Modeling Hurricane Interaction with the Ocean

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Hurricane Workshop
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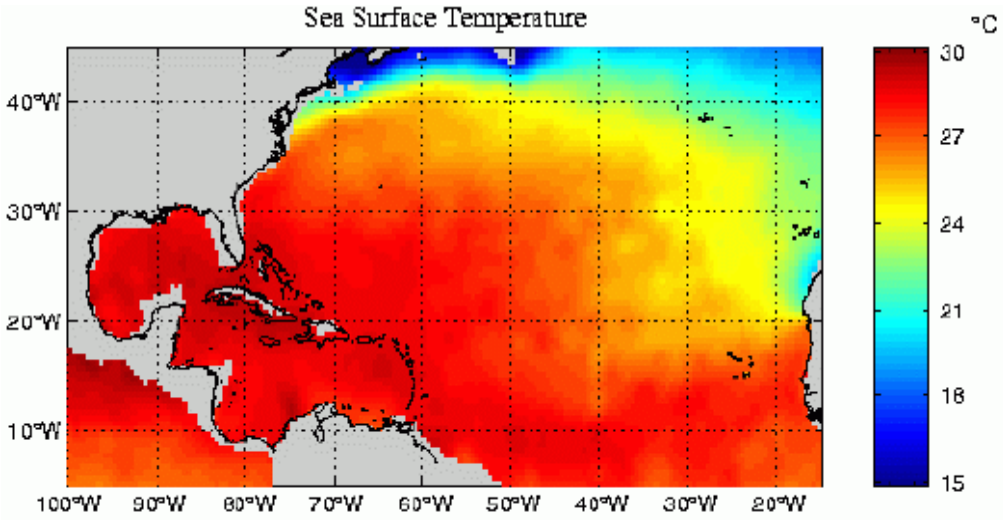
Operational Coupled Tropical Cyclone-Ocean Models

- 2001 – GFDL/POM at NCEP in Atlantic ocean (3D coupling) and Eastern and Central Pacific ocean (1D 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).

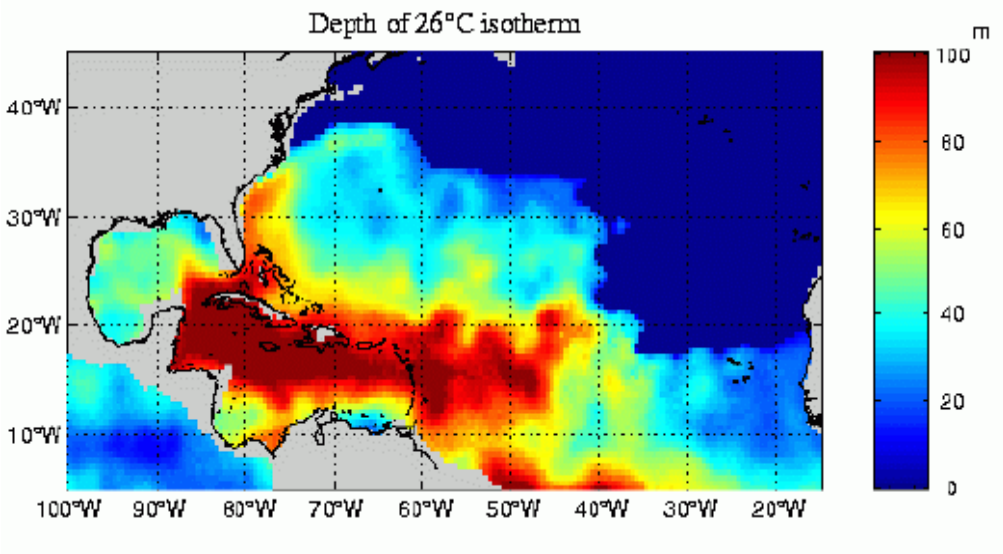
Source: National Geographic

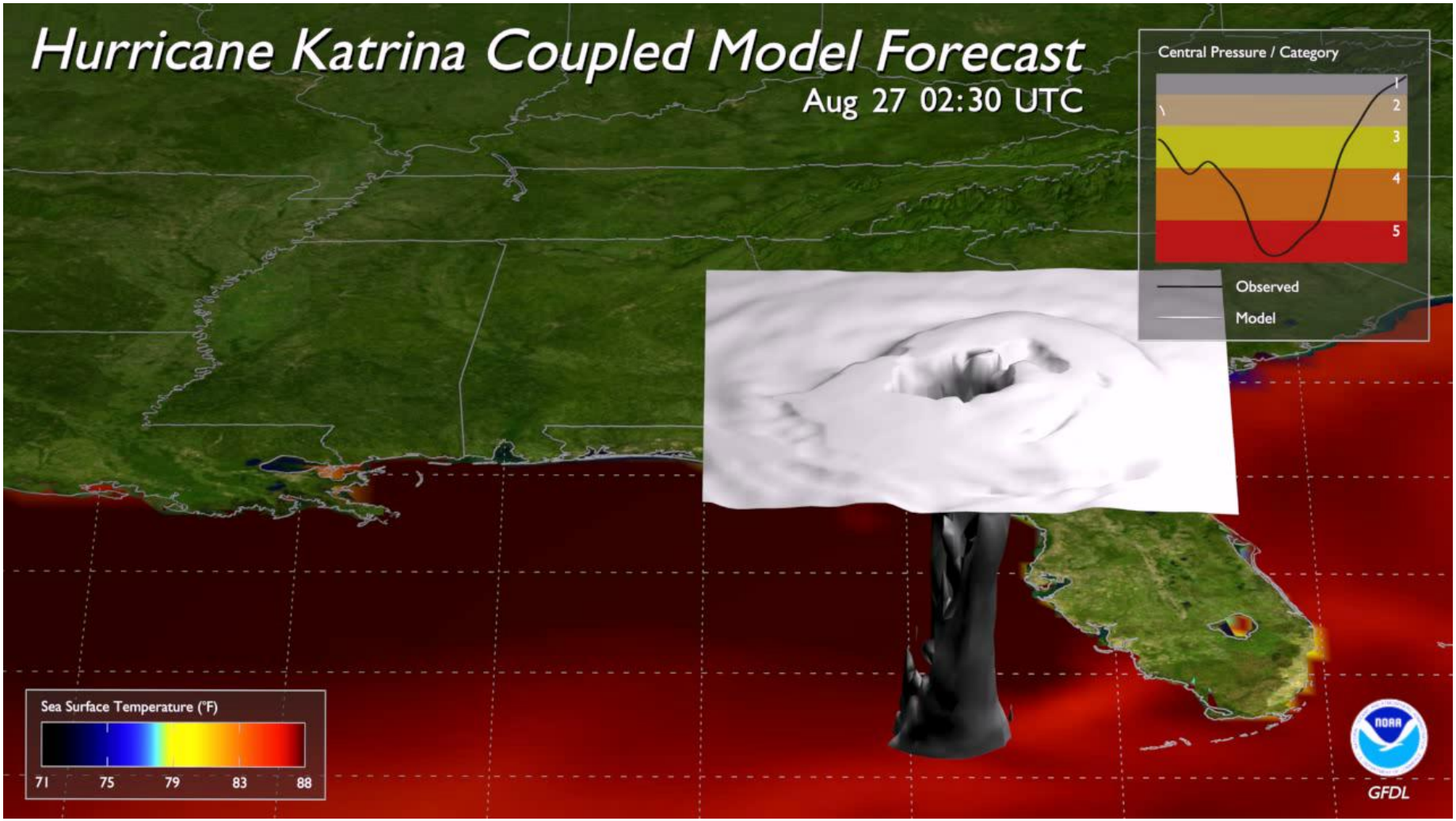
Ocean Temperature Climatology in September

Sea Surface Temperature

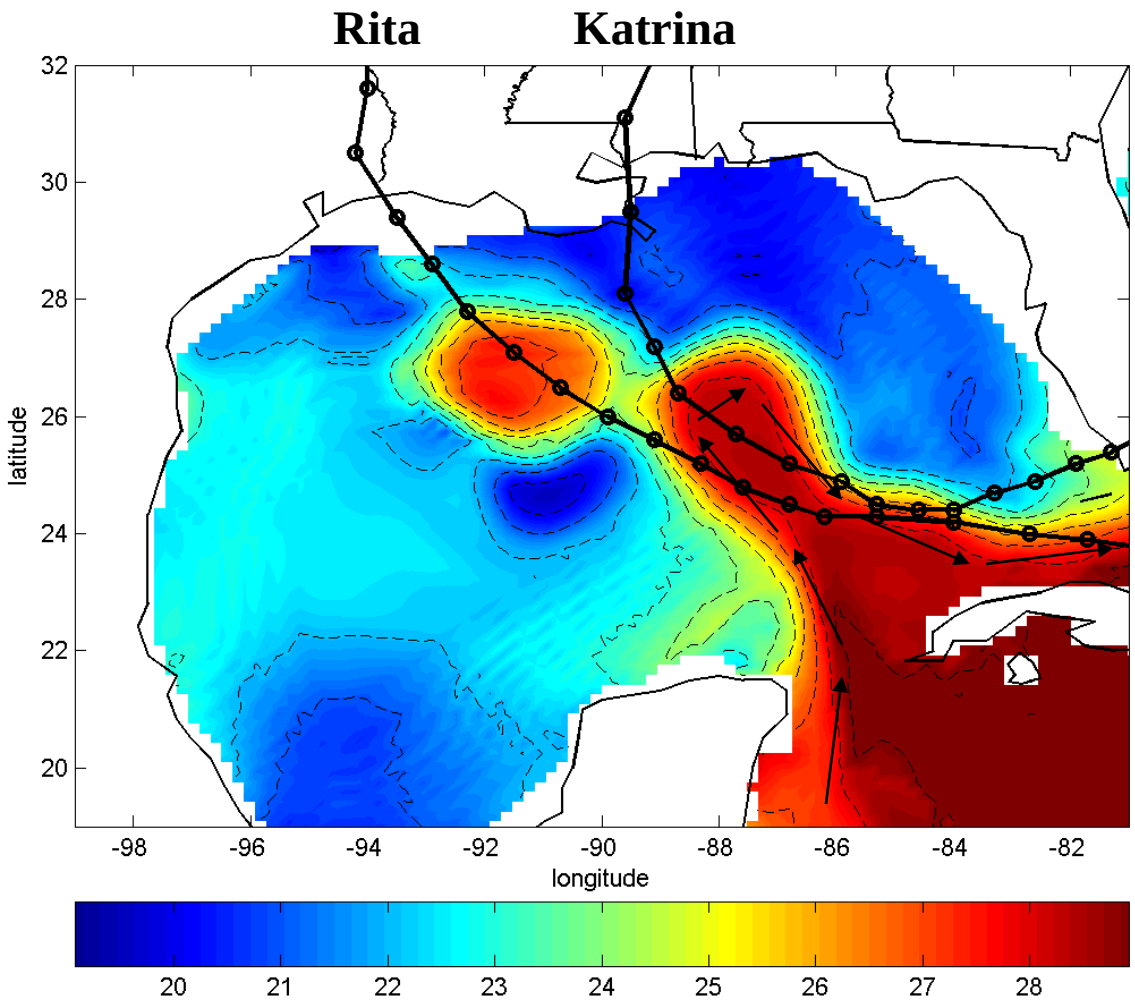


Depth of 26°C water




Hurricane Katrina Coupled Model Forecast
Aug 27 02:30 UTC
Central Pressure / Category
1
2
3
4
5
Observed
Model
Sea Surface Temperature (°F)
71
75
79
83
88
NOAA
GFDL

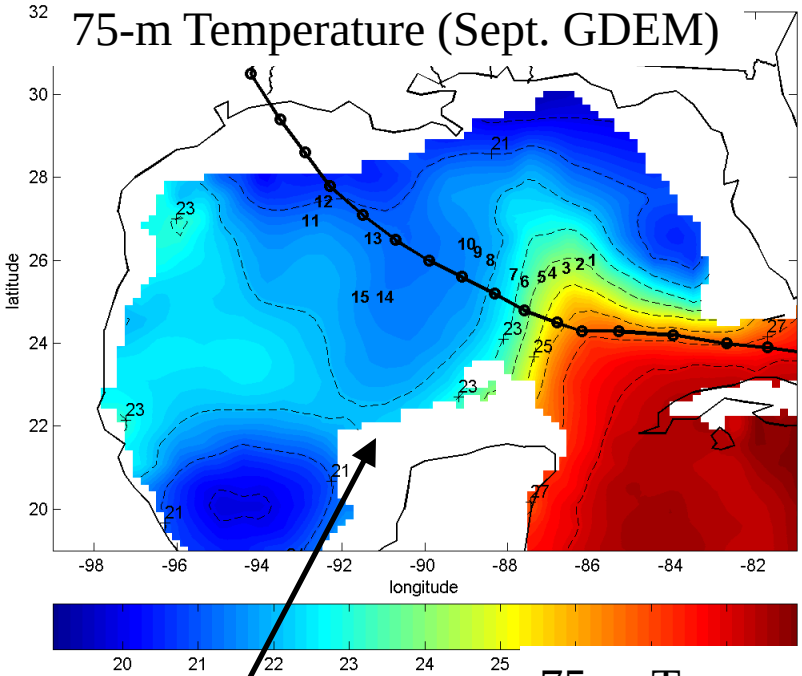
Loop Current and Eddies in Gulf of Mexico

