Operational Hurricane Model Diagnostics at EMC

Hurricane Diagnostics and Verification Workshop
NHC, Miami, FL
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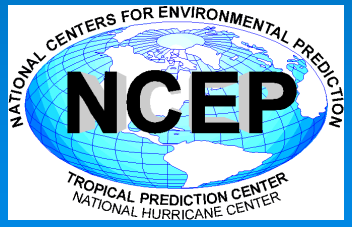


Outline

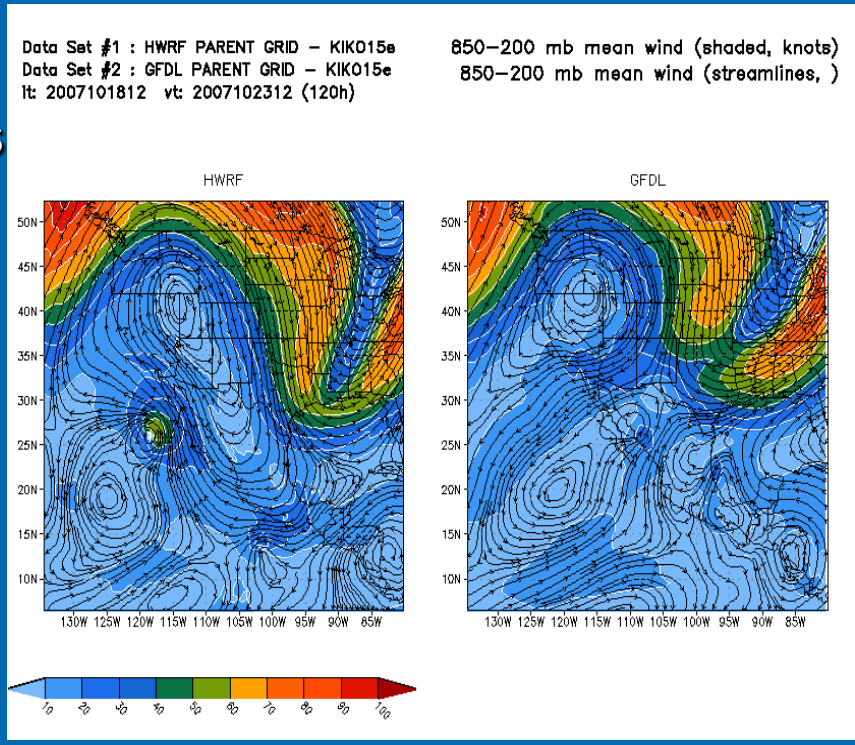
- Overview of Model Diagnostics for Hurricane Forecasts
- Diagnostic Tools
- Specific Issues
  - Evolution of large-scale flow (steering currents and shear patterns)
  - Impact of boundary conditions, vortex initialization
  - Surface physics issues
  - Wind-Pressure relationship
  - Storm size and structure
  - Vortex evolution and interactions with the storm environment

Draft Plan for HFIP Hurricane Model Diagnostics at EMC

- Diagnostics to address track and intensity forecasts from operational hurricane models
- Evaluation of mean layer flow and steering currents for track forecasts
- Evaluation of shear patterns for intensity (and intensity change) forecasts
- Impact of ocean coupling through analysis of surface fluxes, SST, MLD, heat content etc.
- Diagnostics specific to Eastern Pacific storms
- Wind-pressure relationship

Hurricane Diagnostics

- Ongoing and continuous efforts to develop a system for comprehensive model diagnostics for hurricane forecasts
- Primary tasks include:
  - Evaluation of initial storm structure (analyzed),
  - Vortex evolution in the forecasts,
  - Representation of large-scale flow in HWRF and GFDL compared to the GFS
  - Impact of boundary conditions, domain configurations
  - Impact of physics, ocean feedback, horizontal and vertical resolution
  - Evaluation of derived diagnostic products including energy, angular momentum and PV budgets
- **Collaborative effort with Mark DeMaria**



HPLOT capabilities

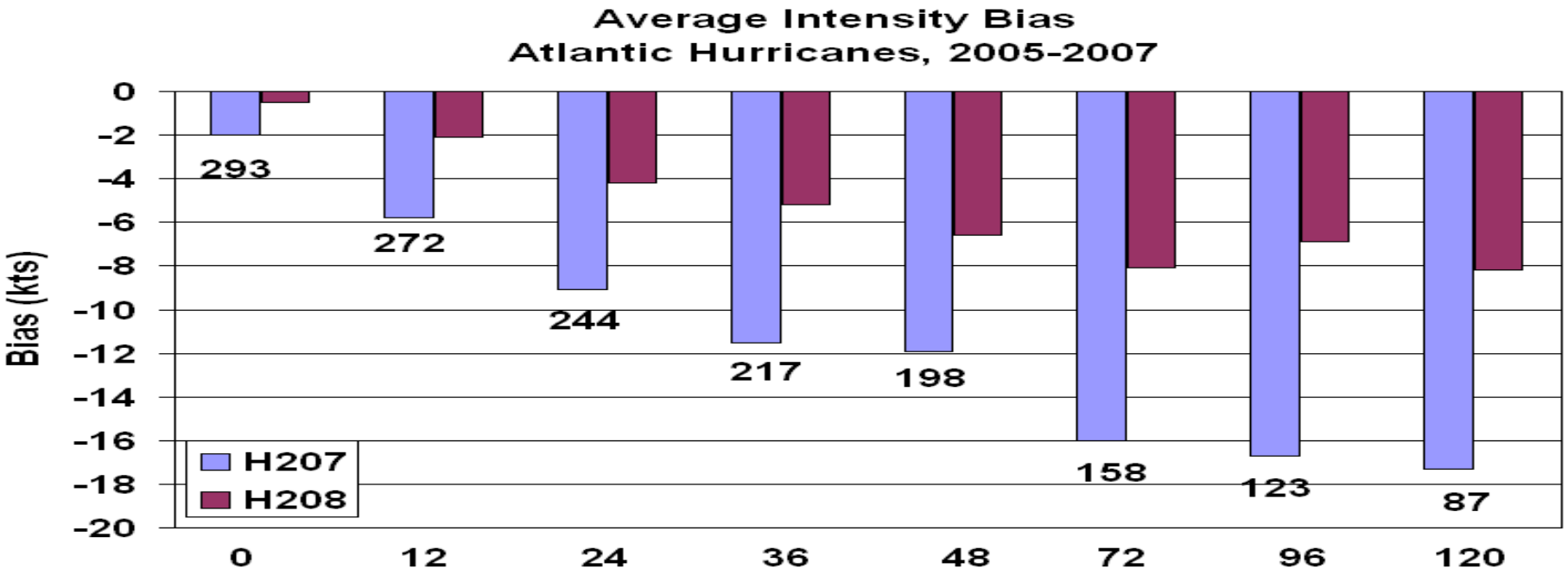
- **Model side-by-side comparison**
- **Standard diagnostics**
  - **vert. shear**
  - **x-sections, etc.**
- **Based on generic software**

Diagnostic Tools: HPLOT

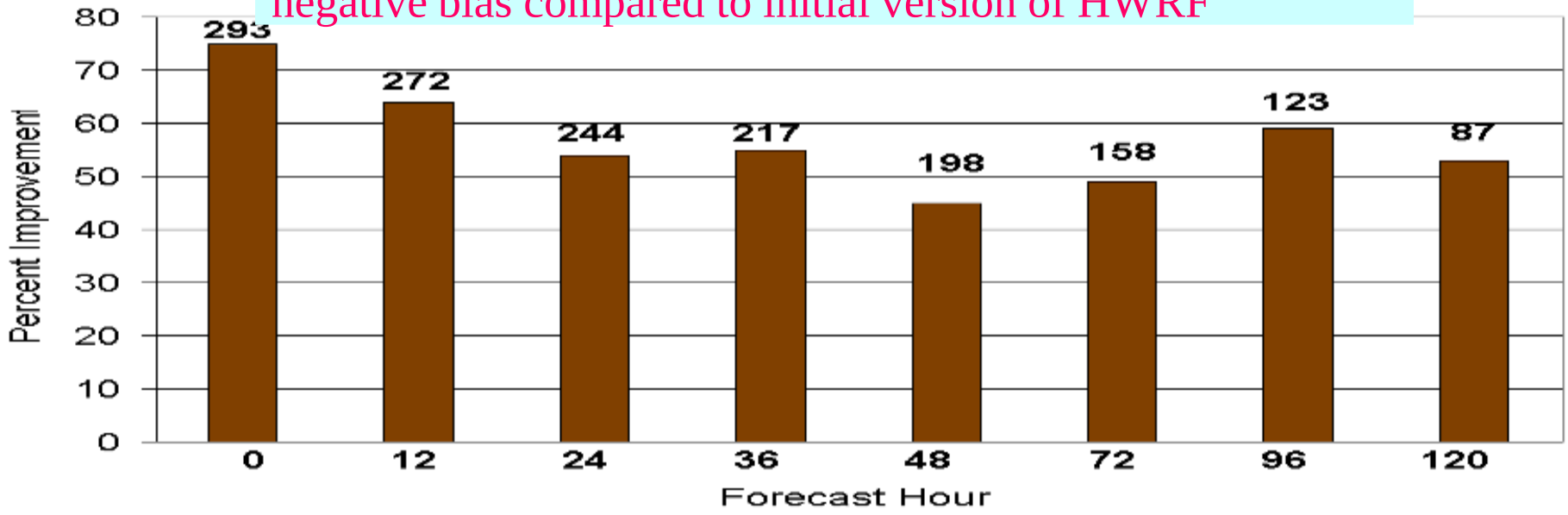
- Developed GUI based plotting program HPLOT (based on initial version developed by Tim Marchok and adapted for HWRF by Marshall Stoner) that allows visualization of several diagnostic components of the forecasts.
- Allows comparison of HWRF forecasts with other model forecasts as well as analysis/observations side by side (including difference plots on a uniform grid)
- Diagnostic measures include mean layer wind, vertical and zonal shear components, skew-T diagrams etc.
- Additional capabilities to compute statistical measures (RMS errors, anomaly correlation etc.) as well as filtering of storm component for evaluation of large-scale flow
- Vortex scale diagnostics include fixed/arbitrary horizontal/ vertical cross-sections of wind, temperature, heating rates, RH etc., azimuthally averaged winds, data on cylindrical coordinates.

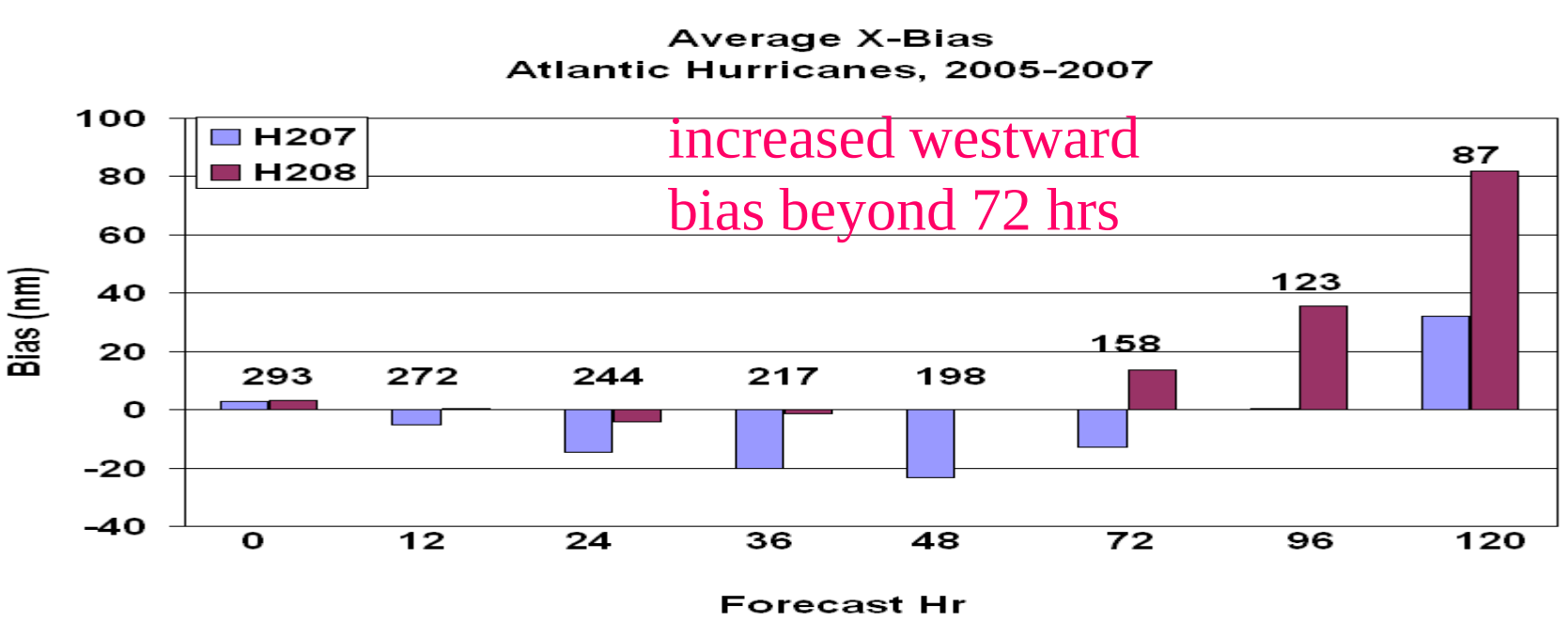
Operational HWRF

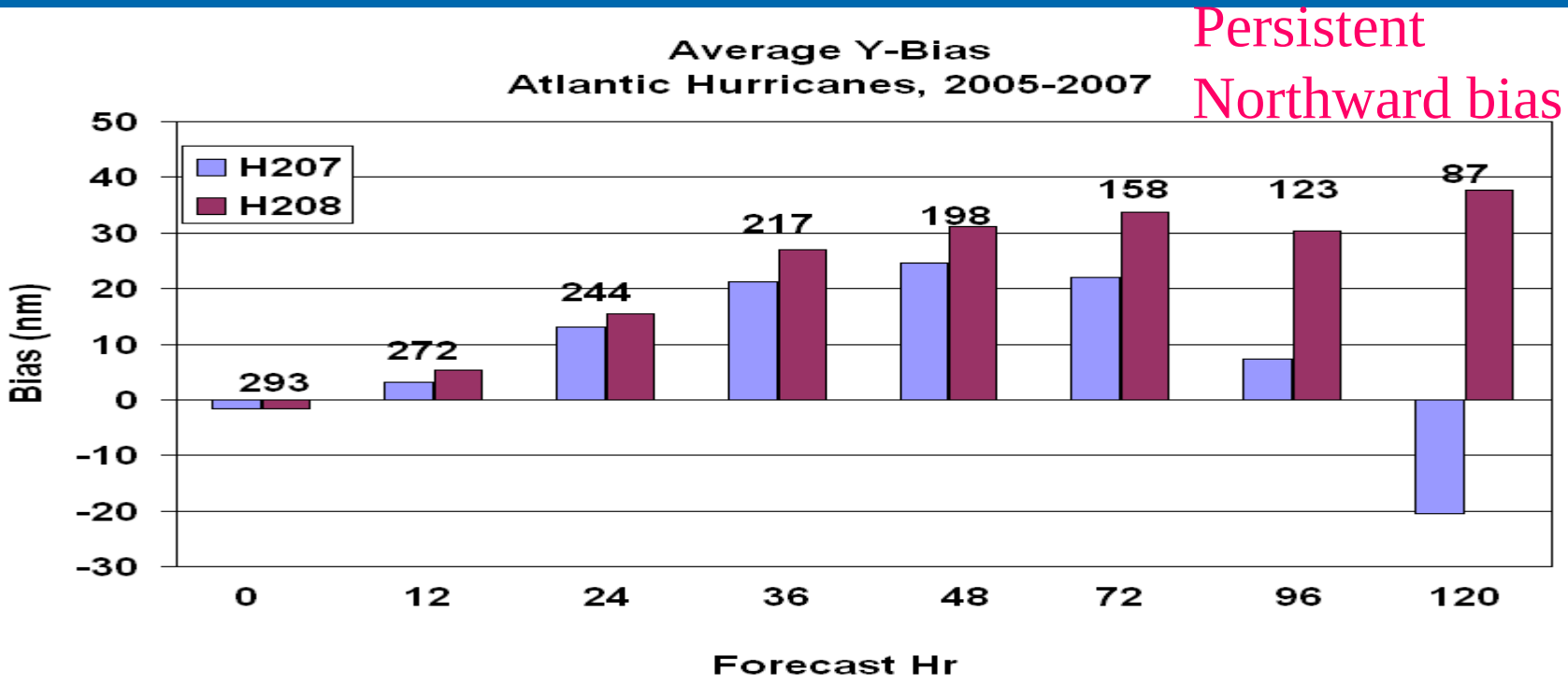
- Pre-implementation testing of HWRF model for the **2004-2005-2006** hurricane seasons – Atlantic & Eastern Pacific
  - Track forecasts in the Atlantic were comparable to GFDL, however, **large track errors in the Eastern Pacific**
  - **Weak bias and large intensity errors in both Atlantic and Eastern Pacific**
- First year of HWRF implementation during **2007** season
  - More short-lived storms, not a very active Atlantic season
  - HWRF performed better than GFDL but not as good as the global model.
  - **Weak intensity bias, large north/west track forecast bias**
  - **Large Eastern Pacific track errors**
  - **Huge sensitivity to changes in vortex initialization**
- HWRF performance during **2008** season
  - Pre-implementation testing showed reduced intensity bias (through improved initialization)
  - Atlantic track errors comparable to GFDL and GFS
  - Several issues - **Bertha, Fay, Ike, Paloma**….
  - Larger EastPac track and intensity errors – **Norbert, Genevieve….**
- **HWRF 2009 – Inclusion of GWD, Changes to initialization, bug fixes (radiation, land surface temp.)**

