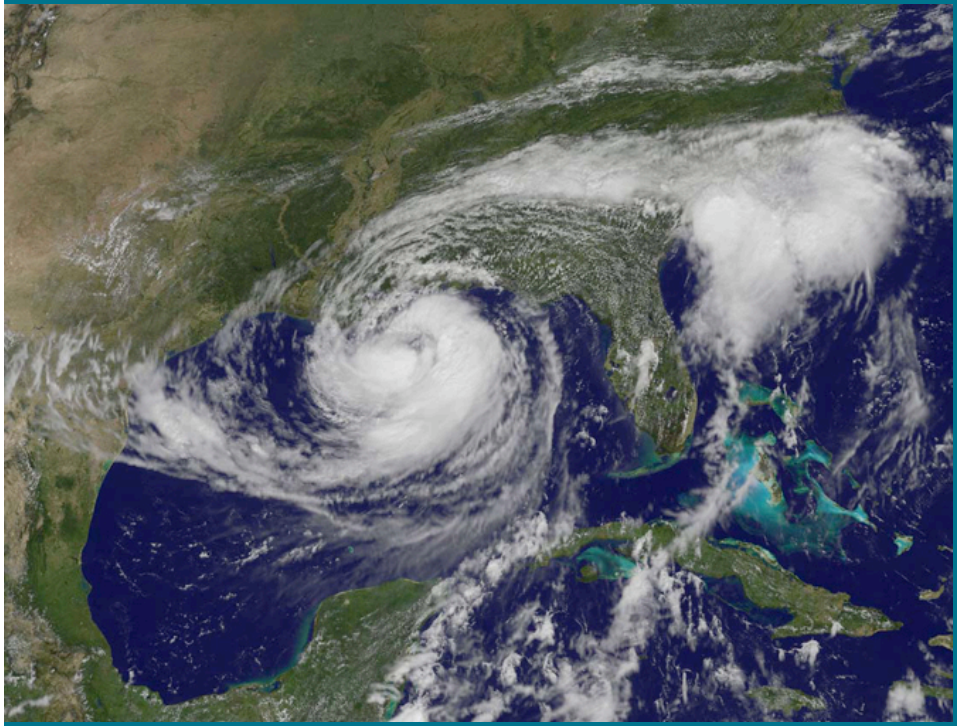
Advancing NOAA's HWRF Prediction System through New and Enhanced Physics of the Air-Sea-Wave Coupling



Isaac Ginis (PI),
Richard Yablonsky (co-PI),
and **Biju Thomas**
University of Rhode Island
HFIP Awards 1st Year Review
Wednesday, May 15, 2013

Thanks to all of our HFIP partners

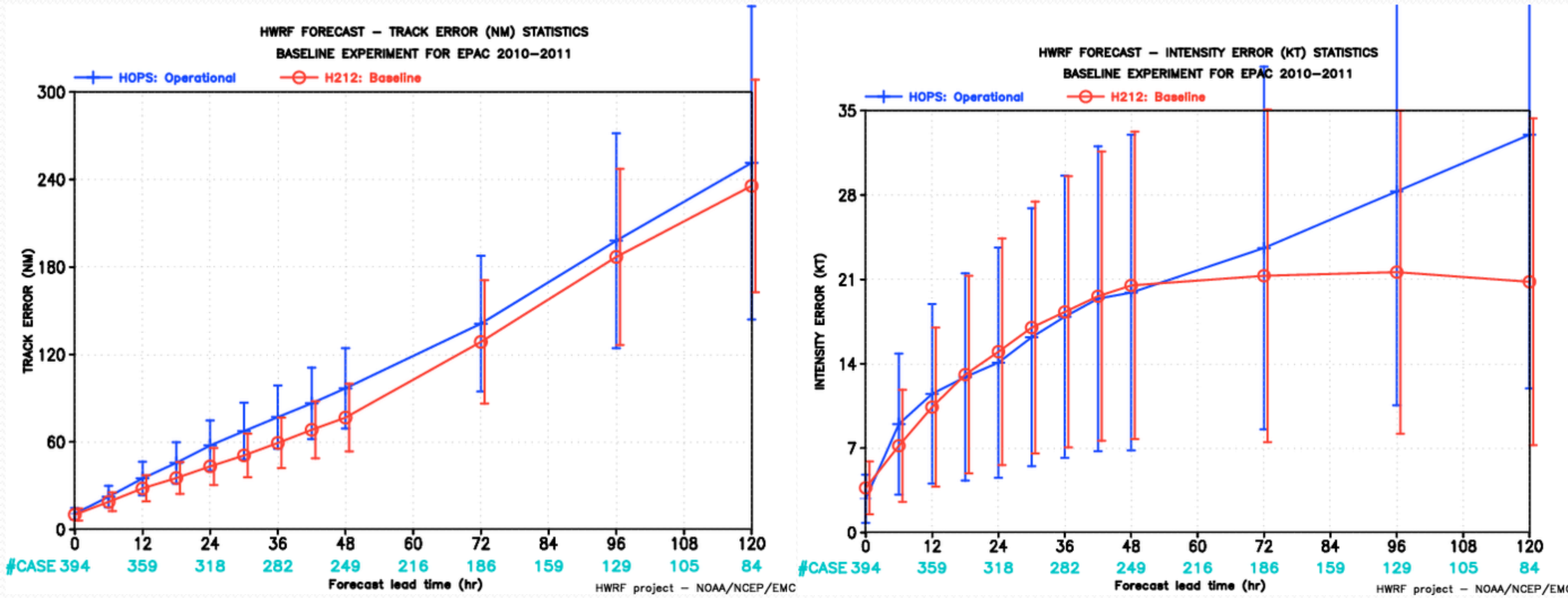
http://www.nasa.gov/mission_pages/hurricanes/archives/2012/h2012_Isaac.html

HFIP Tasks Accomplished During Year 1

- Evaluated 2012 HWRF from an ocean perspective (not shown)
- Coupled HWRF to 1D POM-TC in the eastern Pacific Ocean (implemented operationally in 2012)
- Investigated impact of ocean model resolution under hurricane conditions
- Evaluated different ocean model initializations
- Developed new, high-resolution, transatlantic HWRF/MPIPOM-TC (for real-time testing in 2013)
- Implemented ocean initialization options in MPIPOM-TC with Global HYCOM or RTOFS
- Developed HWRF-WAVEWATCH III-(MPI)POM-TC (for retrospective and real-time testing in 2013)
- Updated the HWRF scientific documentation and users' guide

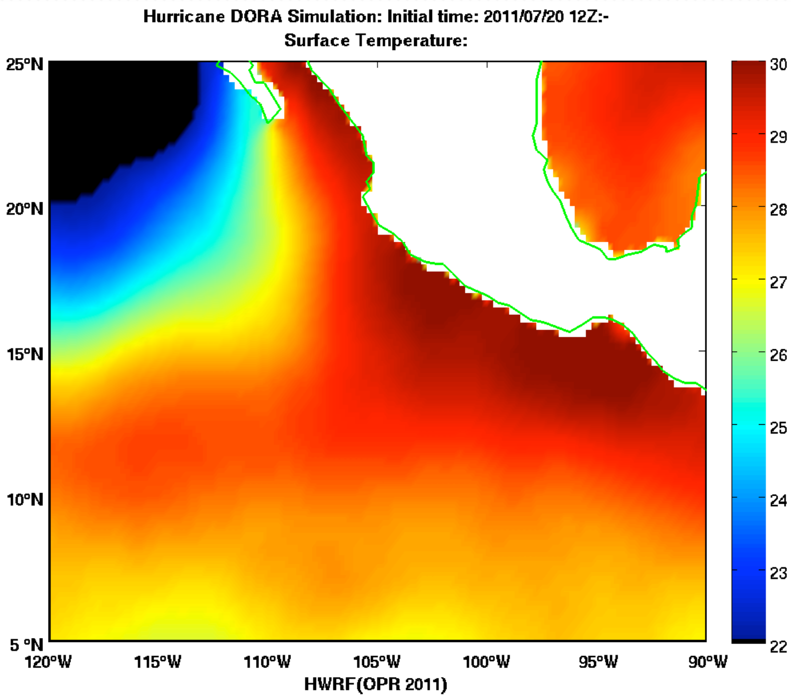
Coupling HWRF to 1D POM-TC in the eastern Pacific Ocean

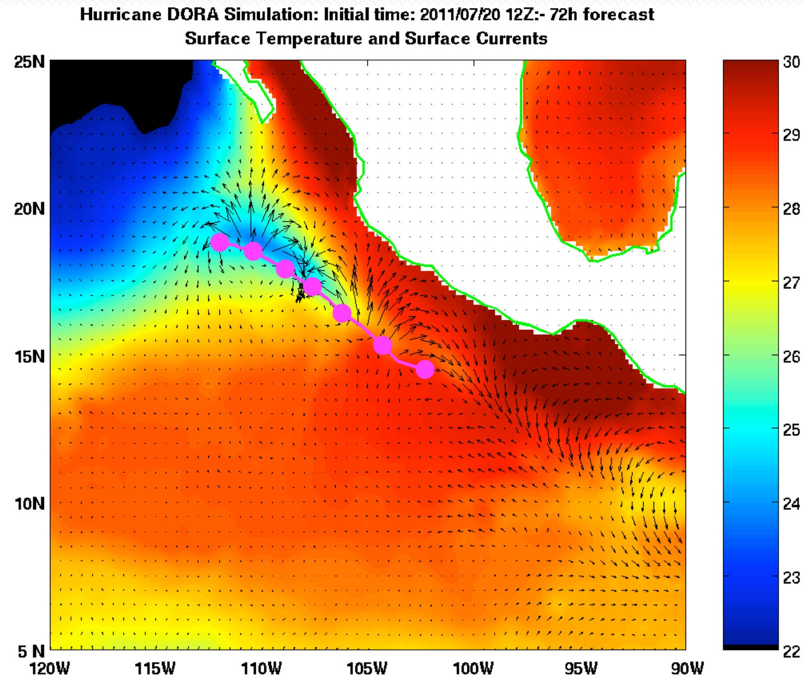
Statistics from 2011 HWRF (uncoupled) & 2012 HWRF (1D coupled) in eastern Pacific



Track (left) and intensity (right) forecast errors in the 2011 (blue) and 2012 (red) HWRF models

2012 HWRF Dora forecast: 2011072012

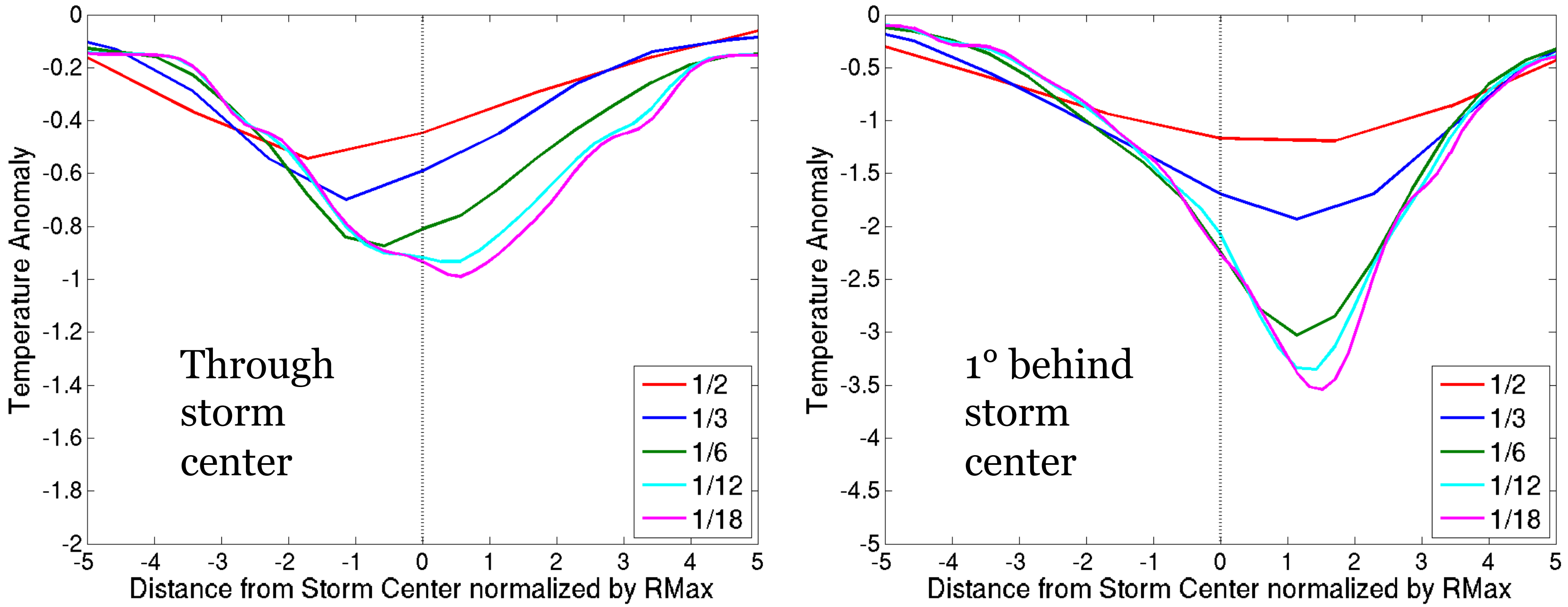




SST 72-h into uncoupled 2011 forecast (left) and 1D coupled 2012 forecast (right) of Hurricane Dora