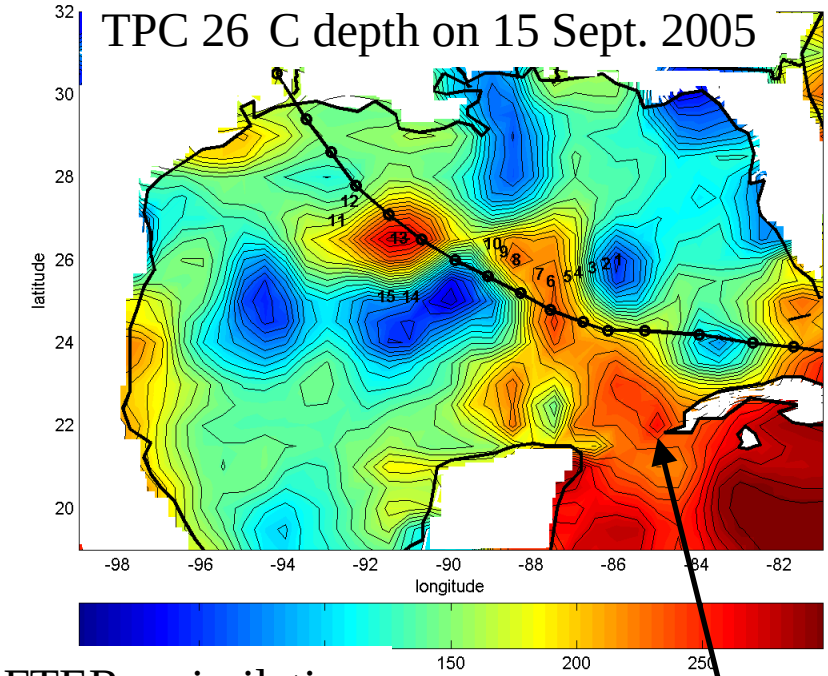


Subsurface (75-m) ocean temperature in advance of Rita initialized in POM 15 September 2005

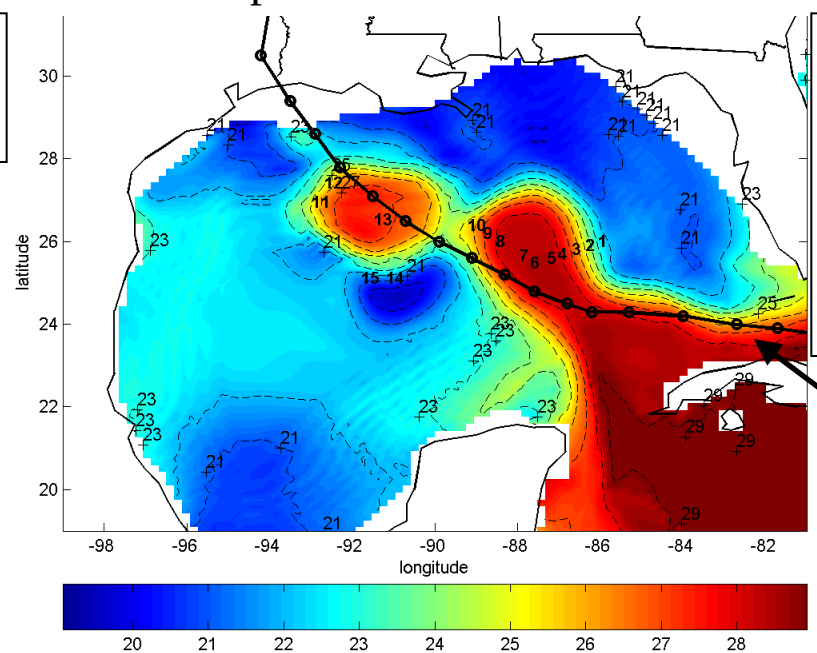
Warm "Loop Current" water and a "Warm Core Ring" extend far into the Gulf of Mexico from the Caribbean… directly under Rita's and Katrina's track

Improved Ocean Model Initialization





75-m Temperature AFTER assimilation



(1) Start with monthly climatology

(2) Adjust LC position & add warm- and cold-core eddies info derived from altimetry

(3) Assimilate SST analysis

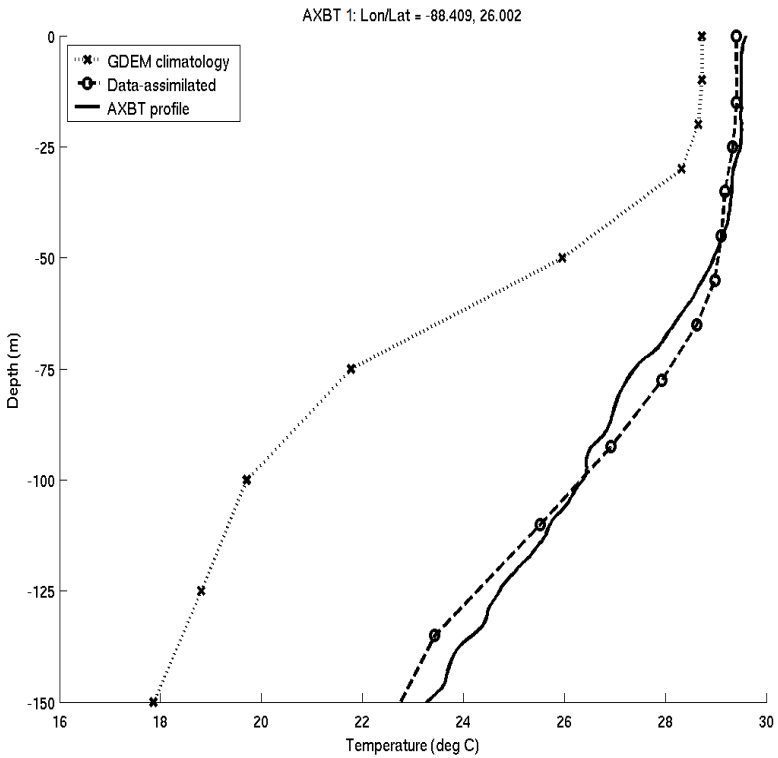
(4) Spin-up ocean currents

Future Hurricane Rita track

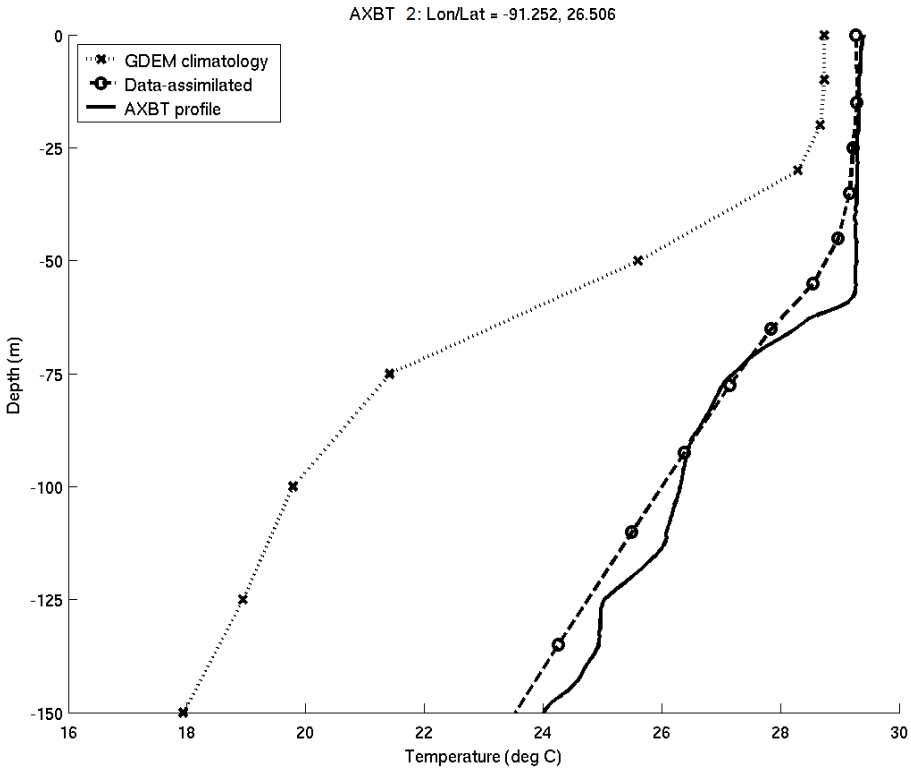
Yablonsky and Ginis (2008)

Examples of Improved Initial Vertical Temperature Structure

Loop Current

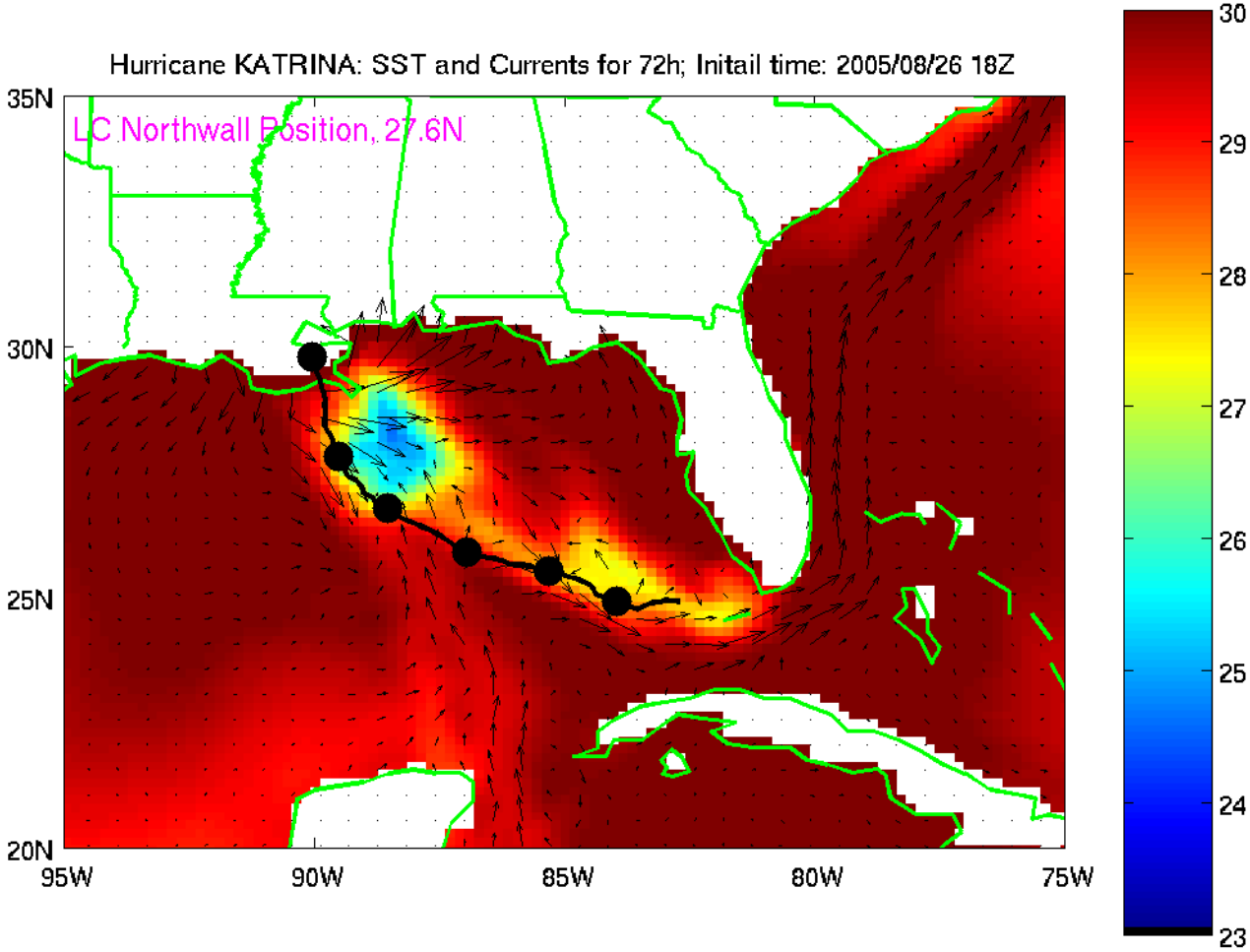


Warm-Core RIng



Yablonsky and Ginis (2008)

