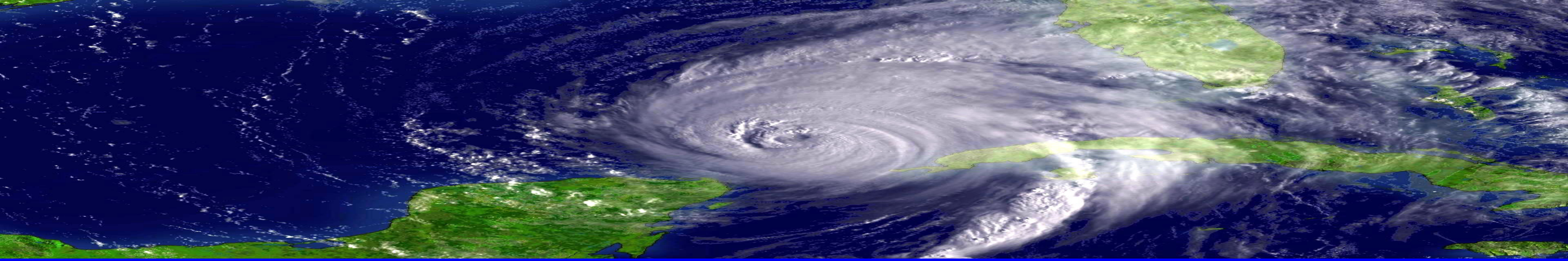

Progress in Developing Coupled Tropical Cyclone-Wave-Ocean Models for Operational Implementations at NOAA and Navy

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Morris Bender, Tetsu Hara, Richard Yablonsky, Biju Thomas, Yalin Fan, Jian-Wen Bao, Chris Fairall, Laura Bianco

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Interdepartmental Hurricane Conference, Savannah, GA March 1-4, 2010

Operational Coupled Tropical Cyclone-Ocean Models

- 2001 – GFDL/POM at NCEP in Atlantic ocean (3D coupling).
- 2004 – GFDL/POM at NCEP in Eastern and Central Pacific (1 D coupling).
- 2007 – HWRF/POM at NCEP in Atlantic ocean (3D coupling).
- 2008 – GFDN/POM at FNMOC in Atlantic ocean (3D coupling) and all other oceans(1D coupling)
- 2009 – GFDN/POM at FNMOC in the Northern Pacific ocean (3D coupling).

Conventional Coupling Between Tropical Cyclone and Ocean Models

Atmospheric Model

Wind speed (U_a)
Temperature (T_a)
Humidity (q_a)

Momentum flux (τ)
Sensible heat flux (Q_H)
Latent heat flux (Q_E)

Air-Sea Interface

Surface current (U_s)
SST (T_s)

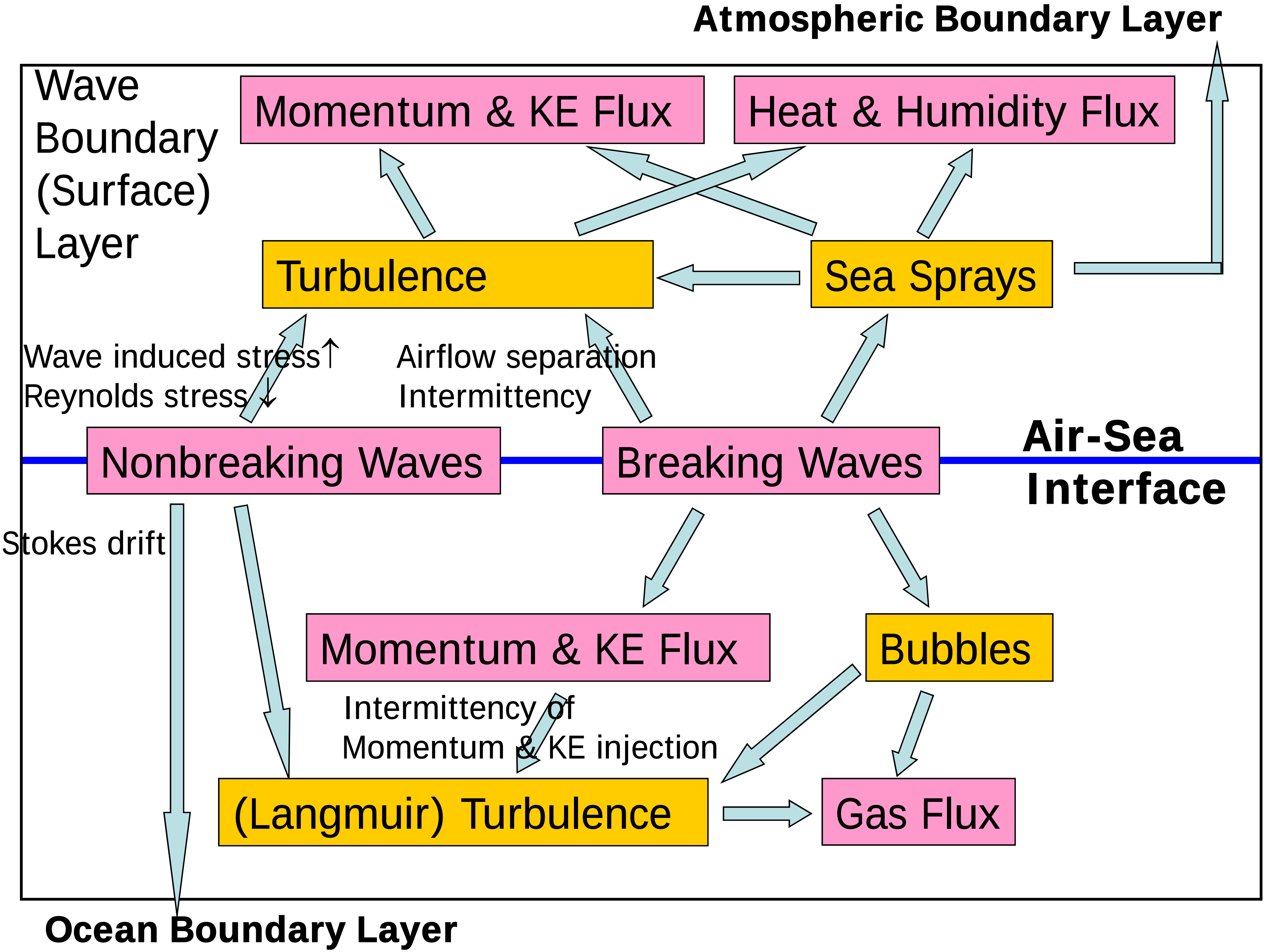
Momentum flux (τ)

Ocean Model

$$\tau = \rho_a C_D \left(U_a - U_s\right)\left(U_a - U_s\right)$$

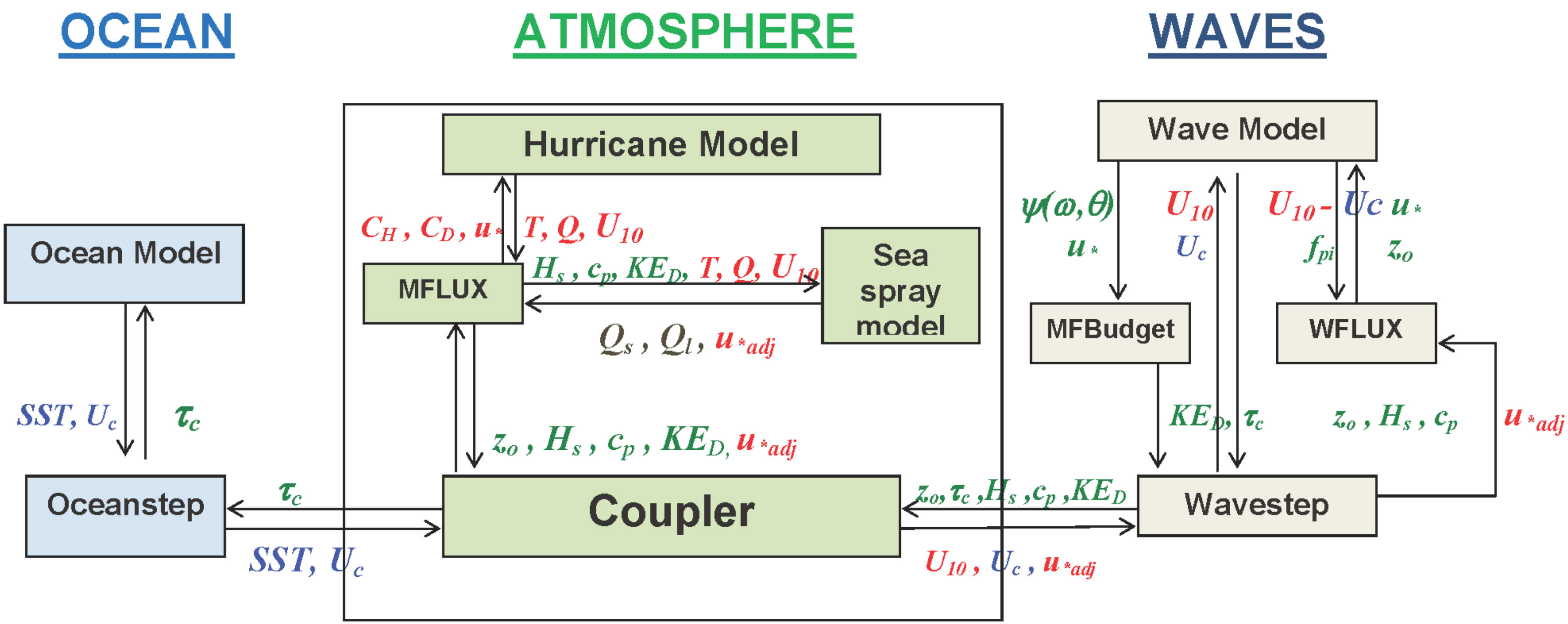
$$Q_H = C_H \left(U_a - U_s\right)\left(T_a - T_s\right)$$

$$Q_E = \frac{L_V}{C_P} C_E \left(U_a - U_s\right)\left(q_a - q_s\right)$$



Atmospheric Boundary Layer
Wave Boundary (Surface) Layer
Momentum & KE Flux
Heat & Humidity Flux
Turbulence
Sea Sprays
Wave induced stress↑
Reynolds stress↓
Airflow separation
Intermittency
Nonbreaking Waves
Breaking Waves
Air-Sea Interface
Stokes drift
Momentum & KE Flux
Bubbles
Intermittency of
Momentum & KE injection
(Langmuir) Turbulence
Gas Flux
Ocean Boundary Layer

