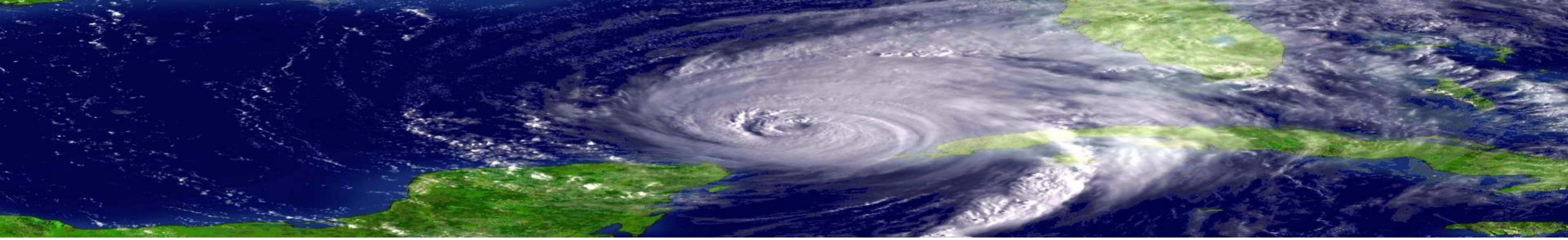


Advances in the modeling of tropical cyclone-ocean interactions

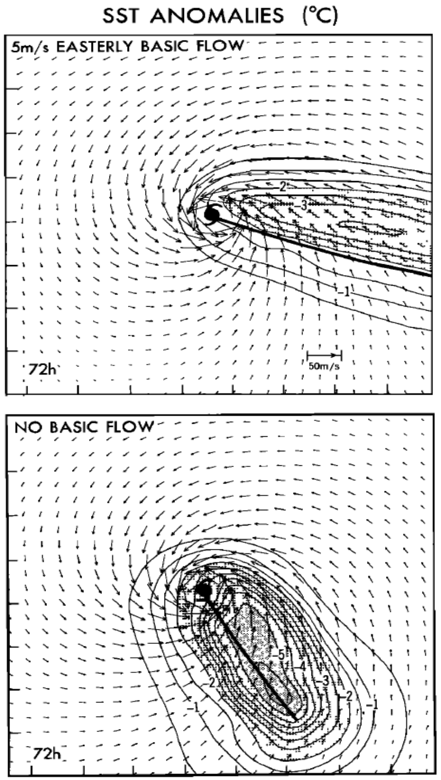
Isaac Ginis

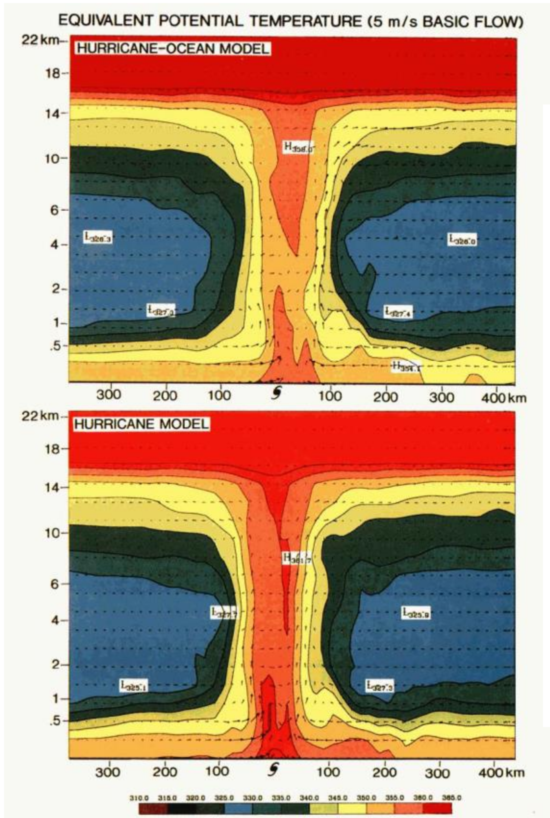
University of Rhode Island

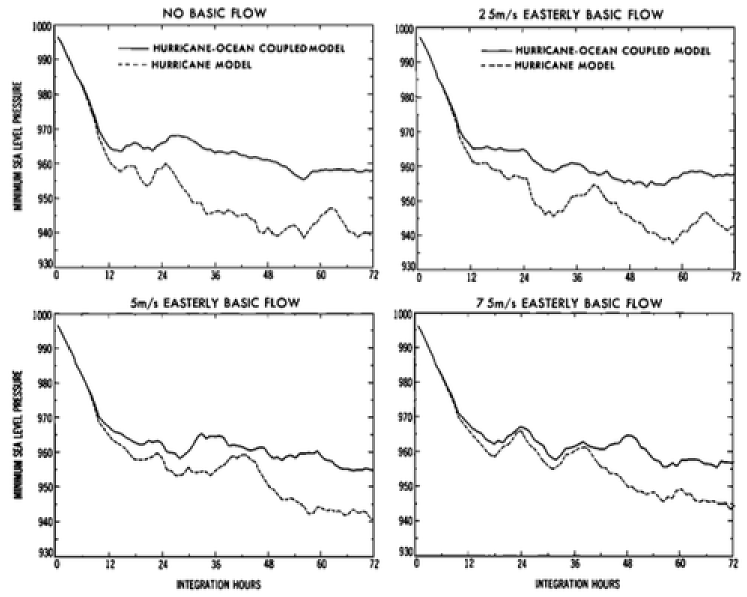
GFDL Hurricane Science Symposium

May 2, 2017

Early research on air-sea interaction with the GFDL hurricane model







- Bender M. A., I. Ginis and Y. Kurihara, **1993**: Numerical simulations of the tropical cyclone-ocean interaction with a high-resolution coupled model. *J. Geophys. Res*., 98, 23 245-23 263.
- Ginis, I., M. A. Bender, and Y. Kurihara, **1994**: A numerical study of the tropical cyclone-ocean interaction. In "*Tropical Cyclone Disasters*" (J. Lighthill and K. A. Emanuel, Eds), Peking University Press, Beijing, 342-355.

Developing a version of the Princeton Ocean Model for tropical cyclones, POM-TC, and its coupling to the GFDL hurricane model

1994-1997 Coupled tropical cyclone-ocean modeling.

1996-1999 A coupled air-sea numerical model for improving operational prediction of Gulf of Mexico and Western Atlantic hurricanes.

First simulations of the ocean response to idealized hurricanes using POM-TC

Cross-section of temperature anomalies normal to the storm track

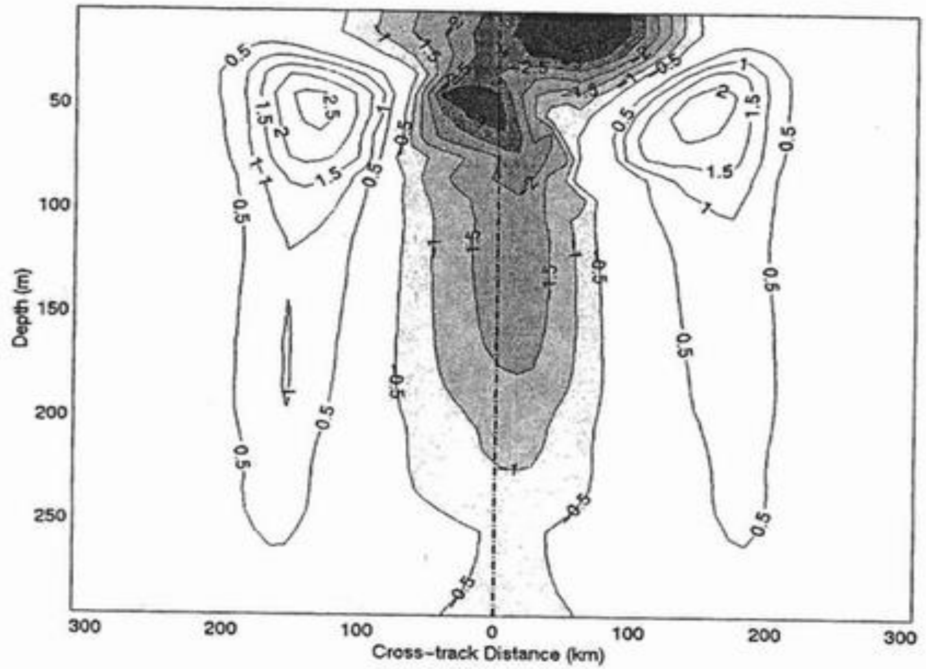
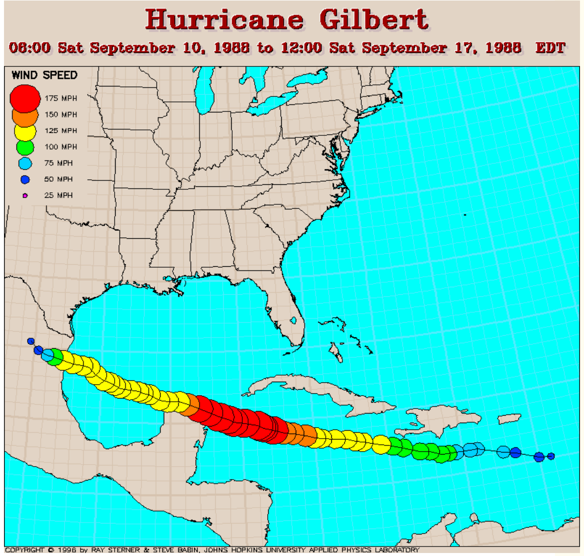
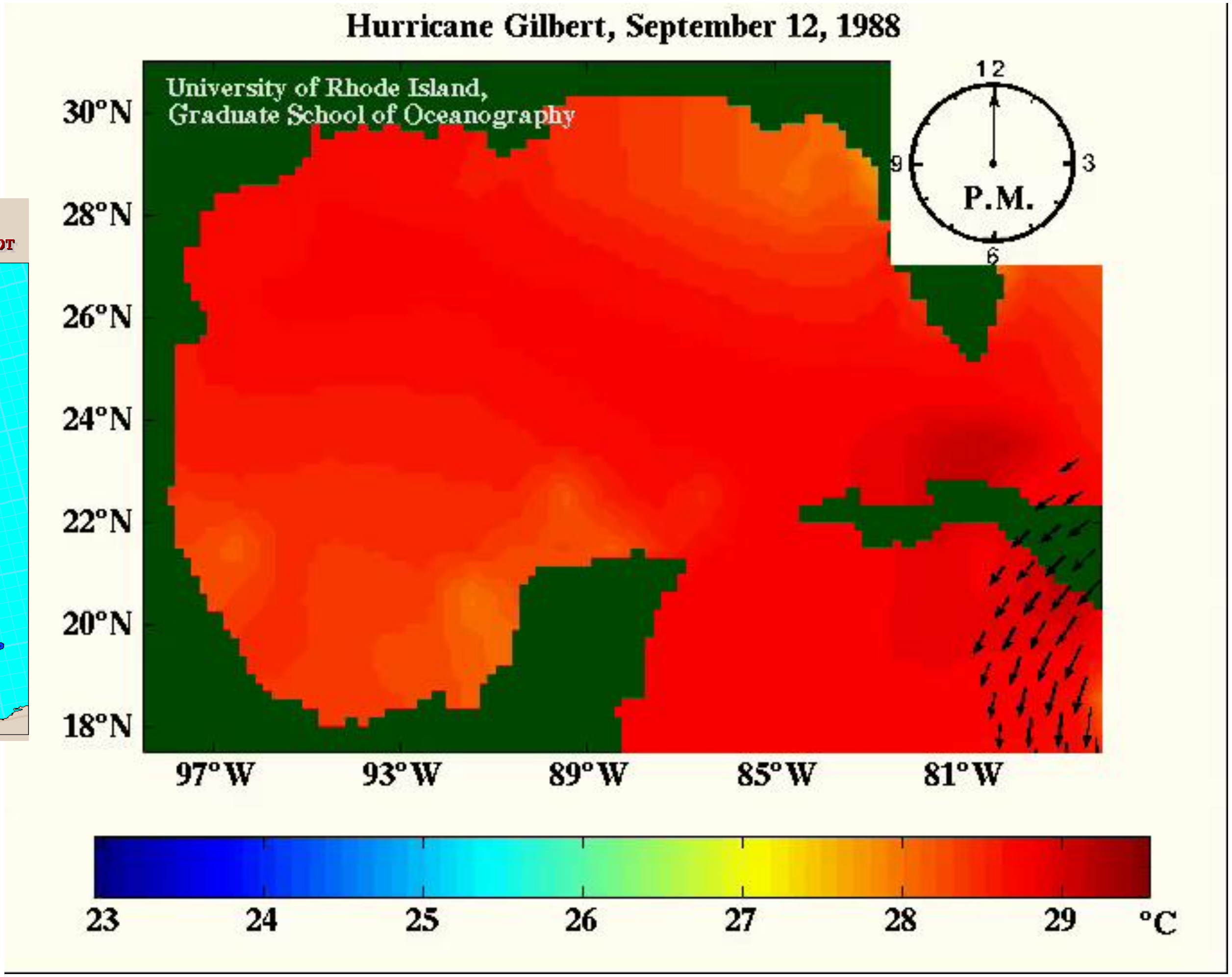


Figure 7: As in Fig. 5, showing the cross-section of temperature anomalies normal to the storm track and 300 km behind the hurricane center. Negative anomalies are shaded. The dashed line is drawn through the hurricane center.

