# Hurricane Modeling at NCEP

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NCEP/Environmental Modeling Center

WHERE AMERICA'S CLIMATE AND WEATHER SERVICES BEGIN

# OVERVIEW

- GFDL Upgrades
- HWRF Development
- HWRF preliminary results

# TRANSITIONING TO HURRICANE WRF

02-03 03-04 05 06 07

Mesoscale Data Assimilation for Hurricane Core

**GFDL** Begin Physics Upgrades — Continue upgrades — Final GFDL upgrades

HWRF T&E

**MM5** → Transition to HWRF

HWRF Operational

(9km/42?L)

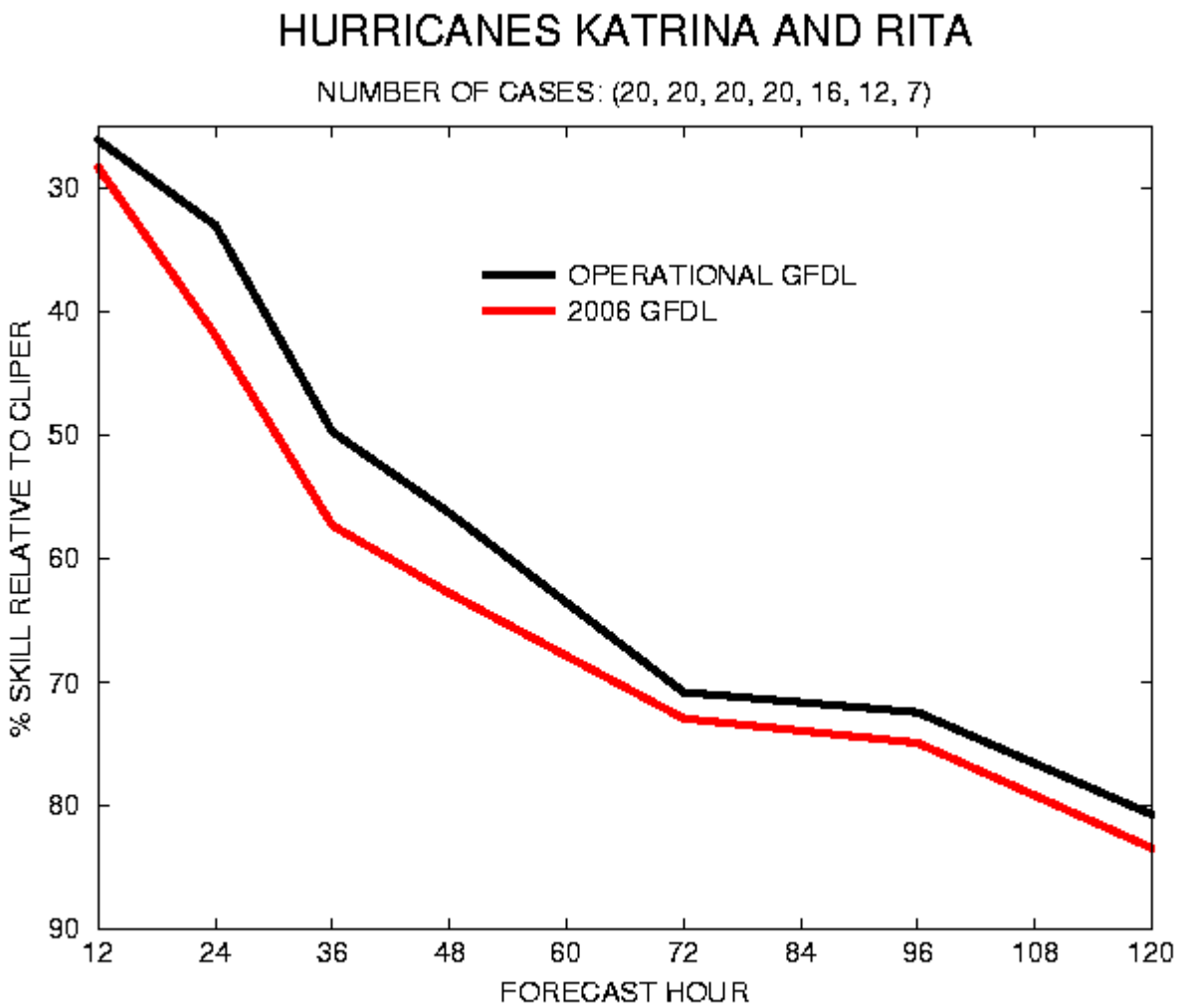
**HWRF** Begin R&D — Prelim. Test - grid, hurricane physics

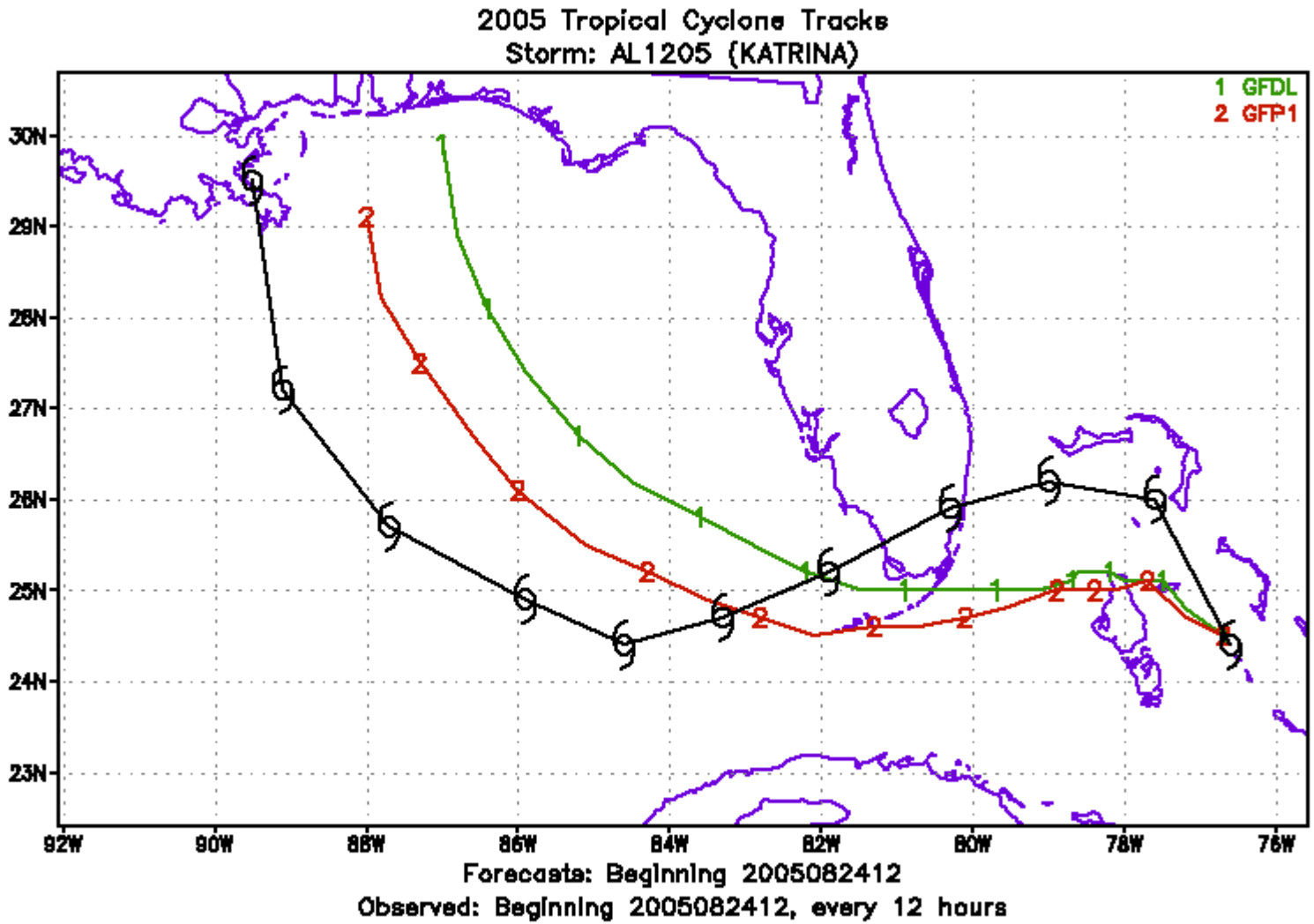
HWRF T&E

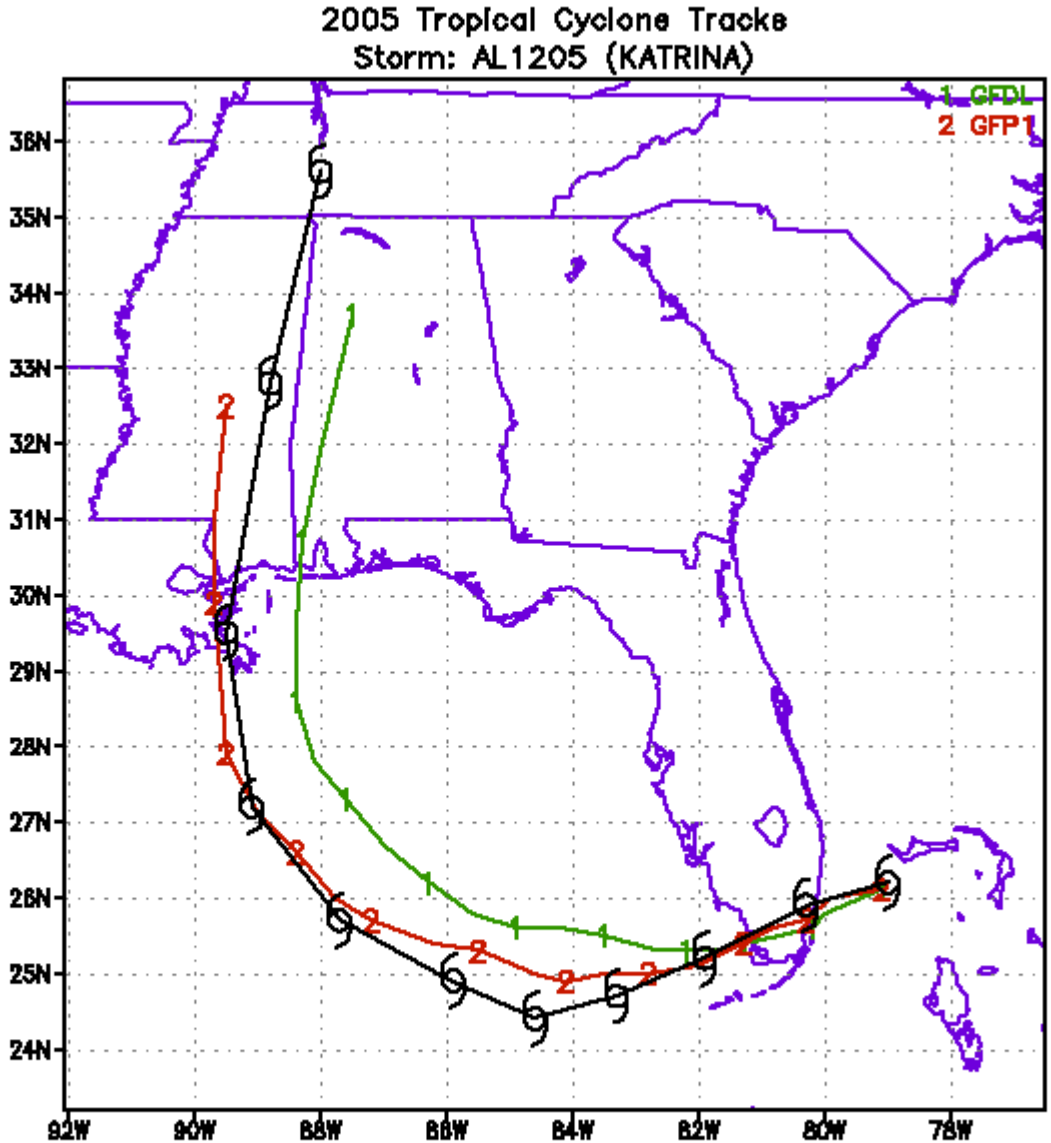
# Proposed GFDL upgrades for ‘06

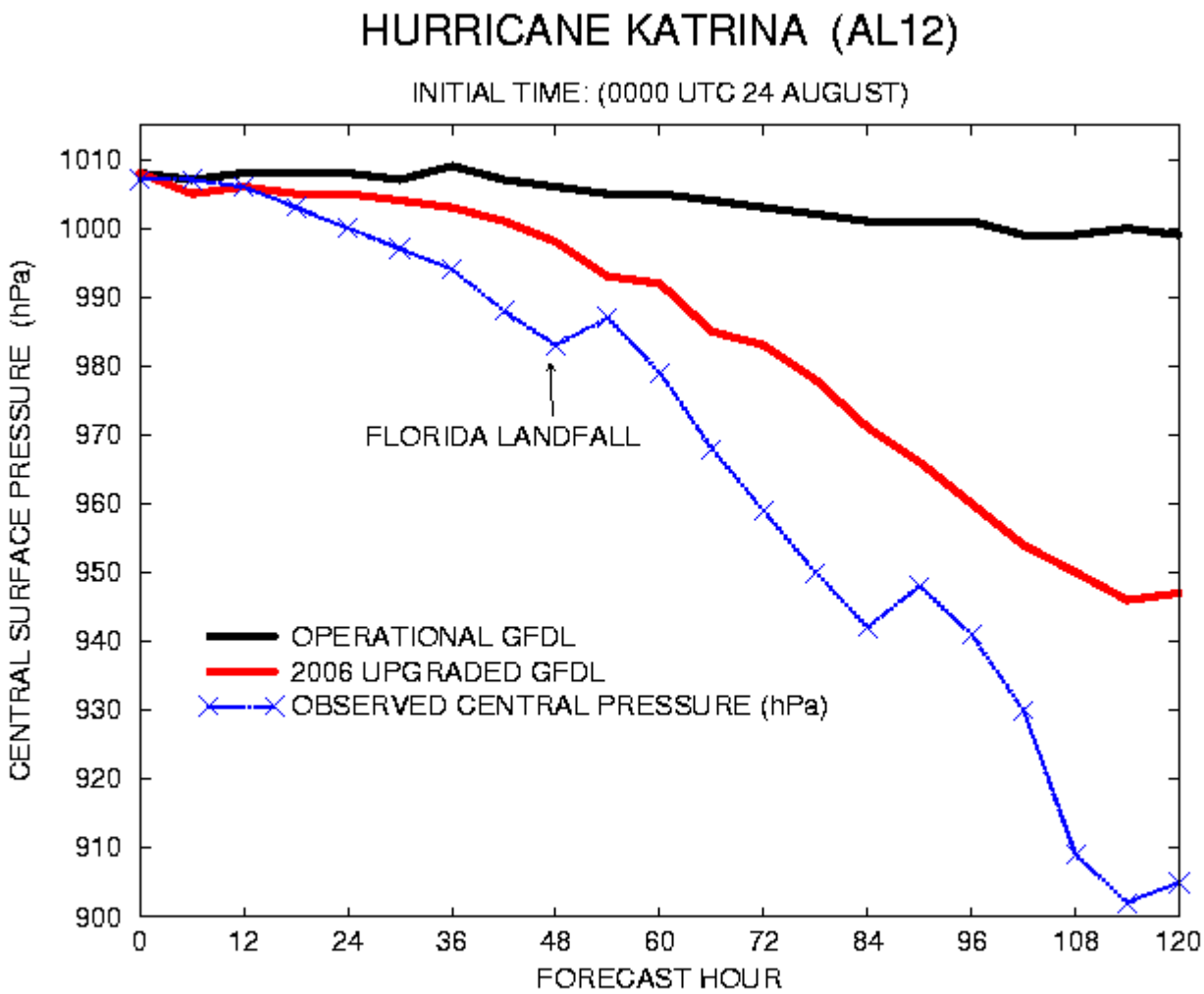
- FERRIER MICROPHYSICS
- IMPROVED AIR-SEA PHYSICS
- CORRECT POSITIONING OF THE LOOP CURRENT
- IMPROVED OCEAN INITIALIZATION
- COUPLING TO WAVES