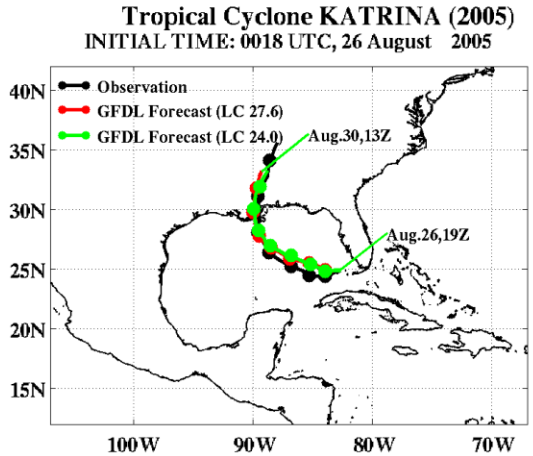
Effect of Loop Current on SST Response in Hurricane Katrina



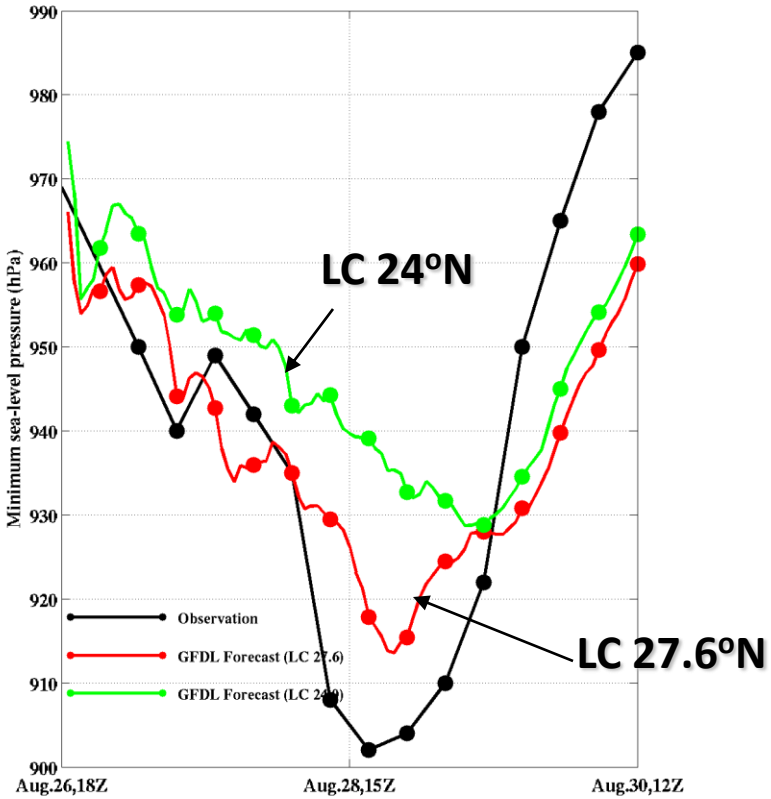
Effect of Loop Current on Hurricane Katrina

August 26th 0018 UTC, 2005

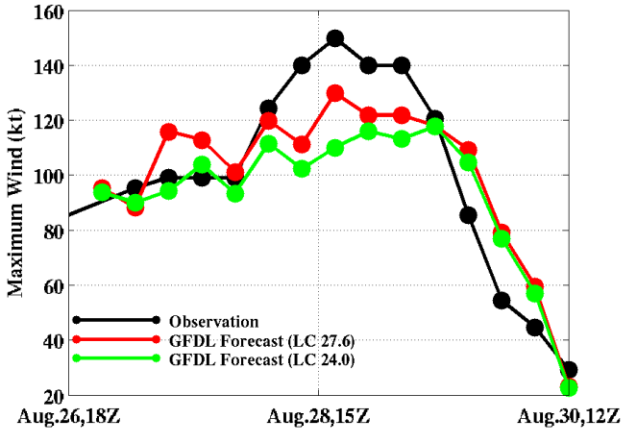
Red – LC 27.6ºN, Green – LC 24ºN



Central Pressure



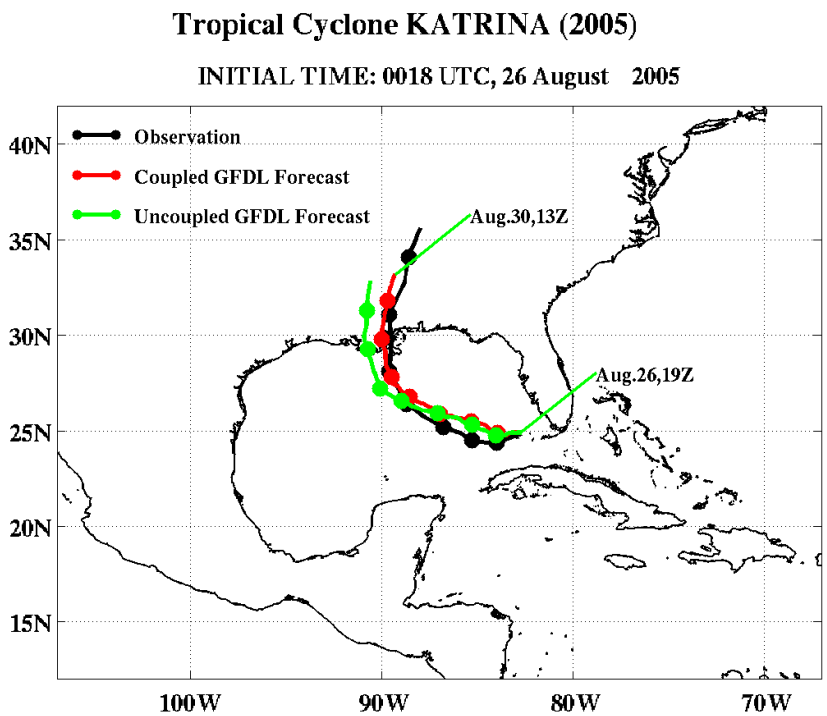
Maximum Winds

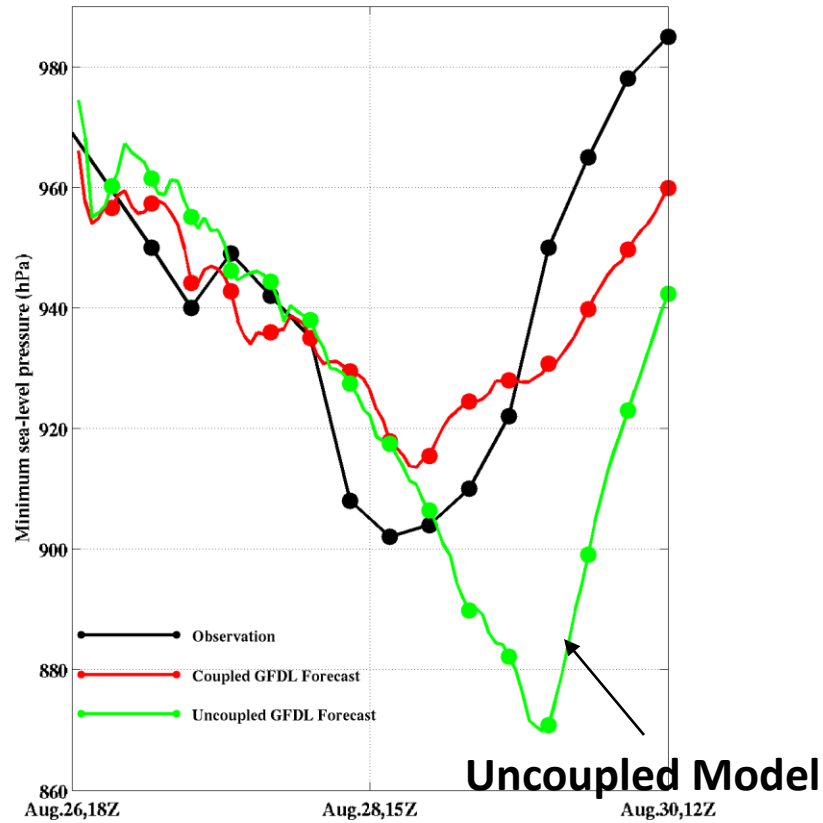


Effect of Ocean Coupling on Hurricane Katrina

August 26th 0018 UTC, 2005

Red – Coupled Model, **Green – Uncoupled Model (fixed SST)**

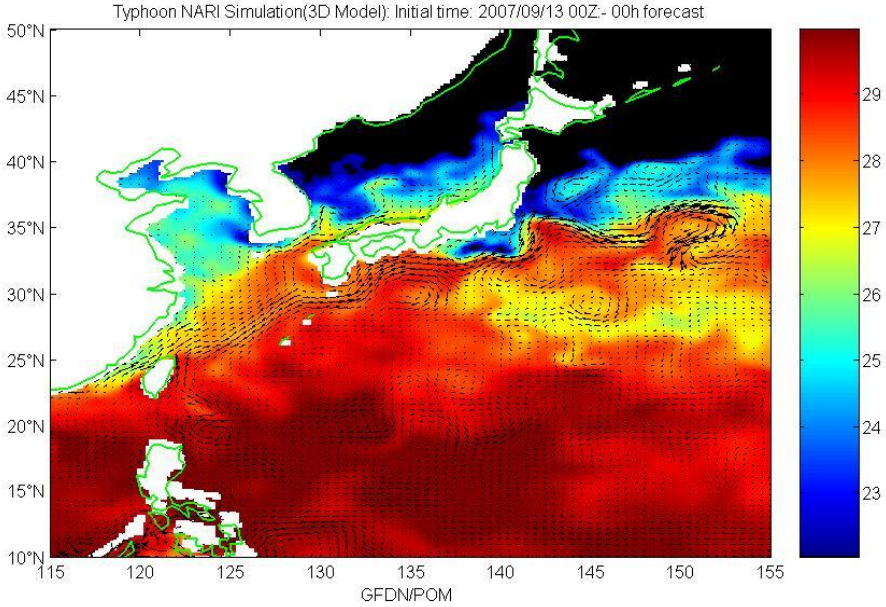




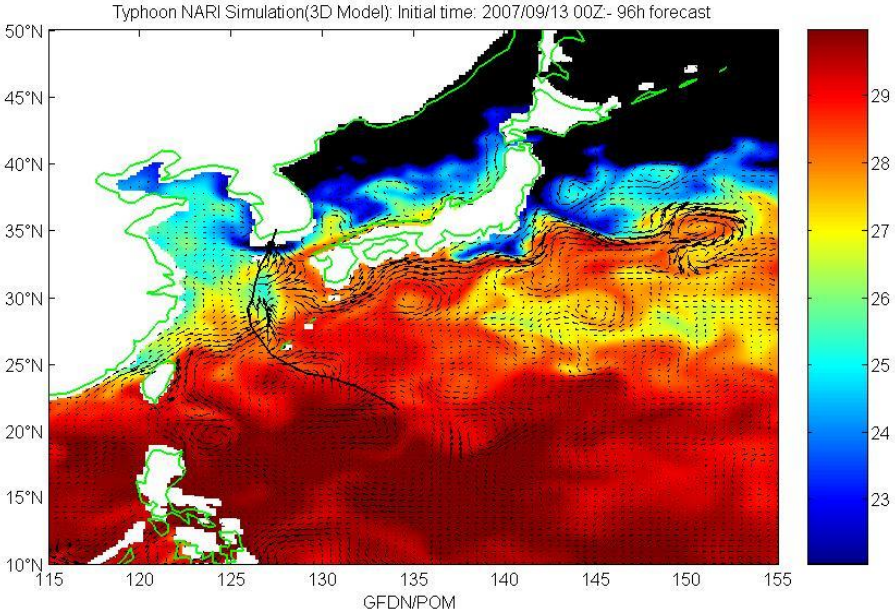
GFDN/POM is initialized from NCODA daily analysis in the Pacific Ocean

Typhoon Nary (2007)