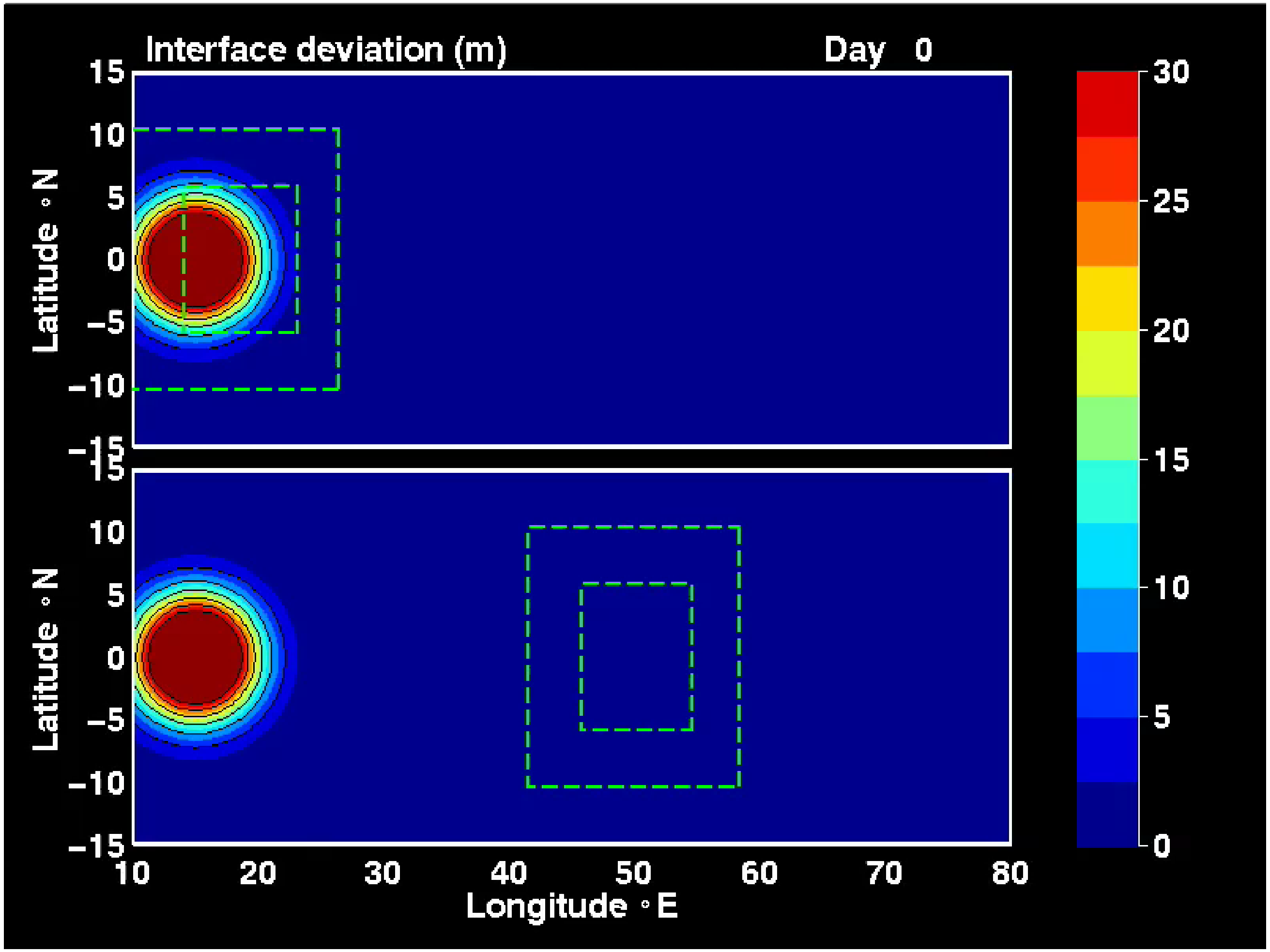
- Ginis I., **1995**: Interaction of tropical cyclones with the ocean. Global Perspectives on Tropical Cyclones, Ch. 5, R. L. Elsberry, Ed., WMO/TD No. 693, World Meteorological Organization, Geneva, Switzerland, 198-260.
- Ginis I., and G. G. Sutyrin, **1995**: Hurricane-generated depth-averaged currents and sea surface elevation. *J. Phys. Oceanogr*., 25, 1218-1242

First simulations of the ocean response to real hurricanes using POM-TC



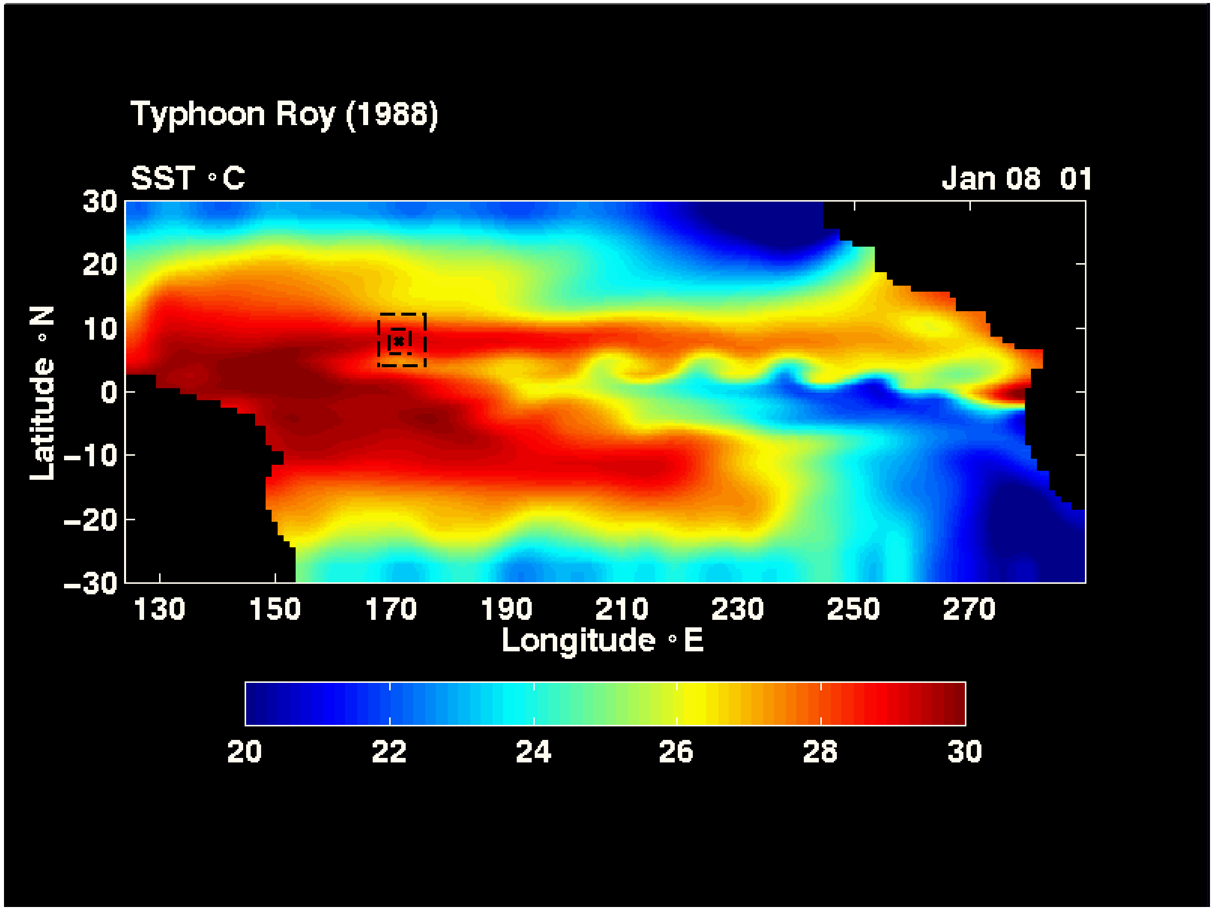


Developing a multi-nested ocean model based on the GFDL hurricane model numerics



Ginis I., R. A. Richardson, and L. M. Rothstein, **1998**: Design of a multiply nested primitive equation ocean model. *Mon. Wea. Rev.*, 126, 1054-1079.

Developing a multi-nested ocean model based on the GFDL hurricane model numerics



Rowley, C., and I. Ginis, **1999**: Implementation of a mesh movement scheme in a multiply nested ocean model and its application to air-sea interaction studies. *Mon. Wea. Rev.*, 127, 1879-1896.

First GFDL-POM coupled simulations of real hurricanes

APRIL 2000 BENDER AND GINIS 925

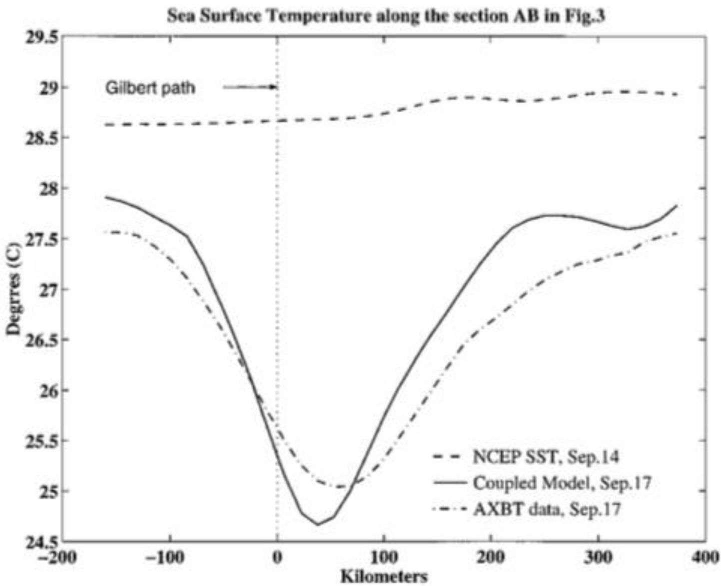


FIG. 4. SST distribution from the coupled experiment (solid line) along section AB in Fig. 3, compared with objectively analyzed AXBT data (dashed–dotted line) from Shay et al. (1992) on 17 Sep 1987. Initial prestorm surface temperature (dashed line) from the NCEP SST global analysis is shown as well.

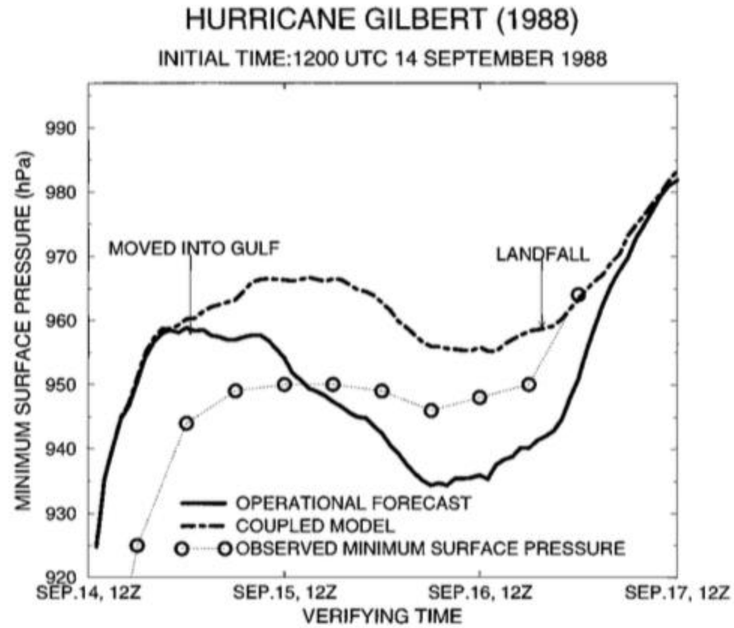


FIG. 5. Time series of minimum sea level pressure for the operational forecast (solid line) and coupled experiment (dotted–dashed line) compared to observed values (thin dotted line, circles indicating values every 6 h) for the forecast of Hurricane Gilbert.

Bender, M.A. and I. Ginis, **2000**: Real case simulations of hurricane-ocean interaction using a high resolution coupled model: Effects on hurricane intensity. *Mon. Wea. Rev*., 128, 917-946.