New Coupled Tropical Cyclone-Ocean Framework
(being implemented into HWRF and GFDN models)

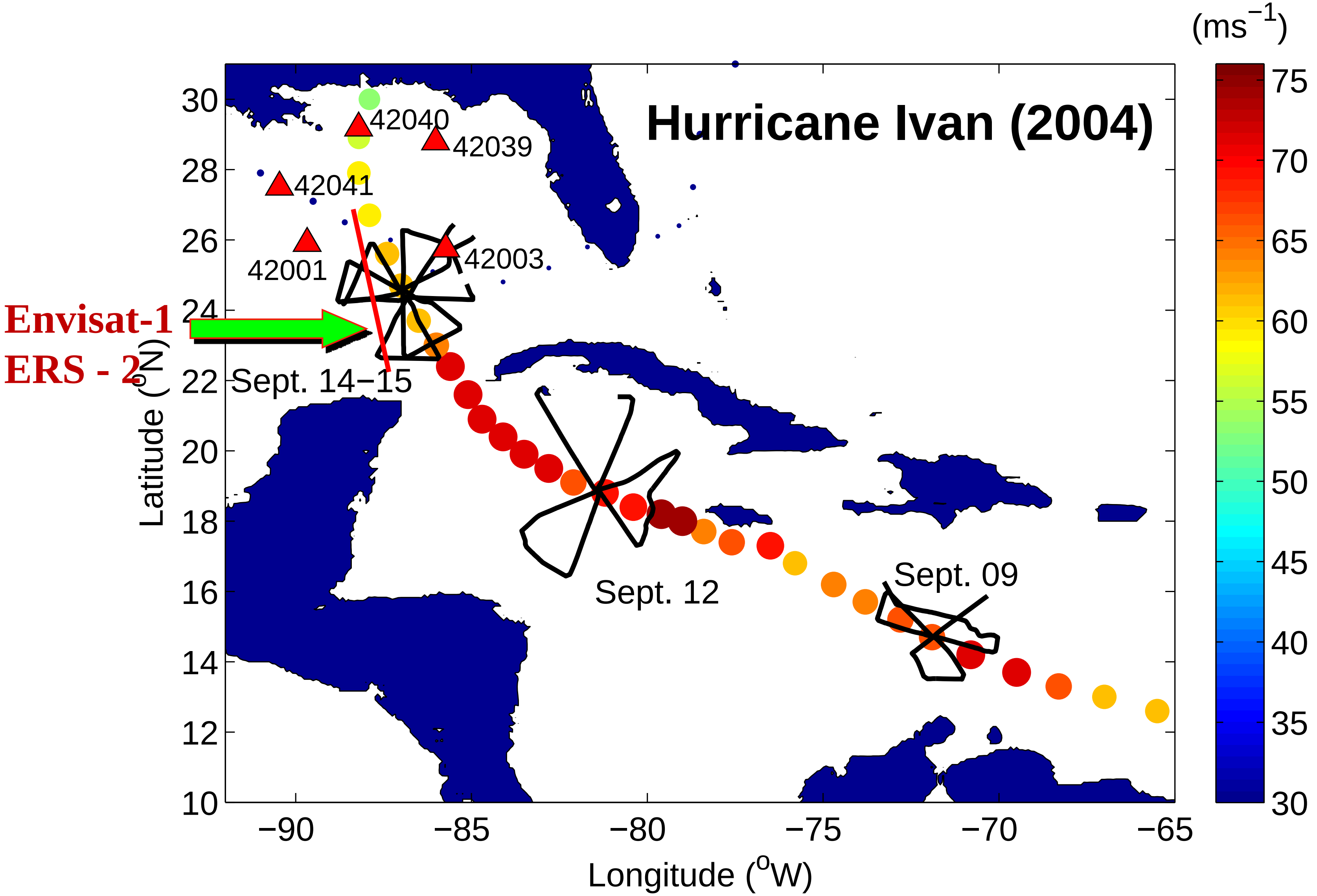


<u>TC model</u>: air-sea heat and momentum fluxes and sea spray source functions explicitly include *SST, sea-state dependence* and *ocean current effects*.

<u>Wave model</u>: is forced by *sea-state dependent momentum flux* and includes *ocean current effects*.