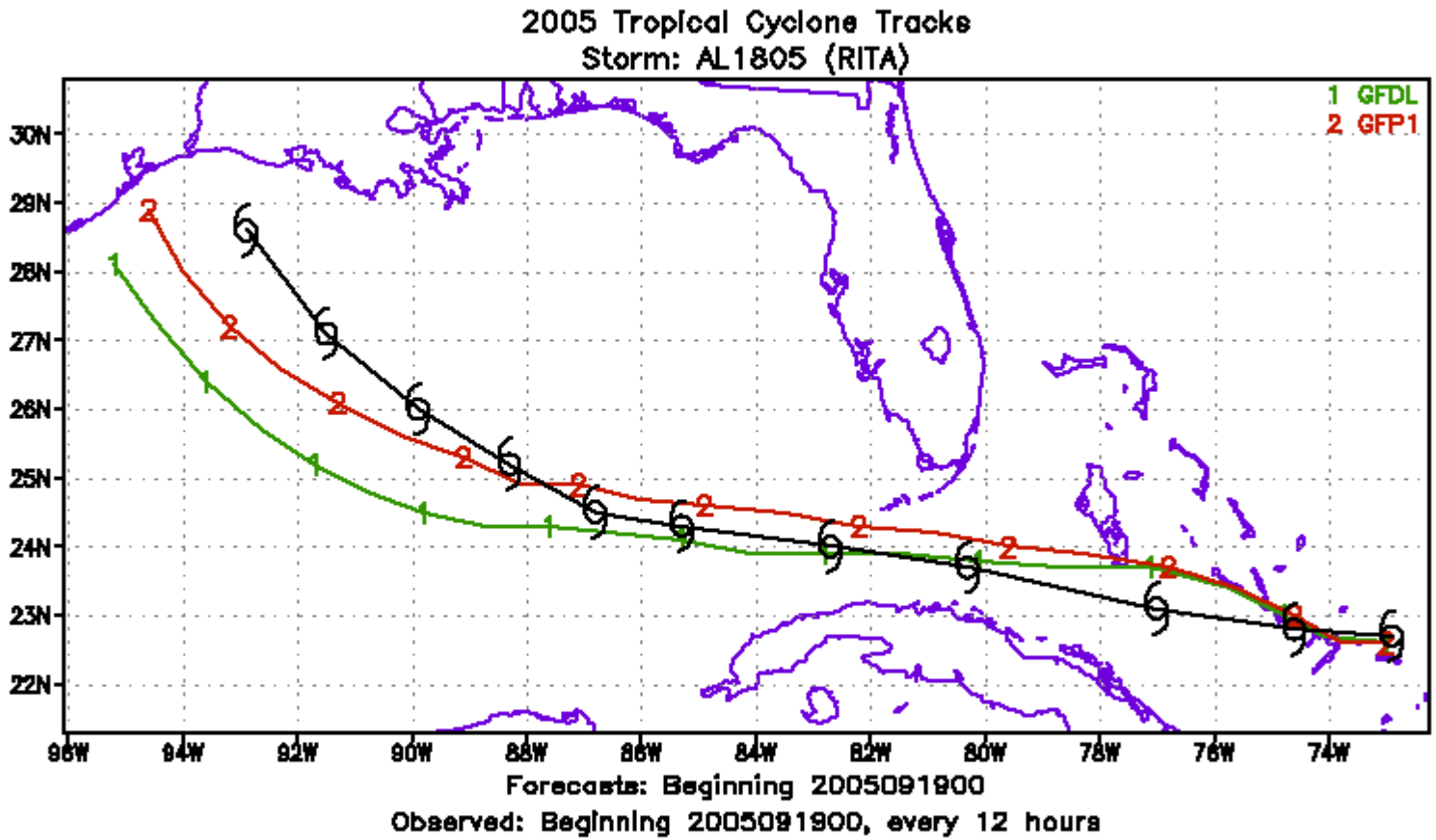
# New physics; improved ocean

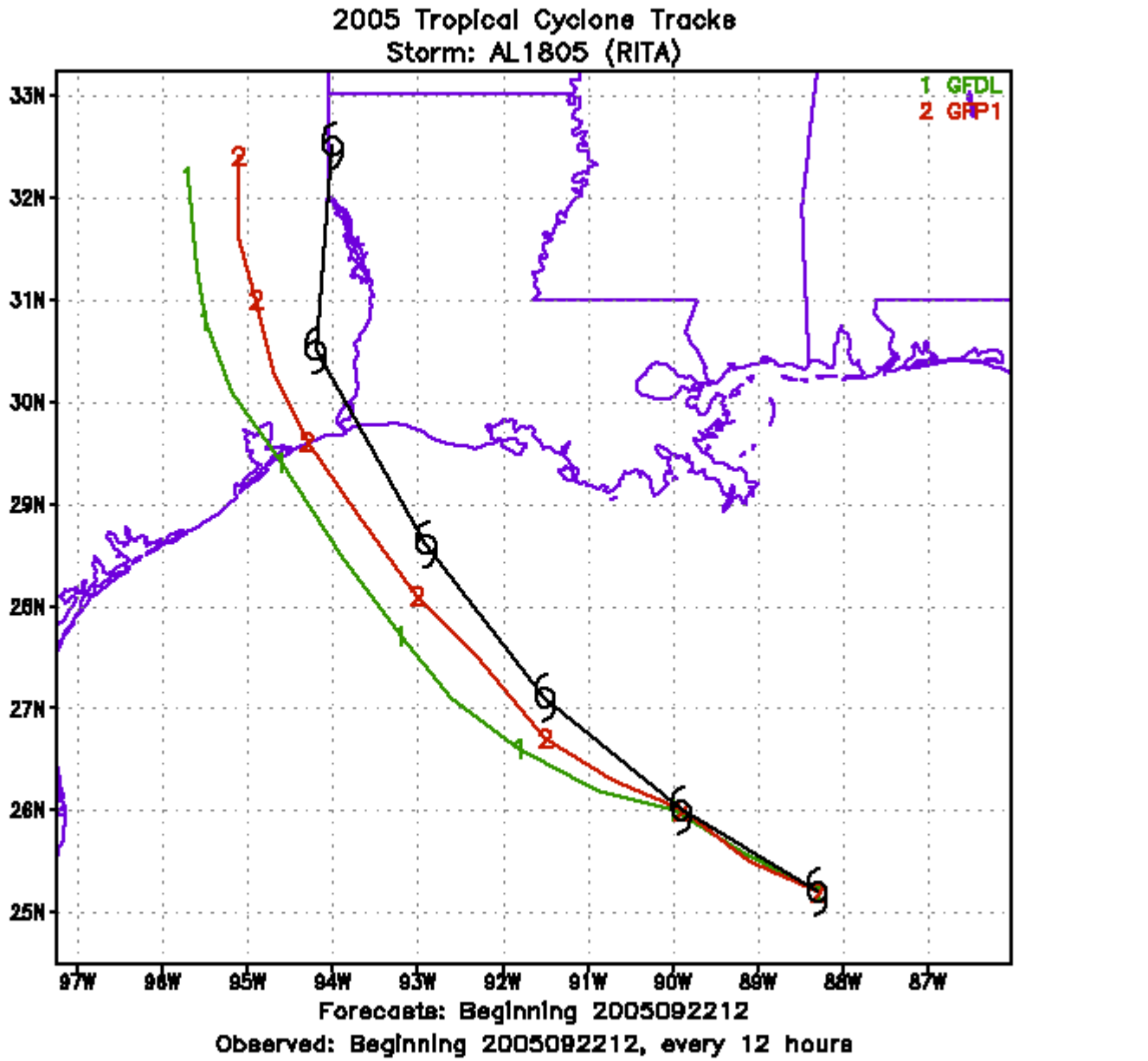



2005 Tropical Cyclone Tracks
Storm: AL1205 (KATRINA)
1 GFDL
2 GFP1
30N
29N
28N
27N
26N
25N
24N
23N
92W
90W
88W
86W
84W
82W
80W
78W
76W
Forecasts: Beginning 2005082412
Observed: Beginning 2005082412, every 12 hours
GFDL Hurricane Dynamics Group

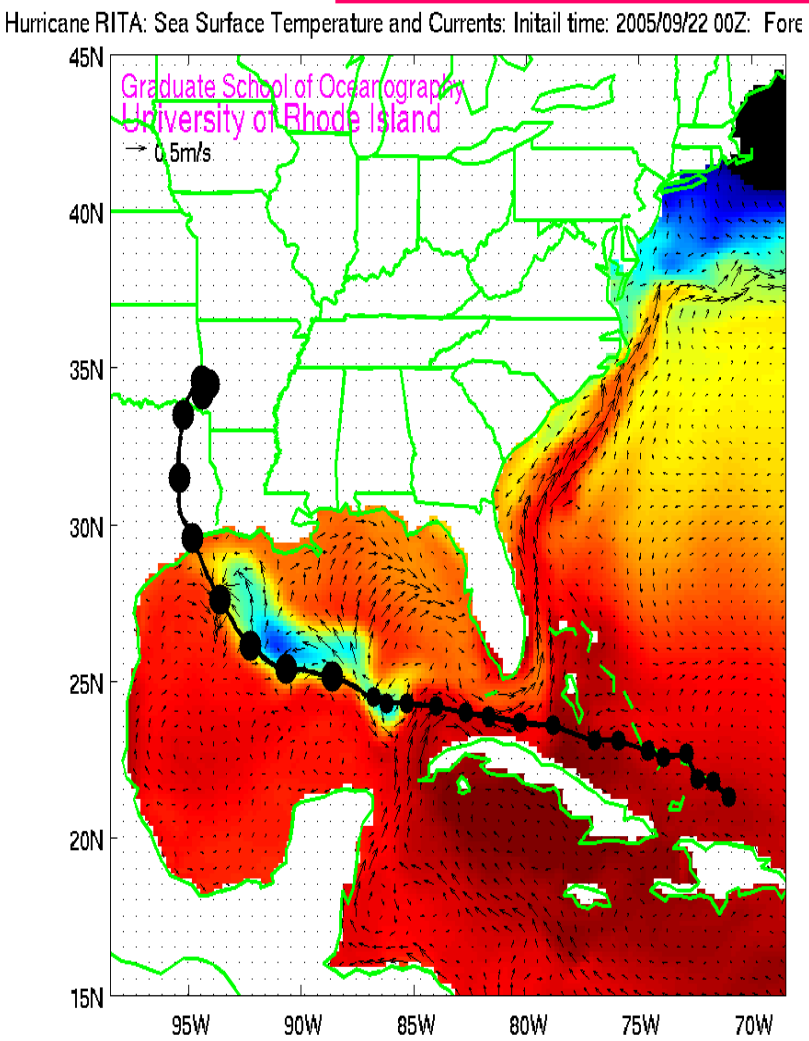

2005 Tropical Cyclone Tracks
Storm: AL1205 (KATRINA)
1 GFDL
2 GFP1
36N
35N
34N
33N
32N
31N
30N
29N
28N
27N
26N
25N
24N
92W
90W
88W
86W
84W
82W
80W
78W
Forecasts: Beginning 2005082512
Observed: Beginning 2005082512, every 12 hours
GFDL Hurricane Dynamics Group

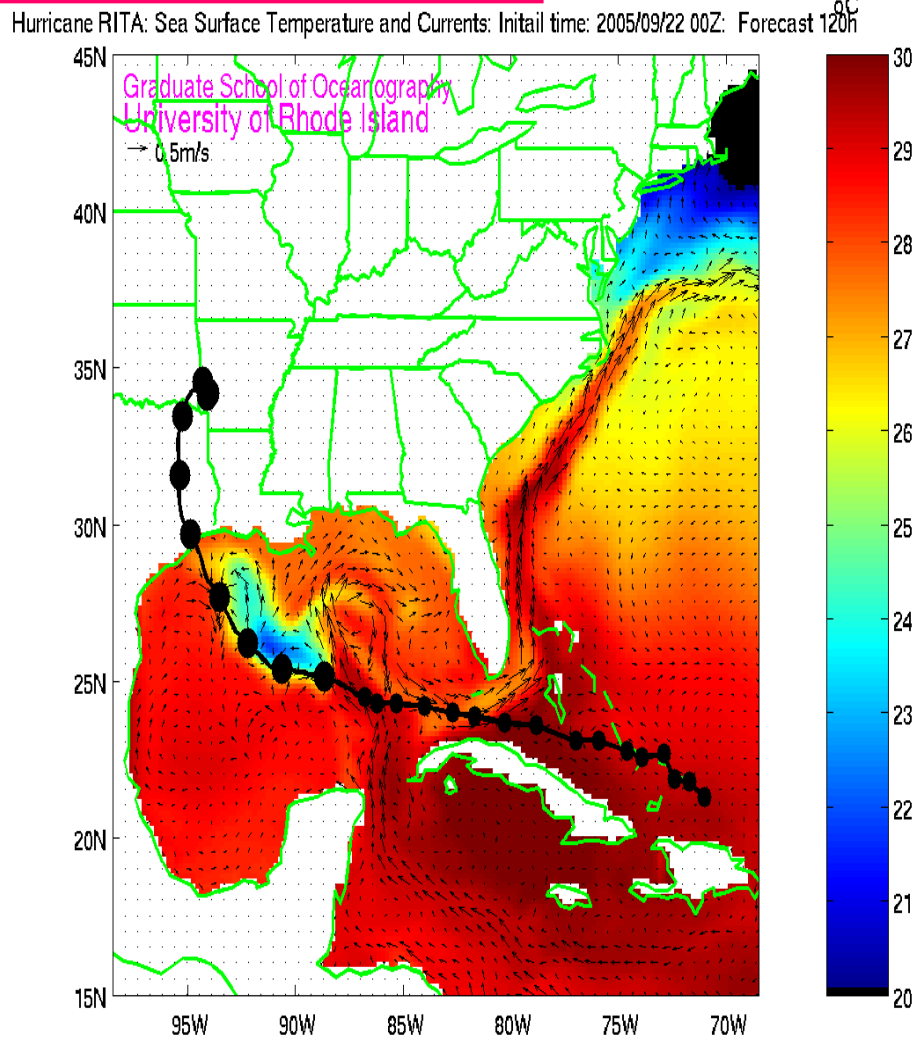

HURRICANE KATRINA (AL12)
INITIAL TIME: (0000 UTC 24 AUGUST)
CENTRAL SURFACE PRESSURE (hPa)
1010
1000
990
980
970
960
950
940
930
920
910
900
0
12
24
36
48
60
72
84
96
108
120
FORECAST HOUR
FLORIDA LANDFALL
OPERATIONAL GFDL
2006 UPGRADED GFDL
OBSERVED CENTRAL PRESSURE (hPa)




2005 Tropical Cyclone Tracks
Storm: AL1805 (RITA)
1 GFDL
2 GFP1
33N
32N
31N
30N
29N
28N
27N
26N
25N
97W
96W
95W
94W
93W
92W
91W
90W
89W
88W
87W
Forecasts: Beginning 2005092212
Observed: Beginning 2005092212, every 12 hours
GFDL Hurricane Dynamics Group