Impact of ocean model resolution under hurricane conditions

Cross-track SST cooling

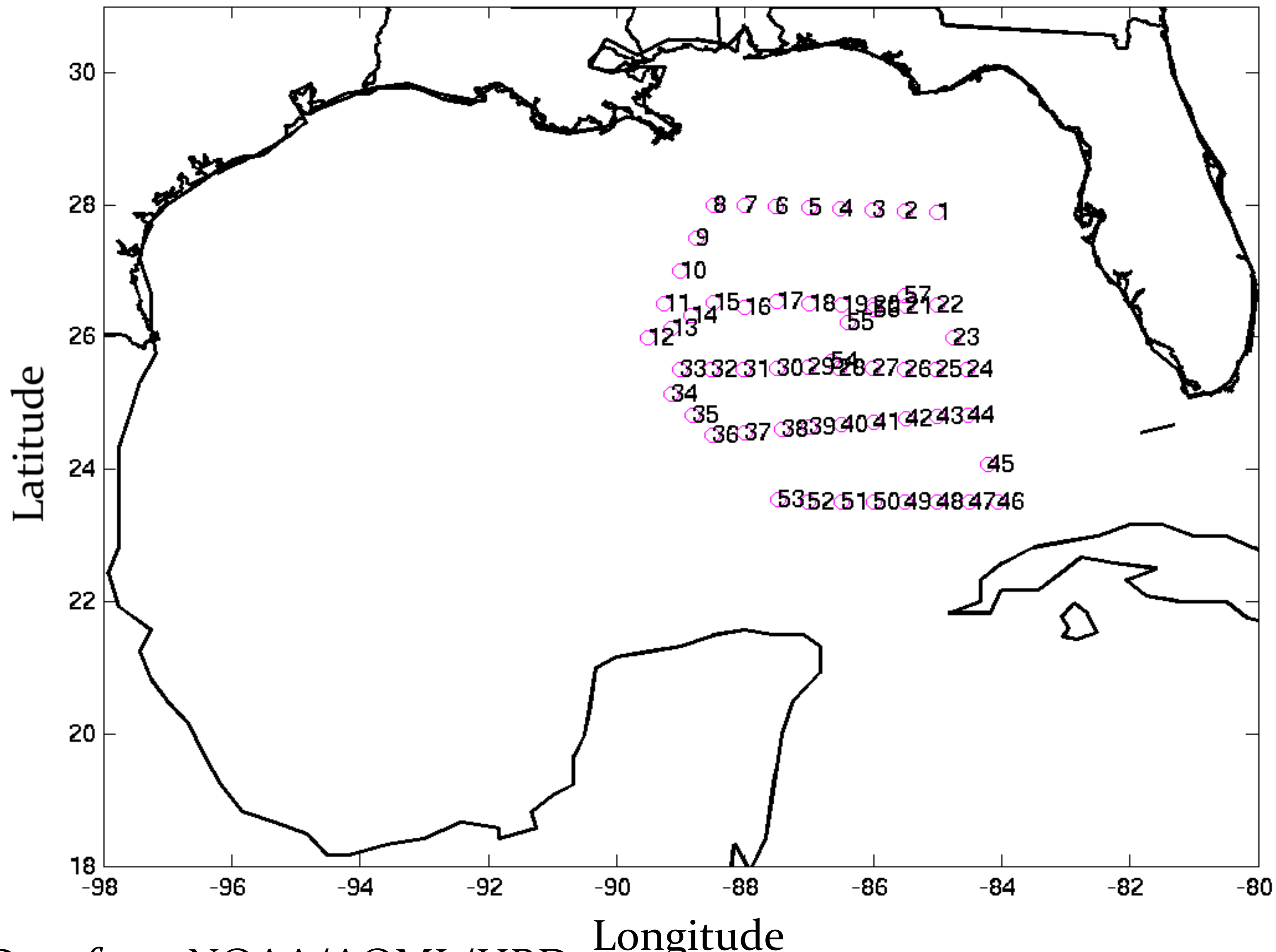


Evaluating ocean model initializations for hurricane prediction

Initializations Tested

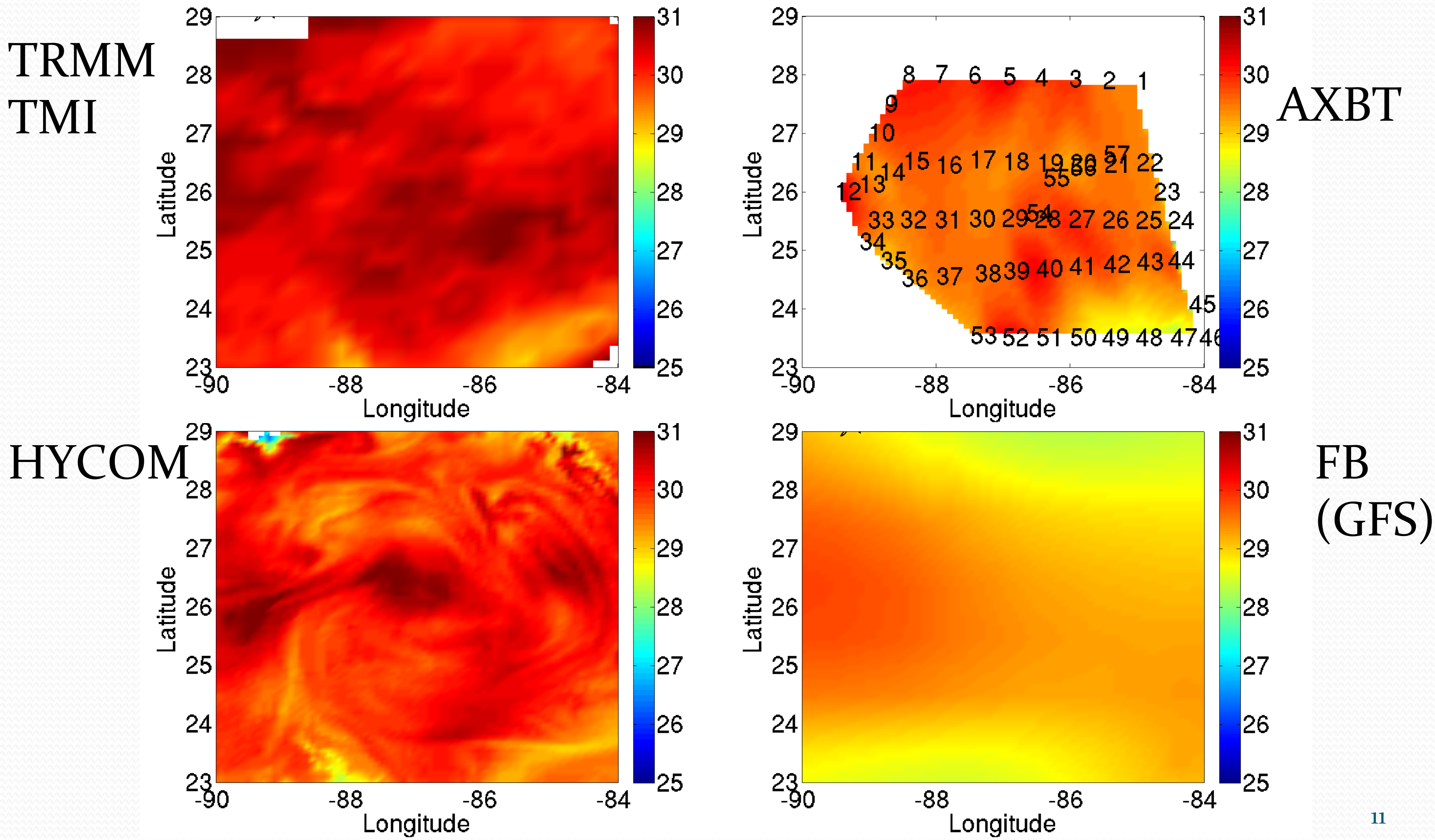
- **HYCOM**: Global HYCOM
- **RTOFS:** Global RTOFS (not shown in the example here)
- **FB**: Feature-based
  - **FB-CCAR**: Feature-based with only Colorado Center for Astrodynamic Research (CCAR) SSH data assimilated
  - **FB-AXBT**: Feature-based with CCAR SSH and AXBT data assimilated to adjust ring position and temperature profiles