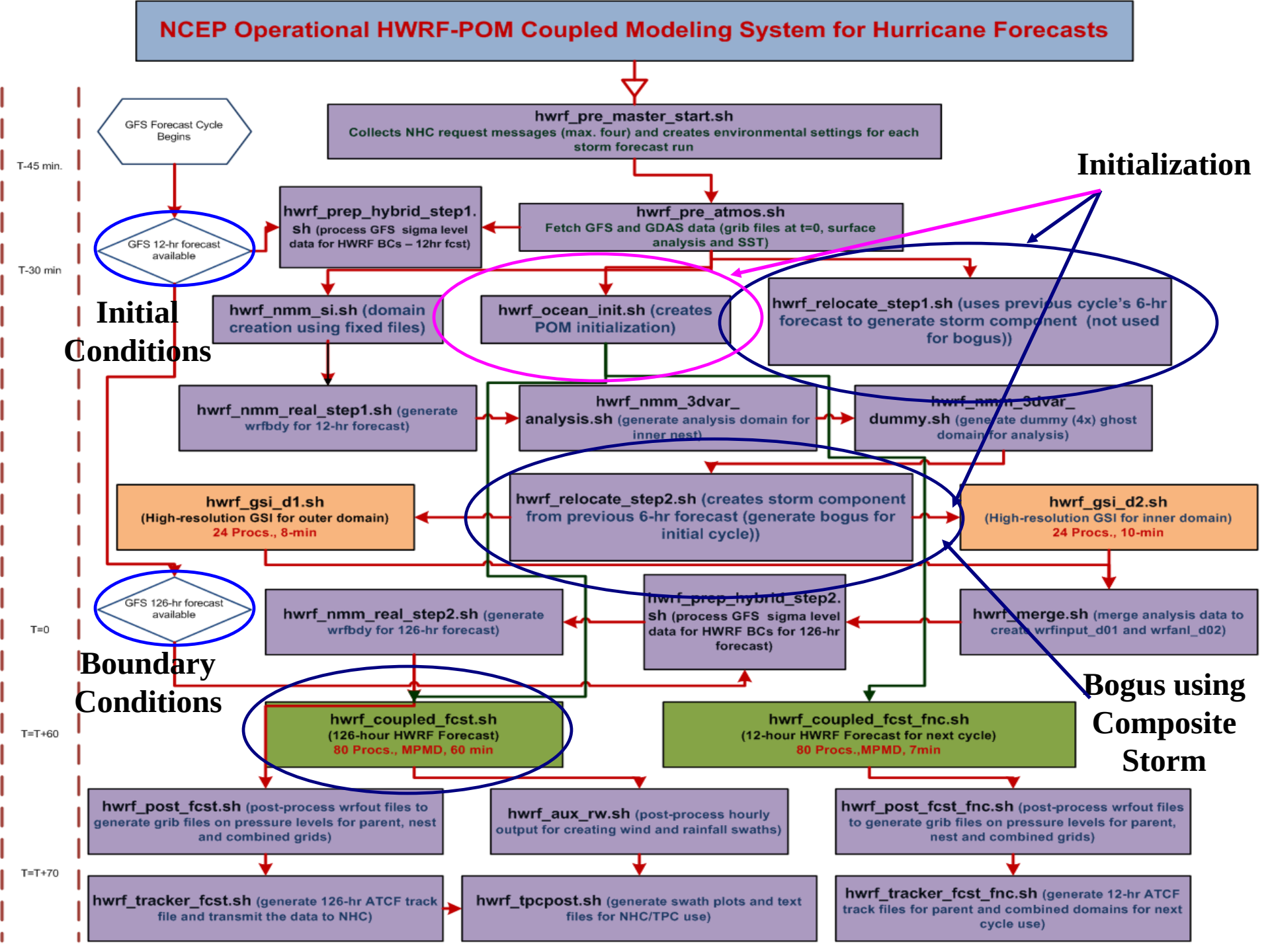


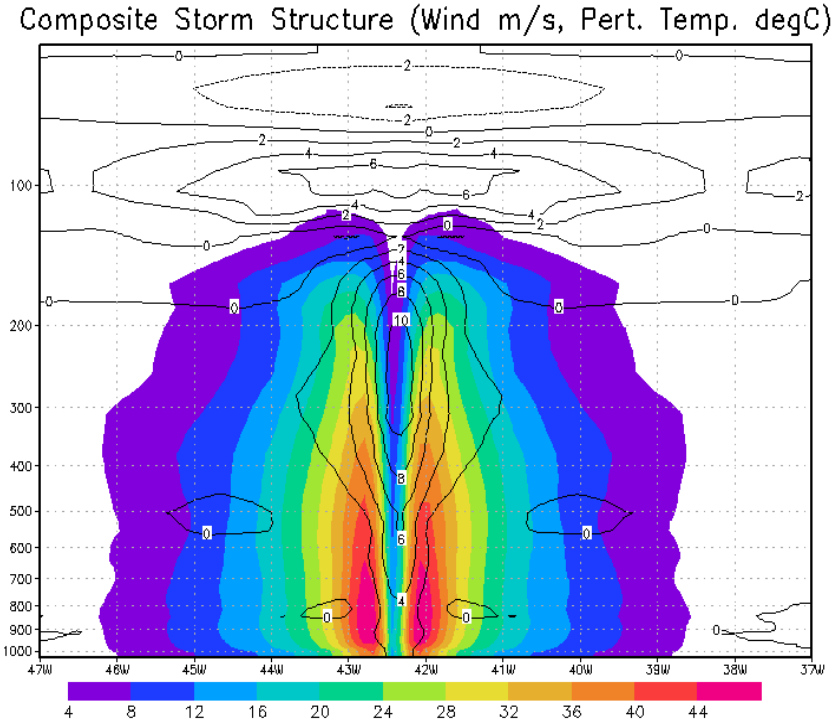
HWRF has a weak intensity bias despite huge reduction of negative bias compared to initial version of HWRF



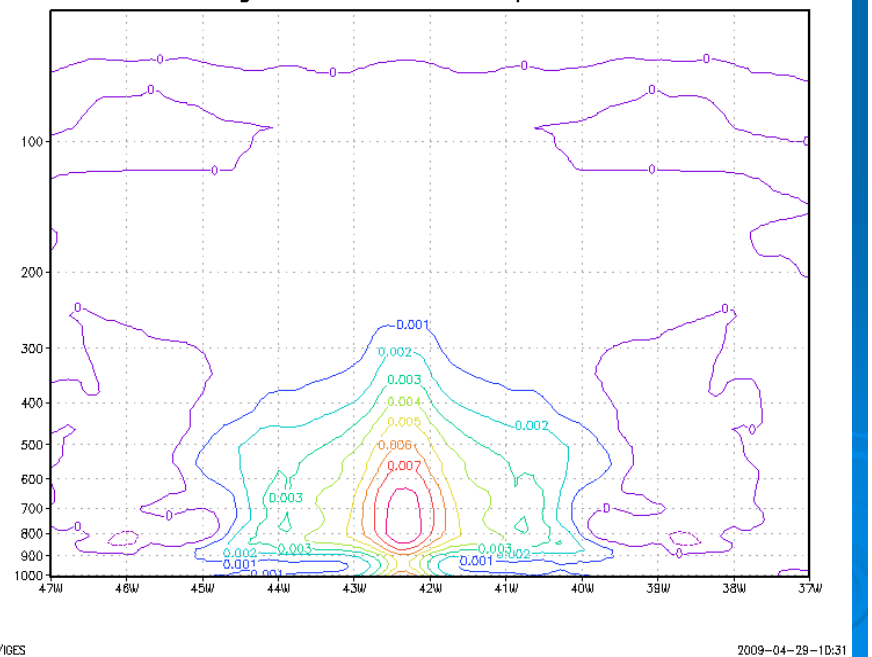

Average X-Bias
Atlantic Hurricanes, 2005-2007
increased westward
bias beyond 72 hrs
H207
H208
Bias (nm)
100
80
60
40
20
0
-20
-40
293
272
244
217
198
158
123
87
0
12
24
36
48
72
96
120
Forecast Hr

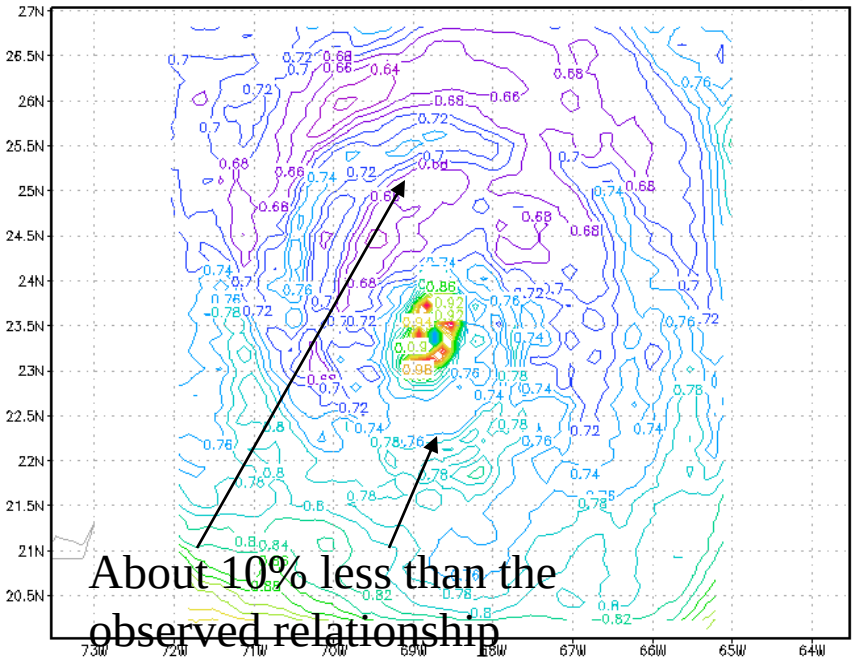

Average Y-Bias
Atlantic Hurricanes, 2005-2007
Persistent
Northward bias
H207
H208
Bias (nm)
50
40
30
20
10
0
-10
-20
-30
293
272
244
217
198
158
123
87
0
12
24
36
48
72
96
120
Forecast Hr


NCEP Operational HWRF-POM Coupled Modeling System for Hurricane Forecasts
GFS Forecast Cycle Begins
T-45 min.
hwrf_pre_master_start.sh
Collects NHC request messages (max. four) and creates environmental settings for each storm forecast run
Initialization
GFS 12-hr forecast available
T-30 min
hwrf_prep_hybrid_step1.sh (process GFS sigma level data for HWRF BCs – 12hr fcst)
hwrf_pre_atmos.sh
Fetch GFS and GDAS data (grib files at t=0, surface analysis and SST)
Initial Conditions
hwrf_nmm_si.sh (domain creation using fixed files)
hwrf_ocean_init.sh (creates POM initialization)
hwrf_relocate_step1.sh (uses previous cycle's 6-hr forecast to generate storm component (not used for bogus))
hwrf_nmm_real_step1.sh (generate wrfbdy for 12-hr forecast)
hwrf_nmm_3dvar_analysis.sh (generate analysis domain for inner nest)
hwrf_nmm_3dvar_dummy.sh (generate dummy (4x) ghost domain for analysis)
hwrf_gsi_d1.sh
(High-resolution GSI for outer domain)
24 Procs., 8-min
hwrf_relocate_step2.sh (creates storm component from previous 6-hr forecast (generate bogus for initial cycle))
hwrf_gsi_d2.sh
(High-resolution GSI for inner domain)
24 Procs., 10-min
GFS 126-hr forecast available
T=0
hwrf_nmm_real_step2.sh (generate wrfbdy for 126-hr forecast)
hwrf_prep_hybrid_step2.sh (process GFS sigma level data for HWRF BCs for 126-hr forecast)
hwrf_merge.sh (merge analysis data to create wrfinput_d01 and wrfanl_d02)
Boundary Conditions
Bogus using Composite Storm
T=T+60
hwrf_coupled_fcst.sh
(126-hour HWRF Forecast)
80 Procs., MPMD, 60 min
hwrf_coupled_fcst_fnc.sh
(12-hour HWRF Forecast for next cycle)
80 Procs.,MPMD, 7min
hwrf_post_fcst.sh (post-process wrfout files to generate grib files on pressure levels for parent, nest and combined grids)
hwrf_aux_rw.sh (post-process hourly output for creating wind and rainfall swaths)
hwrf_post_fcst_fnc.sh (post-process wrfout files to generate grib files on pressure levels for parent, nest and combined grids)
T=T+70
hwrf_tracker_fcst.sh (generate 126-hr ATCF track file and transmit the data to NHC)
hwrf_tpcpost.sh (generate swath plots and text files for NHC/TPC use)
hwrf_tracker_fcst_fnc.sh (generate 12-hr ATCF track files for parent and combined domains for next cycle use)



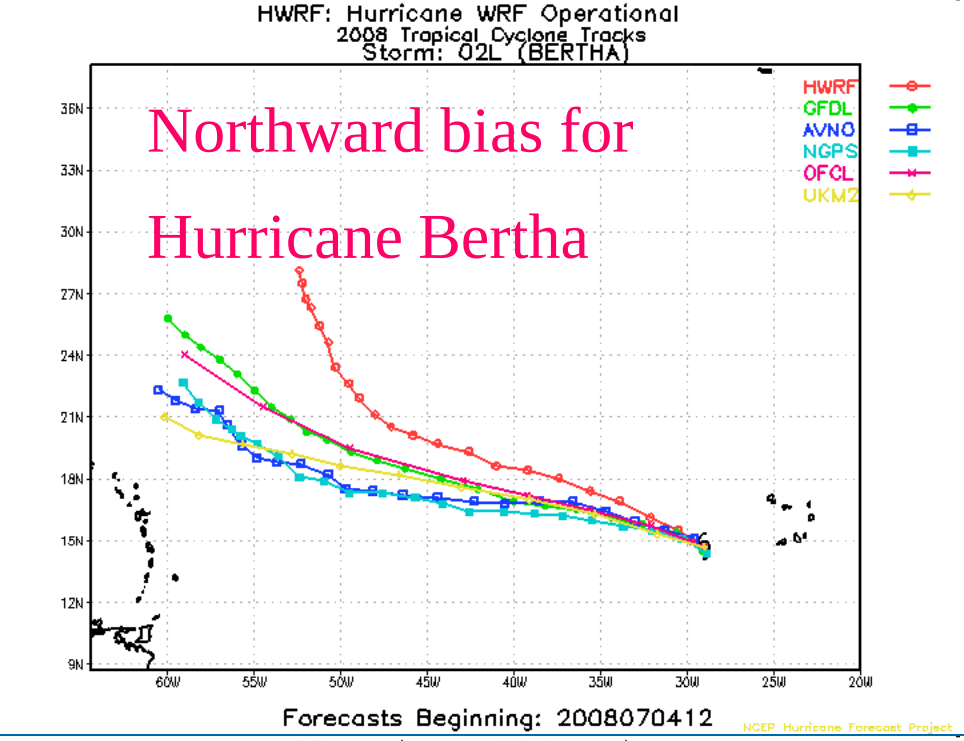
R (km)	Eye-wall (30km)	60	90	120	150	180	210
700mb wind	44.13	39.97	30.37	24.32	19.90	16.02	13.90
850mb wind	46.69	40.90	30.51	24.12	19.88	16.45	14.11
10m wind	35.04	28.38	20.61	16.29	13.59	11.50	9.98
R700	0.79	0.71	0.68	0.67	0.68	0.72	0.72

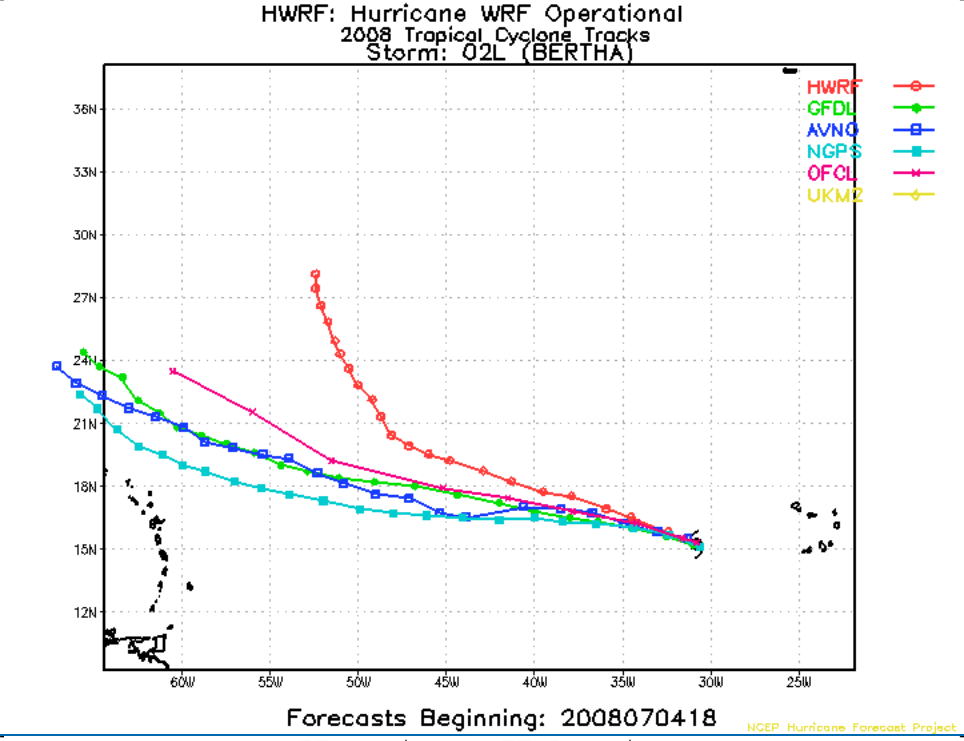


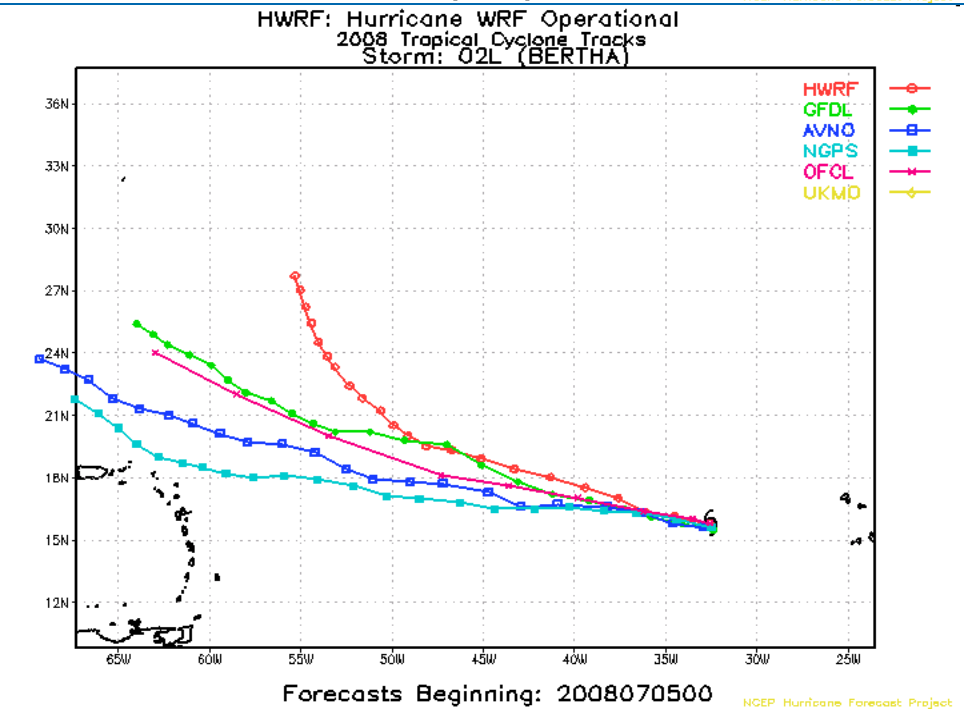


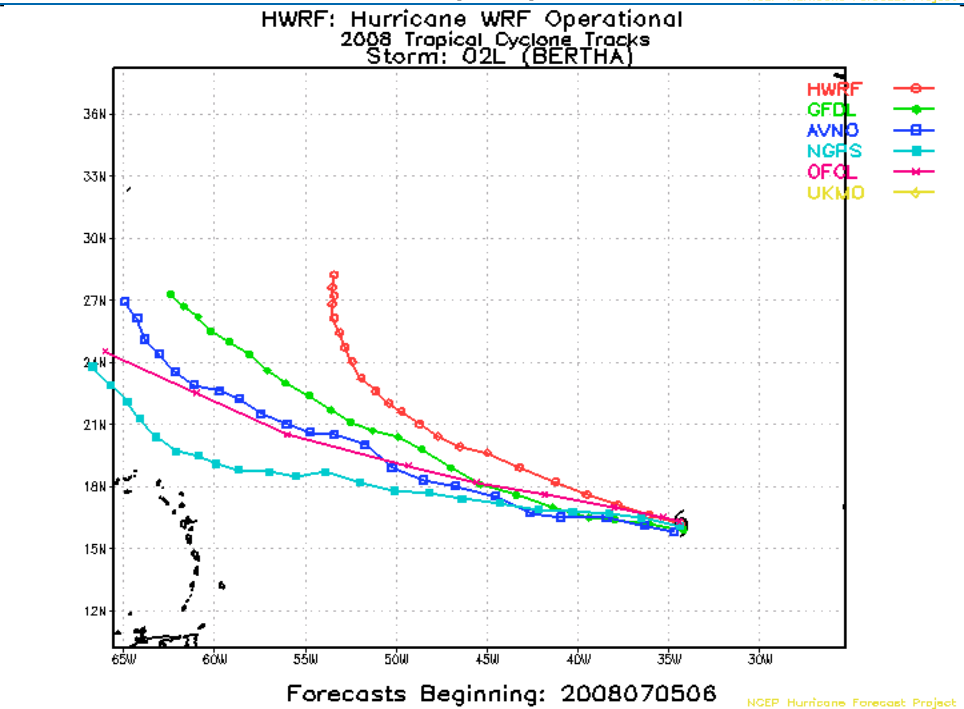
Some specific case studies

- Hurricane Bertha – northward turn in the early stages of HWRF forecasts
- Hurricane Gustav vs. Hurricane Ike
- Tropical Storm Fay
- East-Pac: Hurricane Kiko