# HURRICANE RITA



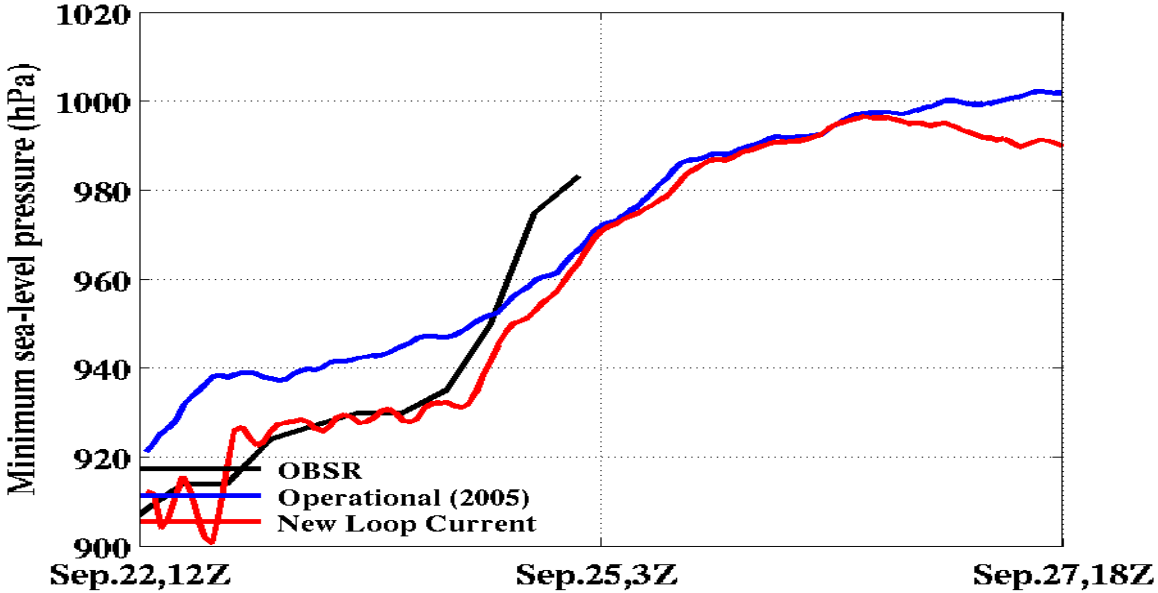



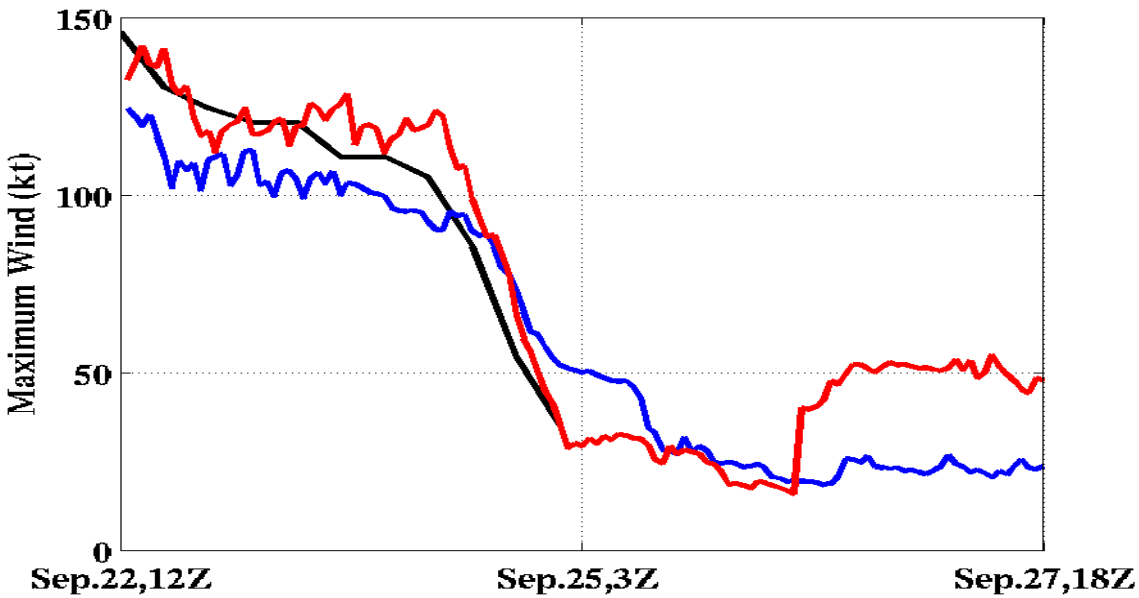

**Old Loop Current**

**Improved Loop Current**

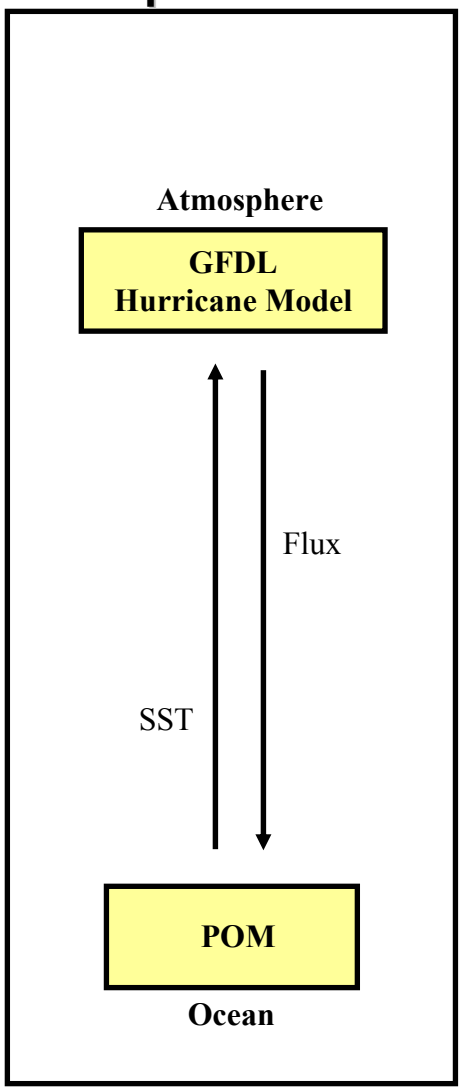
# Tropical Cyclone RITA(2005)

INITIAL TIME: 0012 UTC, 22 September 2005

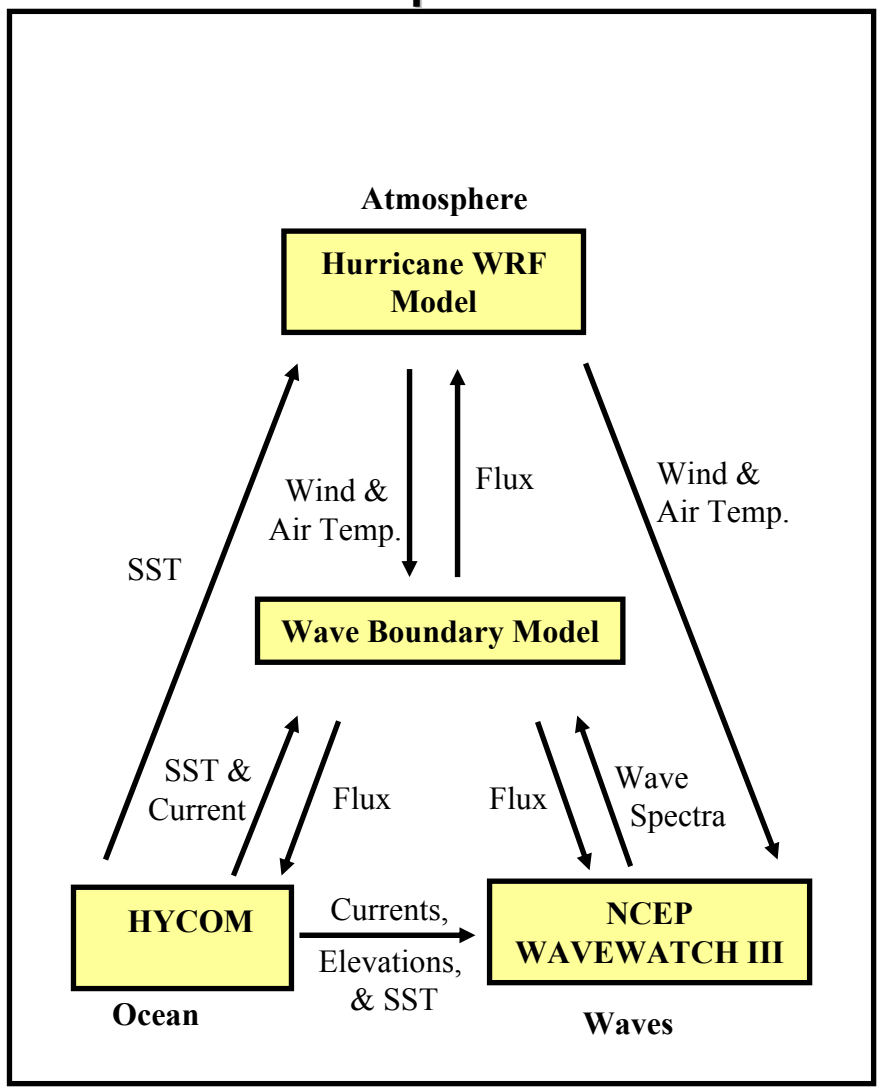


## Operational GFDL/URI Coupled Model




## Near Future Hurricane-Wave-Ocean Coupled Model



## Coupling of WAVEWATCH w/GFDL

## Evaluation of GFDL coupled air-sea physics

**Coupling is complete for GFDL air-sea-wave model (includes new air-sea momentum flux)**

**Evaluation still underway**

**Scheduled for operational implementation for ’06 season**

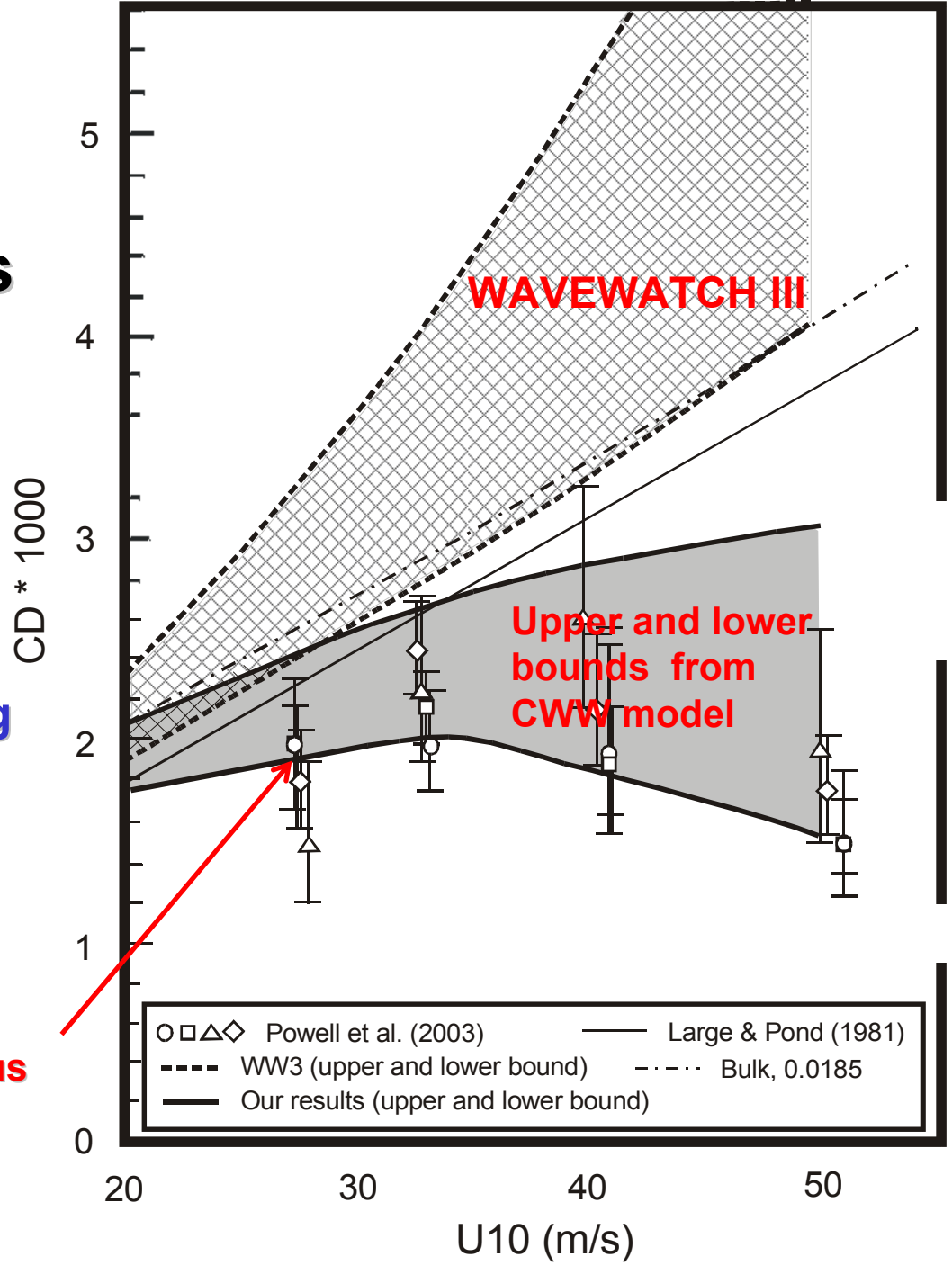
**Roughness replaced by wave-field dependent estimates of z0**

**Flux parameterization changed for reduced drag**

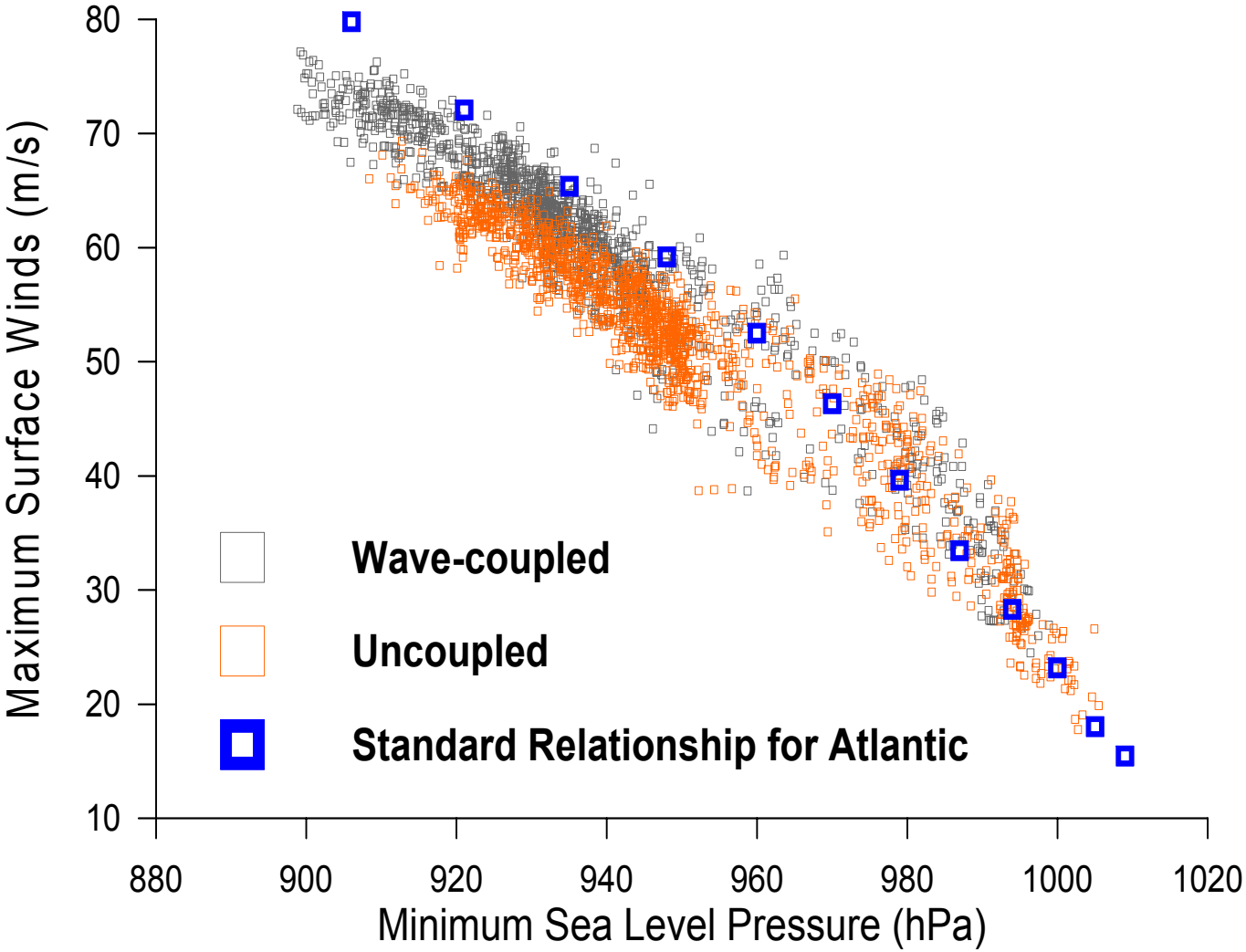
# Cd estimated from CWW model hurricane simulations

- At high wind speeds, $C_d$ levels off and even decrease with wind speed
- Under hurricane wind forcing waves are extremely young at high wind speeds and the young waves produce small drag.