0 hr



96 hr



NCODA analysis will be implemented into GFDN /POM in the Atlantic basin in 2010

Ocean response to hurricane forcing:
1. Vertical mixing/entrainment

ATMOSPHERE

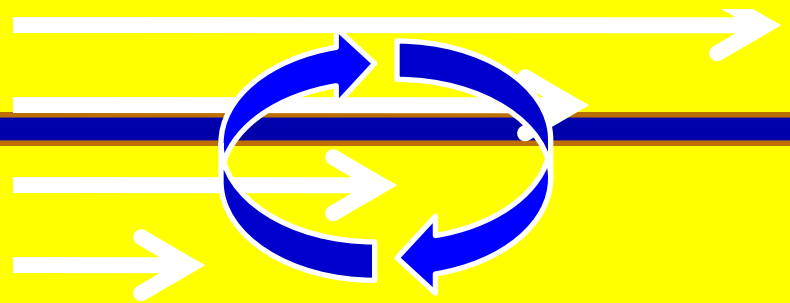
Wind stress → surface layer currents

Current shear → turbulence

Turbulent mixing → entrainment of cooler water

OCEAN

Sea surface temperature decreases



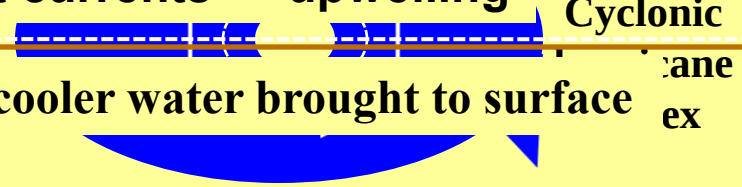
Subsurface temperature increases

This is a 1-D (vertical) process

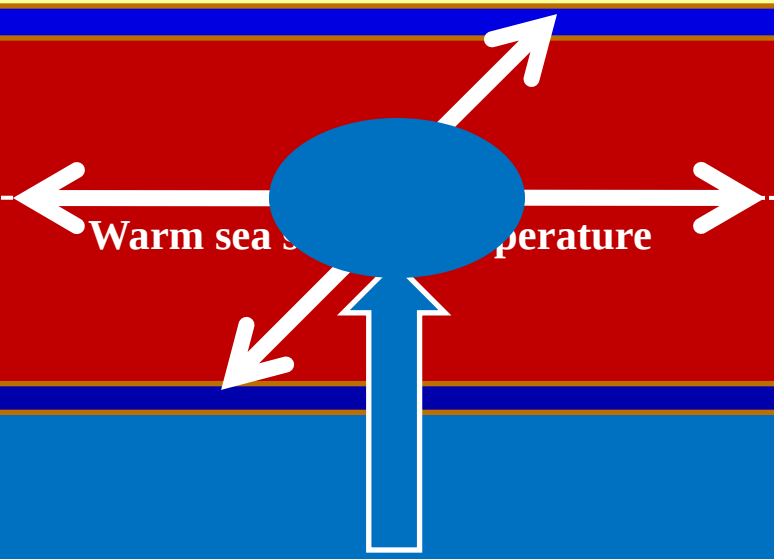
Ocean response to hurricane forcing: 2. Upwelling

Cyclonic wind stress → divergent surface currents

Divergent currents → upwelling



Upwelling → cooler water brought to surface



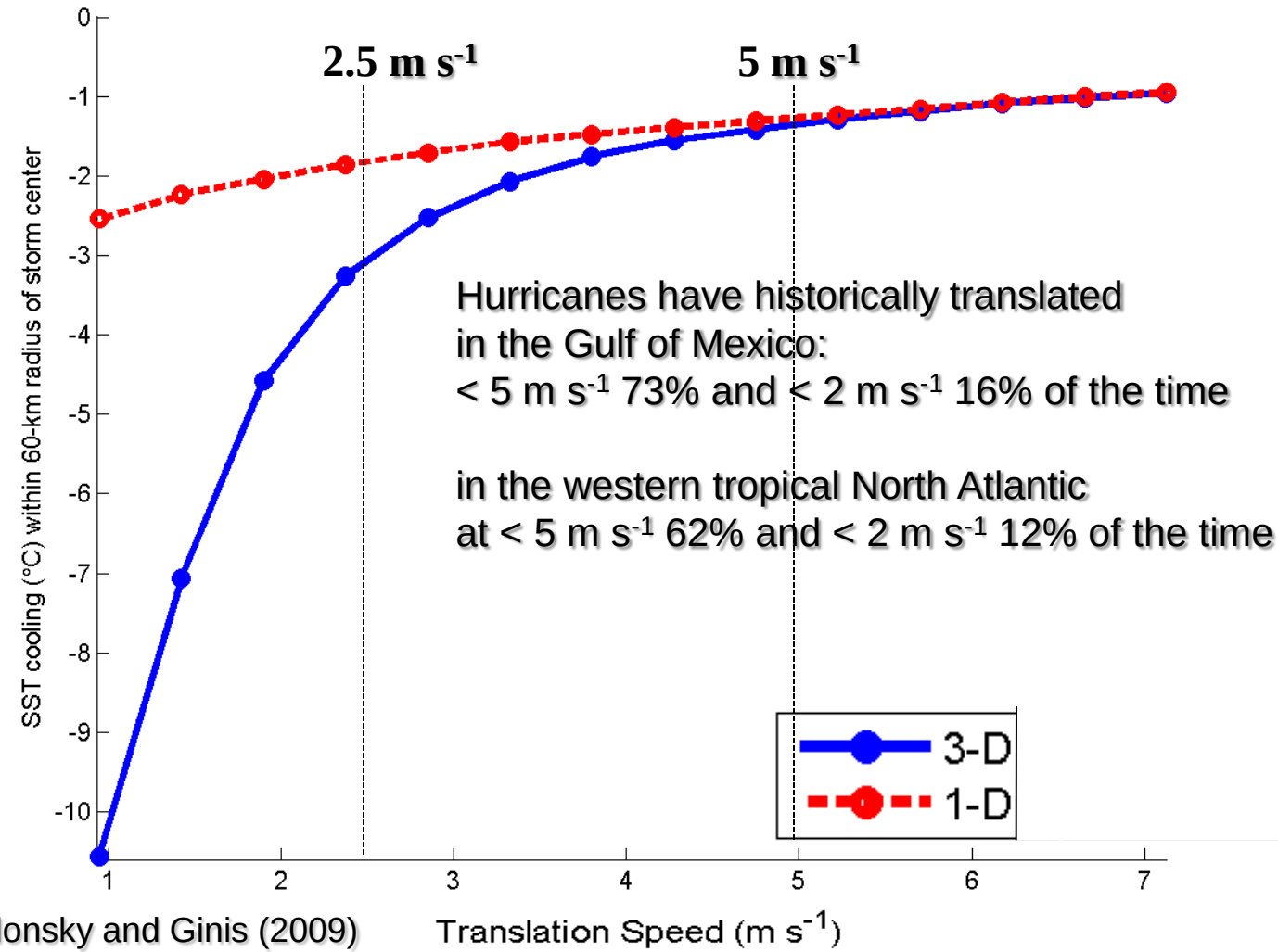
Cool subsurface temperature

ATMOSPHERE

OCEAN

This is a 3-D process

SST cooling within hurricane inner-core in 3D and 1D ocean models

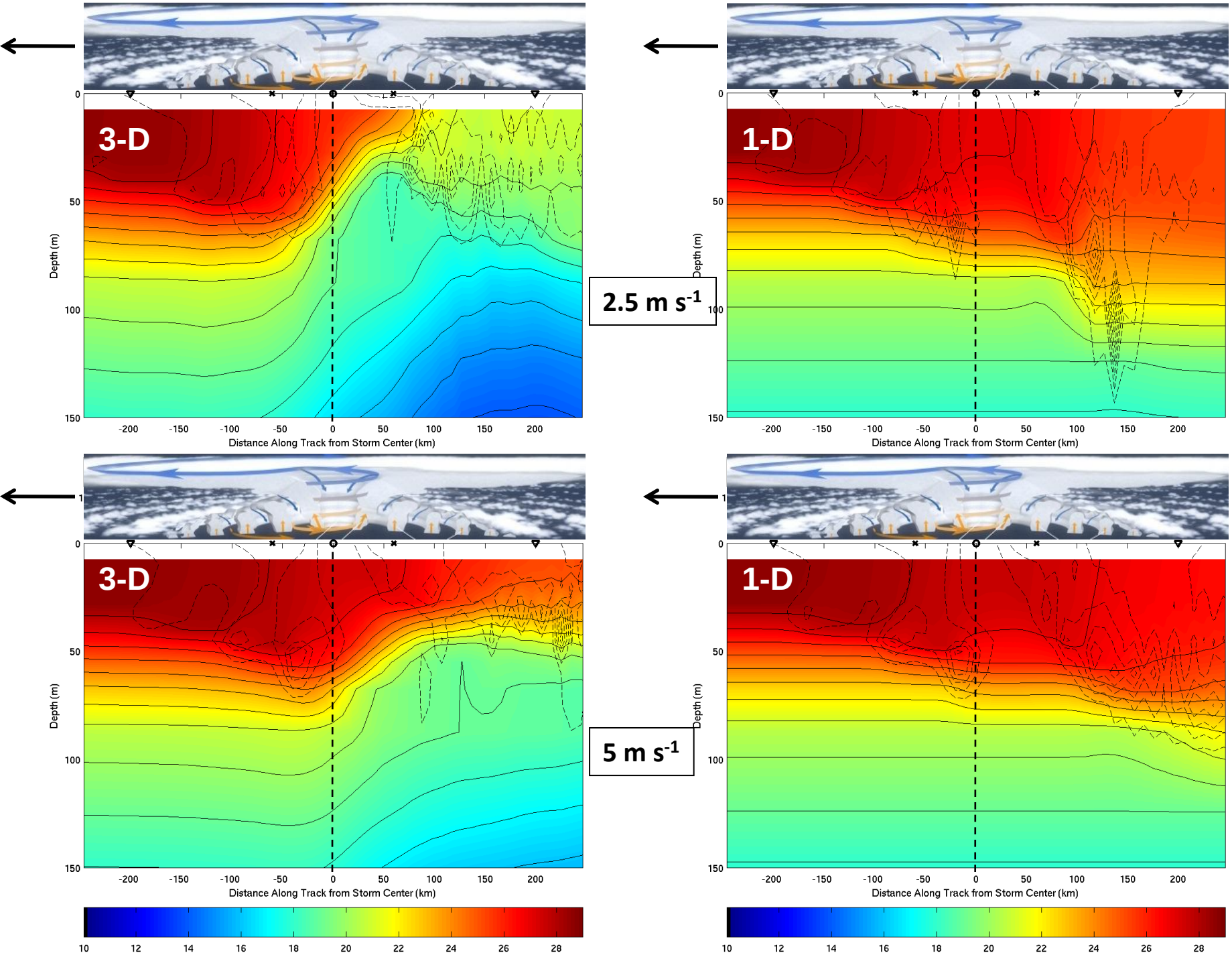


Hurricanes have historically translated in the Gulf of Mexico:
< 5 m s^{-1} 73% and < 2 m s^{-1} 16% of the time

in the western tropical North Atlantic
at < 5 m s^{-1} 62% and < 2 m s^{-1} 12% of the time

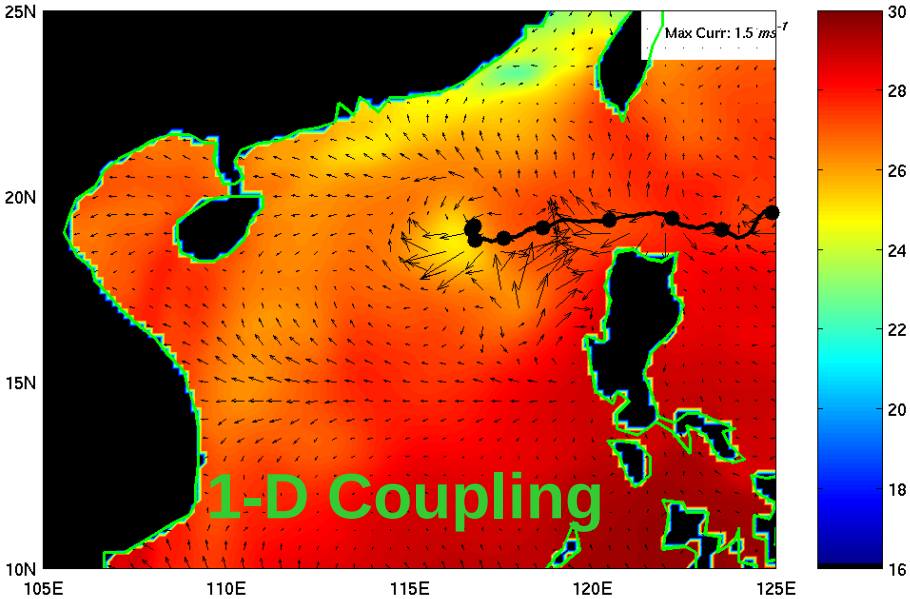
Yablonsky and Ginis (2009)

