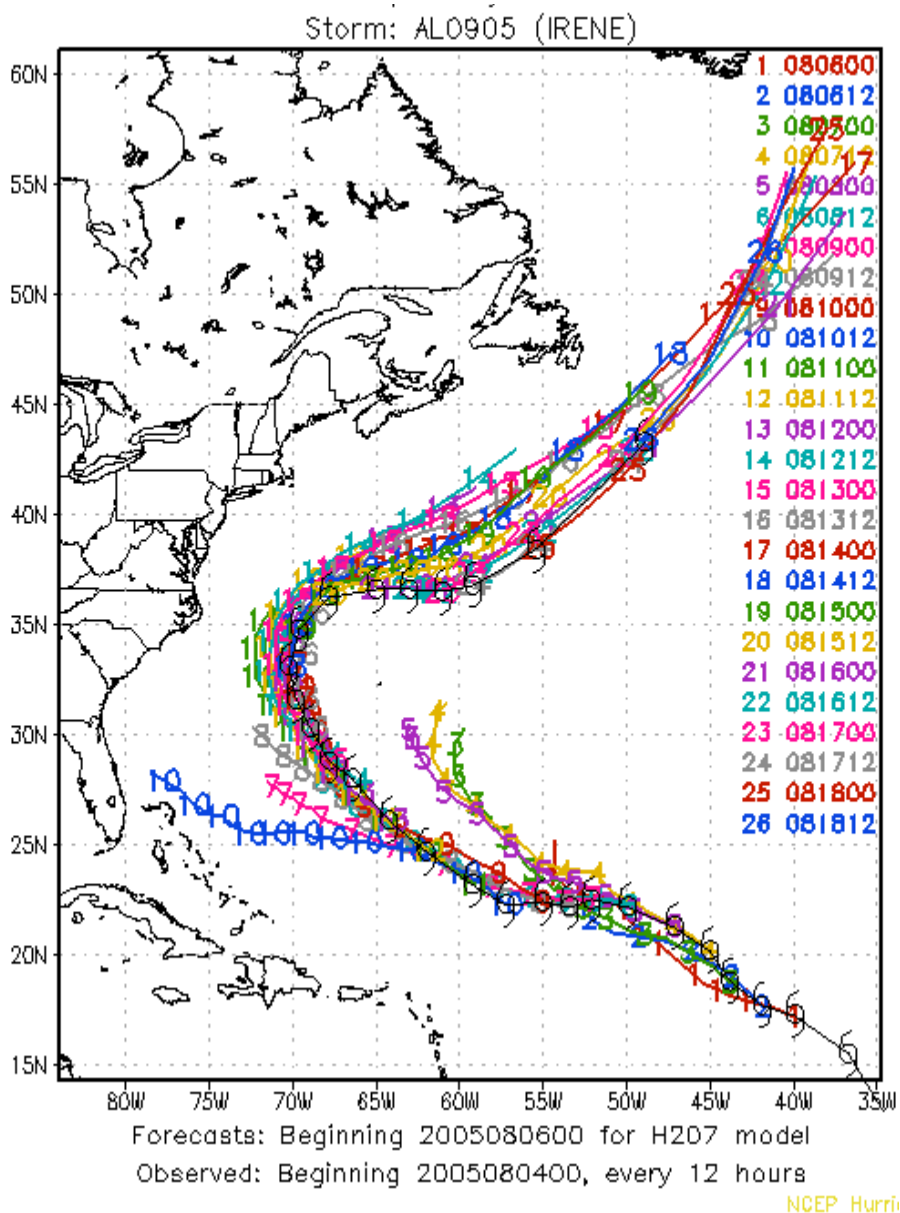

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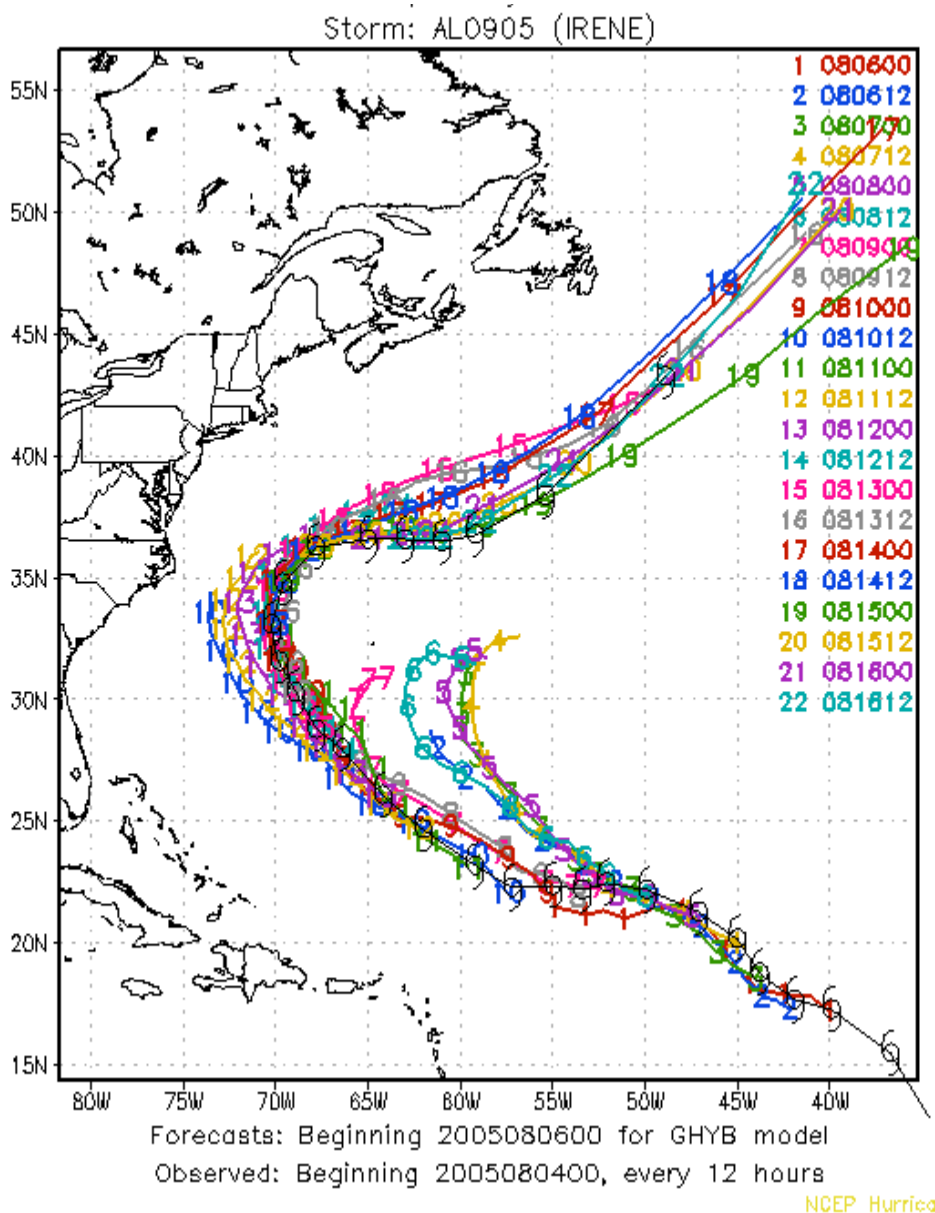

IRENE (2005) TRACKS

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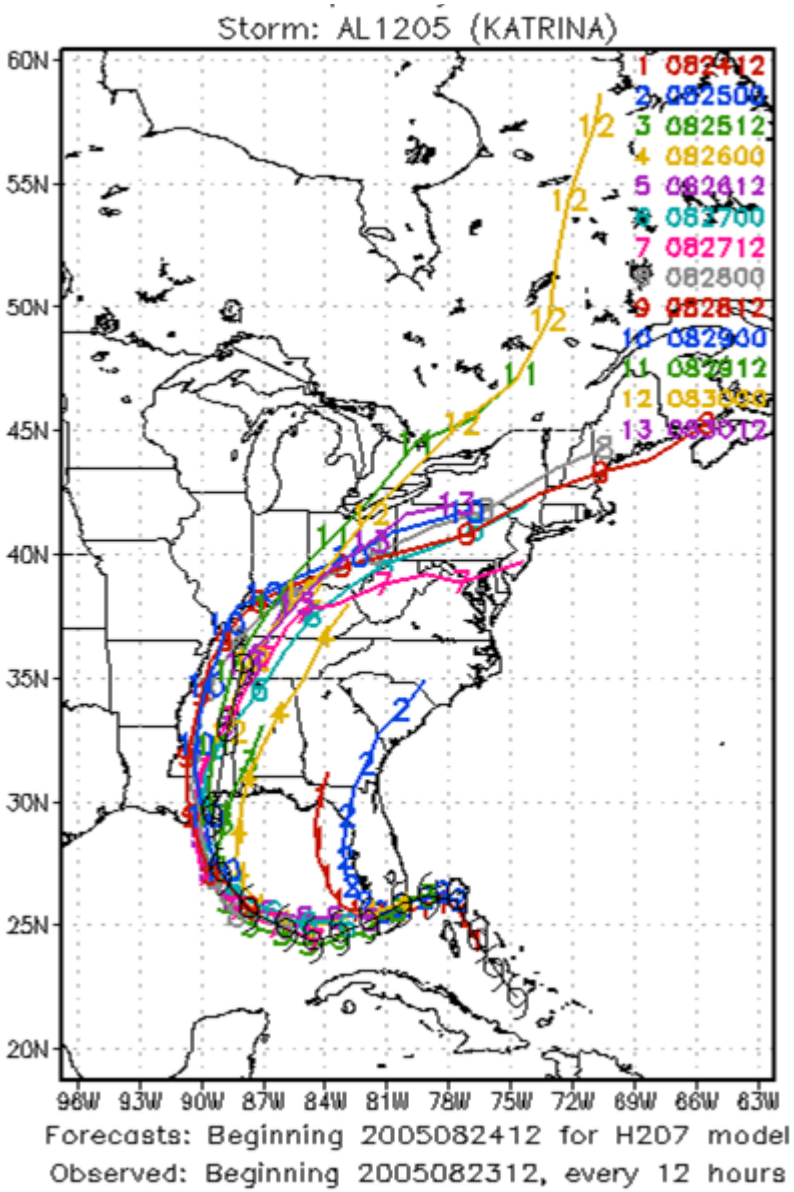

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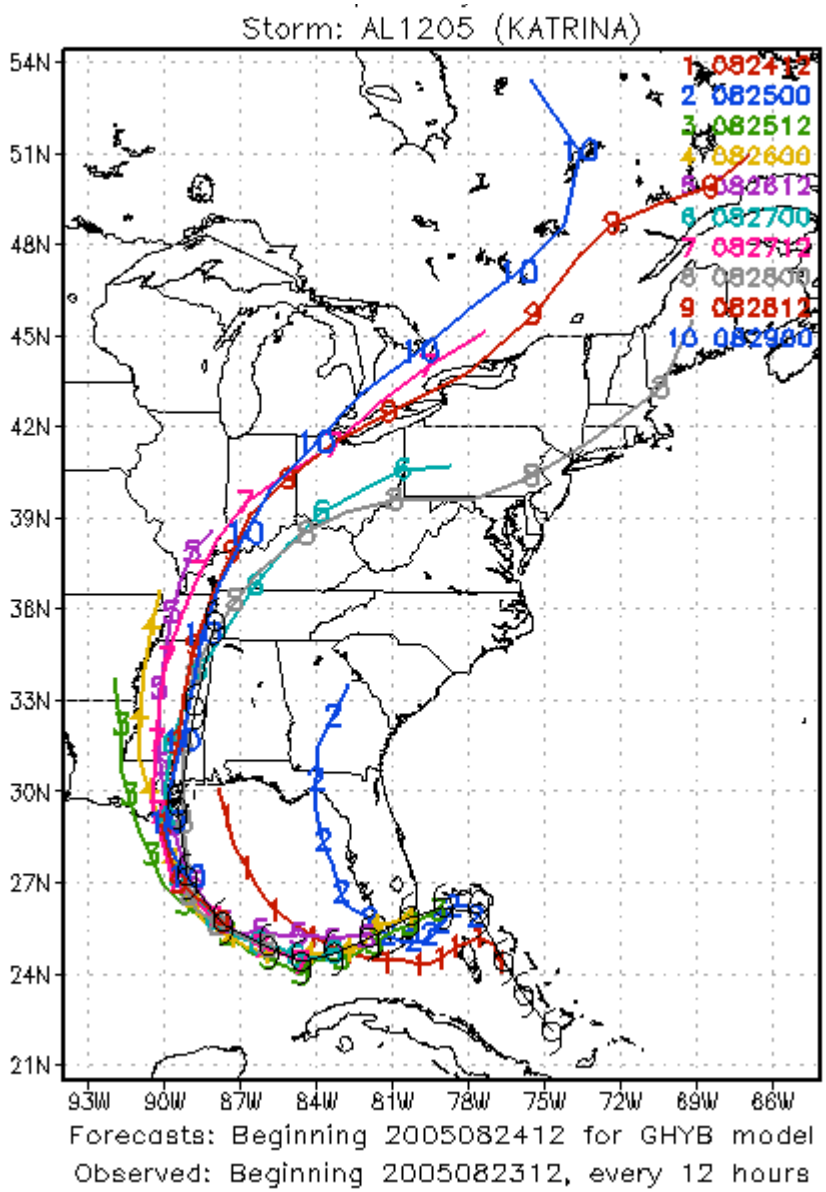

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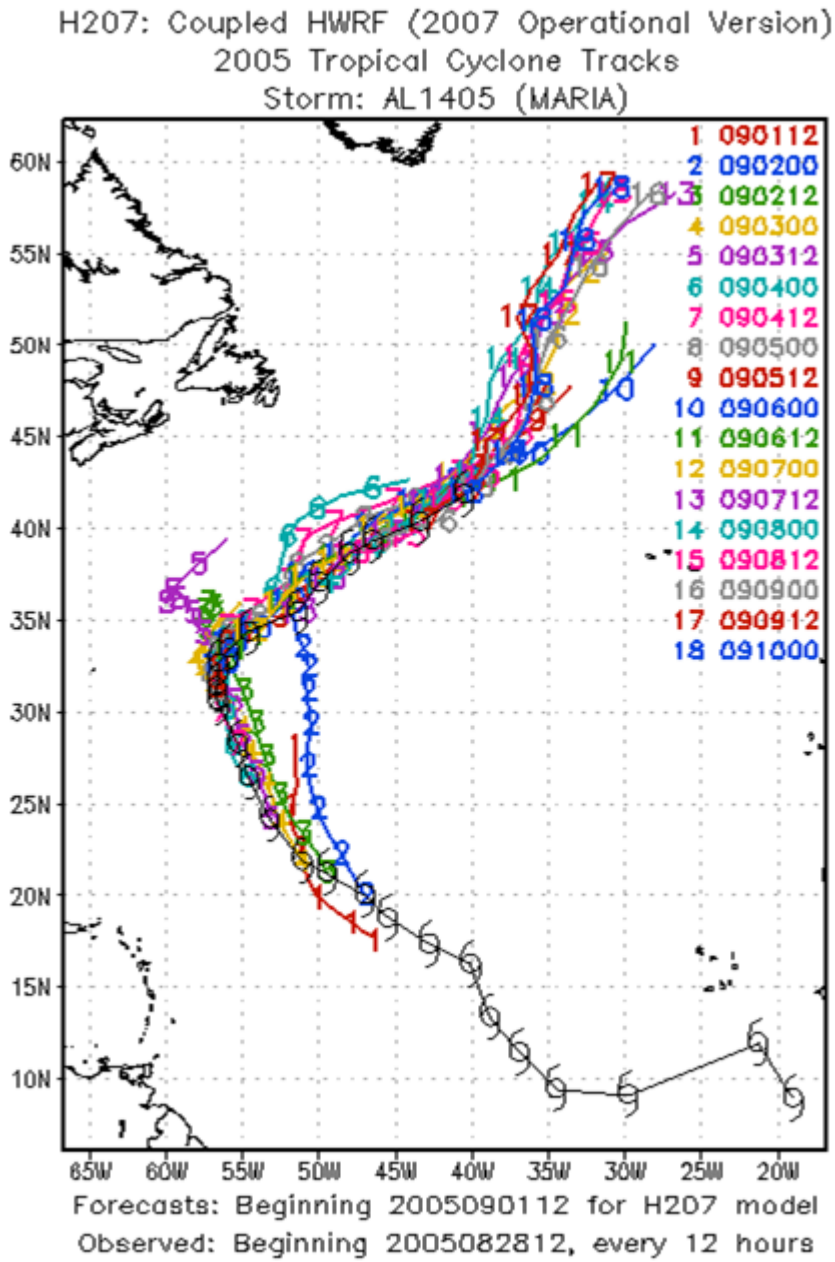

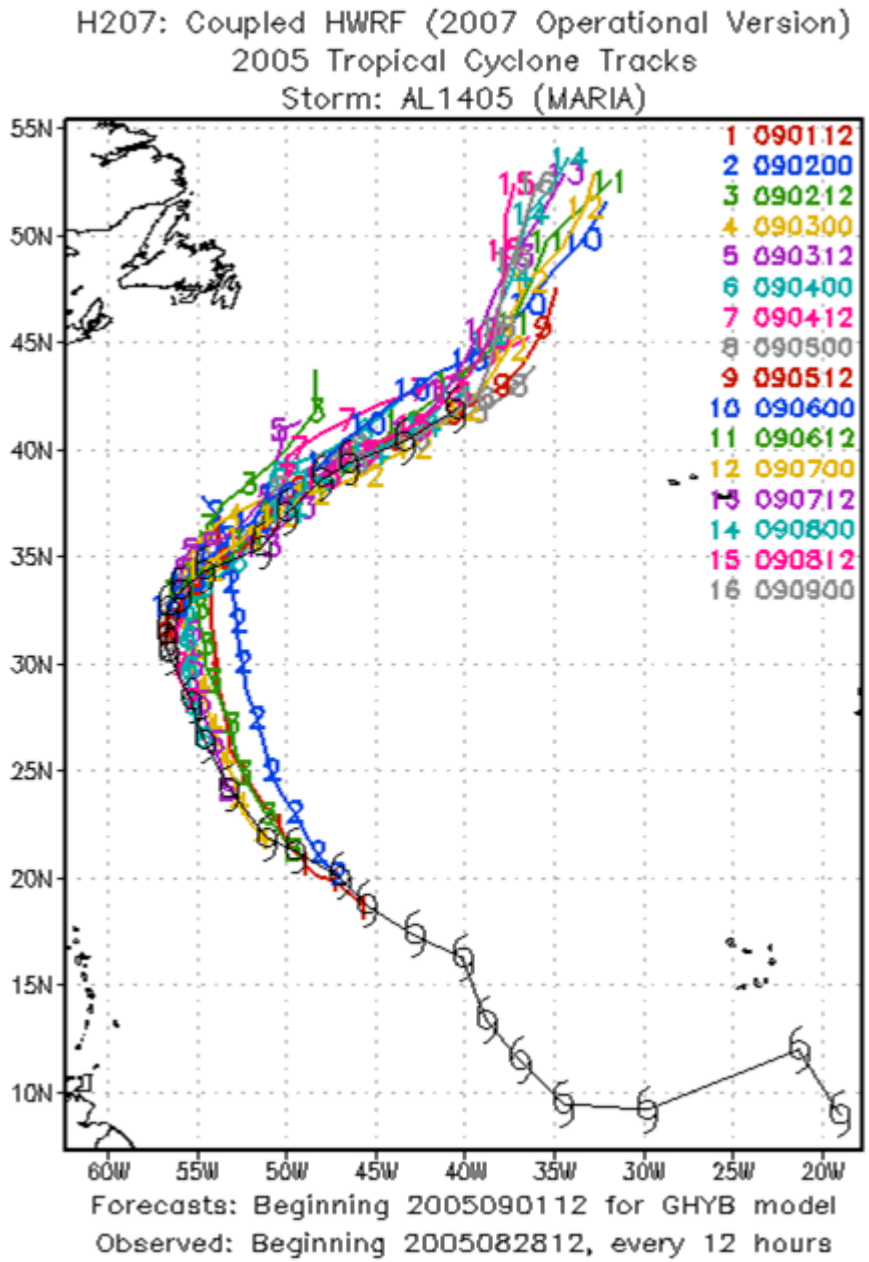

MARIA (2005) TRACKS

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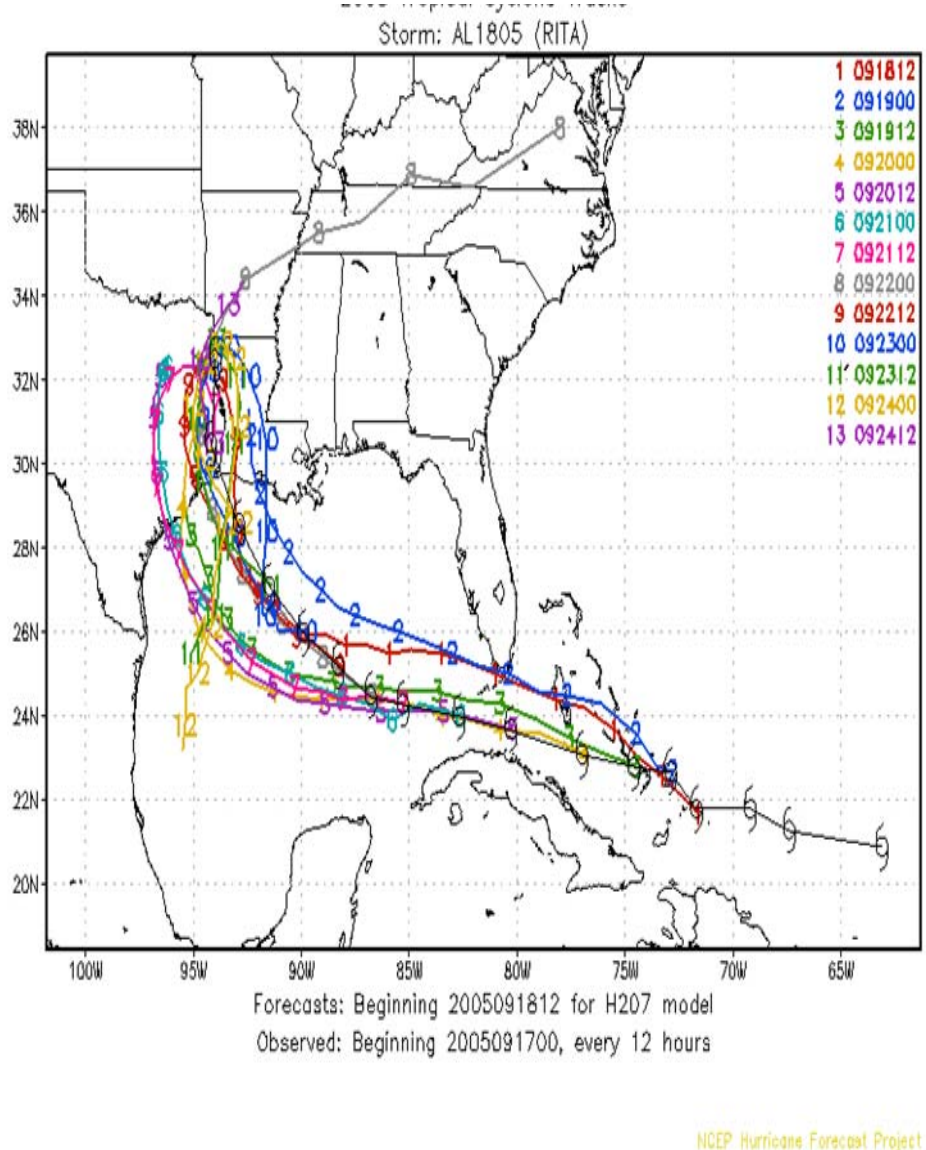