First intensity error analysis of multiple storm simulations with GFDL-POM coupled model

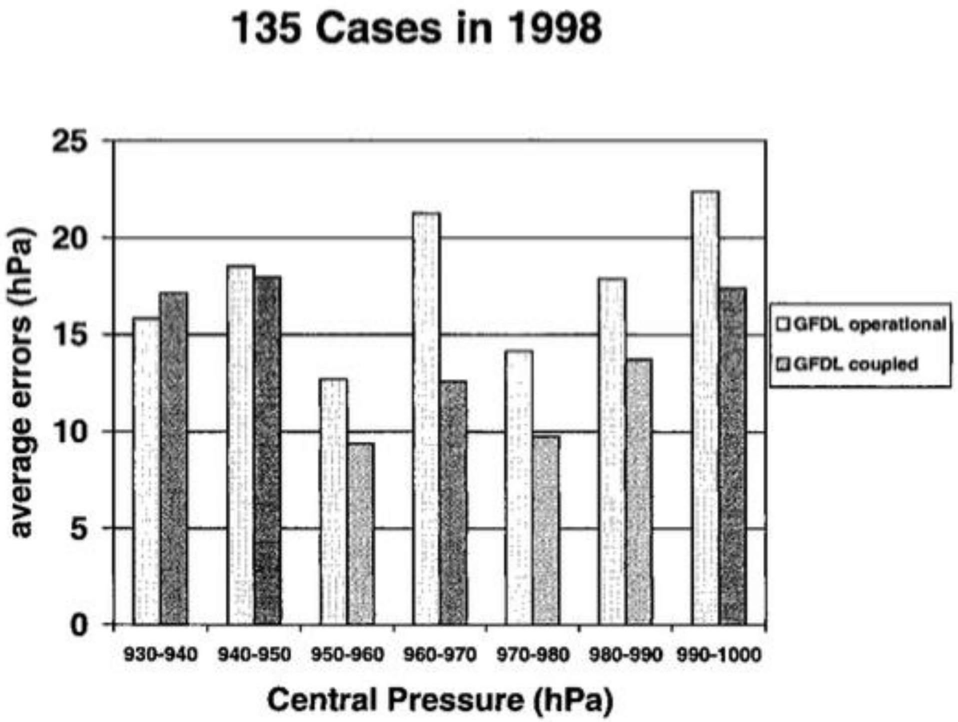


FIG. 24. Comparison between the operational and coupled GFDL model, for the average forecast error of minimum central pressure (hPa) at all forecast time periods, for 135 forecasts run during the 1998 Atlantic hurricane season. The comparison is made for seven categories of storm intensity.

Bender, M.A., and I. Ginis, **2000**: Real case simulations of hurricane-ocean interaction using a high resolution coupled model: Effects on hurricane intensity. *Mon. Wea. Rev.*, 128, 917-946.

Further research on hurricane-ocean interaction and transition of GFDL-POM coupled model to operations

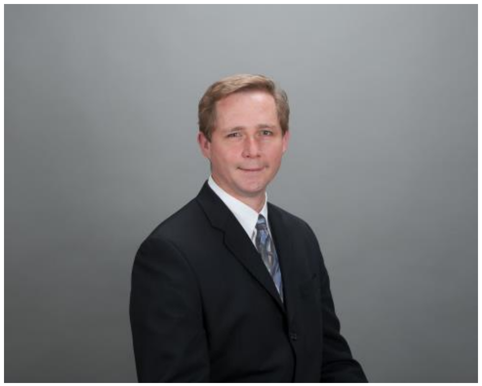
2000-2003 Air-sea fluxes at high wind speeds with application to tropical cyclone intensity prediction.

2001-2003, Transition of a coupled hurricane-ocean model to operational forecasting at the National Centers for Environmental Prediction.

Collaborative Science Technology, and Applied Research (CSTAR) Program

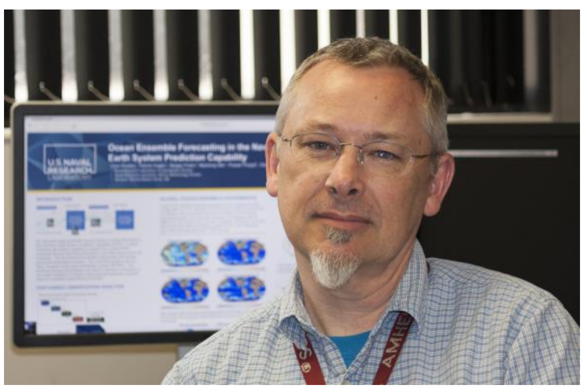
The CSTAR Program represents a NOAA/NWS effort to create a cost-effective transition from basic and applied research to operations and services through collaborative research between operational forecasters and academic institutions which have expertise in the environmental sciences. These activities engage researchers and students in applied research of interest to the operational meteorological community and improve the accuracy of forecasts and warnings of environmental hazards by applying scientific knowledge and information to operational products and services.

URI Students and Post-docs who contributed to the development and transition to operations the coupled GFDL-POM system



Sergei Frolov

Ray Richardson

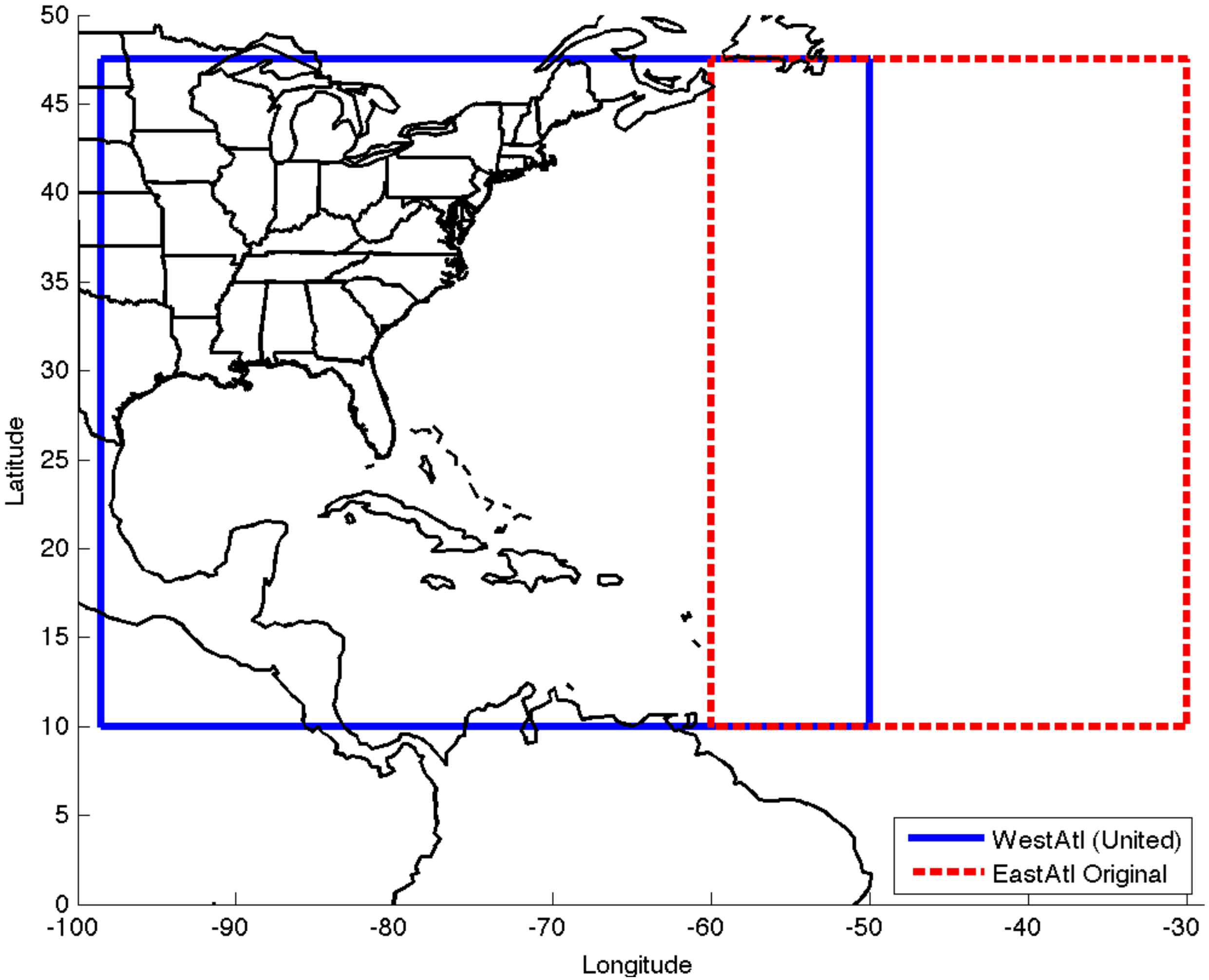


Clark Rowley

Biju Thomas

"That was my first taste of operational modeling, and I've made a career of developing, transitioning, and maintaining ocean and coupled forecast systems." Clark Rowley (NRL)

First operational POM-TC Atlantic domains

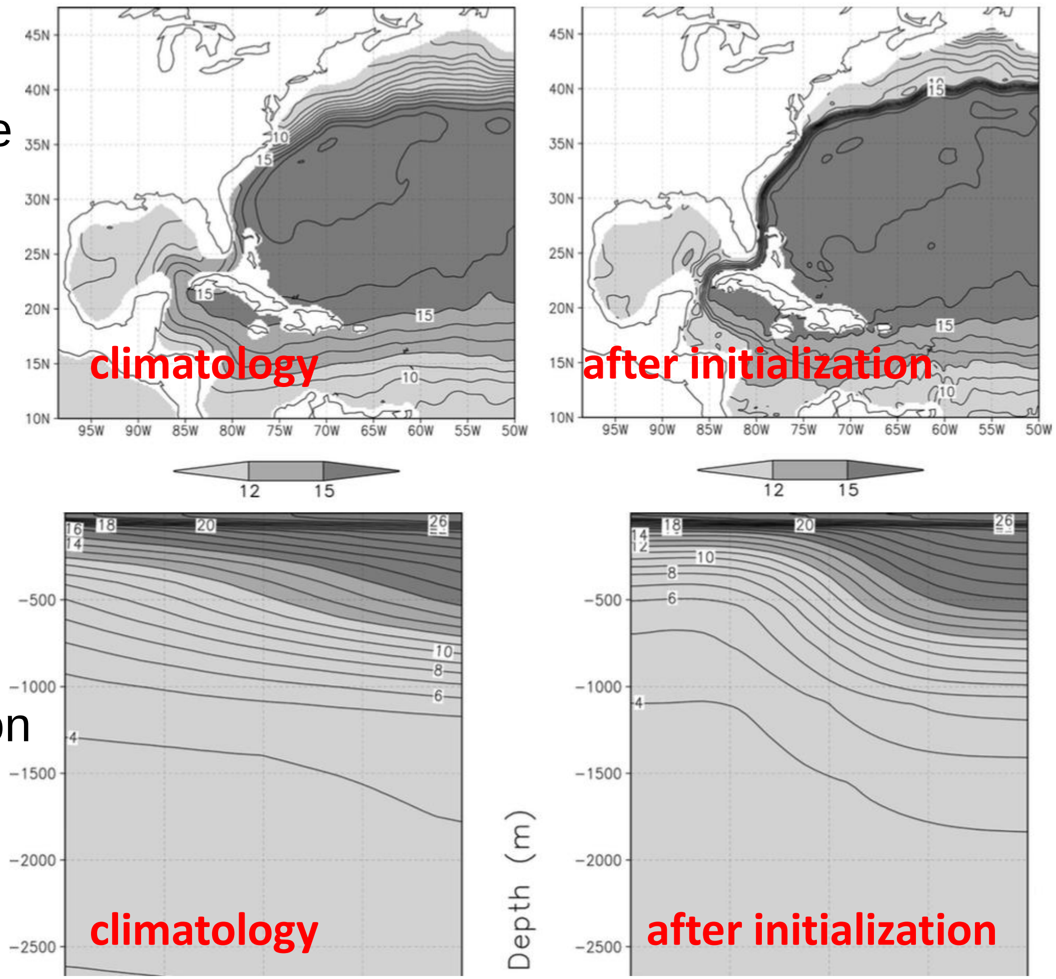


- 23 vertical sigma levels, 18 km grid spacing
- POM-TC was run on 1 (one) CPU!