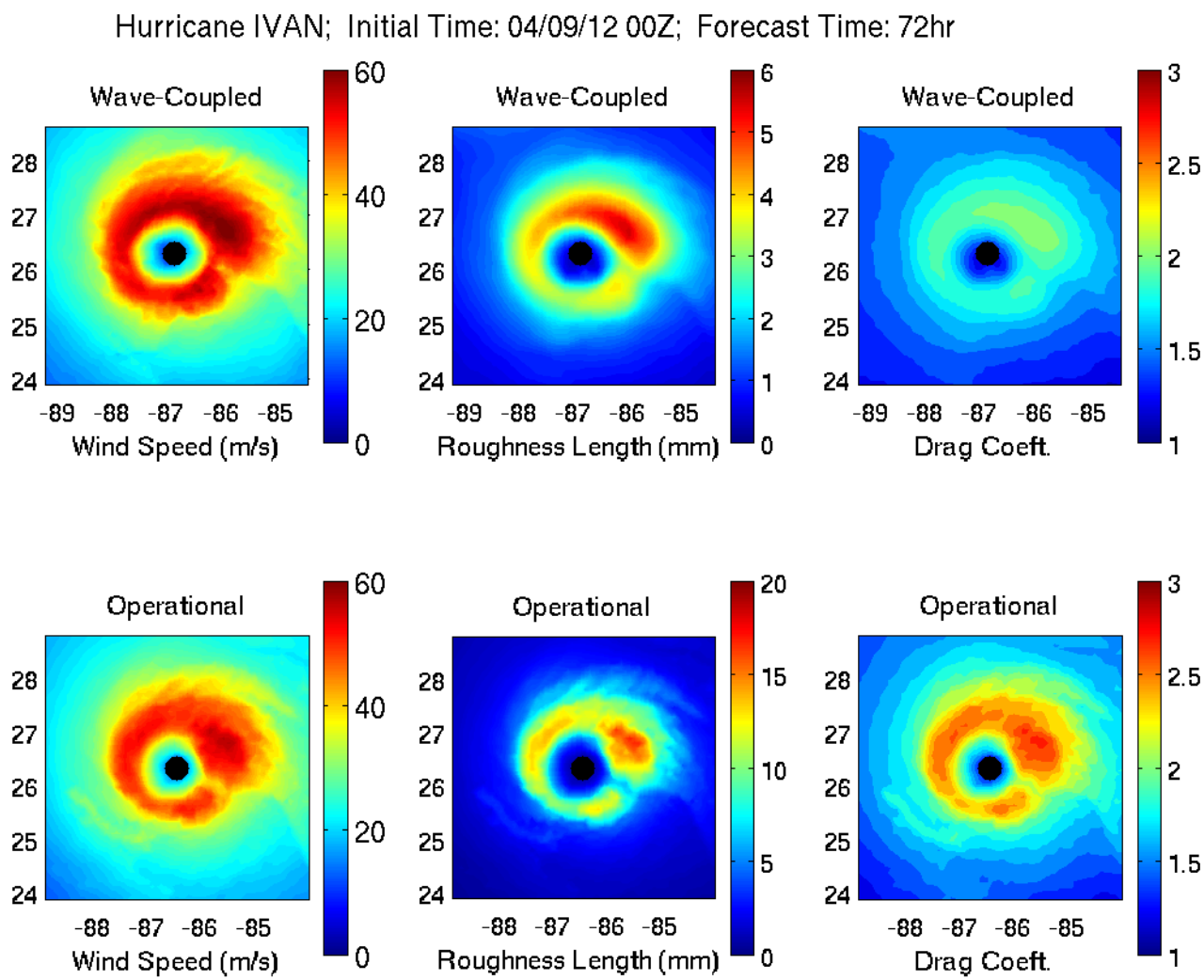
GPS sonde observation under various hurricanes (Powell et al., 2003).



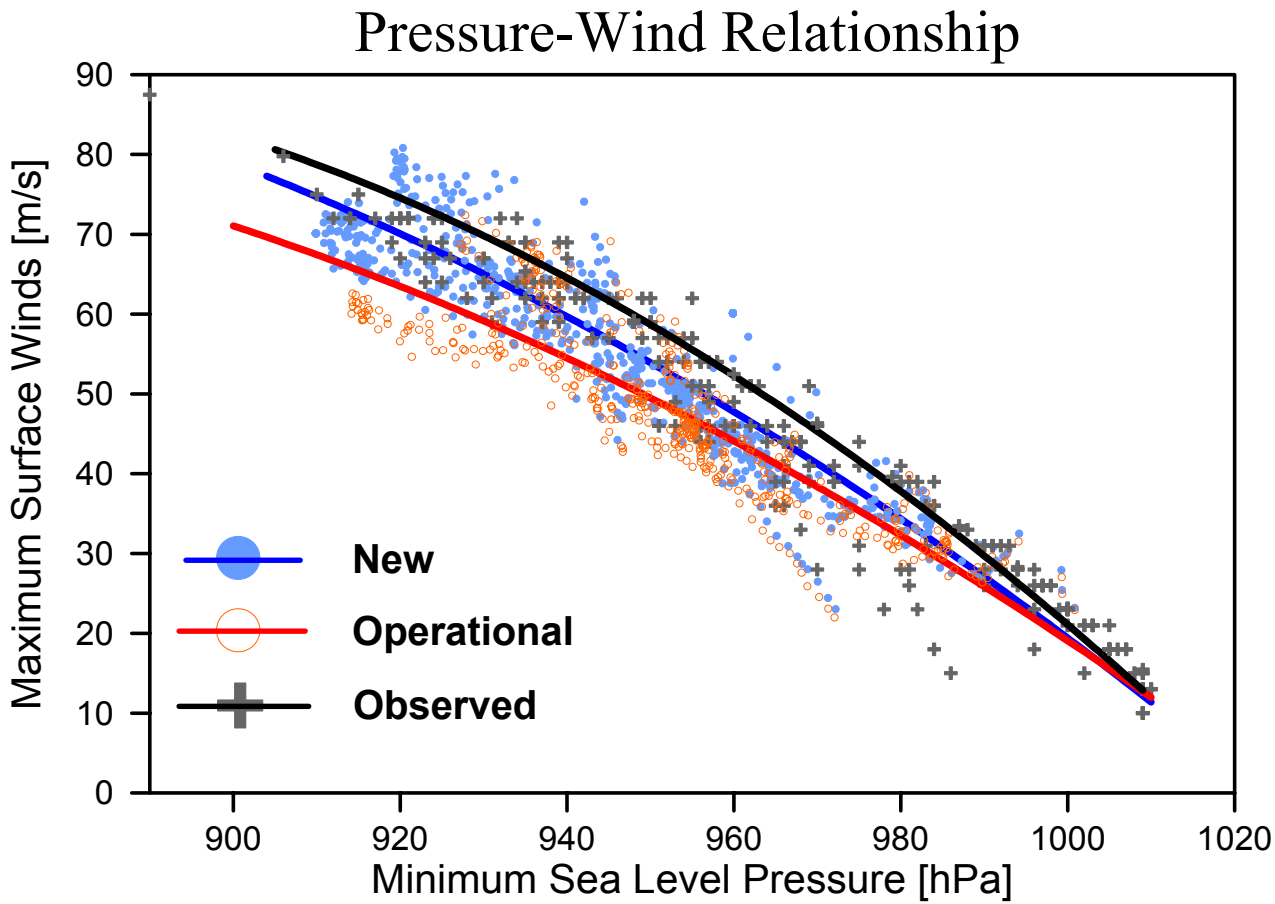
# Pressure-Wind Relationship for Ivan



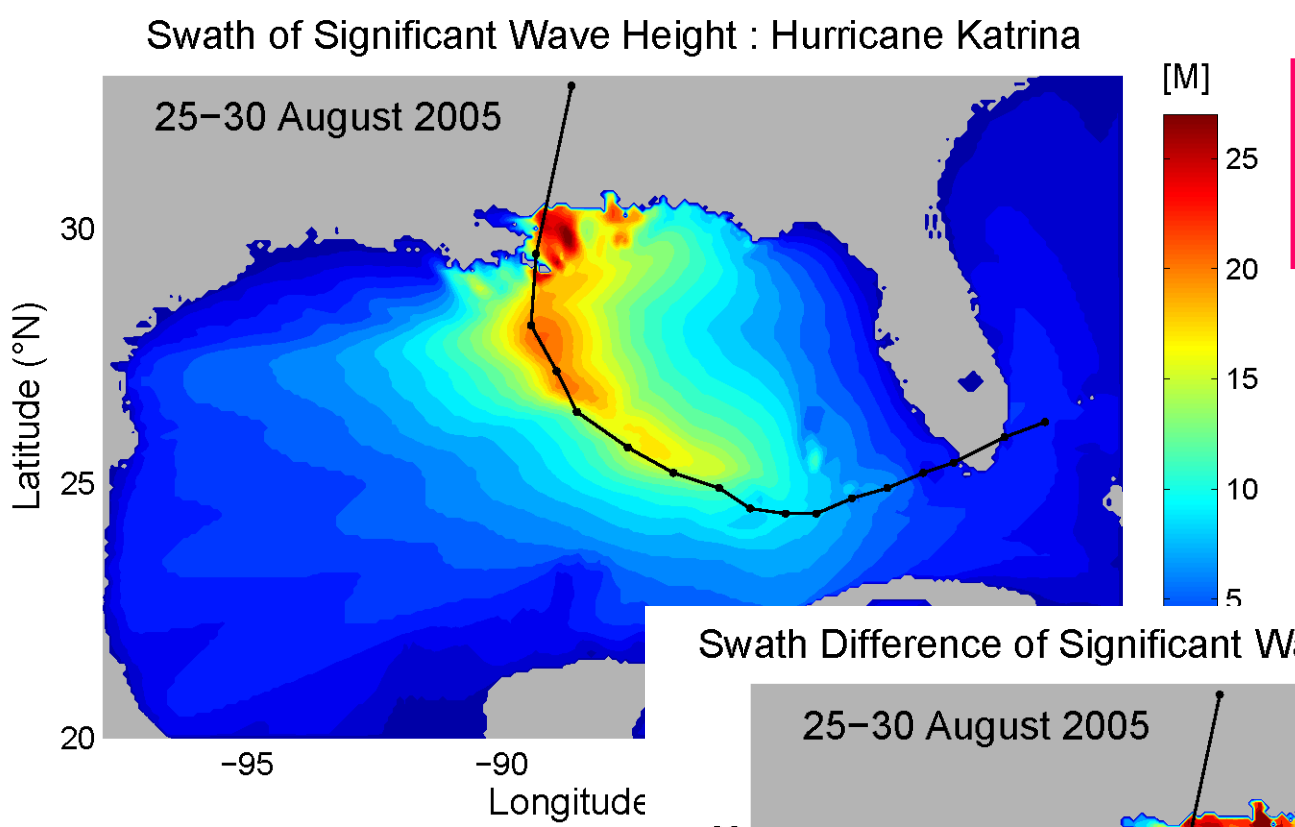

**Preliminary simulations indicate that hurricane intensity and structure can be significantly effected by explicit simulations of surface waves**


Hurricane IVAN; Initial Time: 04/09/12 00Z; Forecast Time: 72hr
Wave-Coupled
Wind Speed (m/s)
Wave-Coupled
Roughness Length (mm)
Wave-Coupled
Drag Coeft.
Operational
Wind Speed (m/s)
Operational
Roughness Length (mm)
Operational
Drag Coeft.
28
27
26
25
24
-89 -88 -87 -86 -85
-88 -87 -86 -85
0 20 40 60
0 1 2 3 4 5 6
0 5 10 15 20
1 1.5 2 2.5 3

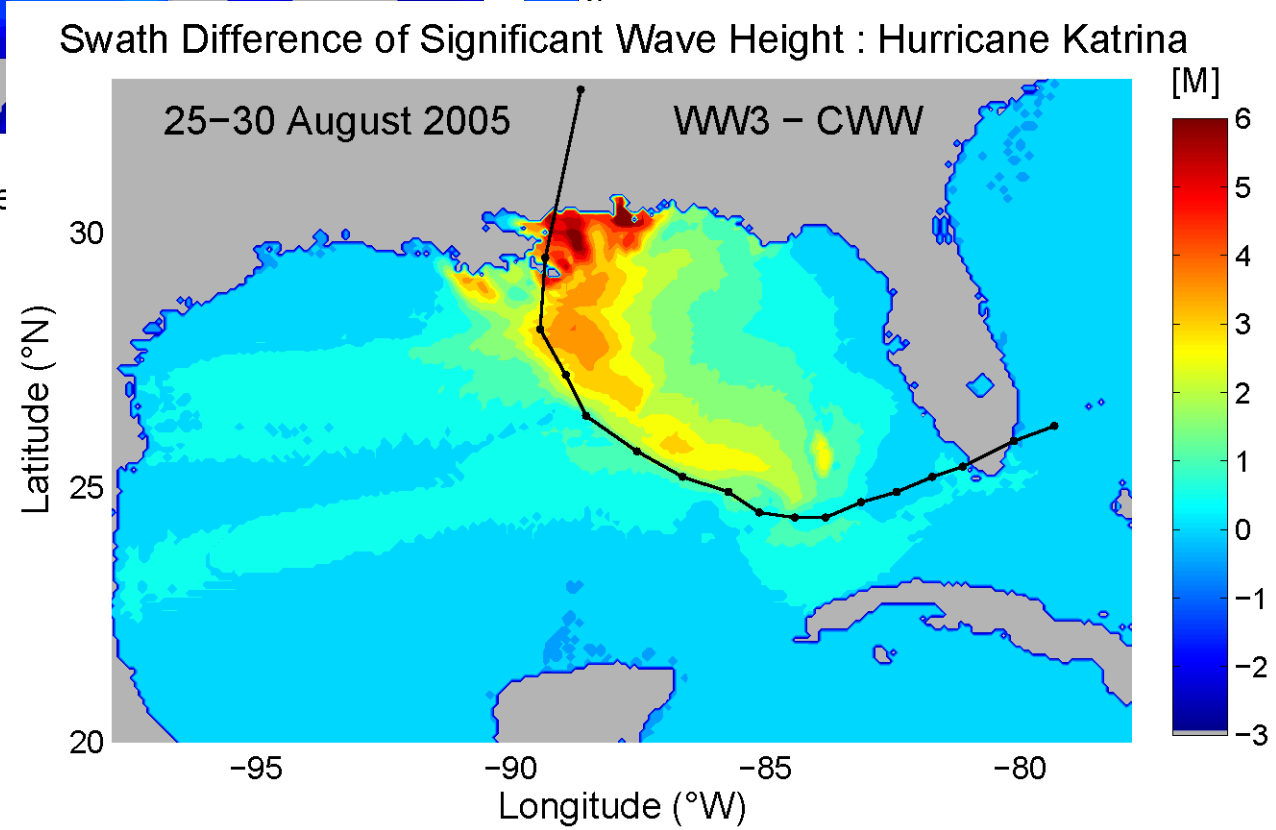
# Effect of Wave Coupling on the GFDL Model Intensity Prediction




Based on eleven forecasts of Hurricane Isabel (2003), Ivan (2004), Frances (2004), Charley (2004), and Jeanne (2004).