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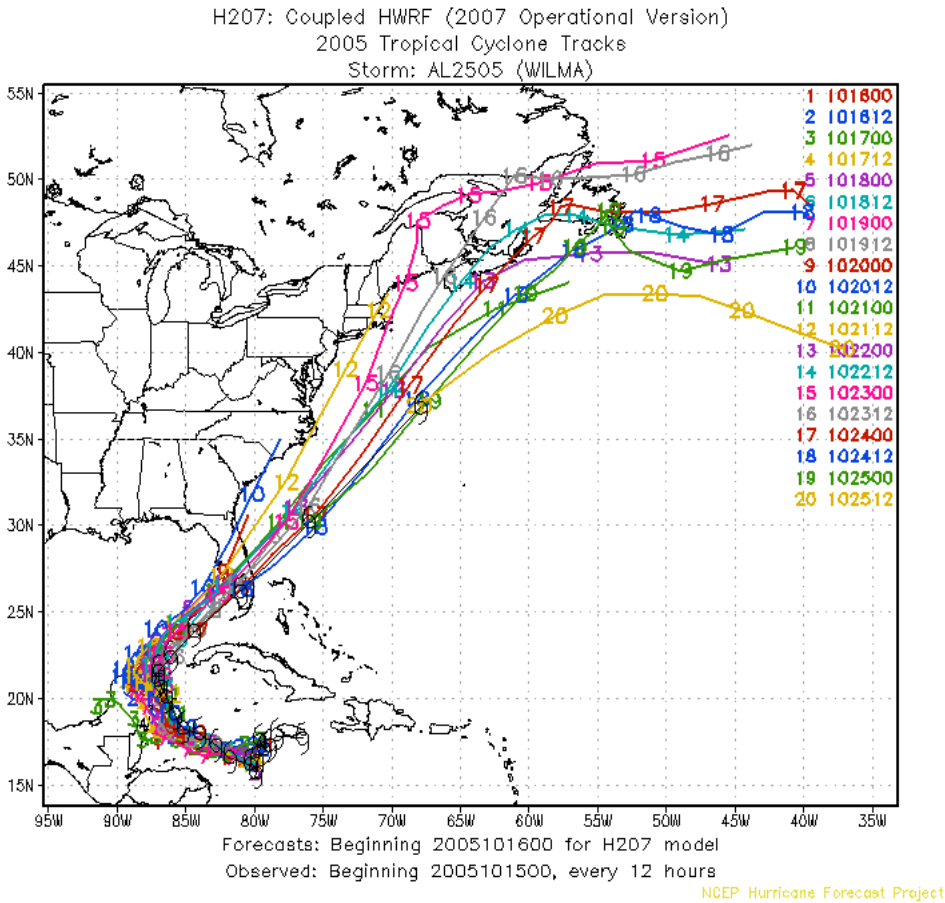
RITA (2005) TRACKS

HWRF



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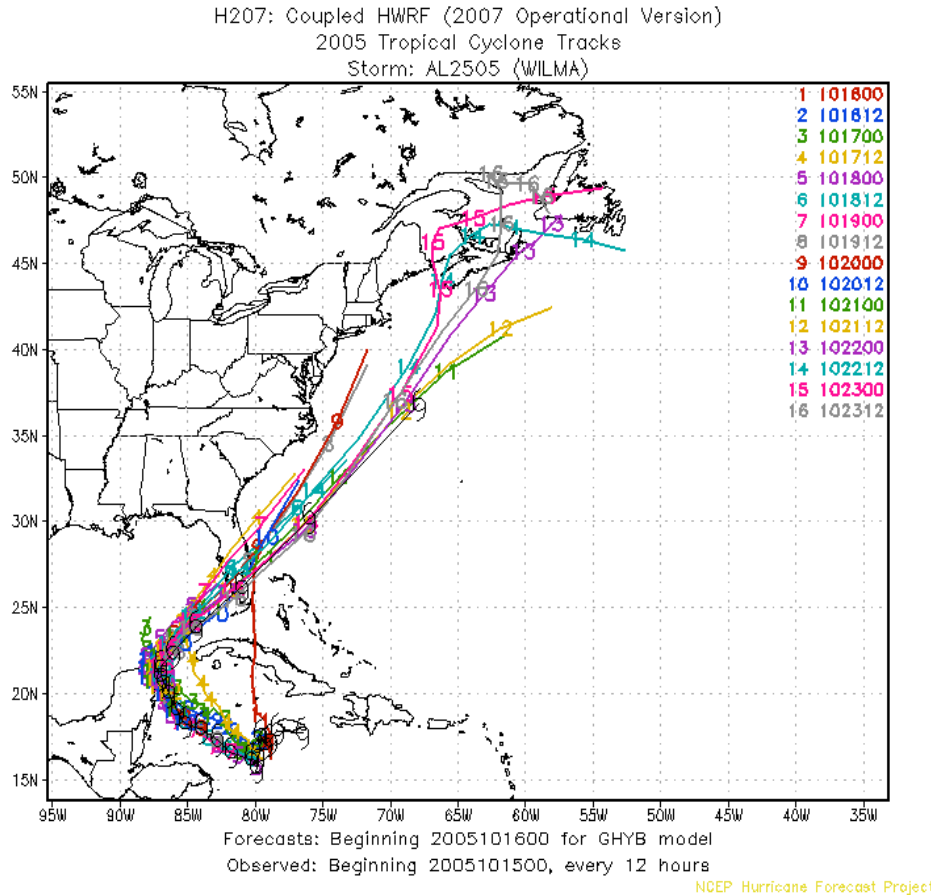
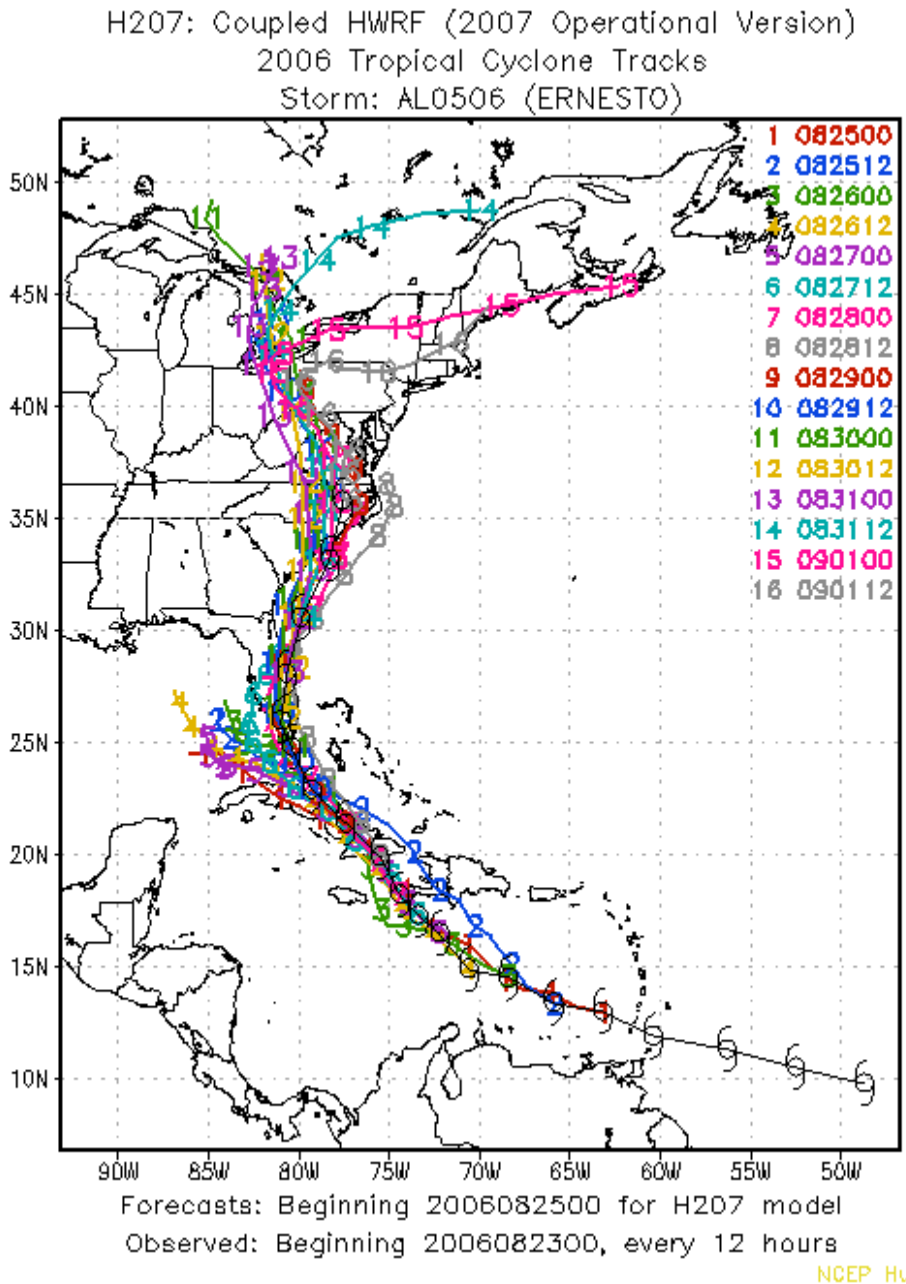
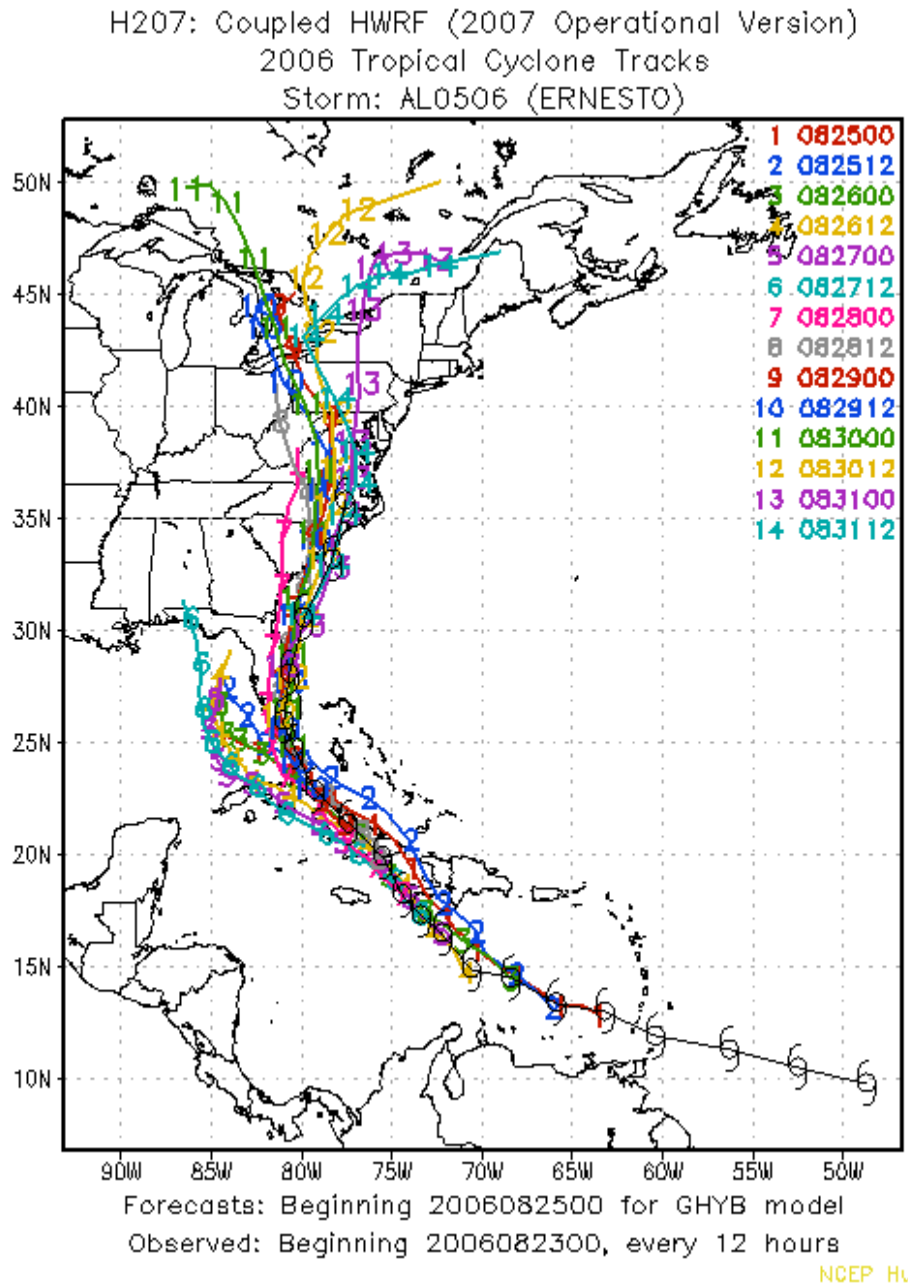
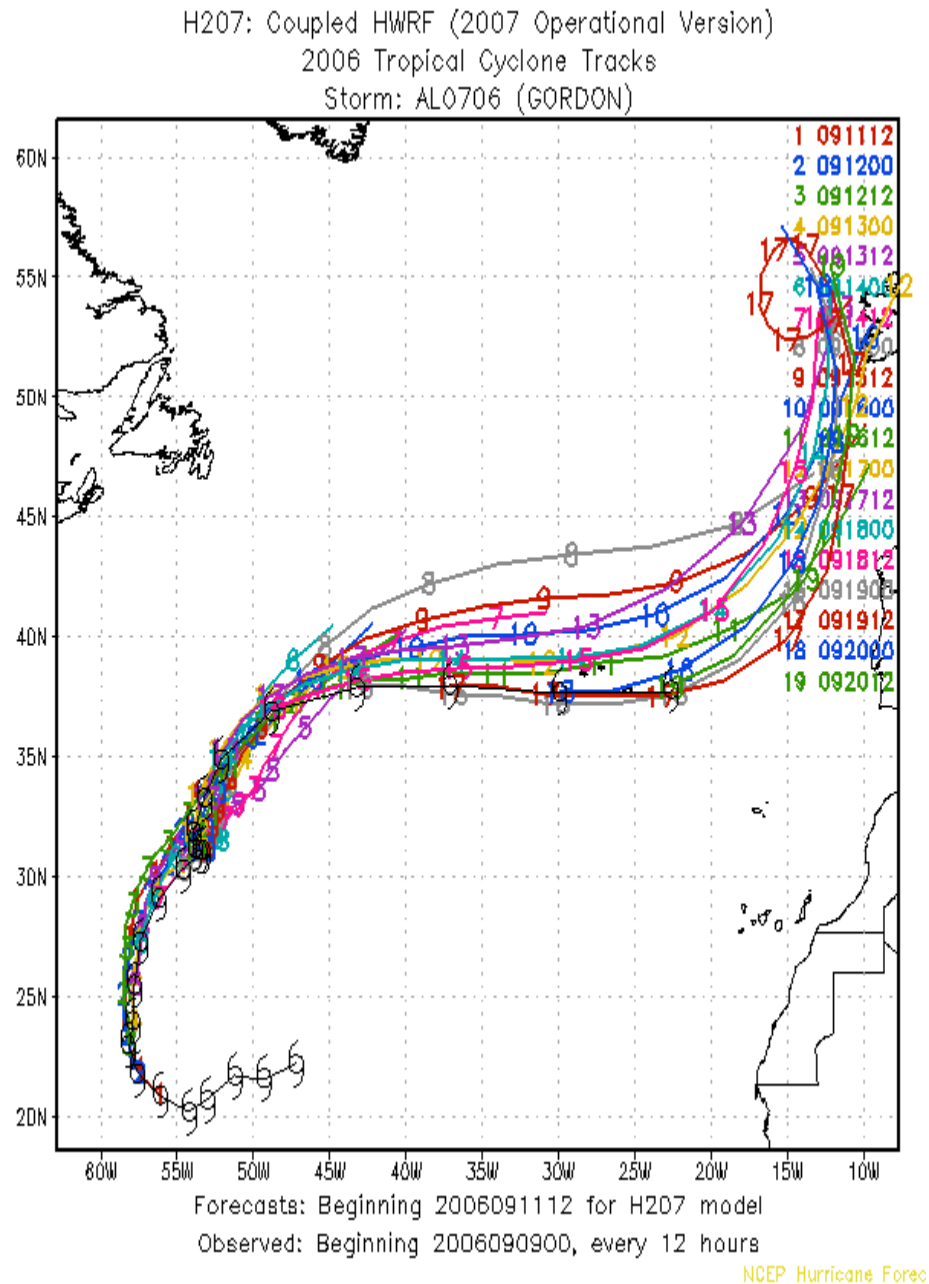