Improving ocean model initialization: feature-based modeling approach

Temperature at 400 m

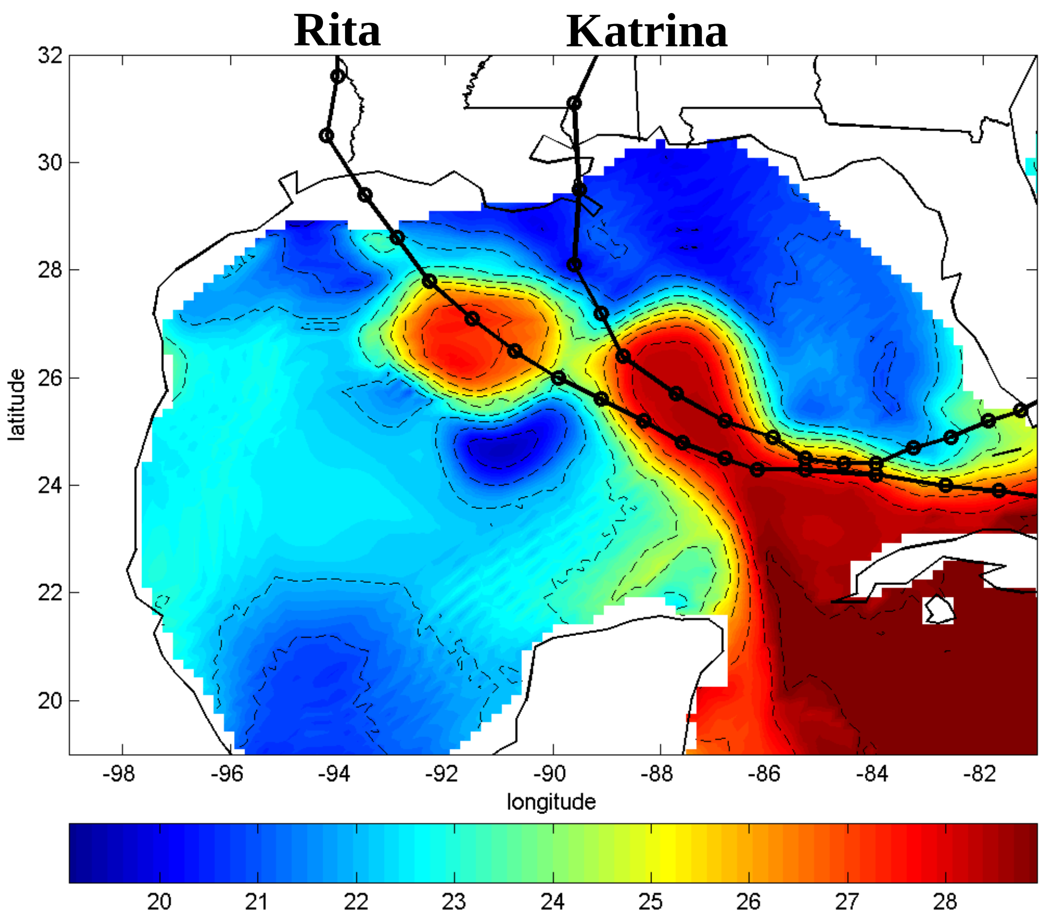
Gulf Stream cross-section



Alexander Falkovich

Falkovich, A., I. Ginis, and S. Lord, **2005**: Ocean data assimilation and initialization procedure for the Coupled GFDL/URI Hurricane Prediction System. J. Atmos. Oceanic Technol., 22, 1918-1932.

Feature-based initialization of the Loop Current and eddies in the Gulf of Mexico

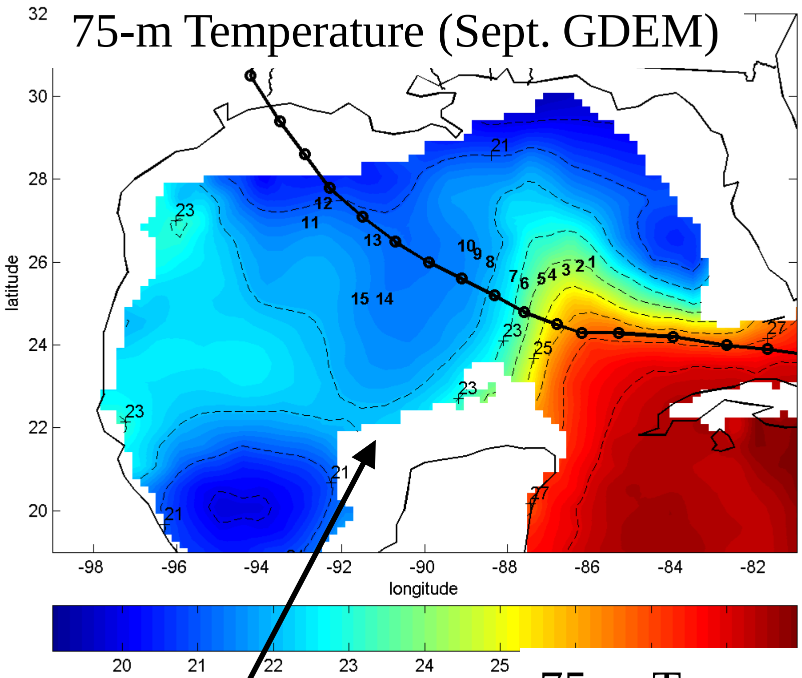


Richard Yablonsky

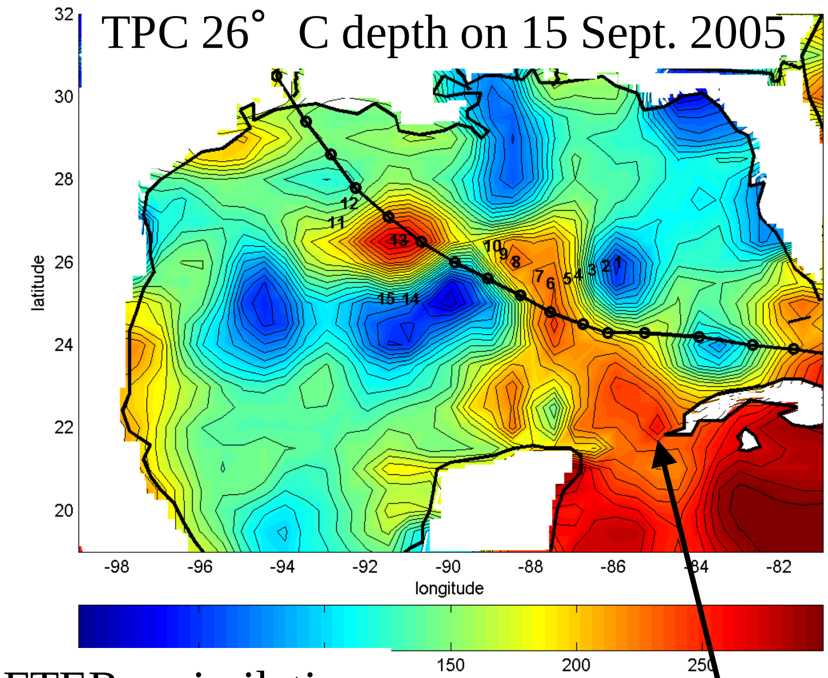
Yablonsky, R. M., and I. Ginis, **2008**: Improving the ocean initialization of coupled hurricane-ocean models using feature-based data assimilation. *Mon. Wea. Rev.*, 136, 2592-2607.

Example of feature-based of initialization

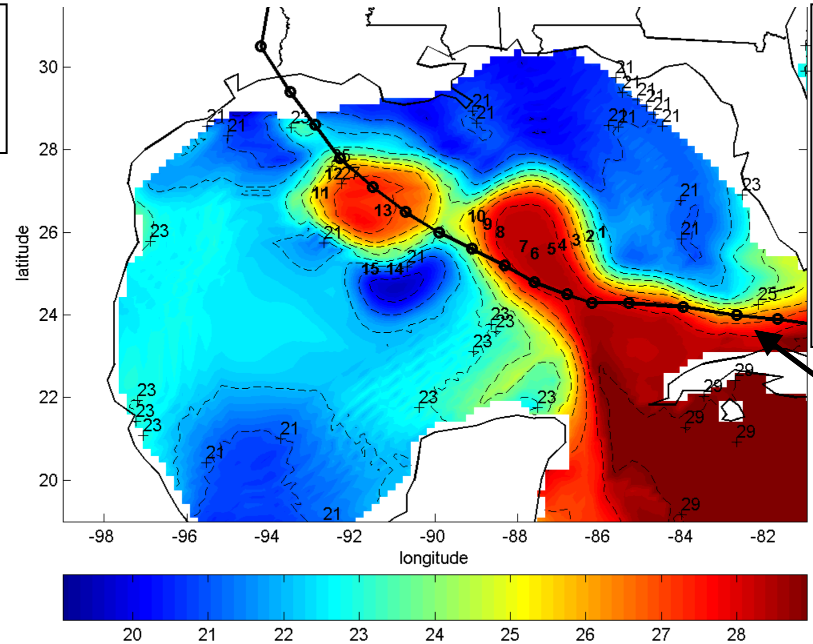
75-m Temperature (Sept. GDEM)



TPC 26° C depth on 15 Sept. 2005



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

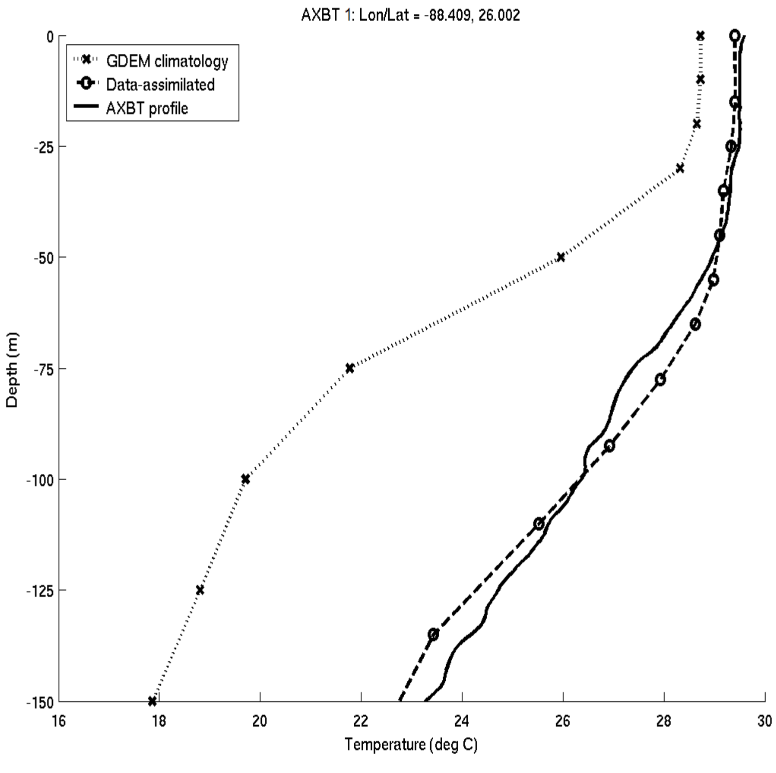
(4) Spin-up ocean currents

Future Hurricane Rita track

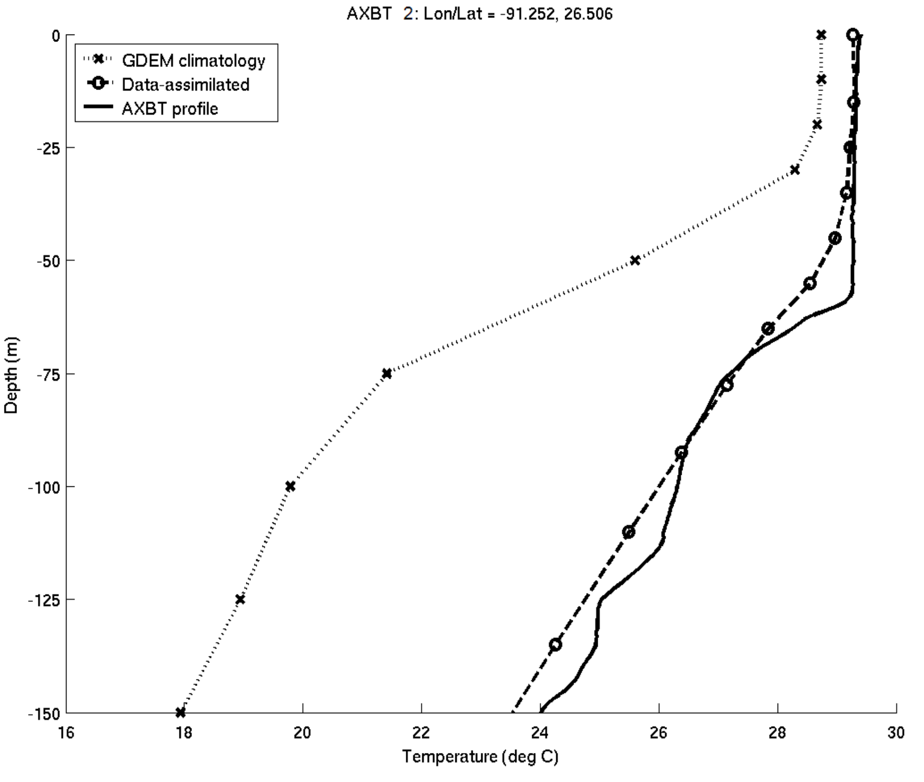
Yablonsky and Ginis (2008)

Examples of improved initial vertical temperature structure in LC and warm-core eddy

