Pre-operational coastal or near-coastal ocean products at NOAA's NCEP/EMC.

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- **I**. experimental Gulf of Mexico ocean data assimilation system built with Hybrid Coordinate Ocean Model (HYCOM) and Navy Coupled Ocean Data Assimilation (NCODA) system: QC, and simulations
- **II**. pre-operational coupled ocean-atmospheric system for hurricanes built with HYCOM+HWRF
- **III**. experimental 3-way coupled HWRF+POM+WaveWatch III

I. NCEP Observation Data and NCODA QC

- NCODA interface for reading NCEP operational data is done for
  - SSH (Jason-2, Jason-3, Cryosat, Saral/Altika)
  - SST (AVHRR, GOES, AMSR2, VIIRS, in-situ)
  - Profiles (BATHY, TESAC (TEmperature/SAlinity/Currents)
- NCODA QC
  - Running in near real-time after successfully been tested
  - Some issues to be solved (availability of some SST data streams, non-essential parameters missing in SST data stream)
  - We are using climate as background, then this is a simplified first step

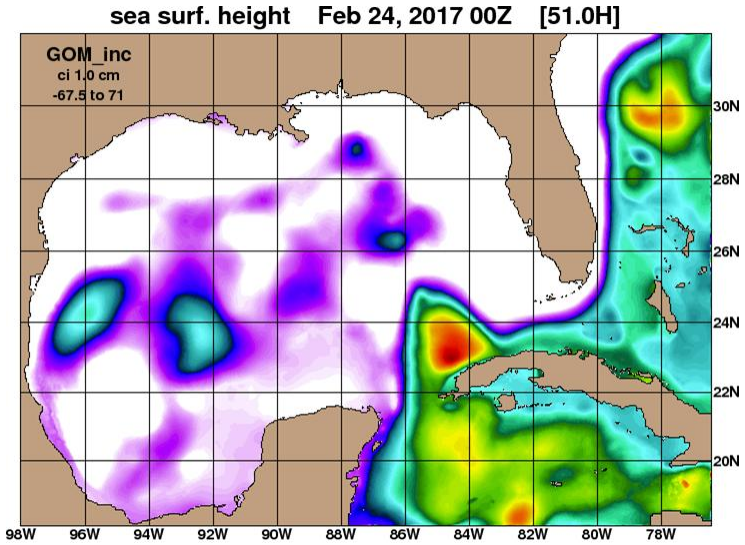
I. HYCOM+NCODA for Gulf of Mexico

- 1/25° grid resolution HYCOM, 36 layers (setup from U.S.NAVY Stennis Gulf of Mexico analysis)
- A "proof of concept" simulation was first done for July 20-August 20 2011, using pre-prepared data from Godae server
- **NCEP setup for 2017**:
  - No tides are included.
  - Initialized from and nested to RTOFS-Global parallel HYCOM+CICE daily instantaneous analysis archives
  - Forced with hourly NCEP GDAS atmospheric forcing
  - NCODA assimilates: T/S profiles, altimeter (using MODAS profiles), satellite SST. Not using high resolution SST
  - Run started February 15, 2017, and was first done for 10 days

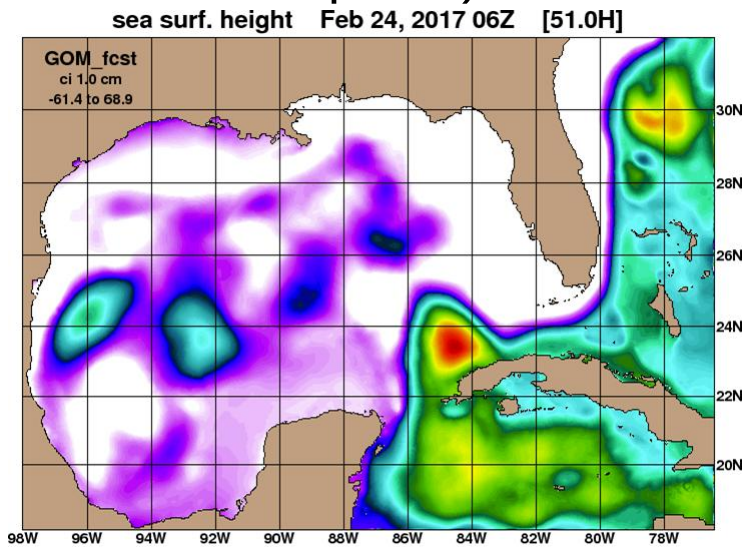
I. HYCOM+NCODA for GOM, near real time. Day 10, 2/24/2017

- An incremental archive is obtained using a HYCOM offline utility to incorporate temp, saln, u, v, pressure increments
- Then, the increments are included into the HYCOM run during the first 6 hours following the analysis

SSH incremental archive



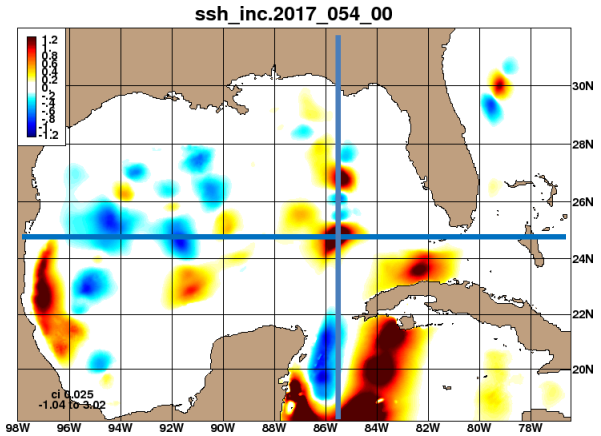
SSH HYCOM, hour 6 (end of incremental update)