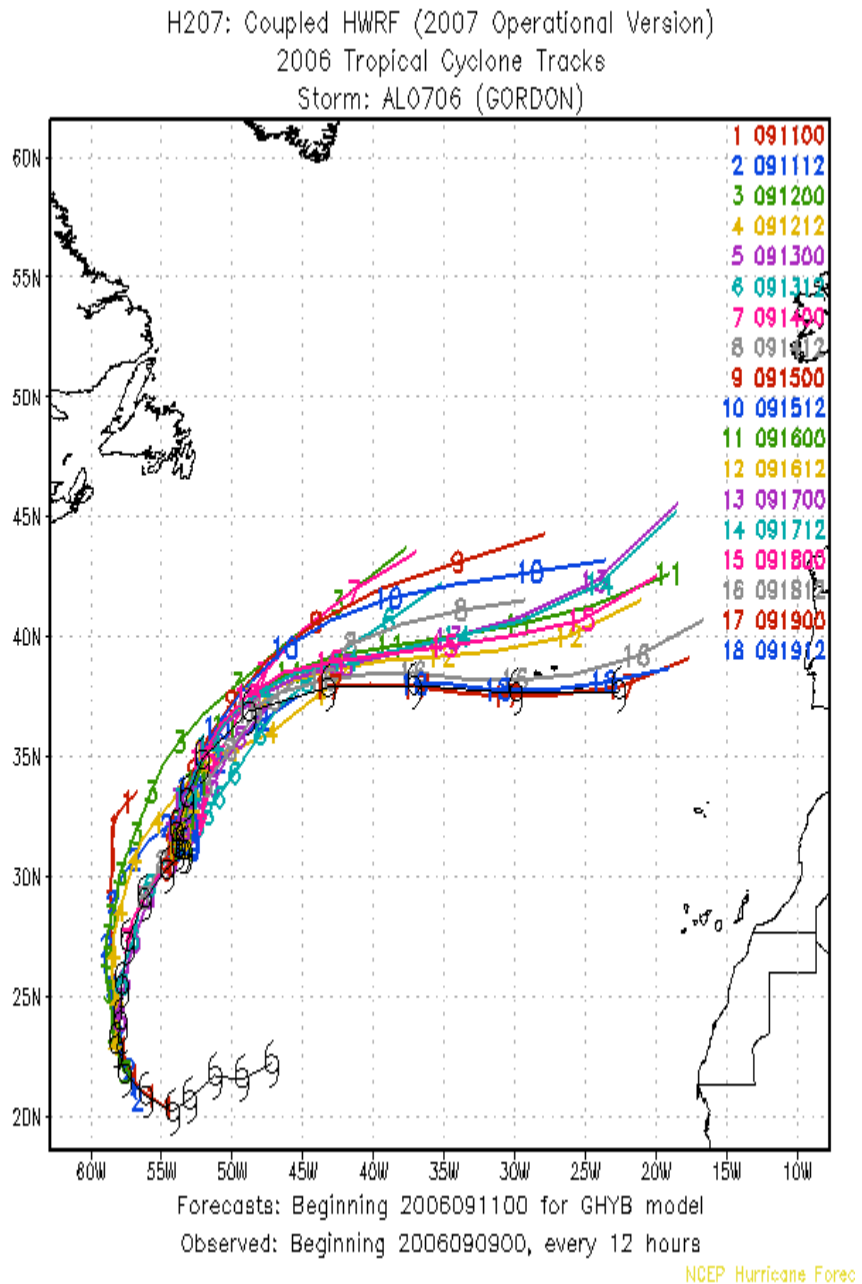
WILMA (2005) TRACKS



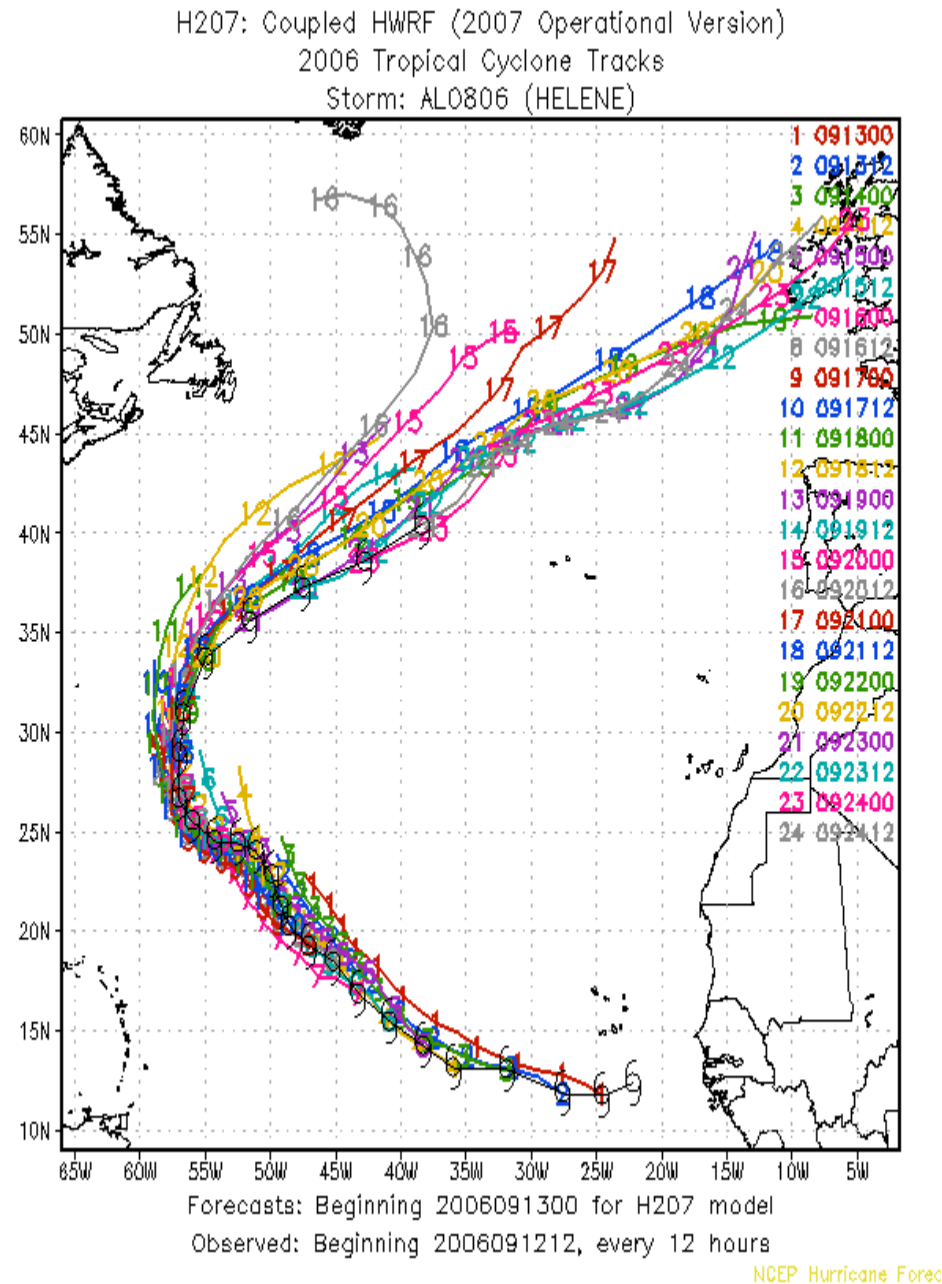


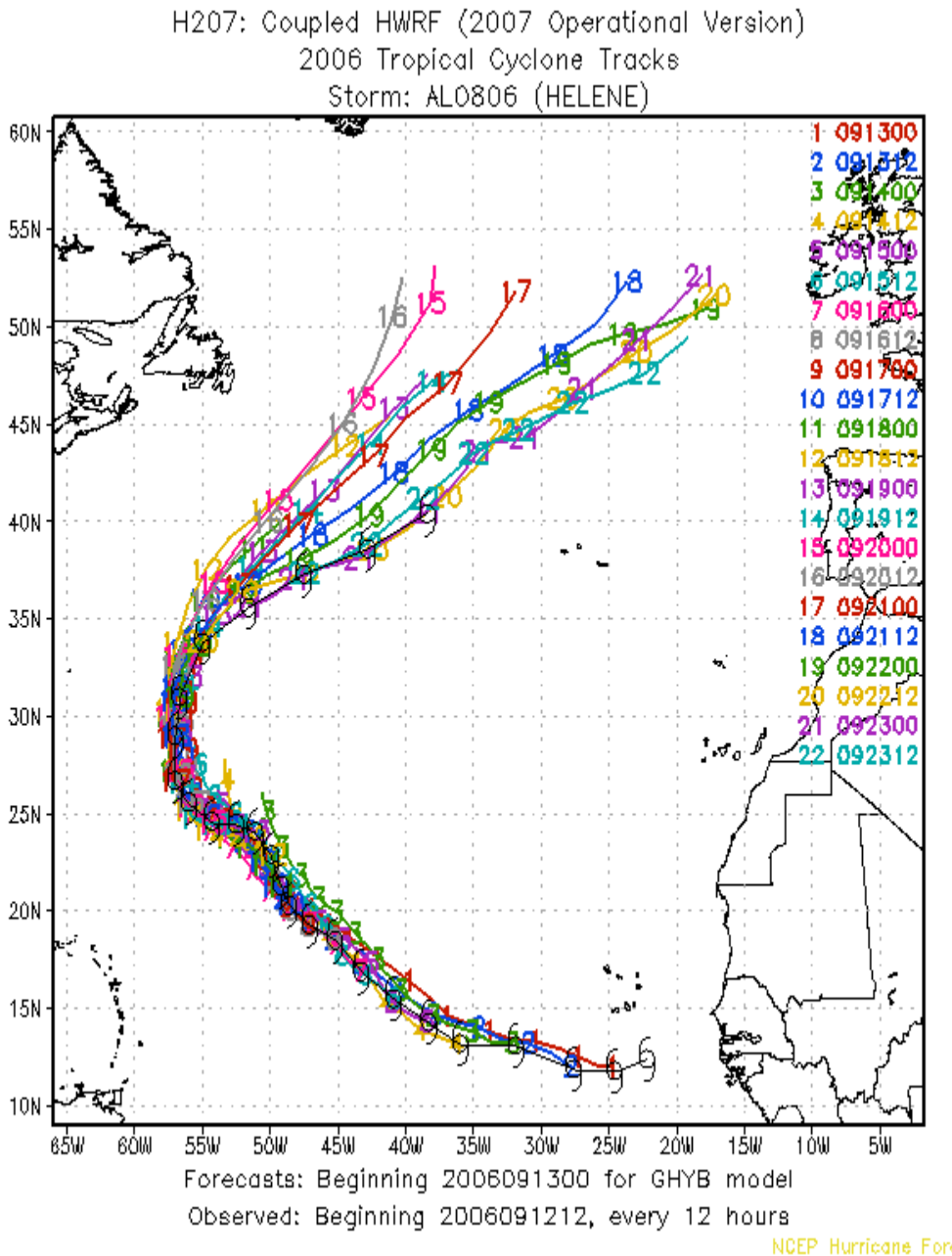
ERNESTO (2006) TRACKS





GORDON (2006) TRACKS





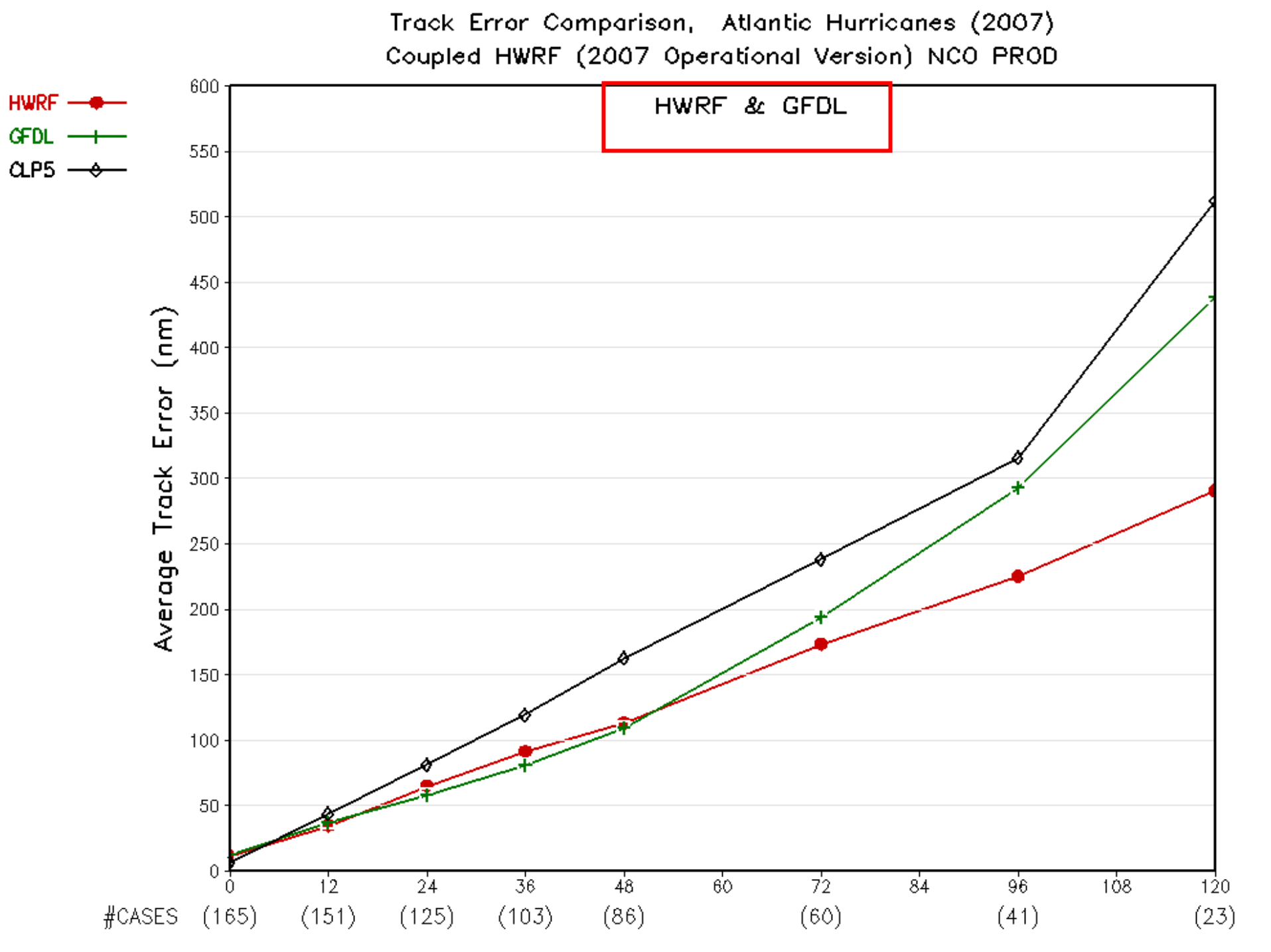
HELENE (2006) TRACKS

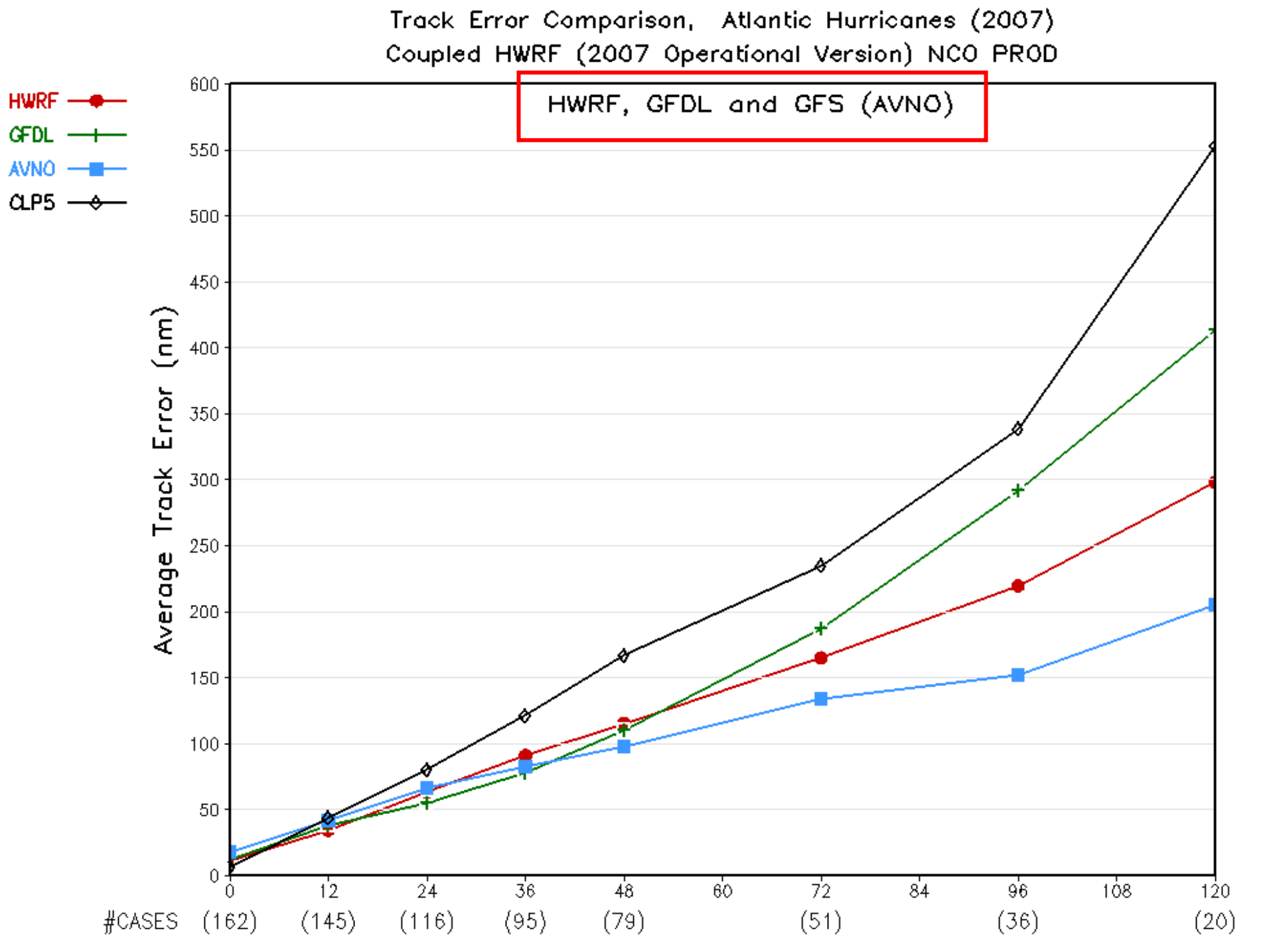
THE HWRF SYSTEM (Initial Operating Capability)

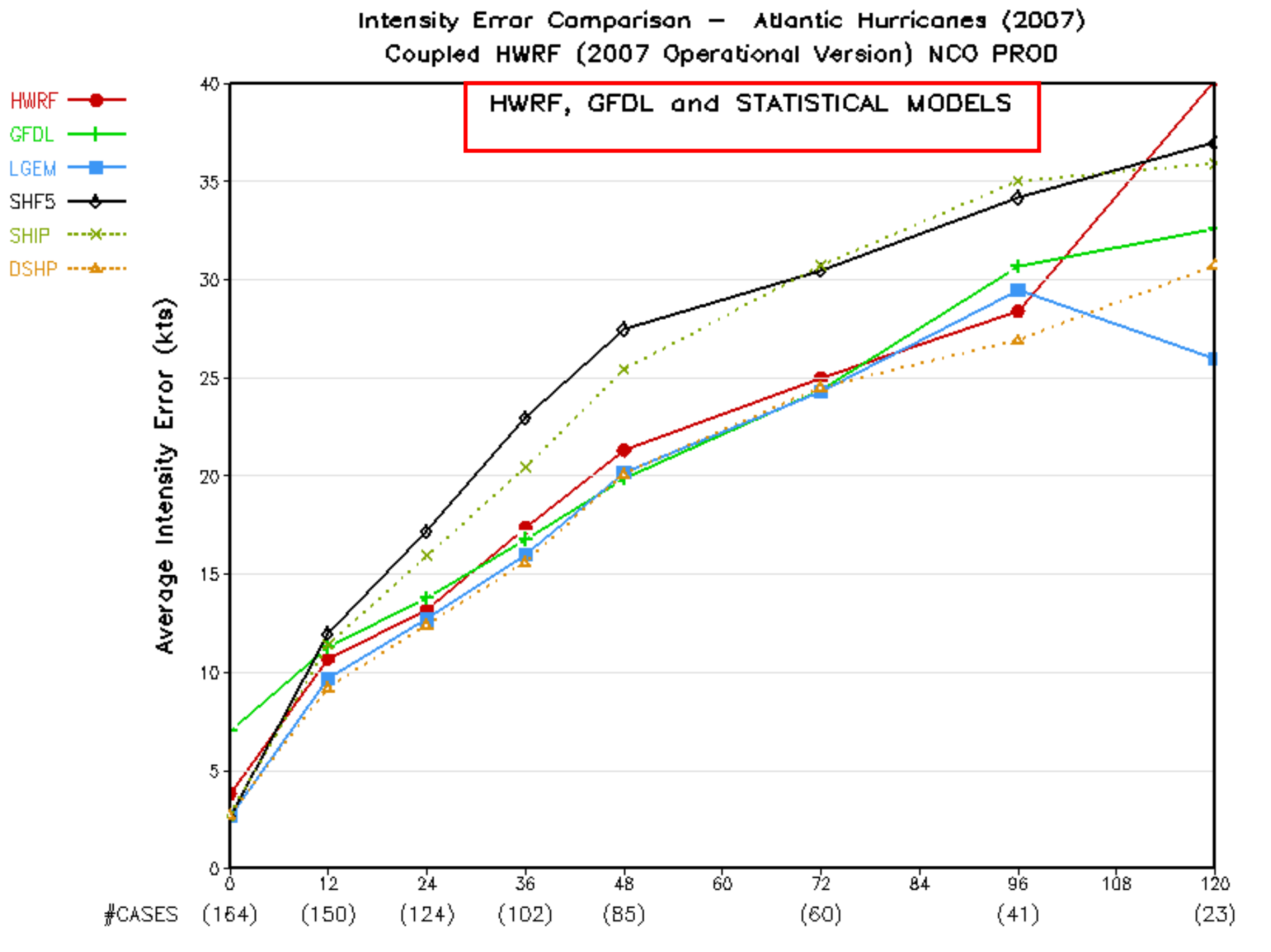
2007

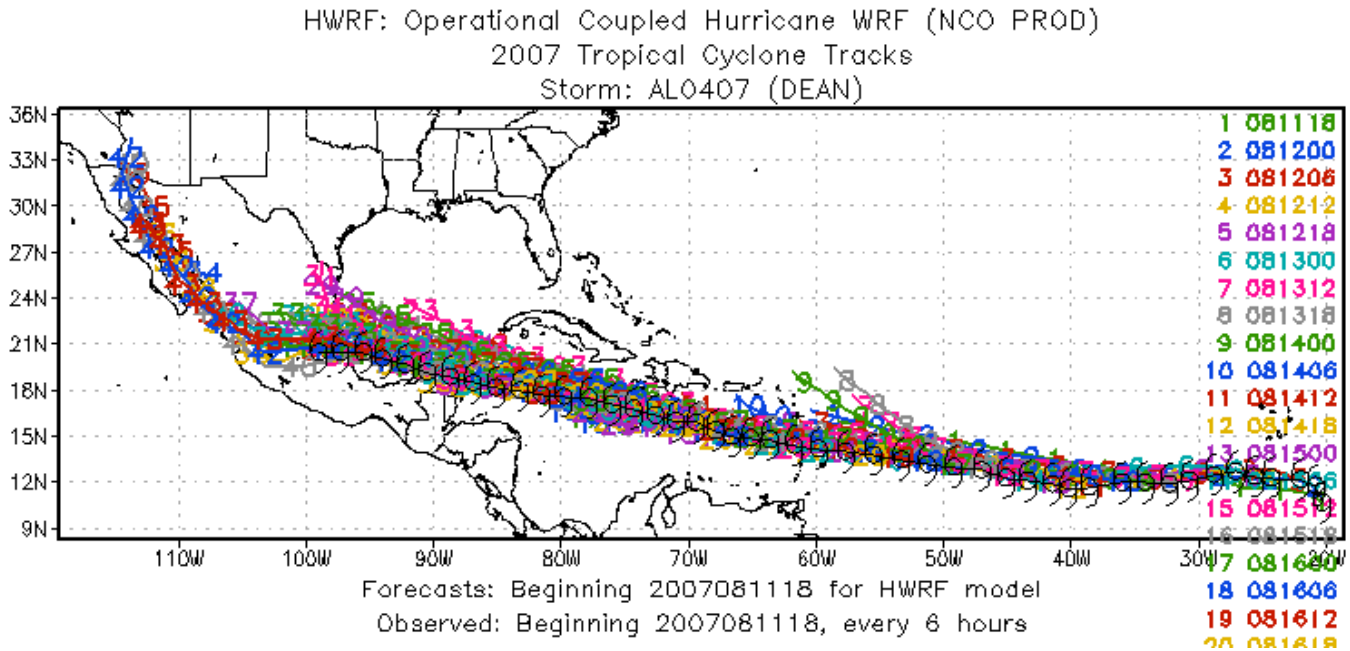
- Movable, 2- way nested grid (9km; 27km/42L; ~75X75)
- Advanced Physics
- Advanced vortex initialization – made use of prototype GSI 3D var (advancement over GFDL bogus)
- POM ocean (w/loop current init – same as GFDL)

2007 HURRICANE SEASON


Track Error Comparison, Atlantic Hurricanes (2007)
Coupled HWRF (2007 Operational Version) NCO PROD
HWRF & GFDL
HWRF
GFDL
CLP5
Average Track Error (nm)
600
550
500
450
400
350
300
250
200
150
100
50
0
0
12
24
36
48
60
72
84
96
108
120
#CASES (165) (151) (125) (103) (86) (60) (41) (23)


Track Error Comparison, Atlantic Hurricanes (2007)
Coupled HWRF (2007 Operational Version) NCO PROD
HWRF, GFDL and GFS (AVNO)
HWRF
GFDL
AVNO
CLP5
Average Track Error (nm)
0
50
100
150
200
250
300
350
400
450
500
550
600
0
12
24
36
48
60
72
84
96
108
120
#CASES (162) (145) (116) (95) (79) (51) (36) (20)


Intensity Error Comparison — Atlantic Hurricanes (2007)
Coupled HWRF (2007 Operational Version) NCO PROD
HWRF, GFDL and STATISTICAL MODELS
HWRF
GFDL
LGEM
SHF5
SHIP
DSHP
Average Intensity Error (kts)
0
5
10
15
20
25
30
35
40
0
12
24
36
48
60
72
84
96
108
120
#CASES
(164)
(150)
(124)
(102)
(85)
(60)
(41)
(23)