<u>Ocean model</u>: is forced by *sea-state dependent momentum fluxes.*

Effect of Wind-Wave-Current Interaction on Hurricane-Generated Waves

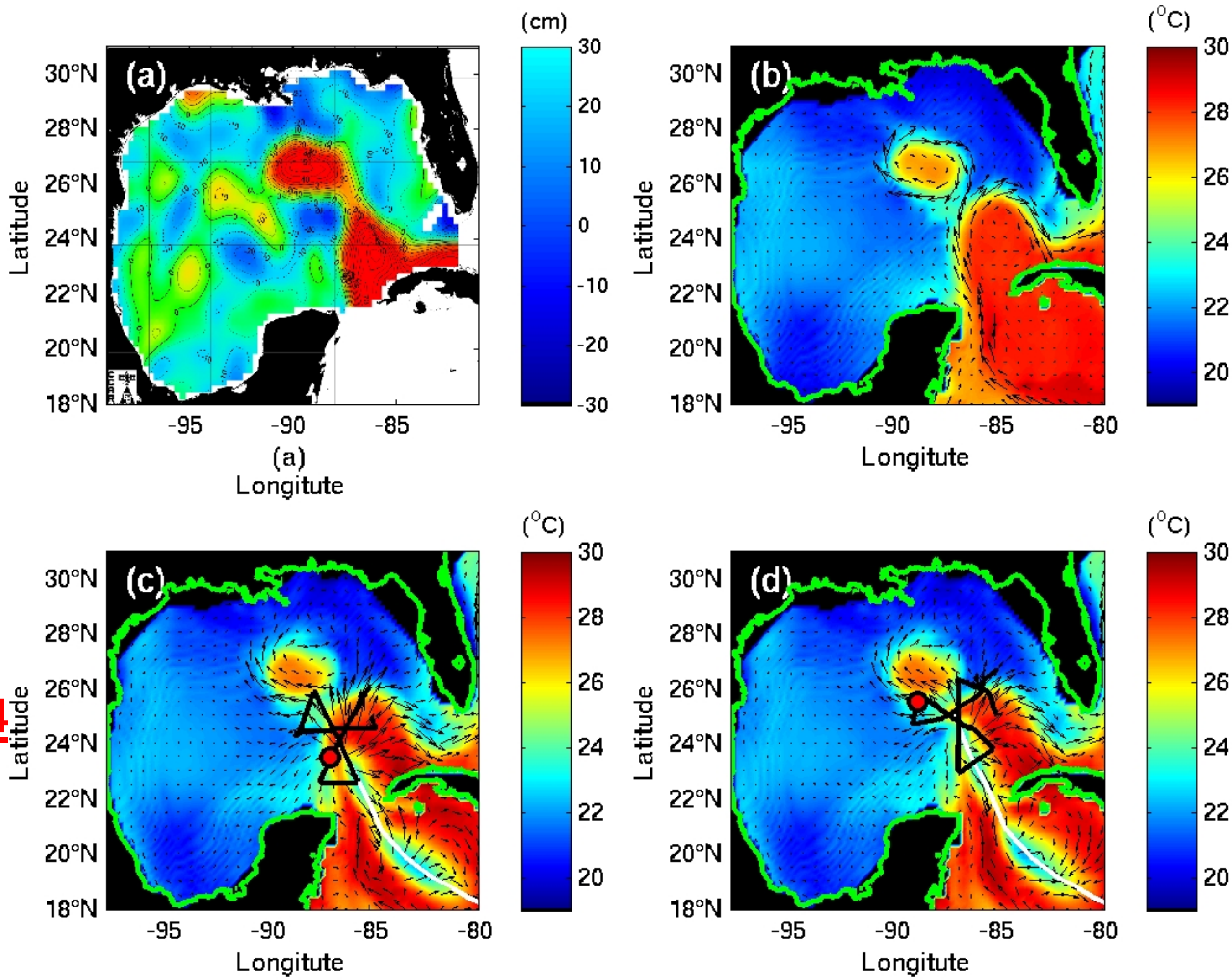


Fan, Ginis, Hara & Walsh ***J. Phys. Oceanogr.*** **(2009)**

Impact of Loop Current and Warm Core Eddy on Hurricane-Generated Surface Waves

Satellite altimetry
Sept.12

Model Temp 70 m
Sept. 12



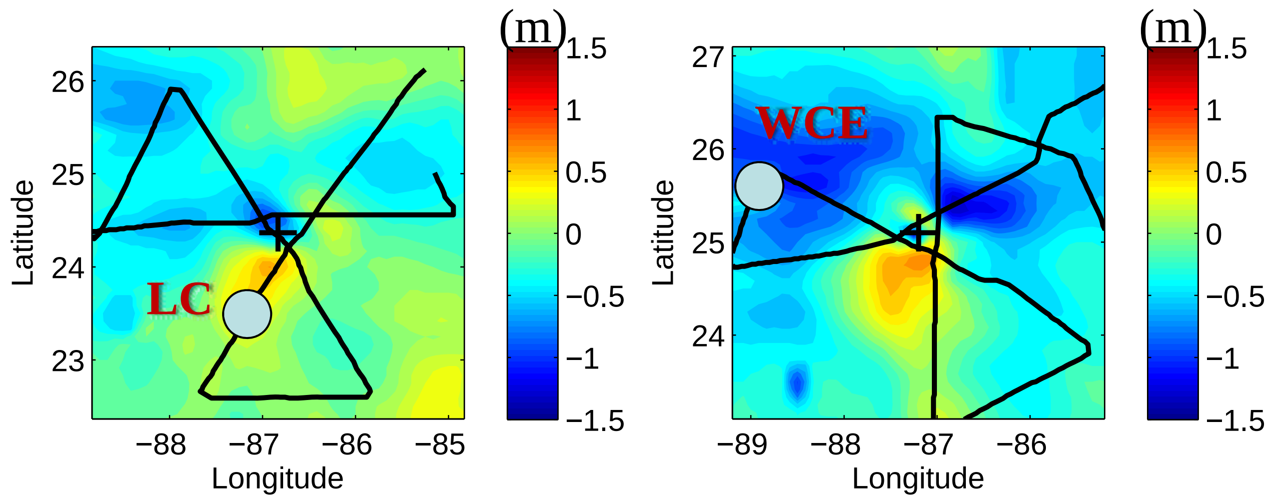
21 UTC
Sept. 14

2:40 UTC
Sept. 15

Impact of Loop Current and Warm Core Eddy on Hurricane-Generated Surface Waves

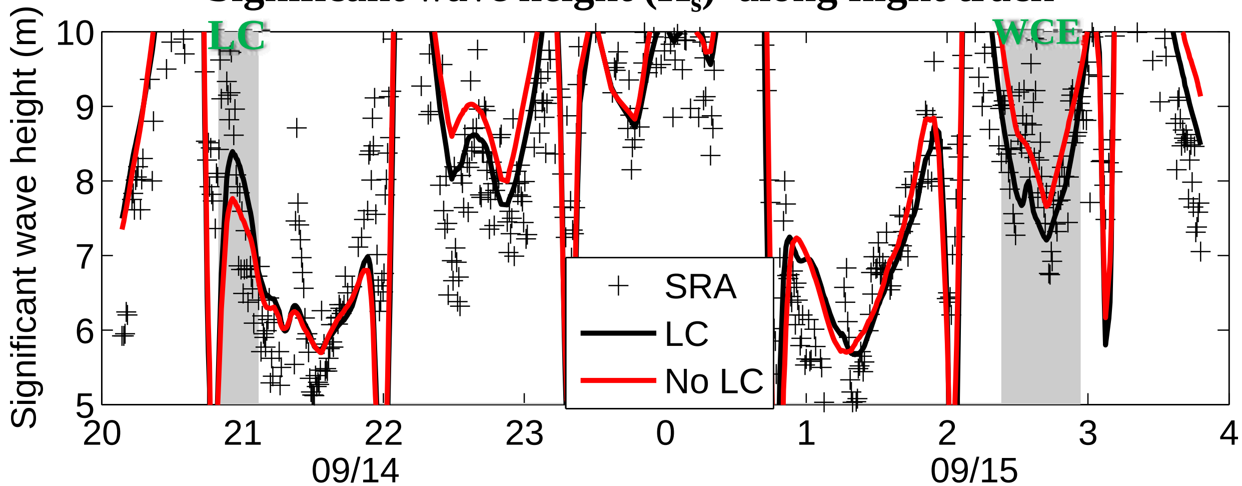
WW3 significant wave height difference with and without LC/WCE

21:00 UTC
Sept.14



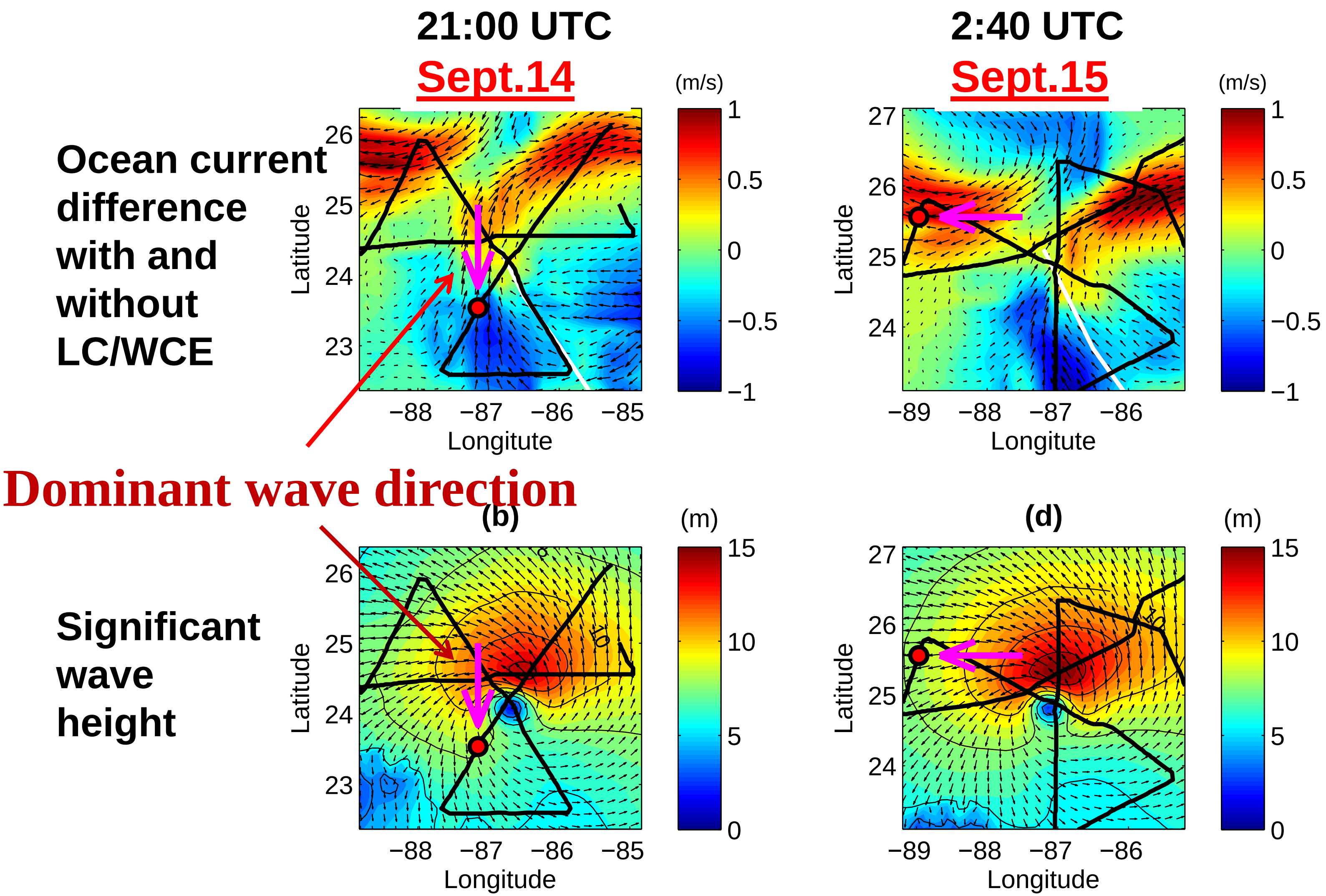
2:40 UTC
Sept. 15

Significant wave height (H_s) along flight track



(c)

Impact of Loop Current and Warm Core Eddy on Hurricane-Generated Surface Waves



Navy's Operational GFDN Model

- GFDN is run at FNMOC of NOGAPS global model. Ocean model is initialized from Navy's NCODA analysis

- Model physics changes implemented in GFDN in 2008 compared to NOAA's GFDL model:
  - Penetrative solar radiation included in ocean model
  - Bug fixed in C_h calculations and coupling interpolation