Loop Current



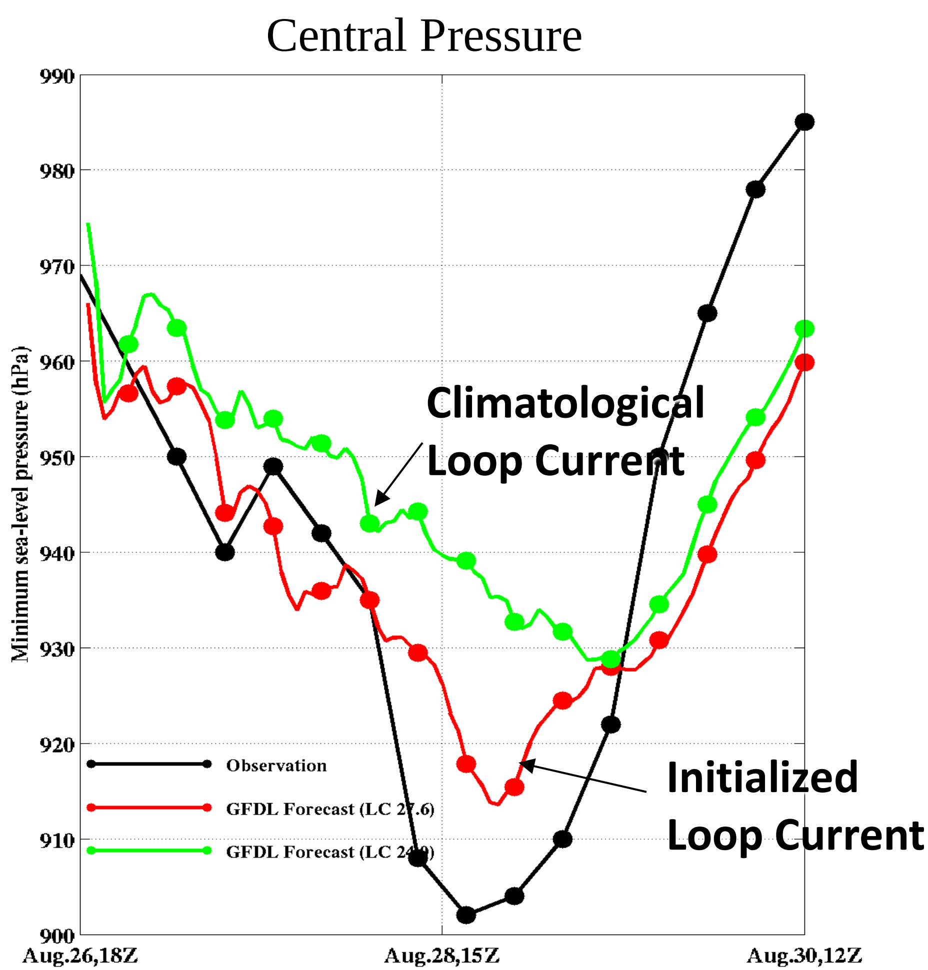
Warm-Core Eddy



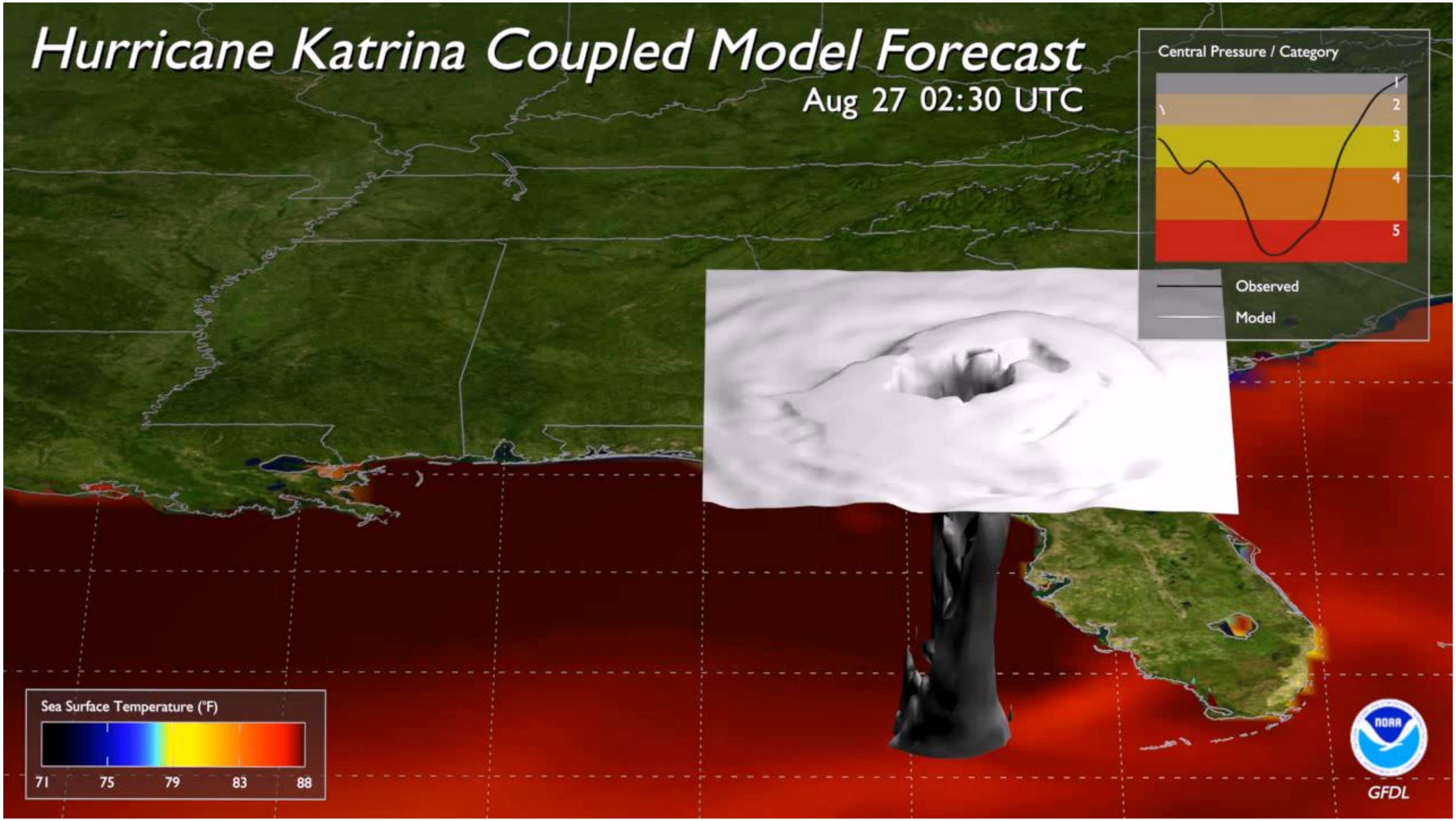
Yablonsky and Ginis (2008)

Effect of the Loop Current on Hurricane Katrina Intensity

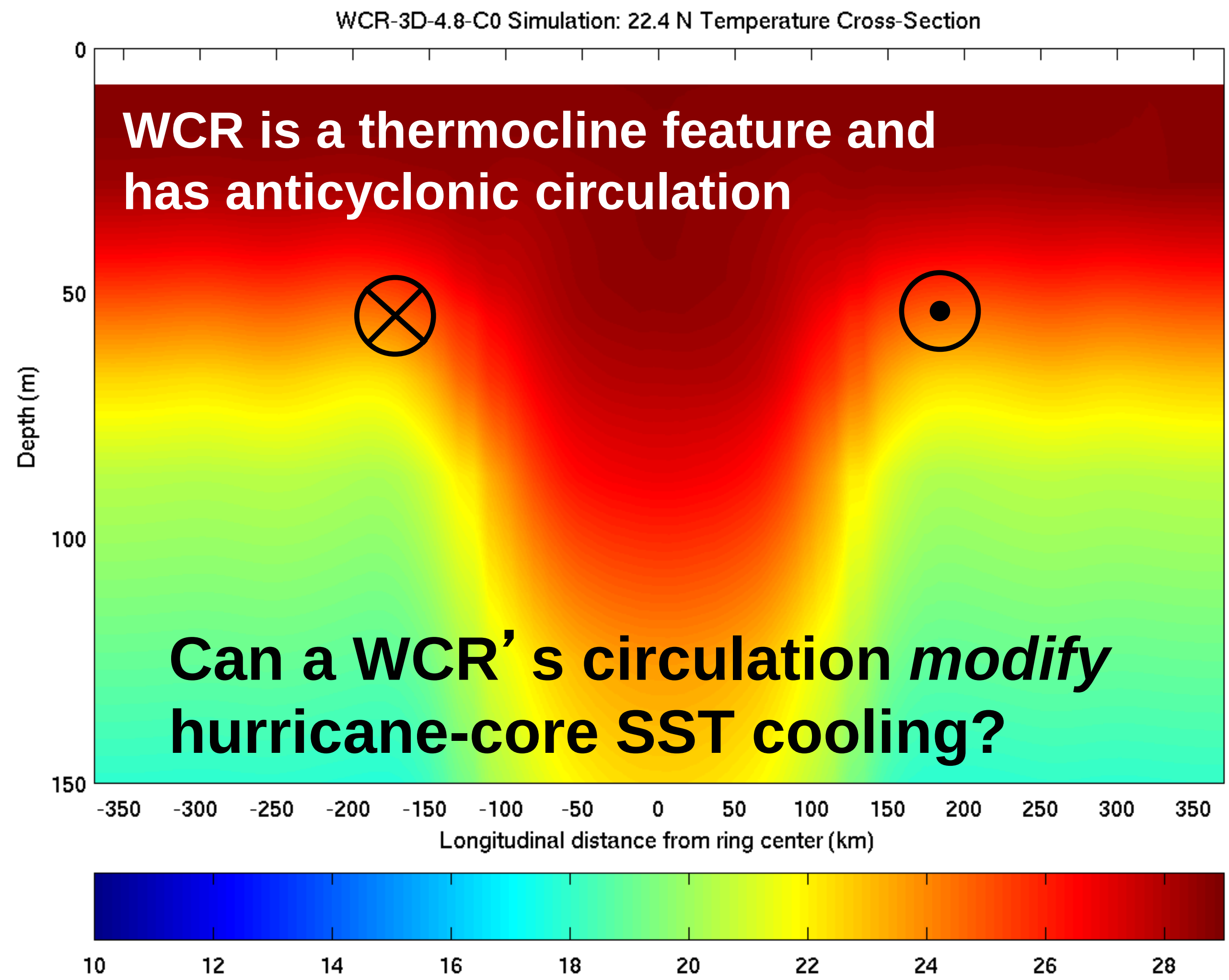
GFDL forecast Initialized Aug. 26, 18Z



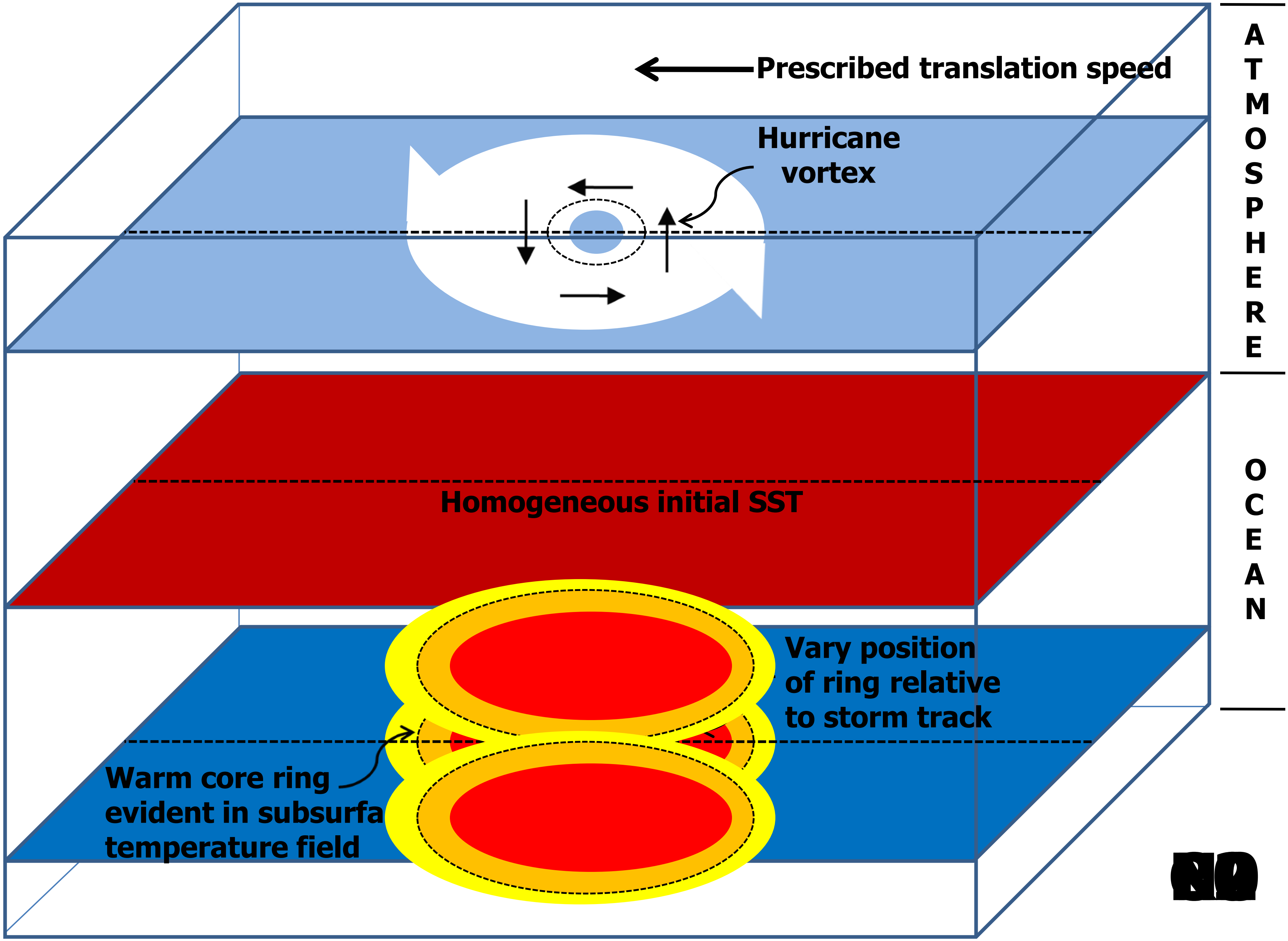
GFDL Hurricane Model Forecast of Hurricane Katrina (2005)