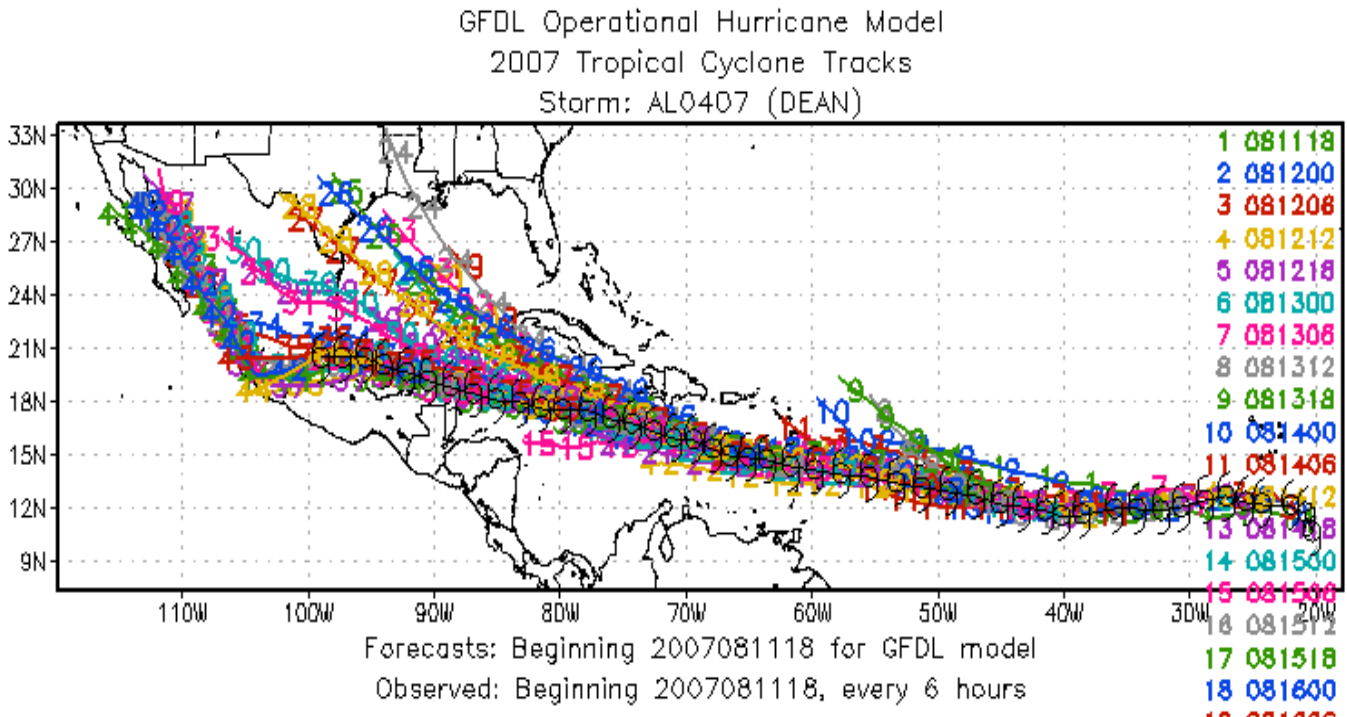


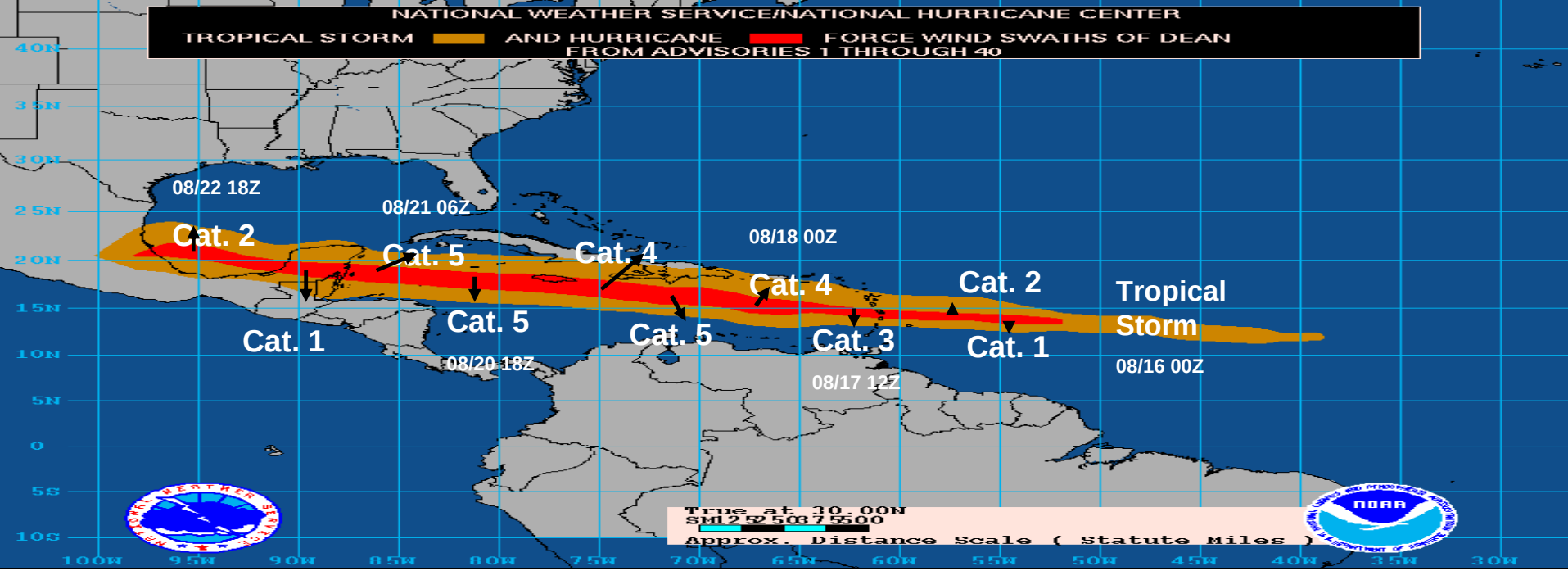
HWRF

Hurricane Dean

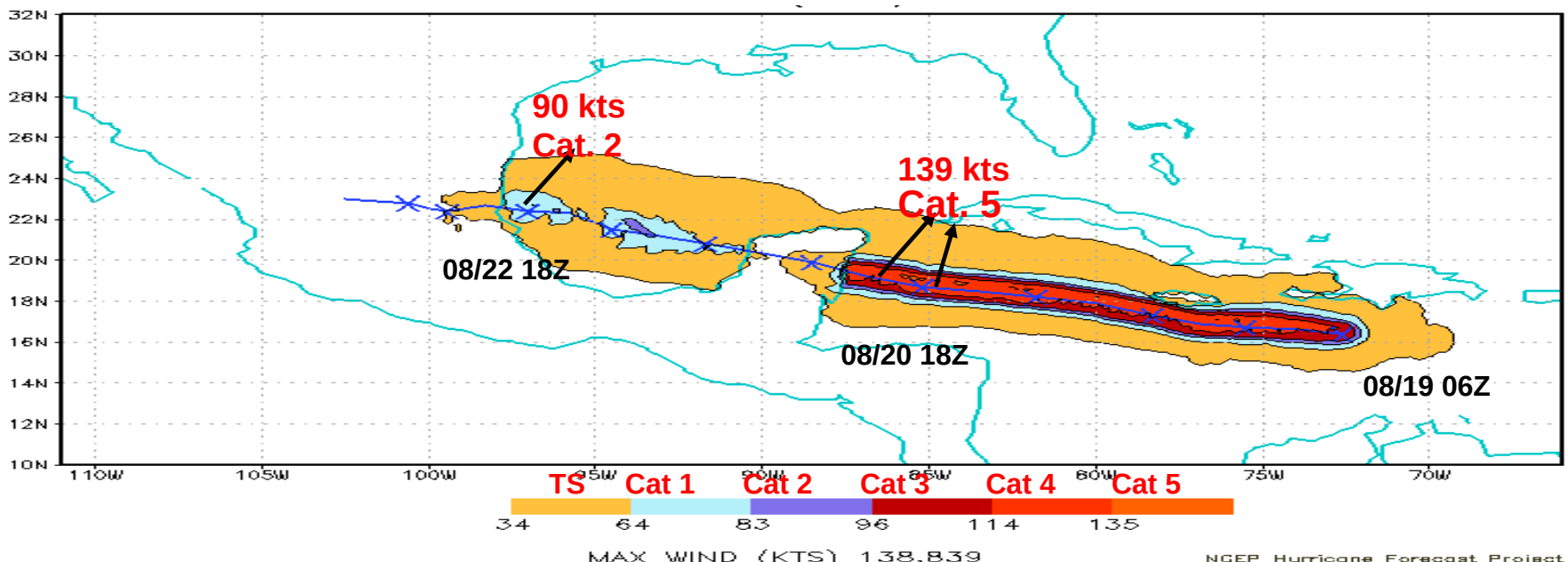
August 11–22, 2007

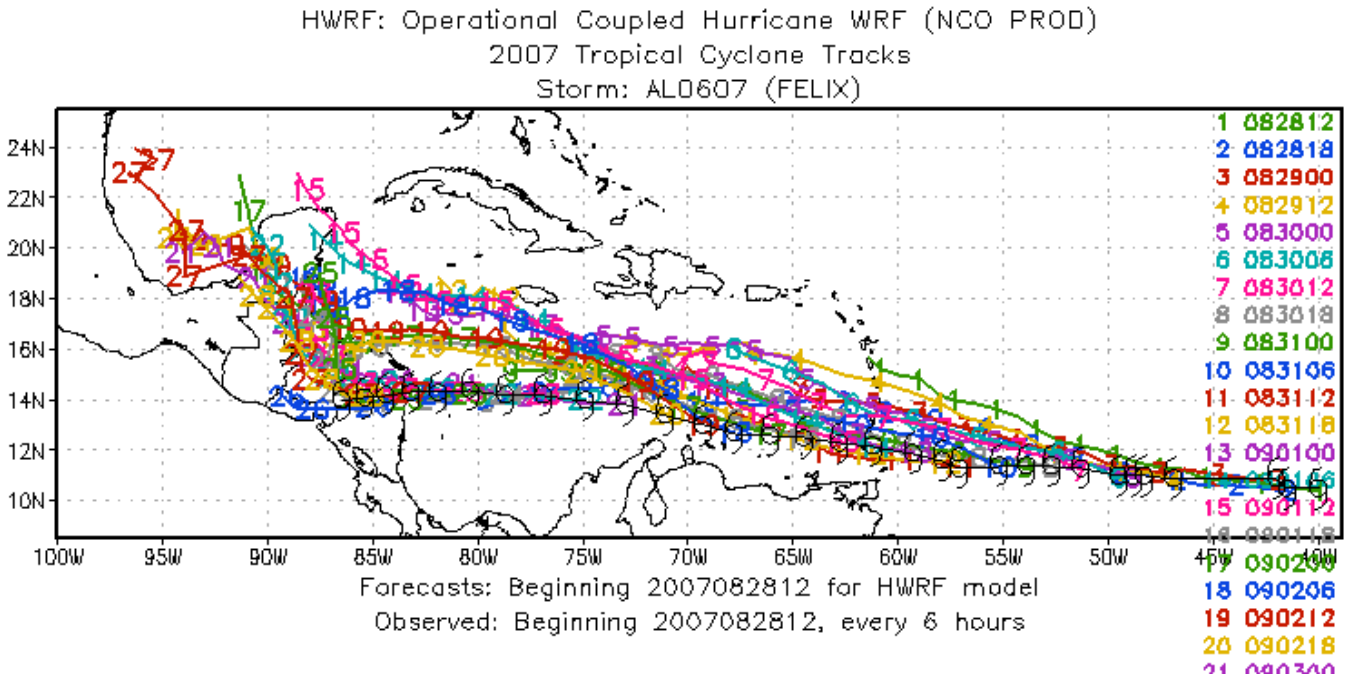
GFDL





Hurricane Dean 5 day forecasts of maximum winds starting from 8/19/06Z



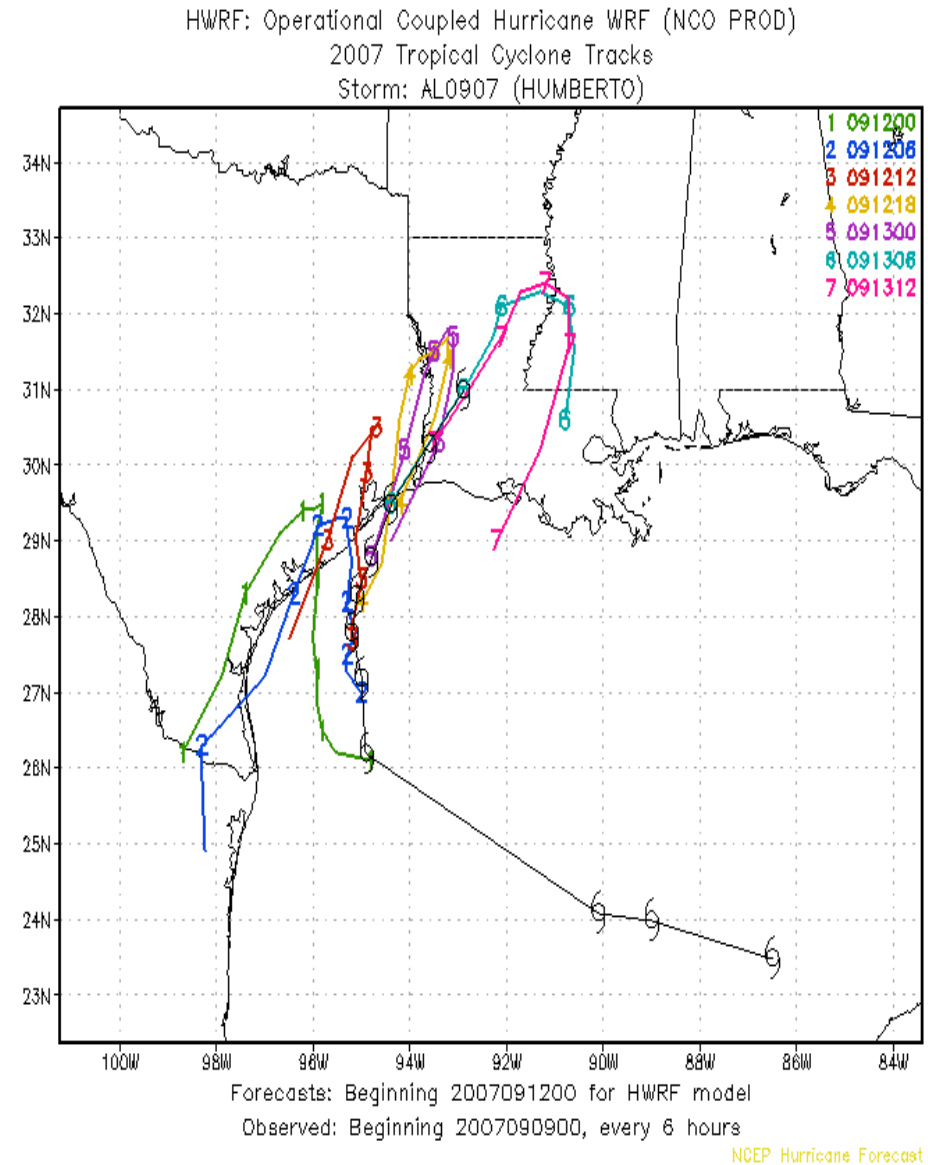


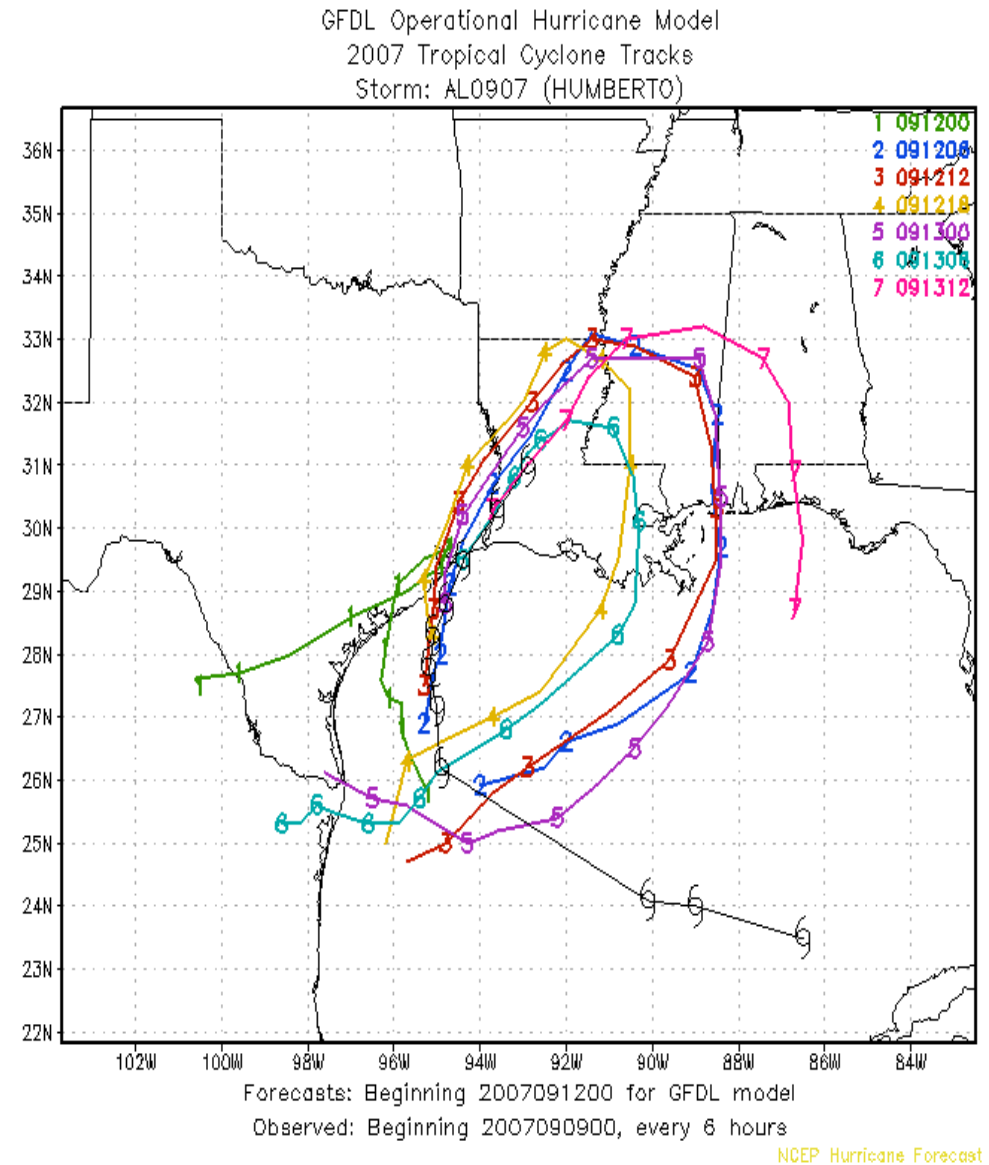
HWRF

Hurricane Felix

Aug. 28–Sep. 05, 2007

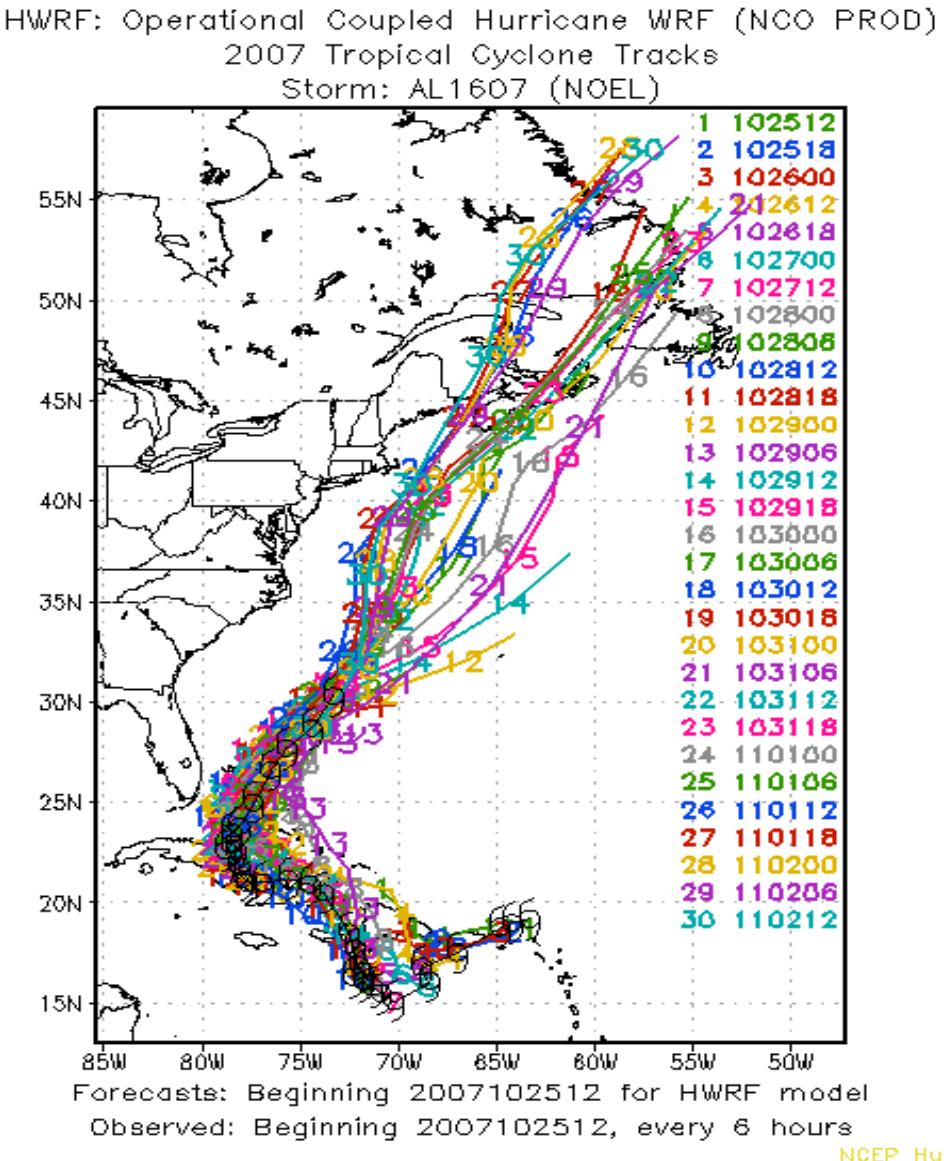
GFDL

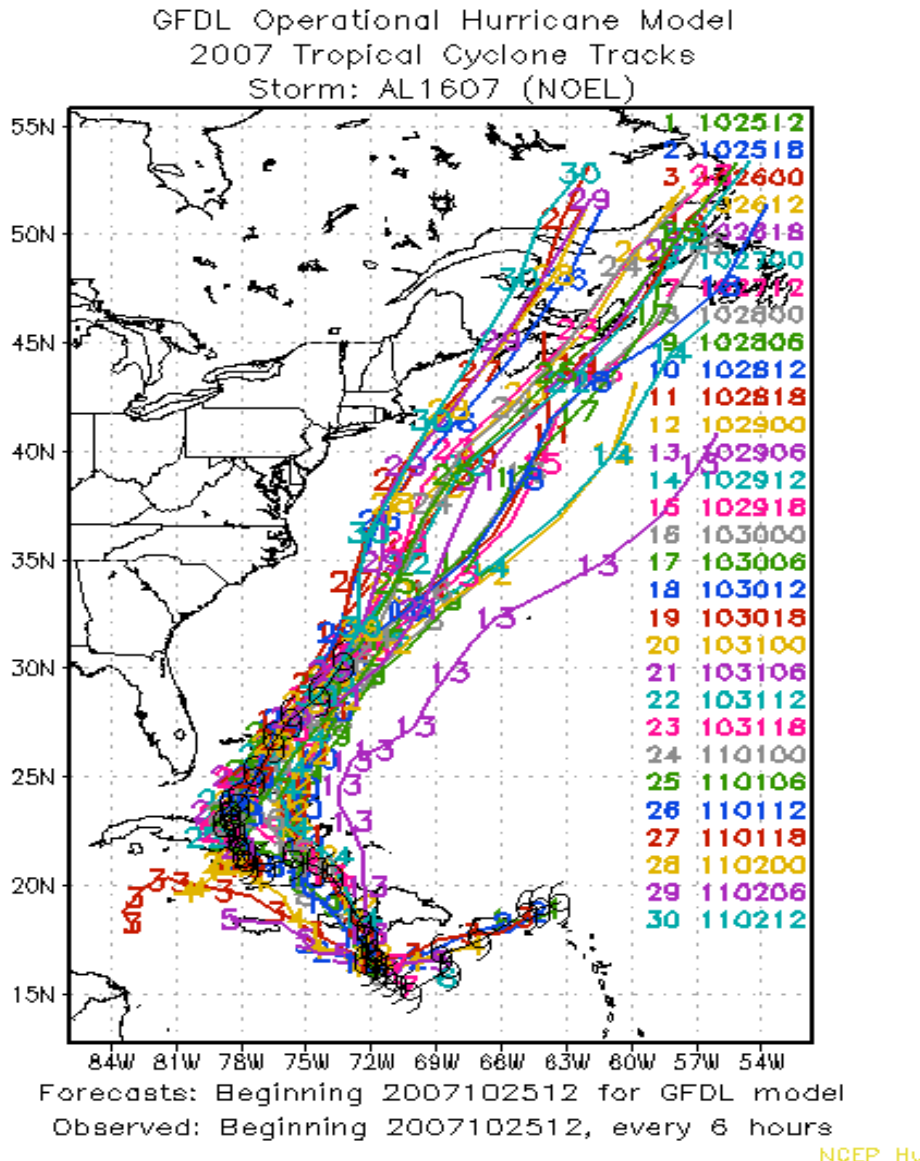




HWRF **Hurricane Humberto** **GFDL**

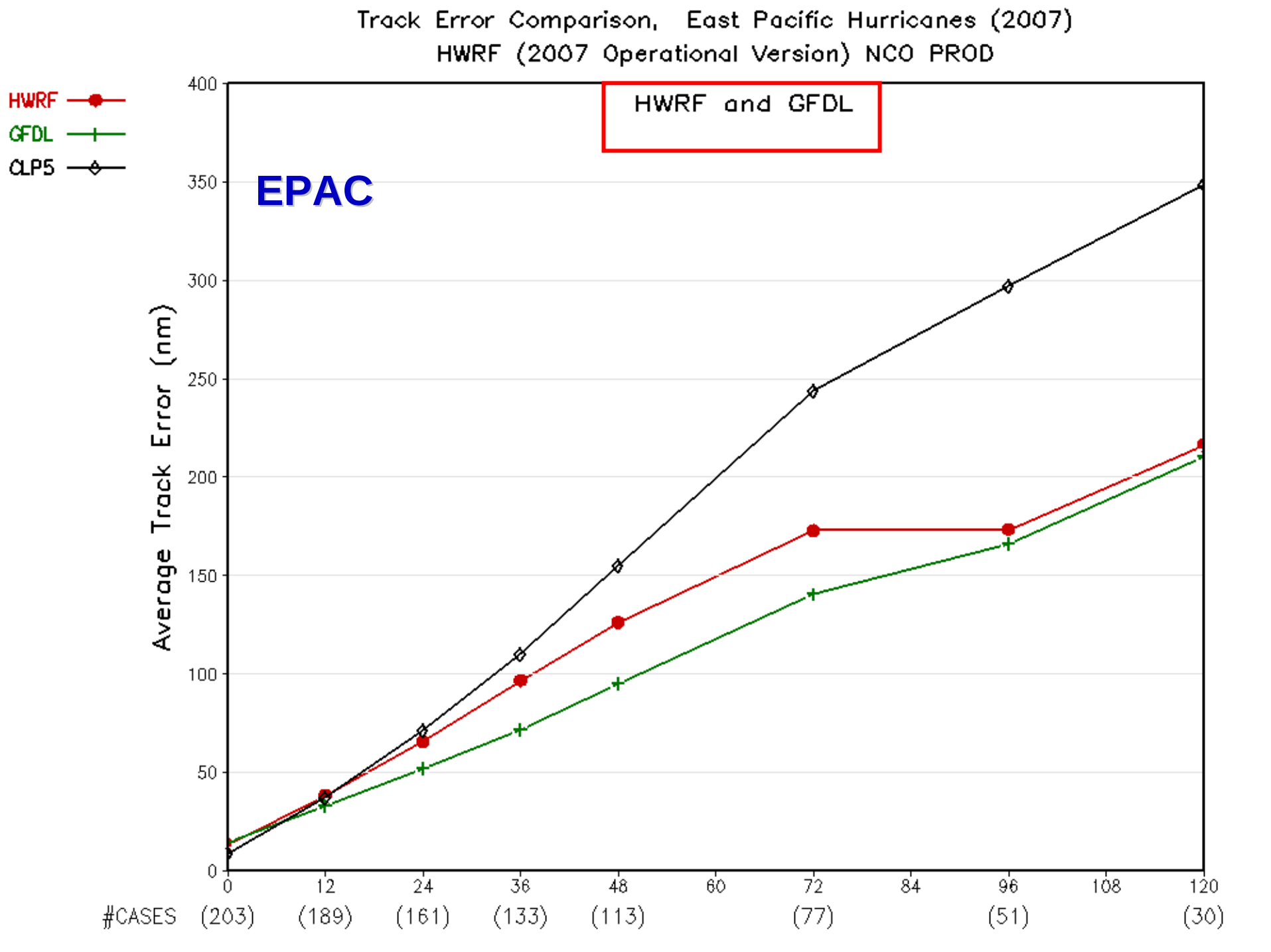
September 12-13, 2007

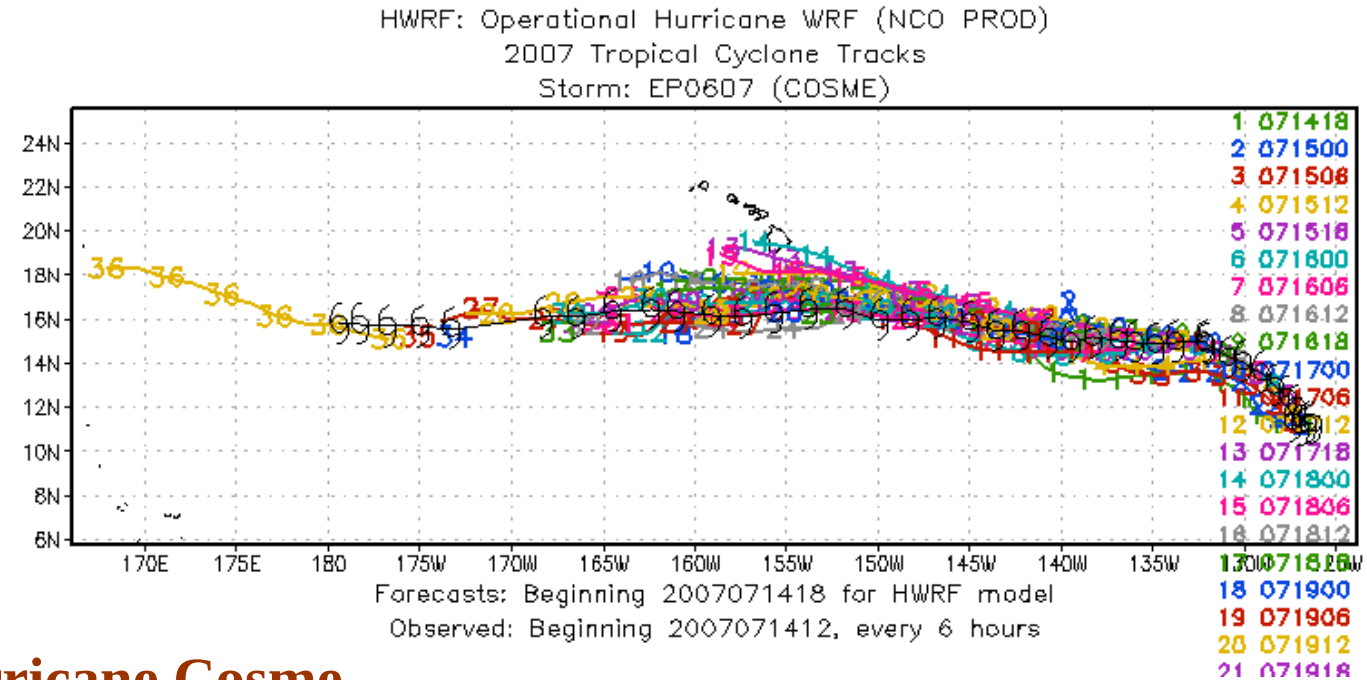




HWRF **Hurricane Noel** **GFDL**

October 25-November 02, 2007


Track Error Comparison, East Pacific Hurricanes (2007)
HWRF (2007 Operational Version) NCO PROD
HWRF
GFDL
CLP5
HWRF and GFDL
EPAC
Average Track Error (nm)
400
350
300
250
200
150
100
50
0
0
12
24
36
48
60
72
84
96
108
120
#CASES
(203)
(189)
(161)
(133)
(113)
(77)
(51)
(30)