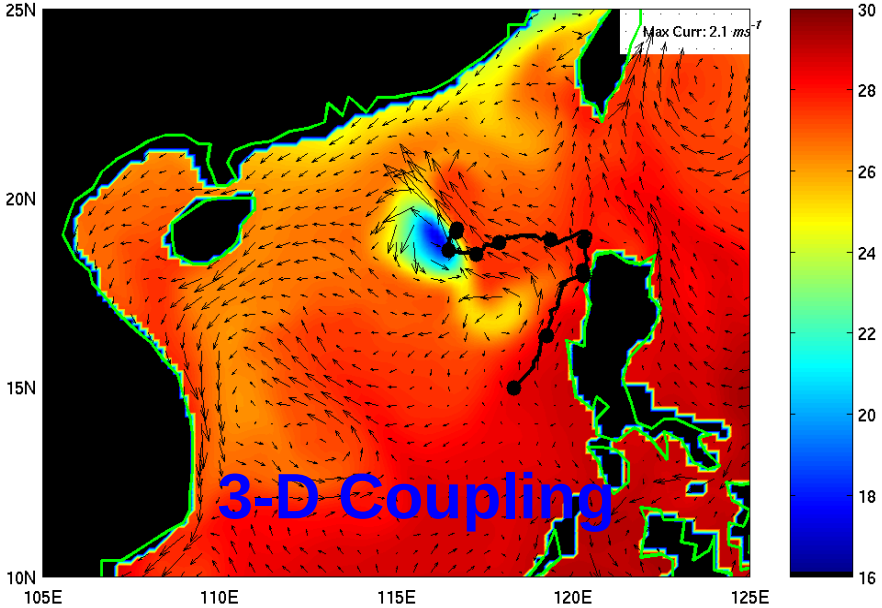
Translation Speed (m s^{-1})


3-D
1-D
2.5 m s-1
5 m s-1
Depth (m)
Distance Along Track from Storm Center (km)
0
50
100
150
-200
-150
-100
-50
0
50
100
150
200
10
12
14
16
18
20
22
24
26
28

GFDN Coupled Model Forecast

Typhoon Cimaron: November 2nd, 0000 UTC, 2006

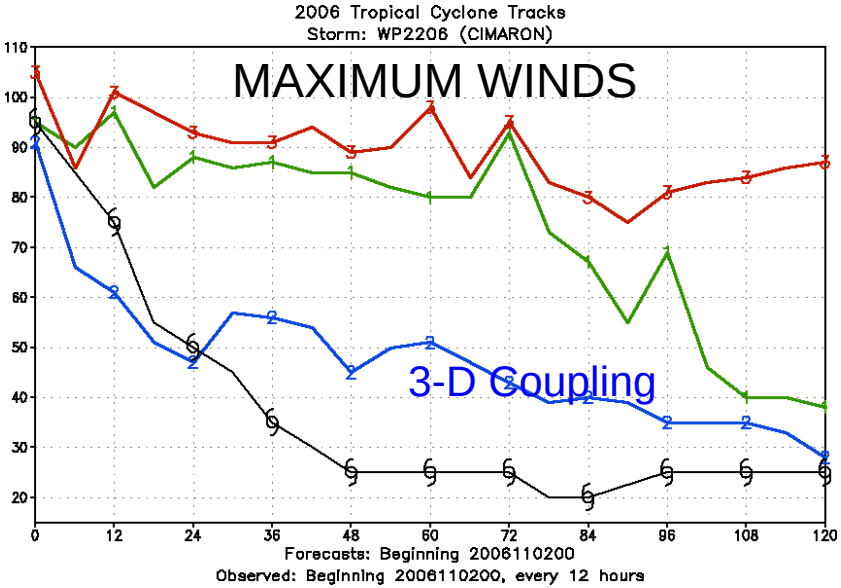


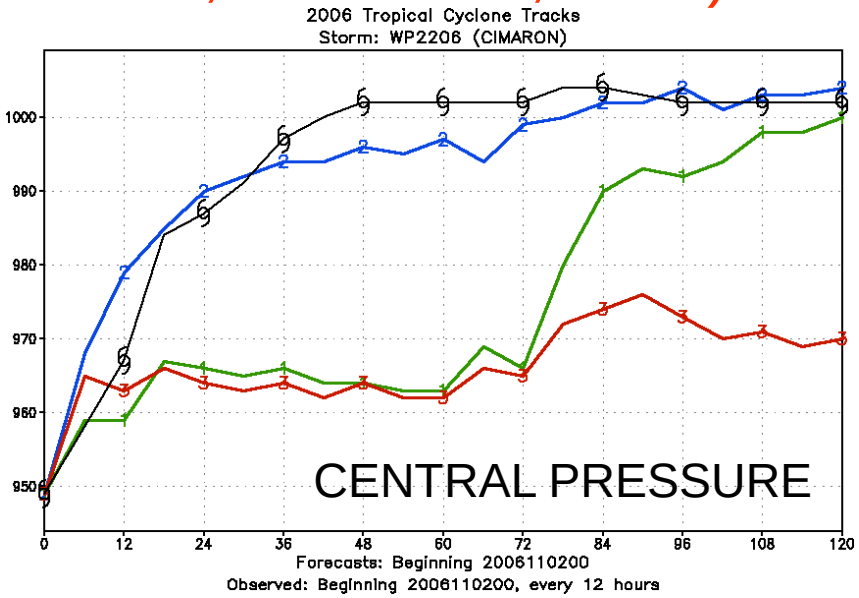


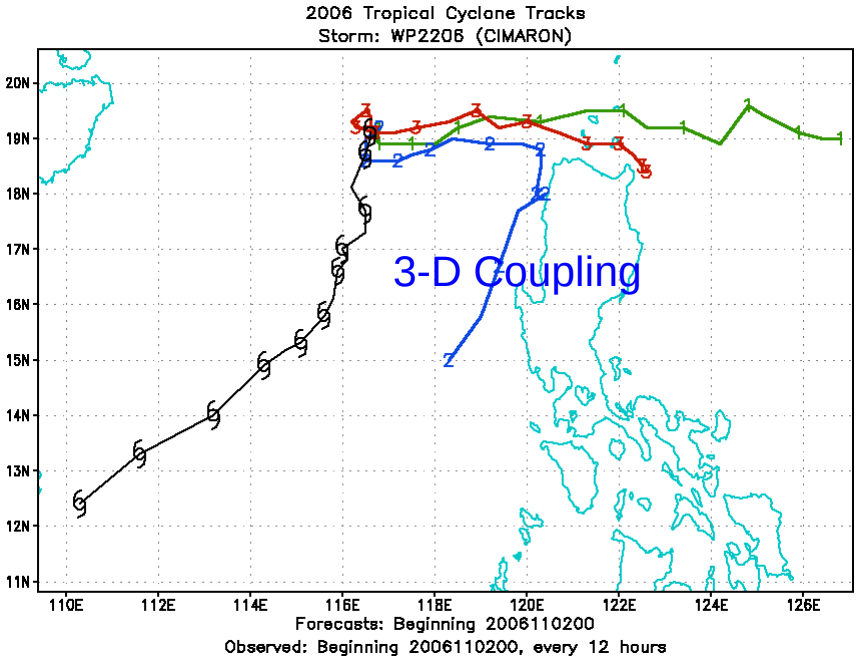
Demonstrates Importance of Upwelling for Slow Moving Storm

Significantly Improved Prediction of Track and Intensity

(Typhoon Cimaron: November 2nd , 0000 UTC, 2006)