HWRF: Hurricane WRF Operational
2008 Tropical Cyclone Tracks
Storm: 02L (BERTHA)
HWRF
GFDL
AVNO
NGPS
OFCL
UKMZ
Northward bias for
Hurricane Bertha
Forecasts Beginning: 2008070412
NCEP Hurricane Forecast Project


HWRF: Hurricane WRF Operational
2008 Tropical Cyclone Tracks
Storm: 02L (BERTHA)
HWRF
GFDL
AVNO
NGPS
OFCL
UKMZ
Forecasts Beginning: 2008070418
NCEP Hurricane Forecast Project


HWRF: Hurricane WRF Operational
2008 Tropical Cyclone Tracks
Storm: 02L (BERTHA)
HWRF
GFDL
AVNO
NGPS
OFCL
UKMO
Forecasts Beginning: 2008070500
NCEP Hurricane Forecast Project


HWRF: Hurricane WRF Operational
2008 Tropical Cyclone Tracks
Storm: 02L (BERTHA)
HWRF
GFDL
AVNO
NGPS
OFCL
UKMO
Forecasts Beginning: 2008070506
NCEP Hurricane Forecast Project

Hurricane Bertha's northward turn - Breaking of sub-tropical high

Evolution of 500 hPa geopotential height
HWRF compared to GFS

lt: 2008070600 vt: 2008070918 (90h)

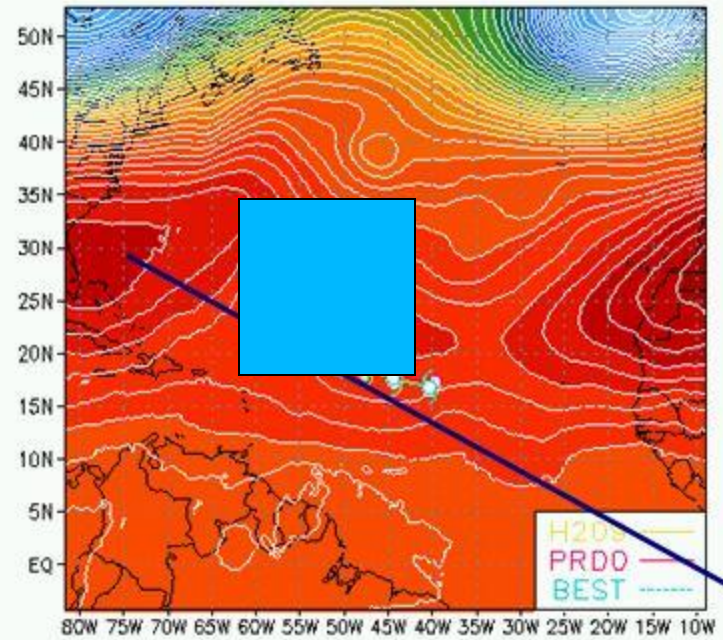
500 mb geopotential height (shaded, m)

RMS V_{850}: 9.5 m/s

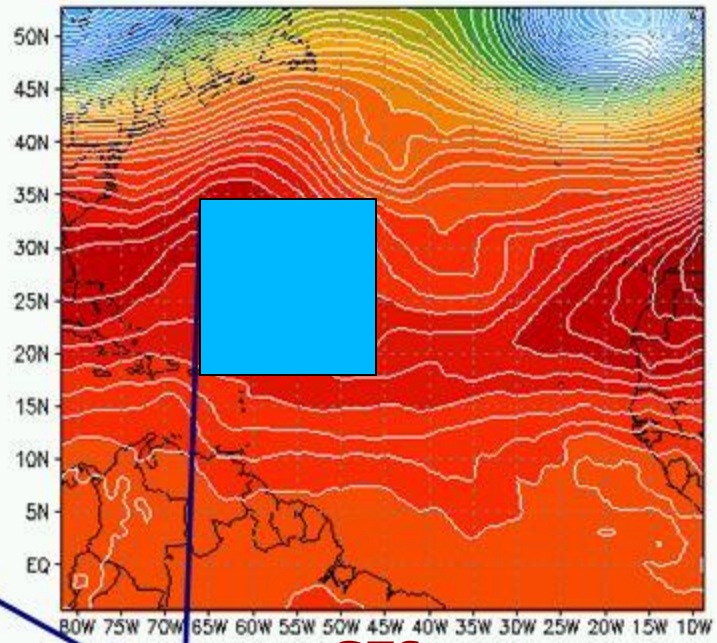
ACC H_{500} : 0.72

RMS V_{850}: 7.3 m/s

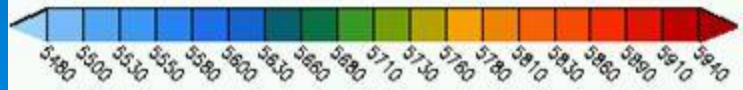
ACC H_{500} : 0.85



HWRF



GFS



Weakening of sub-tropical high

Hurricane Bertha's northward turn - Breaking of sub-tropical high

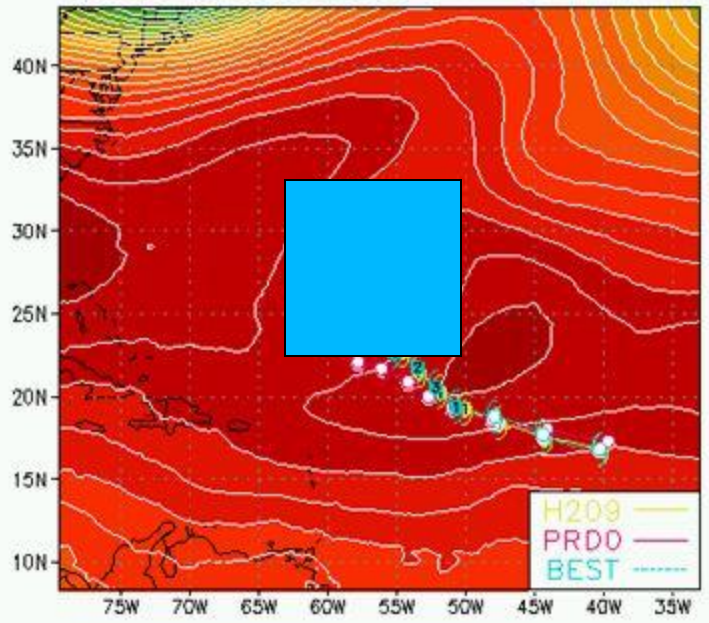
Evolution of 500 hPa geopotential height
HWRF compared to GFS

lt: 2008070600 vt: 2008071100 (120h)

500 mb geopotential height (shaded, m)

RMSE V_{850}: 11.6 m/s

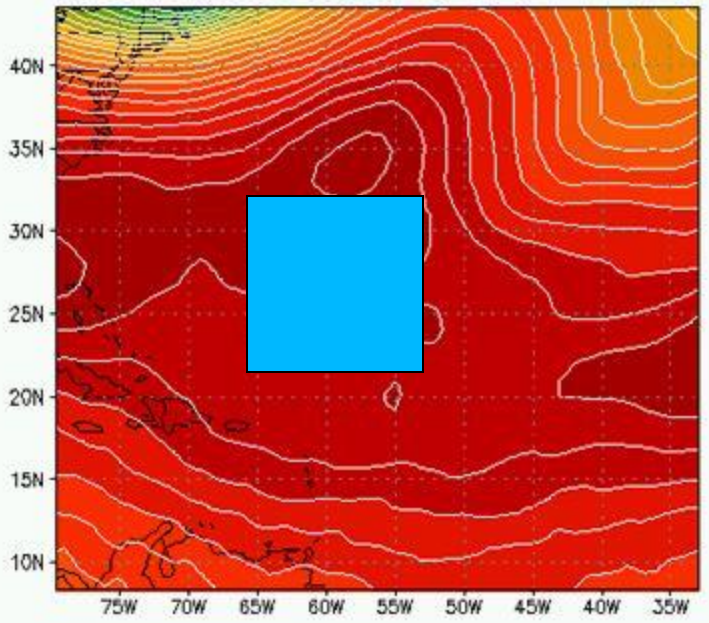
ACC H_{500} : 0.62



HWRF

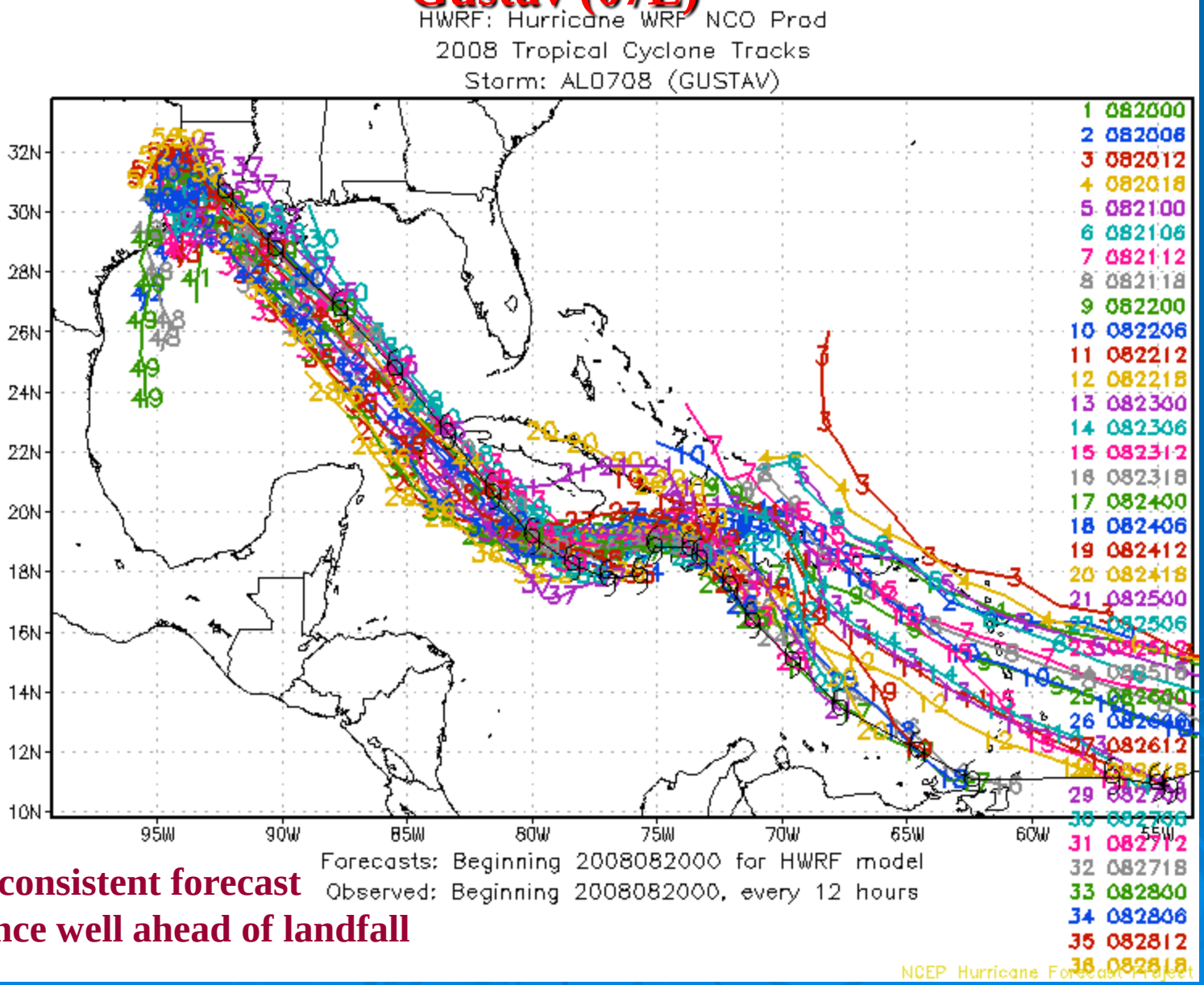
RMSE V_{850}: 8.4 m/s

ACC H_{500} : 0.81



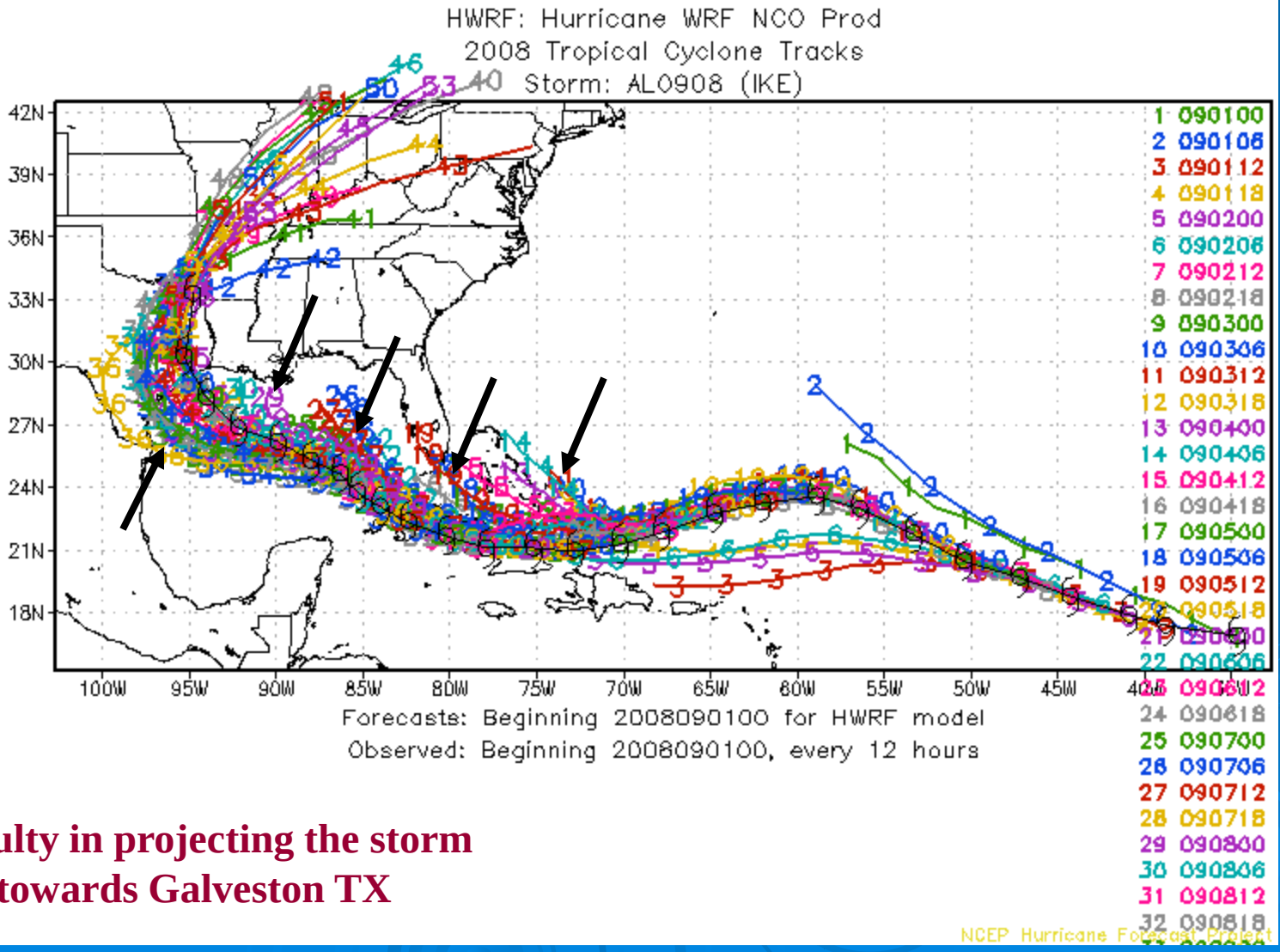
GFS

Gustav (07L)