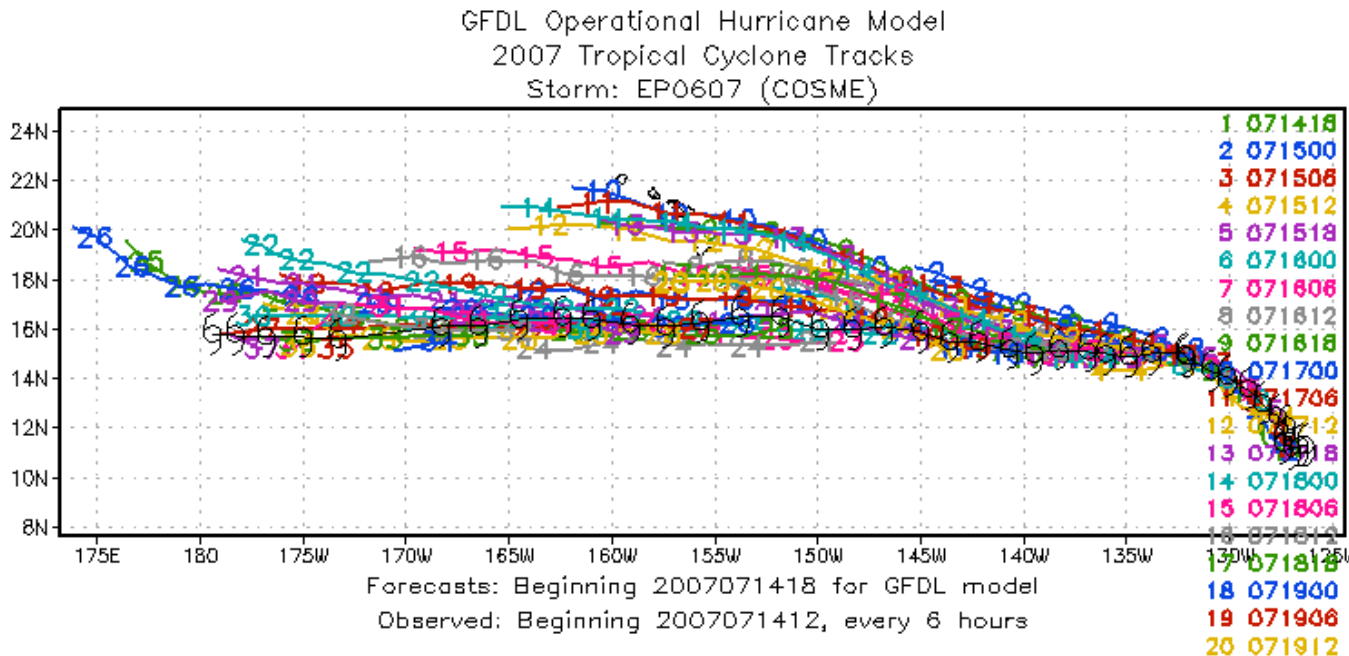


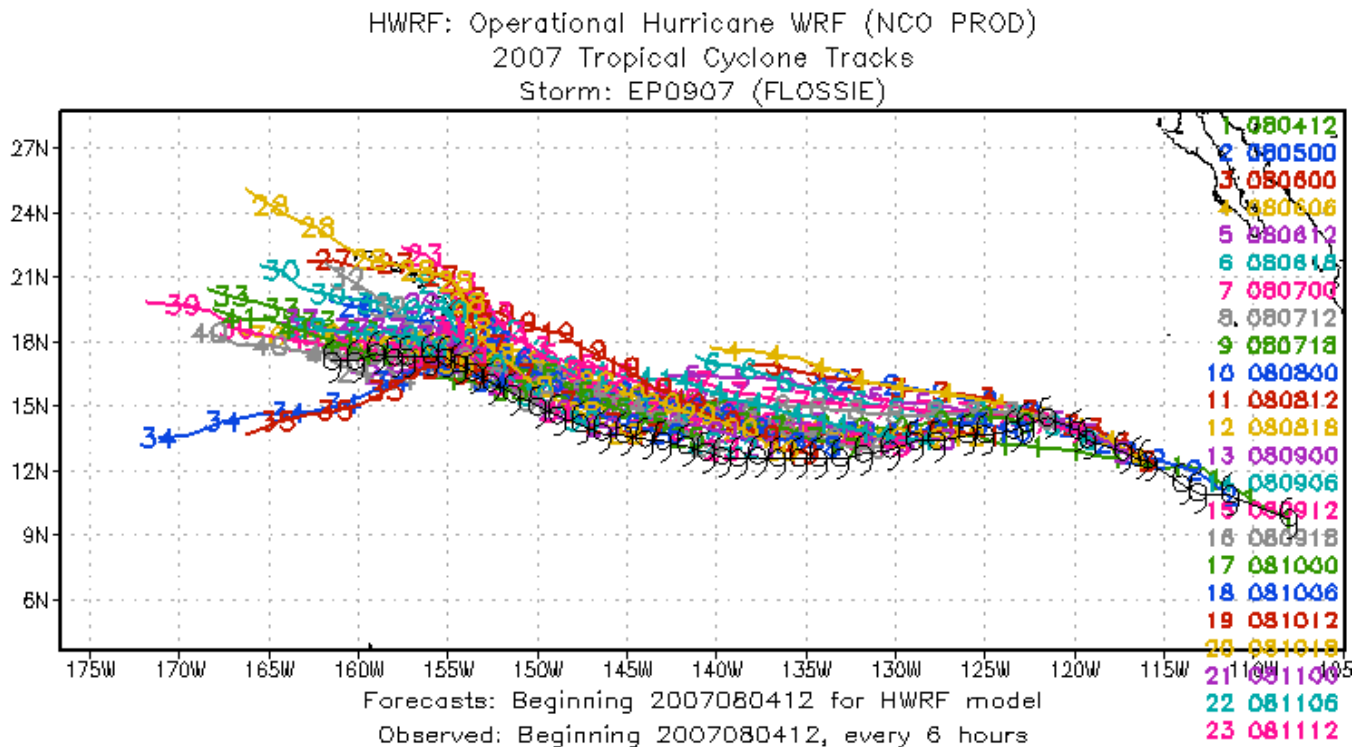
HWRF

Hurricane Cosme

July 14 – 24, 2007

GFDL



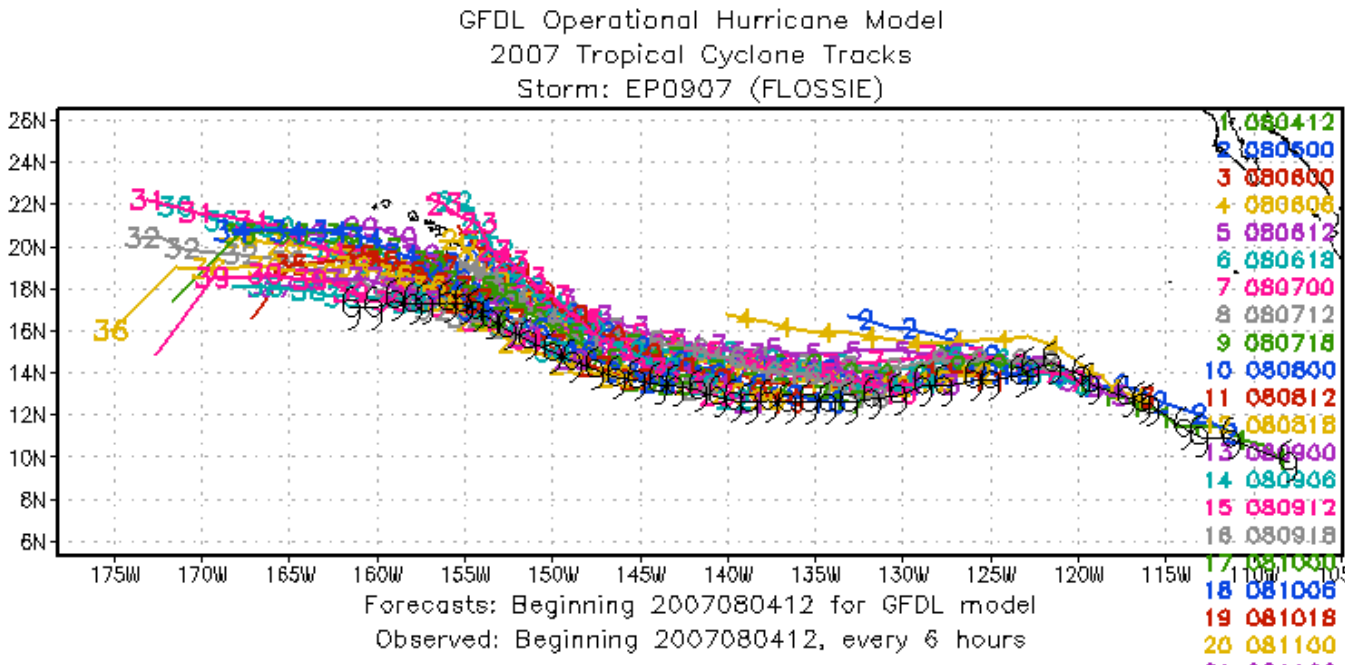


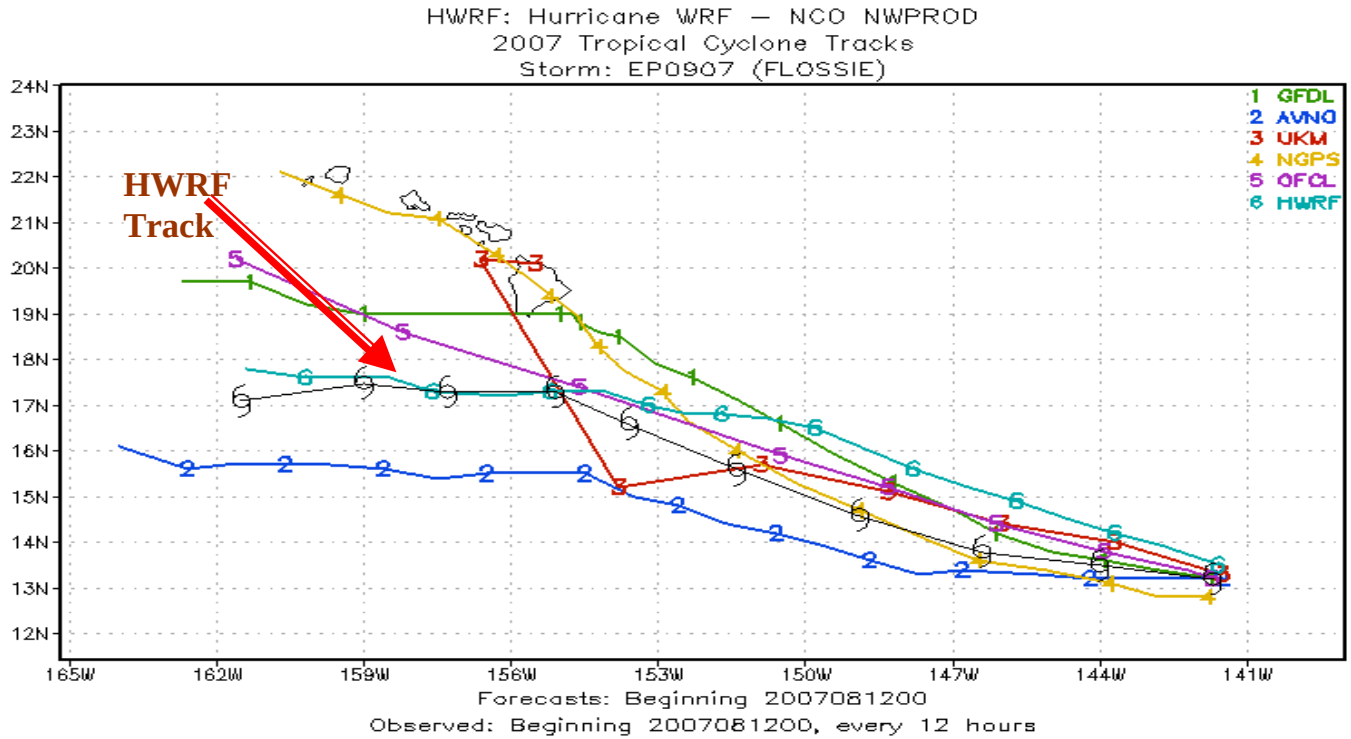
HWRF

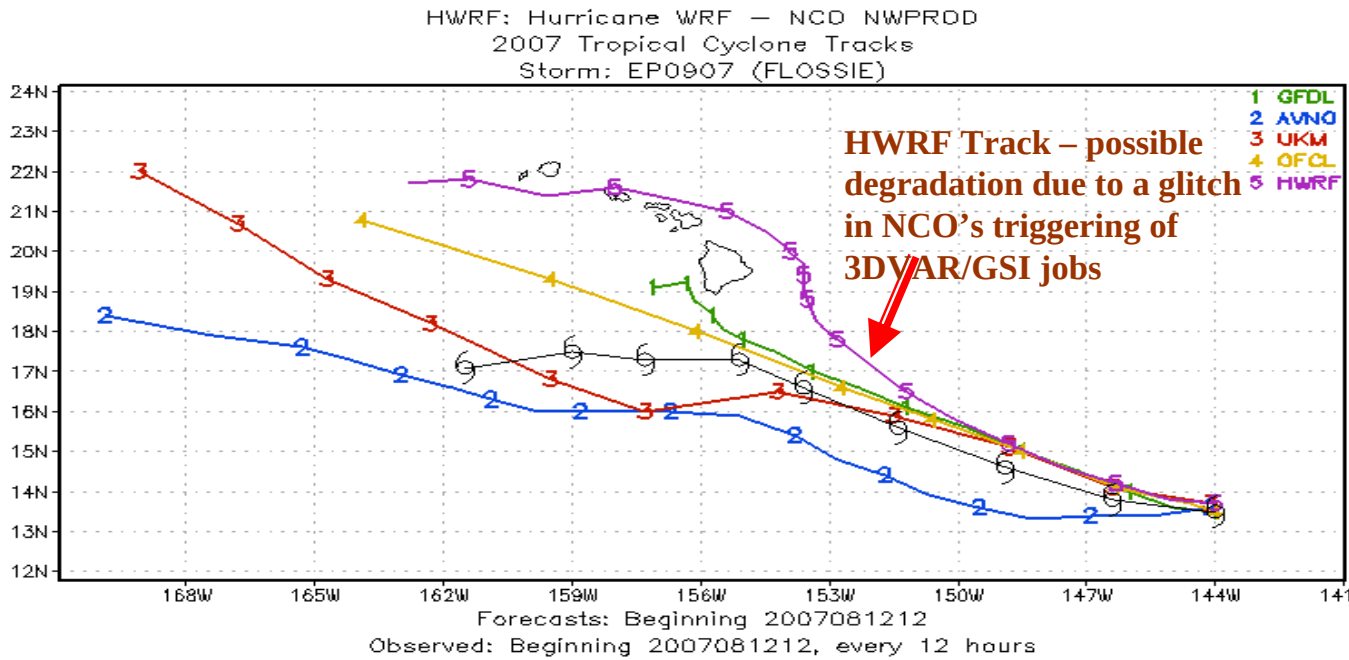
Hurricane Flossie

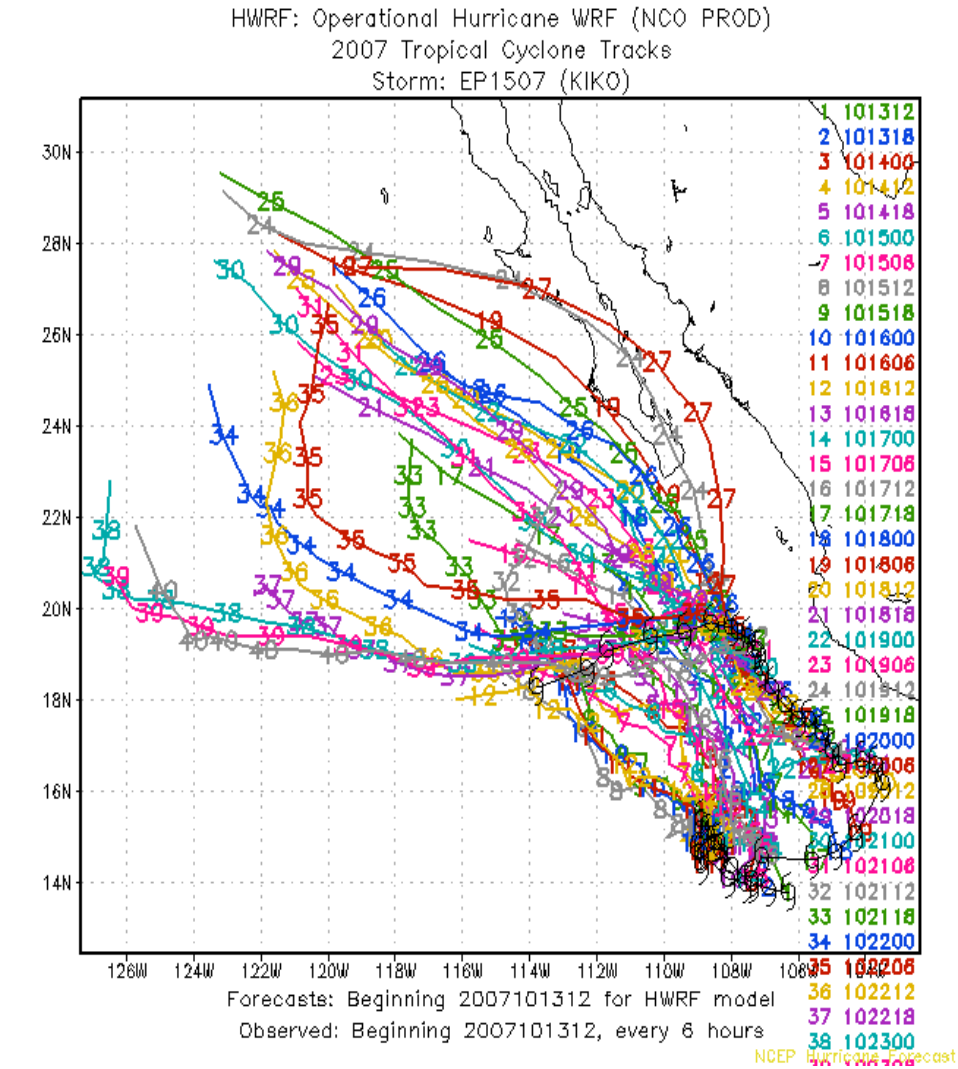
August 04 – 16, 2007

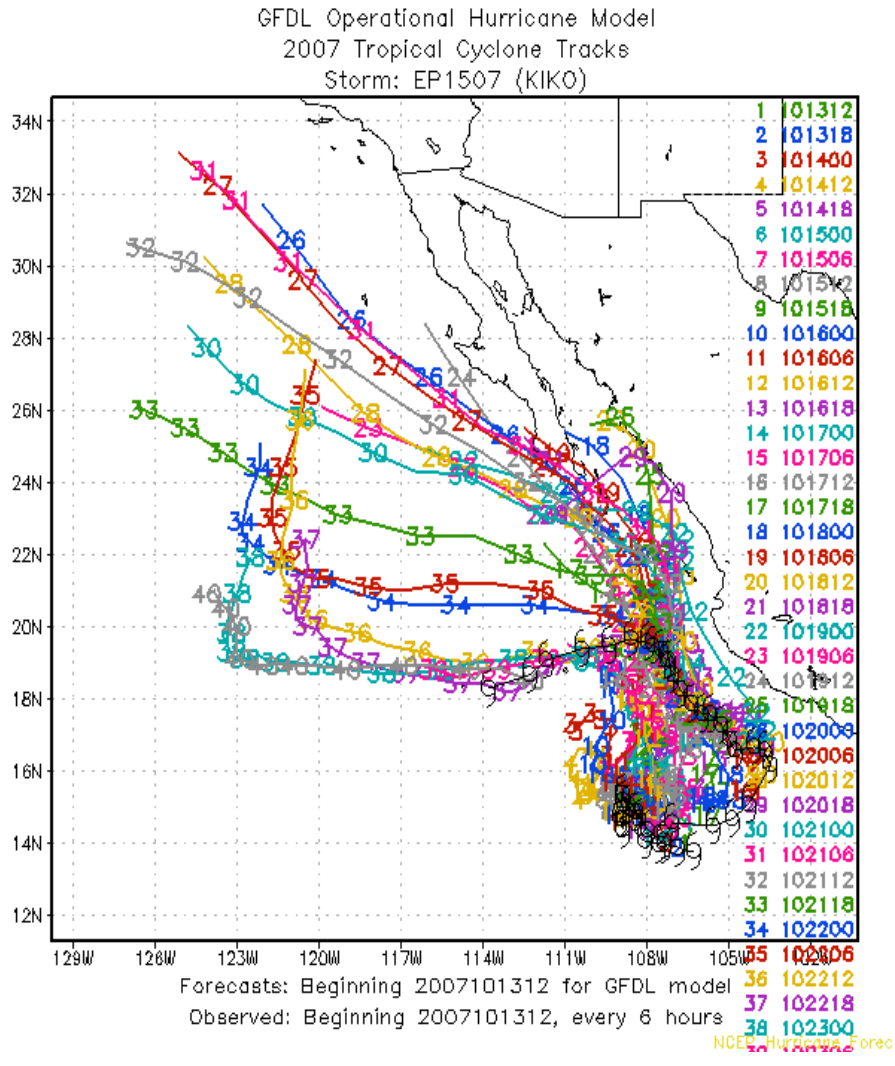
GFDL




HWRF: Hurricane WRF – NCO NWPROD
2007 Tropical Cyclone Tracks
Storm: EP0907 (FLOSSIE)
HWRF Track
1 GFDL
2 AVNO
3 UKM
4 NGPS
5 OFCL
6 HWRF
24N
23N
22N
21N
20N
19N
18N
17N
16N
15N
14N
13N
12N
165W
162W
159W
156W
153W
150W
147W
144W
141W
Forecasts: Beginning 2007081200
Observed: Beginning 2007081200, every 12 hours


HWRF: Hurricane WRF – NCO NWPROD
2007 Tropical Cyclone Tracks
Storm: EP0907 (FLOSSIE)
HWRF Track – possible degradation due to a glitch in NCO's triggering of 3DVAR/GSI jobs
1 GFDL
2 AVNO
3 UKM
4 OFCL
5 HWRF
24N
23N
22N
21N
20N
19N
18N
17N
16N
15N
14N
13N
12N
168W
165W
162W
159W
156W
153W
150W
147W
144W
Forecasts: Beginning 2007081212
Observed: Beginning 2007081212, every 12 hours





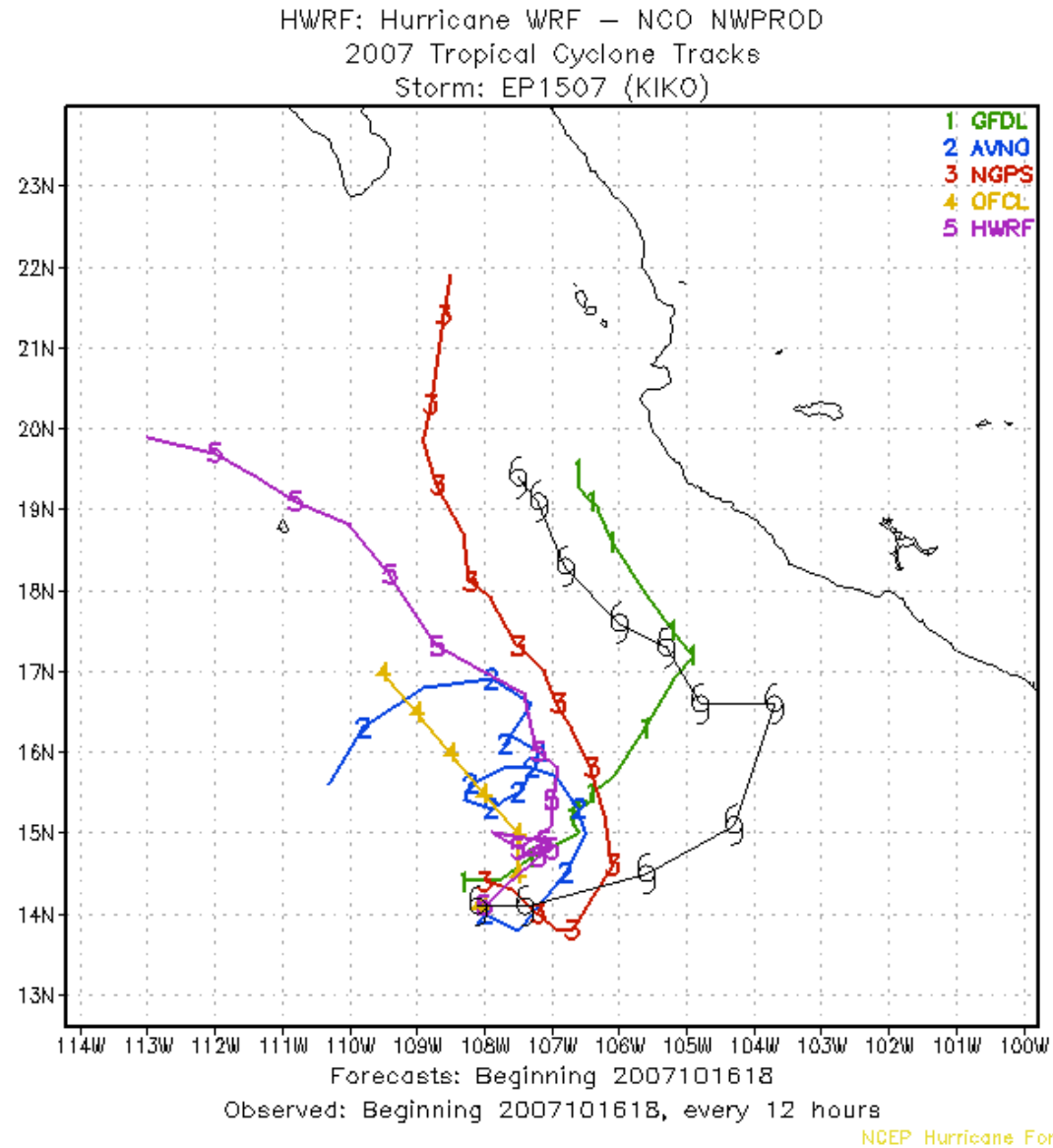
HWRF

GFDL