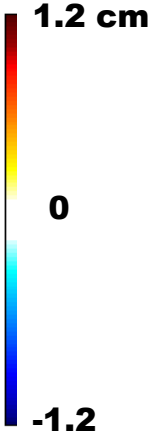


I. HYCOM+NCODA for Gulf of Mexico. Day 9, 2/23/2017

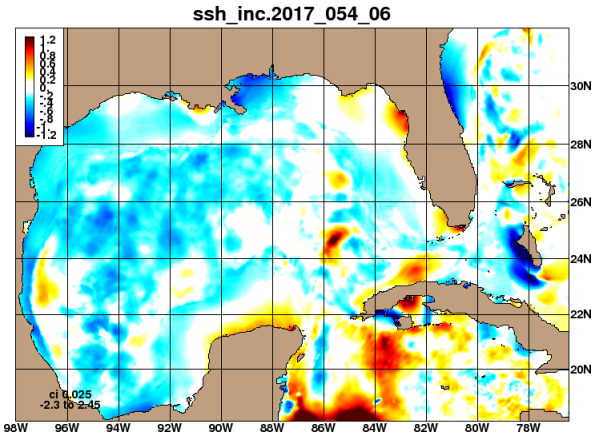
SSH, Analysis – model

Hour 0

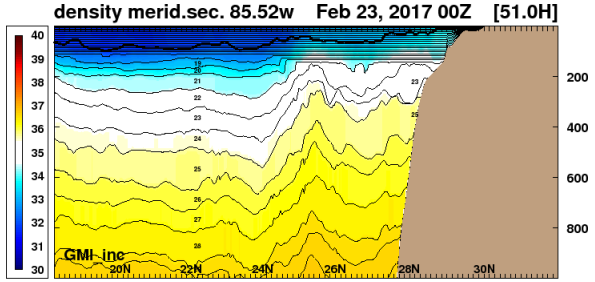


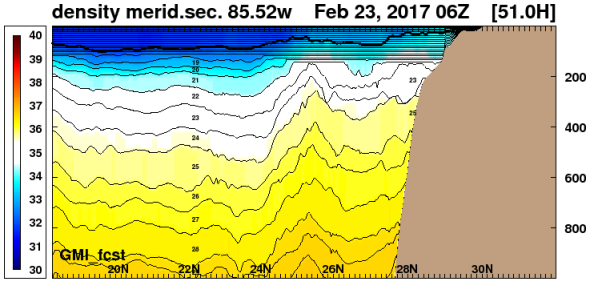


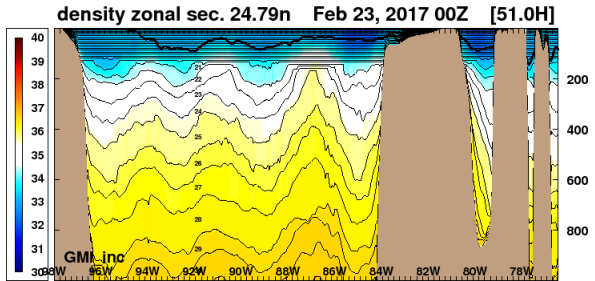
Hour 6

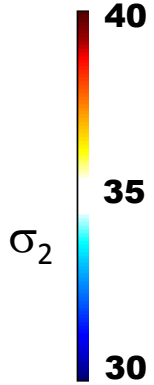


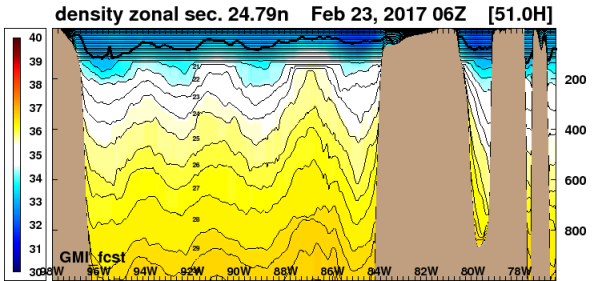
Density sections: Analysis hour 0 and model hour 6