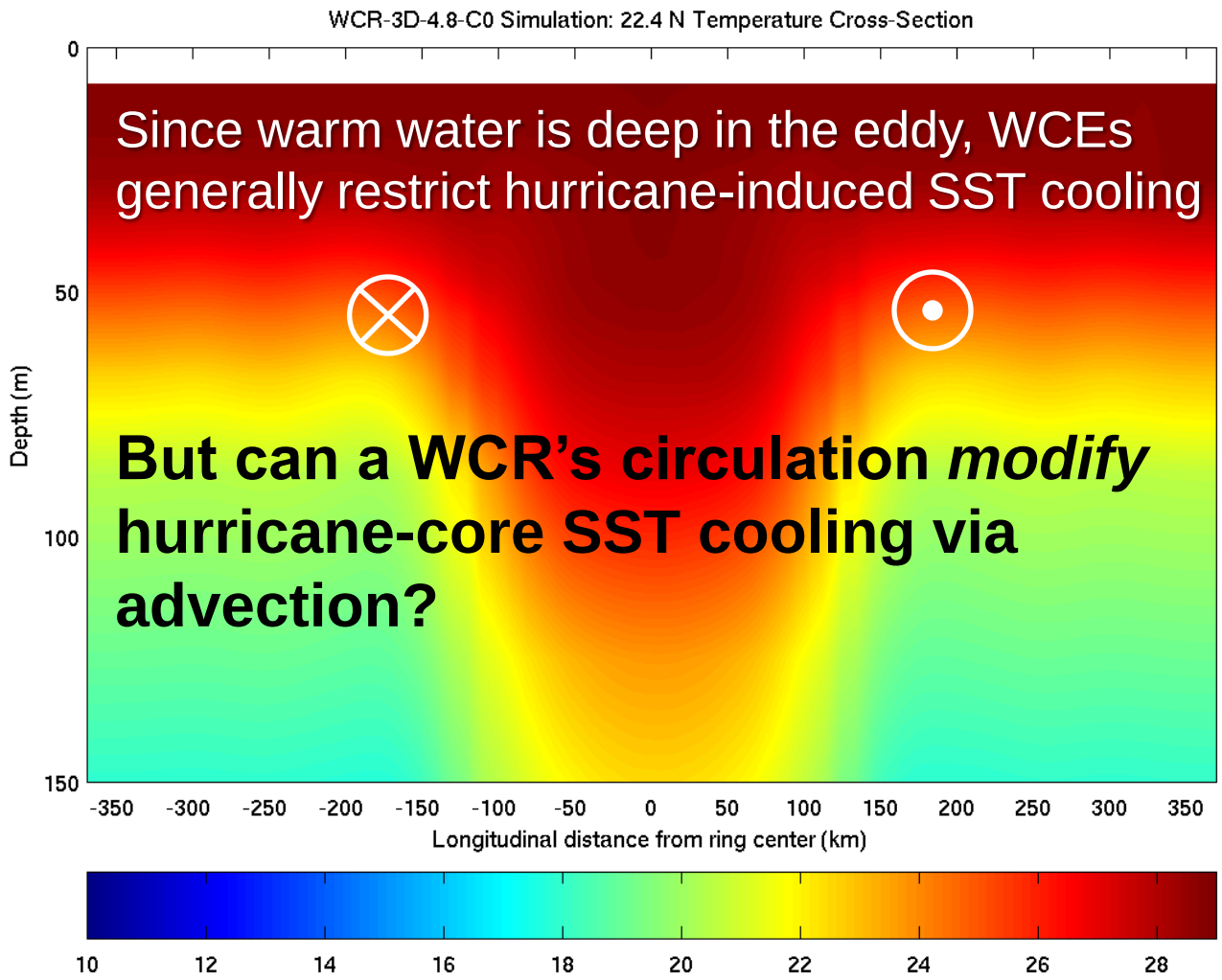


3-D OCEAN COUPLING

1-D OCEAN COUPLING

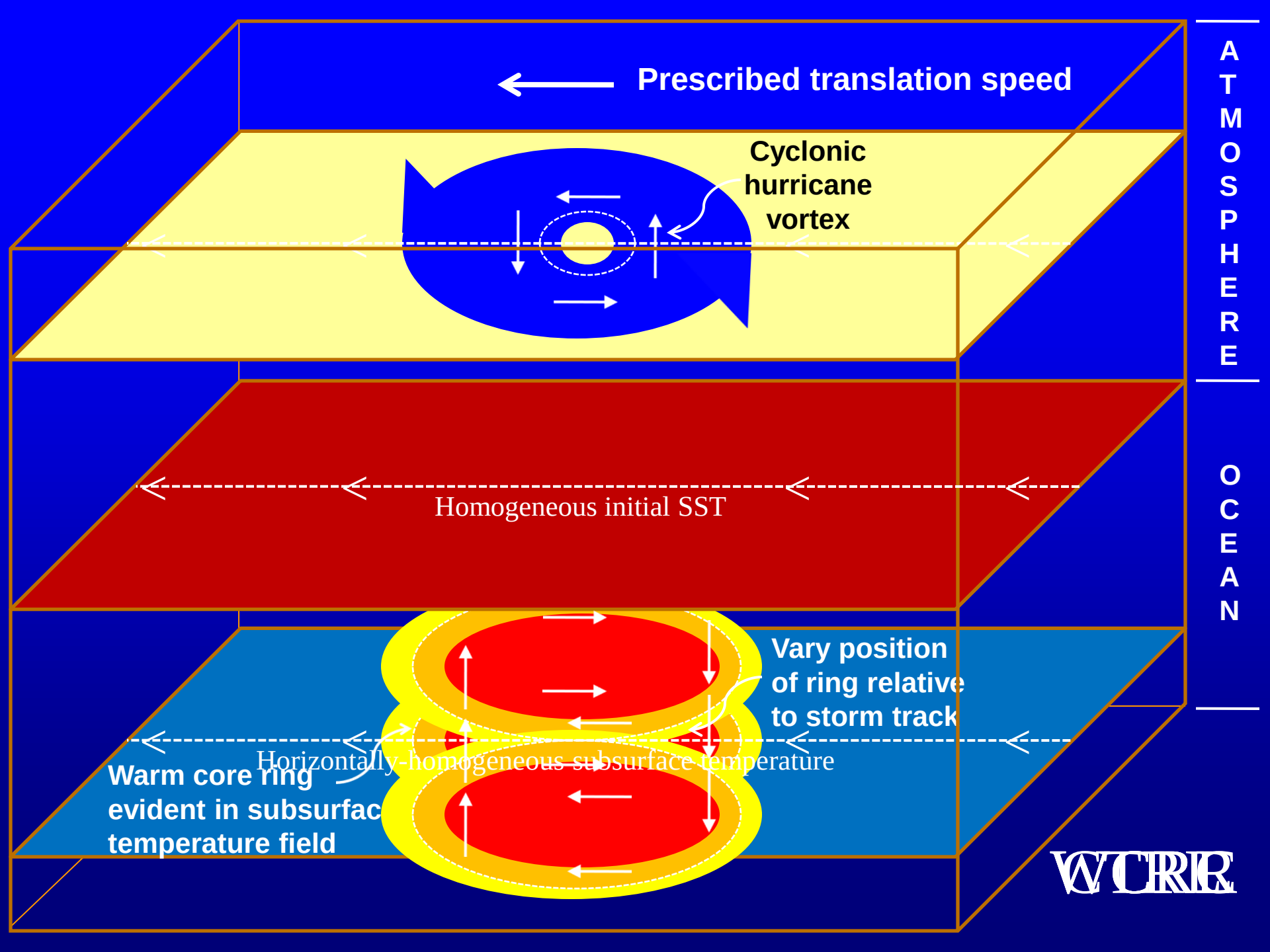
2006 OPERATIONAL GFDN

Warm-core ring is not just high ocean heat content

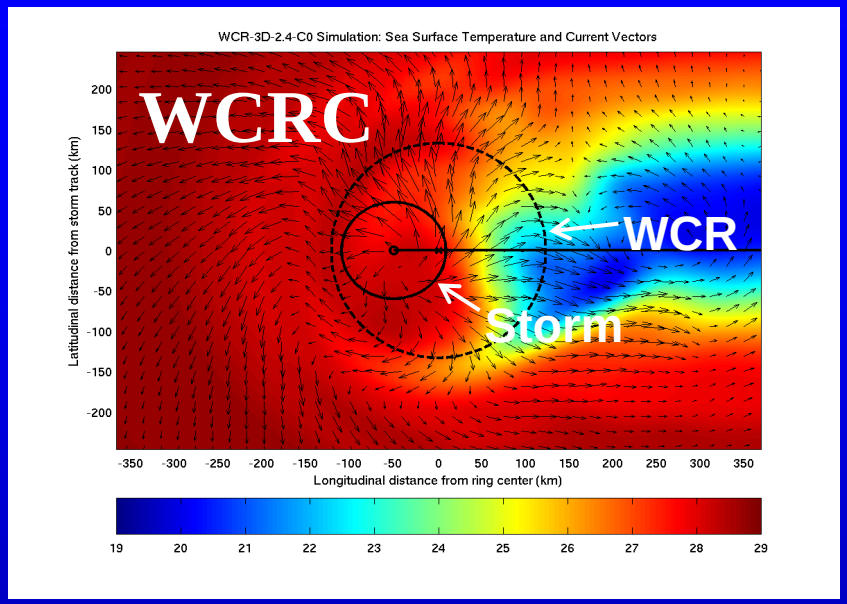


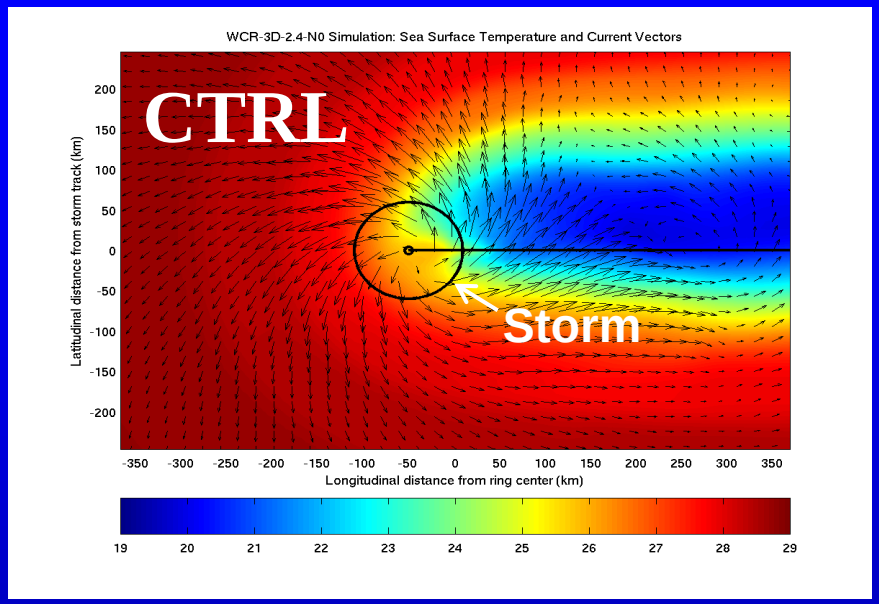
Since warm water is deep in the eddy, WCEs generally restrict hurricane-induced SST cooling

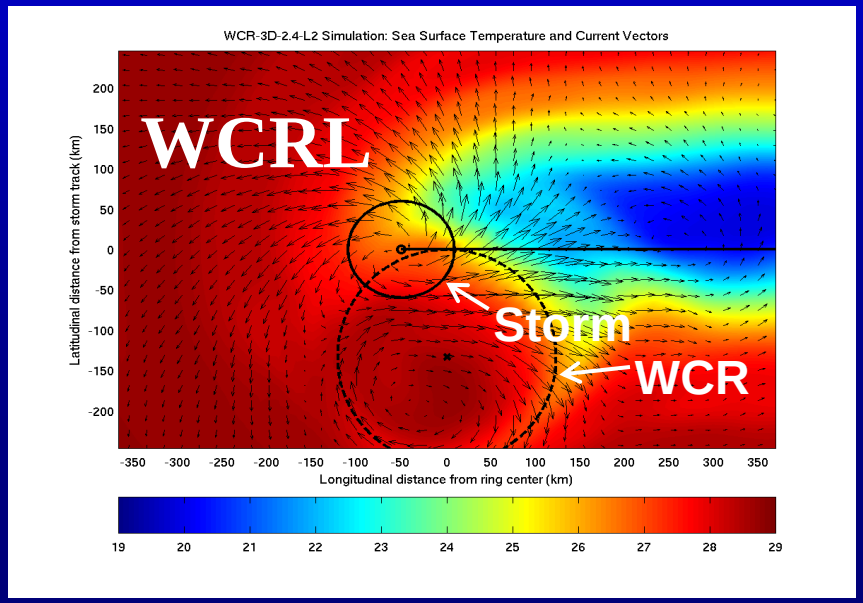
But can a WCR's circulation *modify* hurricane-core SST cooling via advection?

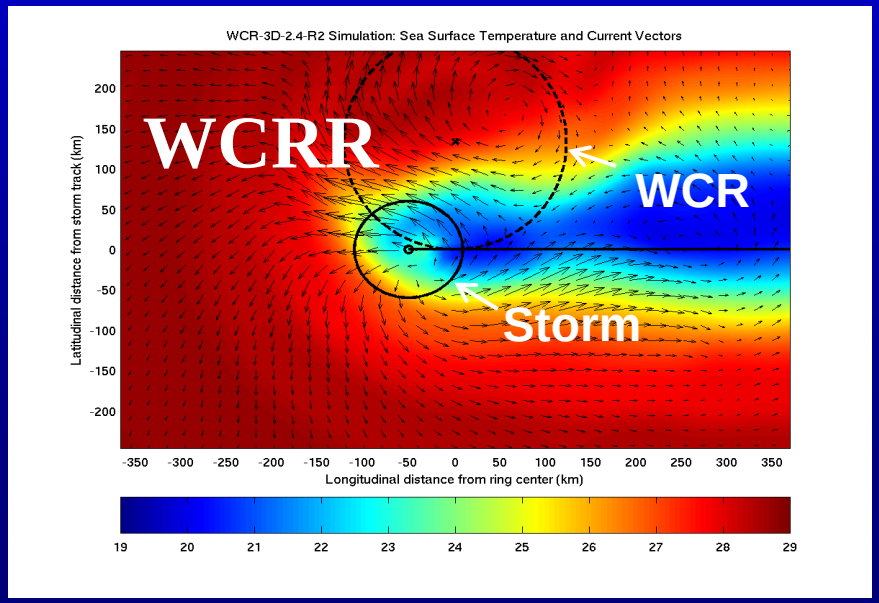

Prescribed translation speed
Cyclonic hurricane vortex
ATMOSPHERE
Homogeneous initial SST
OCEAN
Vary position of ring relative to storm track
Horizontally-homogeneous subsurface temperature
Warm core ring evident in subsurfac temperature field
WCRR

SST and Surface Currents in 4 idealized experiments

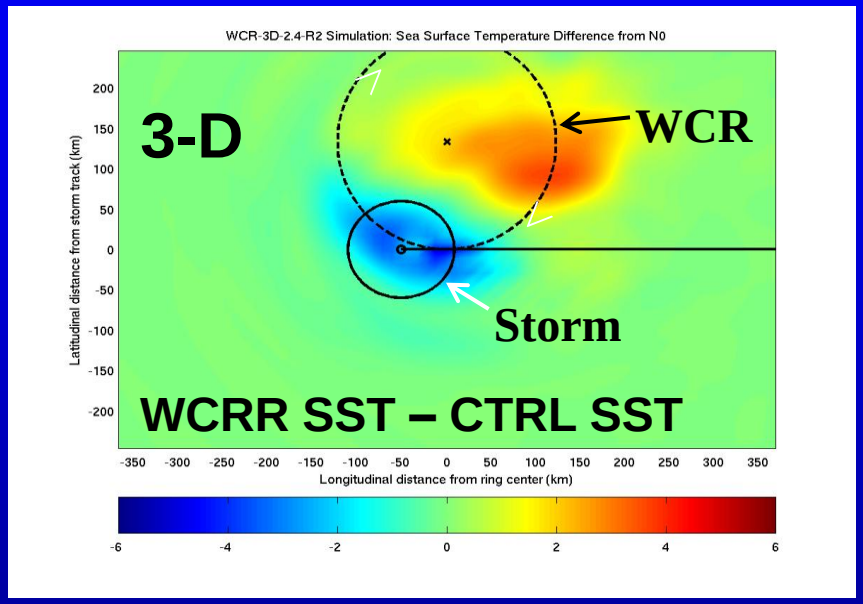


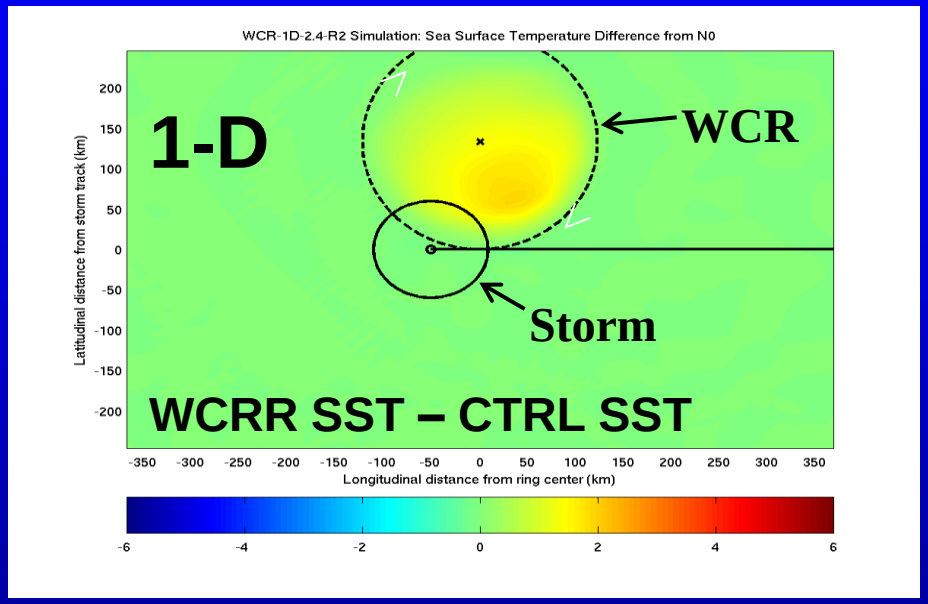






Differences in SST cooling within hurricane inner-core with and without WCR





The presence of a warm core eddy in advance of a hurricane may in some cases create <u>a *less favorable*</u> condition for hurricane intensification