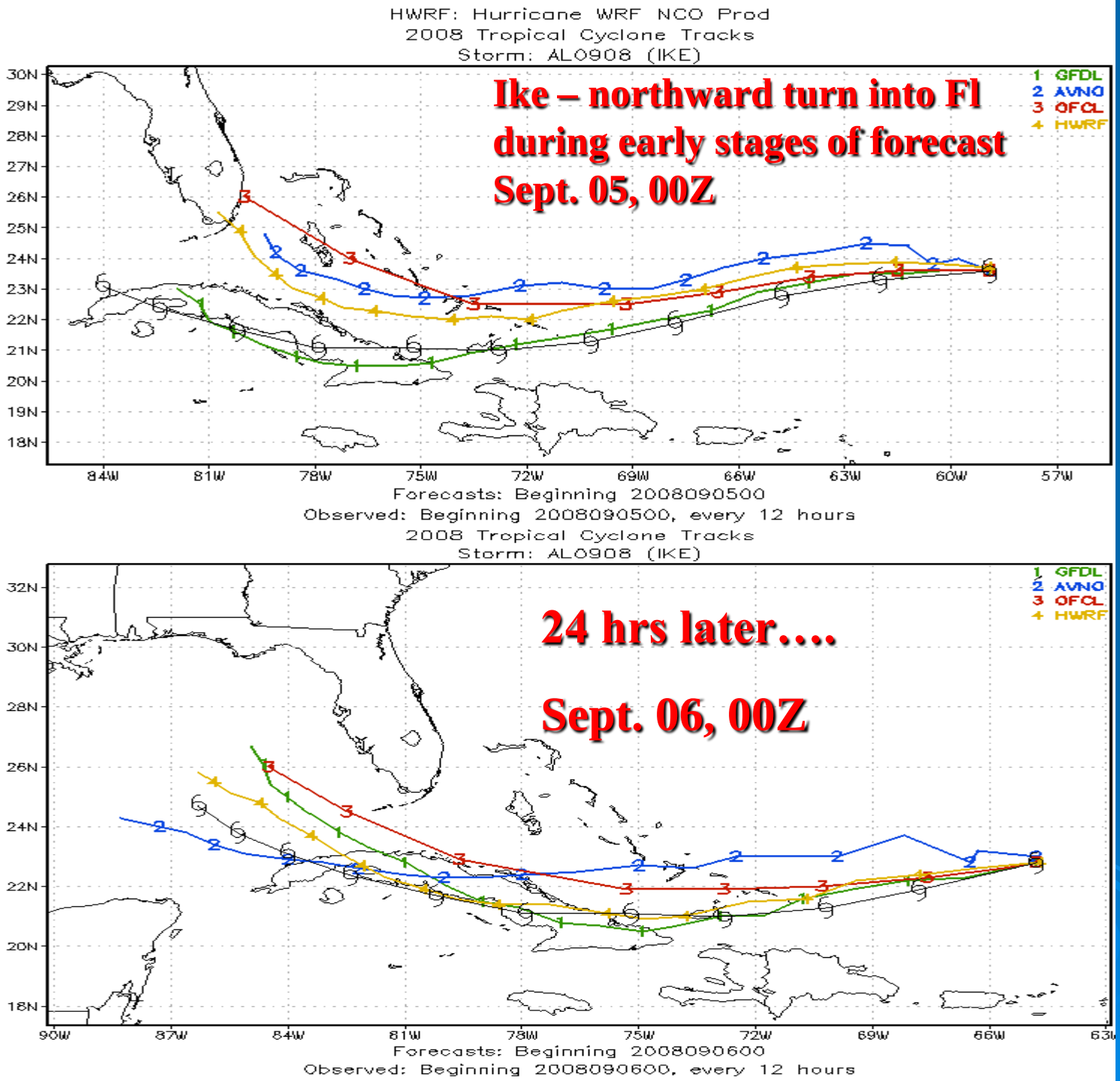


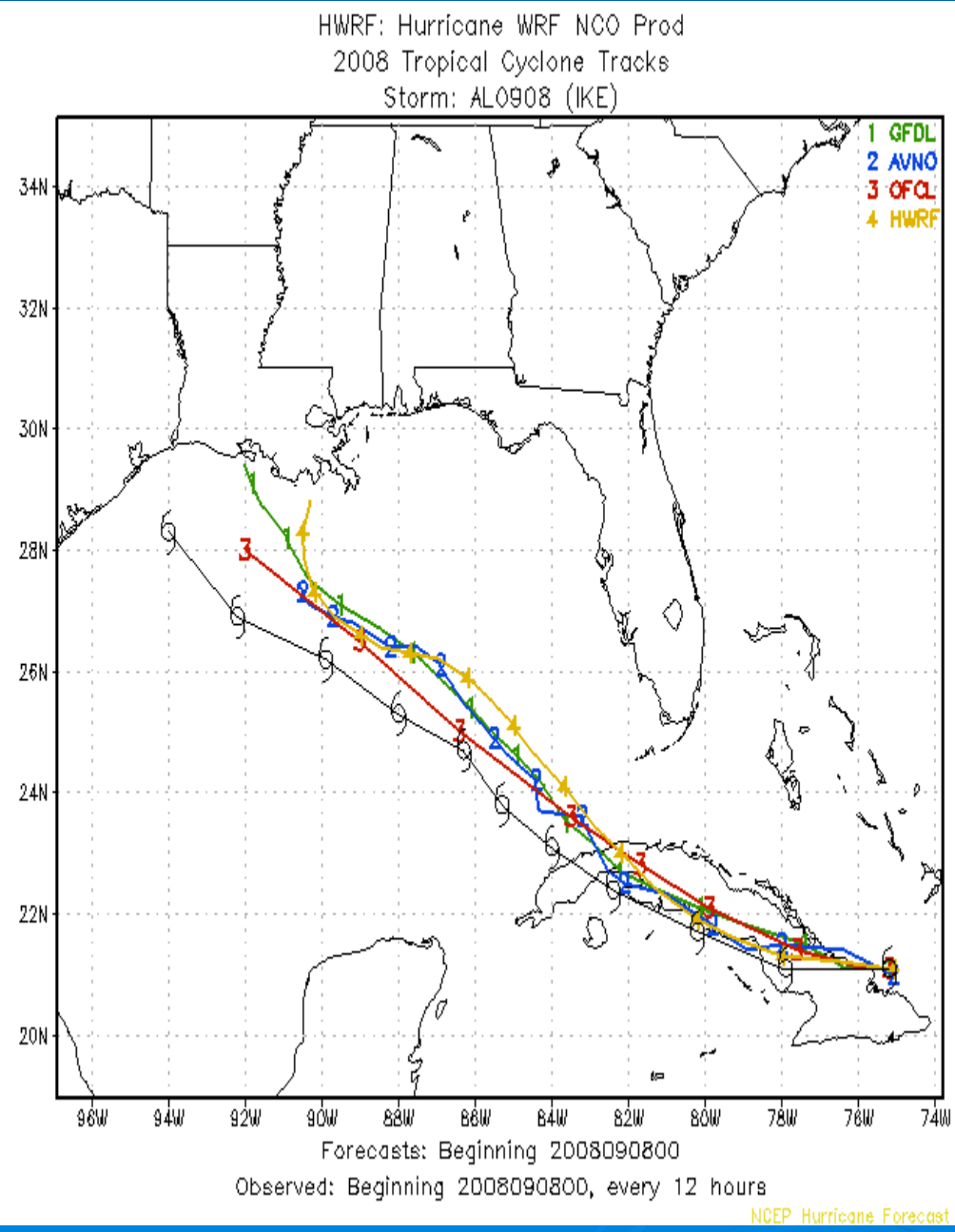
More consistent forecast guidance well ahead of landfall

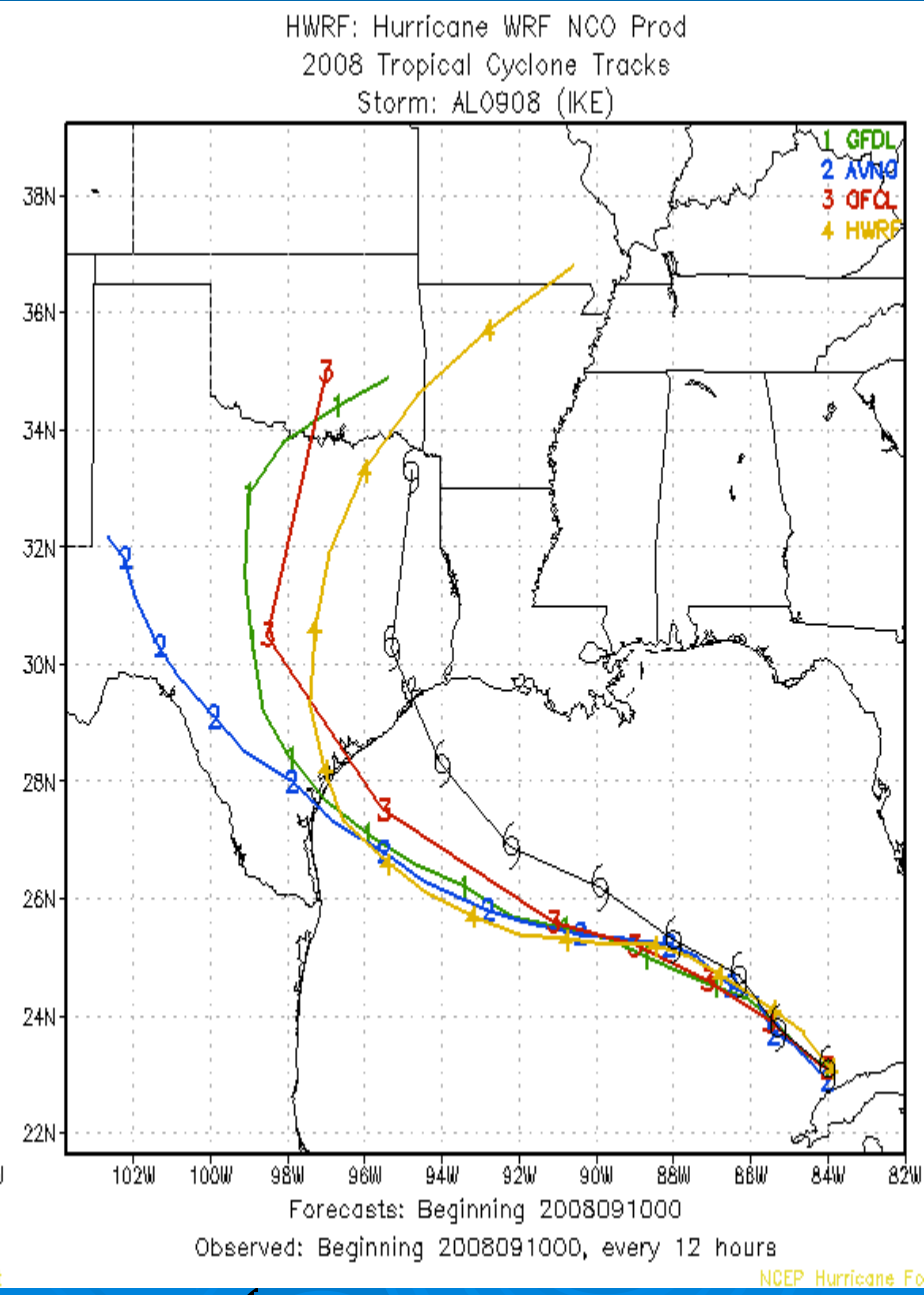
Ike (09L)



Difficulty in projecting the storm track towards Galveston TX

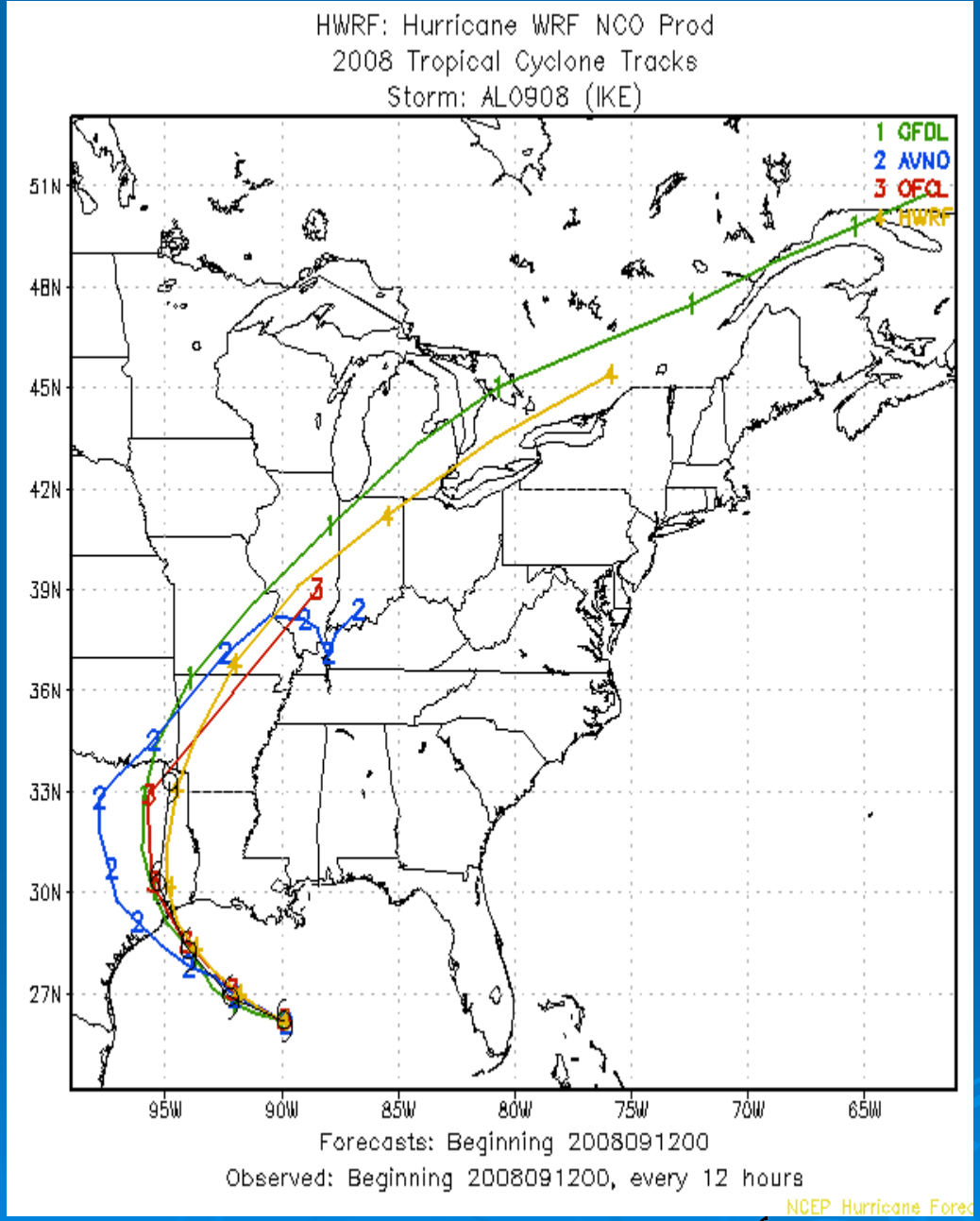

HWRF: Hurricane WRF NCO Prod
2008 Tropical Cyclone Tracks
Storm: AL0908 (IKE)
Ike – northward turn into Fl during early stages of forecast
Sept. 05, 00Z
1 GFDL
2 AVNO
3 OFCL
4 HWRF
30N
29N
28N
27N
26N
25N
24N
23N
22N
21N
20N
19N
18N
84W
81W
78W
75W
72W
69W
66W
63W
60W
57W
Forecasts: Beginning 2008090500
Observed: Beginning 2008090500, every 12 hours
2008 Tropical Cyclone Tracks
Storm: AL0908 (IKE)
24 hrs later….
Sept. 06, 00Z
1 GFDL
2 AVNO
3 OFCL
4 HWRF
32N
30N
28N
26N
24N
22N
20N
18N
90W
87W
84W
81W
78W
75W
72W
69W
66W
Forecasts: Beginning 2008090600
Observed: Beginning 2008090600, every 12 hours