AXBT Survey-July 16, 2009



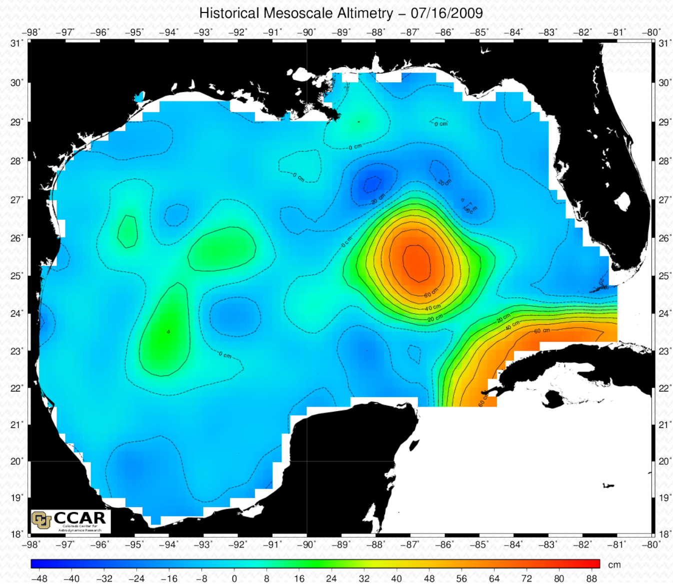
Data from NOAA/AOML/HRD

Sea Surface Temperature

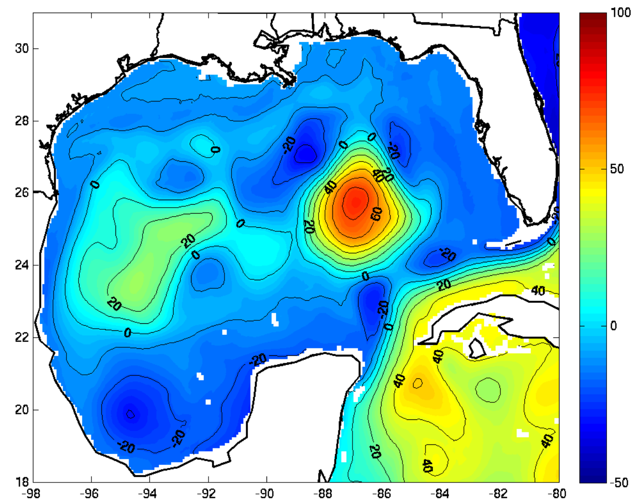


Sea Surface Height

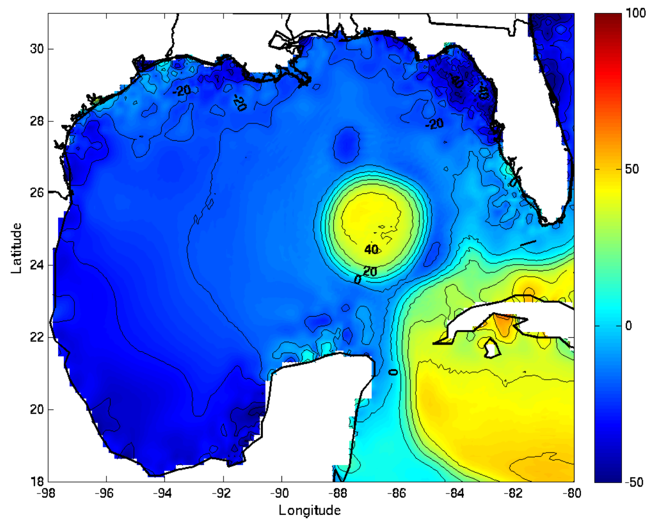
CCAR



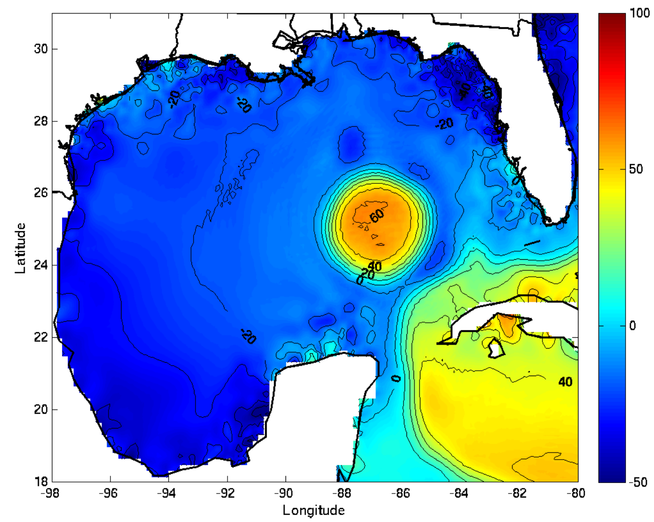
HYCOM



FB-CCAR

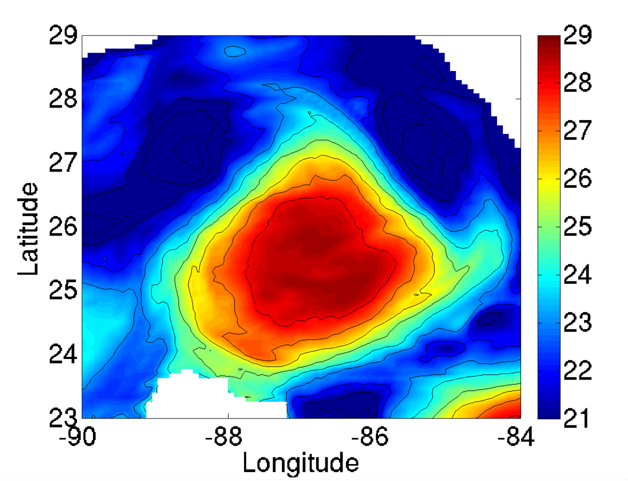


FB-AXBT

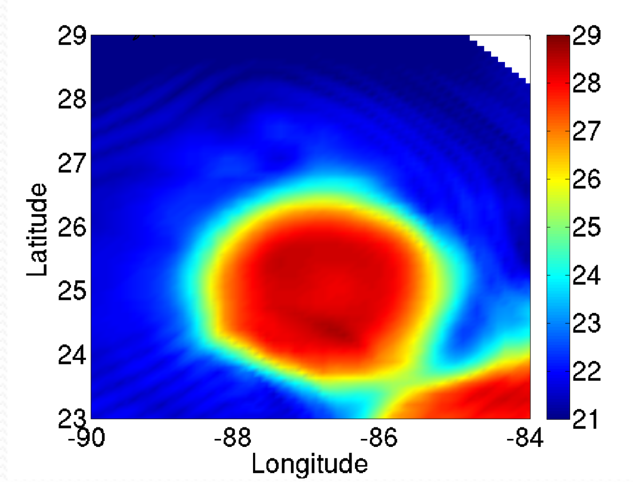


75-m Temperature

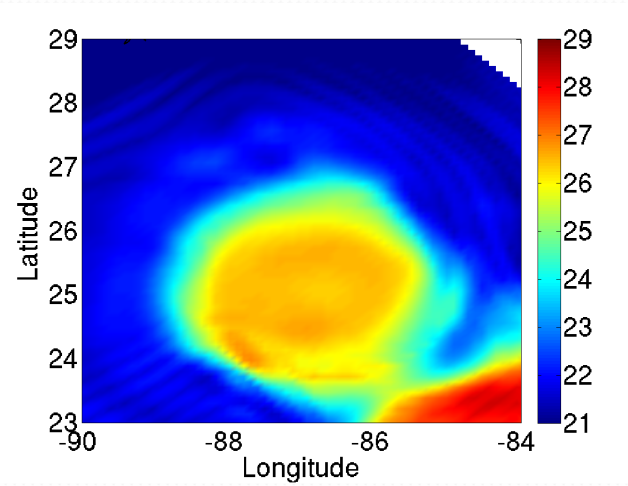
HYCOM



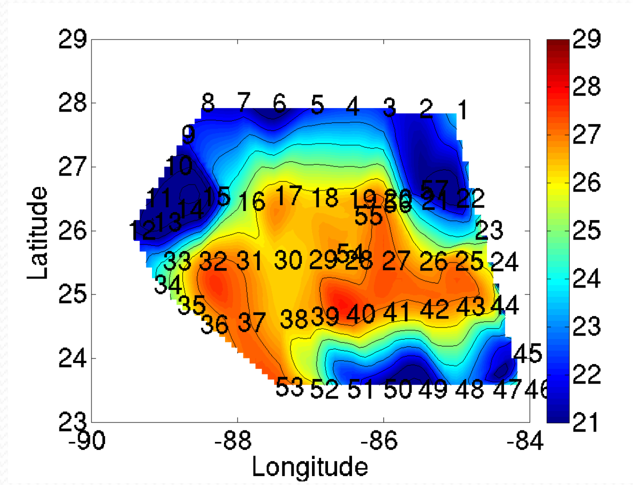
FB-CCAR



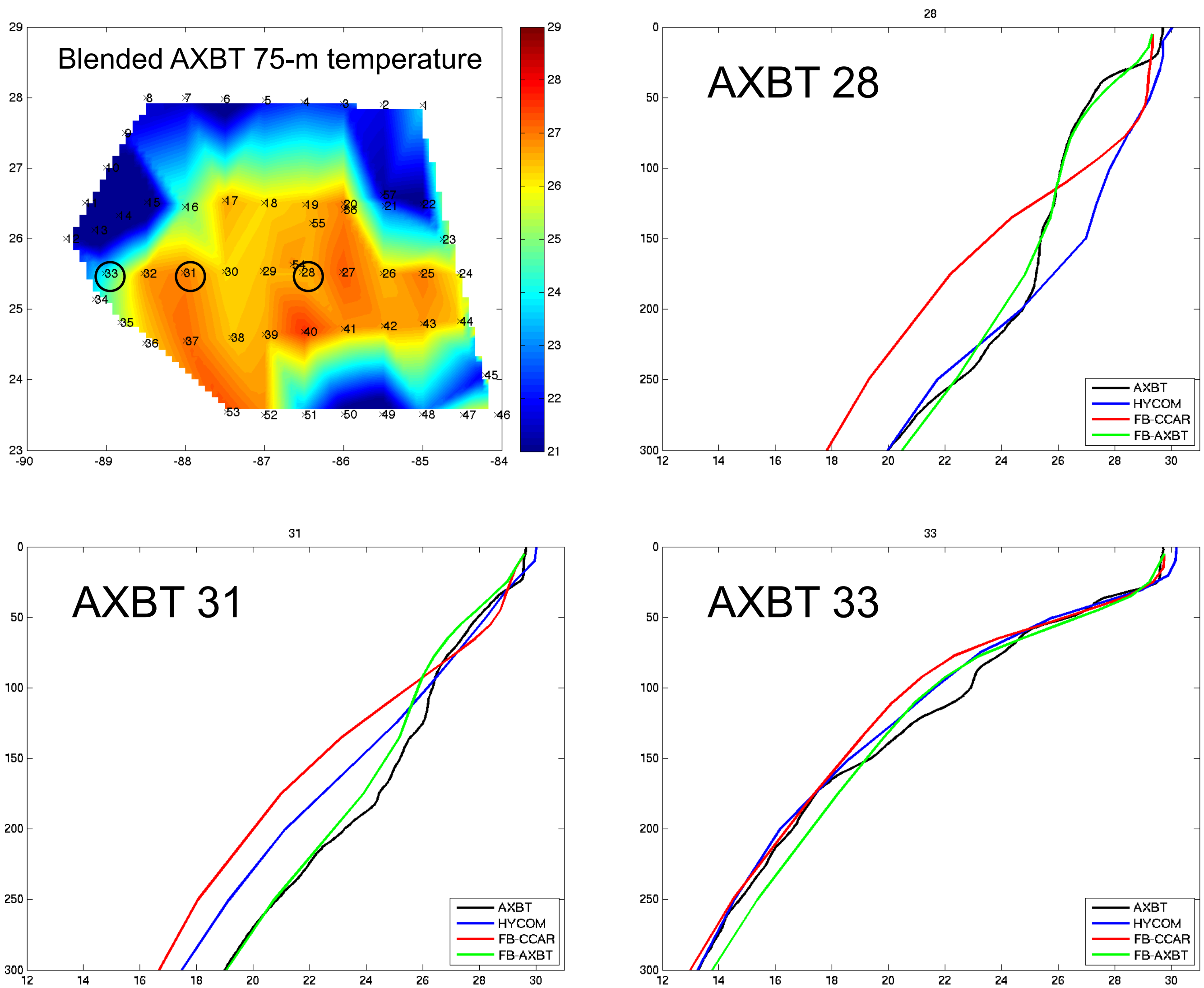
FB-AXBT



AXBT



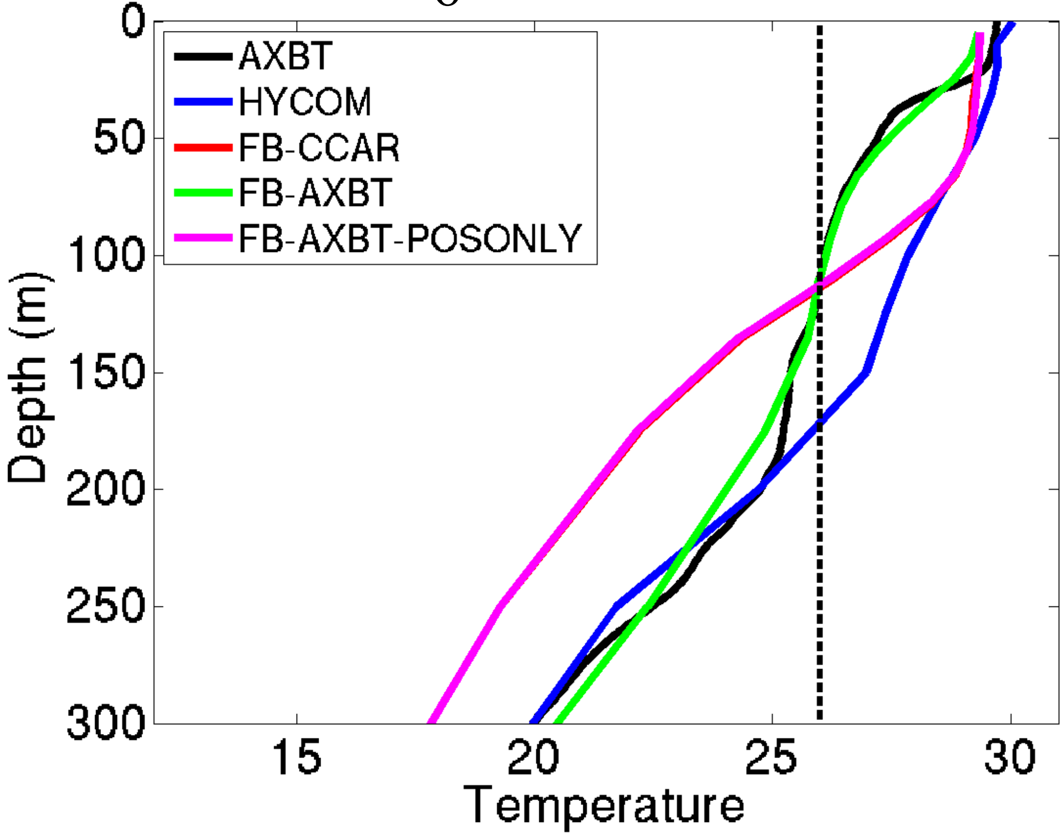
AXBT temperature profiles



Temperature profiles (upper 300 m) are from Global HYCOM (blue), feature-based model without AXBT assimilation (red), feature-based model with AXBT assimilation (green), and AXBT observation (black)