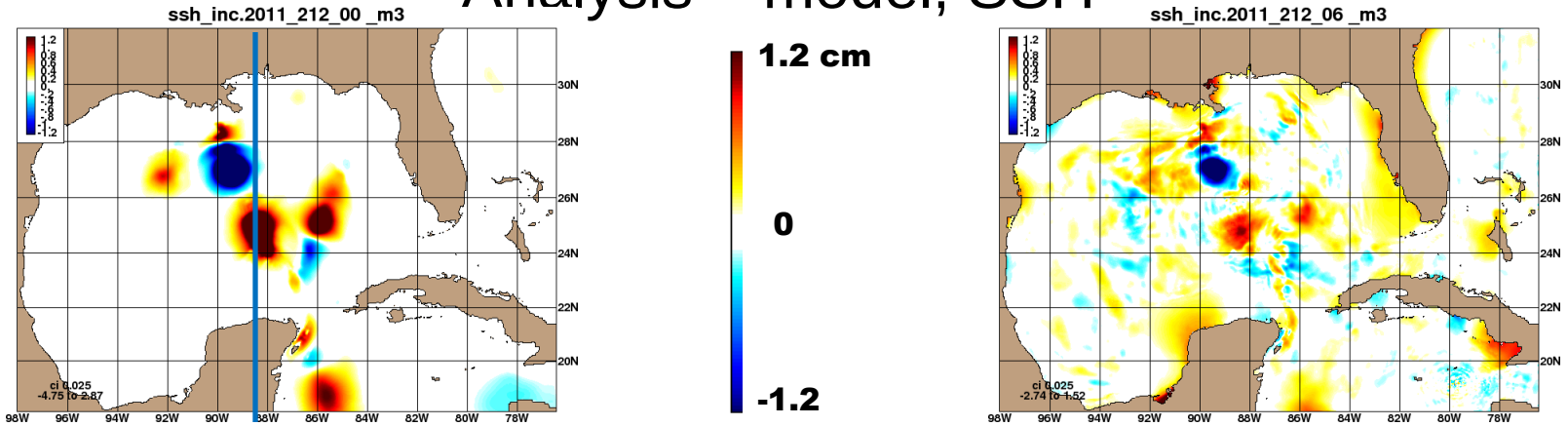


I. Historical simulation, HYCOM+NCODA for Gulf of Mexico, Day 10, 7/31/2011(1 month simulation)

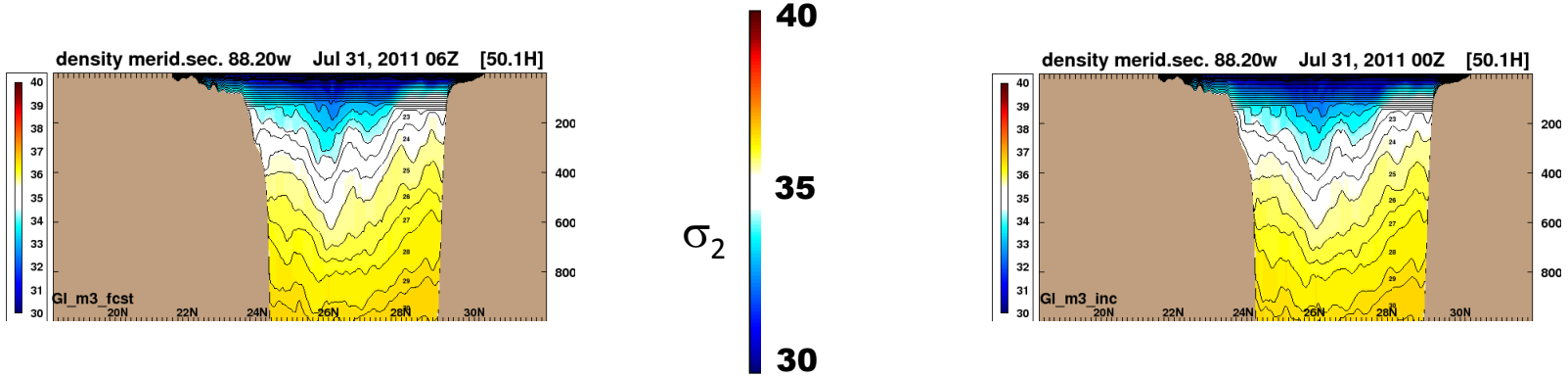
Hour 0

Hour 6

Analysis – model, SSH



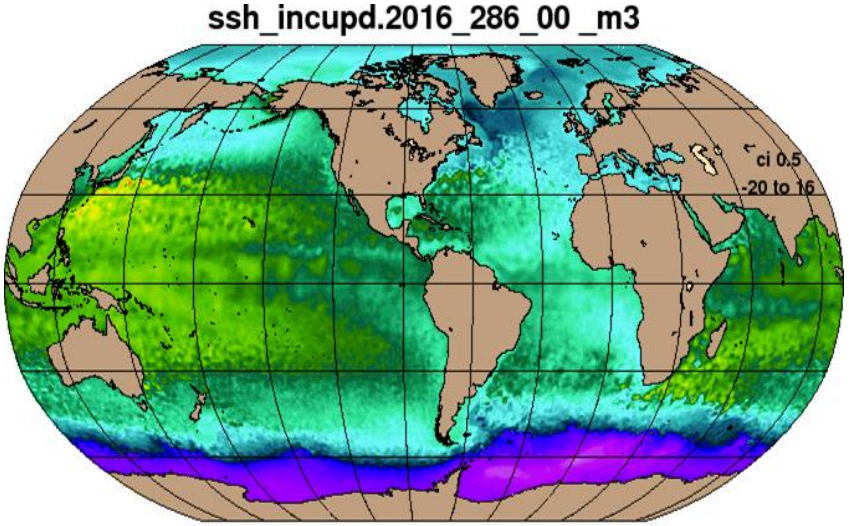
Analysis hour 0, and model hour 6



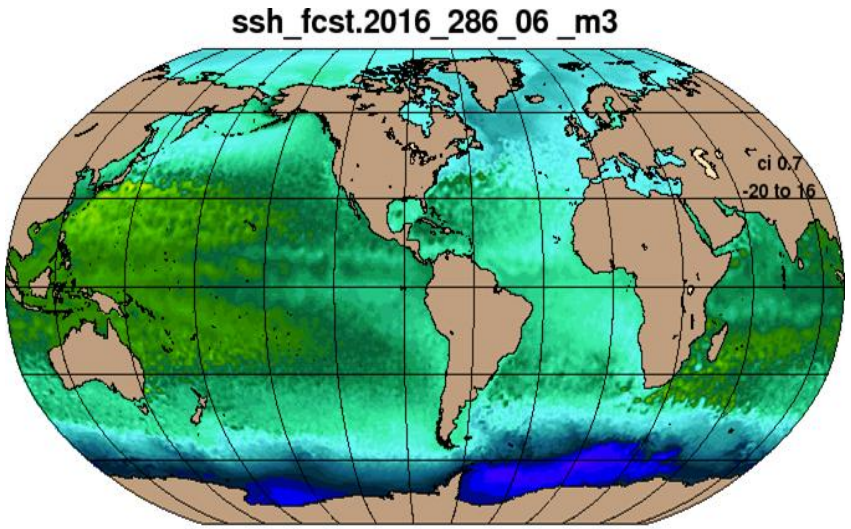
I. HYCOM+NCODA Global 1/12°,canned data, Oct. 2016

- Intent to produce analysis in the global domain operationally, in the (> 1year) future
- T/S profiles, satellite SST assimilation. (SSH assimilation is work in progress for the global domain, not included yet)

SSH incremental archive



SSH HYCOM, hour 6 (end of incremental update)



I. HYCOM+NCODA Summary

- QC data is being produced in near-real time, using NCODA, from NCEP data tanks. Climatology is used as background
- Experimental Gulf of Mexico hindcasts with NCODA+HYCOM are being produced in near real time
- Work on NCODA+HYCOM for the global domain is in progress

II. Hurricane/Typhoon studies (Hyun-Sook Kim and collaborators)

Pre-operational coupled HWRF+HYCOM

- Western North Pacific
- Hurricane Blanca in Eastern Pacific
- Planned to go operational this season for the Western Pacific

II. HYCOM-HWRF coupled Hurricane Forecasting

HYCOM initial and boundary conditions from data assimilated ocean state

- **Initial state**:

48 hr forecast starting from NCODA based US Navy nowcast

- **Ocean lateral boundary conditions**:

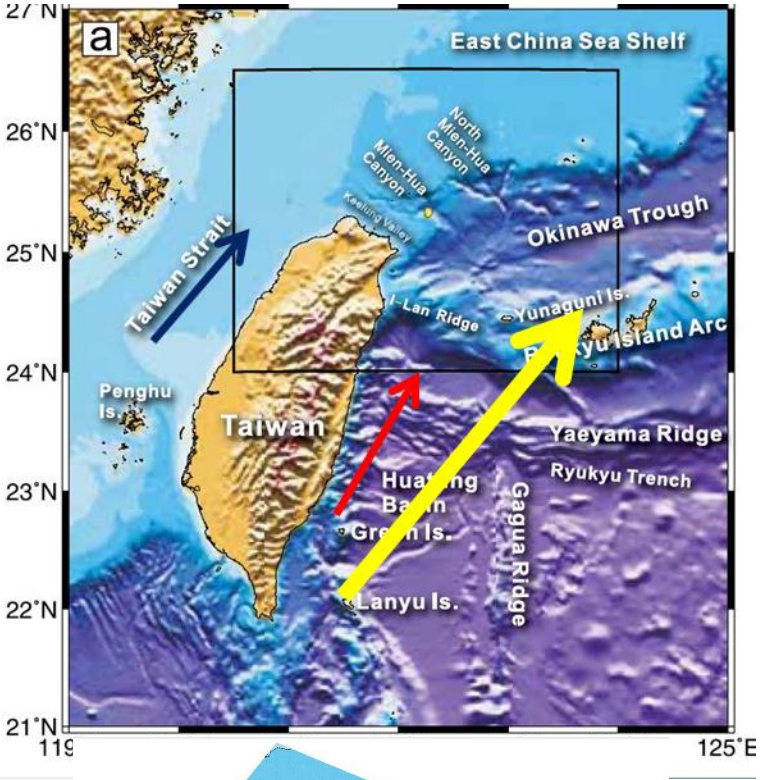
From 6 day Rtofs-Global forecasts, every hour (surface and barotropic variables) and every 6 hours (layer variables).

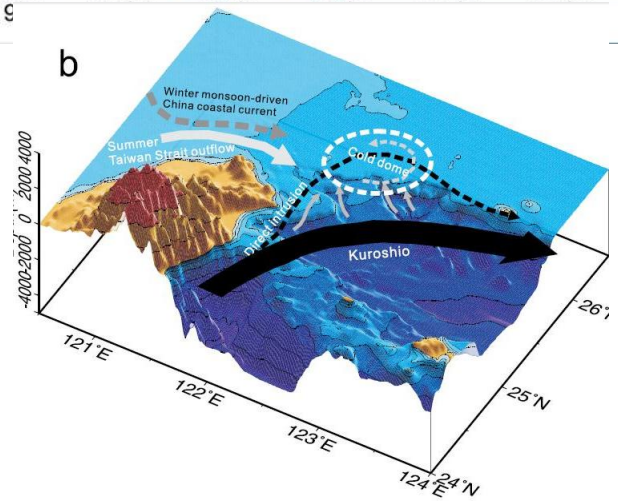
- **Major improvement expected**

- **Near future ocean data assimilation** in the hurricane domain

- **9 HYCOM tropical cyclone domains**, one of them in the NW Pacific.

II. Western North Pacific





Region rich in currents influencing typhoon development and maintenance:

Kuroshio current, bringing warm tropical water

Marginal seas

20-30% of total typhoons over the WNP hit Taiwan.

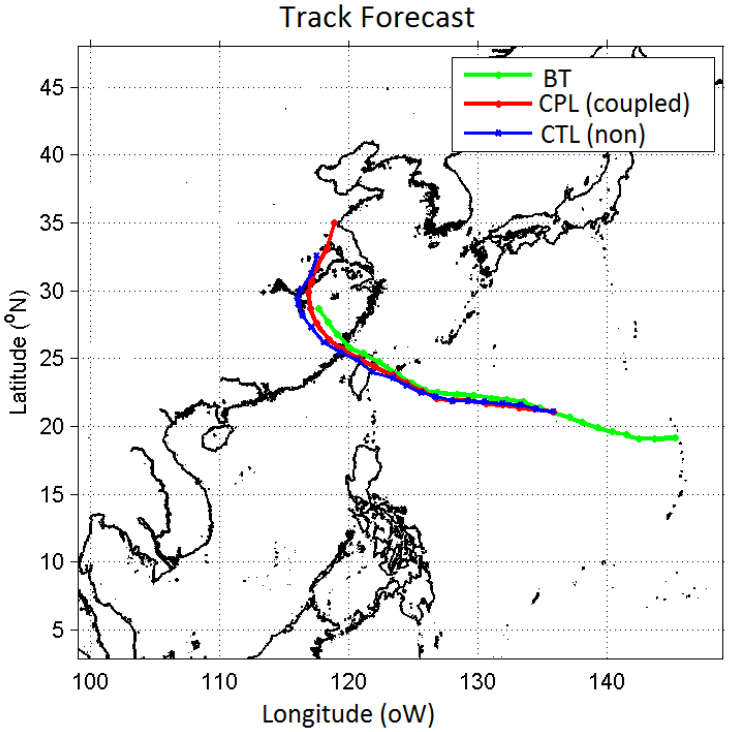
East China Sea and Taiwan Strait are major fishing grounds, and typhoons are major driving force to higher bio-geo-chemical activities.