Tropical Storm Kiko

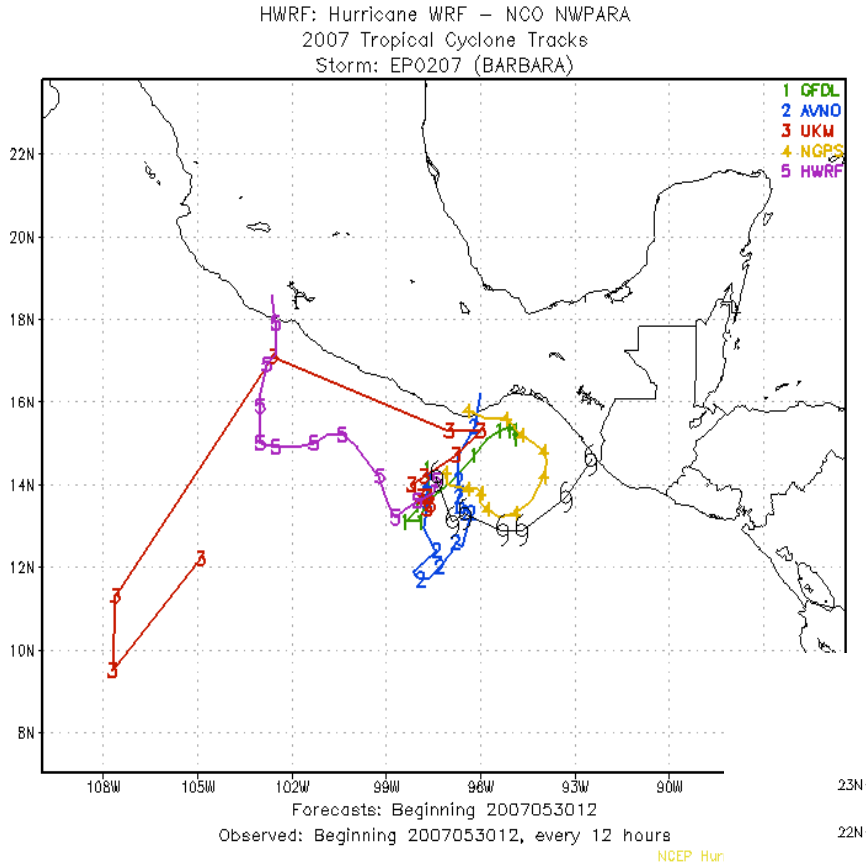
July 14 – 24, 2007

TS KIKO

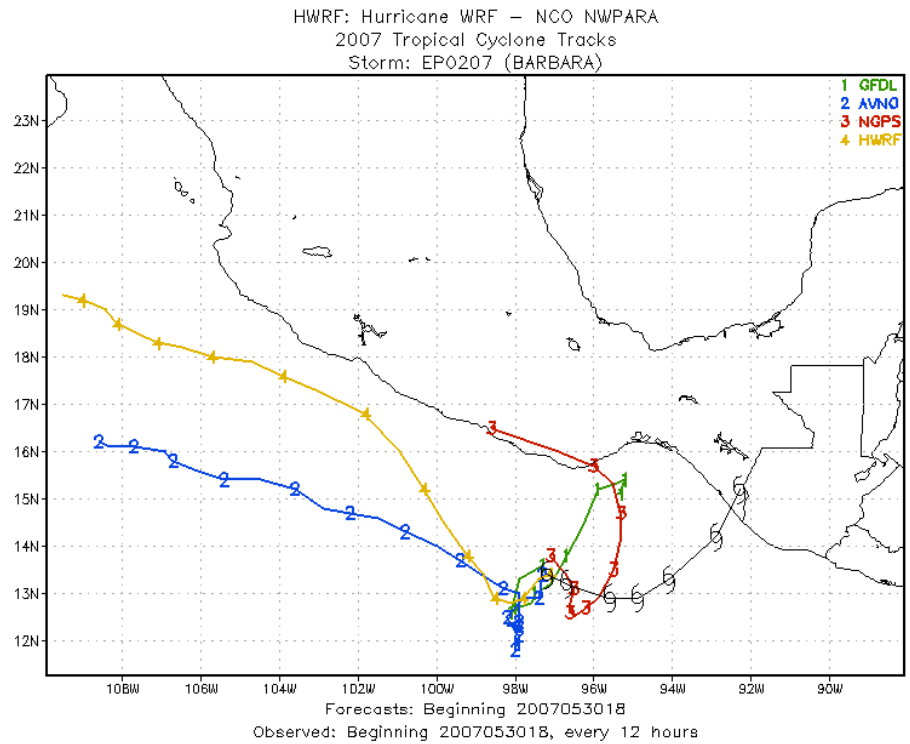

HWRF: Hurricane WRF – NCO NWPROD
2007 Tropical Cyclone Tracks
Storm: EP1507 (KIKO)
1 GFDL
2 AVNO
3 NGPS
4 OFCL
5 HWRF
23N
22N
21N
20N
19N
18N
17N
16N
15N
14N
13N
114W 113W 112W 111W 110W 109W 108W 107W 106W 105W 104W 103W 102W 101W 100W
Forecasts: Beginning 2007101618
Observed: Beginning 2007101618, every 12 hours
NCEP Hurricane Forecast Project

TS BARBARA

HWRF



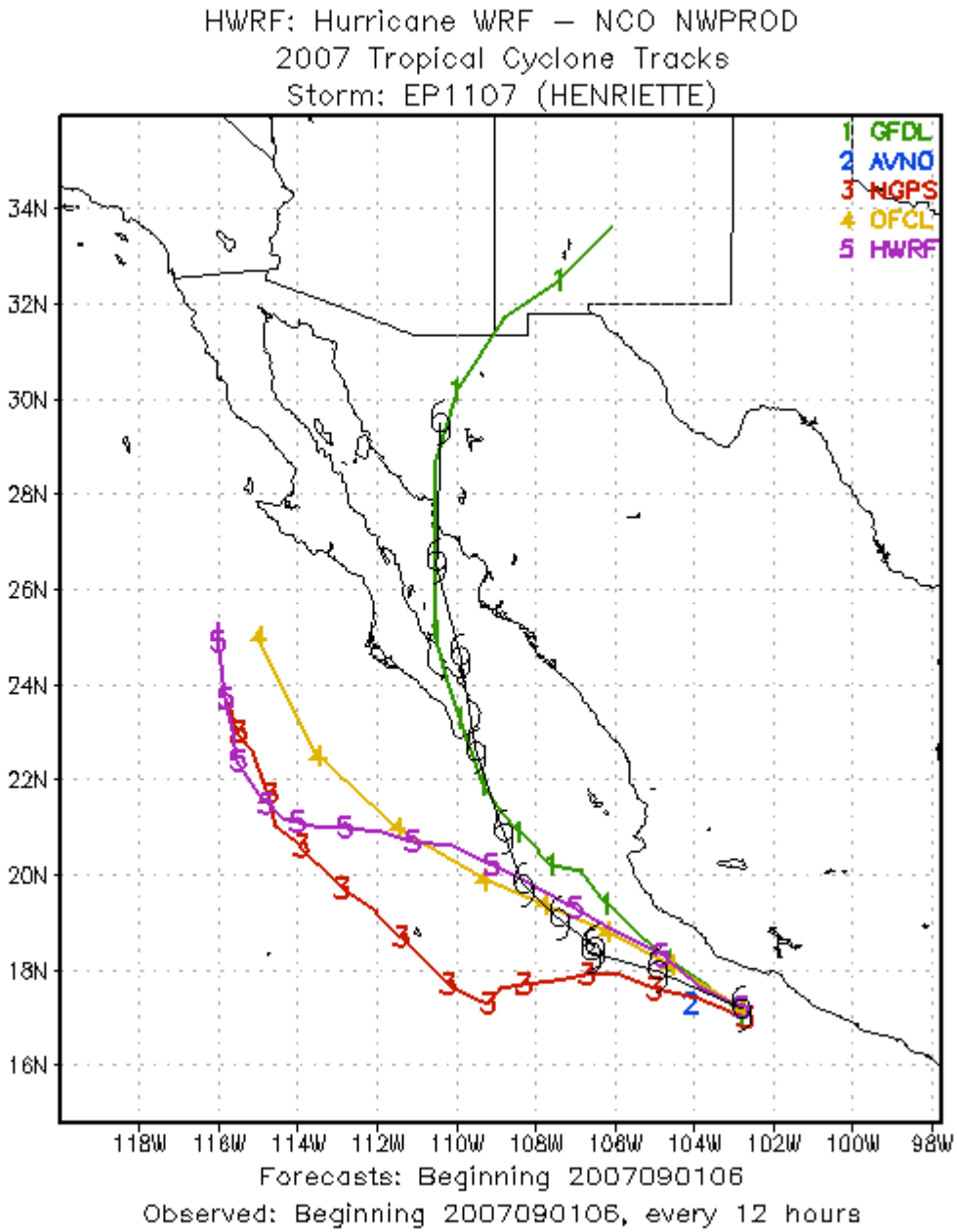
HWRF



Hurricane Henriette

GFDL

Nearly a perfect forecast…..



2008 IMPLEMENTATION

- **UPGRADE HURRICANE INITIALIZATION**

- **BEGIN TO ASSIMILATE AIRBORNE RADAR OBS (run off line in parallel) - pioneering effort by EMC to initialize hurricane vortex**

- **COUPLE TO HYCOM (including data assimilation for ocean obs, e.g. AXBT's)**

- **UPGRADE PHYSICS, e.g. air-sea fluxes**

NOAA's Aircraft in Hurricanes

Working on flight strategies for GIV and P-3's

Working to obtain resources for flight hrs/add'l crews

Operational requirement for core data at 0Z, 12Z to initialize HWRF core circulation (06,18Z ?)