Conventional Coupling Between Atmospheric 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

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

$$Q_H = C_H (U_a - U_s)(T_a - T_s)$$

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

Traditional Assumptions of Air-Sea Coupling May Not Valid in Hurricane Conditions

- Momentum and enthalpy exchange coefficients are function of *wind speed* only (sea state dependence is neglected)

- Momentum flux into currents is identical to wind stress (momentum gained/lost by surface waves is neglected)

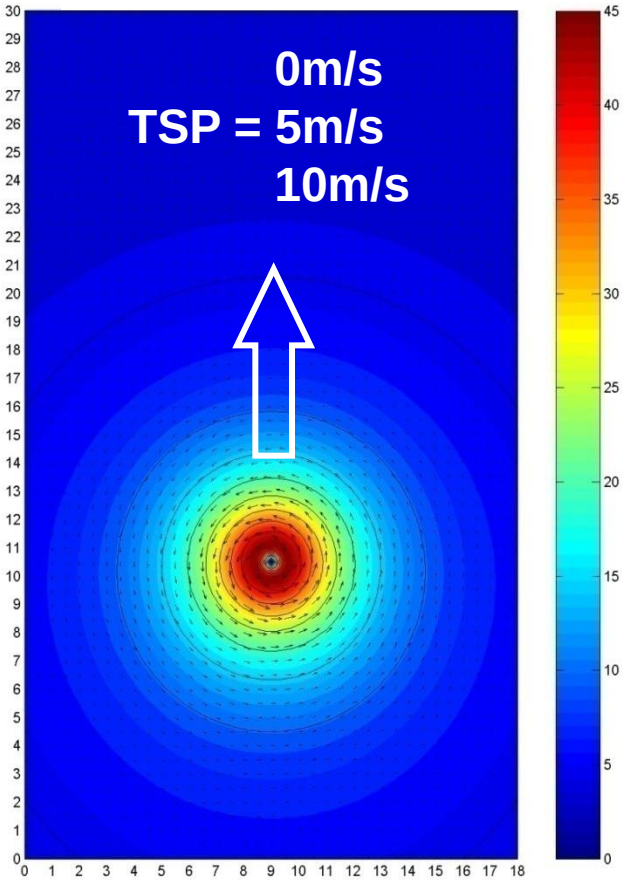
- Also neglected:
  - Wind-wave-current interaction
  - Sea spray effects

Waves Generated by Tropical Cyclones

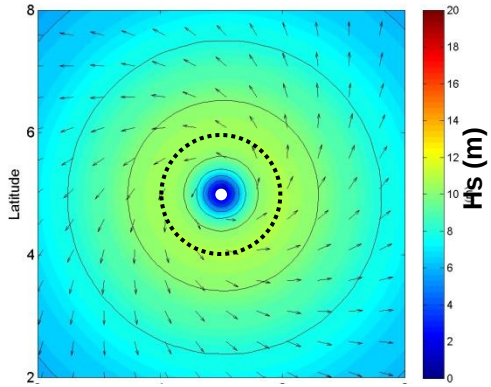
WAVEWATCH III wave model calculations

Wave Field

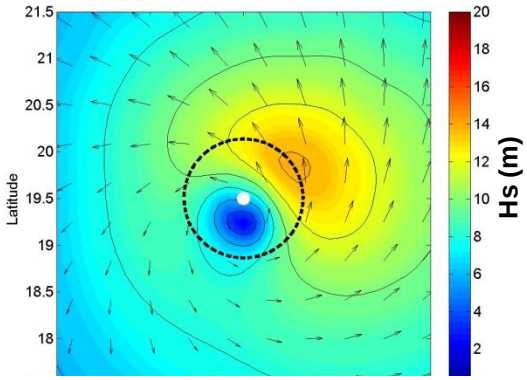
Wind Field (m/s)



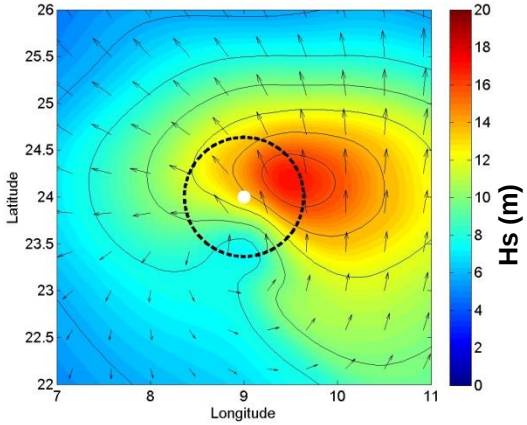
TSP 0m/s



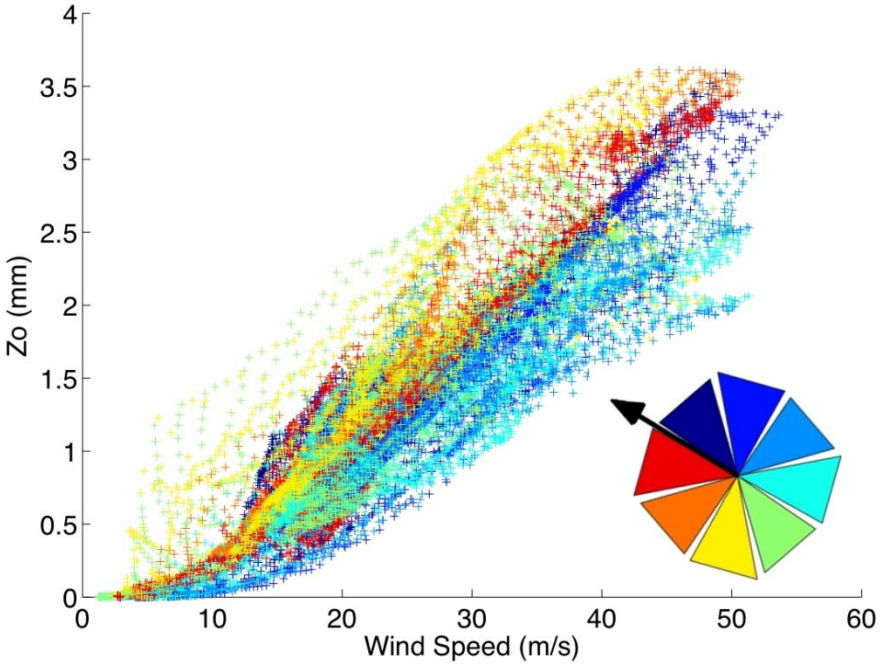
TSP 5m/s

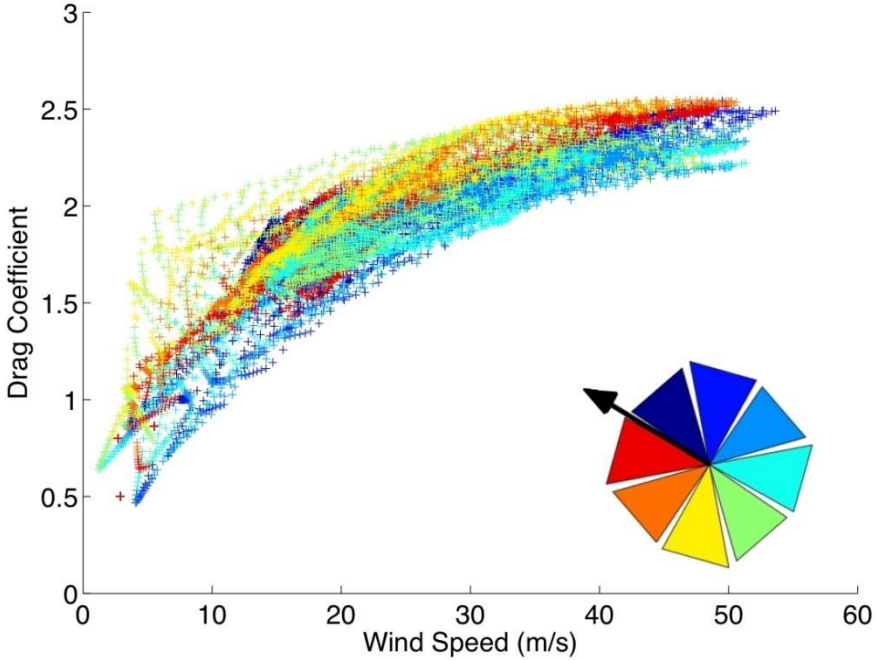


TSP 10m/s



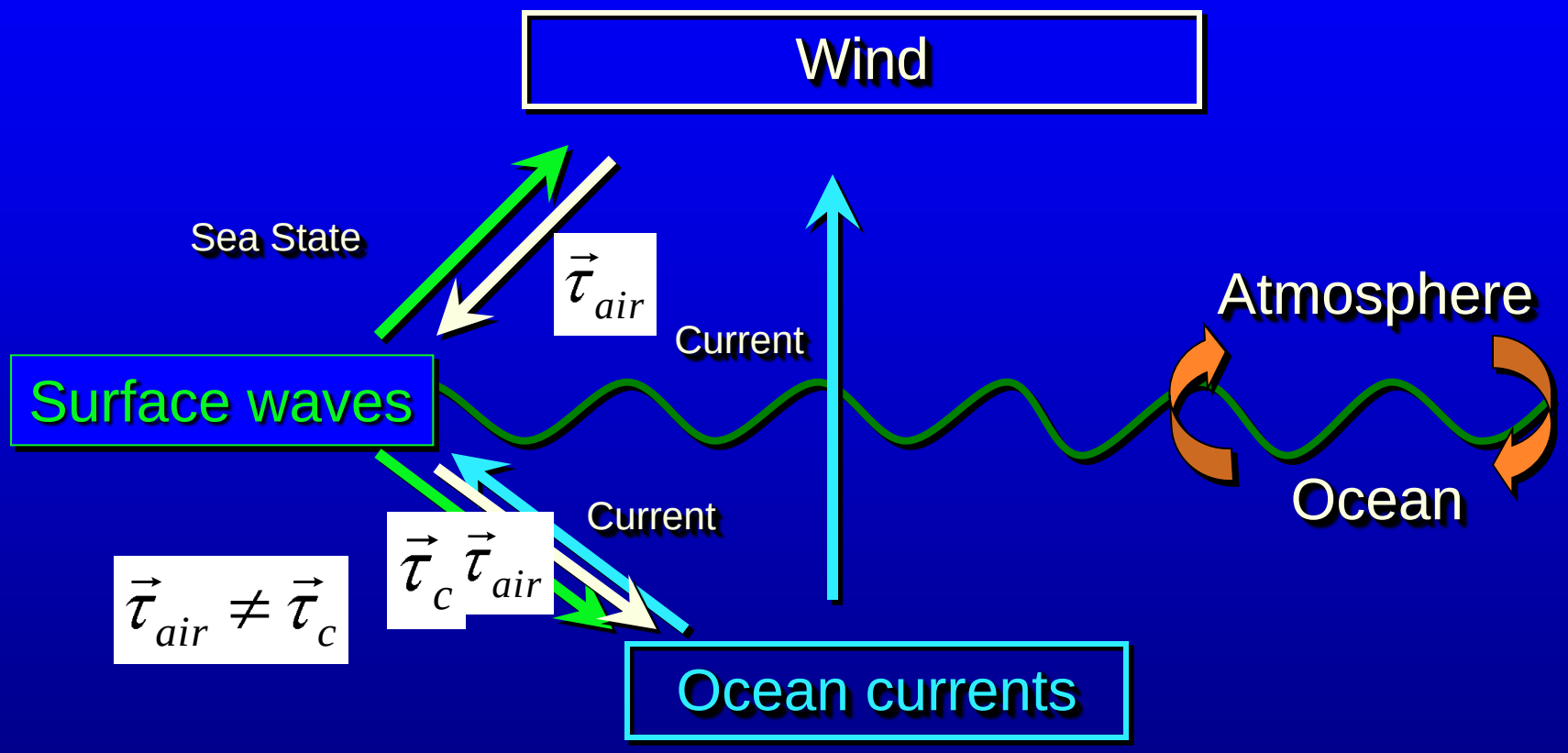
Sea State Dependence of Surface Parameters