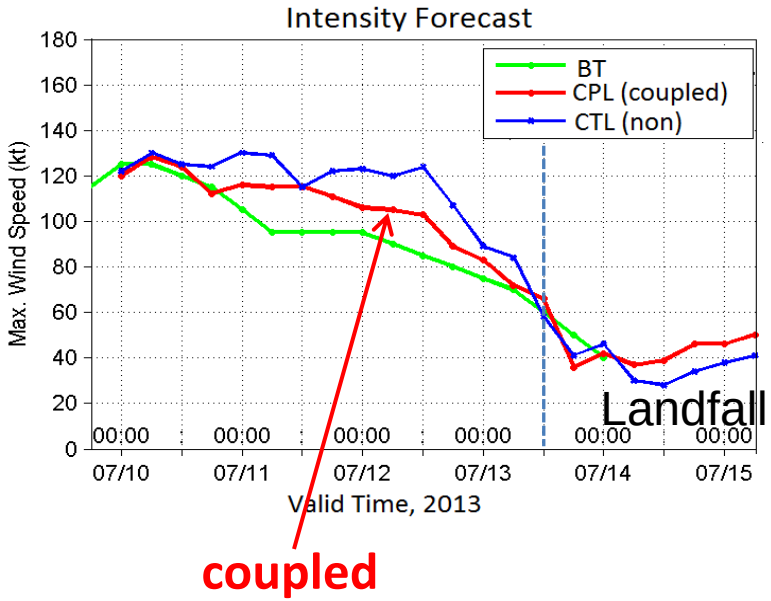
Efforts are underway in EMC for typhoons coupled models including realistic ocean state.

II. Typhoon Forecast Comparisons

between Coupled (CPL) and Non-Coupled (control/CTL)

Soulik (2013) IC=2013/07/10 00Z . Simulations produced in 2013





Non-Coupled HWRF: positive bias for intensity forecast.
3D ocean coupling improves the positive bias for this case
(but in other cases, non-coupled under-prediction of intensity is not overcome by coupling: Typhoon Jelawat, 2012)

Atm. ➔ the air-sea interaction parameterization and Initial Condition (IC)

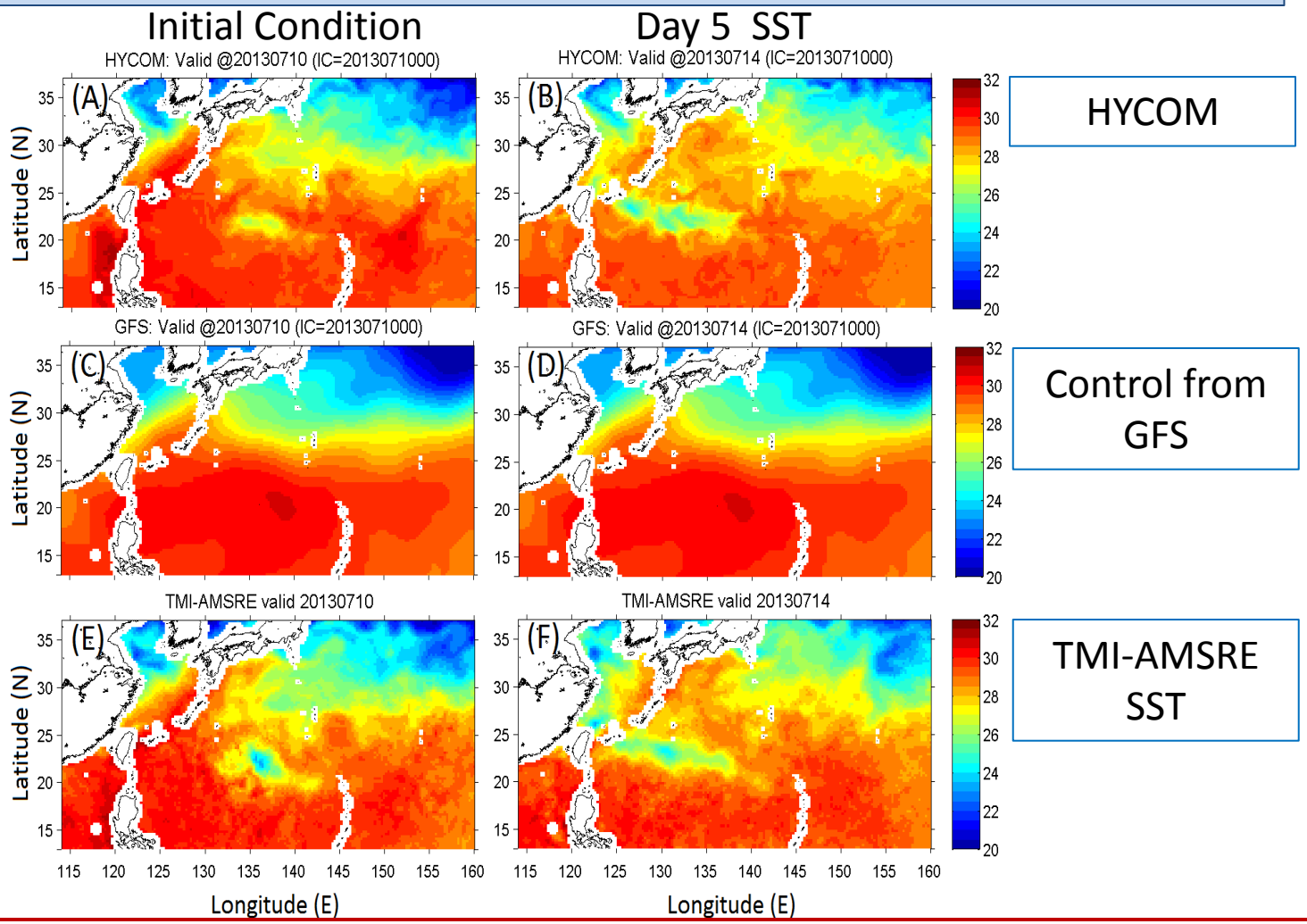
Ocn. ➔ IC better representing the upper structure (SST, MLD, MLT, dT/dZ, mixing physics).

II. SST Comparisons

Example:
Soulik (2013)
7/8 – 7/13

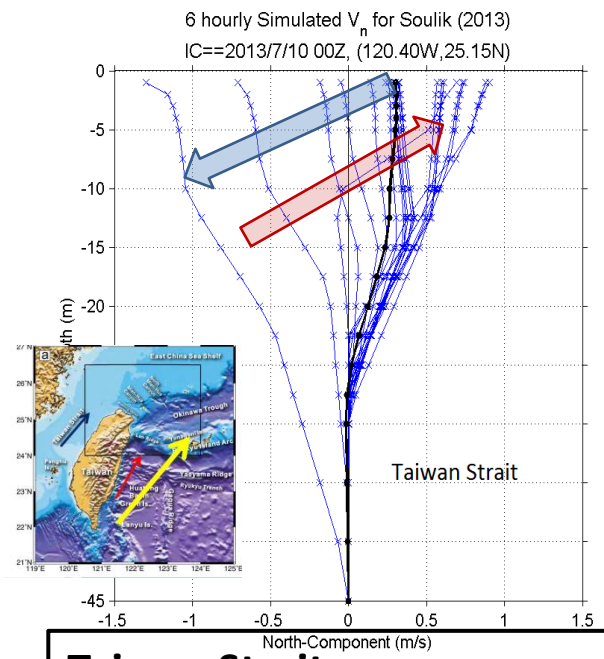
SST Cooling Comparison

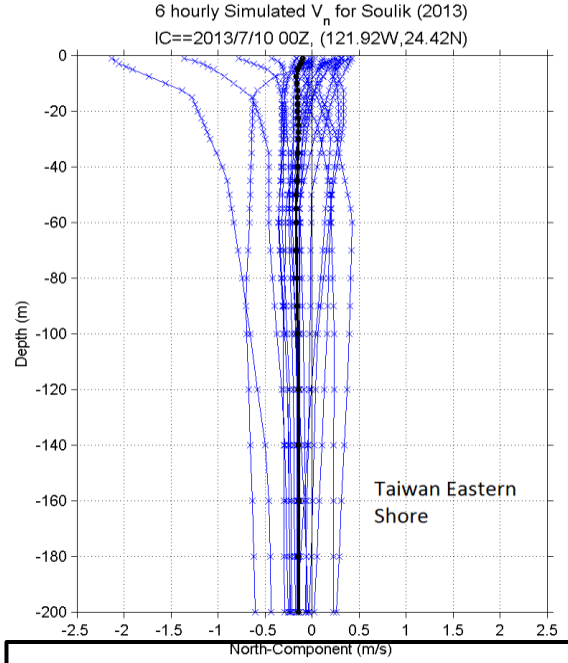
Magnitude of SST cooling is *O*(<4°C)