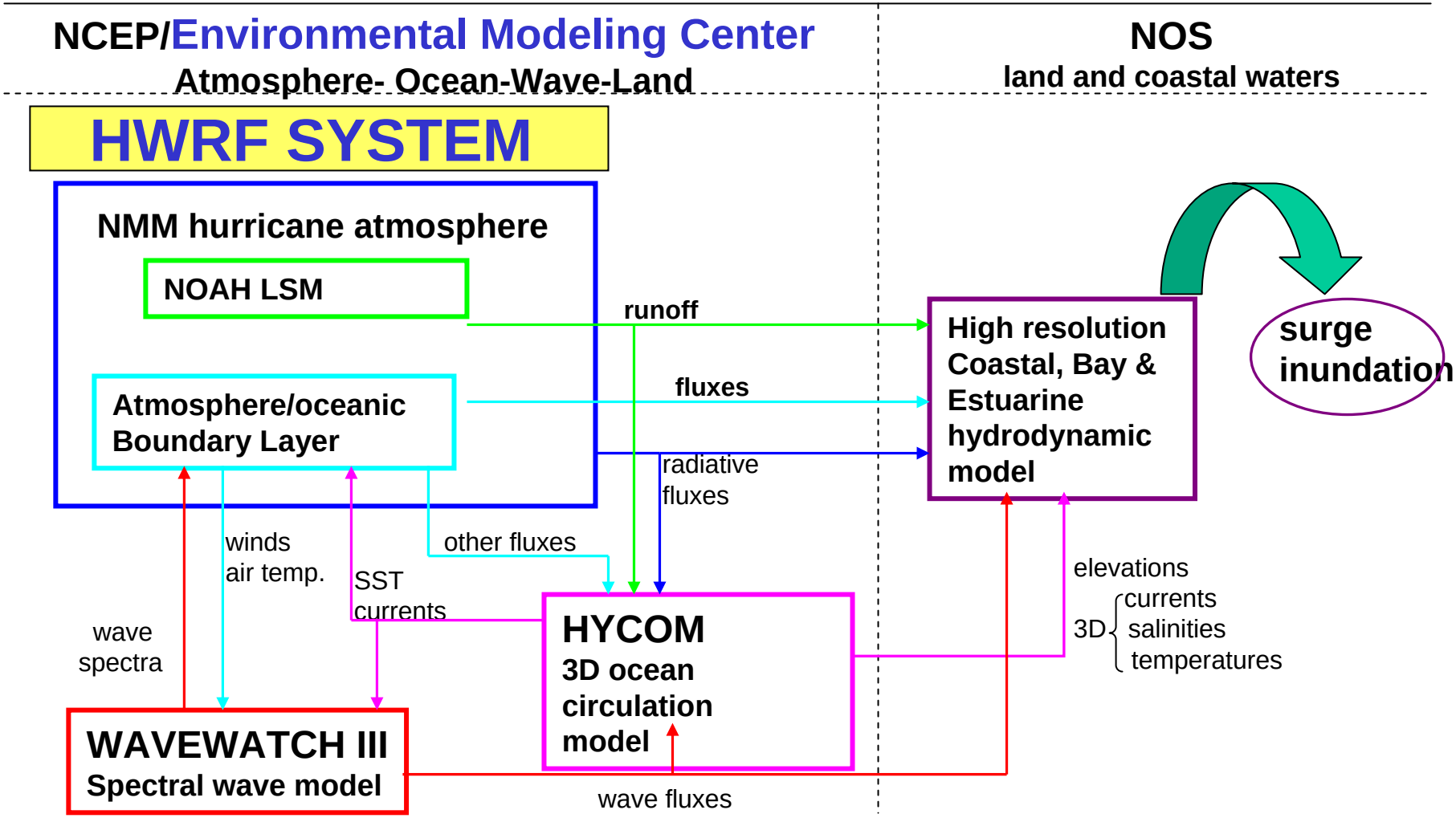
Operational requirement for AXBT's

Two mission profiles: Environment & CORE

Observations: GPS, Radar, AXBT's

New operational status of P-3's

Hurricane-Wave-Ocean-Surge-Inundation Coupled Models



2008-2012 HURRICANE UPGRADE PLAN

- **Data assimilation:**

Advanced initialization for hurricane core - assimilate airborne doppler radar obs (new radar on GIV, P-3's) to define storm strength and storm structure in HWRF analyses. (will run in parallel in '07)

Continuous upgrades to HWRF hurricane core initialization through advanced 4-D data assimilation for winds and reflectivity (requires nearly continuous obs for hurricane structure from storm top to surface beginning in depression stages through evolution of storm lifecycle). Augment doppler data with GPS sondes. Also, explore use of satellite microwave data.

- **Model resolution upgrades:**

Increase in resolution: Horizontal 3-6km. /Vertical resolution ~100levels (dependent on results of current studies).

Hurricane Ensembles: Hi-res hurricane model ensembles, e.g. 4km? Multi model ensembles? (e.g. GFDL, GFDN, HWRF) Work on development of HWRF ensembles in progress.

- **Model Physics: Continuous upgrades to atm/ocean boundary layer (fluxes), microphysics, deep convection (cloud resolving scales?), radiation**

- **Coupling to land surface model w/ adv. Sfc. Physics for improved rainfall forecasts at landfall. Important input to hydrology and streamflow models to address inland flooding.**

- **Advance Wave Model (WAVEWATCH III) to forecast waves up to the beach, ie: improve non-linear interactions, surf zone shallow water physics, wave interactions with currents**

- **ALL hurricane model physics upgrades dependent on allowable resolution, e.g. affordable complexity of microphysics, sea spray, explicit representation of all clouds.**

Advancing HURRICANE WRF System

08 09 10 11 12

Mesoscale Data Assimilation for Hurricane Core

Radial velocities Advance reflectivity - 4DVAR

Atm. Model physics and resolution upgrades (continuous)

Atm/ocean boundary layer: wave drag, enthalpy fluxes

Microphysics, radiation

Incr. Res: 4-6km/100L?

HWRF Ensembles

Land surface Coupling

Waves: multi-grid/surf-zone physics

Ocean: 4km. - continuous upgrades in Ocean Data Assimilation

HWRF and the community

- **Process of interviewing HWRF support person at DTC**
- **1st DTC HWRF tutorial – 2009**
- **HWRF team establishing many working collaborations, e.g. FSU, CSU, Univ. of Hawaii, PSU**

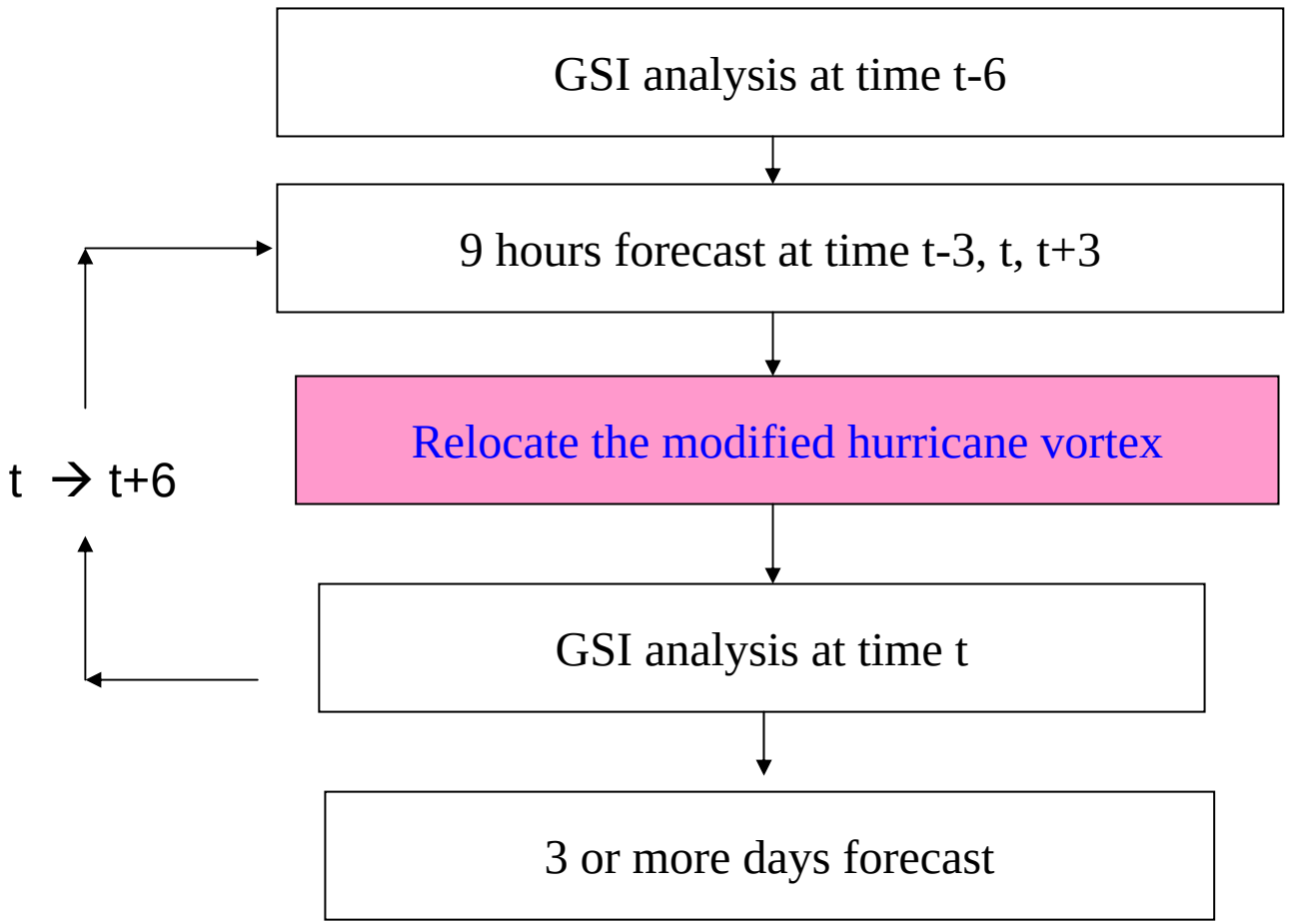
THANK YOU

FOR YOUR

ATTENTION…

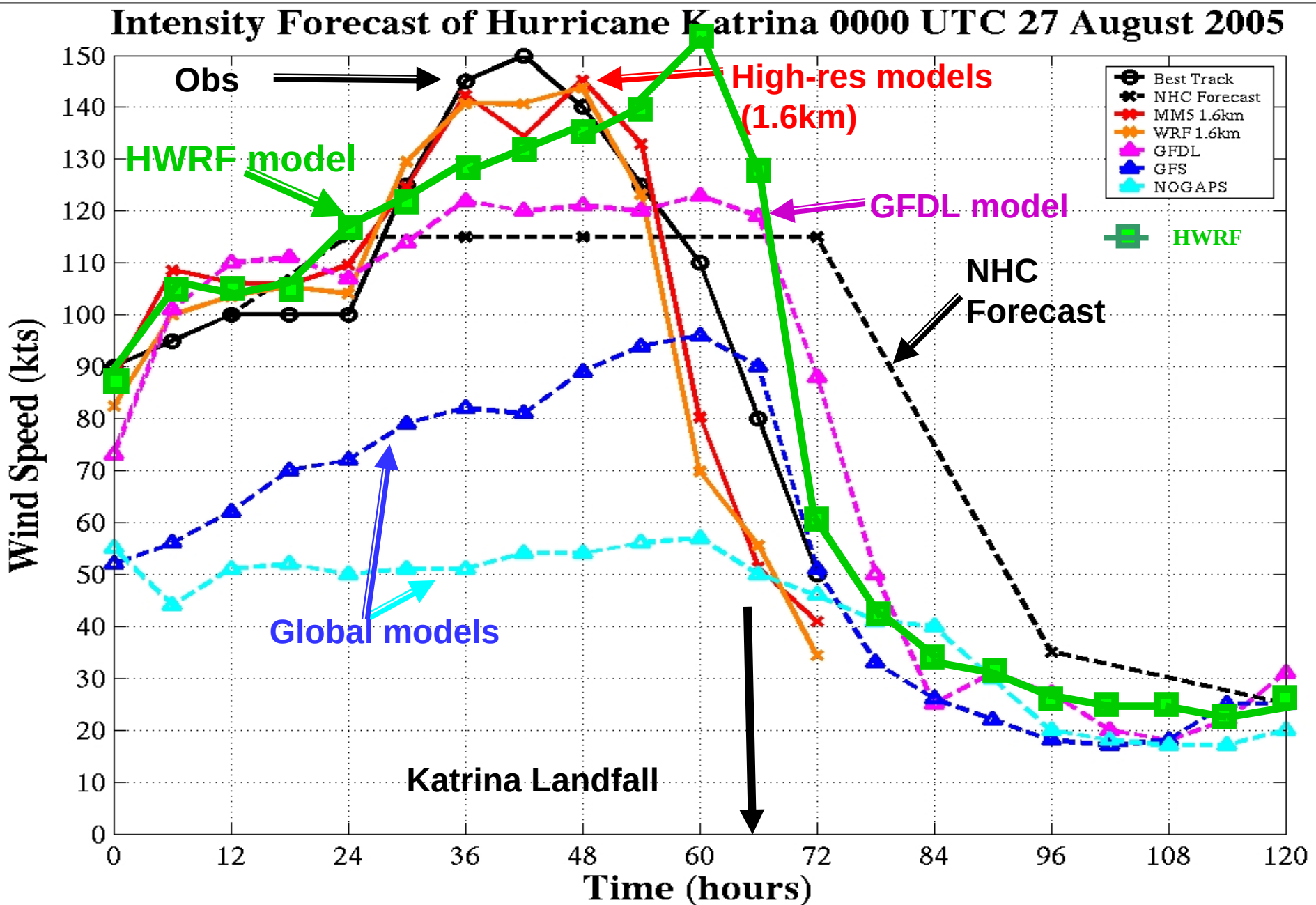
Hurricane Initialization in HWRF model

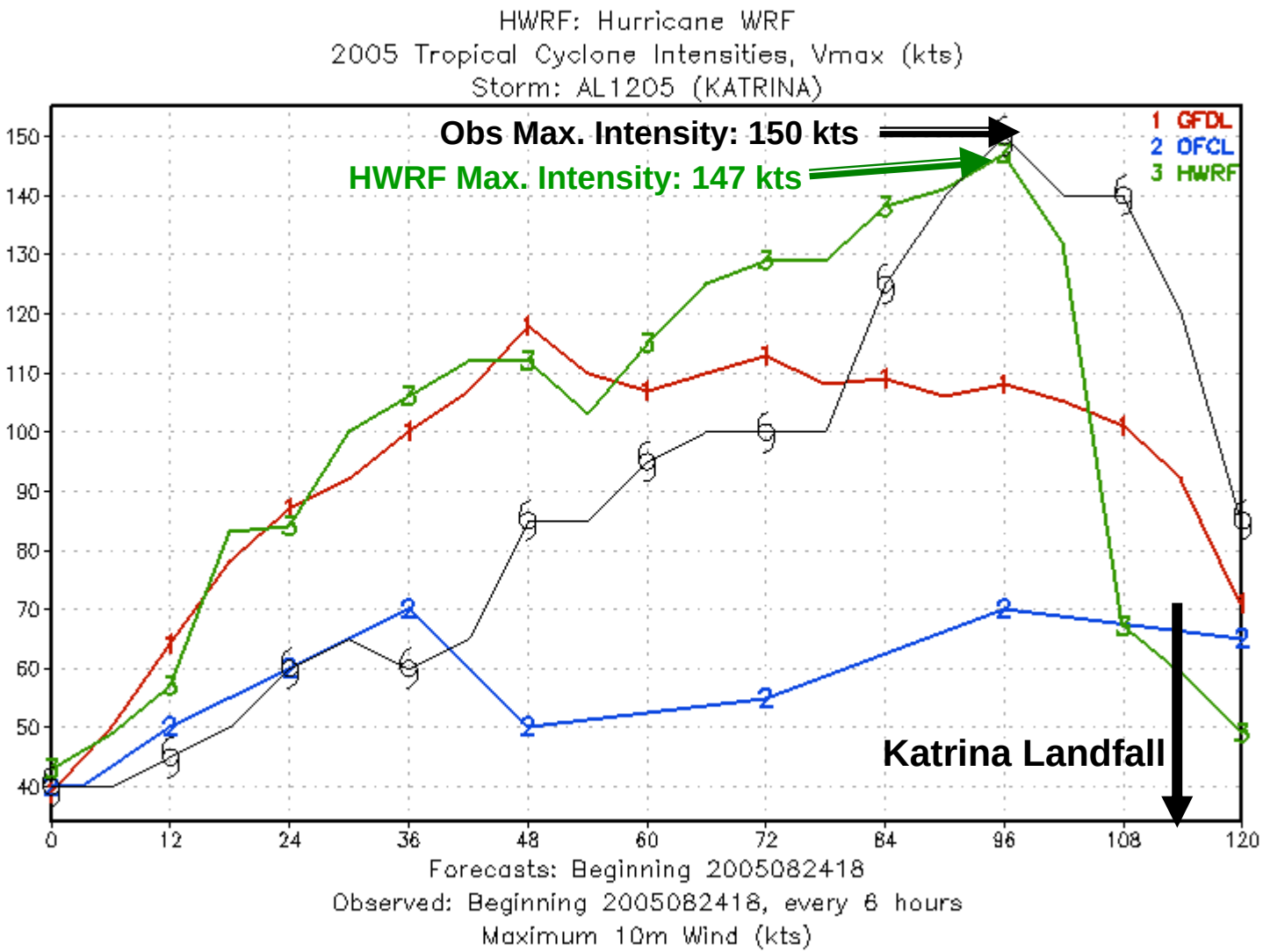
- Regional GSI analysis cycle (3D VAR)

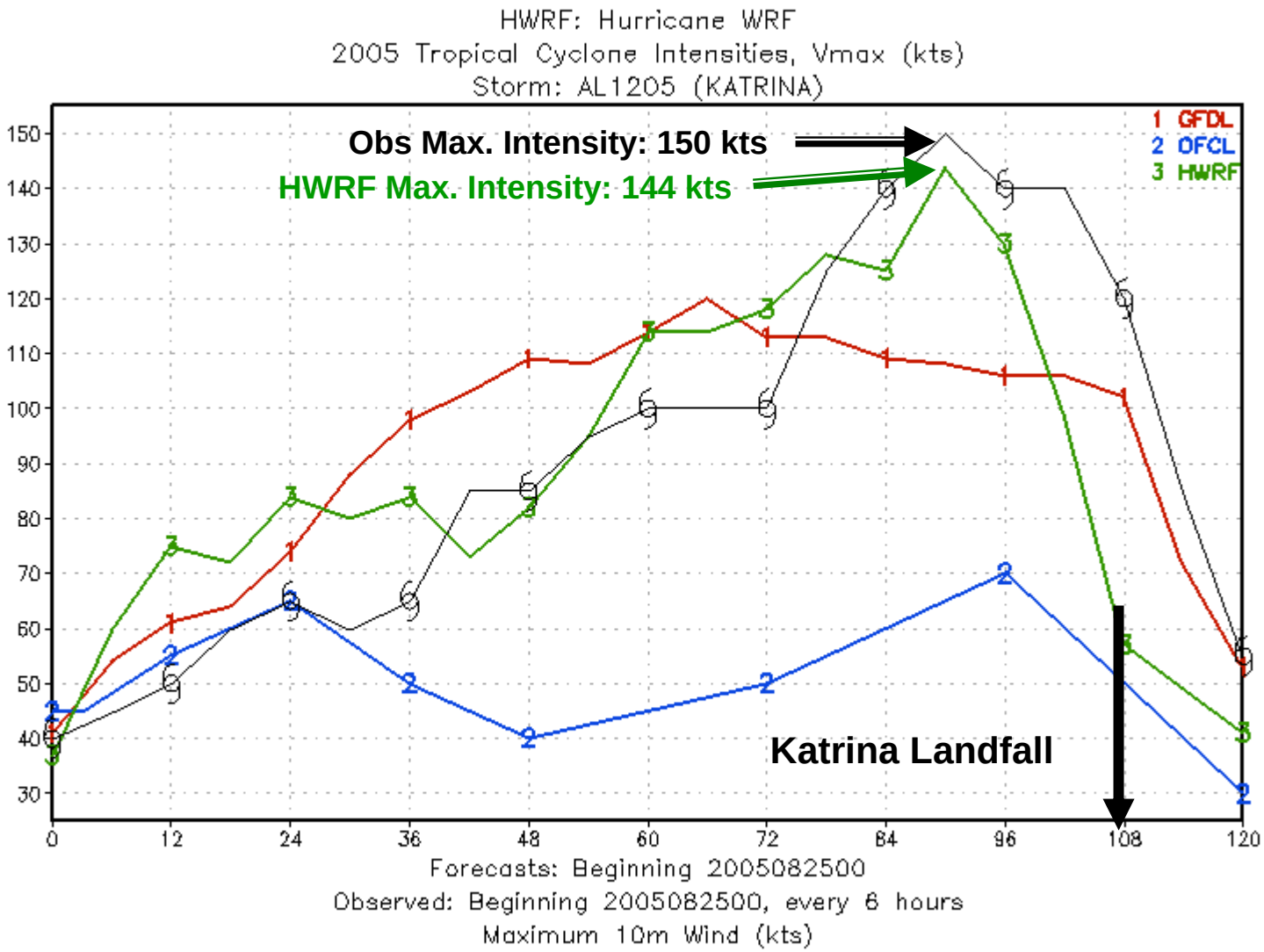


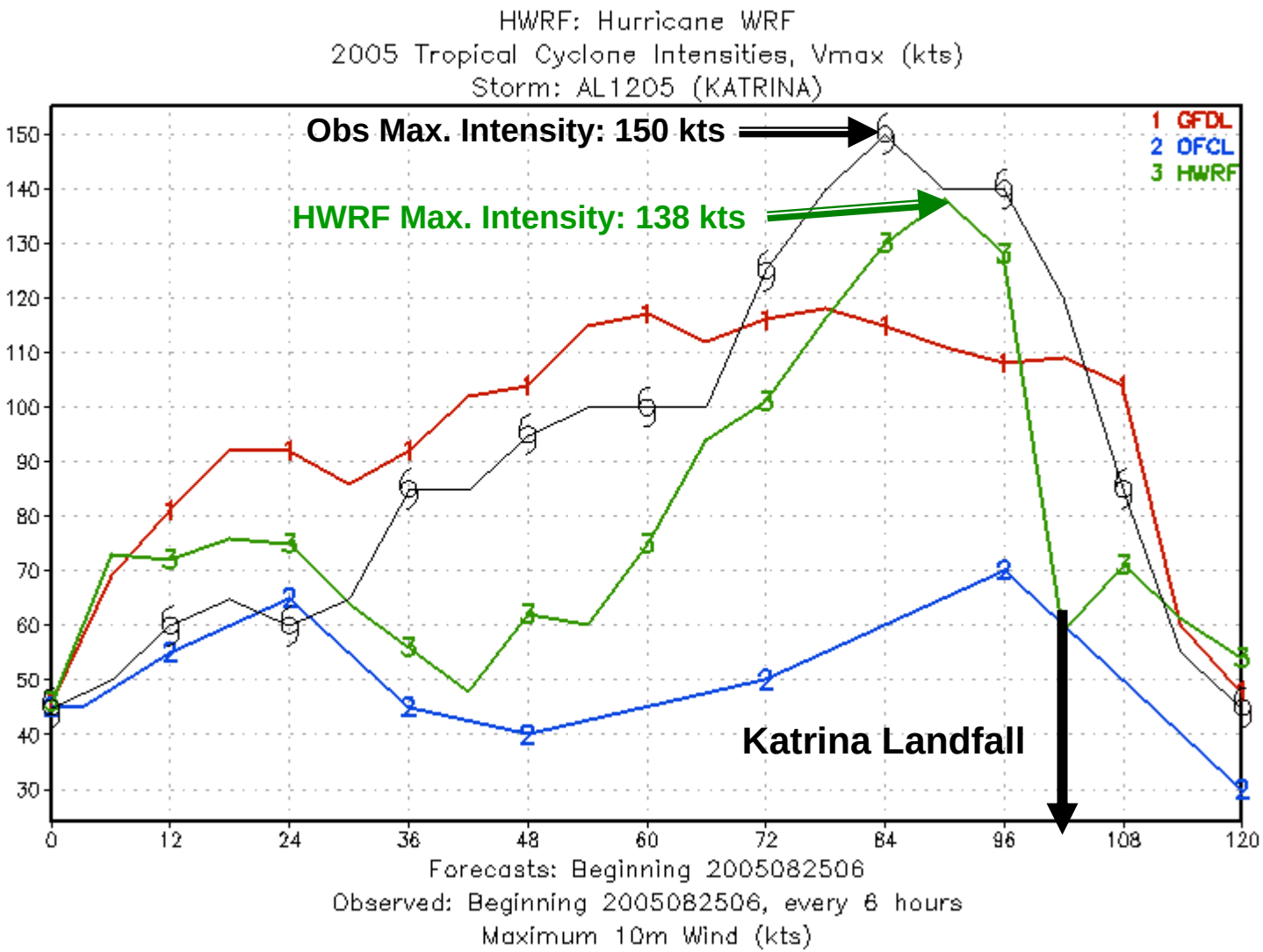
- Hurricane vortex modification
  - Intensity correction
  - Better balanced wind, temperature and pressure fields
  - Storm depth correction
  - Moisture and hydrometeor correction
- GSI analysis
  - Airborne radar data (parallel run)