GFDL hurricane-wave-ocean research model

Wind-Wave-Current Interaction

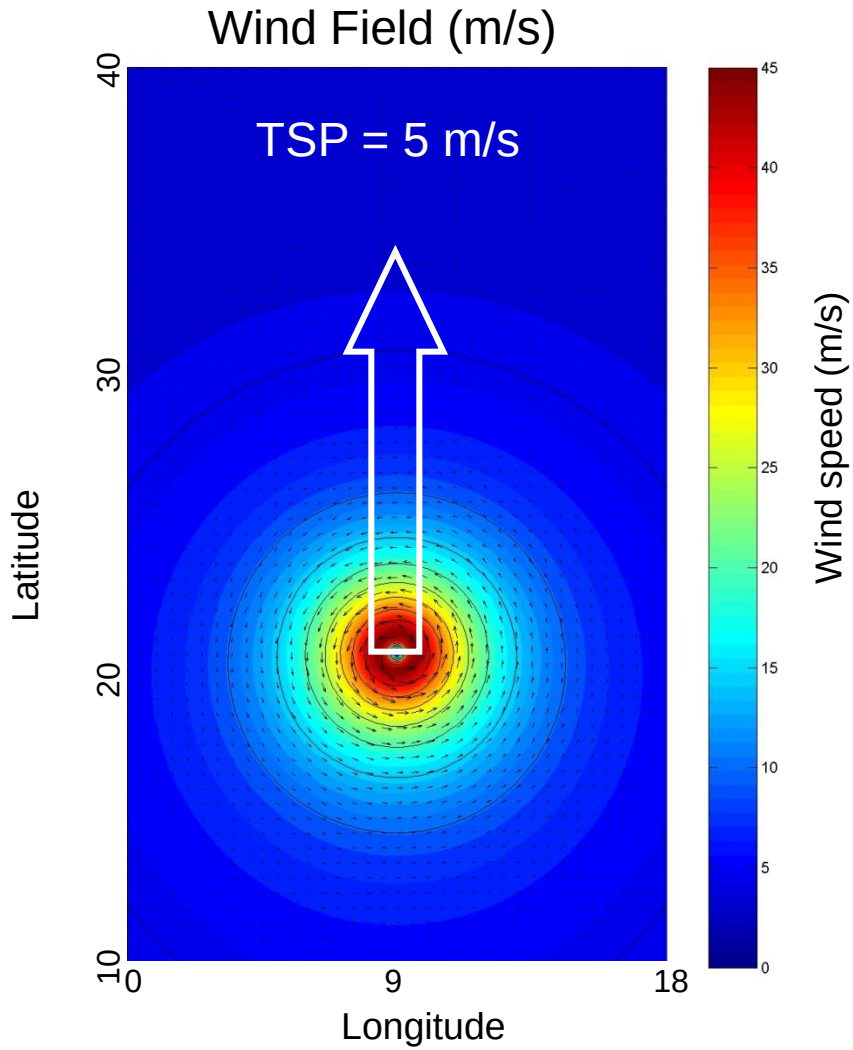


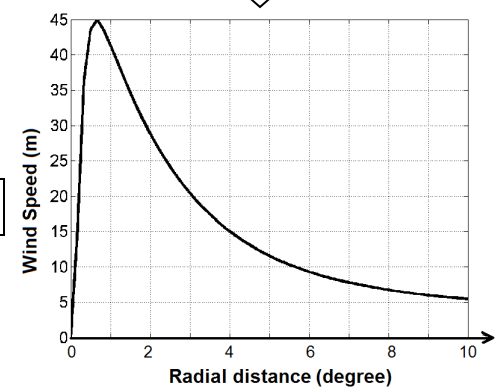
Fan, Y., I. Ginis, T. Hara, W. Wright, and E. Walsh, 2009a,. *J. Phys. Oceanogr.*, 39, 2097-2116
Fan, Y., I. Ginis, and T. Hara, 2009b,. *J. Phys. Oceanogr.*, 39, 1019-1034.
Fan, Y., I. Ginis, and T. Hara, 2010. *J. Phys. Oceanogr.*, in review.

Difference Between Wind Stress (τ_{air}) and Momentum Flux into Ocean (τ_c): Idealized Experiment

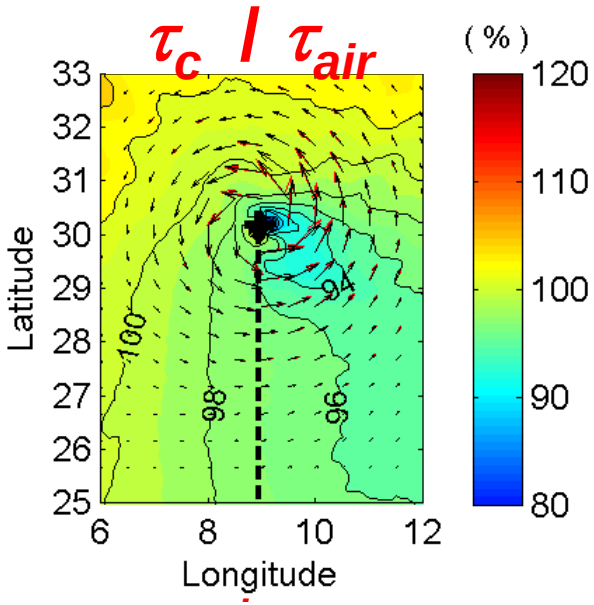
Holland Hurricane Wind Model

Input parameters:
Maximum wind speed (MWS)
Radius of MWS (RMW)
Central & environmental sea-level pressure



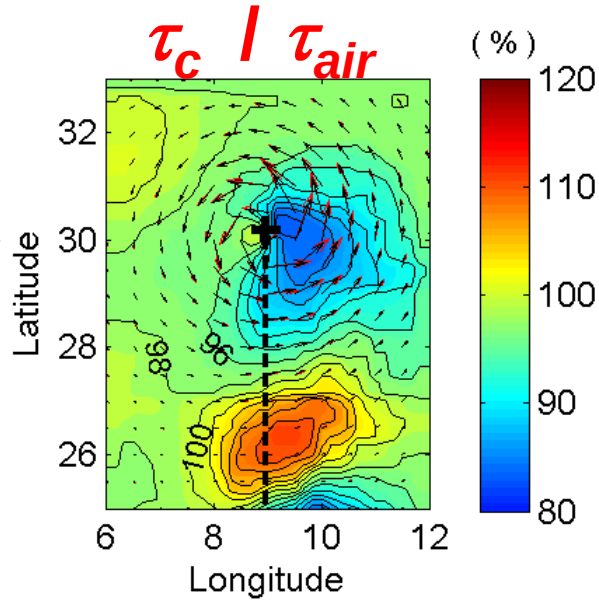


Effect of Wind-Wave-Current Interaction on Momentum Fluxes into Ocean



Effect of waves (flux budget)

Effect of wind-wave-current interaction



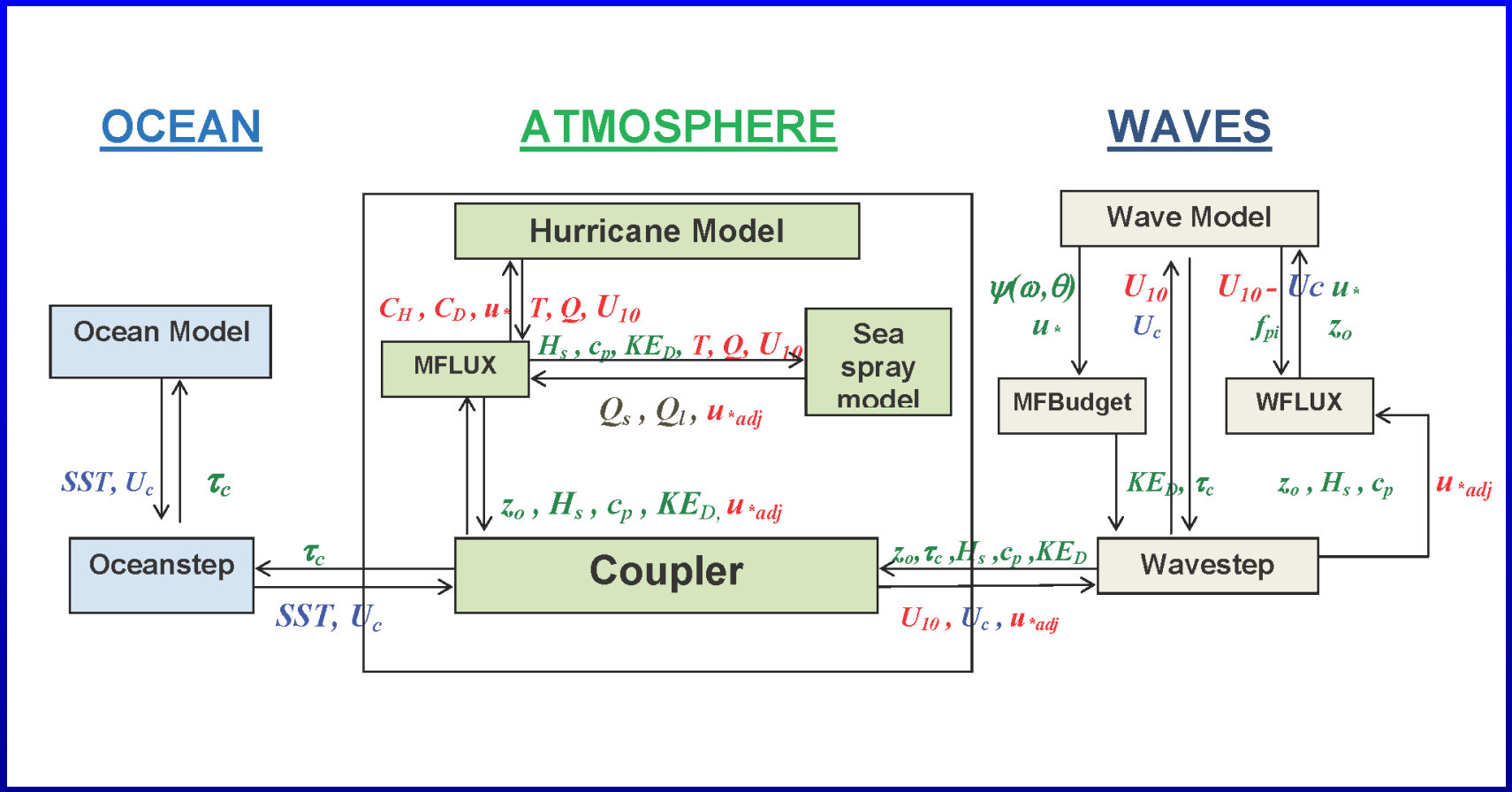
Air-Sea Coupling Strategies for Tropical Cyclone Models

- In the TC model, parameterizations of the air-sea heat and momentum fluxes and sea spray source functions explicitly include *SST*, *sea state dependence* and *ocean current effects*.

- The wave model is forced by *sea-state dependent momentum flux* and includes *ocean current effects*.

- The ocean model is forced by *sea-state dependent momentum fluxes.*

Coupled Hurricane-Wave-Ocean Framework



- Implemented in GFDL model in a research mode.
- To be implemented in HWRF later this year