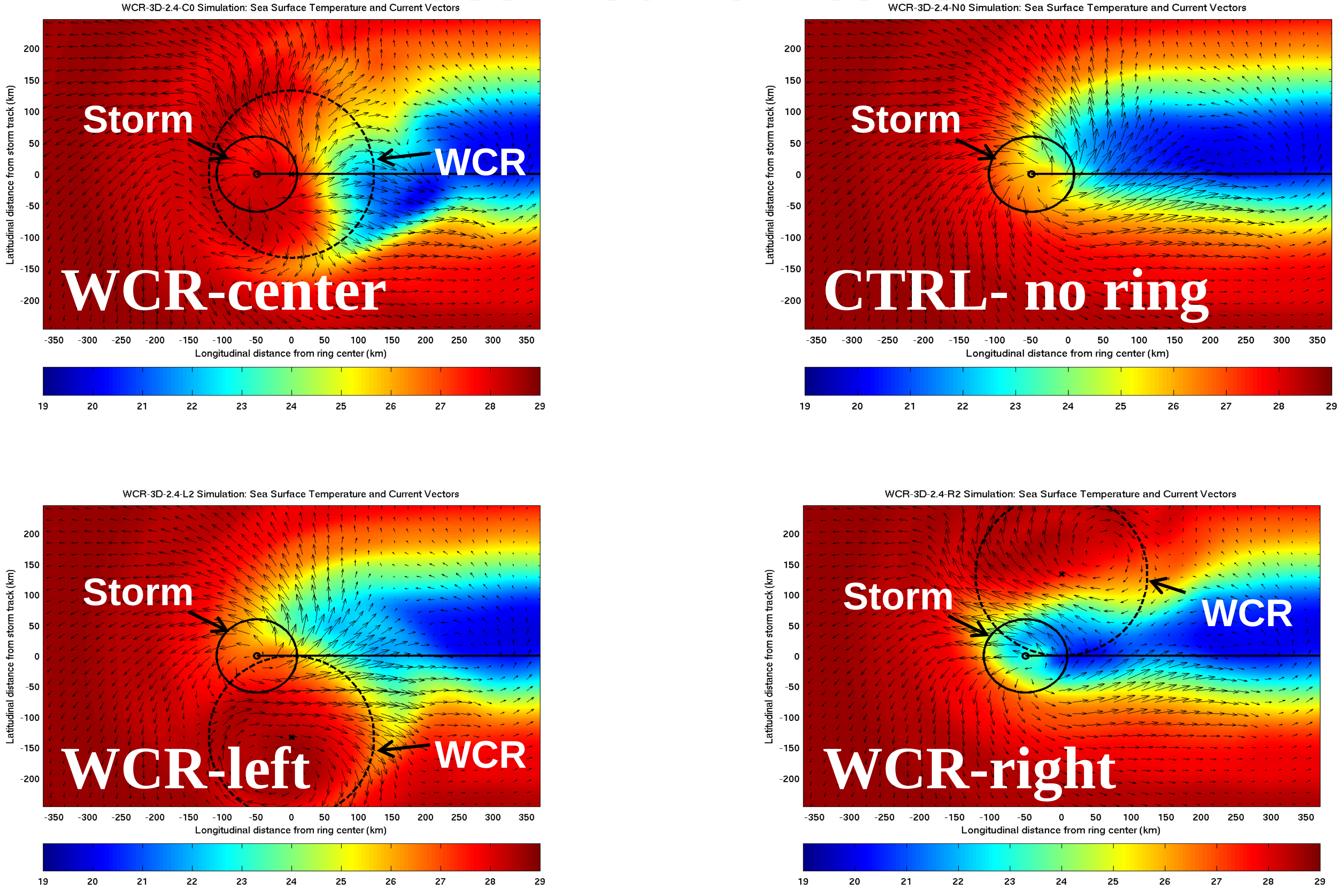
Warm-core ring is not just high ocean heat content



Yablonsky, R. M., and I. Ginis, **2013**: Impact of a warm ocean eddy's circulation on hurricane-induced sea surface cooling with implications for hurricane intensity. *Mon. Wea. Rev.*, 141, 997-1021.

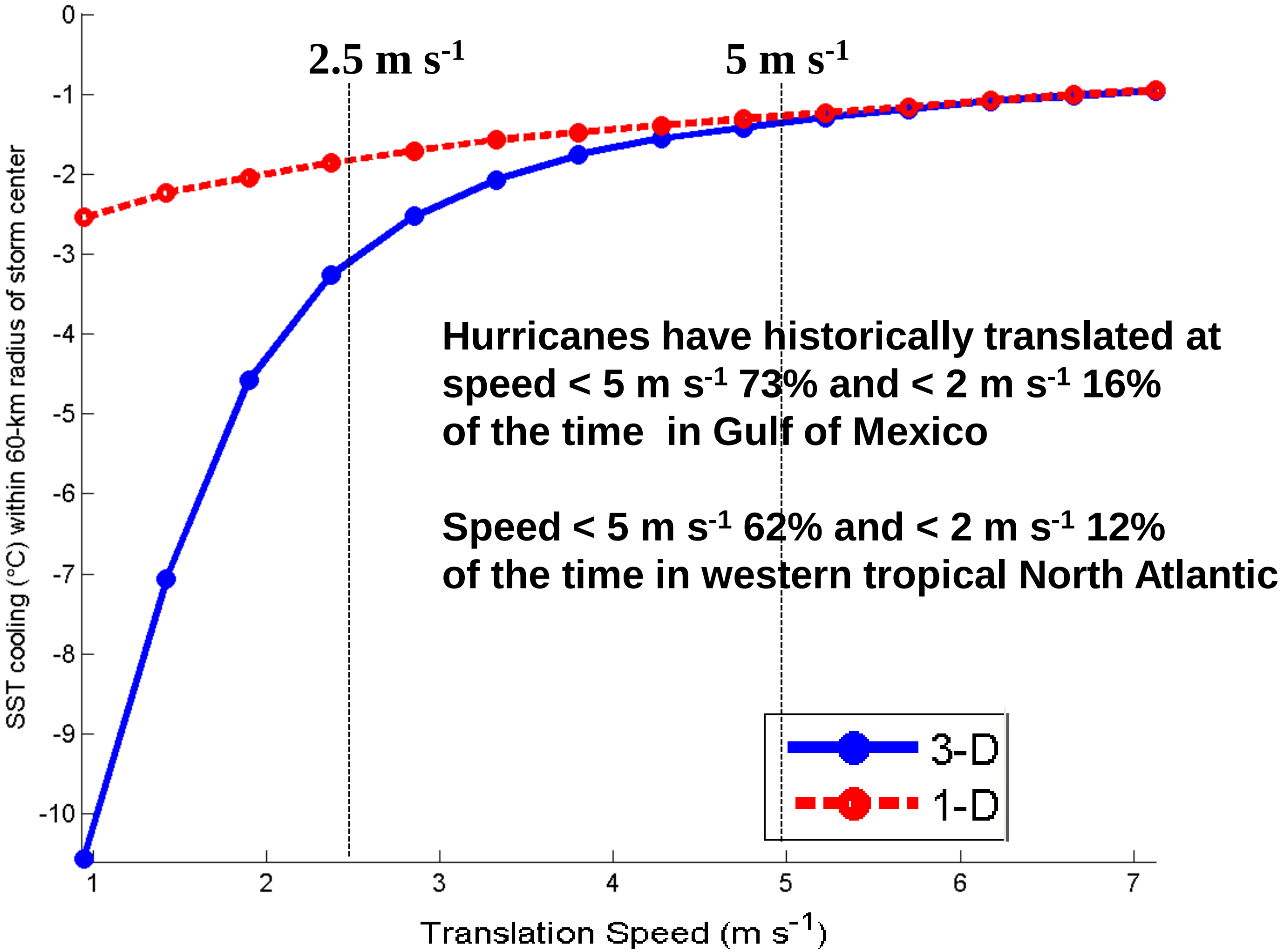

Prescribed translation speed
Hurricane vortex
A T M O S P H E R E
Homogeneous initial SST
O C E A N
Vary position of ring relative to storm track
Warm core ring evident in subsurfa temperature field

Effect of WCR location on SST and Currents in an idealized hurricane



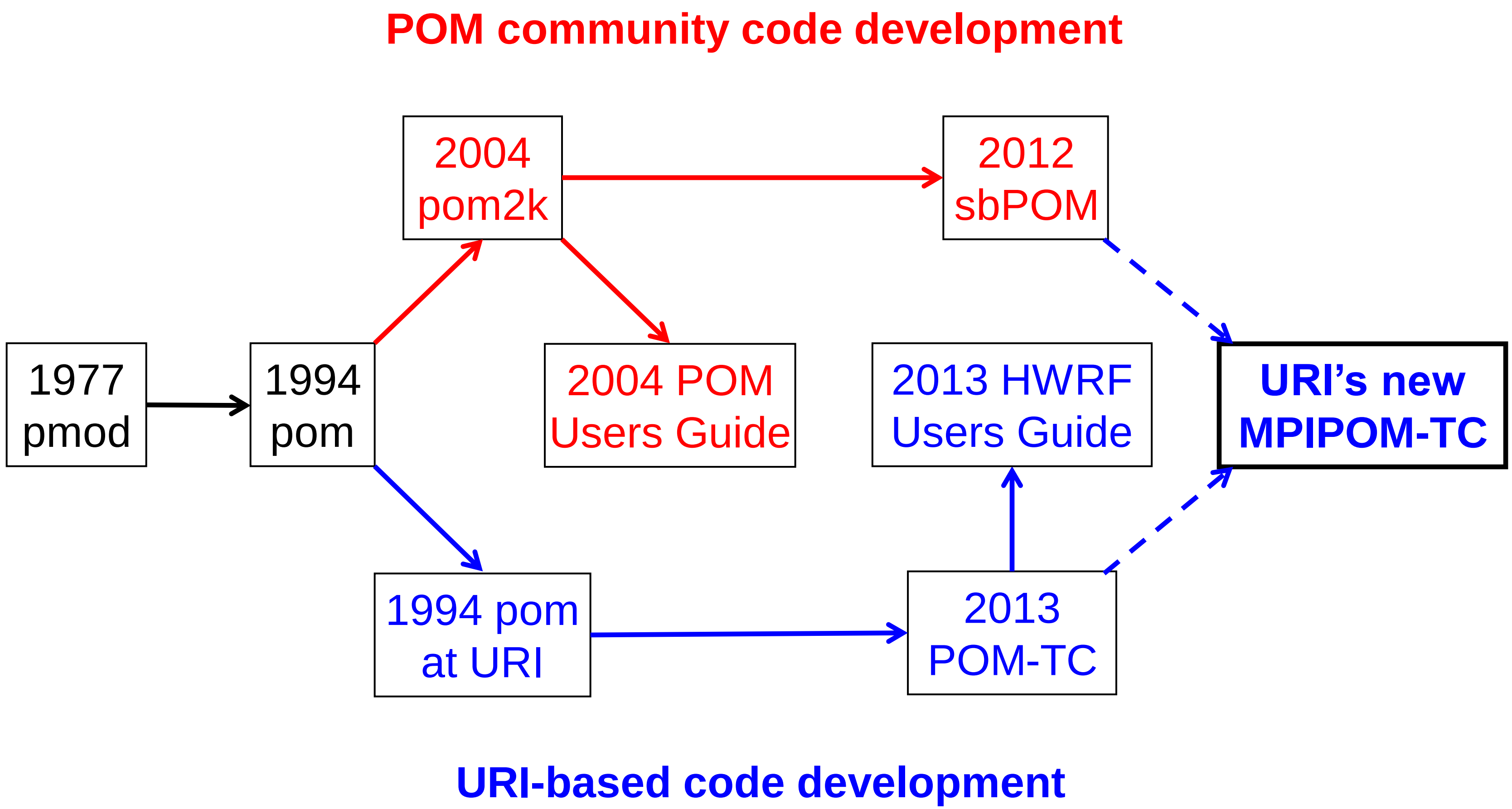
Yablonsky, R. M., and I. Ginis, **2013**: Impact of a warm ocean eddy's circulation on hurricane-induced sea surface cooling with implications for hurricane intensity. Mon. Wea. Rev., 141, 997-1021.