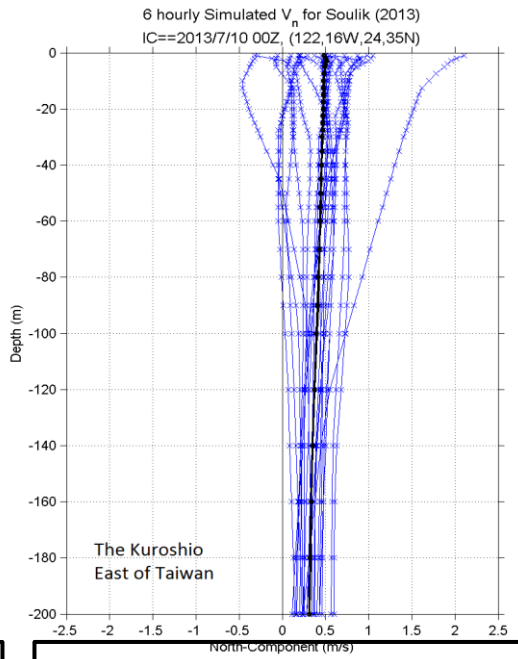


Improvement of Intensity Forecasts should include SST feedback
➔ Ocean Coupling.
Atm. ➔ the air-sea interaction parameterization and IC.
Ocn. ➔ IC better representing the upper structure (SST,MLD, dT/dZ, mixing physics).

II. Northward Velocity around Taiwan







Taiwan Strait:

Northward currents change to *southward* before and during the storm passages (blue arrow); They restore back to northward after the storm (red arrow). Similar to Zhang et al. 2019.
(black line=mean profile)

Eastern shore:

Currents in the area is in general weakly northward. During the storm passage they switch to southward at a speed of ~10 times larger than the initial speed. They restore back to northward after the storm.

The Kuroshio:

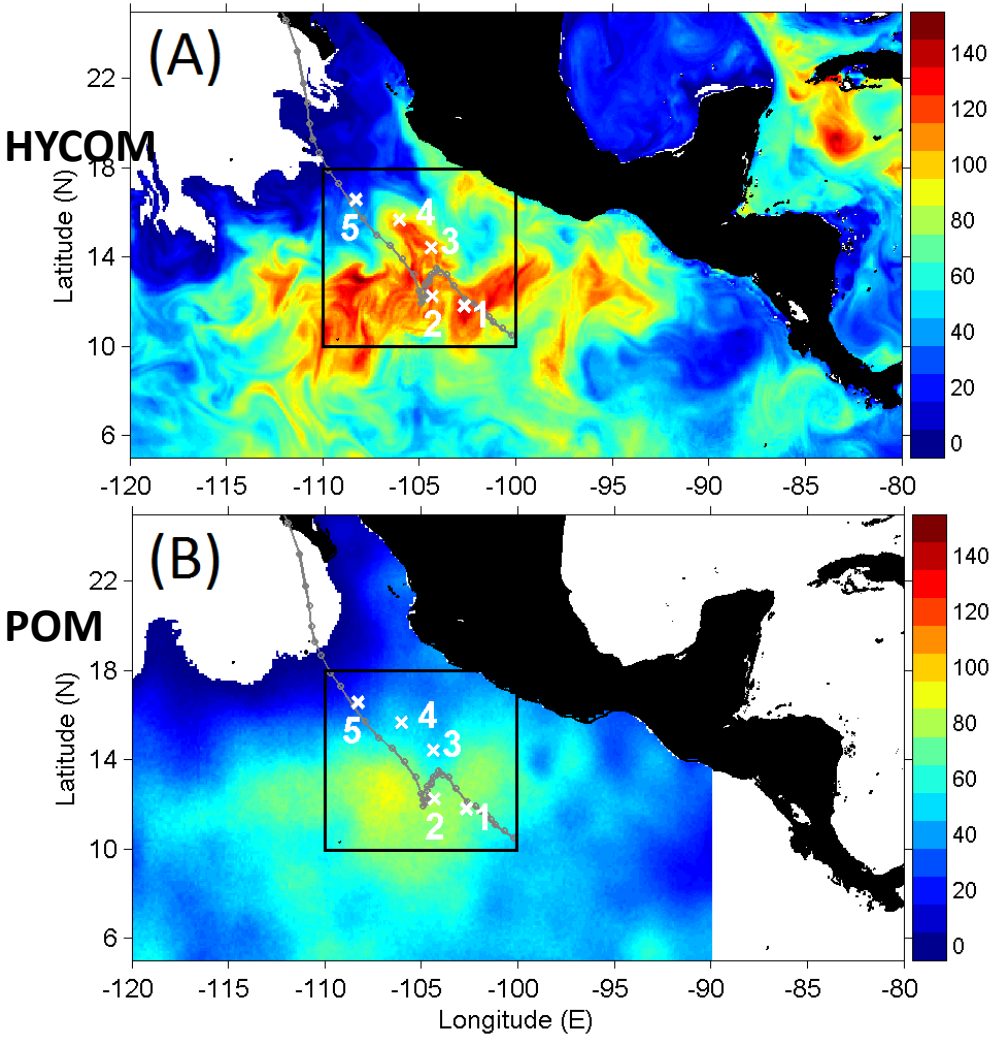
The northward speed is an order 0.5 m/s. Depending on the storm coordinates, the currents become weaker or stronger.

Upwelling effects (not shown)

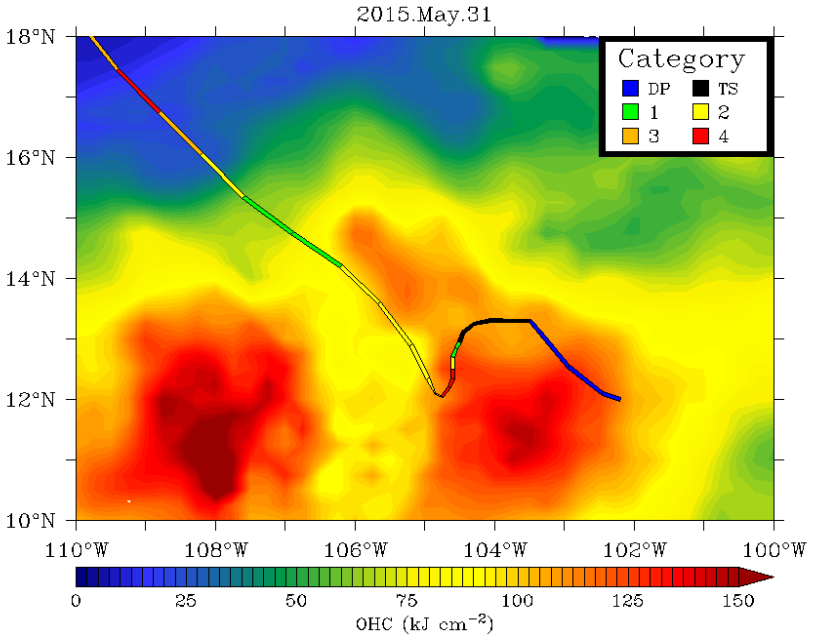
Driving force for the variability is wind stress. With new version, we can also estimate the currents driven by the Pressure Gradient Force, in particular for the Taiwan Strait and the shallow waters around the Island.