Development of High-Resolution GFDN

- Atmospheric grid resolutions

Operational GFDN:	**High-Resolution GFDN**
Mesh 1: 75^{o}x75^o – 1/2^o res	**Mesh 1: 75^{o}x75^o – 1/2^o res**
Mesh 2: 11^{o}x11^o – 1/6^o res	**Mesh 2: 11^{o}x11^o – 1/6^o res**
Mesh 3: 5^{o}x5^o – 1/12^o res	**Mesh 3: 5^{o}x5^o – 1/18^o res**

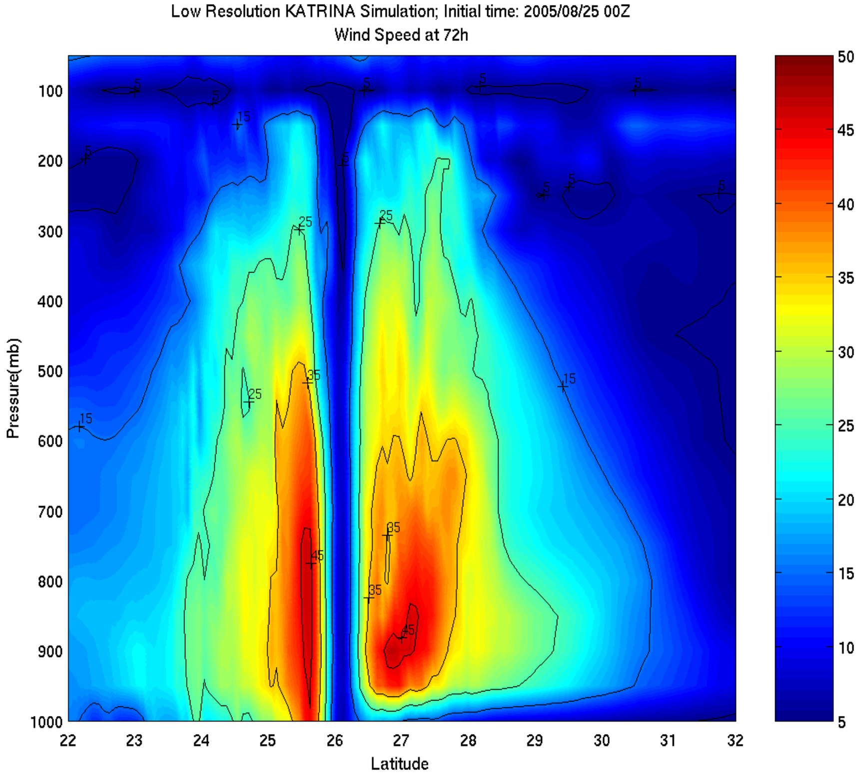
- Princeton Ocean Model grid resolutions

Operational GFDN: 1/6^o

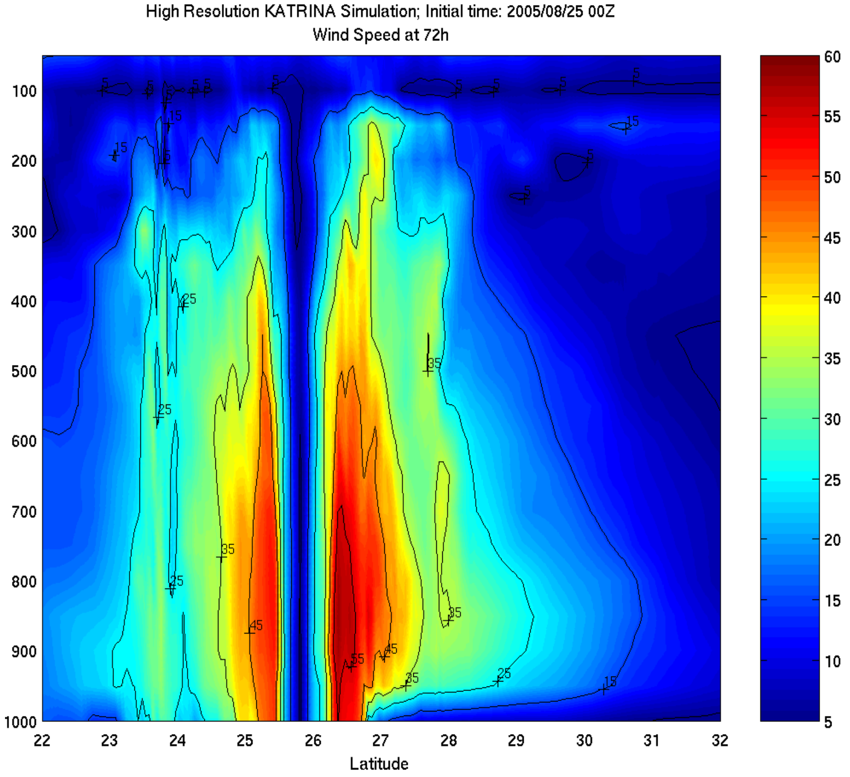
High-Resolution GFDN: 1/12^o

Wind Speed Cross-Section (72h)
Katrina: August 25th, 0z forecast
Improved Structure with Higher Resolution

1/12th Degree Resolution

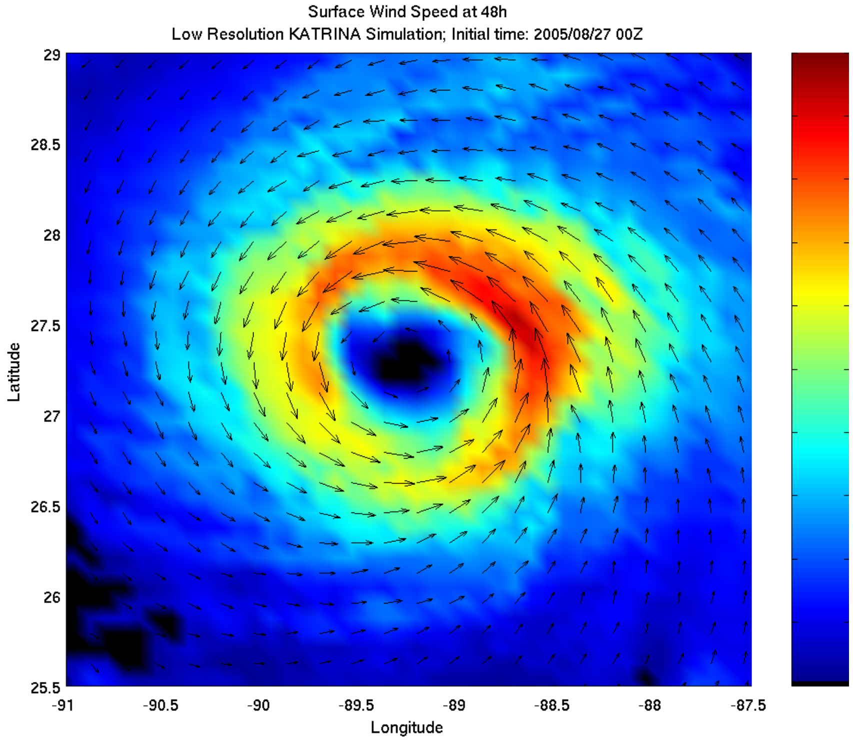


1/18th Degree Resolution

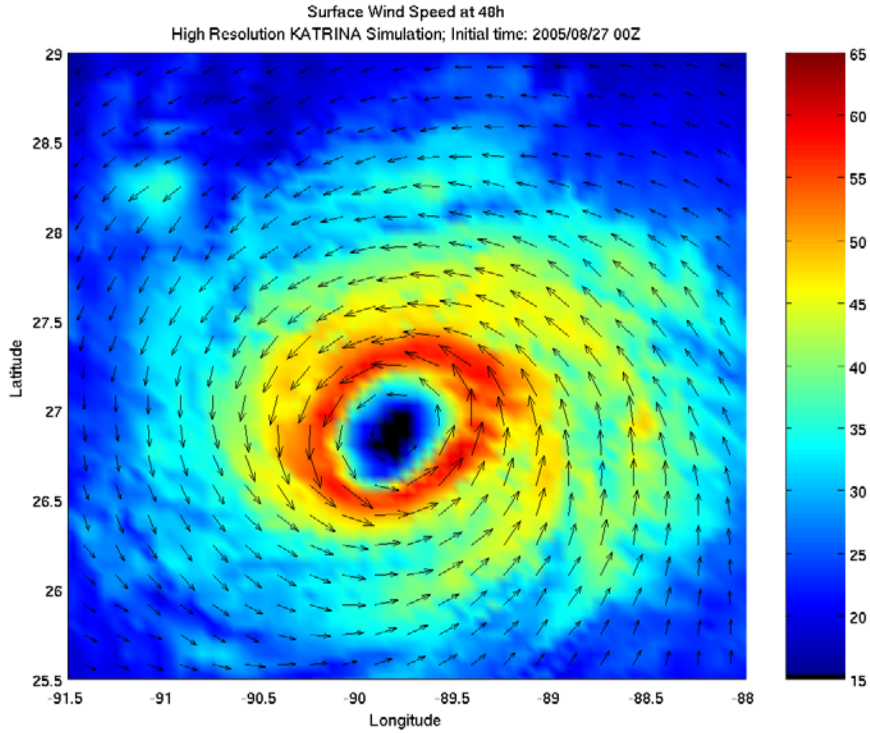


Surface Winds (72 hr)
Katrina: August 25th, 0z forecast
Improved Structure with Higher Resolution