# Impact of wave coupling



# Results

**Waves and storm structure more realistically represented**

**High degree of sensitivity on track by heat and moisture fluxes**

**Impact of sea spray?**

**A lot more work to be done……..**

## GFDL/LSM Coupling (Slab vs. LSM)

**Upgrade to LSM for 1/12 degree resolution**

**Detailed case analysis carried out for 2004-2005 (5 day forecasts)**

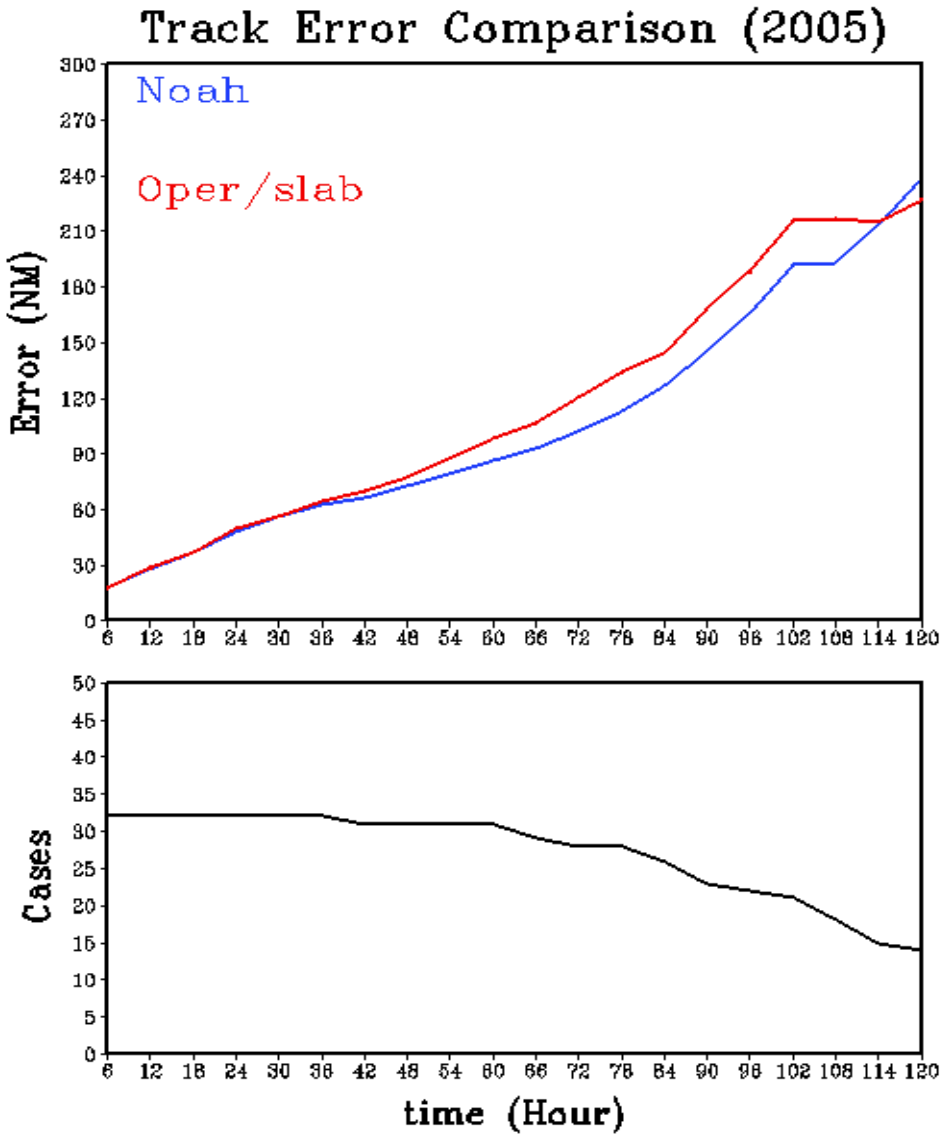
**32 cases**

**Also 25 cases between 1998-2005**

**Impact on precipitation and track**

**Impact confined to near surface atmosphere in short range**

**Significant changes in large scale circulation in both lower and mid atmosphere by 5 days**


Track Error Comparison (2005)
Noah
Oper/slab
Error (NM)
300
270
240
210
180
150
120
90
60
30
0
6 12 18 24 30 36 42 48 54 60 66 72 78 84 90 96 102 108 114 120
Cases
50
45
40
35
30
25
20
15
10
5
0
6 12 18 24 30 36 42 48 54 60 66 72 78 84 90 96 102 108 114 120
time (Hour)

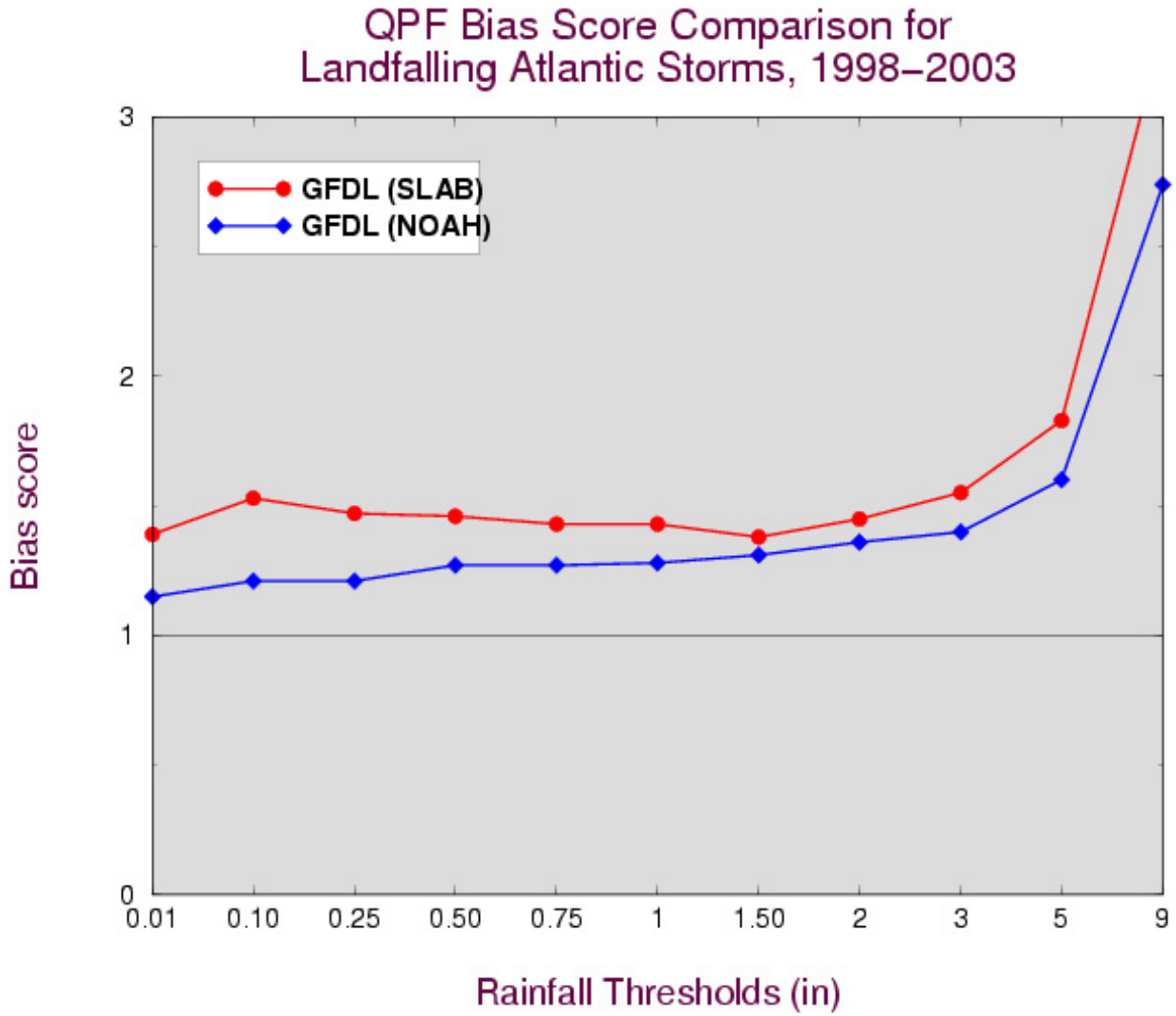

QPF Bias Score Comparison for
Landfalling Atlantic Storms, 1998–2003
GFDL (SLAB)
GFDL (NOAH)
Bias score
0
1
2
3
0.01
0.10
0.25
0.50
0.75
1
1.50
2
3
5
9
Rainfall Thresholds (in)

Figure 2

## Preliminary Results

**Impact on rainfall: Some reduction of bias**

**Impact on track: Mixed results – degradation on track in ’04 season, slight improvement in track in ’05 season**

**Revisit problem after HWRF IOI**

# TRANSITIONING TO HURRICANE WRF

02-03 03-04 05 06 07

Mesoscale Data Assimilation for Hurricane Core

**GFDL** Begin Physics Upgrades — Continue upgrades — Final GFDL upgrades

HWRF T&E

**MM5** → Transition to HWRF

HWRF Operational

(9km/42?L)

**HWRF** Begin R&D — Prelim. Test - grid, hurricane physics

HWRF T&E

# THE HURRICANE WRF (HWRF)

# PREDICTION SYSTEM

- Will replace the GFDL in 2007
- Coupled air-sea-land prediction system
- Advanced data assimilation for hurricane vortex
- Advanced physics for high resolution
- Land surface coupled to hydrology/inundation
- Nested wave prediction
- Coupling to dynamic storm surge

# Pre-Implementation Strategy for HWRF

## FOR THE HWRF IOI: HWRF MUST PERFORM AT LEAST AS WELL AS THE GFDL MODEL

## GFDL UPGRADES

- ✓UPGRADE GFDL PHYSICS WITH GFS PHYSICS ('02)
- ✓INCREASE GFDL RESOLUTION ('05)

- TEST AND IMPLEMENT MICROPHYSICS
- UPGRADE AIR-SEA PHYSICS
- WAVE COUPLING

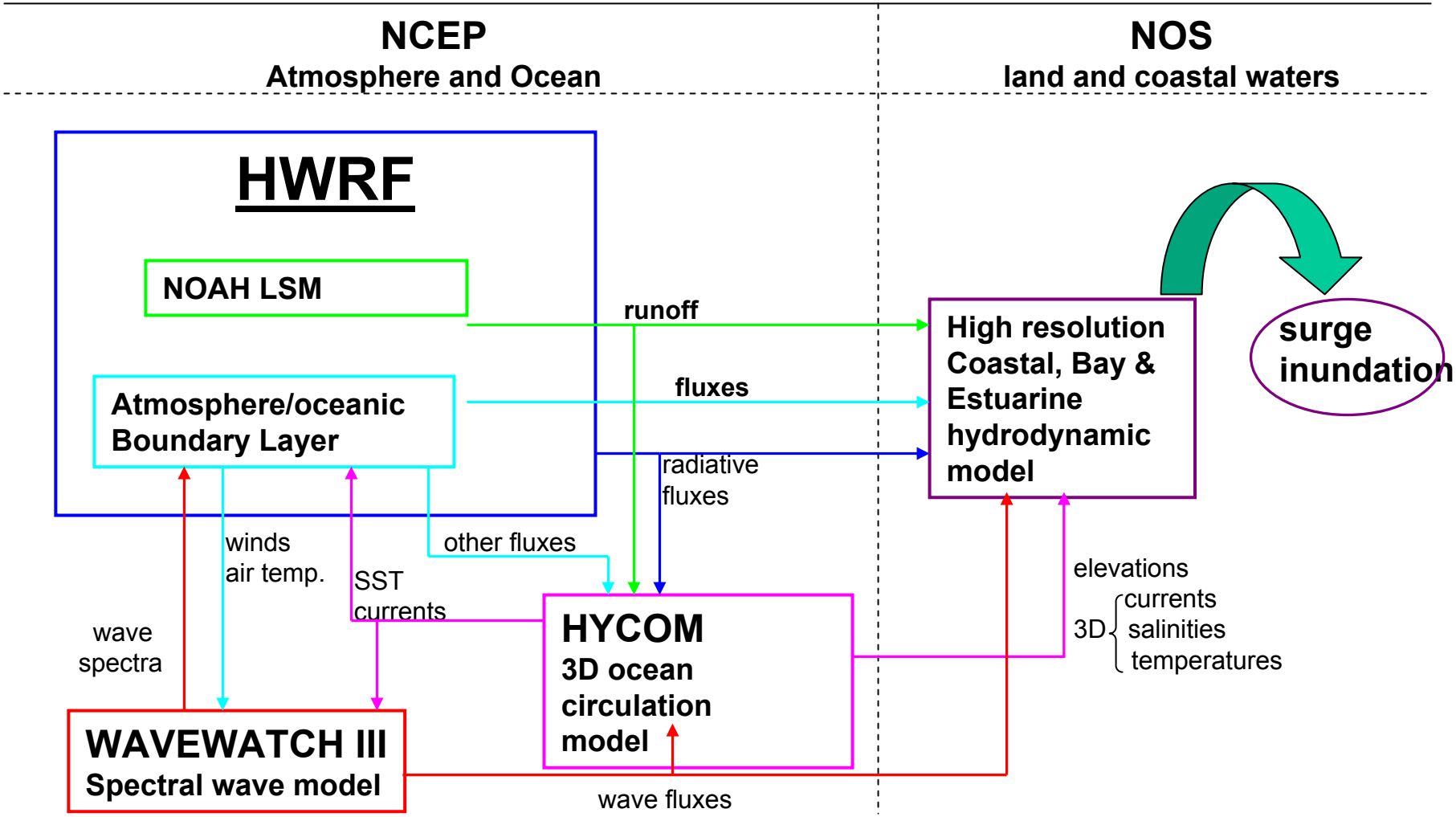
# CONTINUED: PRE-IMP HWRF STRATEGY

- CARRY OUT T&E ON UPGRADED GFDL SYSTEM (GFDL FROZEN ’06 hurricane season)
- MIGRATE ALL PHYSICS TO HWRF
- PERFORM EXTENSIVE COMPARISONS BETWEEN GFDL AND HWRF FOR MULTIPLE SEASONS AND STORMS

# DEVELOPMENT OF THE HWRF SYSTEM

- Development of movable, nested grid (Gopal)
- Development of Physics (Bob T., Morris B., Isaac G.)
- Initialization of hurricane vortex (Qing-fu)
- HYCOM Development (Carlos L., et al.)
- Coupling to WAVEWATCH III (+ multi-scale model) (Hendrik)
- Development/Upgrade of hurricane verification system (Intensity/structure, ppt)
- (Coupling to storm surge-wave coupled model (EMC, NOS – Frank Aikman) (2010?)
- HWRF ensembles