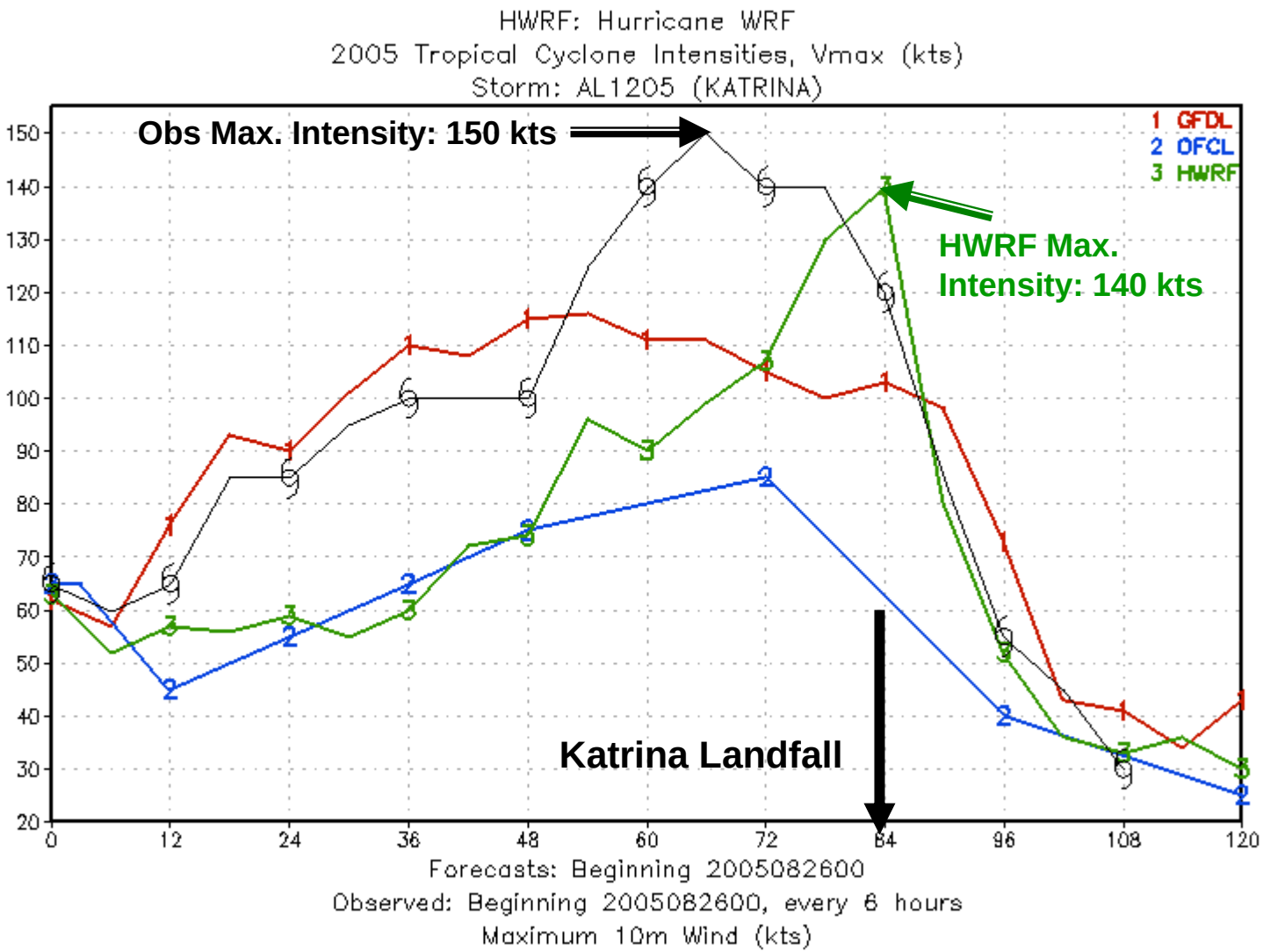
- **From 114 hrs to 60 hrs before landfall, seven HWRF forecasts predicted rapid intensification of Hurricane Katrina, predicting Category 5 Hurricane**
- **Three HWRF forecasts predicted Category 3 landfall for Hurricane Katrina**
- **Three HWRF forecasts of max. intensity coincided with observed maximum intensity**

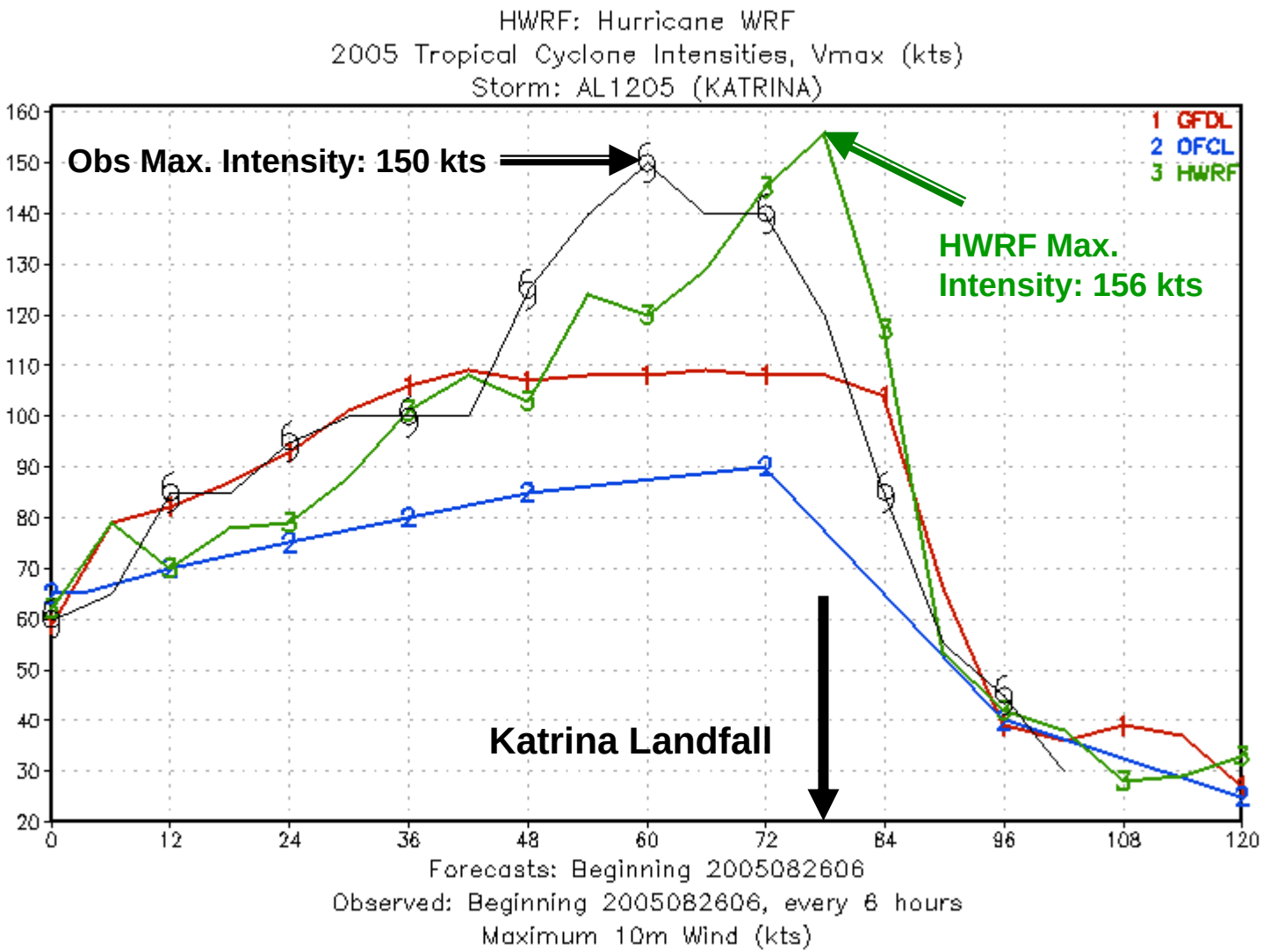

Intensity Forecast of Hurricane Katrina 0000 UTC 27 August 2005
Obs
High-res models
(1.6km)
HWRF model
GFDL model
HWRF
NHC
Forecast
Global models
Katrina Landfall
Best Track
NHC Forecast
MM5 1.6km
WRF 1.6km
GFDL
GFS
NOGAPS
Wind Speed (kts)
Time (hours)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
0
12
24
36
48
60
72
84
96
108
120

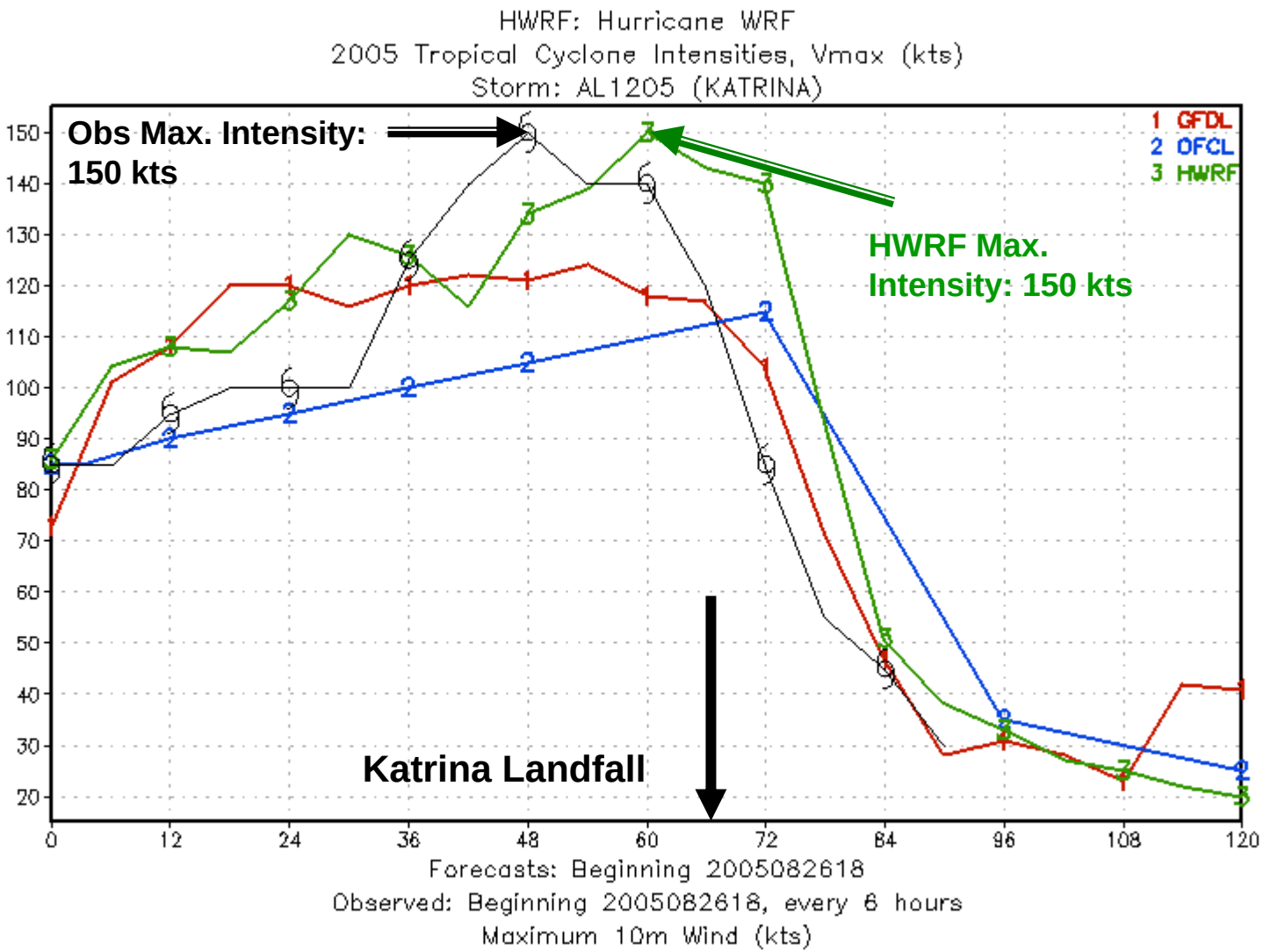

HWRF: Hurricane WRF
2005 Tropical Cyclone Intensities, Vmax (kts)
Storm: AL1205 (KATRINA)
Obs Max. Intensity: 150 kts
HWRF Max. Intensity: 147 kts
1 GFDL
2 OFCL
3 HWRF
Katrina Landfall
150
140
130
120
110
100
90
80
70
60
50
40
0
12
24
36
48
60
72
84
96
108
120
Forecasts: Beginning 2005082418
Observed: Beginning 2005082418, every 6 hours
Maximum 10m Wind (kts)

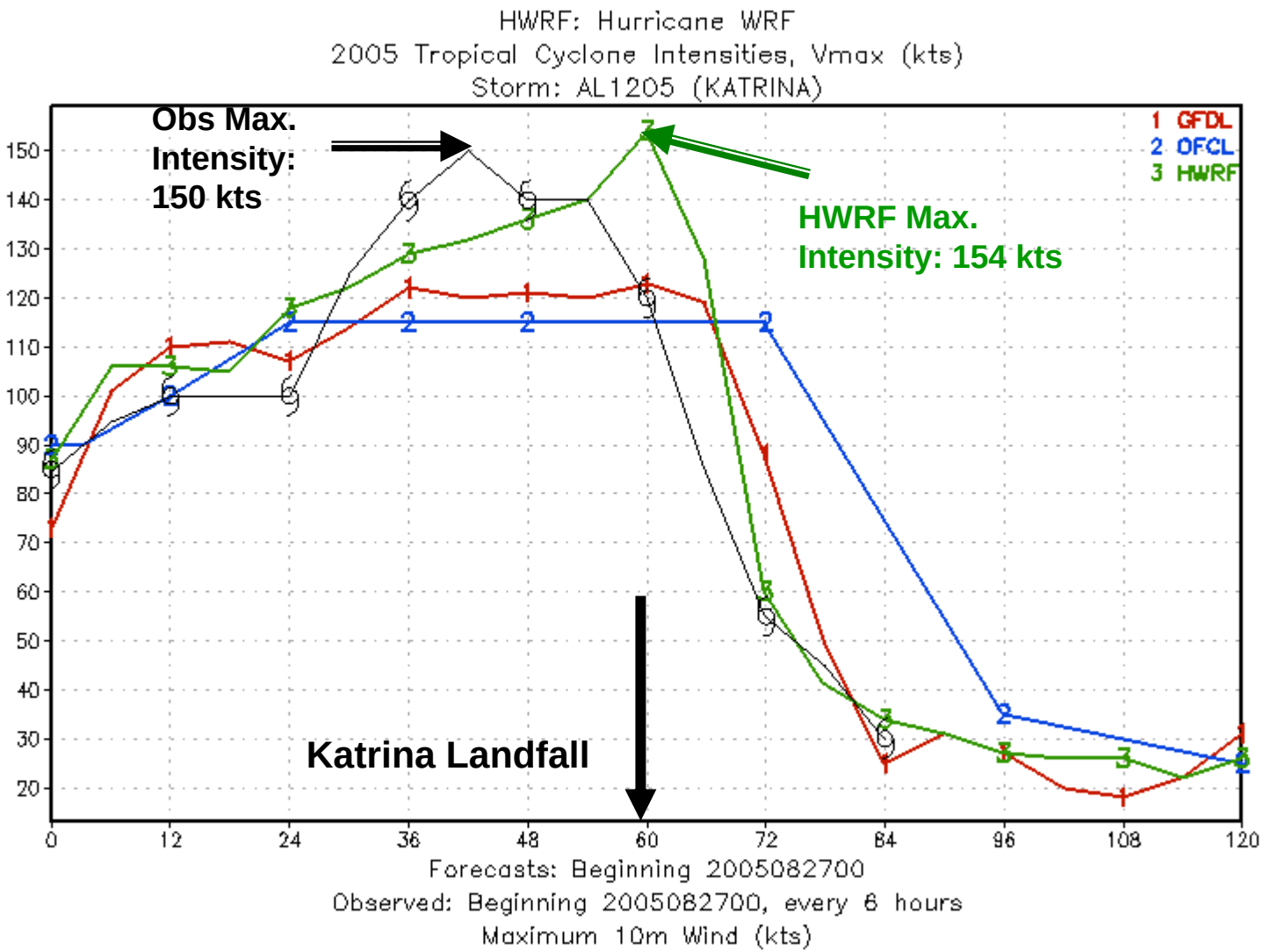

HWRF: Hurricane WRF
2005 Tropical Cyclone Intensities, Vmax (kts)
Storm: AL1205 (KATRINA)
Obs Max. Intensity: 150 kts
HWRF Max. Intensity: 144 kts
1 GFDL
2 OFCL
3 HWRF
Katrina Landfall
150
140
130
120
110
100
90
80
70
60
50
40
30
0
12
24
36
48
60
72
84
96
108
120
Forecasts: Beginning 2005082500
Observed: Beginning 2005082500, every 6 hours
Maximum 10m Wind (kts)


HWRF: Hurricane WRF
2005 Tropical Cyclone Intensities, Vmax (kts)
Storm: AL1205 (KATRINA)
Obs Max. Intensity: 150 kts
HWRF Max. Intensity: 138 kts
1 GFDL
2 OFCL
3 HWRF
Katrina Landfall
150
140
130
120
110
100
90
80
70
60
50
40
30
0
12
24
36
48
60
72
84
96
108
120
Forecasts: Beginning 2005082506
Observed: Beginning 2005082506, every 6 hours
Maximum 10m Wind (kts)


HWRF: Hurricane WRF
2005 Tropical Cyclone Intensities, Vmax (kts)
Storm: AL1205 (KATRINA)
Obs Max. Intensity: 150 kts
1 GFDL
2 OFCL
3 HWRF
HWRF Max.
Intensity: 140 kts
Katrina Landfall
150
140
130
120
110
100
90
80
70
60
50
40
30
20
0
12
24
36
48
60
72
84
96
108
120
Forecasts: Beginning 2005082600
Observed: Beginning 2005082600, every 6 hours
Maximum 10m Wind (kts)


HWRF: Hurricane WRF
2005 Tropical Cyclone Intensities, Vmax (kts)
Storm: AL1205 (KATRINA)
1 GFDL
2 OFCL
3 HWRF
Obs Max. Intensity: 150 kts
HWRF Max.
Intensity: 156 kts
Katrina Landfall
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
0
12
24
36
48
60
72
84
96
108
120
Forecasts: Beginning 2005082606
Observed: Beginning 2005082606, every 6 hours
Maximum 10m Wind (kts)


HWRF: Hurricane WRF
2005 Tropical Cyclone Intensities, Vmax (kts)
Storm: AL1205 (KATRINA)
Obs Max. Intensity:
150 kts
1 GFDL
2 OFCL
3 HWRF
HWRF Max.
Intensity: 150 kts
Katrina Landfall
150
140
130
120
110
100
90
80
70
60
50
40
30
20
0
12
24
36
48
60
72
84
96
108
120
Forecasts: Beginning 2005082618
Observed: Beginning 2005082618, every 6 hours
Maximum 10m Wind (kts)


HWRF: Hurricane WRF
2005 Tropical Cyclone Intensities, Vmax (kts)
Storm: AL1205 (KATRINA)
Obs Max. Intensity: 150 kts
HWRF Max. Intensity: 154 kts
Katrina Landfall
1 GFDL
2 OFCL
3 HWRF
150
140
130
120
110
100
90
80
70
60
50
40
30
20
0
12
24
36
48
60
72
84
96
108
120
Forecasts: Beginning 2005082700
Observed: Beginning 2005082700, every 6 hours
Maximum 10m Wind (kts)

	Observed Maximum Intensity is 150 kts on 18Z, Aug. 28, 2005			**Observed Intensity at Landfall is 110 kts on 12Z, Aug. 29, 2005**		
Forecast Start Date	HWRF Max. Intensity	Valid Time (Forecast Hour) (HWRF)	Observed Valid Time for maximum intensity	Landfall Intensity of HWRF	Landfall Valid Time (Forecast Hour) (HWRF)	Observed Valid Time for landfall
18Z, Aug. 24, 2005	**147**	**18Z, Aug. 28, 2005 (96 hrs)**	**96 hrs**	67	06Z, Aug. 29, 2005 (108 hrs)	114 hrs
00Z, Aug. 25, 2005	**144**	**18Z, Aug. 28, 2005 (90 hrs)**	**90 hrs**	**99**	06Z, Aug. 29, 2005 (102 hrs)	108 hrs
06Z, Aug. 25, 2005	**138**	06Z, Aug. 29, 2005 (96 hrs)	84 hrs	**128**	**12Z, Aug. 29, 2005 (102 hrs)**	**102 hrs**
00Z, Aug. 26, 2005	**140**	**18Z, Aug. 28, 2005 (66 hrs)**	**66 hrs**	80	00Z Aug. 29, 2005 (90 hrs)	84 hrs
06Z, Aug. 26, 2005	**156**	12Z, Aug. 29, 2005 (78 hrs)	60 hrs	**117**	18Z, Aug. 29, 2005 (84 hrs)	78 hrs
18Z, Aug. 26, 2005	**150**	06Z, Aug. 29, 2005 (60 hrs)	48 hrs	94	00Z, Aug. 30, 2005 (78 hrs)	66 hrs
00Z, Aug. 27, 2005	**154**	12Z, Aug. 29, 2005 (60 hrs)	42 hrs	60	00Z, Aug. 30, 2005 (72 hrs)	60 hrs