Effect 3D vs 1D ocean model on SST cooling within hurricane inner-core



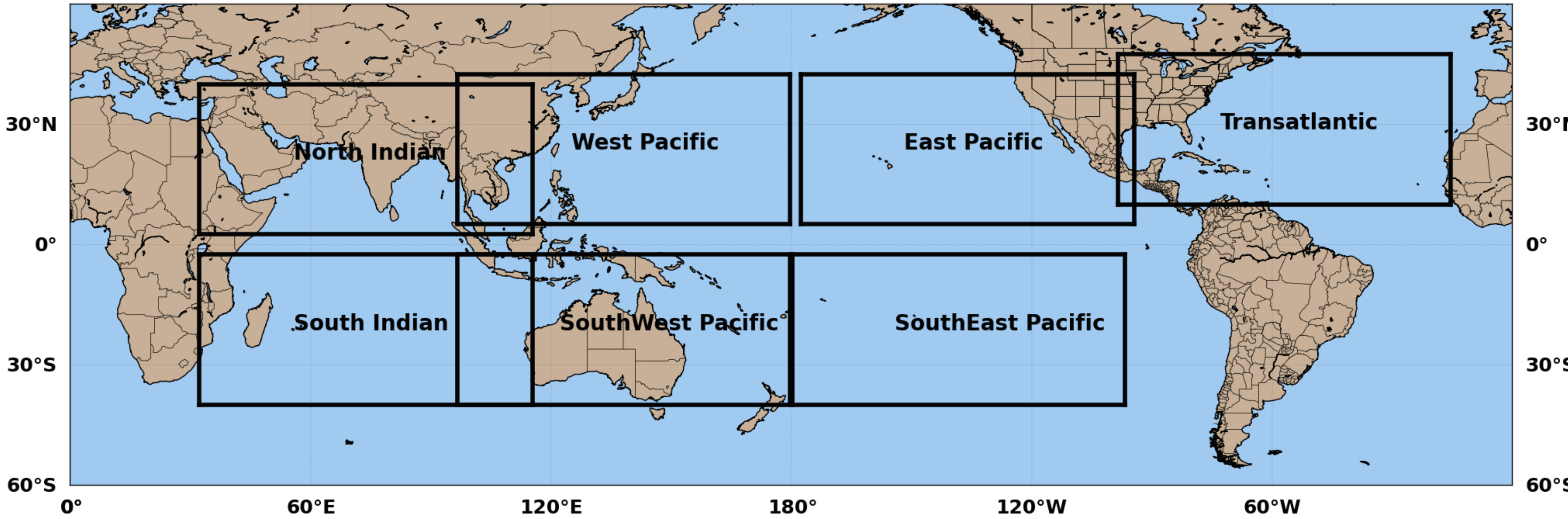
Yablonsky, R. M., and I. Ginis, **20**09: Limitation of one-dimensional ocean models for coupled hurricane-ocean model forecasts. *Mon. Wea. Rev.*, 137, 4410-4419

Developing parallel version of POM-TC (MPIPOM-TC)



Yablonsky, R. M., I. Ginis, B. Thomas, **2015**: Ocean modeling with flexible initialization for improved coupled tropical cyclone-ocean prediction, *Environmental Modelling & Software*, 67, 26-30.

MPIPOM domains worldwide



- MPIPOM-TC uses MPI software to run efficiently on multiple processors, allowing for both higher grid resolution and a larger ocean domain than POM-TC

- MPIPOM-TC accepts flexible initialization options (currently runs off RTOFS operationally in HWRF)

Research on air-sea fluxes in hurricanes with explicit wave coupling

Motivation: air-sea fluxes and turbulent mixing above/below sea surface are significantly modified by surface waves in high wind conditions.

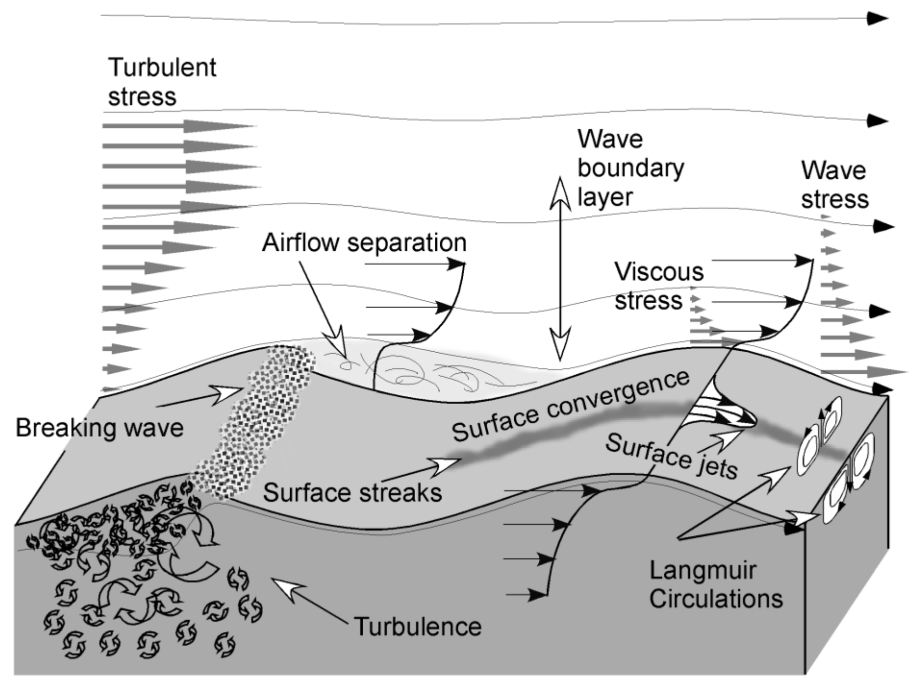
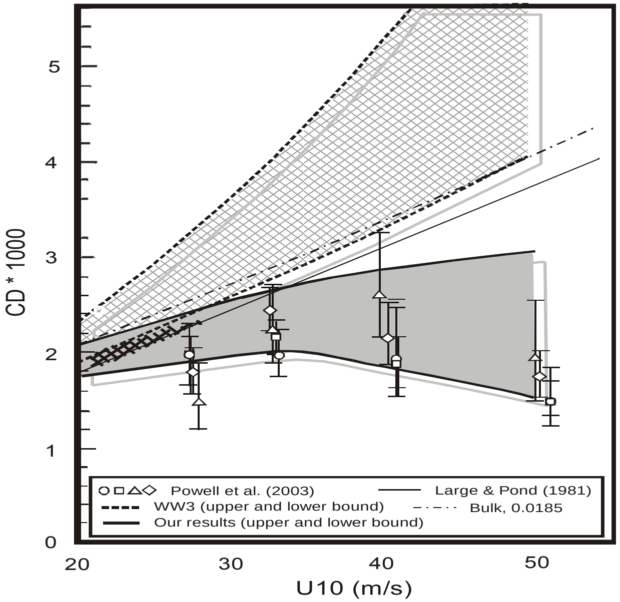
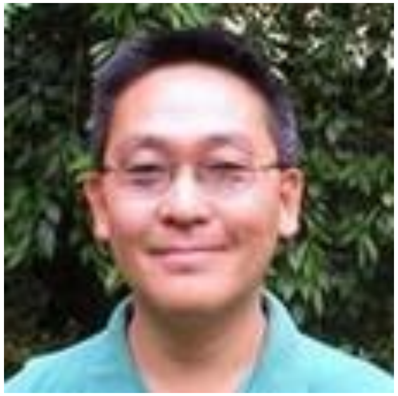


Image courtesy of Fabrice Veron

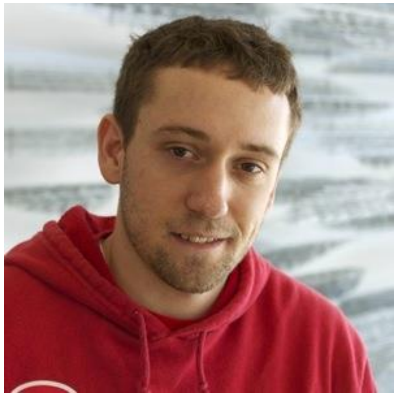
Sea-state dependent drag coefficient under hurricane conditions



Il Ju Moon



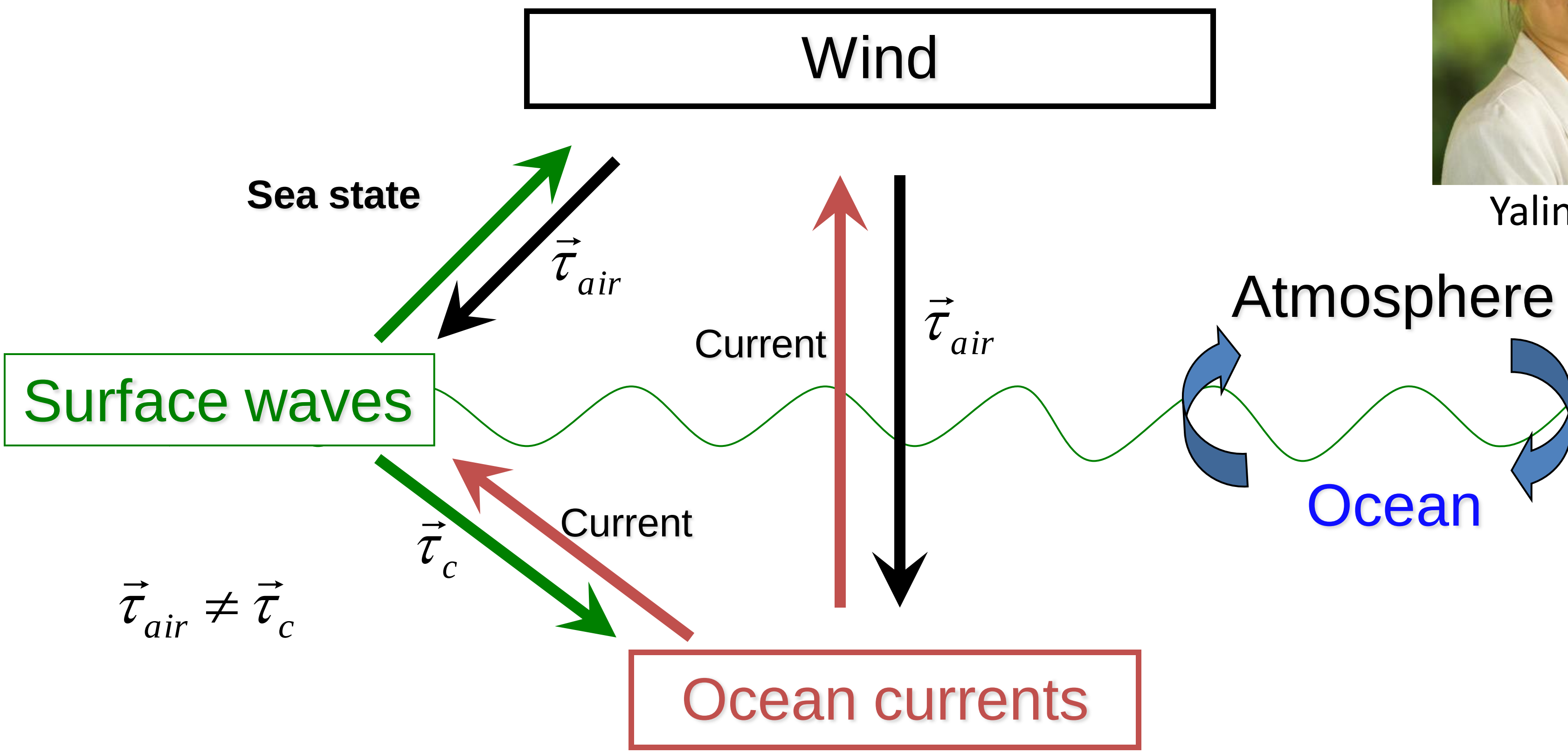
Tetsu Hara



Brandon Reichl

- Moon, I.-J., I. Ginis, and T. Hara, **2004**: Effect of surface waves on air-sea momentum exchange. Part II: Behavior of drag coefficient under tropical cyclones, *J. Atmos. Sci.*, 61, 2334–2348
- Moon, I.-J., I. Ginis, and T. Hara, **2004**: Effect of surface waves on Charnock coefficient under tropical cyclones, *Geophys. Res. Lett*., 31, L20302.
- Moon, I.-J., I. Ginis, T. Hara, and B. Thomas, **2007**: A physics-based parameterization of air-sea momentum flux at high wind speeds and its impact on hurricane intensity predictions. *Mon. Wea. Rev.*, 135, 2869-2878.
- Moon, I.-J., I. Ginis, and T. Hara, **2008**: Impact of the reduced drag coefficient on ocean wave modeling under hurricane conditions. *Mon. Wea. Rev*., 136, 1217-1223.
- Reichl, B. G., T. Hara, and I. Ginis, **2014**: Sea state dependence of the wind stress over the ocean under hurricane winds. *J. Geophys. Res*., 119, 30-51.