# Hurricane-Wave-Ocean-Surge-Inundation Coupled Models



# Evaluation of HYCOM

**HYCOM configured for Atlantic (same as POM)**

**1/6 degree;  same forcing**

**Initialization of Gulf Stream and loop current**

**Ongoing verification**

**Experiments with Dennis, Katrina storm surge**

POM

HYCOM

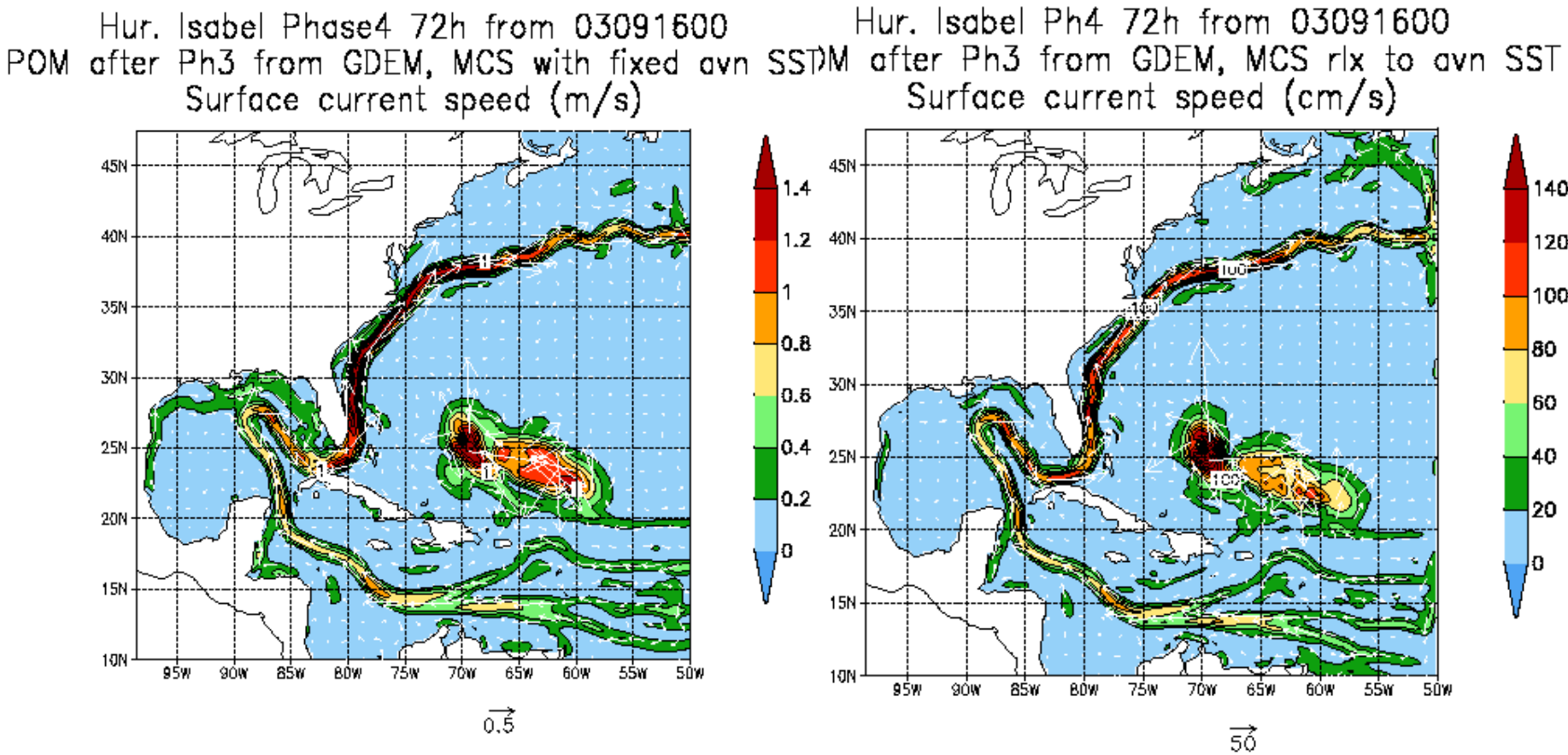
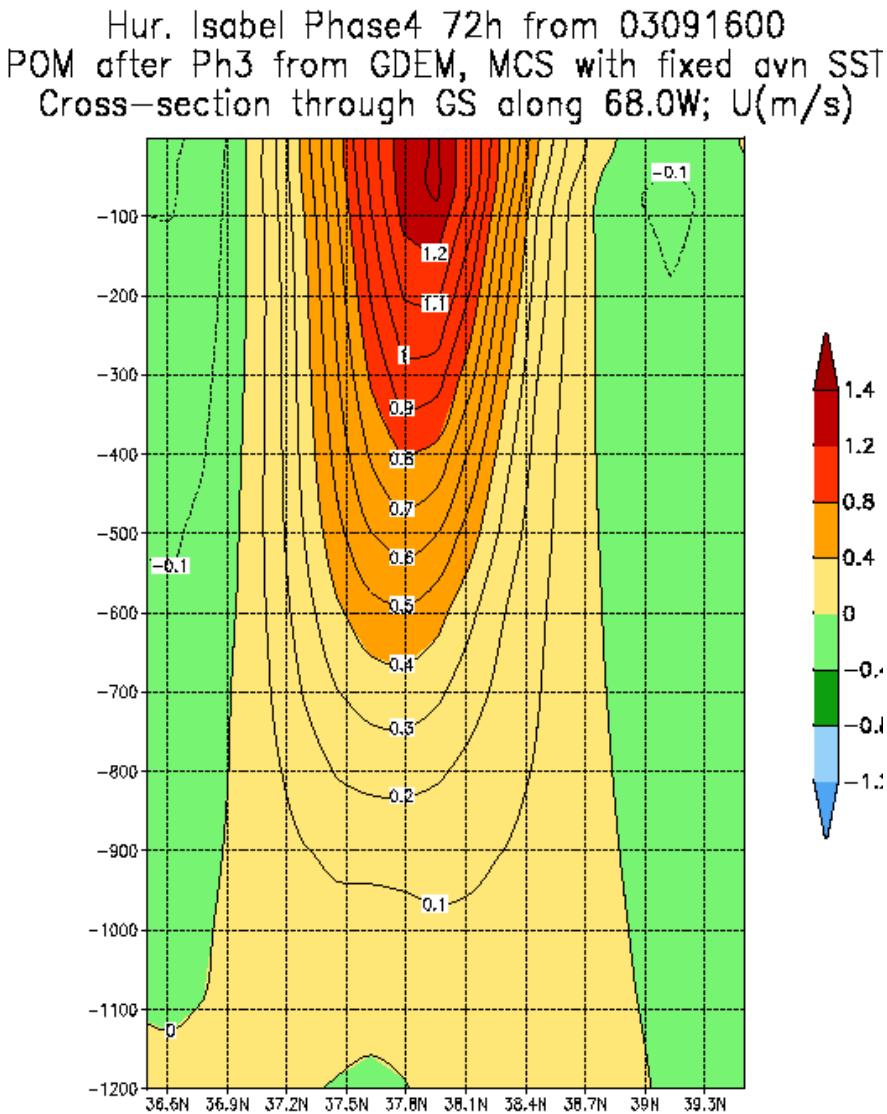


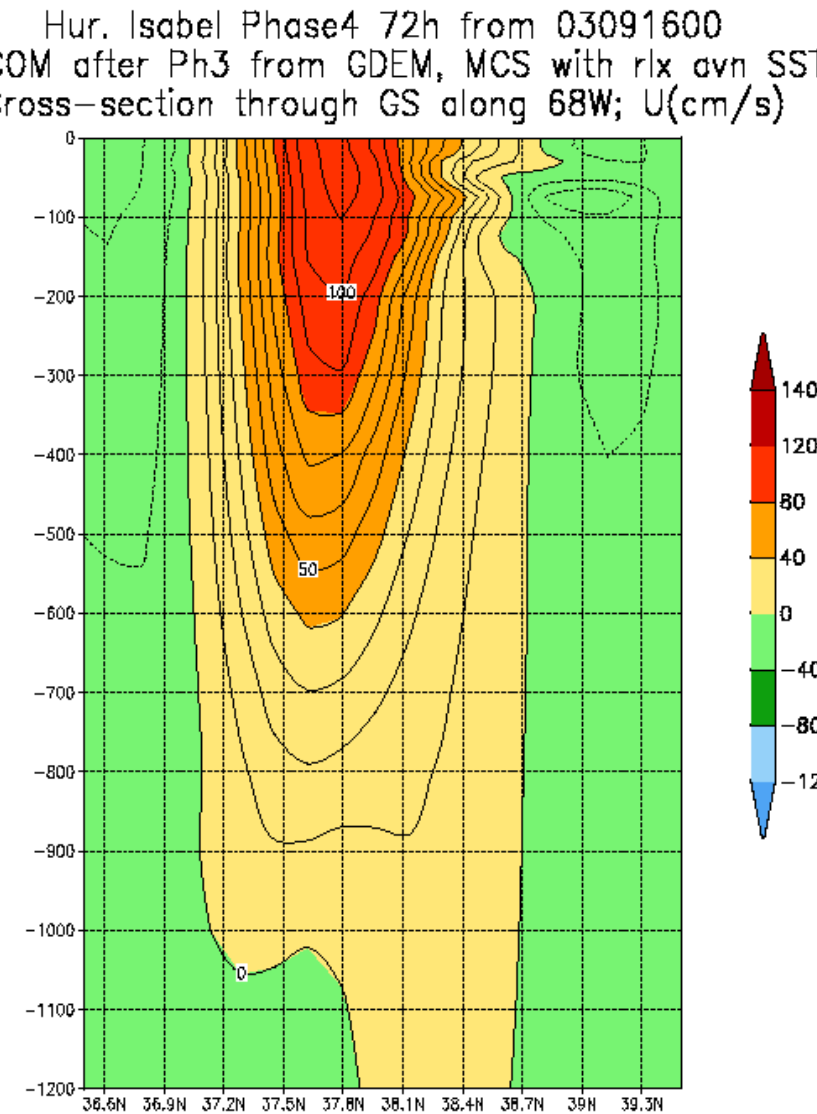

Figure 1

# POM

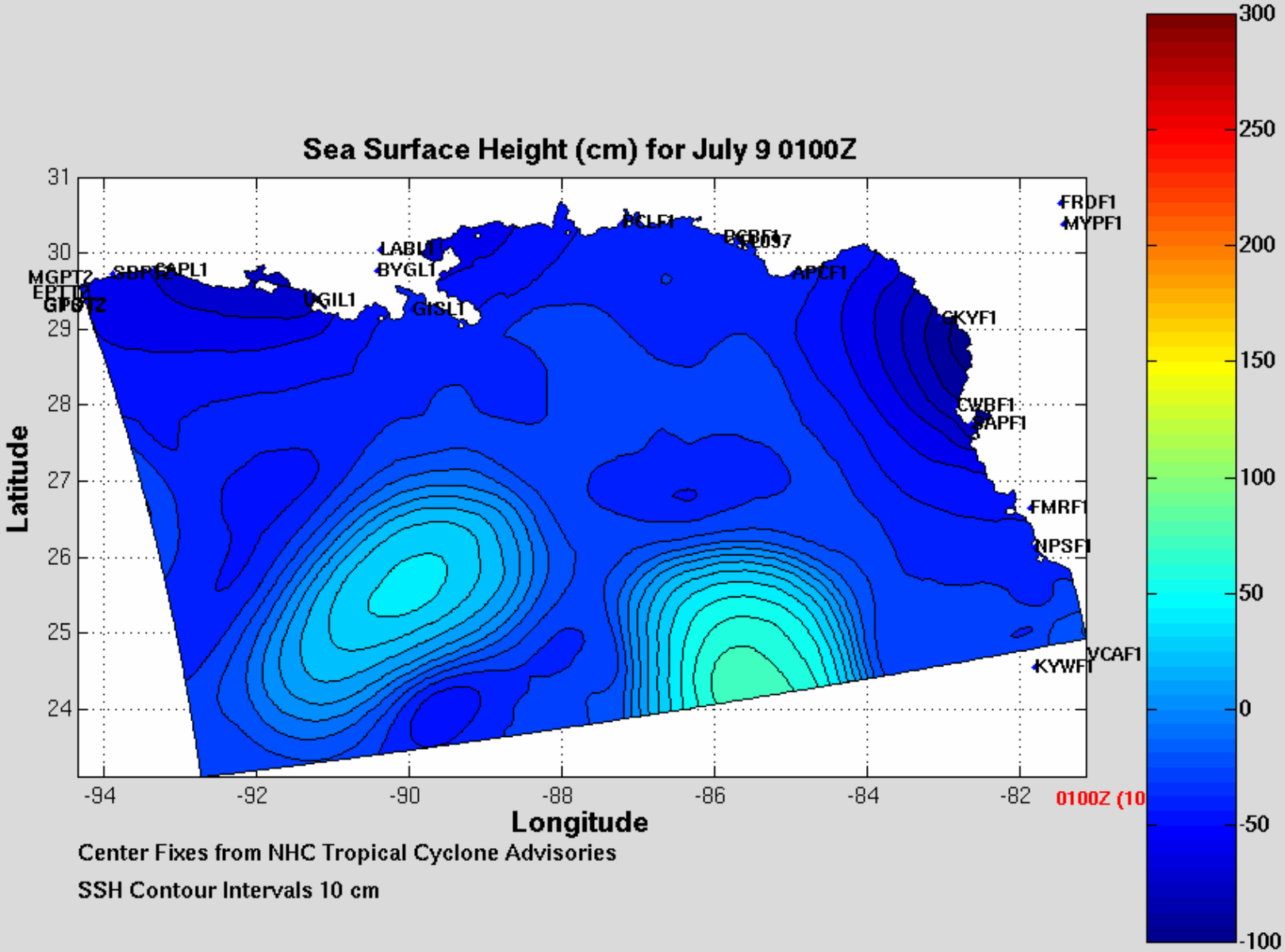



A.Falkovich, GMB/EMC/NCEP

# HYCOM




A.Falkovich, NMAB/EMC/NCEP




Center Fixes from NHC Tropical Cyclone Advisories

SSH Contour Intervals 10 cm

# 1. Required Observations & 2. Data Assimilation

- **Environmental flow – 3-D VAR in progress**

  **In-situ: G-IV, Driftsondes (?), UAV's (?)**

  **Satellite: NEXT GENERATION INSTRUMENTS**

- **Ocean data assimilation – new effort at EMC (GODAS)**

  **AXBT's ,Buoy, altimeter, ARGO**

- **Hurricane core – substantial R&D necessary for hi-res****

  **G-IV upgrades (new initiative) , P-3's Airborne doppler radars**

  **88-D Level II data**

** **critical effort to address initialization problem to advance intensity/structure forecasts – EMC is developing scale dependent error covariances**

# HWRF Data Analysis

1. Create 3D data sets for outer nest and inner nest, as well as the boundary conditions for the outer nest from GFS 6h forecast fields
2. Interpolate HWRF 6h forecast data onto the new HWRF grids in the overlap area to create the guess fields.
3. Separate hurricane vortex from the guess fields.
4. Correct the hurricane intensity before inserting the storm at the observed location (for both inner nest and outer nest)
5. Run GDAS for both inner nest and outer nest
6. Merge two data sets near the inner nest boundary

# Aircraft in Hurricanes

**Need to develop flight strategies for GIV and P-3's**

**Two mission profiles:** **Environment & core**

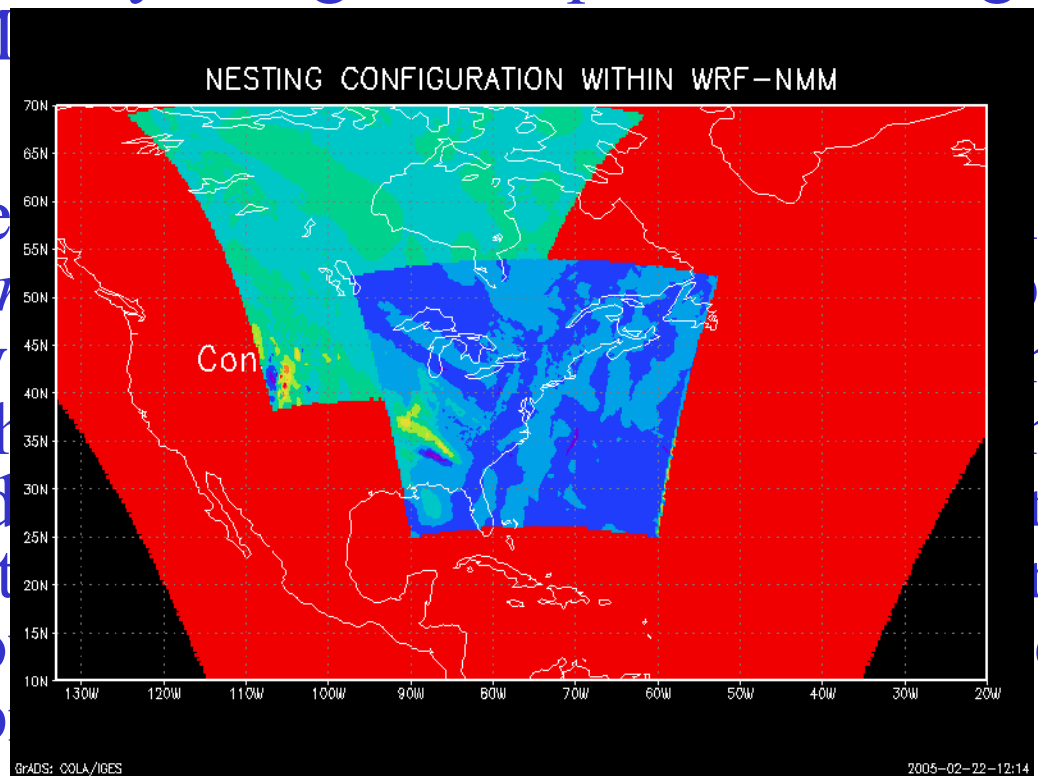
**Observations:** **GPS, AXBT's, Radar**