1/12th Degree Resolution

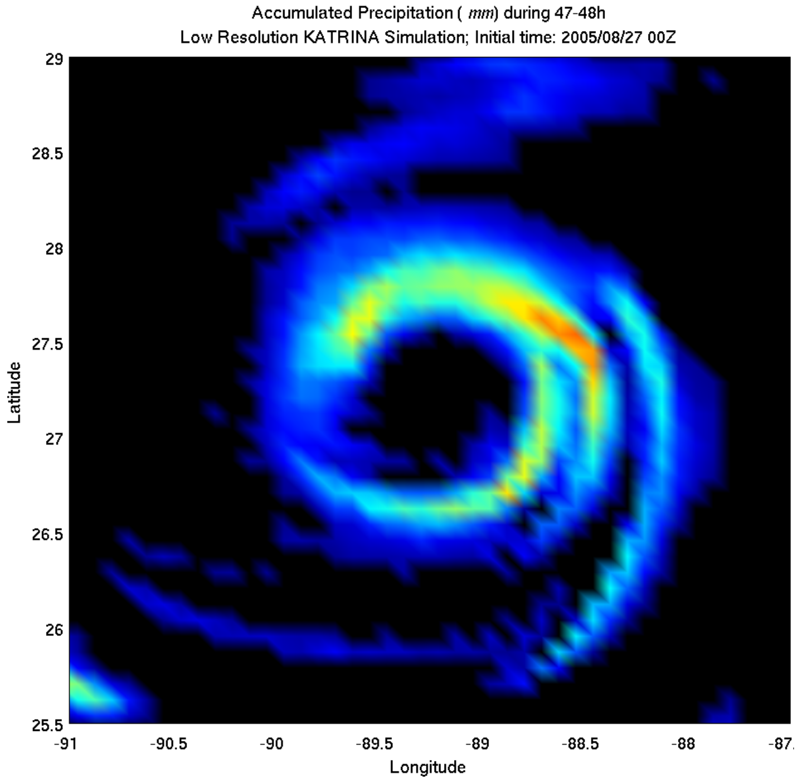


1/18th Degree Resolution

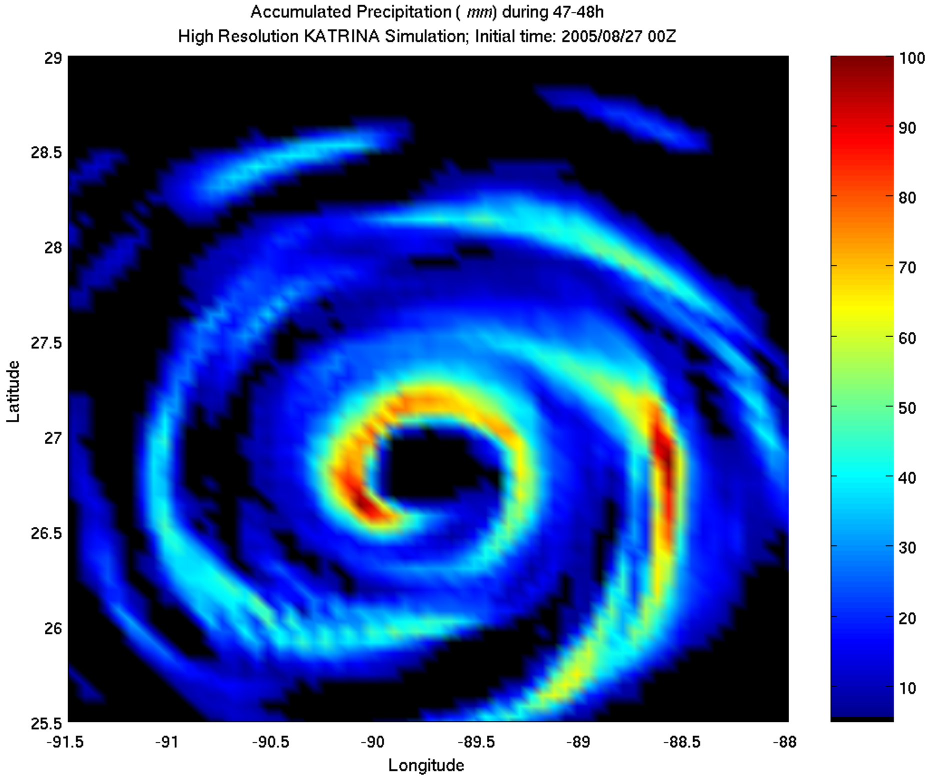


Accumulated precipitation (47-48 hr)
Katrina: August 25th, 0z forecast
Improved Structure with Higher Resolution

1/12th Degree Resolution



1/18th Degree Resolution

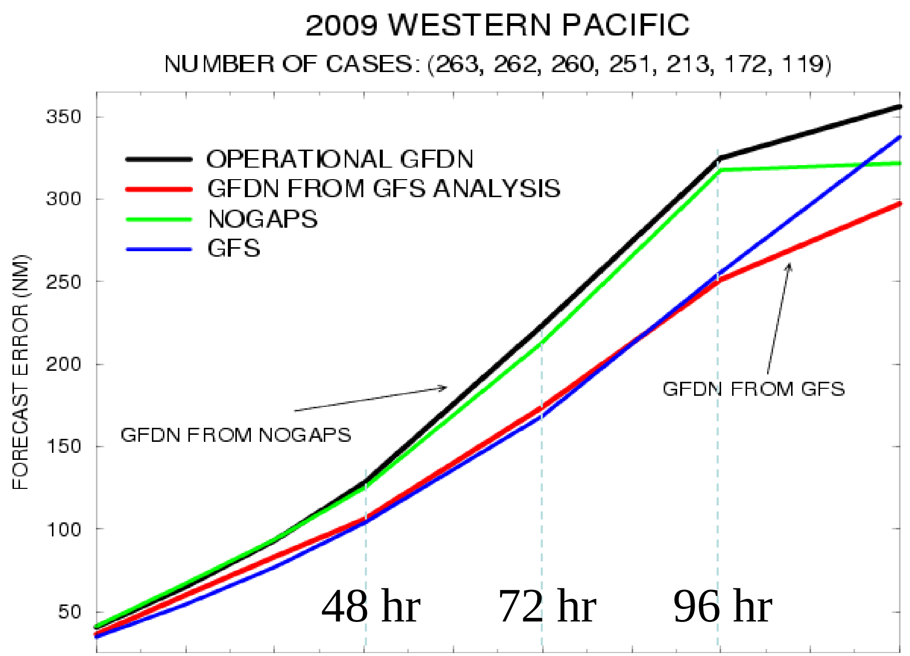


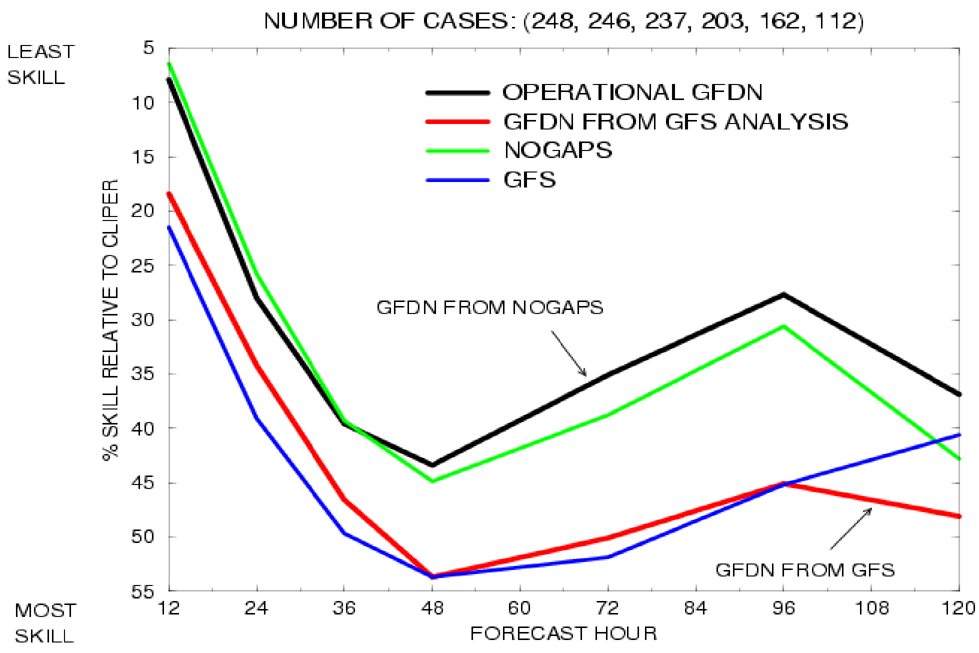
Effect of Global Model on GFDN Forecasts in Western Pacific

- 266 forecasts in 2009 were rerun in the Western Pacific using the GFS global model for initial and boundary conditions.

- No changes were made in the ocean model initialization.