Ocean Heat Content (OHC)

$$OHC = \int_0^{D_{26}} \rho c_p (T - 26) dz$$



Upper-ocean temperature profile near WCR center at location of AXBT #28

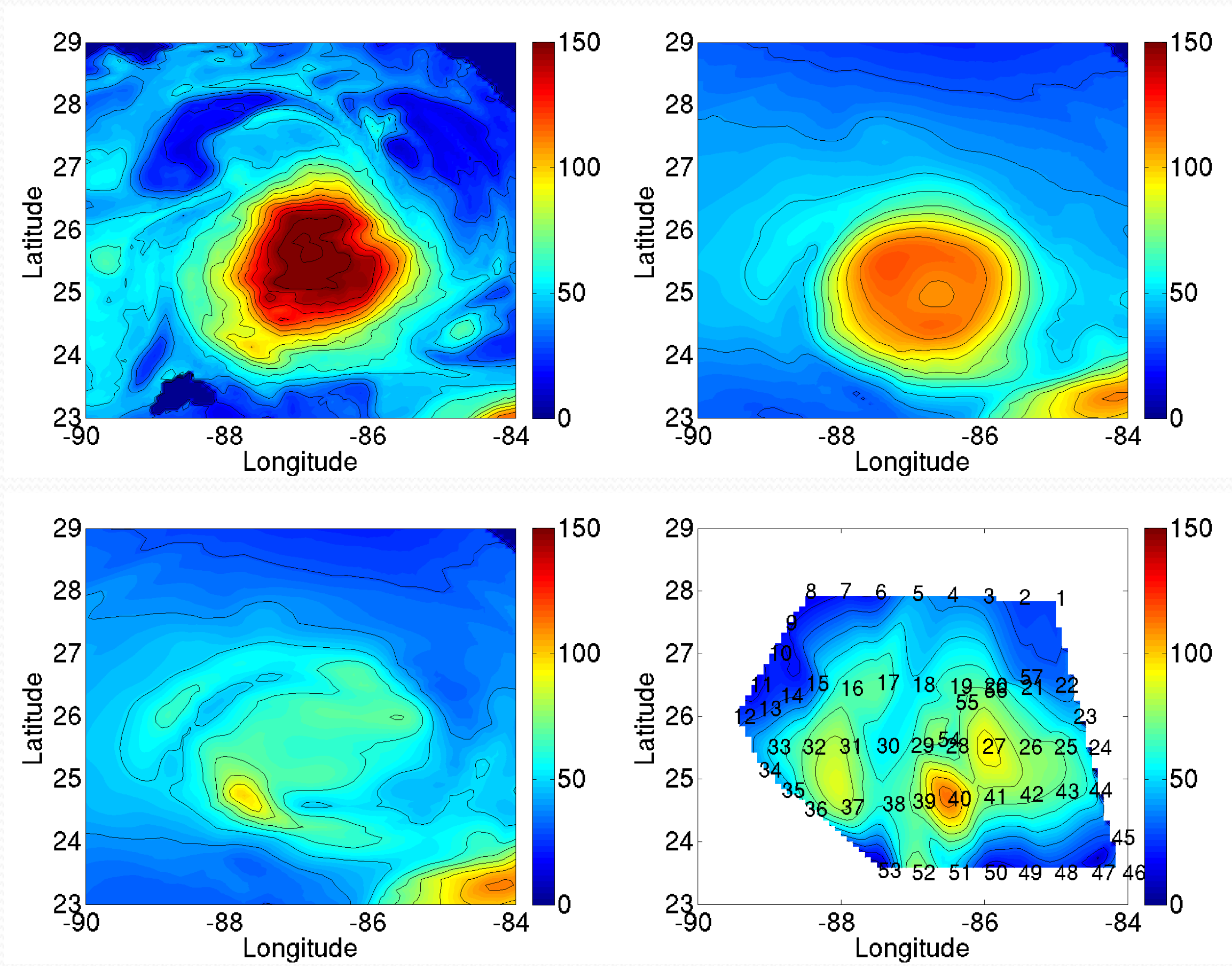
Ocean Heat Content (cont'd)

HYCOM

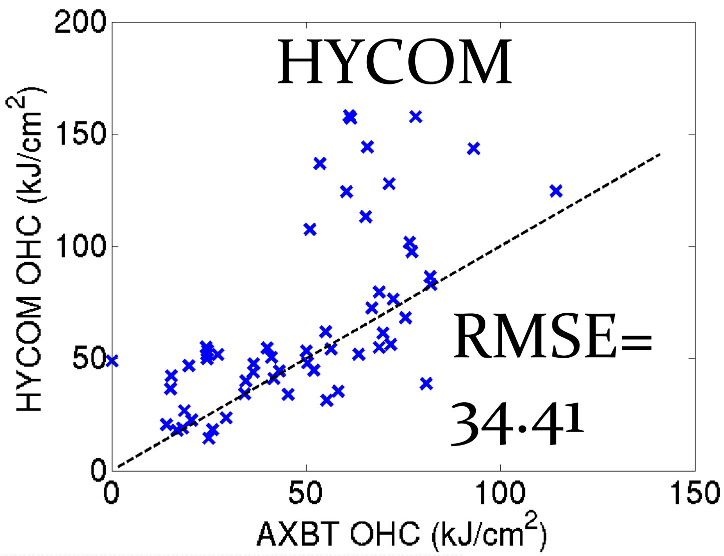
FB-CCAR

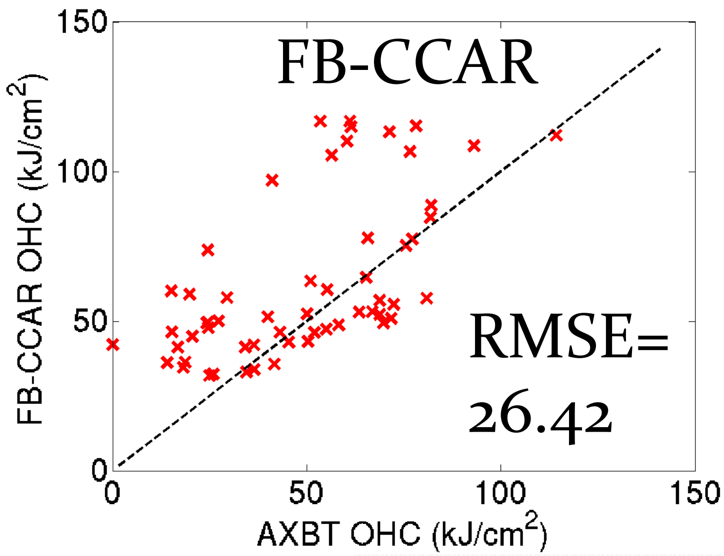
FB-AXBT

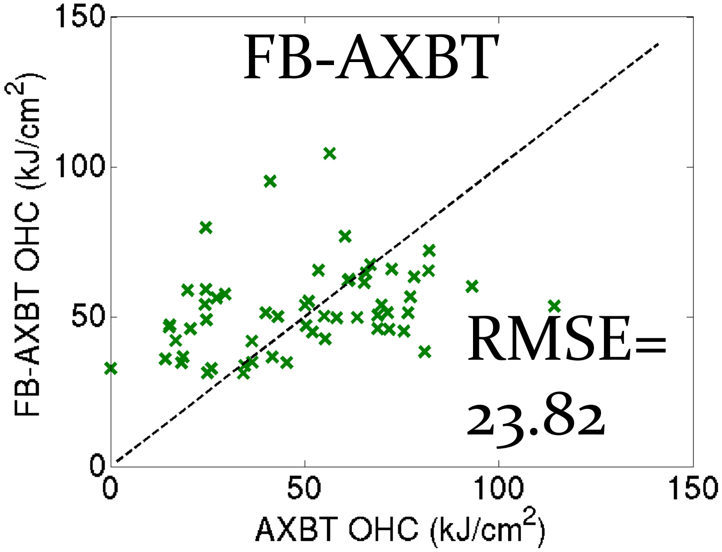
AXBT



Ocean Heat Content (cont'd)