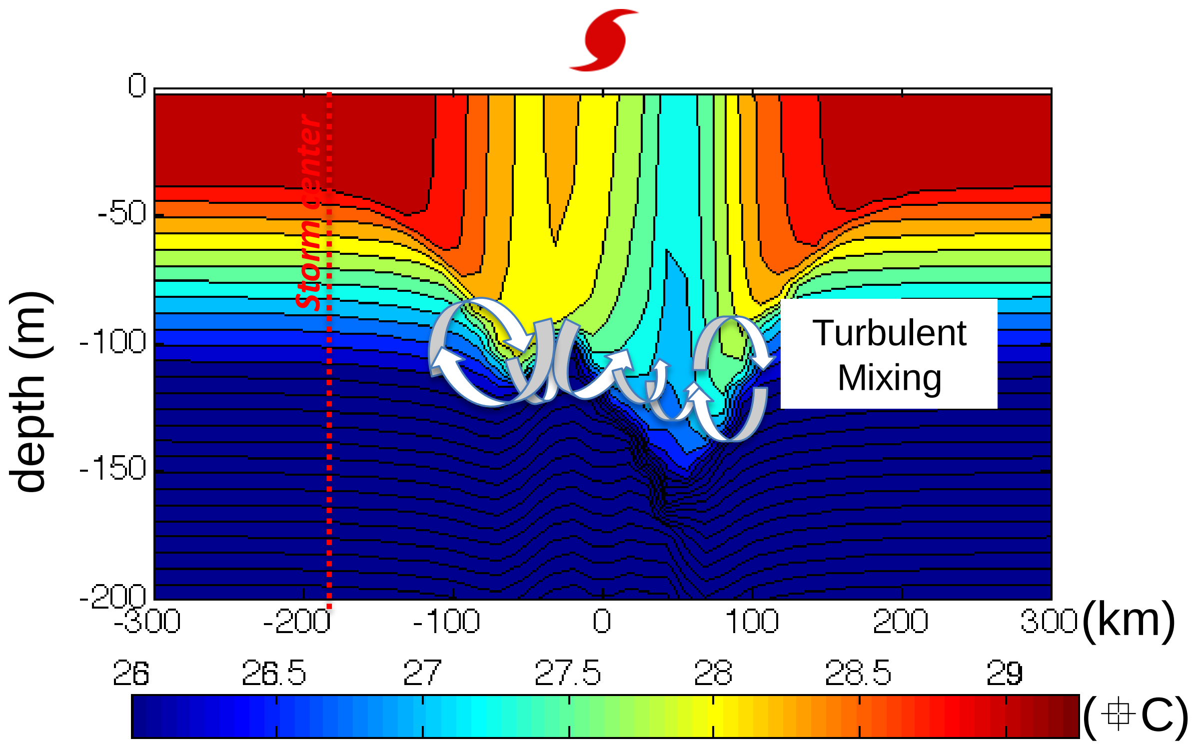
Wind-Wave-Current Interaction in hurricanes

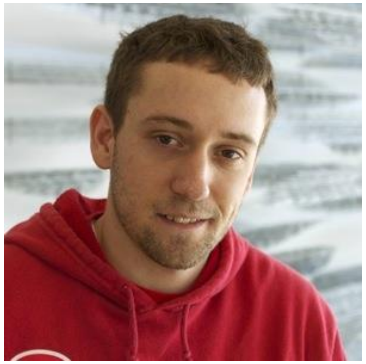


Yalin Fan

- Fan, Y., I. Ginis, and T. Hara, **2010**: Momentum flux budget across air-sea interface under uniform and tropical cyclones winds. *J. Phys. Oceanogr*., 40, 2221-2242.
- Fan, Y., I. Ginis, and T. Hara, **2009**: The effect of wind-wave-current interaction on air-sea momentum fluxes and ocean response in tropical cyclones. *J. Phys. Oceanogr*., 39, 1019-1034.

Wave-driven Langmuir turbulence in hurricane conditions

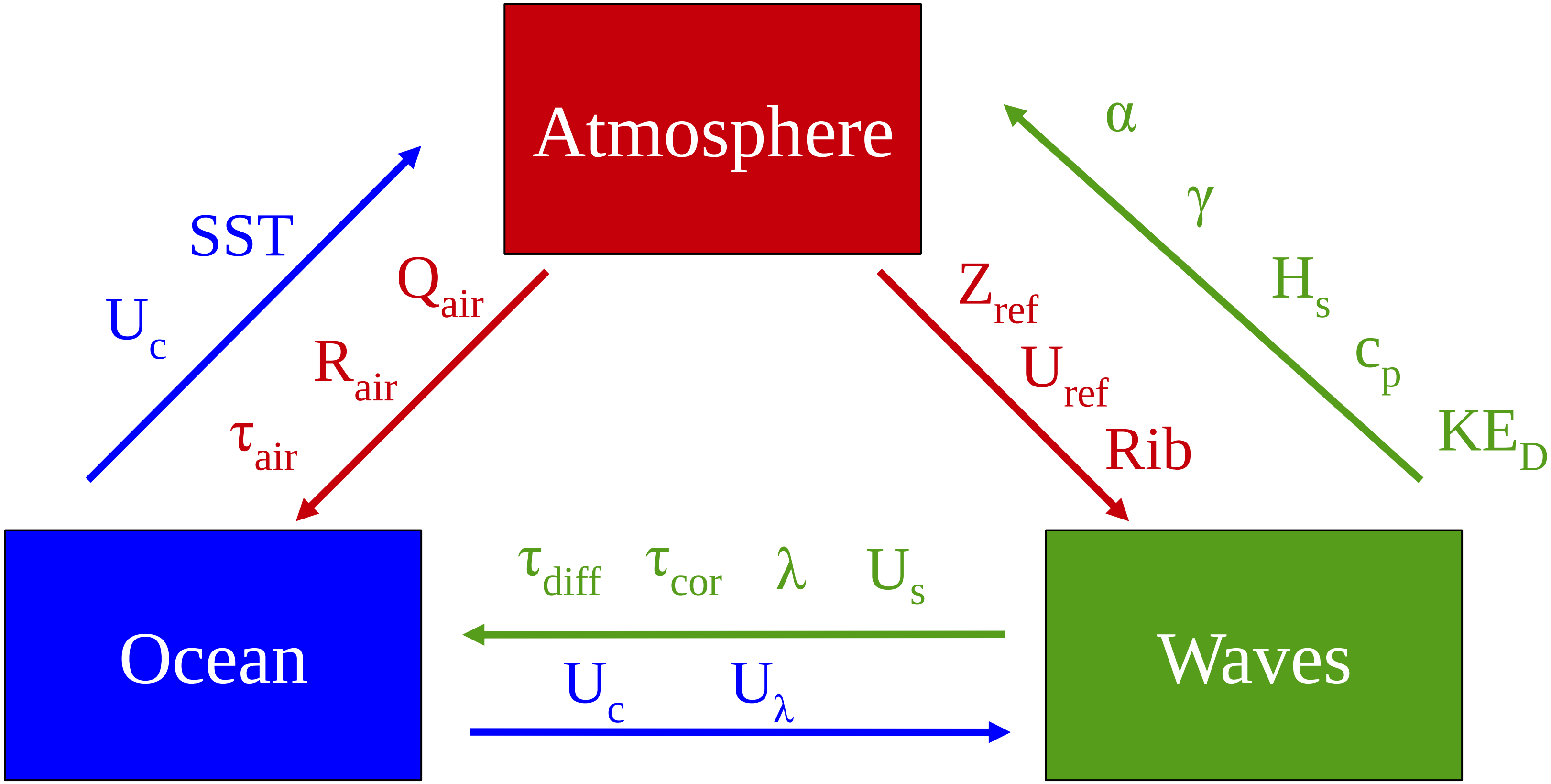




Brandon Reichl

- Reichl, B. G., I. Ginis, T. Hara, B. Thomas, T. Kukulka and D. Wang **2016**: Impact of Sea-State-Dependent Langmuir Turbulence on the Ocean Response to a Tropical Cyclone*. Mon. Wea. Rev*., 144, 4569-4590.
- Reichl, B. G., D. Wang, T. Hara, I. Ginis and T. Kukulka **2016**: Langmuir Turbulence Parameterization in Tropical Cyclone Conditions. Langmuir Turbulence Parameterization in Tropical Cyclone Conditions. *J. Phys. Oceanogr*., 46, 863-886.

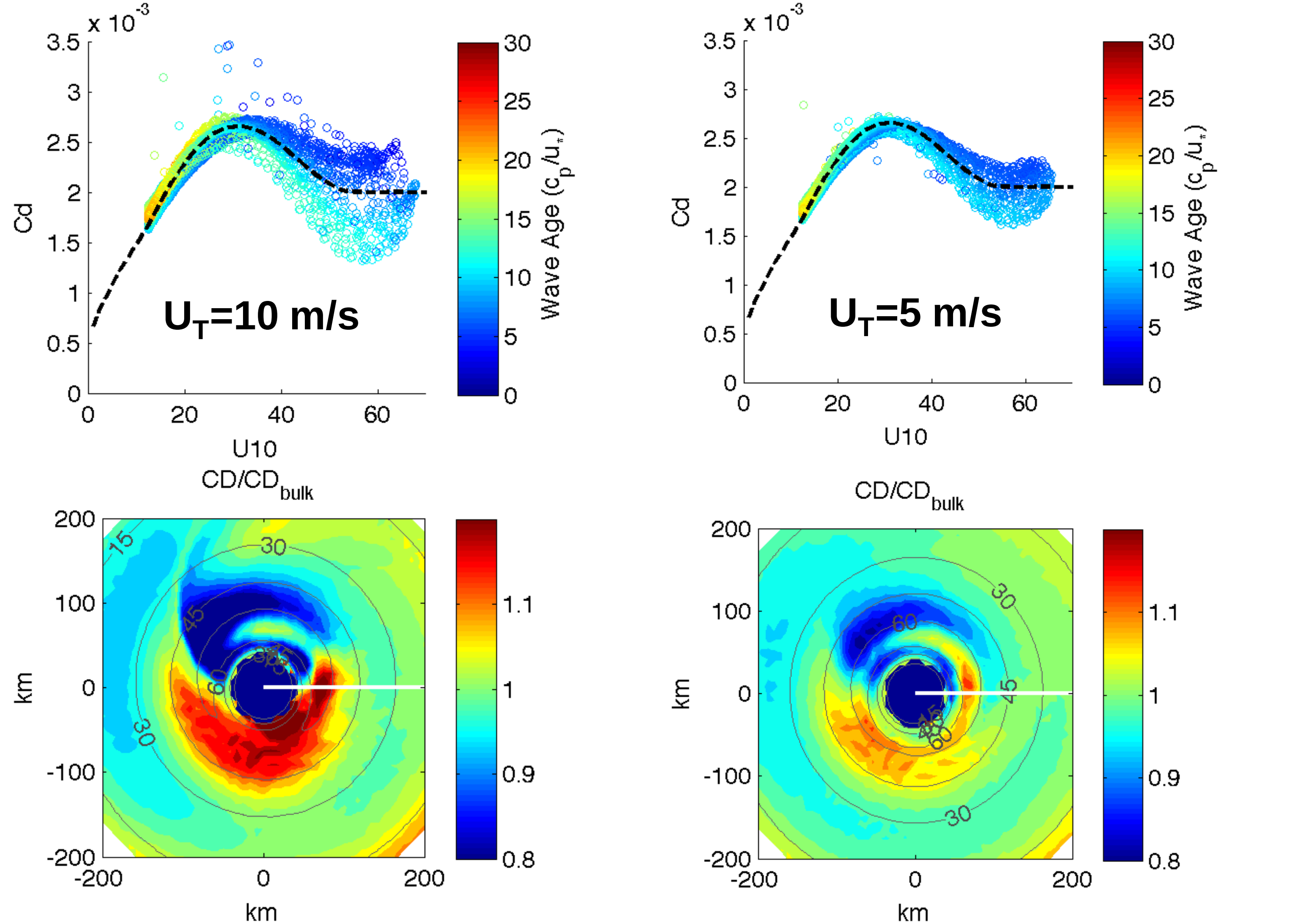
3-way atmosphere-wave-ocean framework for hurricane models



- **Atmospheric model:** air-sea fluxes depend on **sea state**
- **Wave model:** forced by **sea state** dependent wind forcing
- **Ocean model:** forced by **sea state** dependent wind stress modified by **growing or decaying wave fields** and **Coriolis-Stokes effect.** Turbulent mixing is modified by the Stokes drift (**Langmiur turbulence**).

Examples of sea state dependent C_d with explicit wave coupling

RMS= 70 km, U_{10max}= 65 m/s



Summary

- Close collaboration between GFDL and URI has been instrumental in the success of the GFDL coupled hurricane model.
- Support by NOAA Joint Hurricane Testbed and HFIP provided to URI was critical for transitioning the hurricane research at URI to operations.
- The MPIPOM-TC has been successfully transitioned from the GFDL hurricane model to the operational HWRF coupled system.