Average Track Errors

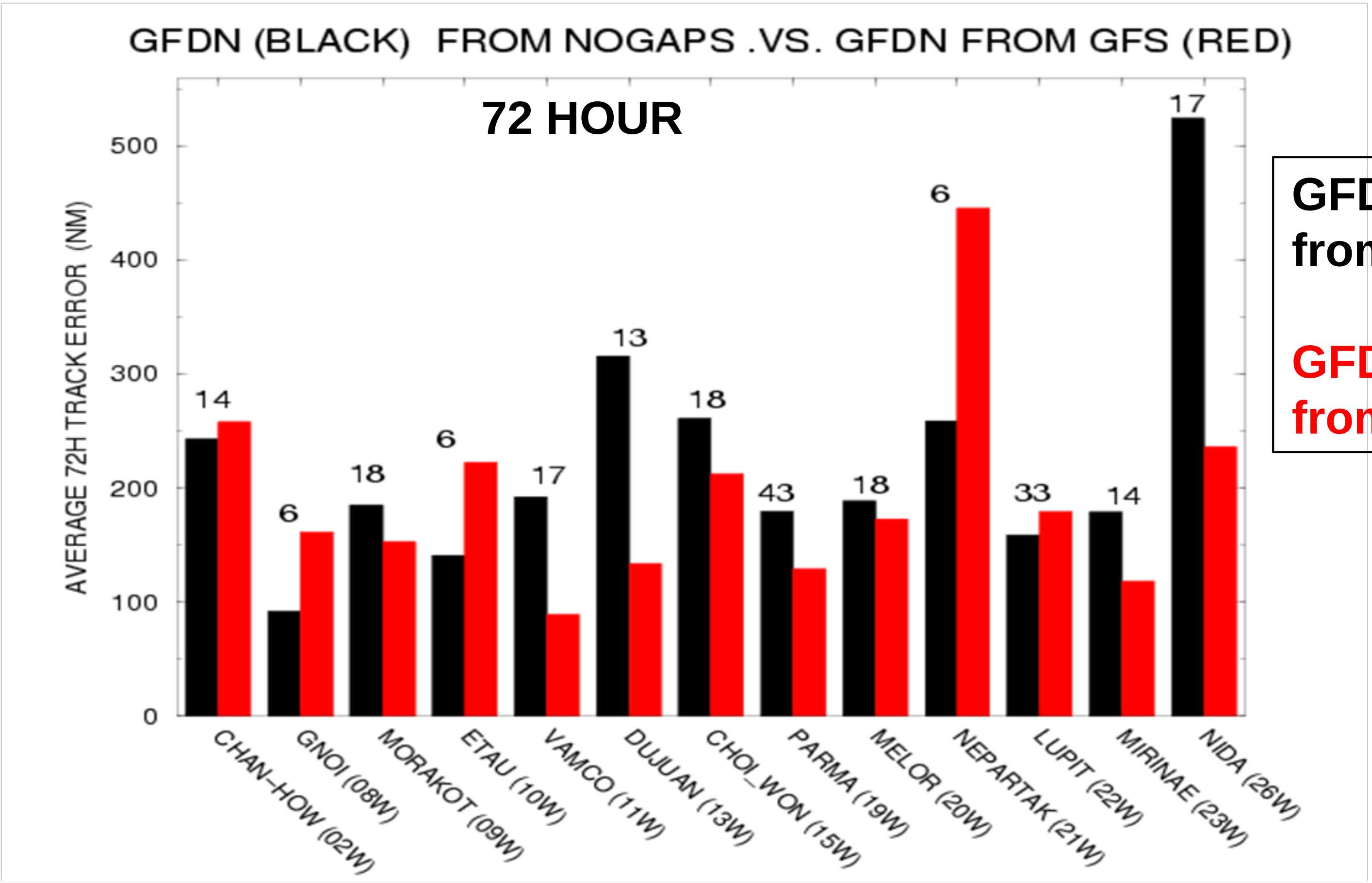




←

NORMALIZED ERRORS RELATVIE TO CLIPPER

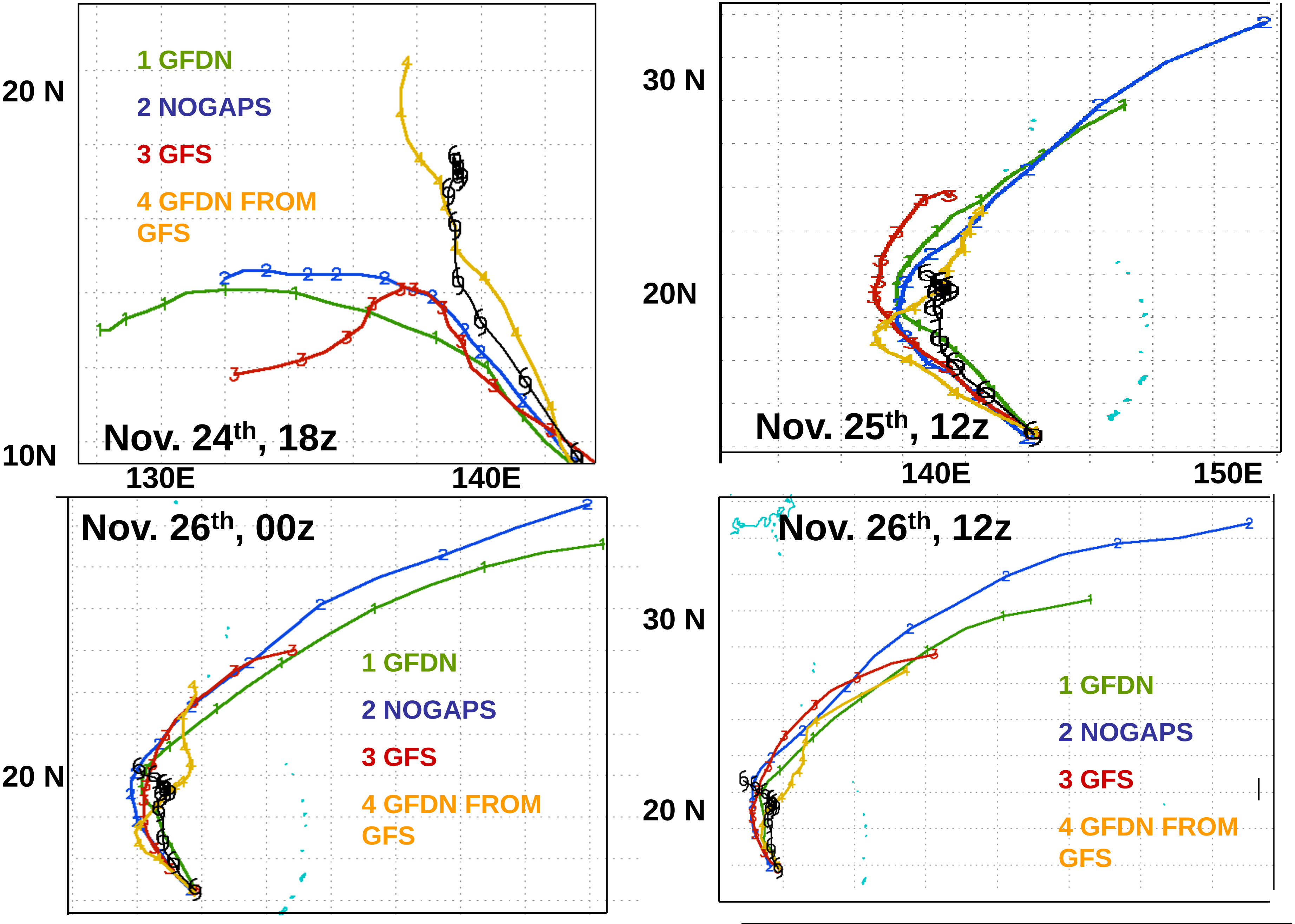
Track Errors for Each Storm



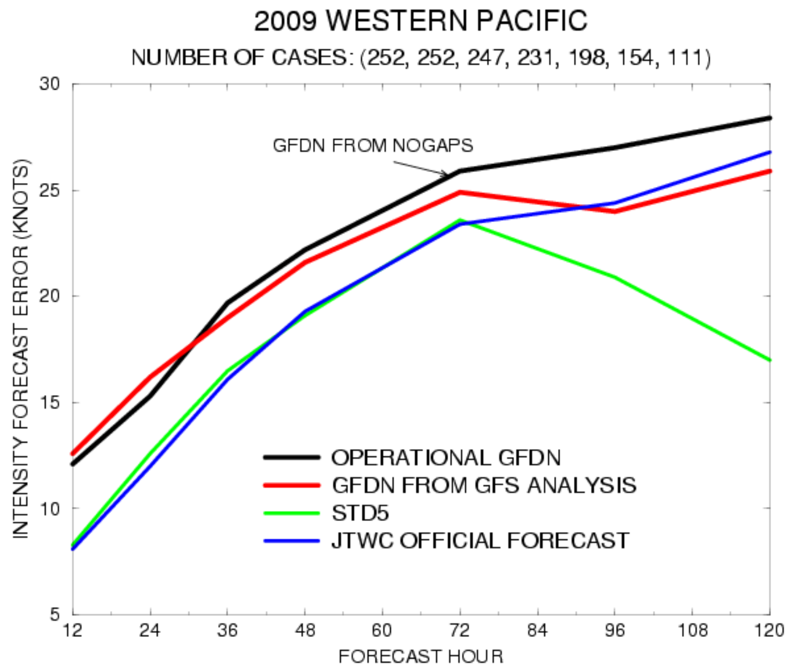
GFDN
from NOGAPS (black)