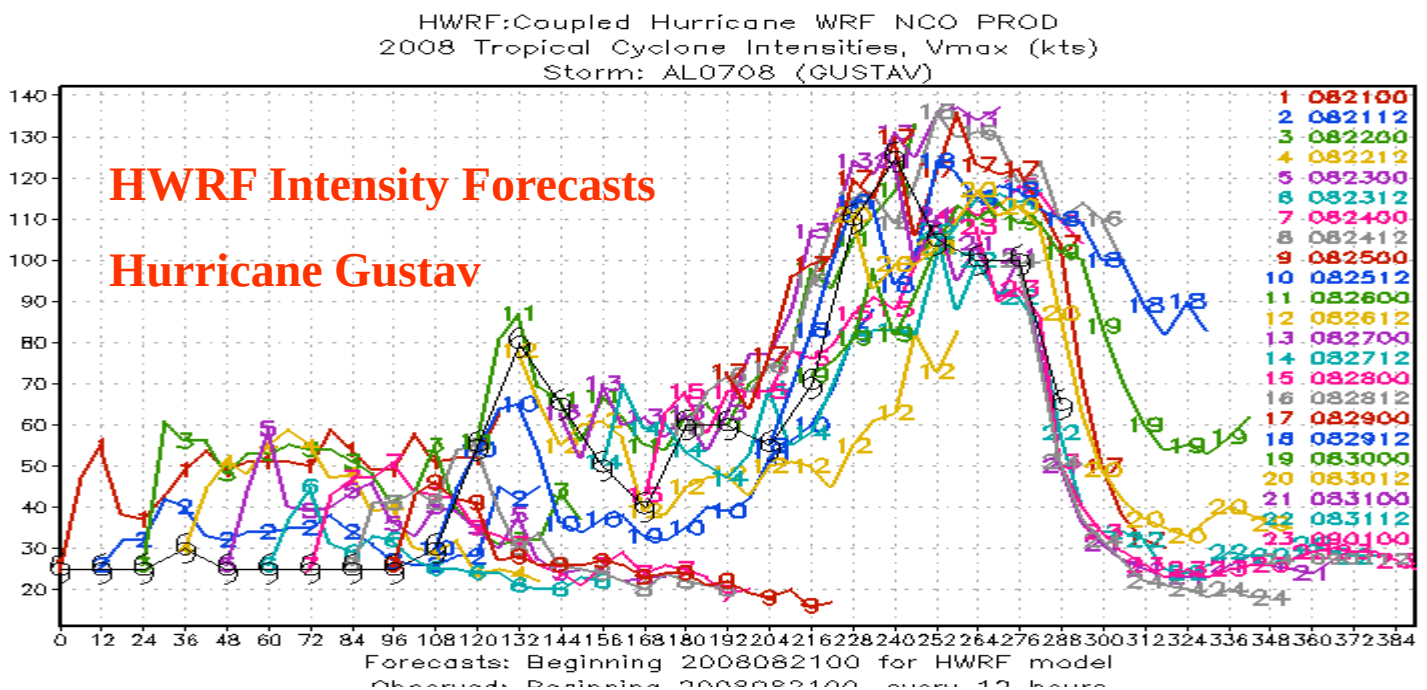


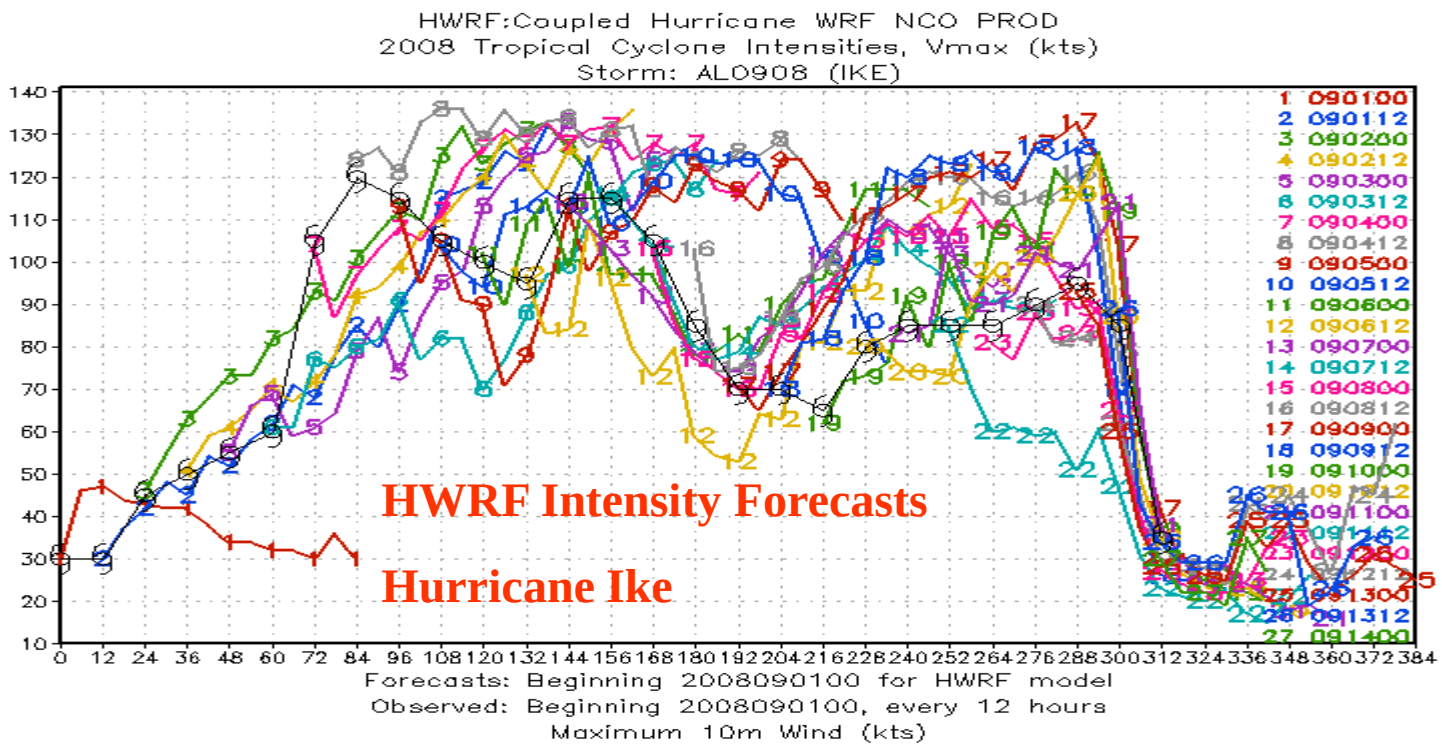
48 hrs later…. Sep. 08 00Z

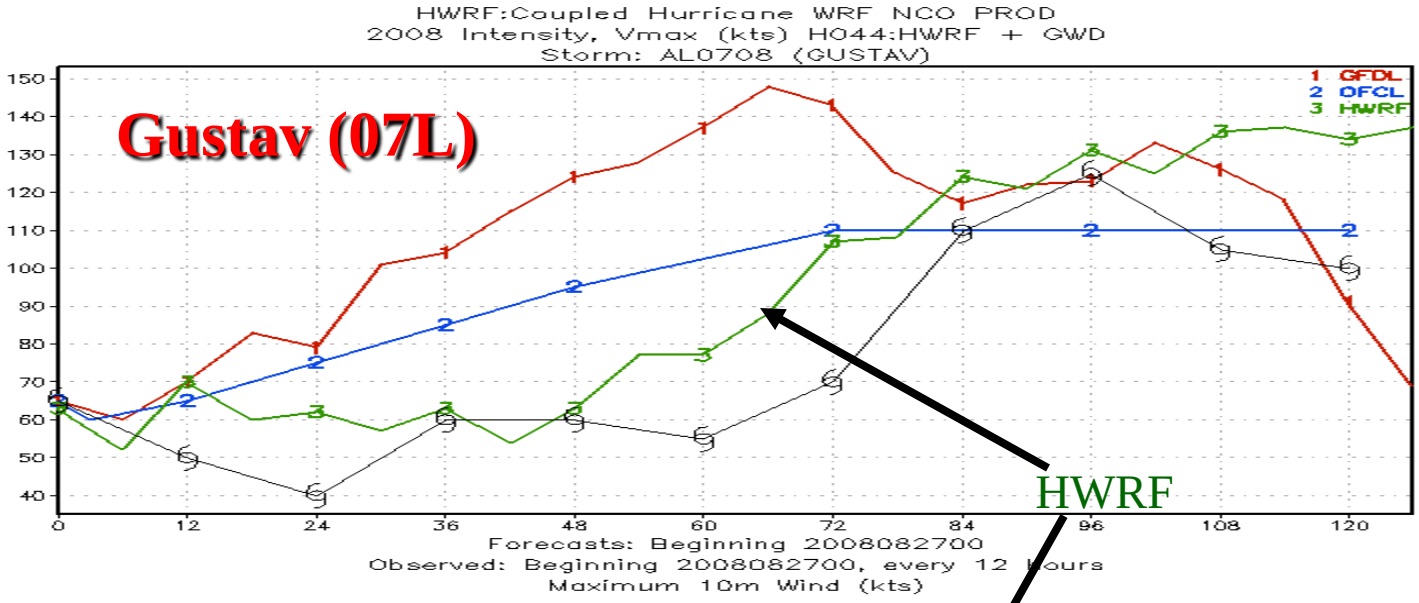
48 hrs later…. Sep. 10 00Z

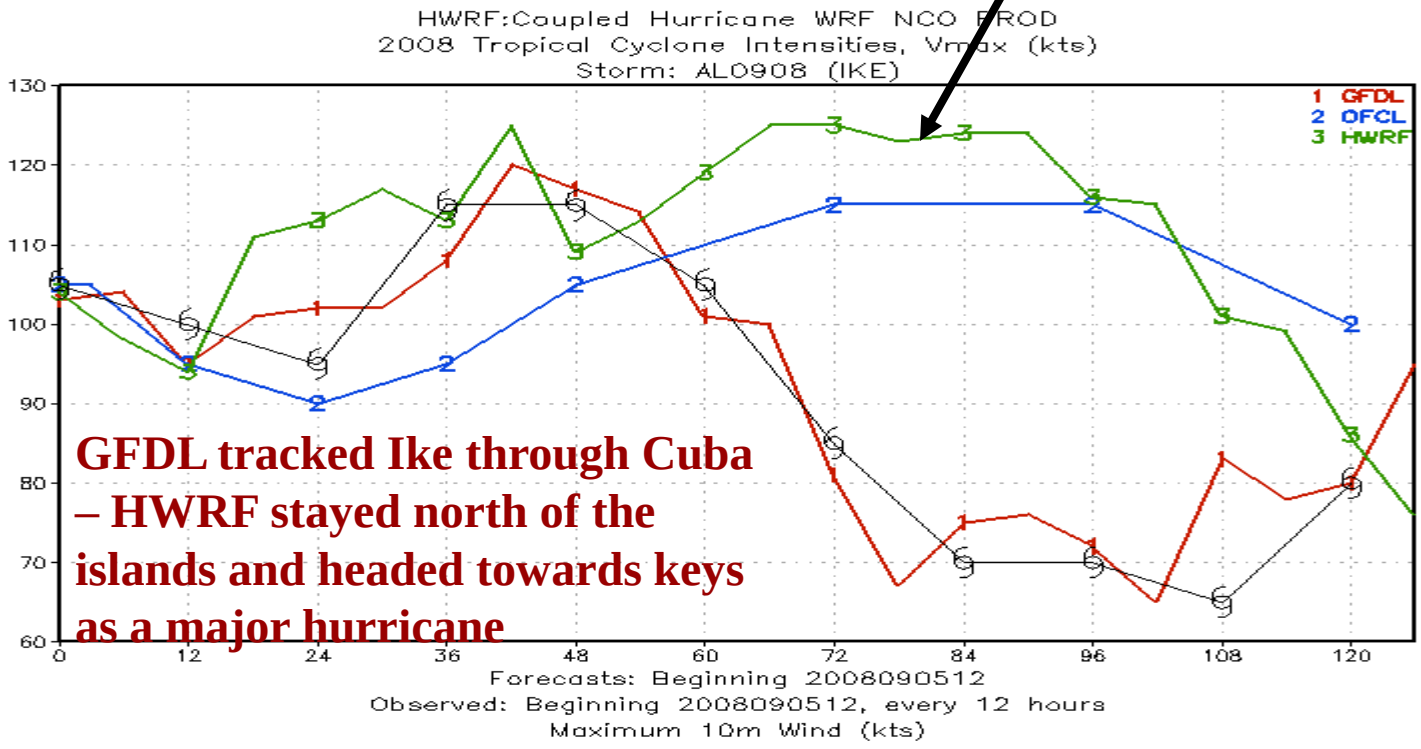


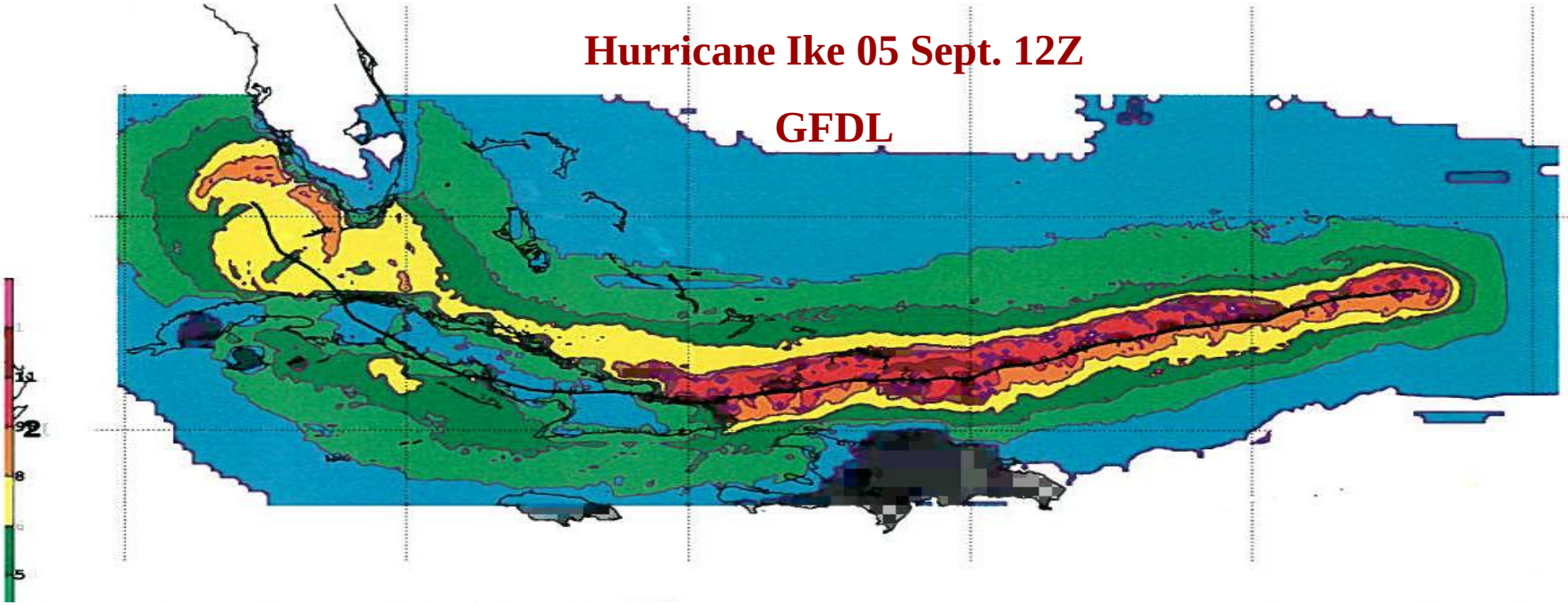
Sep. 12 00Z, 36 hrs before landfall

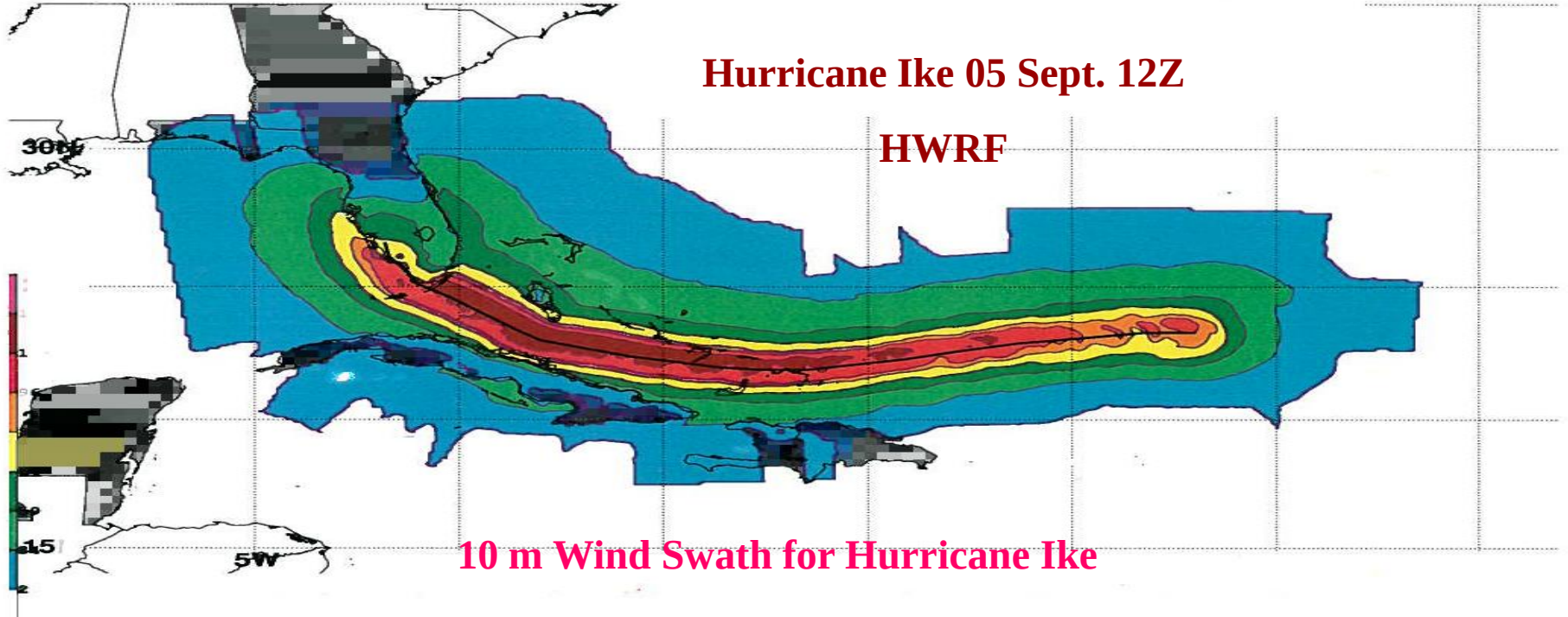

HWRF:Coupled Hurricane WRF NCO PROD
2008 Tropical Cyclone Intensities, Vmax (kts)
Storm: AL0708 (GUSTAV)
HWRF Intensity Forecasts
Hurricane Gustav
Forecasts: Beginning 2008082100 for HWRF model


HWRF:Coupled Hurricane WRF NCO PROD
2008 Tropical Cyclone Intensities, Vmax (kts)
Storm: AL0908 (IKE)
HWRF Intensity Forecasts
Hurricane Ike
Forecasts: Beginning 2008090100 for HWRF model
Observed: Beginning 2008090100, every 12 hours
Maximum 10m Wind (kts)


HWRF:Coupled Hurricane WRF NCO PROD
2008 Intensity, Vmax (kts) HO44:HWRF + GWD
Storm: AL0708 (GUSTAV)
1 GFDL
2 OFCL
3 HWRF
Gustav (07L)
HWRF
Forecasts: Beginning 2008082700
Observed: Beginning 2008082700, every 12 hours
Maximum 10m Wind (kts)


HWRF:Coupled Hurricane WRF NCO PROD
2008 Tropical Cyclone Intensities, Vmax (kts)
Storm: AL0908 (IKE)
1 GFDL
2 OFCL
3 HWRF
GFDL tracked Ike through Cuba – HWRF stayed north of the islands and headed towards keys as a major hurricane
Forecasts: Beginning 2008090512
Observed: Beginning 2008090512, every 12 hours
Maximum 10m Wind (kts)