**Requirement for operational status of P-3's**

# Status of NMM-WRF NESTING

- A horizontal mesh refinement capability is currently being developed for the E-grid based NM

- The c mesh *curr* etween a low ne or more high mentary grid ne way nest rds allo eted by Feb



## Preliminary HWRF results:

**HWRF – ran 4X daily throughout ’05 hurricane season for all storms – system very stable and reliable**

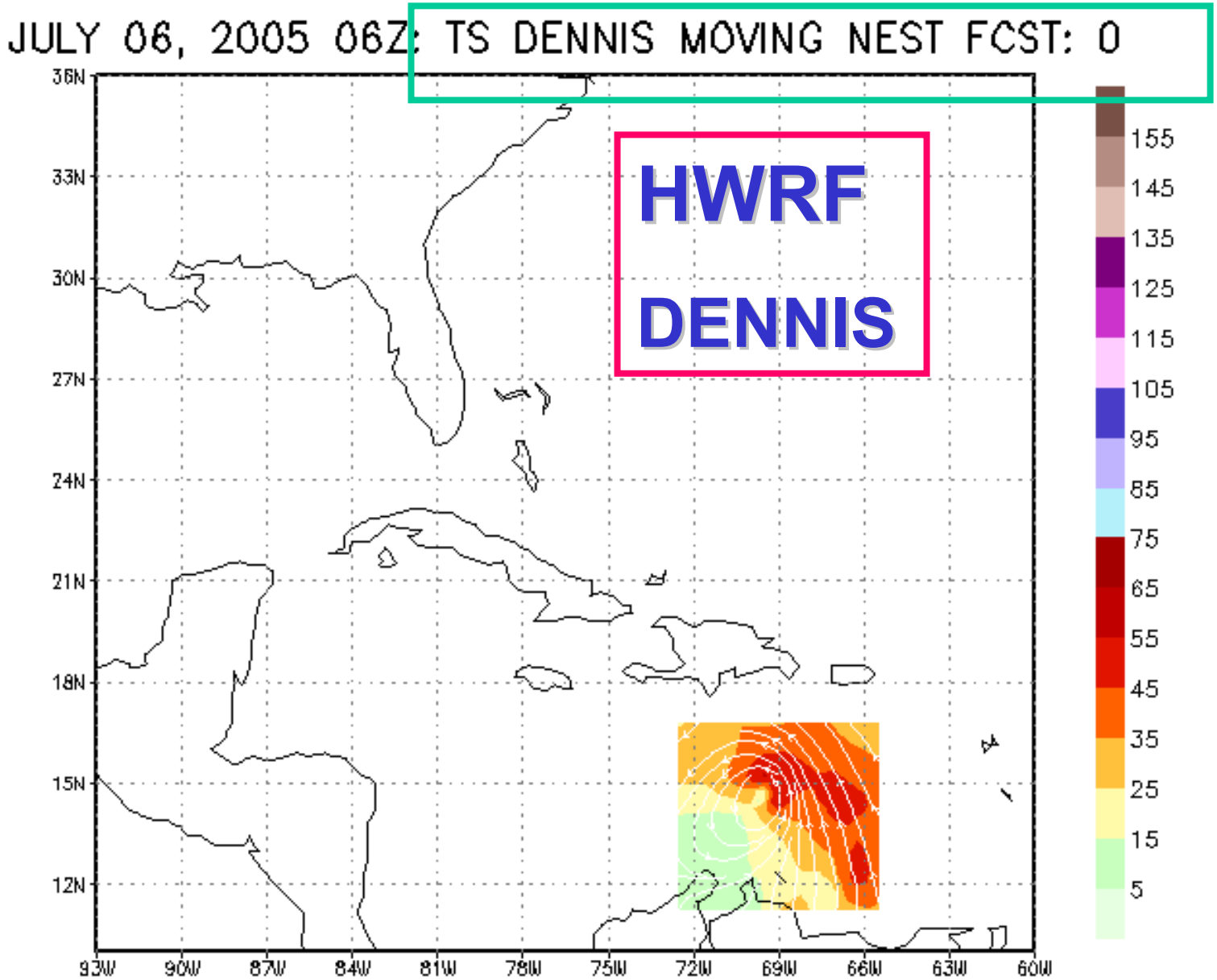
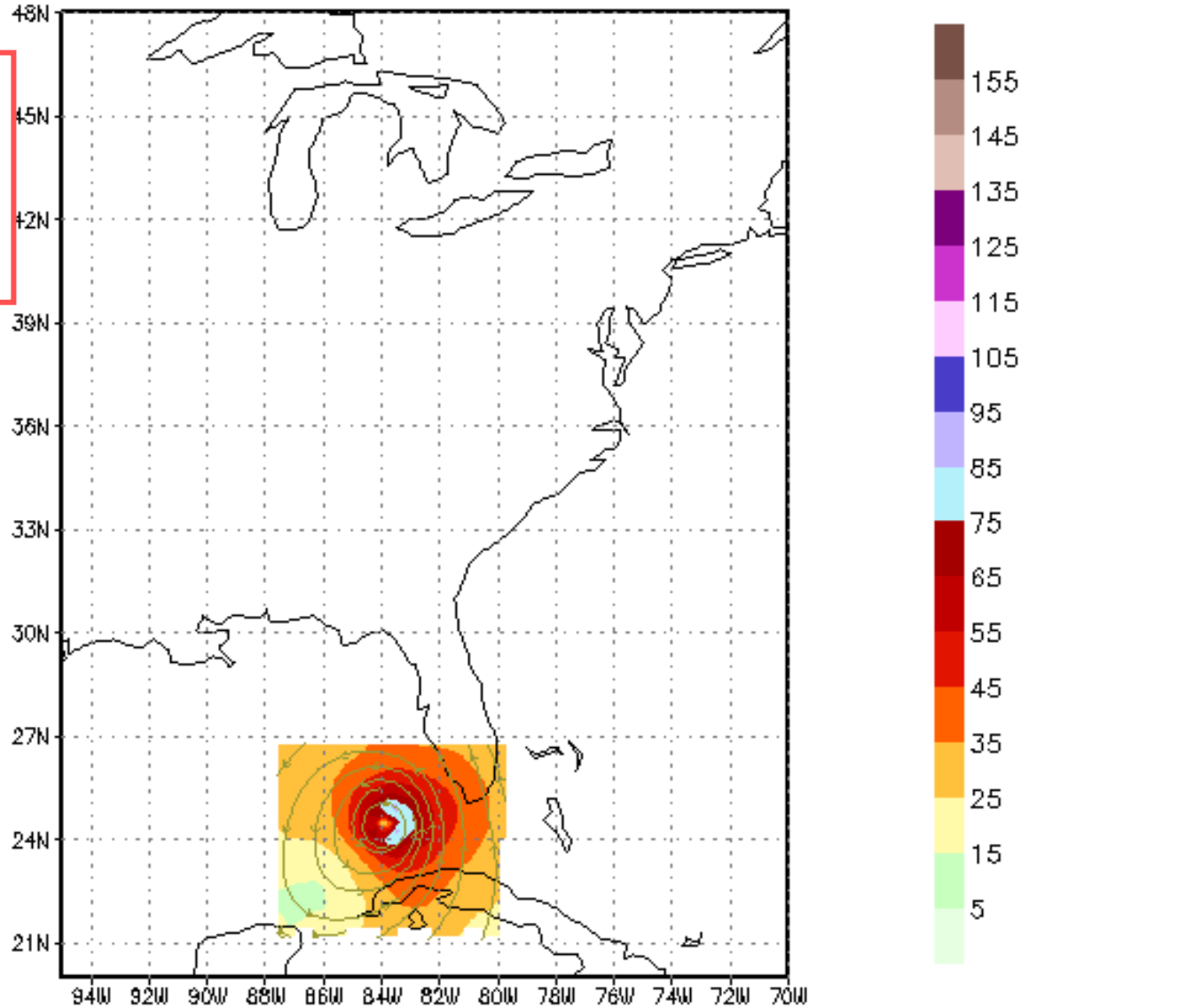
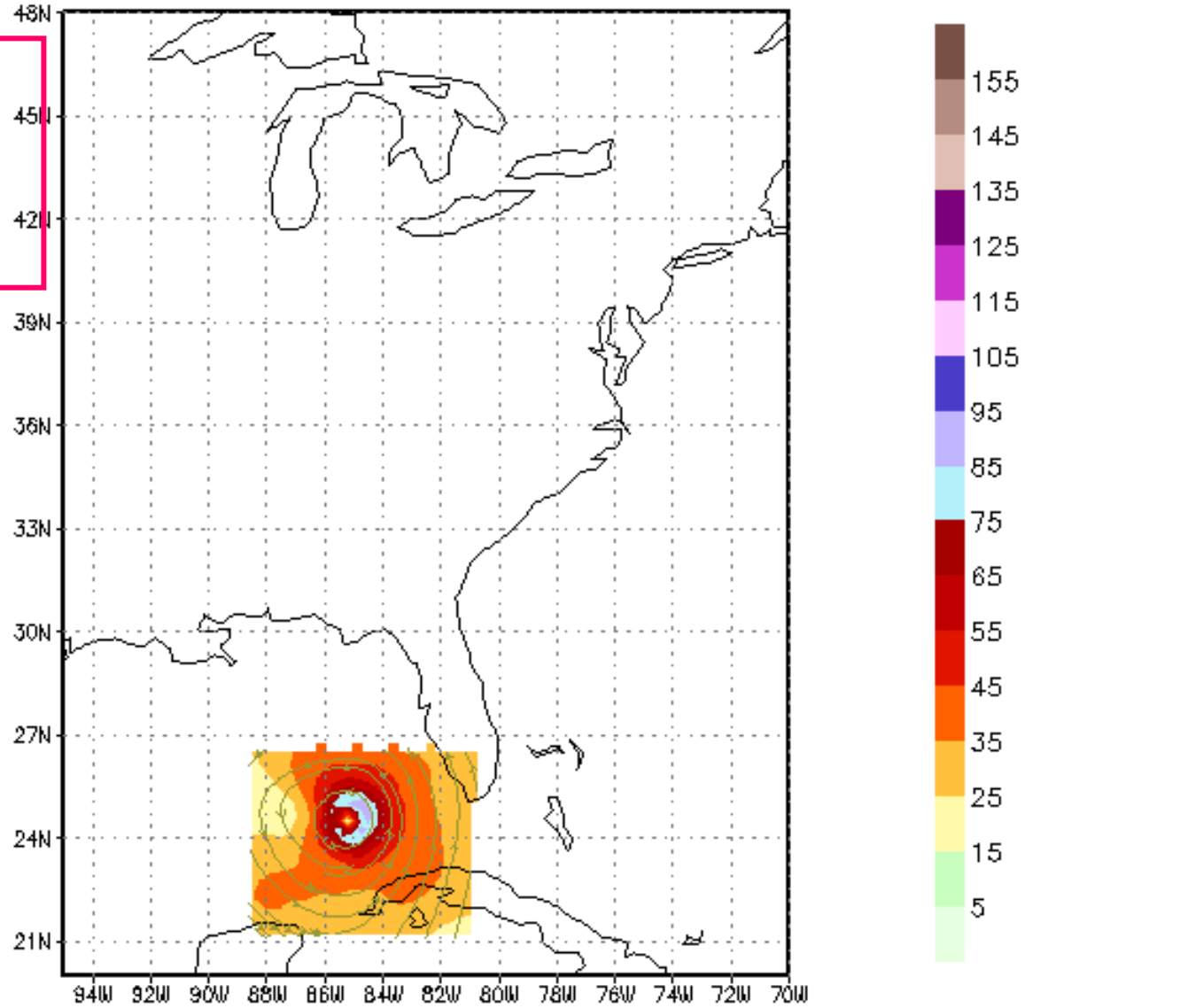

JULY 06, 2005 06Z: TS DENNIS MOVING NEST FCST: 0
HWRF
DENNIS
36N
33N
30N
27N
24N
21N
18N
15N
12N
93W
90W
87W
84W
81W
78W
75W
72W
69W
66W
63W
60W
155
145
135
125
115
105
95
85
75
65
55
45
35
25
15
5