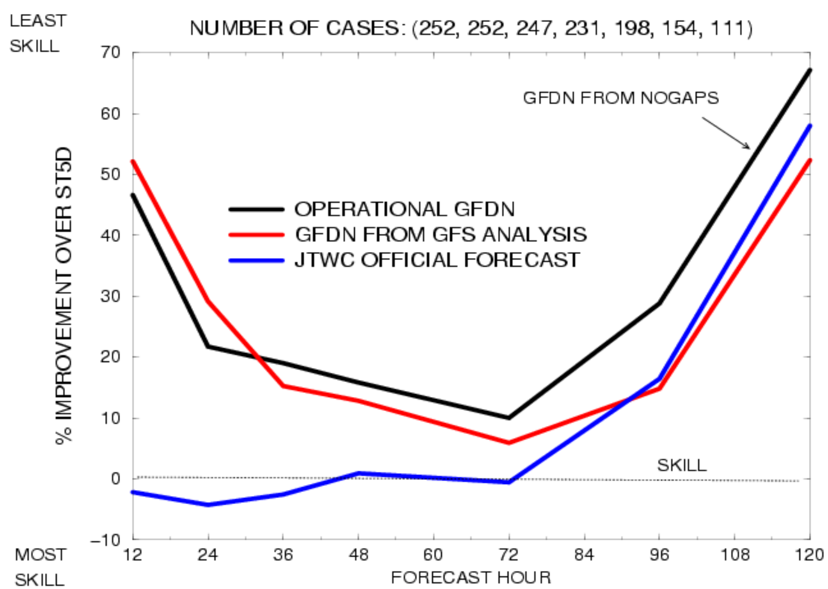
GFDN
from GFS (red)

Typhoon Nida (25W)



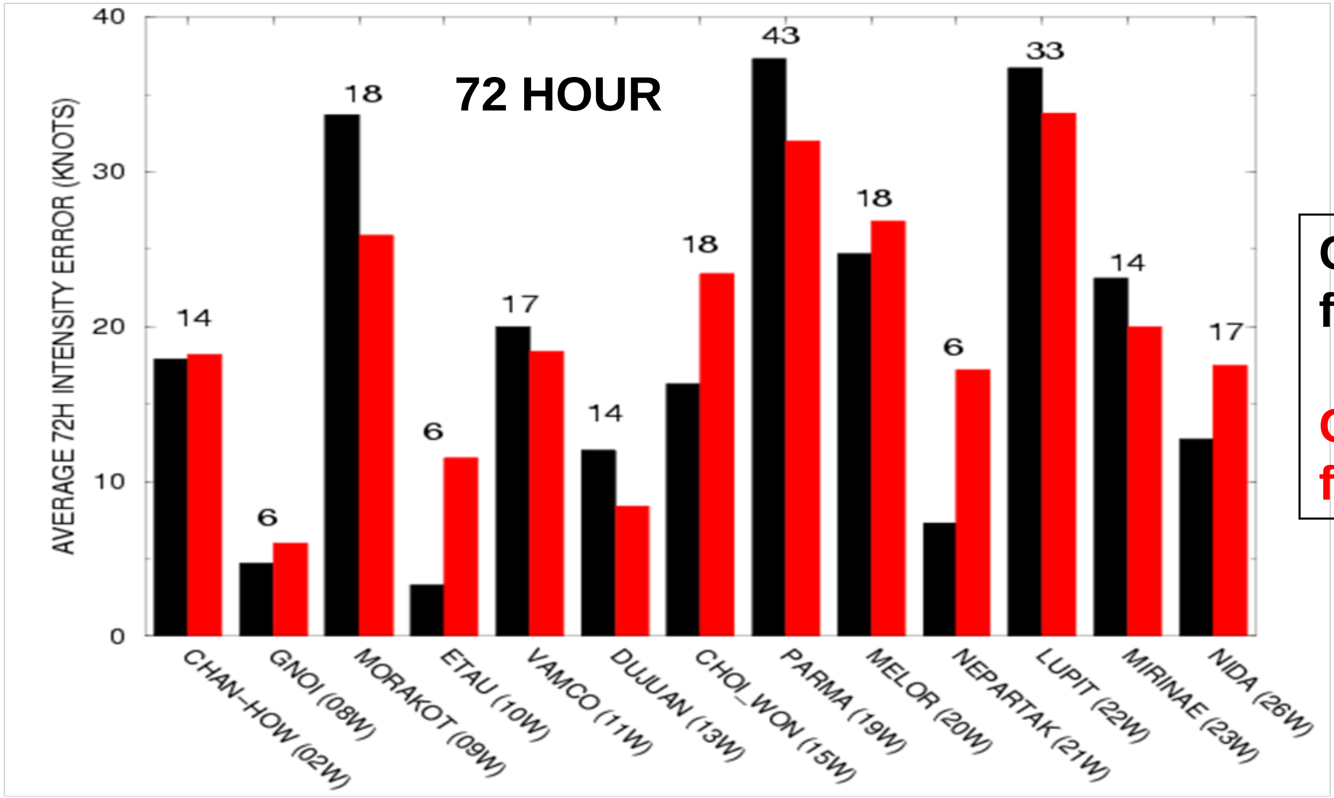
Average Intensity Error





NORMALIZED ERRORS RELATIVE TO ST5D

Intensity Errors for Each Storm



GFDN
from NOGAPS (black)

GFDN
from GFS (red)

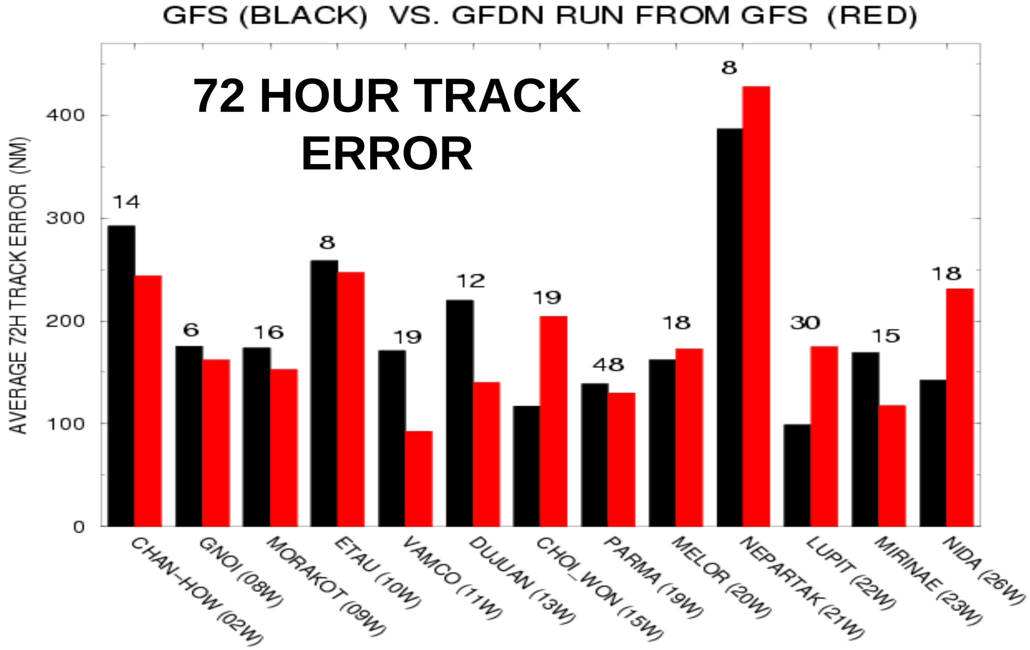
Conclusions

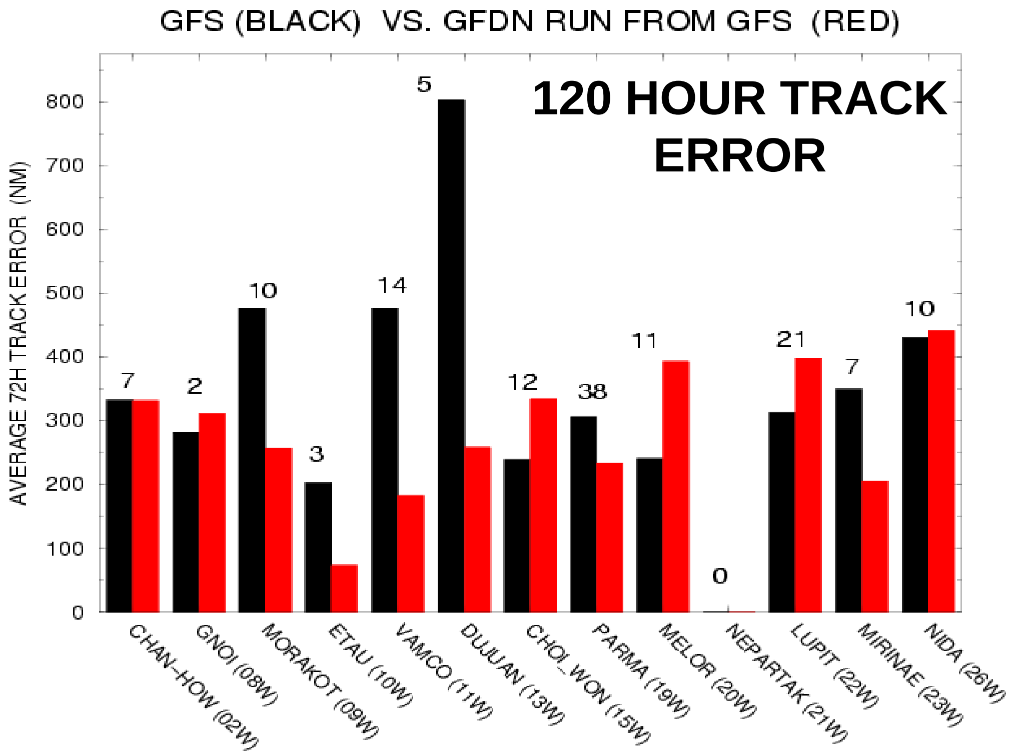
- Increased horizontal resolution in GFDN model improves horizontal and vertical structures in simulated tropical cyclones. Initial test results suggest that some model physics may need to be retuned for better performance.