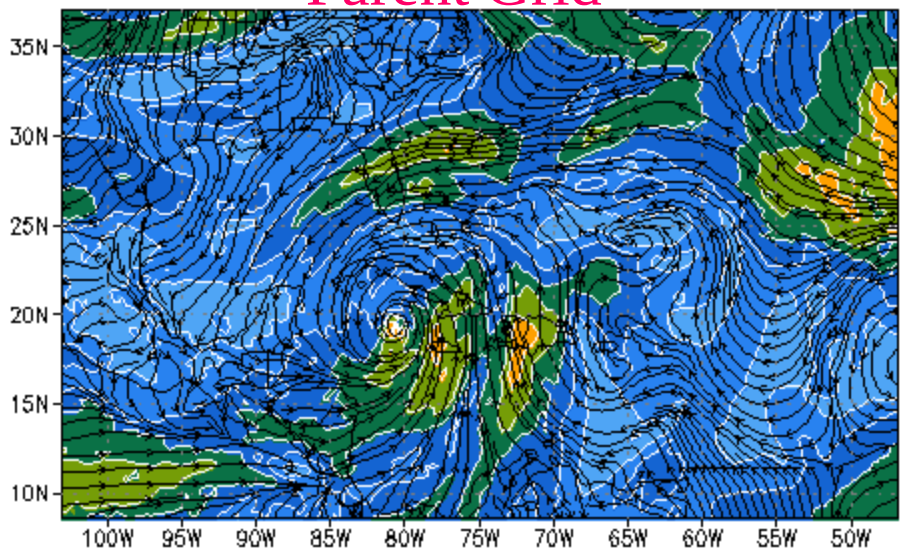


10 m Wind Swath for Hurricane Ike

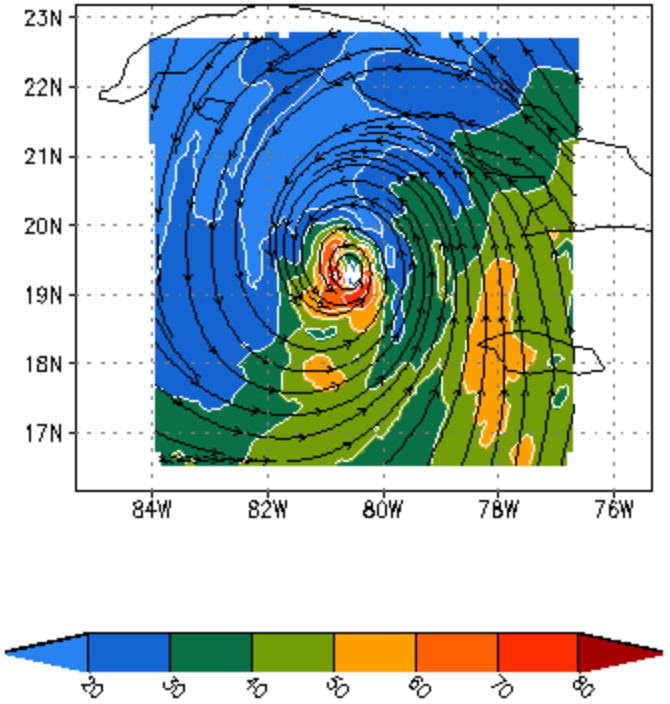
HWRF – GUSTAV07I
it: 2008082700 vt: 2008082912 (60h)

850–200 mb vertical shear (shaded, knots)
10m wind circulation (streamlines,)

Parent Grid



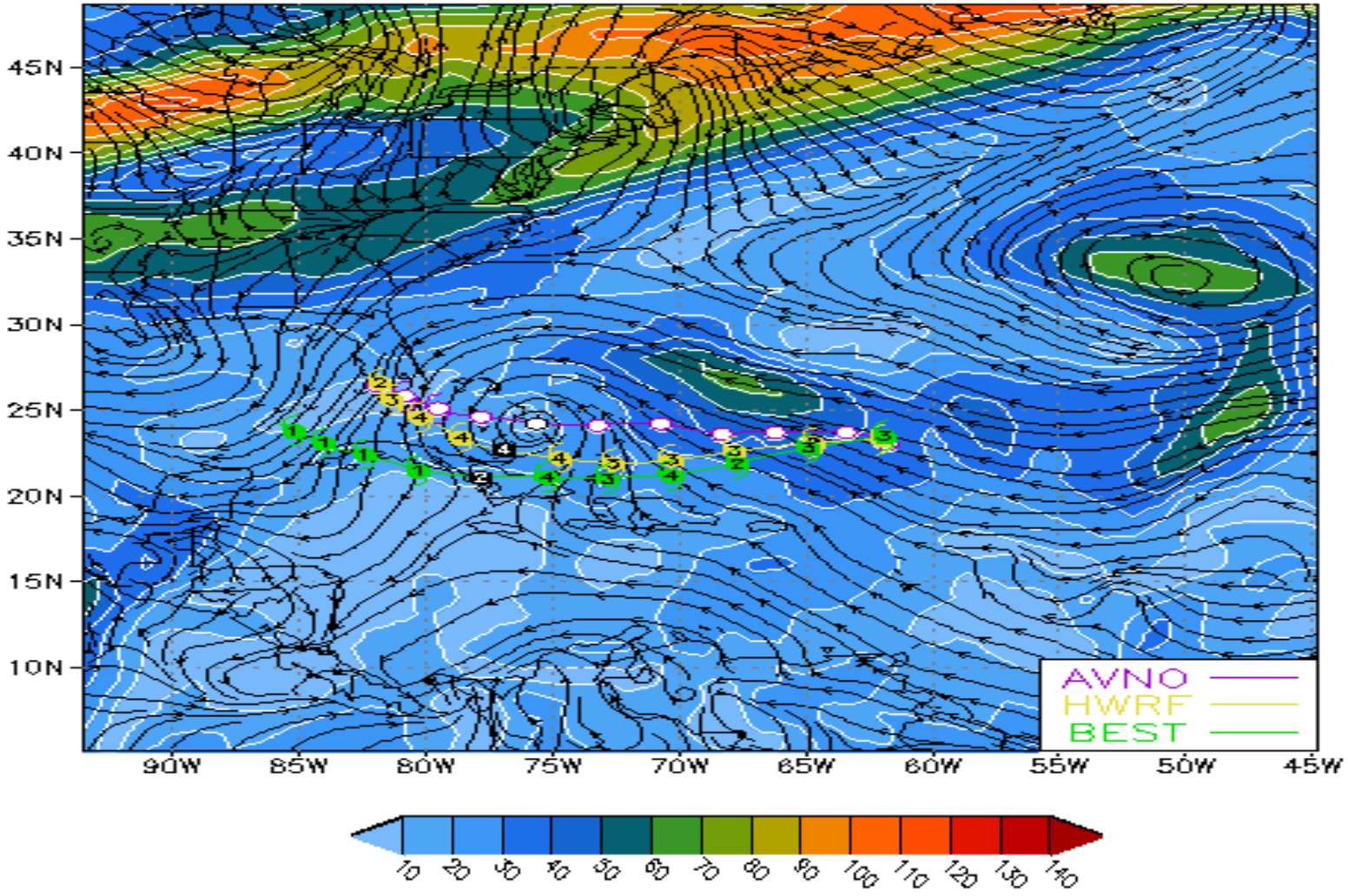
Nest Grid



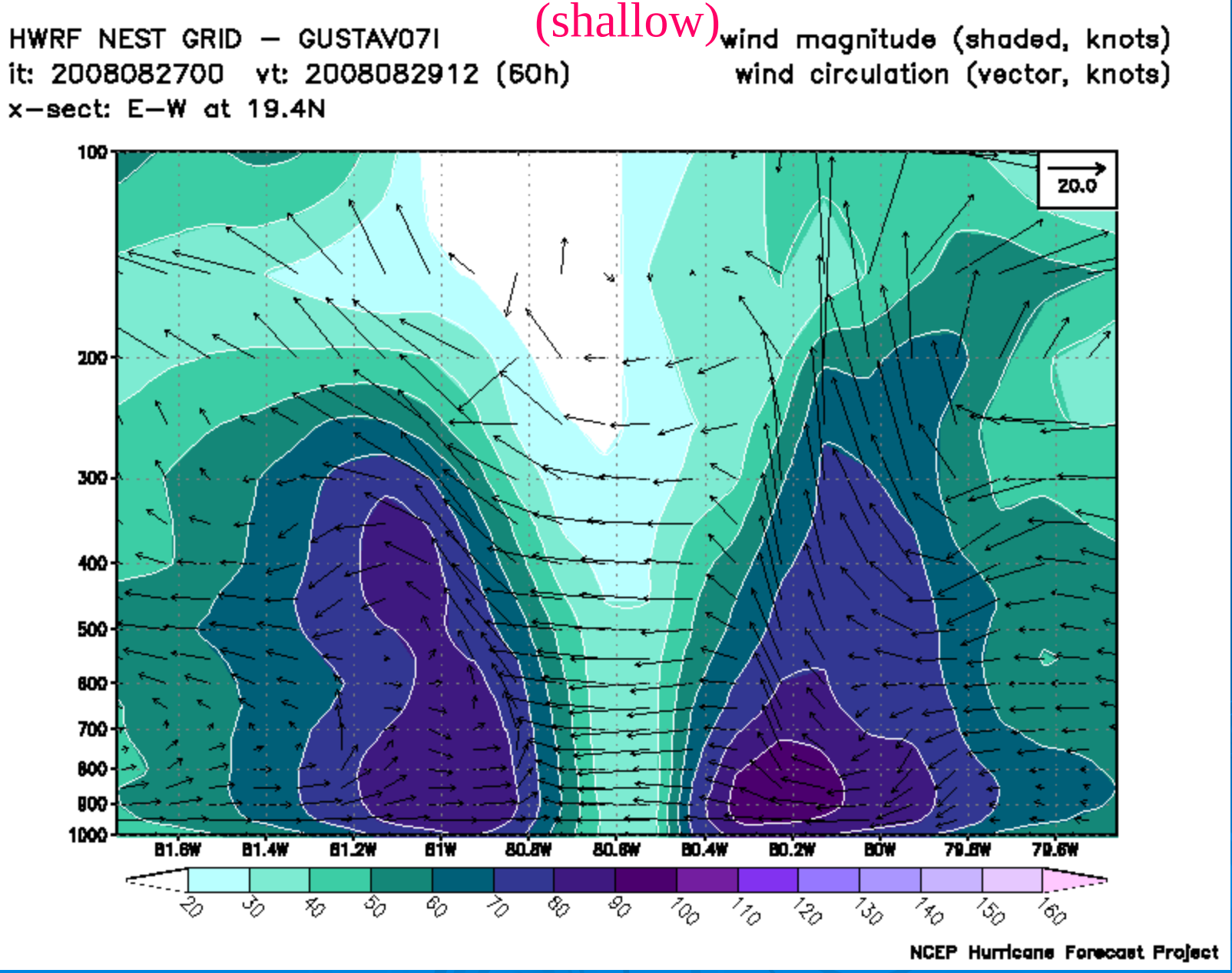
HWRF Shear Patterns associated with Gustav

AVNO — IKE09I
it: 2008090512 vt: 2008090812 (72h)

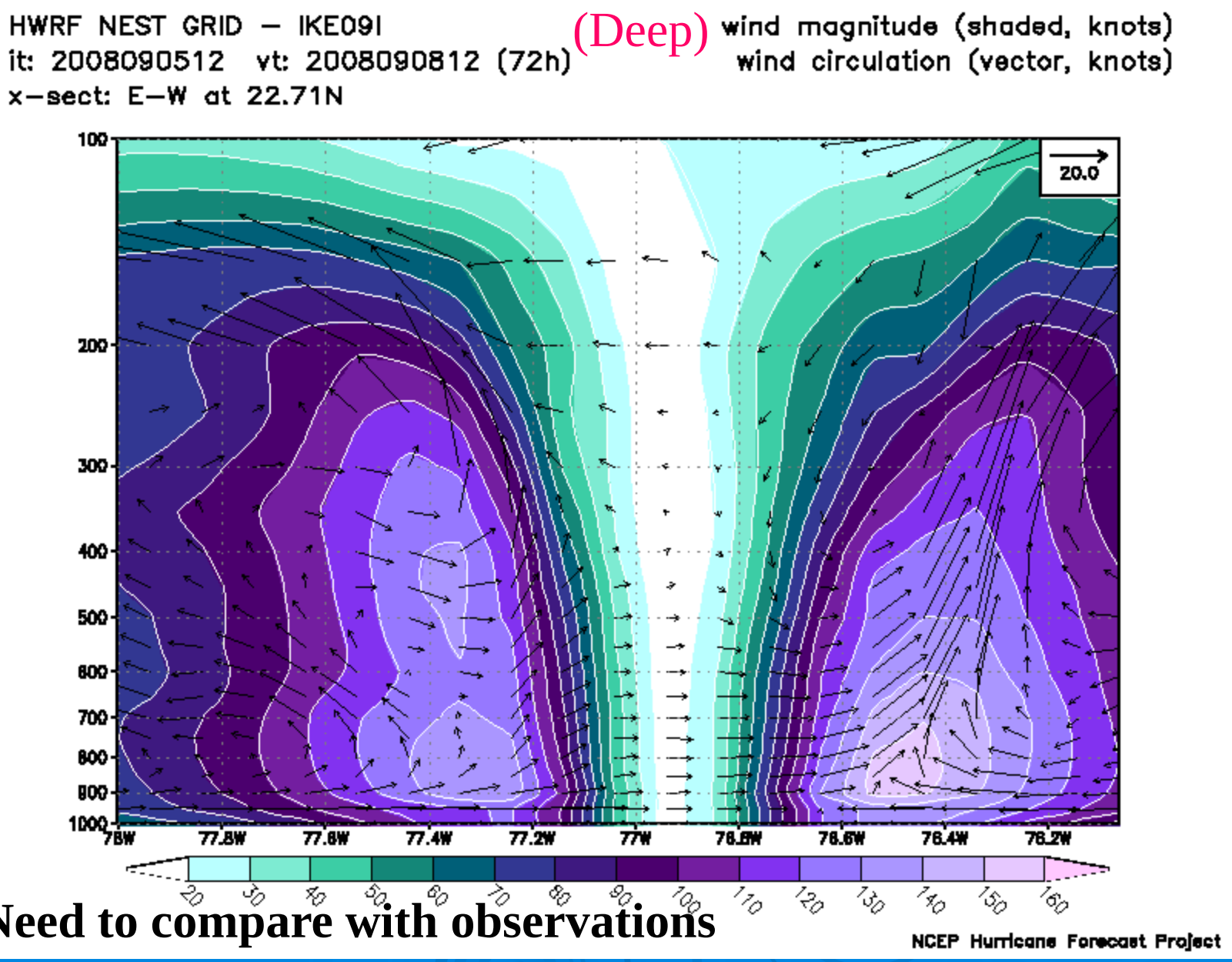
GFS Shear Patterns associated with Ike



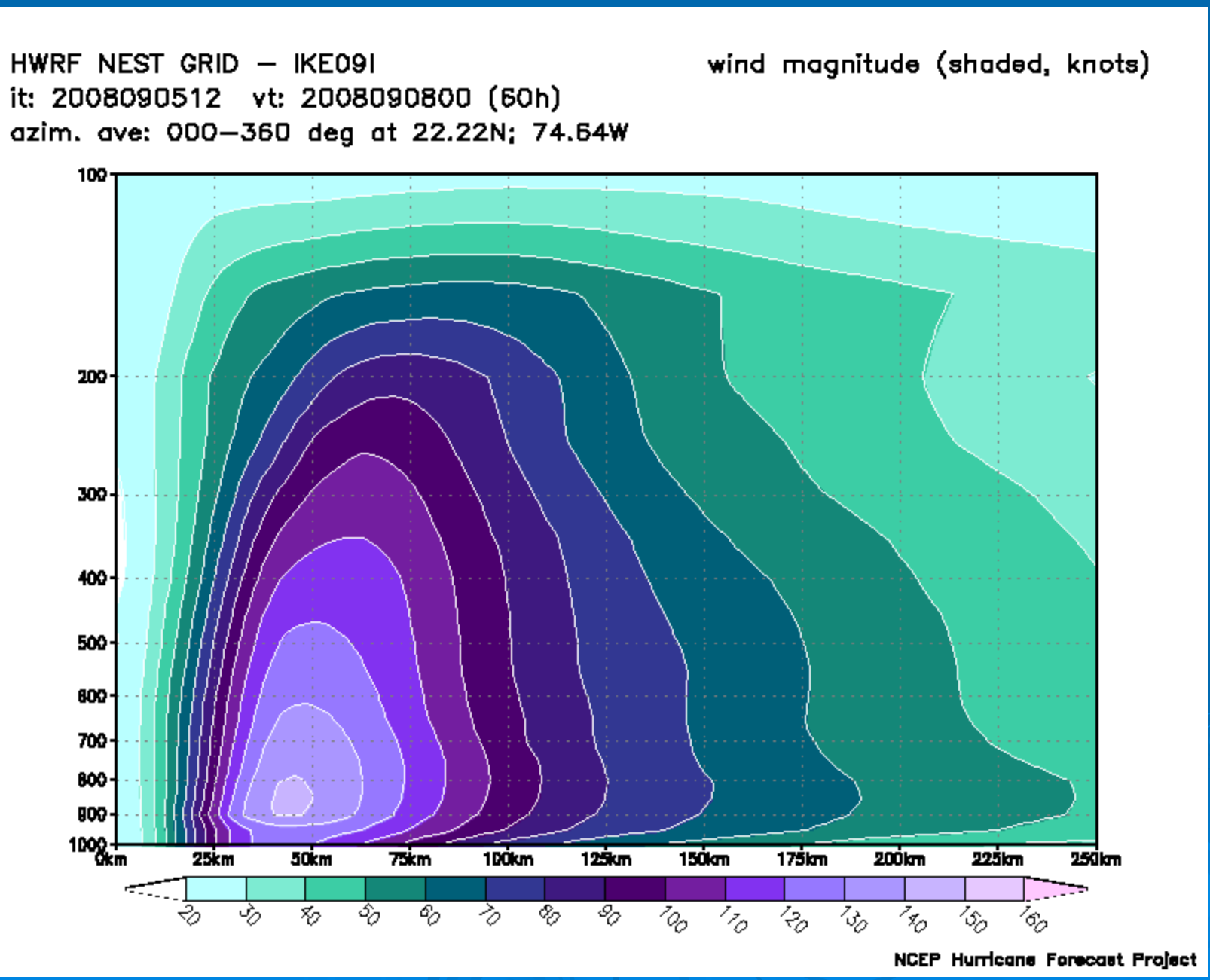
Vertical cross-section of Hurricane Gustav (shallow)