II. Eastern Pacific, Hurricane Blanca

Ocean Heat Content (OHC) for May 31, 2015

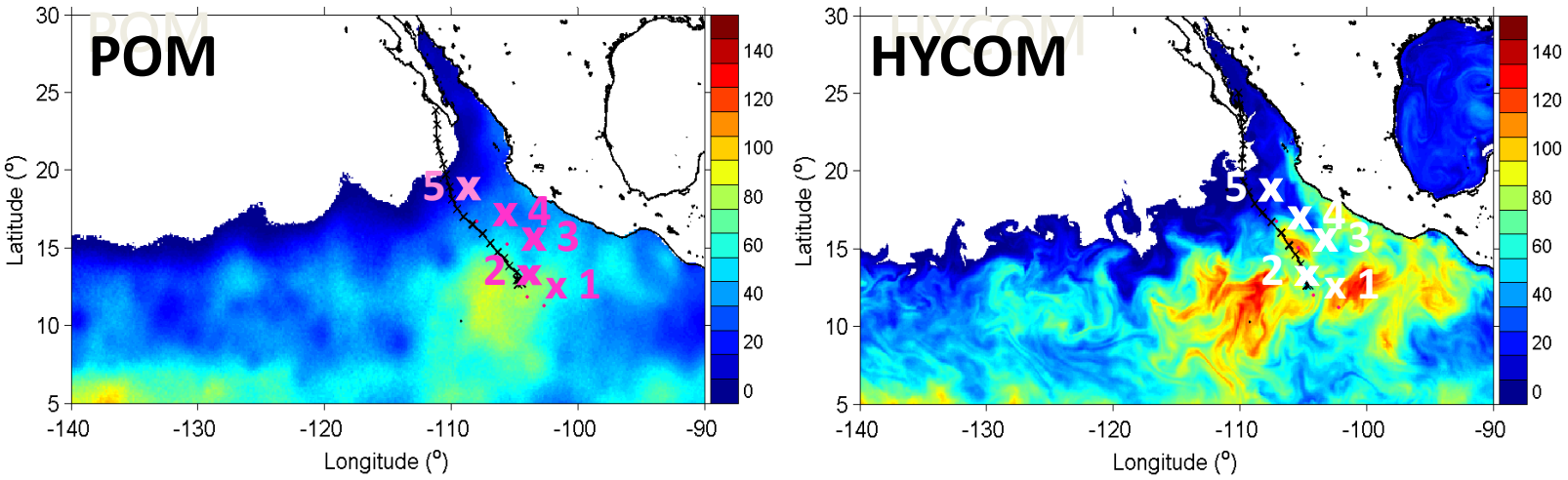


SPORTS , Shay et al



II. Eastern Pacific, Hurricane Blanca

Ocean Heat Content: initial field, and OHC vs Argo



	Argo	POM	HYCOM
	OHC , kJcm^{-2}	**POM-Argo**	**HYCOM-Argo**
Mean, locations 1-5	92	-35.5	4.1
RMS difference		24.0	2.7

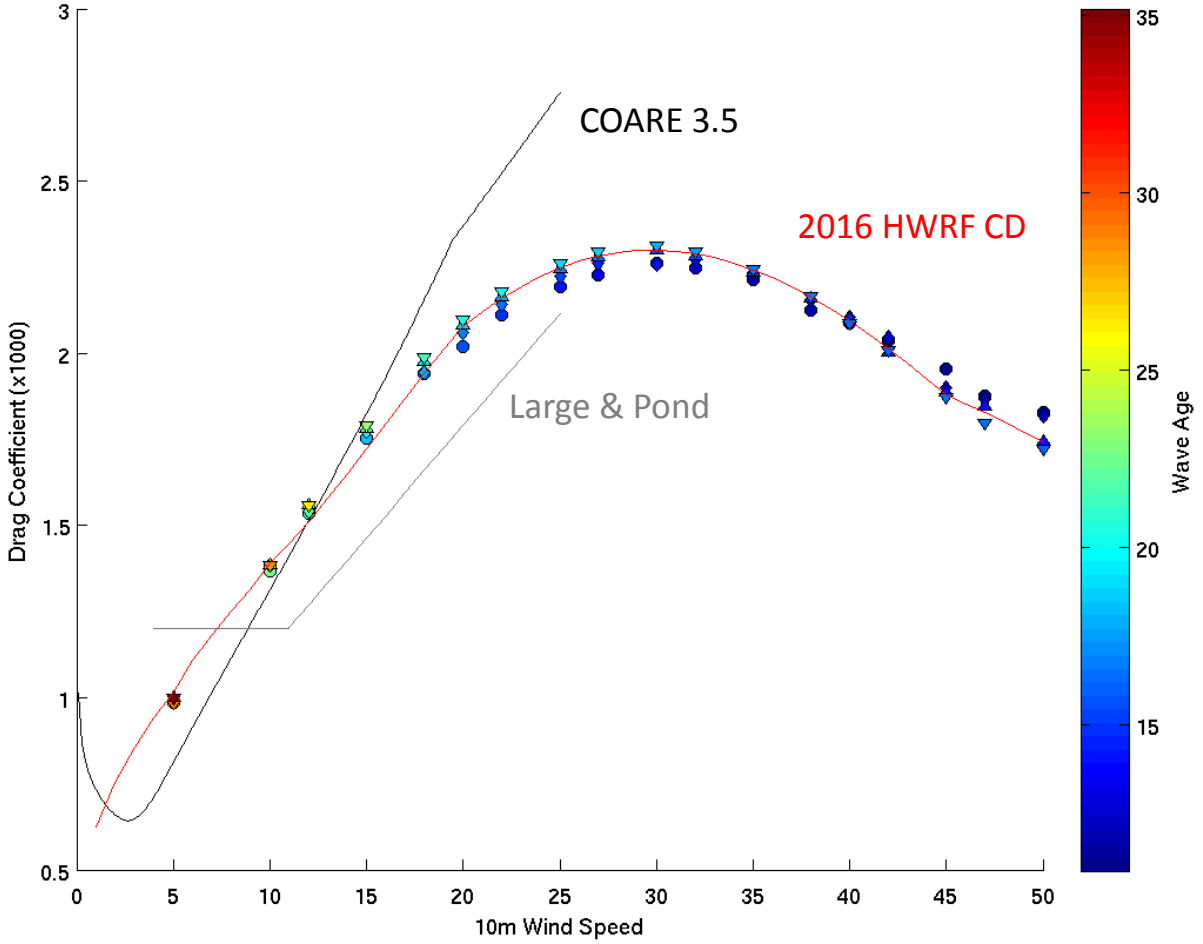
II. Summary, HWRF+HYCOM, Pacific Ocean

- Initialization for coupled atmosphere-ocean hurricane forecast simulations have a correct representation of the real ocean state, subject to sub-seasonal and decadal variability
- Western Pacific coupled HWRF+HYCOM improved intensity forecast for typhoon Soulik. This is typical for strong storms
- Hurricane Blanca in Eastern Pacific: Ocean Heat Content improved in coupled HWRF+HYCOM
- Upcoming upgrade in NCEP hurricane forecasts: Possible use of HYCOM+HWRF for NW Pacific and Northern Indian Ocean, and NCEP mesoscale atmospheric model HMON, coupled with HYCOM or uncoupled, for other regions