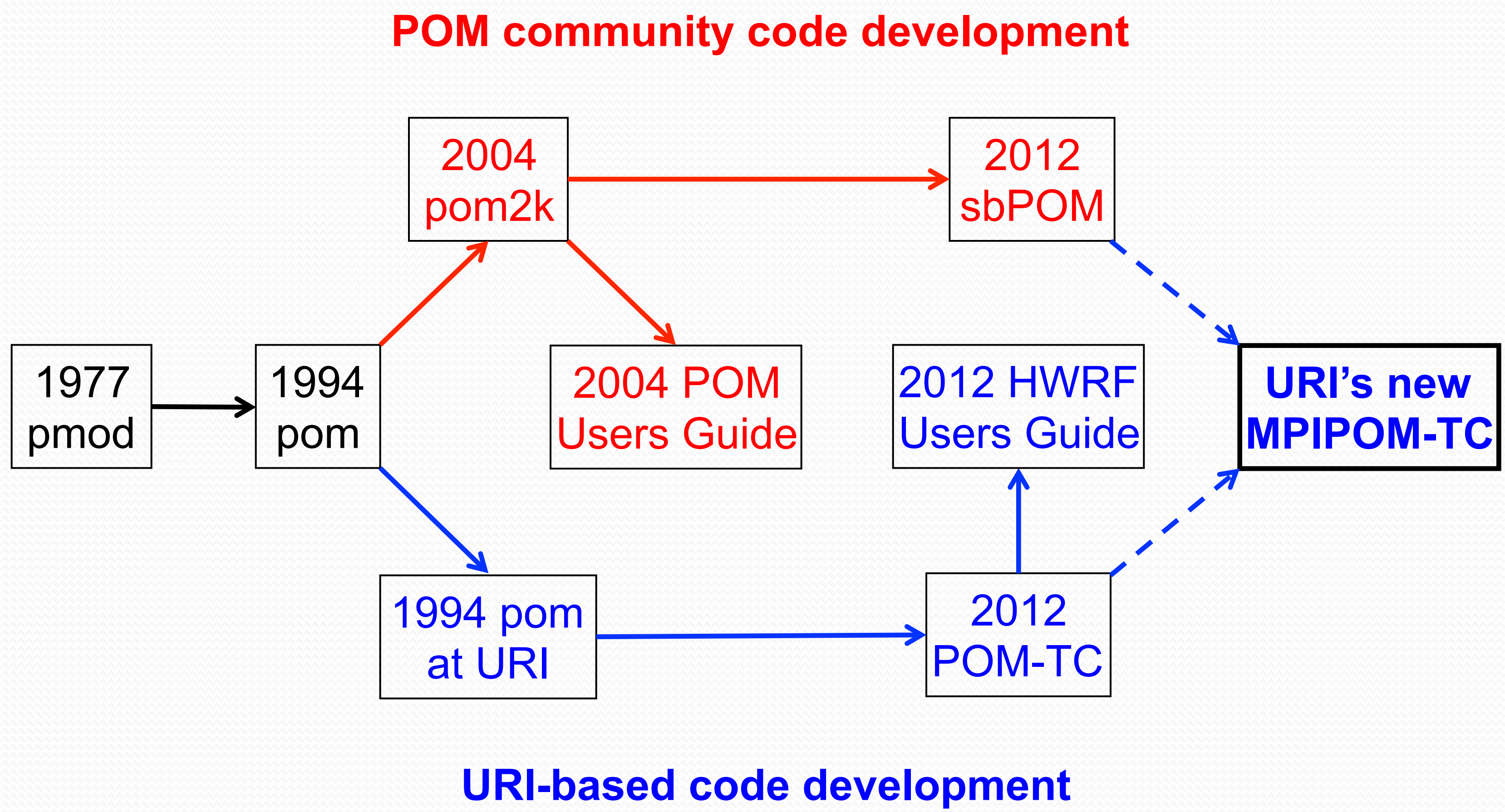






Transatlantic MPIPOM-TC with FB initialization for operations

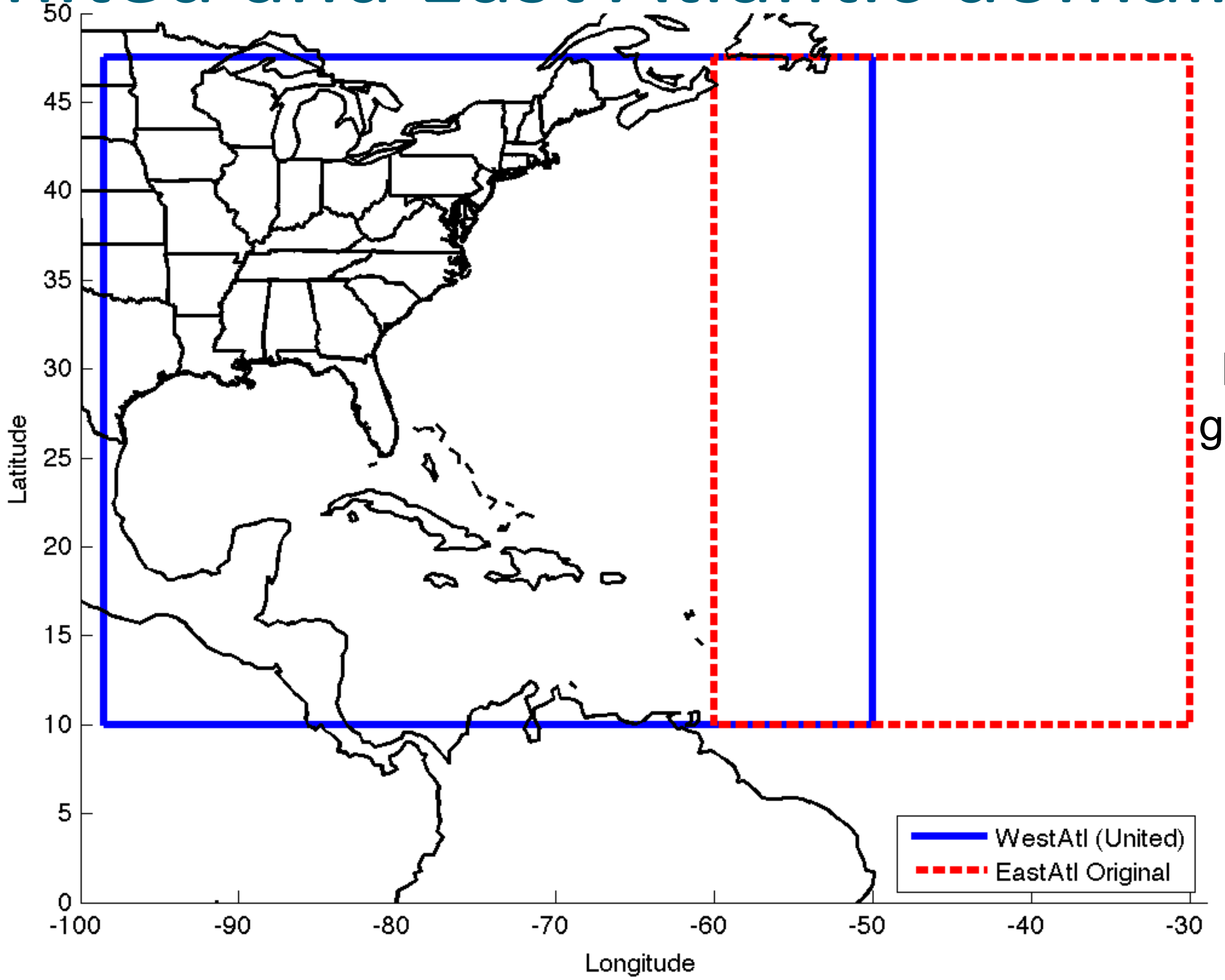
Developing a new MPIPOM-TC at URI



Why create a new MPIPOM-TC?

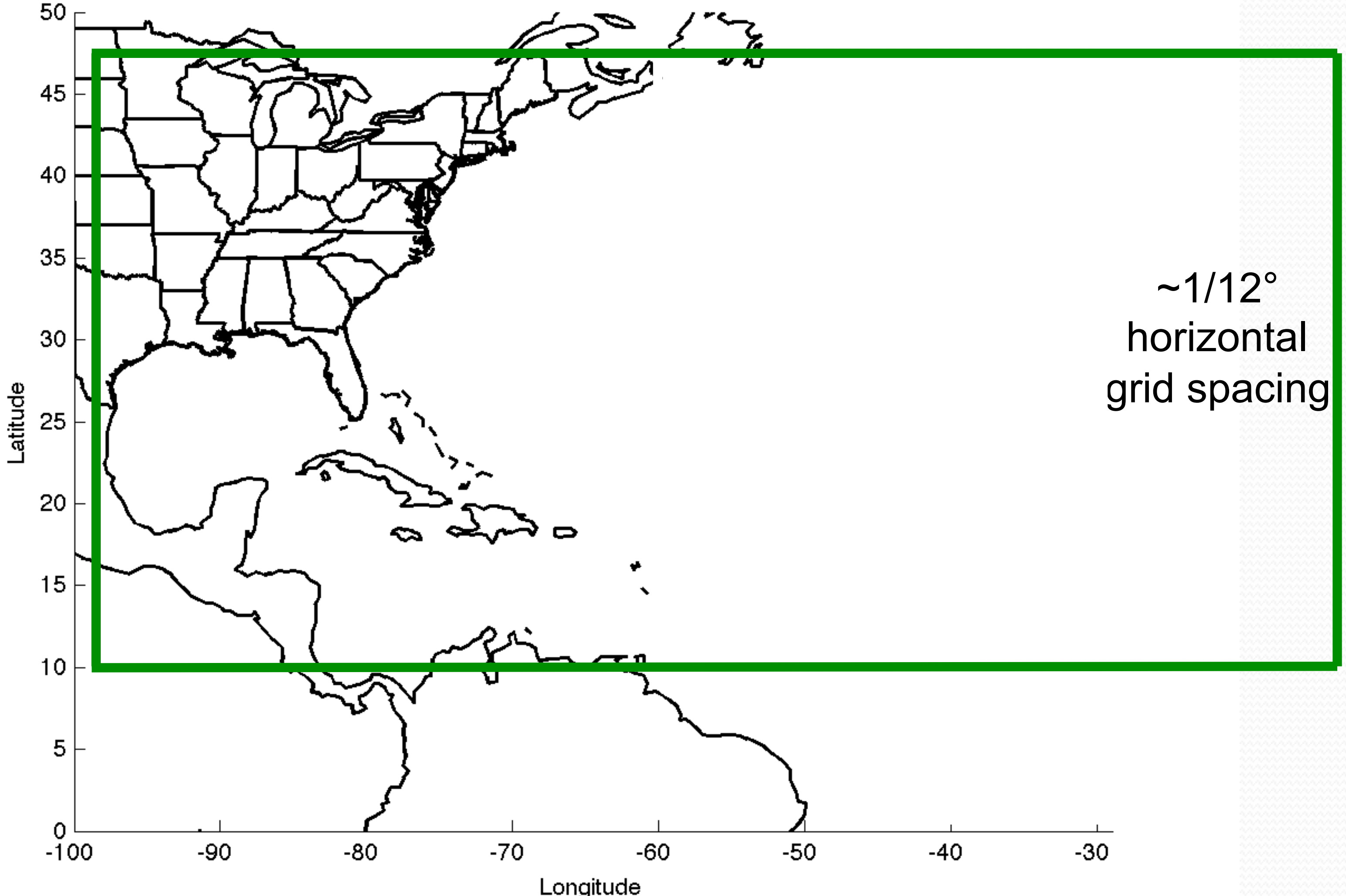
- MPIPOM-TC uses MPI software to run on efficiently on multiple processors, allowing for both higher grid resolution and a larger ocean domain than POM-TC
- MPIPOM-TC accepts flexible initialization options
- MPIPOM-TC is an adaptation of sbPOM, which has community support and includes 18 years of physics updates and bug fixes
- MPIPOM-TC is a modernized code with netCDF I/O

HWRF's 2012 operational POM-TC United and East Atlantic domains



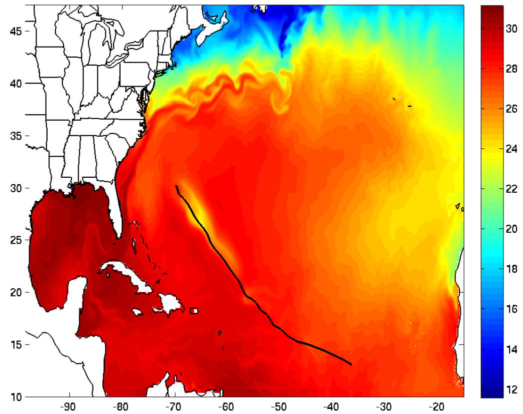
~1/6° horizontal grid spacing

URI's MPIPOM-TC transatlantic domain

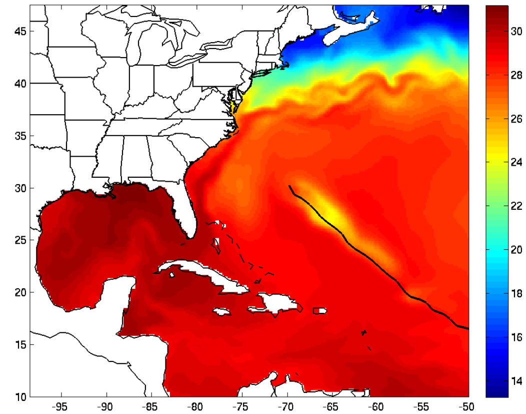


MPIPOM-TC vs. POM-TC (FB initialization): Katia wind forcing through 00Z 08 Sep 2011

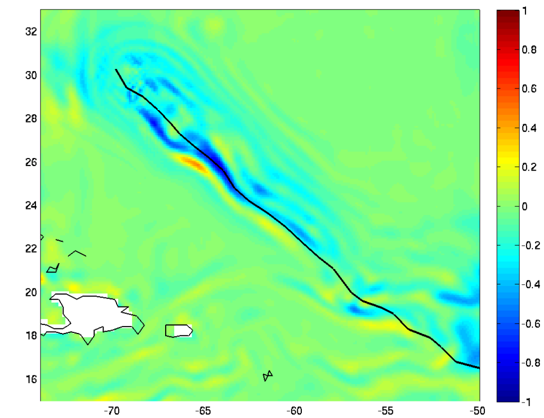
MPIPOM-TC SST (full domain)



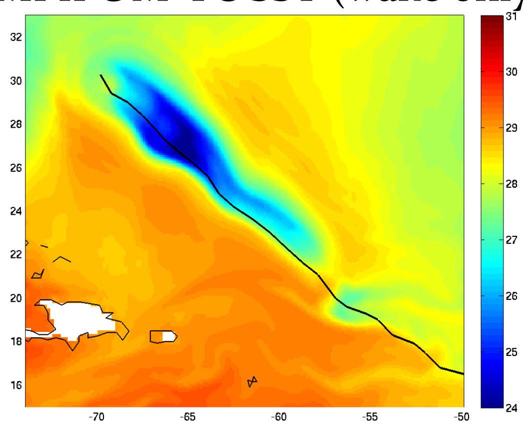
POM-TC SST (full domain)



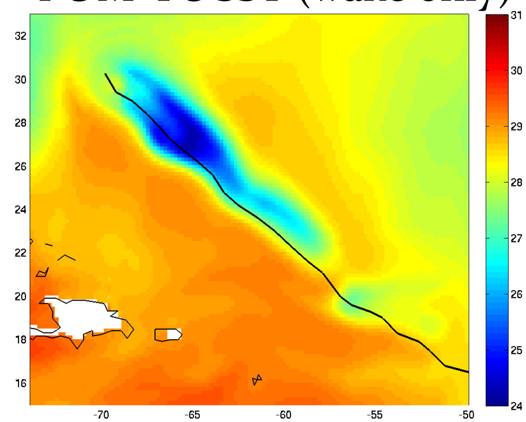
MPIPOM-TC – POM-TC SST



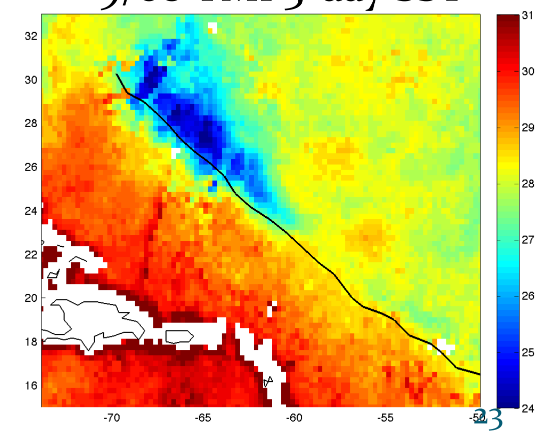
MPIPOM-TC SST (wake only)