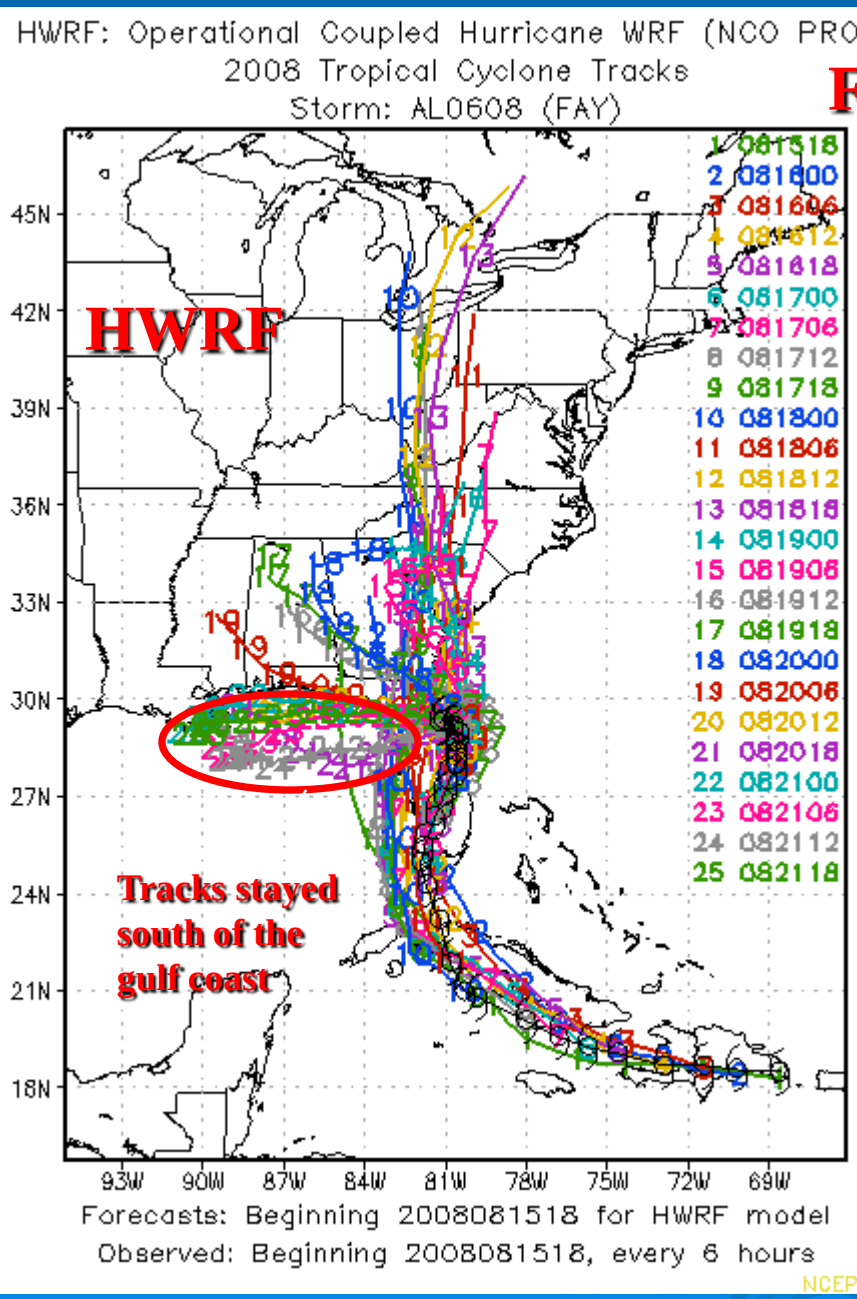
Vertical cross-section of Hurricane Ike

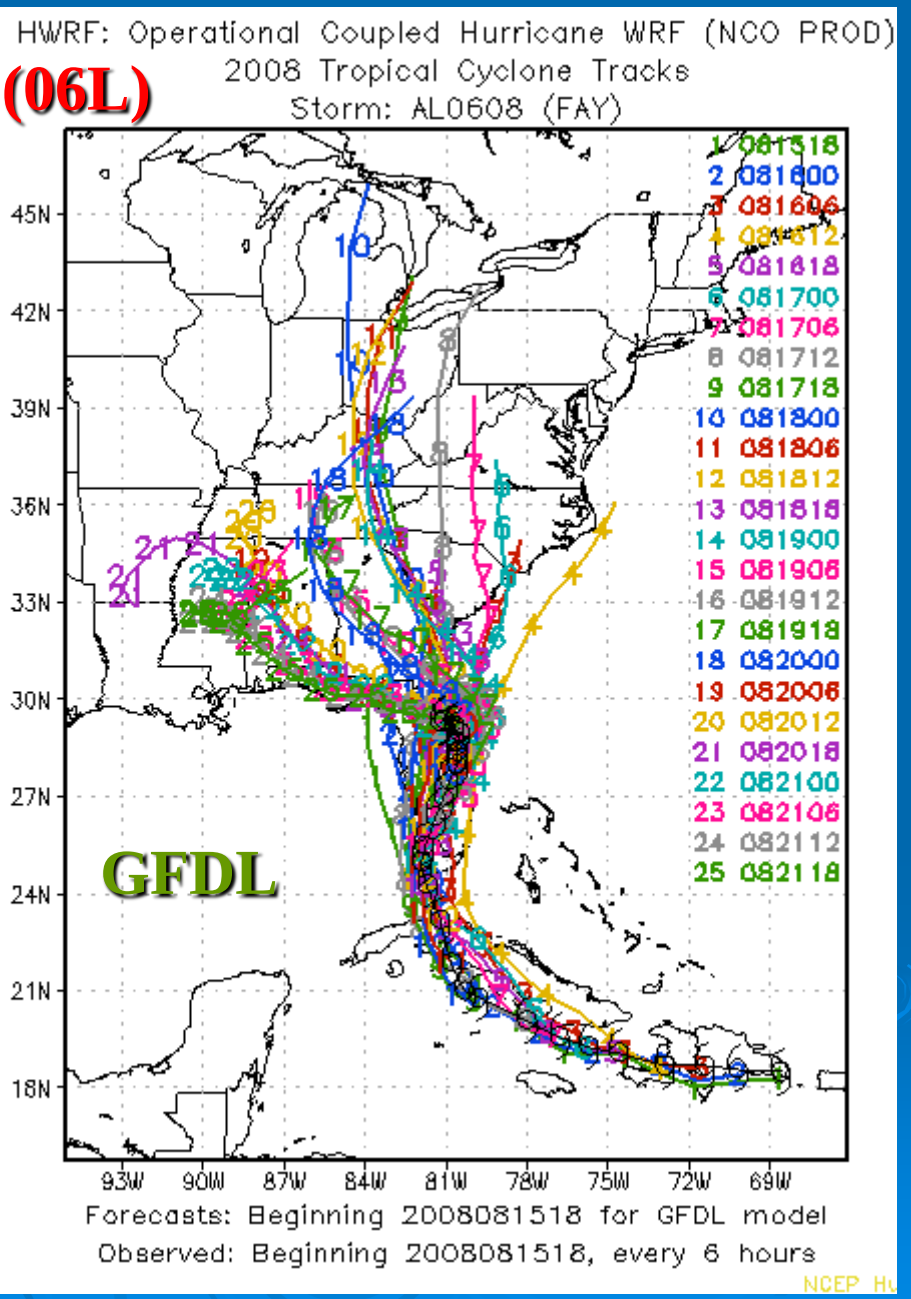


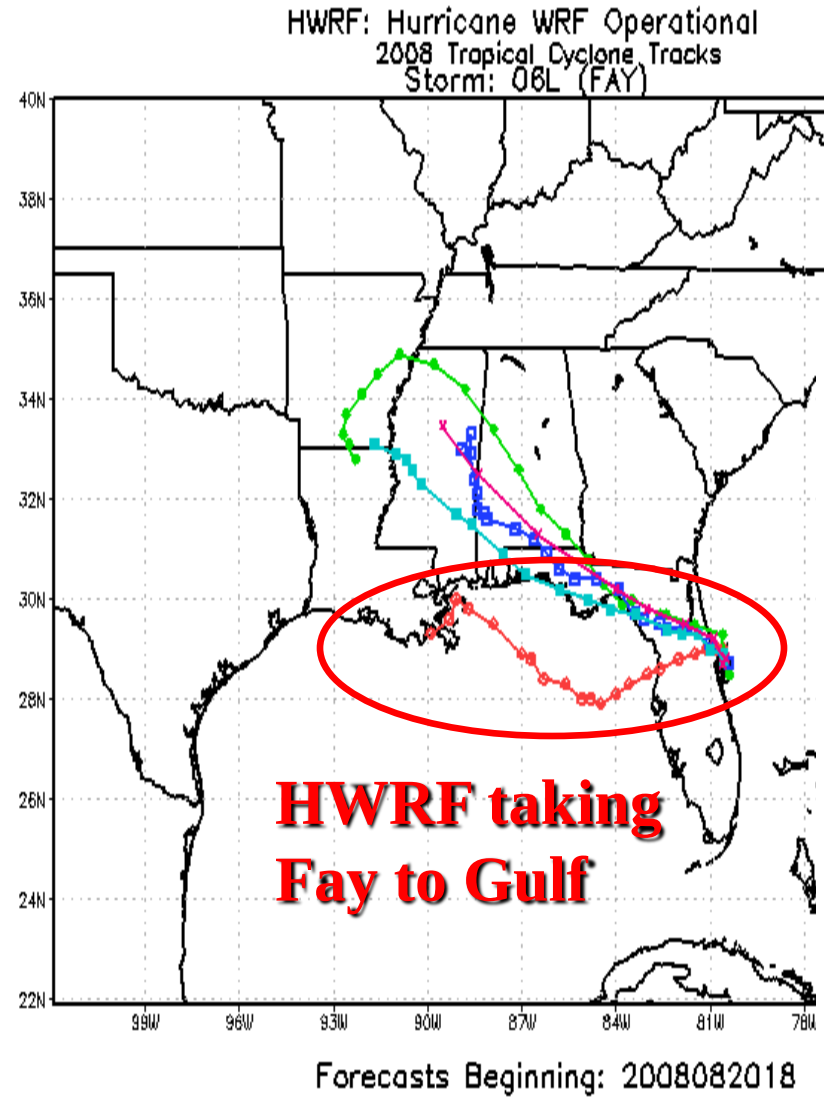
Need to compare with observations

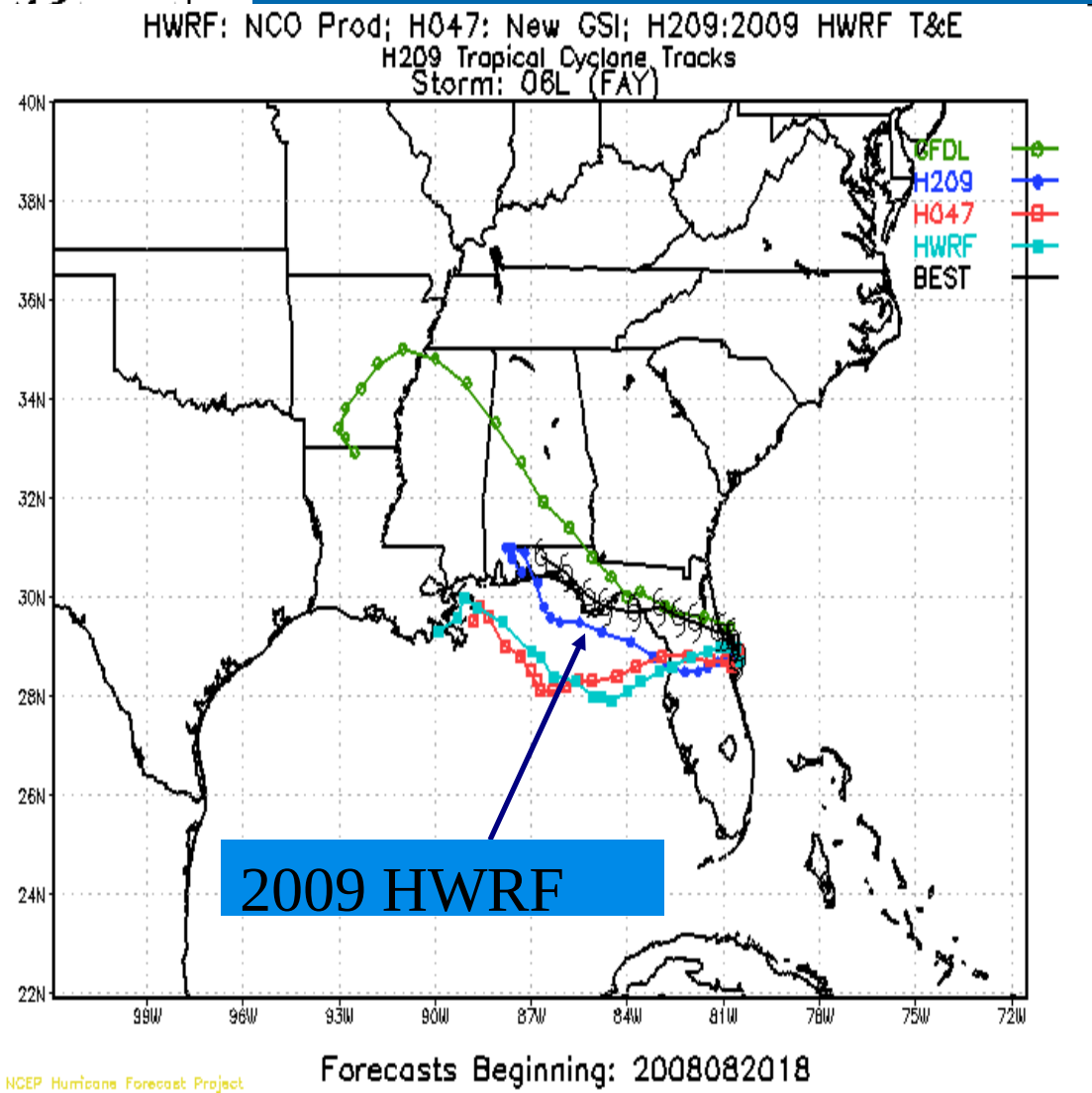

HWRF NEST GRID – IKE09l
it: 2008090512 vt: 2008090800 (60h)
azim. ave: 000–360 deg at 22.22N; 74.64W
wind magnitude (shaded, knots)
100
200
300
400
500
600
700
800
900
1000
0km
25km
50km
75km
100km
125km
150km
175km
200km
225km
250km
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
NCEP Hurricane Forecast Project

Fay (06L)


HWRF: Operational Coupled Hurricane WRF (NCO PROD)
2008 Tropical Cyclone Tracks
Storm: AL0608 (FAY)
HWRF
Tracks stayed south of the gulf coast
1 081518
2 081600
3 081606
4 081612
5 081618
6 081700
7 081706
8 081712
9 081718
10 081800
11 081806
12 081812
13 081818
14 081900
15 081906
16 081912
17 081918
18 082000
19 082006
20 082012
21 082018
22 082100
23 082106
24 082112
25 082118
45N
42N
39N
36N
33N
30N
27N
24N
21N
18N
93W
90W
87W
84W
81W
78W
75W
72W
69W
Forecasts: Beginning 2008081518 for HWRF model
Observed: Beginning 2008081518, every 6 hours

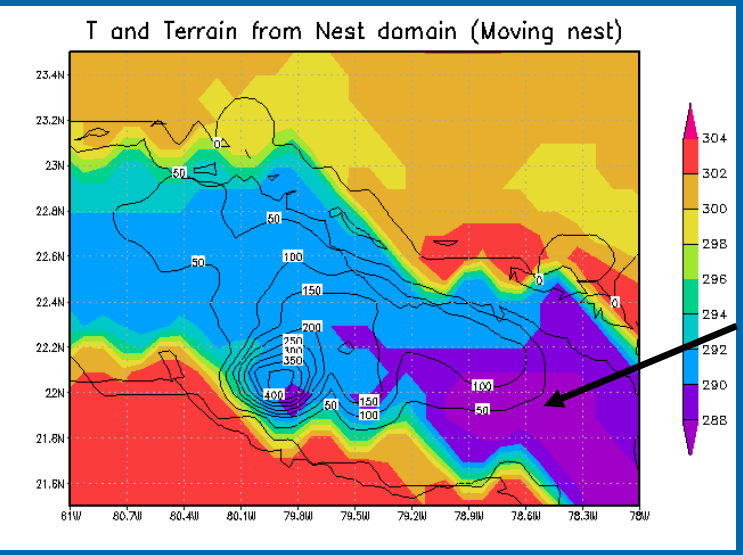

HWRF: Operational Coupled Hurricane WRF (NCO PROD)
2008 Tropical Cyclone Tracks
Storm: AL0608 (FAY)
GFDL
1 081518
2 081600
3 081606
4 081612
5 081618
6 081700
7 081706
8 081712
9 081718
10 081800
11 081806
12 081812
13 081818
14 081900
15 081906
16 081912
17 081918
18 082000
19 082006
20 082012
21 082018
22 082100
23 082106
24 082112
25 082118
45N
42N
39N
36N
33N
30N
27N
24N
21N
18N
93W
90W
87W
84W
81W
78W
75W
72W
69W
Forecasts: Beginning 2008081518 for GFDL model
Observed: Beginning 2008081518, every 6 hours





Possibly due to cooler land surface temperatures in HWRF nest domain

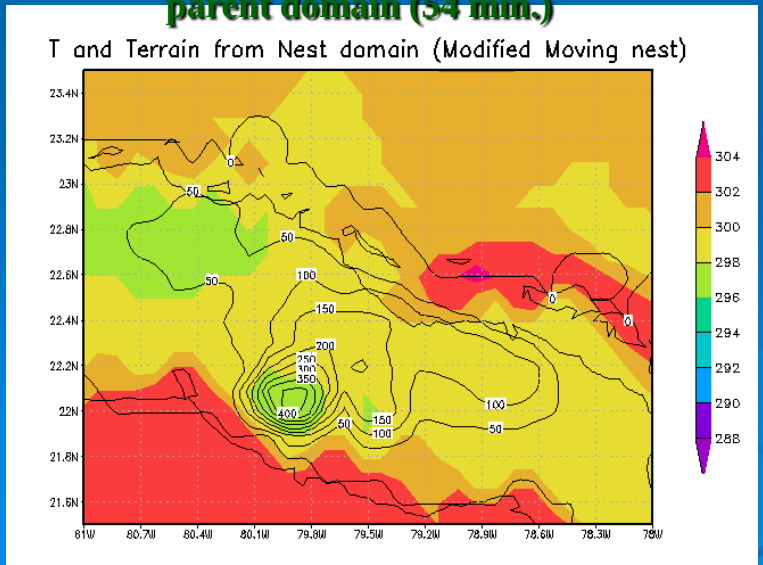
Cold Land Surface Temperatures in HWRF moving grid



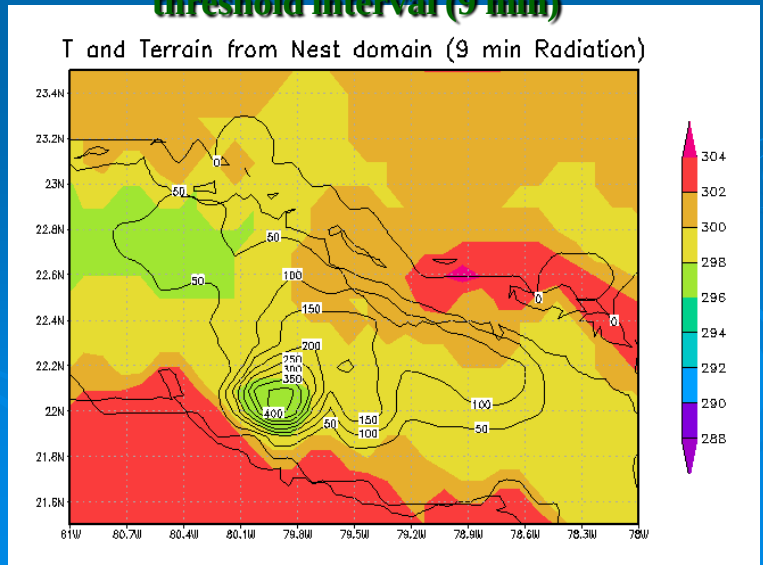
Cooler (by about 6-10 deg) land surface temperatures due to irregular computation of radiation in the inner domain (due to nest motion)