III. Fluxes in Coupled Atmosphere-Wave-Ocean Models (J. Meixner and collaborators)

- Three way coupled atmosphere-wave-ocean (AWO) model, allowing for sea-state dependent air-sea fluxes.
- WAVEWATCH III calculates the wind stress, with a reduced drag coefficient for wind speeds greater that 20 m/s as in FY2016 operational HWRF.
- Storm intensities are better predicted in the three-way coupled system

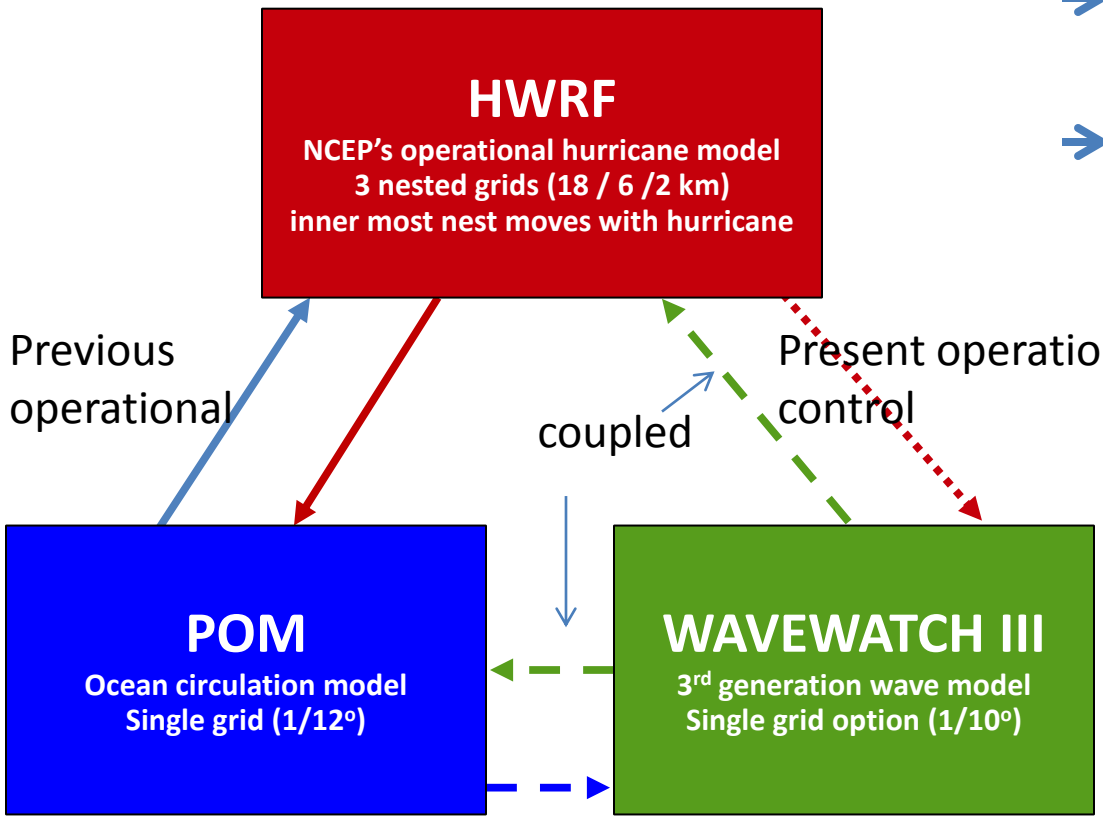
III. Sea State Dependent Drag



Experiment was run to determine tail level parameters to match 2016 HWRF drag coefficient

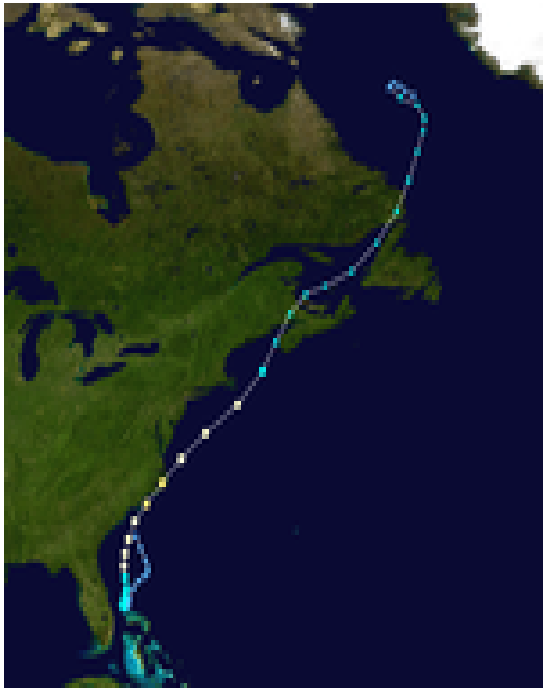
III. AWO Coupled Model

Use NCEP Coupler with 360s time step

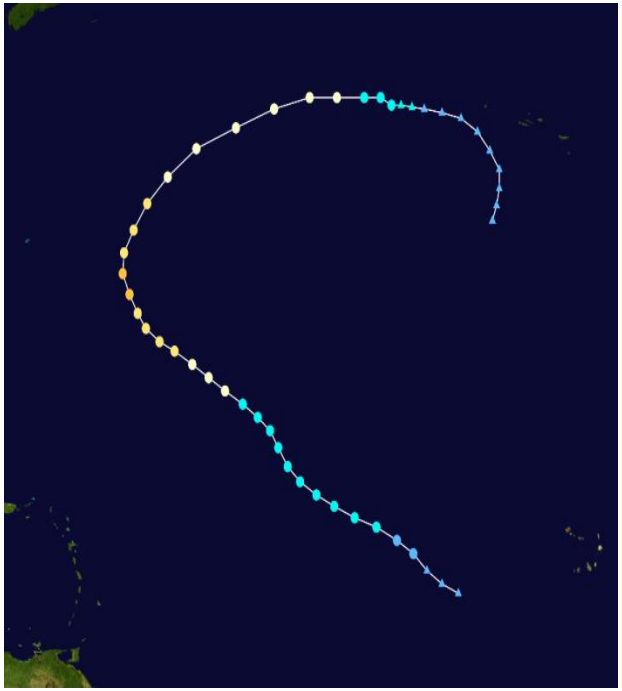


- **Atmosphere → Waves (control)**
  - Wind field (lowest level wind, height)
  - Stability Richards number
- **Waves → Atmosphere (coupled)**
  - Sea state dependent drag formulation (Reichl et al 2014)
- **Waves → Ocean**
  - Wave modified wind stress (Fan et al 2010)
  - Coriolis Stokes Drift Forcing / Stokes drift
  - Mean wave length (for current field)
- **Ocean → Waves**
  - Surface current (for relative wind speed)
  - Current at depth (for wave – current interaction)
- **Atmosphere → Ocean (operational)**
  - Surface fluxes
- **Ocean → Atmosphere**
  - Sea surface temperature
  - Sea surface currents