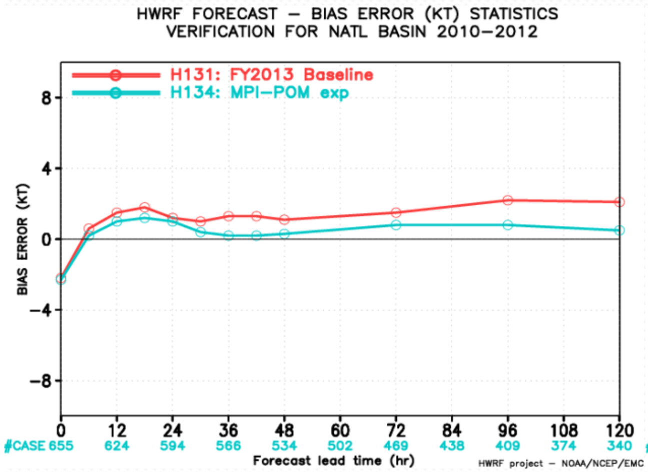
POM-TC SST (wake only)



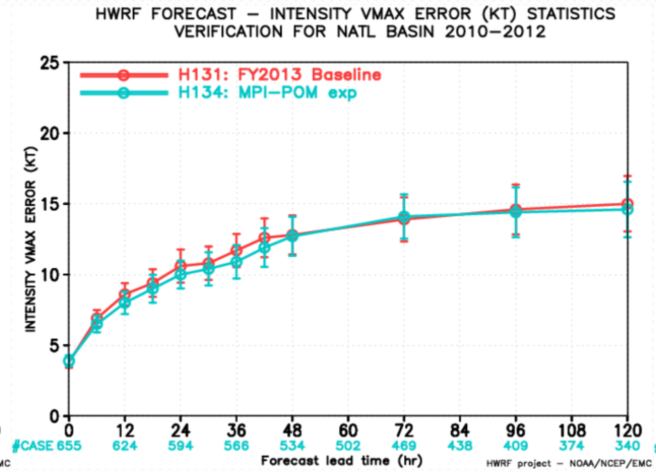
9/08 TMI 3-day SST



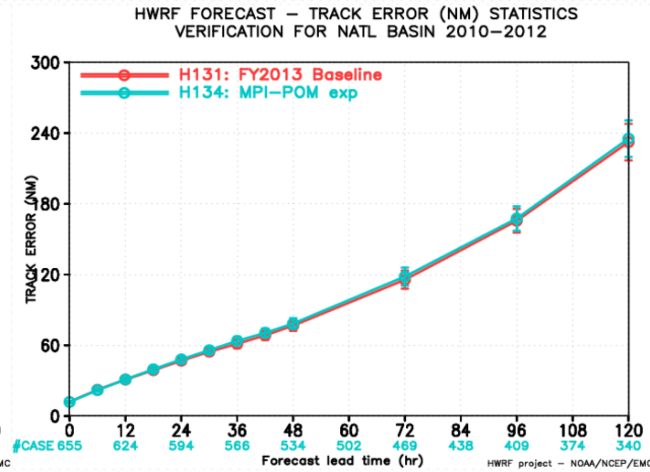
MPIPOM-TC vs. POM-TC (FB initialization): HWRF statistics from 655 cases (2010-2012)



Intensity Bias*



Intensity Error*



Track Error*

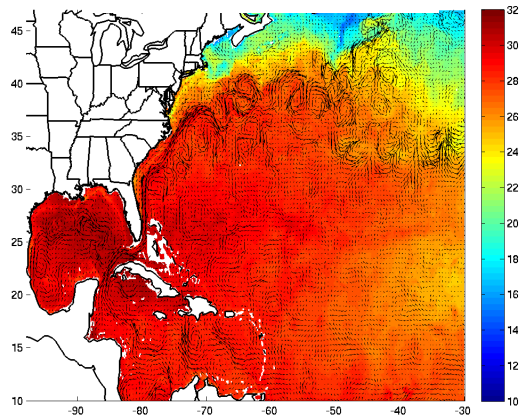
- HWRF positive intensity bias is reduced with MPIPOM-TC (H134) compared to POM-TC (H131)
- HWRF intensity error is slightly reduced with MPIPOM-TC (H134) compared to POM-TC (H131)
- HWRF track error is virtually unaffected with MPIPOM-TC (H134) compared to POM-TC (H131)

* Courtesy of EMC

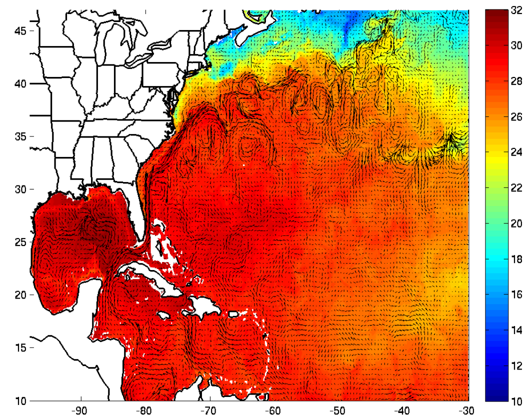
Transatlantic MPIPOM-TC with Global HYCOM or RTOFS initialization

MPIPOM-TC: Global HYCOM or Global RTOFS initialization (20120828)

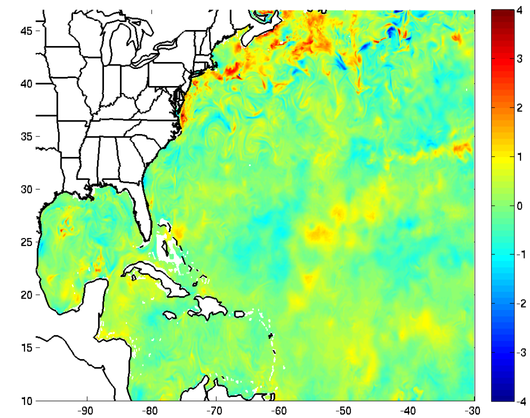
HYCOM SST init



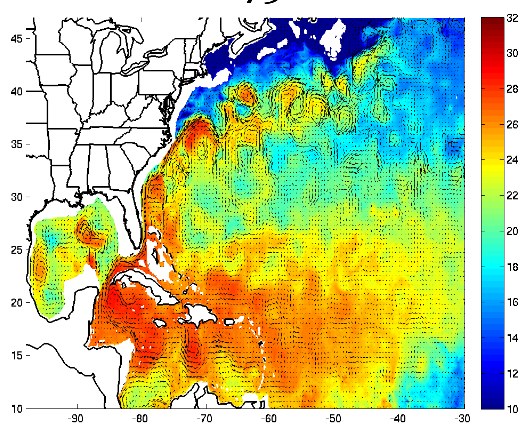
RTOFS SST init



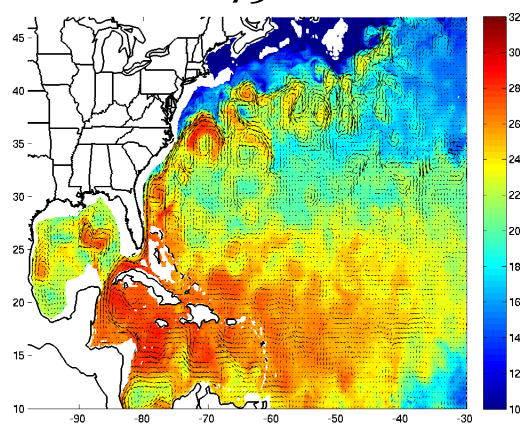
HYCOM-RTOFS SST init



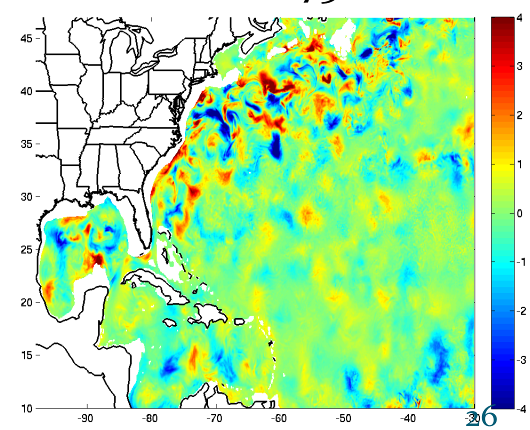
HYCOM 75-m T init



RTOFS 75-m T init



HYCOM-RTOFS 75-m T init



Developing HWRF-WAVEWATCH III-(MPI)POM-TC

HWRF three-way coupled Air-Sea Interface Module (ASIM)

ASIM implemented in HWRF includes the following physical processes affected by surface waves:

- ***Hurricane model***

surface stress includes effects of **sea state, directionality of wind and waves**, **sea spray**, and **surface currents**

- ***Wave model***

forced by **sea state-dependent wind stress** and includes effects of **ocean currents**

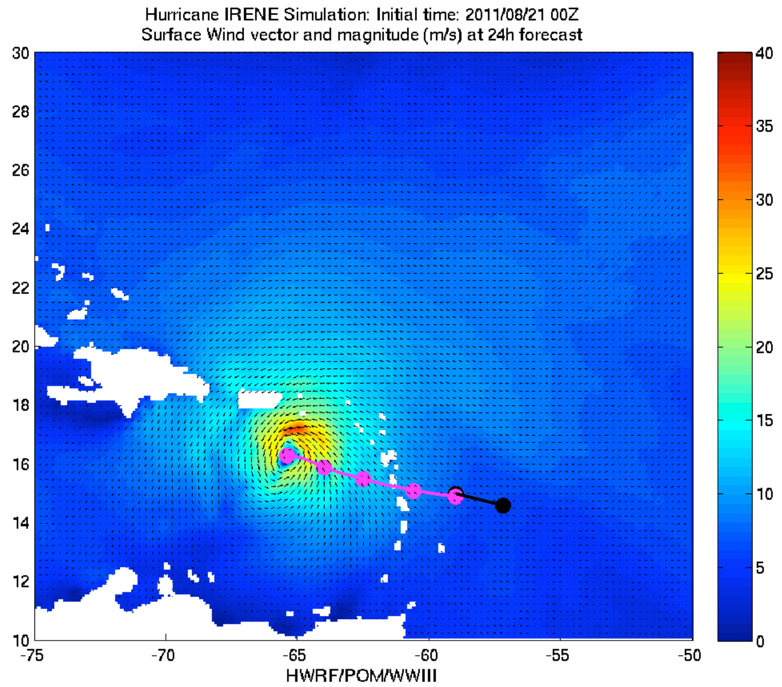
- ***Ocean model***

forced by **sea state-dependent wind stress,** modified by **growing or decaying wave fields** and **Coriolis-Stokes forcing**; turbulent mixing is modulated by the Stokes drift (**Langmuir turbulence**)