- Experimental GFDN runs using GFS global model in the Western Pacific show improved forecasts skill for both track and intensity compared to the operational GFDN model

- Coupling with the WAVEWATCH wave model and introducing sea spray effects is in progress.

Track Errors in GFDN and GFS for Each Storm

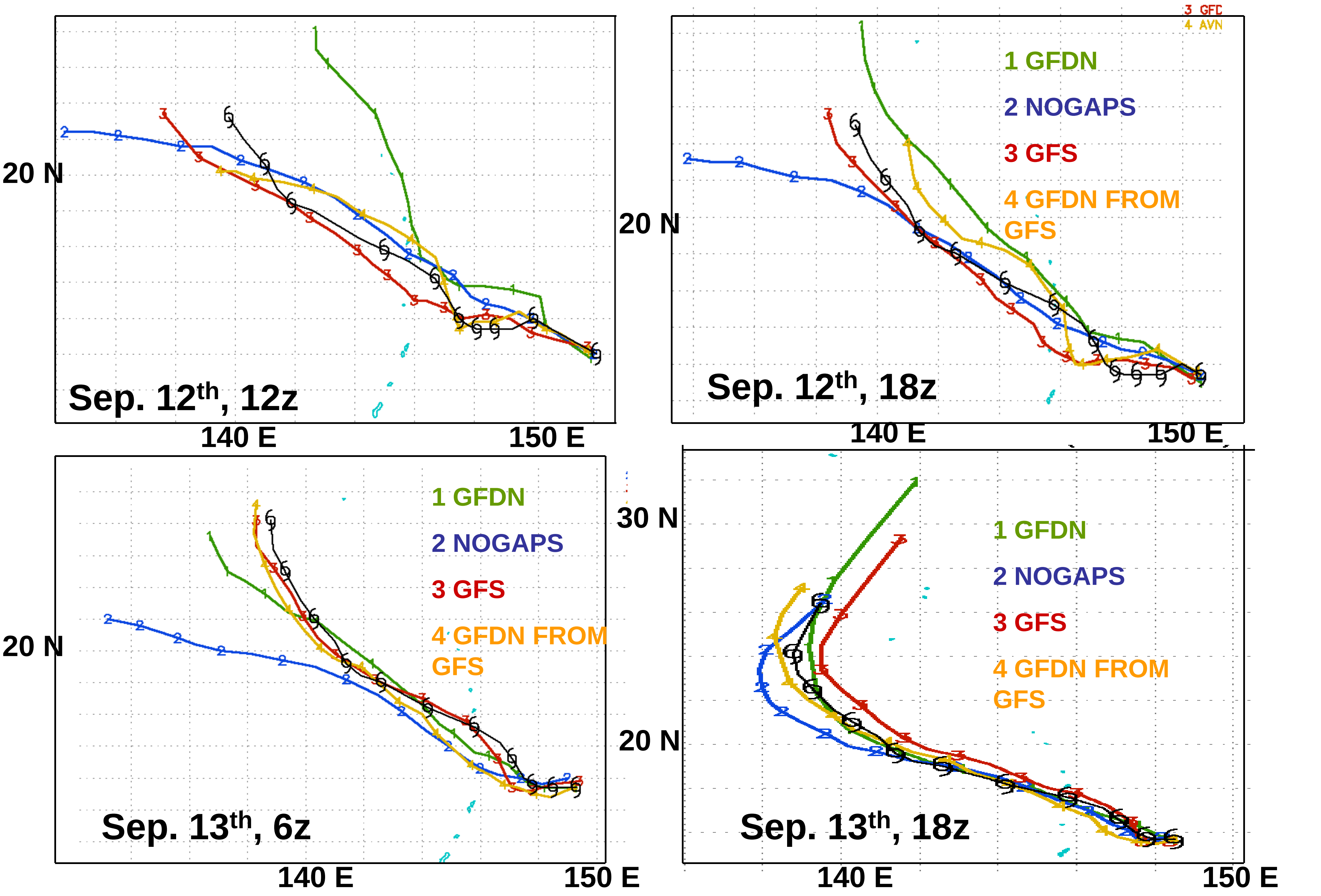


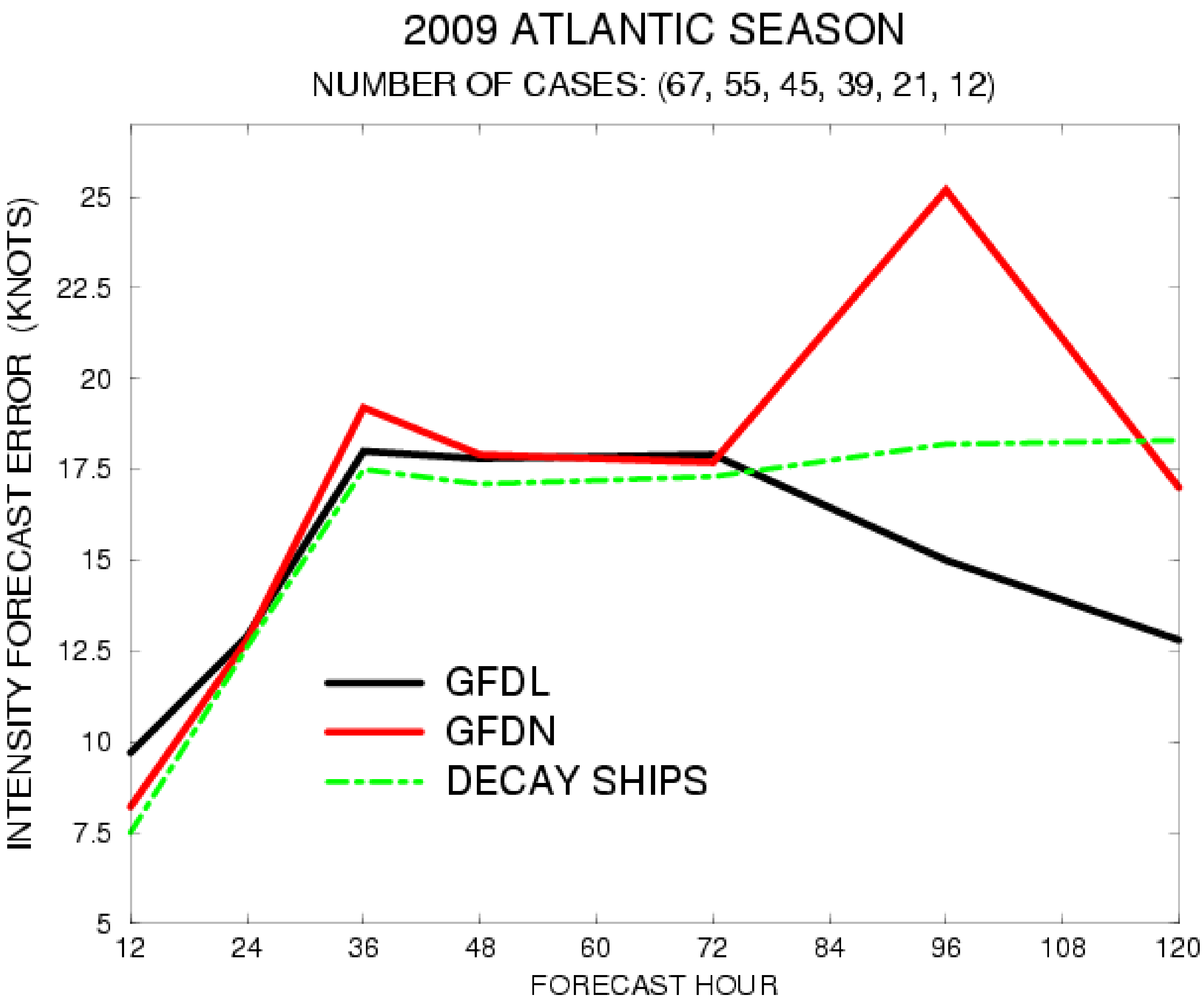


GFS (black)

GFDN from GFS (red)

Typhoon CHOI-WAN (15W)




2009 ATLANTIC SEASON
NUMBER OF CASES: (67, 55, 45, 39, 21, 12)
INTENSITY FORECAST ERROR (KNOTS)
FORECAST HOUR
GFDL
GFDN
DECAY SHIPS
5
7.5
10
12.5
15
17.5
20
22.5
25
12
24
36
48
60
72
84
96
108
120