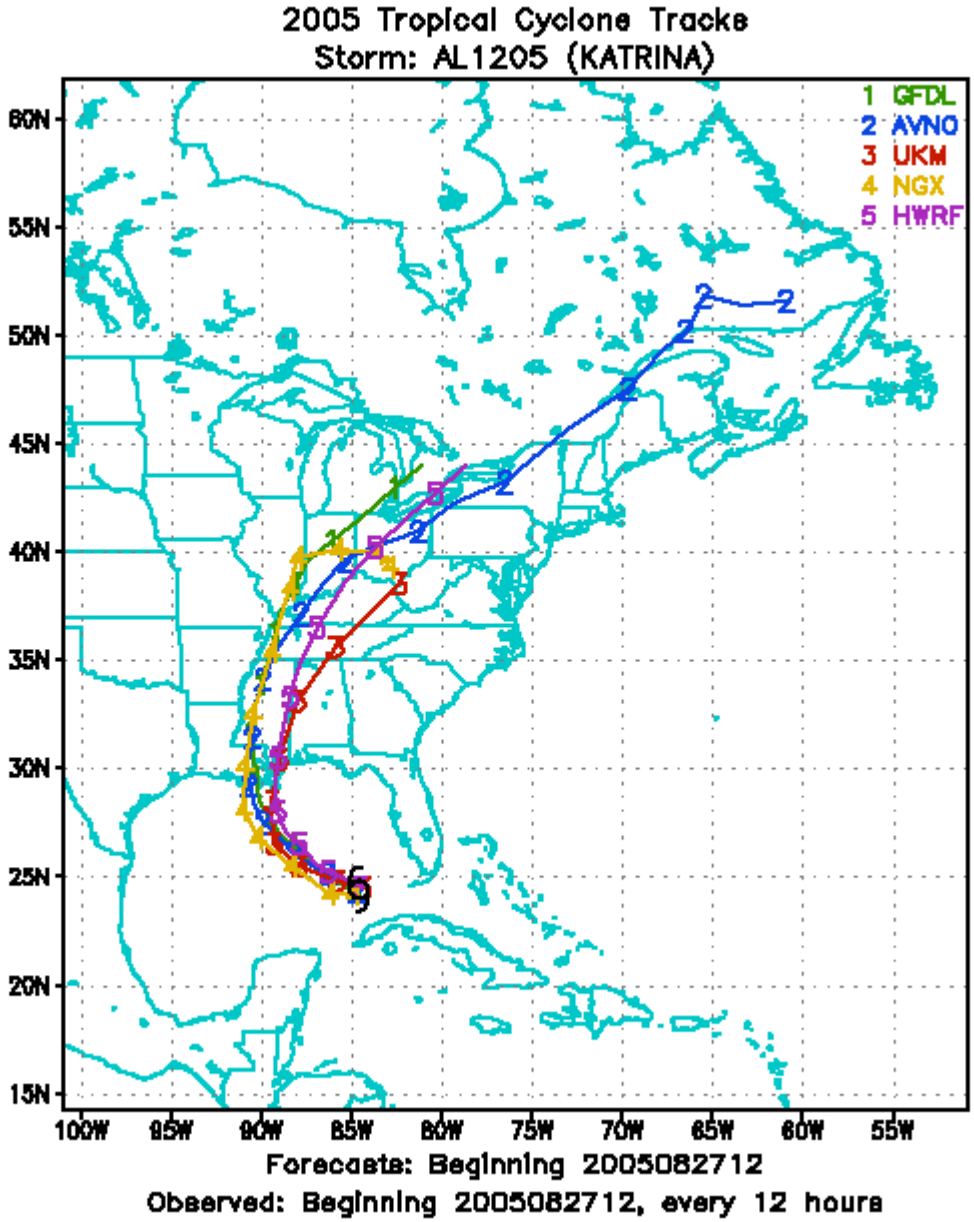
Figure 4

# Hurricane Katrina

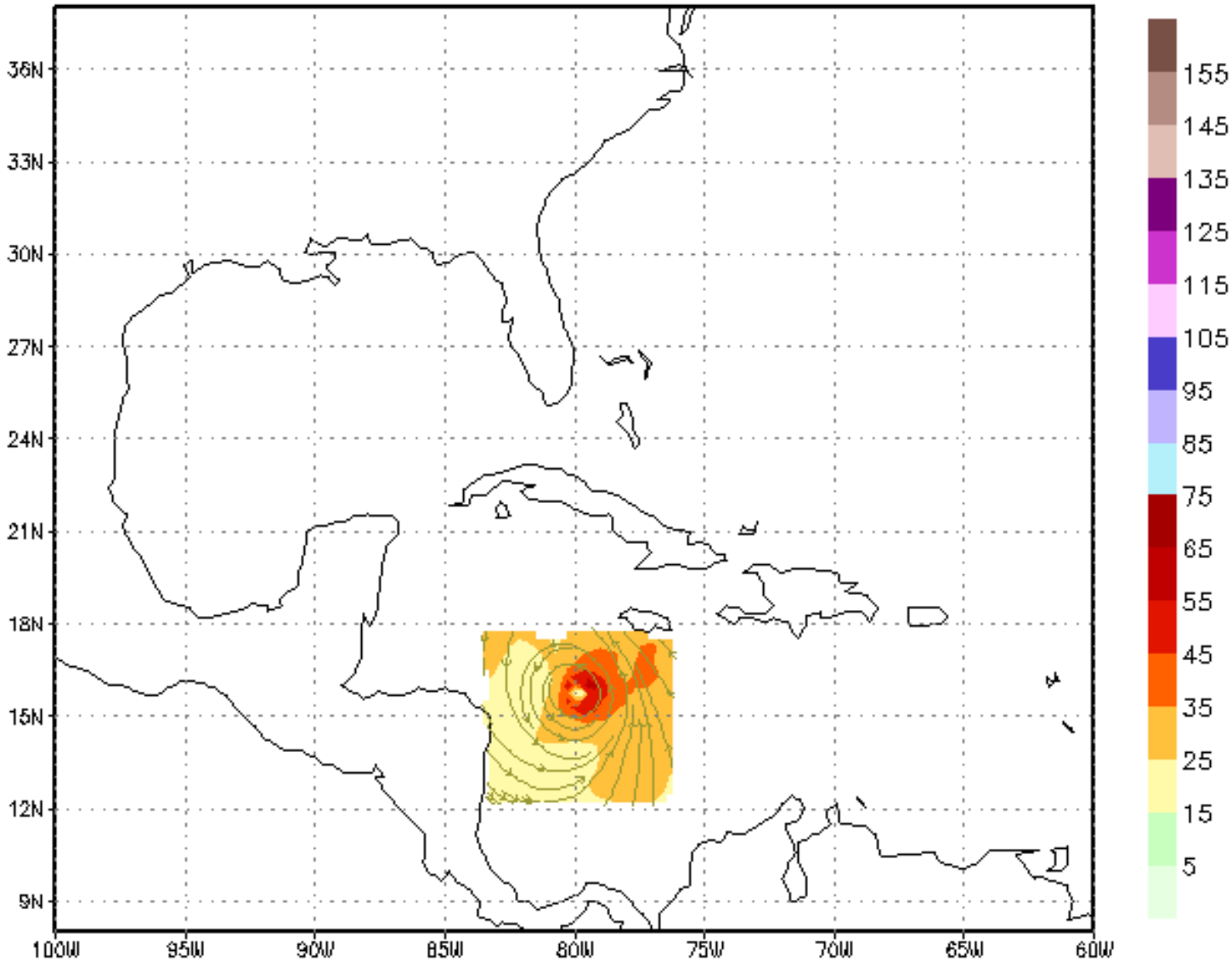


# Hurricane Katrina



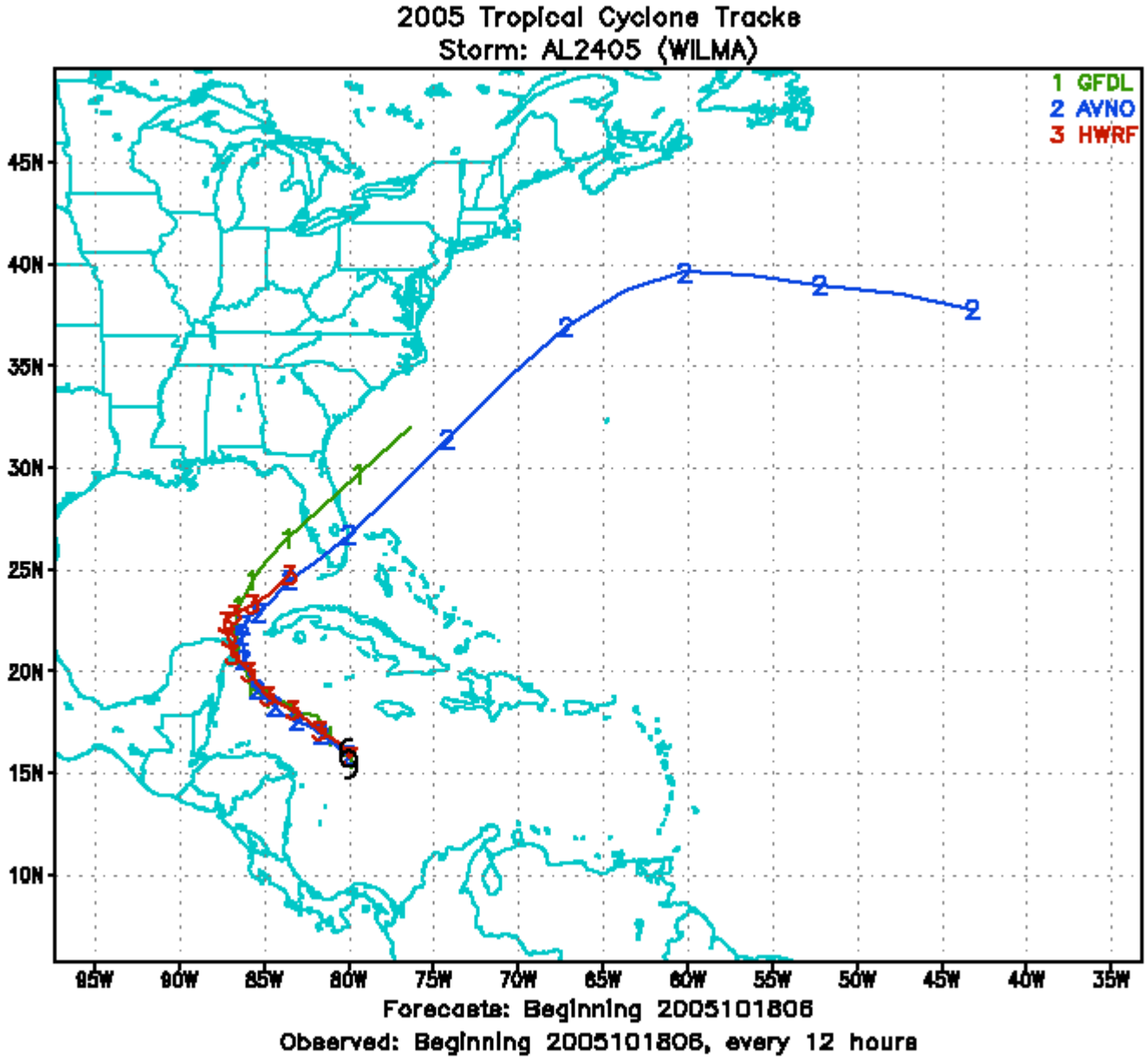

2005 Tropical Cyclone Tracks
Storm: AL1205 (KATRINA)
1 GFDL
2 AVNO
3 UKM
4 NGX
5 HWRF
60N
55N
50N
45N
40N
35N
30N
25N
20N
15N
100W
95W
90W
85W
80W
75W
70W
65W
60W
55W
Forecasts: Beginning 2005082712
Observed: Beginning 2005082712, every 12 hours
NCEP Hurricane Forecast Project

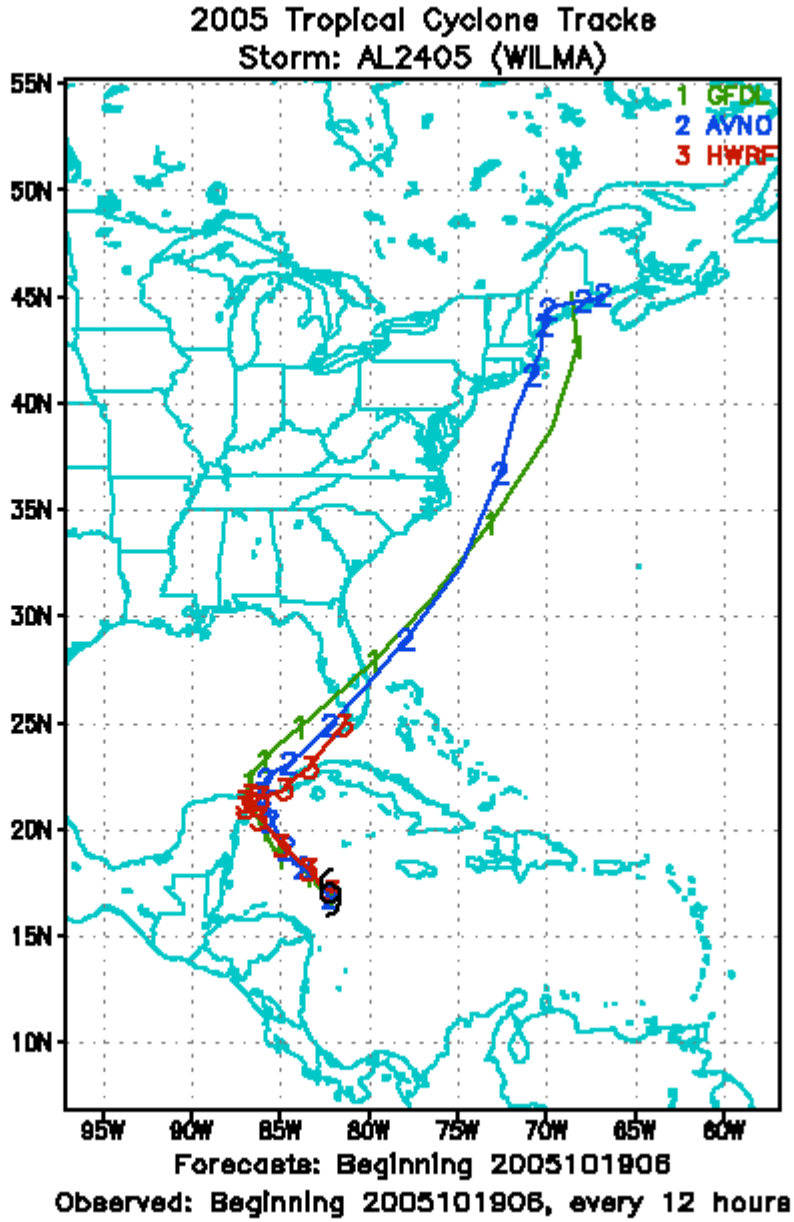
# OCT 18, 2005 06Z: HURRICANE WILMA MOVING NEST FCST: 0




GrADS: COLA/IGES

2005-10-18-10:54


2005 Tropical Cyclone Tracks
Storm: AL2405 (WILMA)
1 GFDL
2 AVNO
3 HWRF
45N
40N
35N
30N
25N
20N
15N
10N
95W
90W
85W
80W
75W
70W
65W
60W
55W
50W
45W
40W
35W
Forecasts: Beginning 2005101806
Observed: Beginning 2005101806, every 12 hours
NCEP Hurricane Forecast Project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1 GFDL
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55N
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40N
35N
30N
25N
20N
15N
10N
95W
90W
85W
80W
75W
70W
65W
60W
Forecasts: Beginning 2005101906
Observed: Beginning 2005101906, every 12 hours
NCEP Hurricane Forecast Project

# Development of Collaborations

**HWRF WORKSHOP – JUNE 2002**

**(45 attendees)**

**HWRF TUTORIAL – Oct. 2004**

**(26 attendees)**

**AIR-SEA WORKSHOP – MAY 2005**

**(35 attendees)**

**WRF/NMM Tutorial – Sept 2005, Feb. 2006**

# Advanced Science Issues

**Fundamental questions (process/sensitivity studies):**

1. **Relative role of vortex vs. environment in influencing intensity.**
2. **What is the hurricane "core" circulation? How do we define? Difficult even for mature storms. More elusive for weaker circulations. (RAINEX?)**
3. **Role of air-sea on intensification/weakening. Always? Sometimes? Role of oceanic heat content?**
4. **Determinants of structure and relationship with preexisting wave disturbance. Relationship between structure and intensity?**

4. Role of inner core processes for intensification/weakening, e.g. eyewall replacement cycles, mixing.

# Modeling Issues

## Physics

- Role of radiation for hurricane problem?
- Complexity of microphysics AND interaction of microphysics with radiation for hurricane problem.
- Relative role of Physics- air-sea, microphysics, convection on intensity change in various egnvironments (sheared vs. non-shear)
- Atmosphere/oceanic boundary layer for coupled air-sea-wave problem. Momentum (wave drag) and enthalpy fluxes (sea spray complexity?)

- **Resolution -** relative importance of horizontal vs. vertical resolution for modeling intensity/structure (important consideration for ops)

- **Land Surface Coupling -** Complexity of coupling w/HWRF? Sensitivity of LSM on track, structure/intensity, rainfall? Future coupling with hydrology/inundation models.

- **Diagnostics/Verification** - Development of mesocale verification techniques are required for all stages of storm evolution in terms of vortex scale and environment (atmosphere/ocean). What obs are required to support this? (e.g, IFEX. most obs are for mature stage)

- **Development of Advanced Probabilistic Guidance**

**HWRF Ensembles -**

**Optimal configuration (initial conditions, resolution, members) for HWRF for operations (both for NCEP ops and for TPC?)**

**Will use of multi model ensembles (MME) be tractable for this problem several years from now as is the use now of MME for track ?**

# SUMMARY

- WE'RE MAKING PROGRESS
- LOTS OF WORK TO BE DONE for IOI

improving INTENSITY/STRUCTURE FORECASTS ARE ORDER OF MAGNITURE MORE DIFFICULT THAN WAS TRACK FORECASTS…… NO QUICK FIXES!

**Advances in hurricane prediction (track, intensity/structure, ppt, waves, storm surge) will take….**

***a lot of work, a united tropical community, a LONG term commitment…..*** **and** ***close collaboration w/ operational system...***

# THANK YOU FOR YOUR ATTENTION!

**(Please send $$$ to surgi@noaa.gov)**