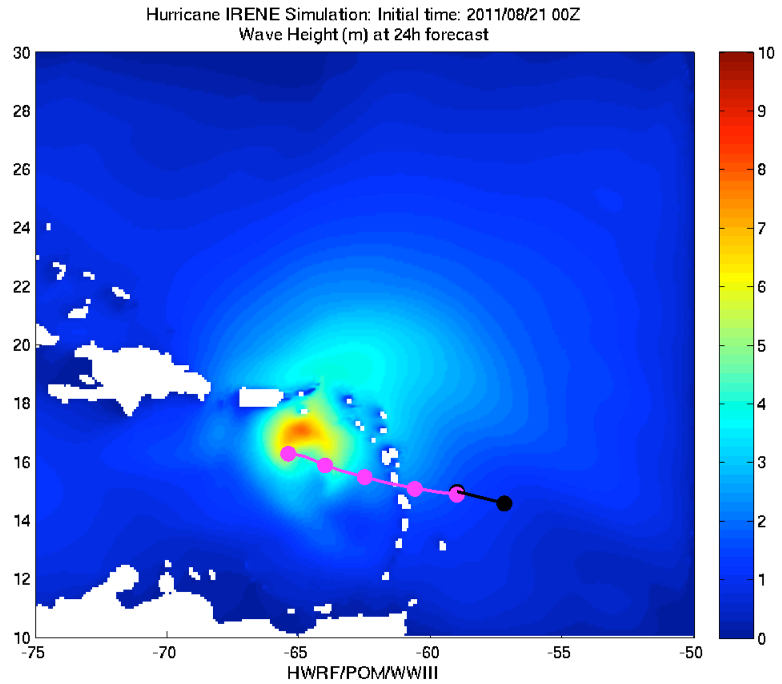
Example of HWRF-WW3-POM-TC forecast

Hurricane Irene: 2011/08/21 00Z

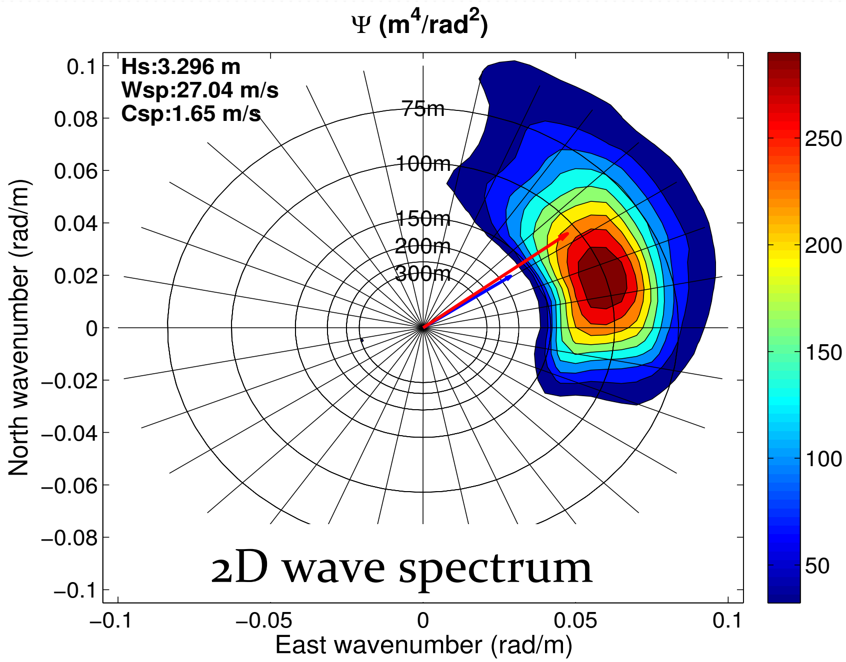
Surface wind

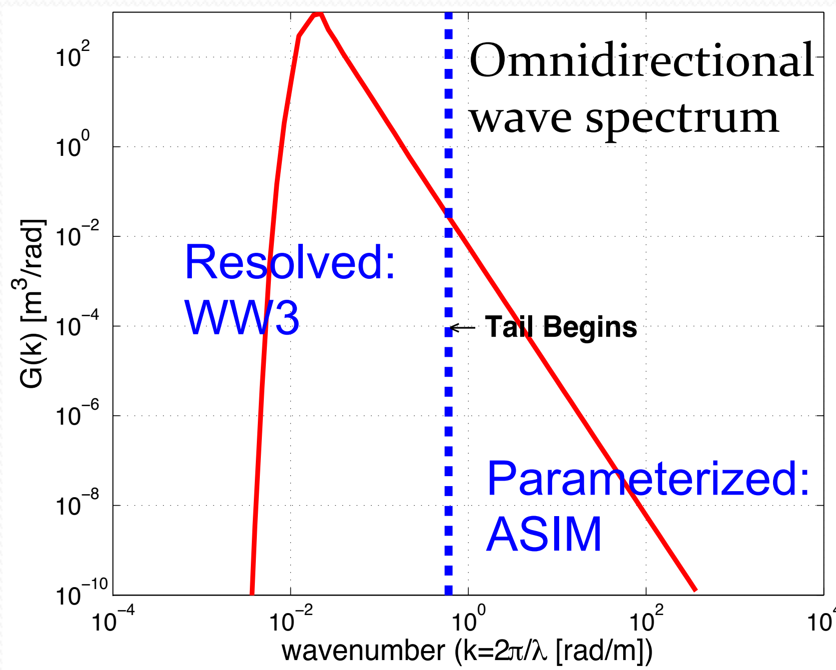


Significant wave height



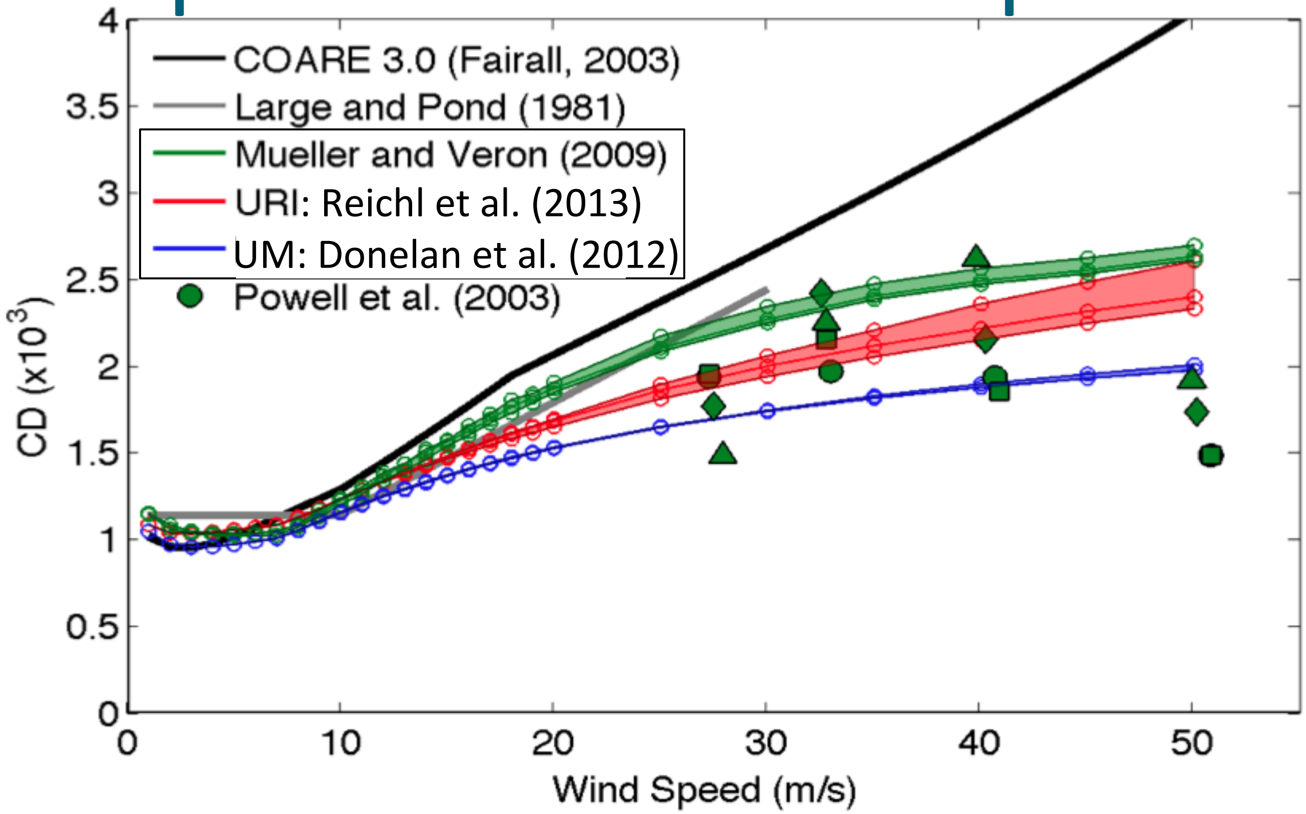
Sea-state dependent C_d





- Form drag is obtained by integrating the 2D *wave spectrum* times *growth rate* over all wavenumbers/directions
- The short wave spectral tail and growth rate are parameterized in ASIM using different theoretical and empirical methods

C_D vs. wind for different ASIM parameterization options

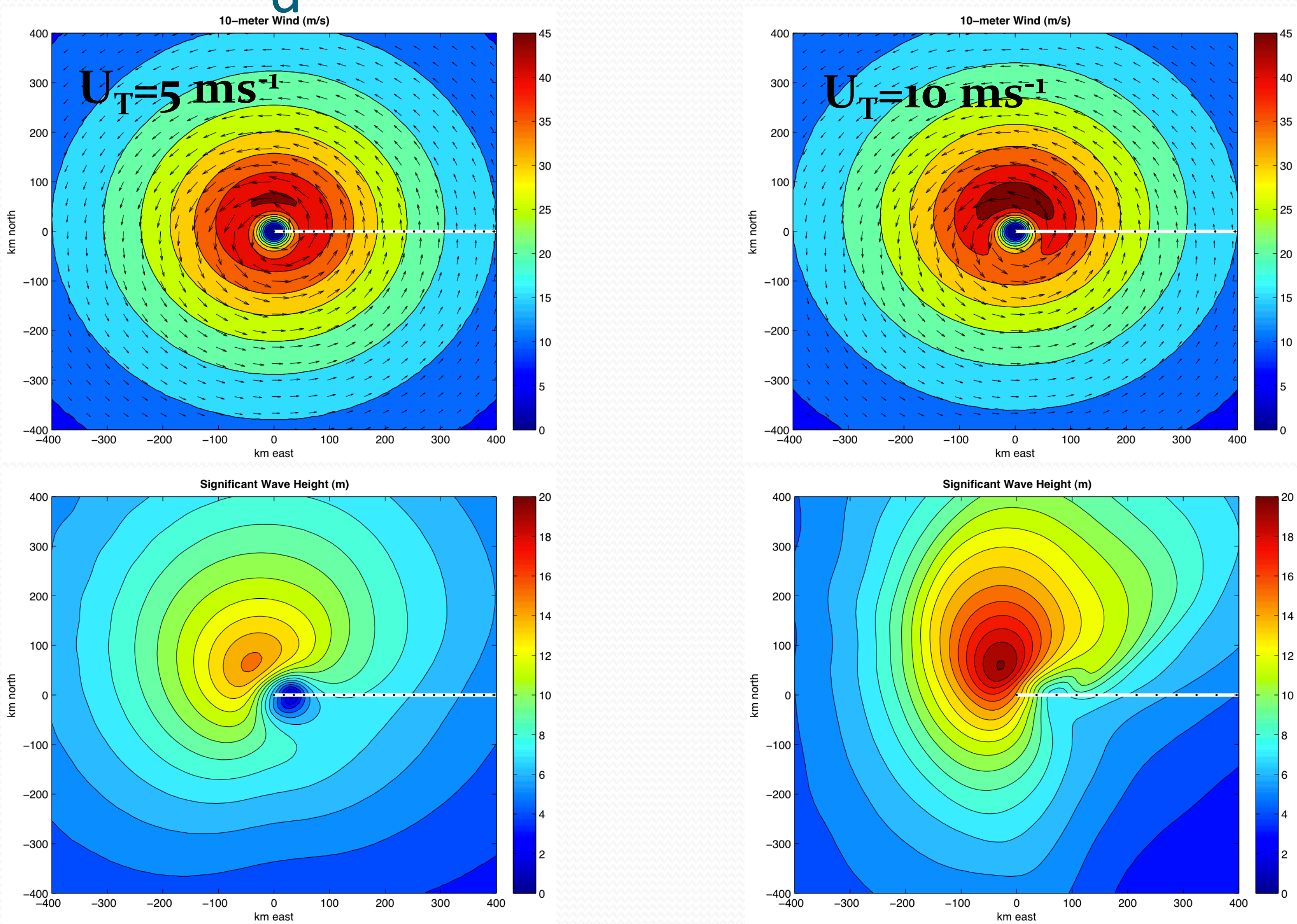


ASIM includes three sea-state dependent C_d parameterization options tested here using an empirically-derived wave spectrum from the Joint North Sea Wave Project (Elfounhaily et al. 1997)