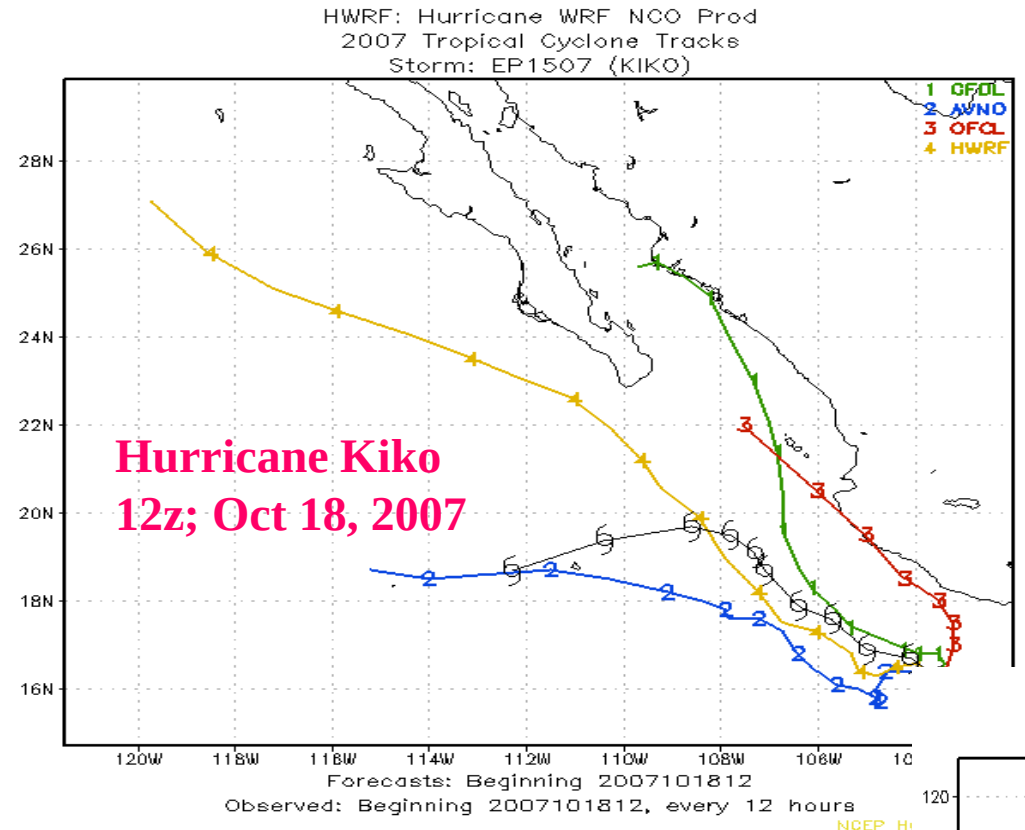
Problem solved by calling radiation for the nest at regular intervals

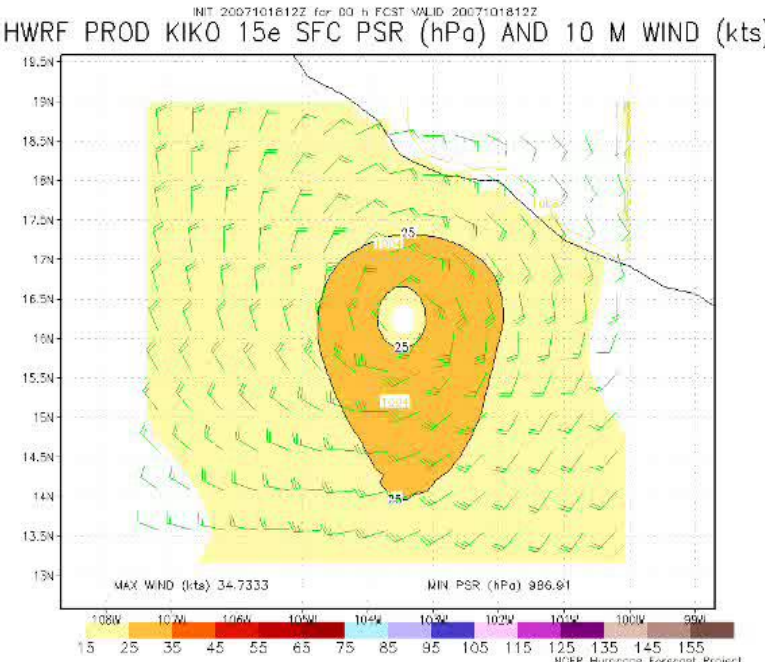
Radiation consistent with parent domain (54 min.)

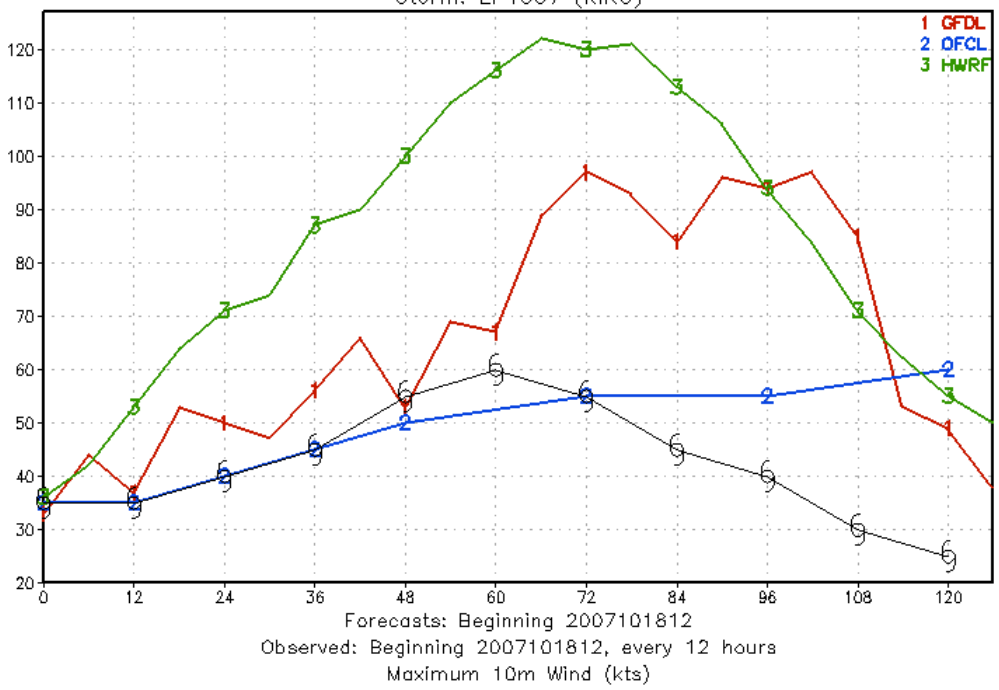


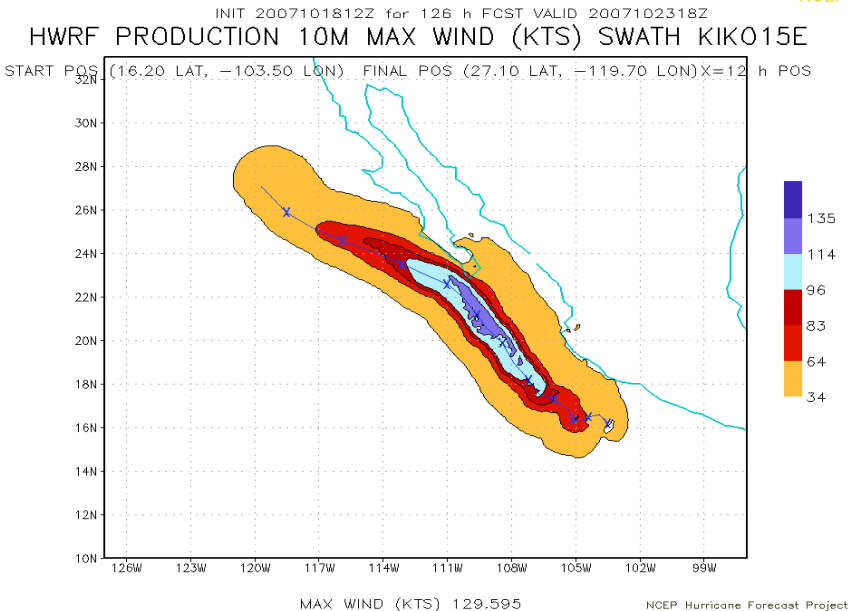
Radiation called at nest motion threshold interval (9 min)




HWRF: Hurricane WRF NCO Prod
2007 Tropical Cyclone Tracks
Storm: EP1507 (KIKO)
1 GFDL
2 AVNO
3 OFCL
4 HWRF
Hurricane Kiko
12z; Oct 18, 2007
Forecasts: Beginning 2007101812
Observed: Beginning 2007101812, every 12 hours


INIT 2007101812Z for 00 h FCST VALID 2007101812Z
HWRF PROD KIKO 15e SFC PSR (hPa) AND 10 M WIND (kts)
MAX WIND (kts) 34.7333
MIN PSR (hPa) 986.91

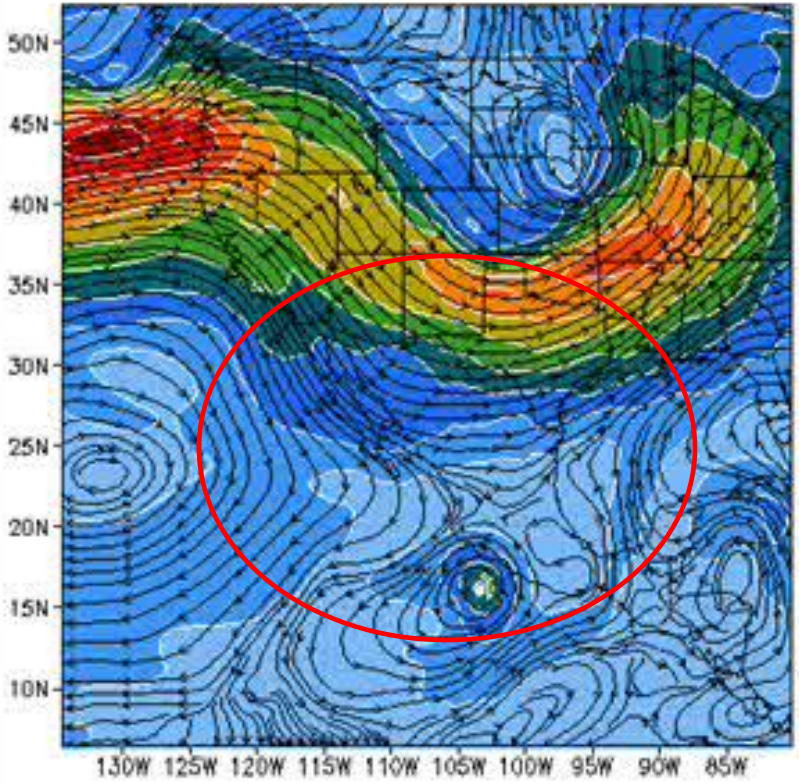

HWRF:Coupled Hurricane WRF NCO PROD
2007 Tropical Cyclone Intensities, Vmax (kts)
Storm: EP1507 (KIKO)
1 GFDL
2 OFCL
3 HWRF
Forecasts: Beginning 2007101812
Observed: Beginning 2007101812, every 12 hours
Maximum 10m Wind (kts)


INIT 2007101812Z for 126 h FCST VALID 2007102318Z
HWRF PRODUCTION 10M MAX WIND (KTS) SWATH KIKO15E
START POS (16.20 LAT, −103.50 LON) FINAL POS (27.10 LAT, −119.70 LON) X=12 h POS
MAX WIND (KTS) 129.595
NCEP Hurricane Forecast Project

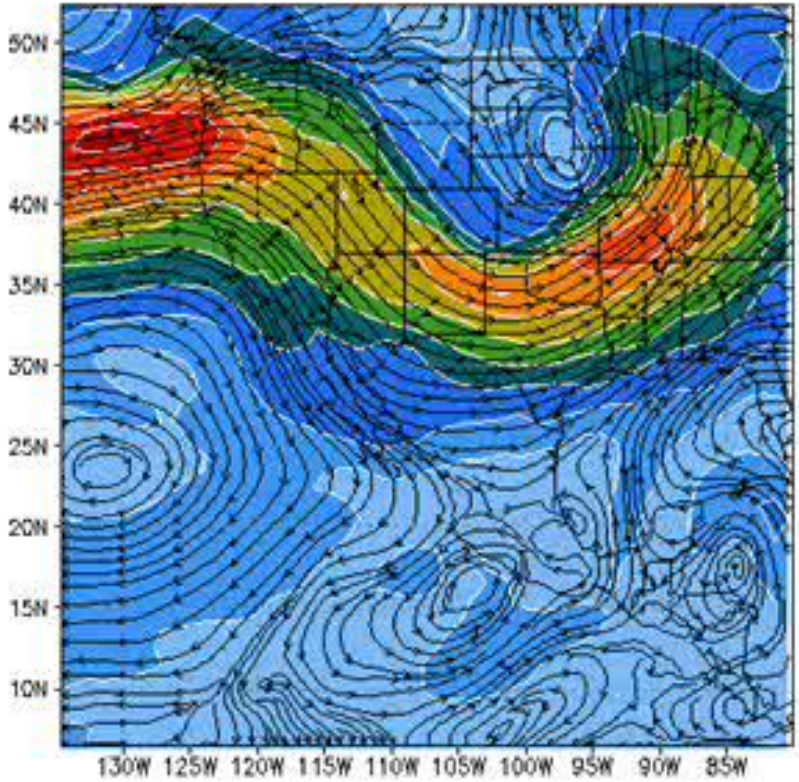
Data Set #1 : HWRF PARENT GRID – KIKO15e
Data Set #2 : GFDL PARENT GRID – KIKO15e
It: 2007101812 vt: 2007101812 (00h)

850–200 mb mean wind (shaded, knots)
850–200 mb mean wind (streamlines,)

HWRF

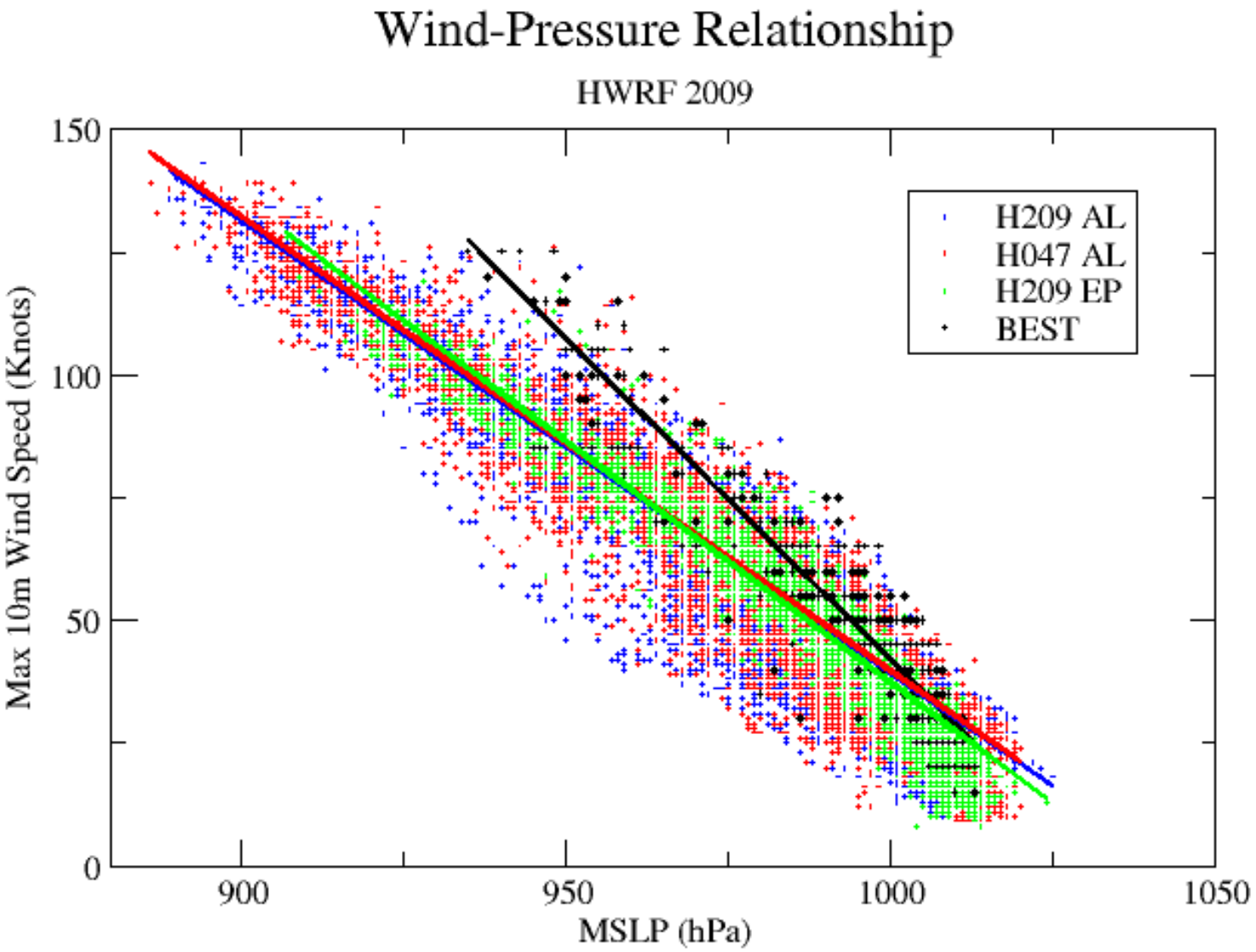


GFDL



Other problem issues

- Topographical differences between models
- Surface flux formulations & land surface modeling
- Wind-pressure relationship
- Eastern Pacific Basin: west/ northwestward bias in tracks
- Eastern Pacific Basin: Initial storm size and structure issues


Wind-Pressure Relationship
HWRF 2009
Max 10m Wind Speed (Knots)
MSLP (hPa)
150
100
50
0
900
950
1000
1050
H209 AL
H047 AL
H209 EP
BEST

Fundamental questions (process/sensitivity studies):

- Relative role of vortex vs. environment in influencing intensity.
- Role of ocean. Role of Oceanic heat content.
- Processes within atmosphere-ocean boundary layer on intensity/structure changes.
- Determinants of structure and relationship with preexisting wave disturbance. Relationship between structure and intensity.
- Role of inner core processes for intensification/ weakening, e.g. eyewall replacement cycles, mixing.
- Relative role of physics, e.g. Air-sea, microphysics, convection etc. on intensity change in various environments (sheared vs. non-shear)

Thanks for your attention.

Questions/Comments?