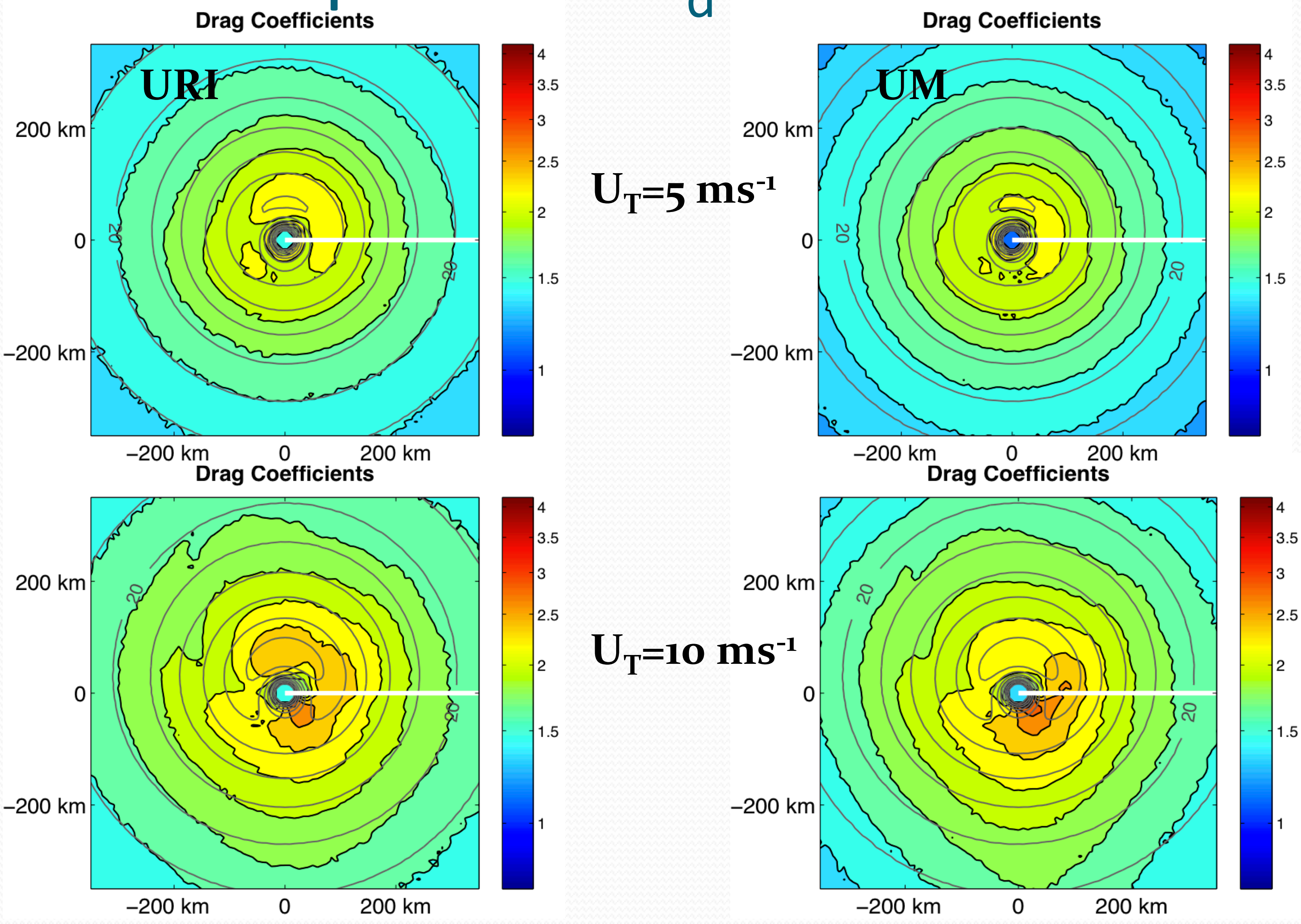
Investigating sea-state dependent C_d in idealized hurricane

Wind Speed (m/s)

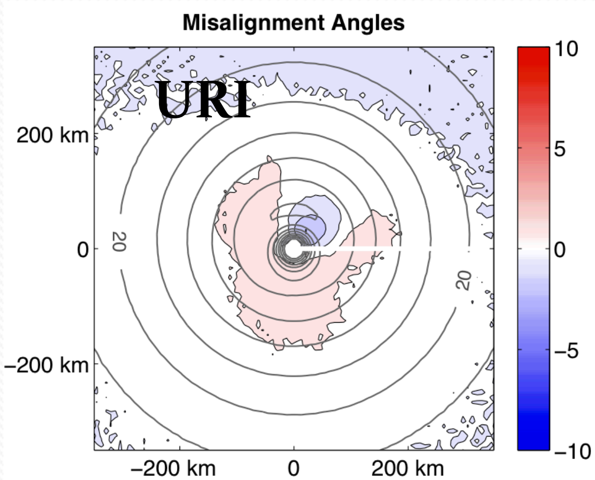
H_s (m)



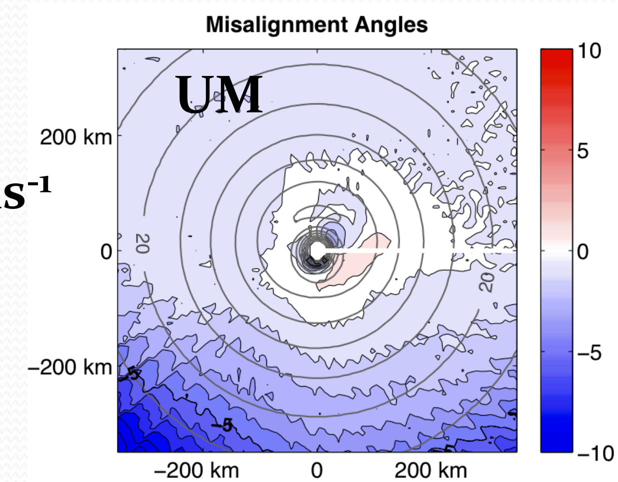
Sea-state dependent C_d: URI vs. UM method

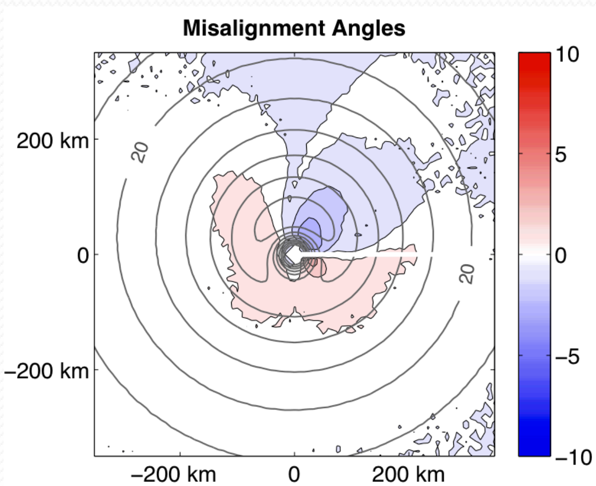


Misalignment angle between surface stress and wind

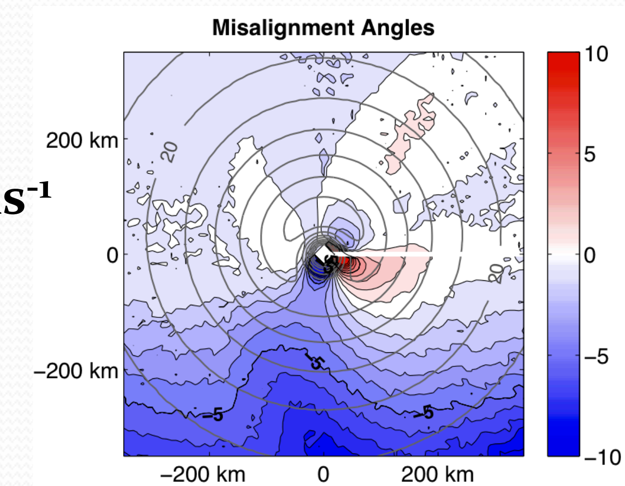


U_T=5 ms^{-1}





U_T=10 ms^{-1}



Effects of surface waves on ocean currents/turbulence

$$\frac{\partial}{\partial t}U_{c\alpha} + \frac{\partial}{\partial x_\beta}\left(U_{c\alpha}U_{c\beta}\right) + \frac{\partial}{\partial z}\left(WU_{c\alpha}\right) - \varepsilon_{\alpha\beta z} f U_{c\beta} = -\frac{1}{\rho}\frac{\partial P}{\partial x_\alpha} + \frac{\partial \bar{\tau}_{t\alpha}}{\partial z}$$

Turbulence closure (modified by wave effects)

$$\bar{\tau}_{t\alpha} = \tau_{air\alpha} - \frac{\partial}{\partial t}M_\alpha - \frac{\partial}{\partial x_\beta}MF_{\alpha\beta} - \tau_{s\alpha} \quad at \quad z = \hat{\eta}$$

ASIM momentum flux budget

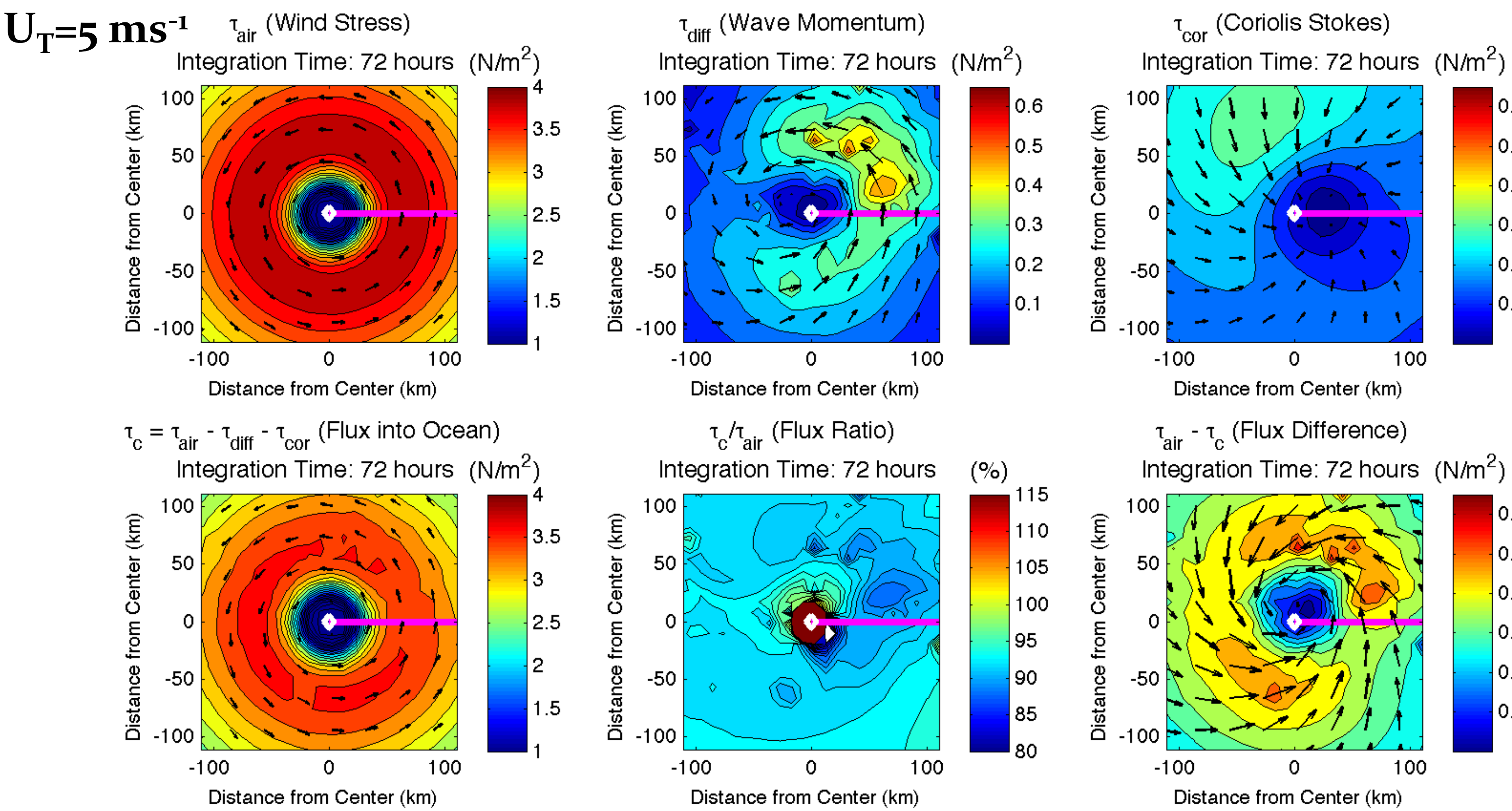
$$M_\alpha = \int_{-\infty}^{\hat{\eta}} u_{s\alpha}\,dz \qquad MF_{\alpha\beta} = \int_{-\infty}^{\hat{\eta}} S_{\alpha\beta}\,dz \qquad \tau_{s\alpha} = -\int_{-\infty}^{\hat{\eta}} \varepsilon_{\alpha\beta z} f u_{s\beta}\,dz$$

(red circle) : wave-dependent momentum flux budget terms (Fan et al. 2010)

(yellow circle) : Coriolis-Stokes forcing term (Polton et al. 2005)

(green circle) : Langmuir turbulence effect – will be included in the turbulence closure model (in collaboration with Tobias Kukulka, U. Delaware)

ASIM momentum flux budget terms in idealized hurricane



Plans for Year 2 of HFIP funding

- Evaluating EMC's H213 (2013 operational HWRF) vs. H136 (H213 + MPIPOM-TC) reruns from the 2010-2012 Atlantic & East Pacific hurricane seasons, plus 2013 real-time evaluation
- Evaluating H213 + HYCOM reruns (if available from EMC) in comparison to H213 and H136, plus 2013 real-time evaluation
- Continuing with MPIPOM-TC initial condition development and evaluation (Global HYCOM, Global RTOFS, etc.)
- Continuing to ensure all MPIPOM-TC upgrades are included in the HWRF repository, scientific documentation, & users' guide
- Coupled HWRF-WW3-(MPI)POM-TC evaluation in retrospective and 2013 real-time runs