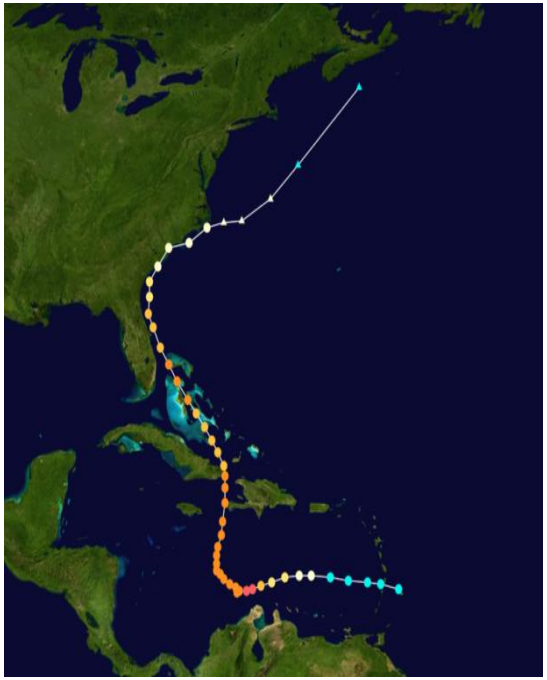
III.Test Cases



Hurricane Arthur
July 1st – July 5th , 2014
Category 2 storm



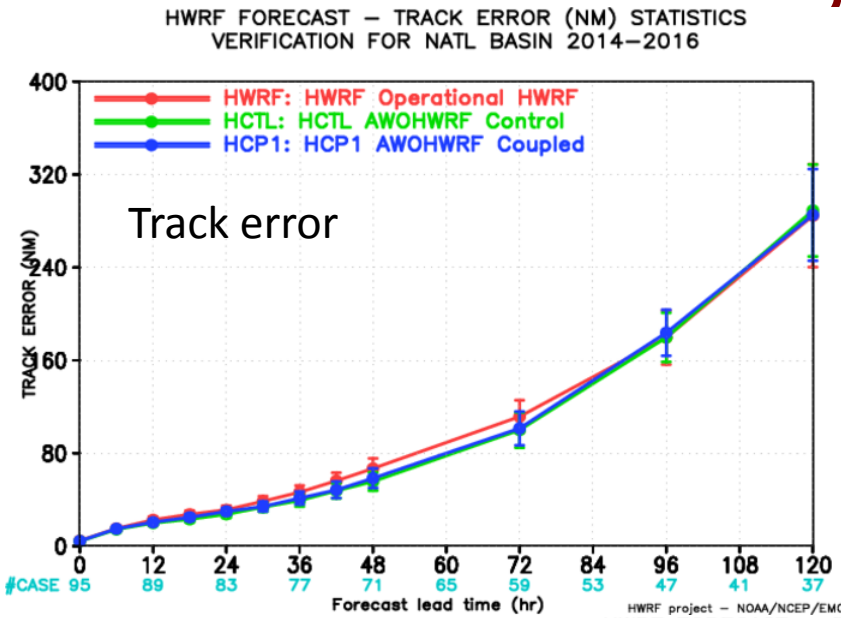
Hurricane Edouard
Sept 11th – Sept 19th , 2014
Category 3 storm

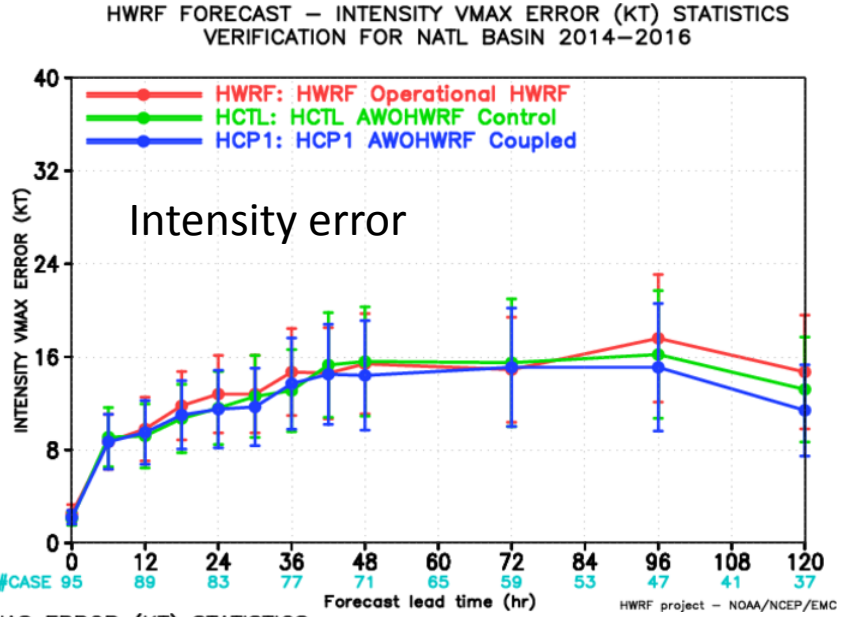


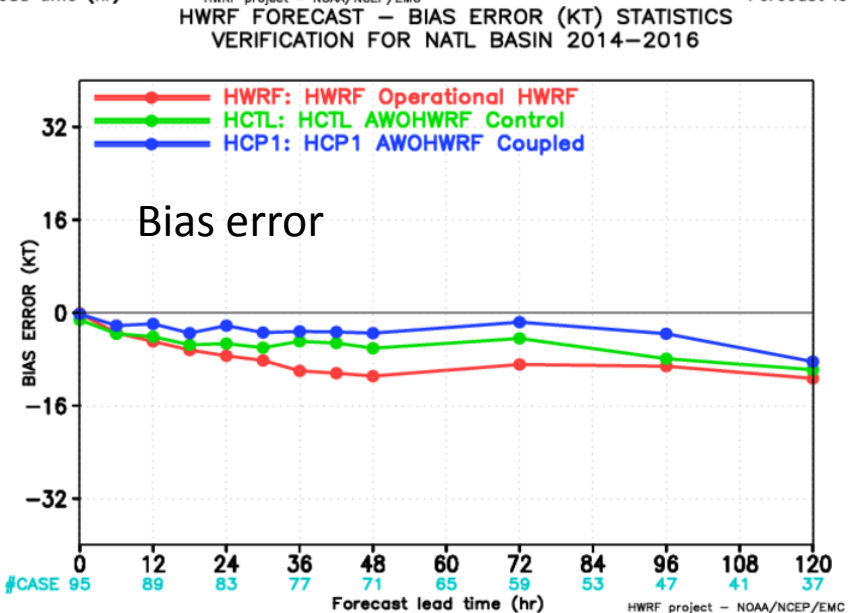
Hurricane Matthew
Sept 28th – Oct 10th , 2016
Category 5 storm

Source: wikipedia

III. AWO coupling for Arthur, Edouard, Matthew

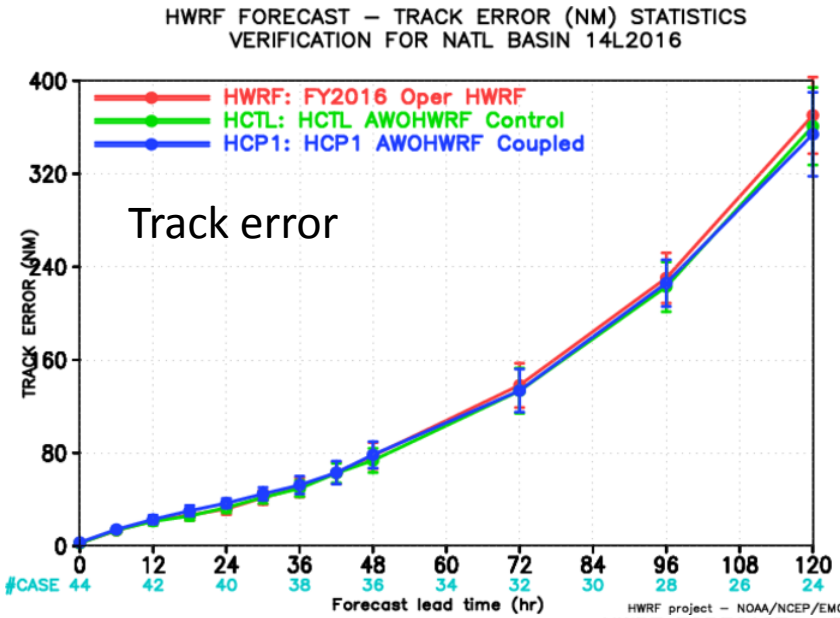


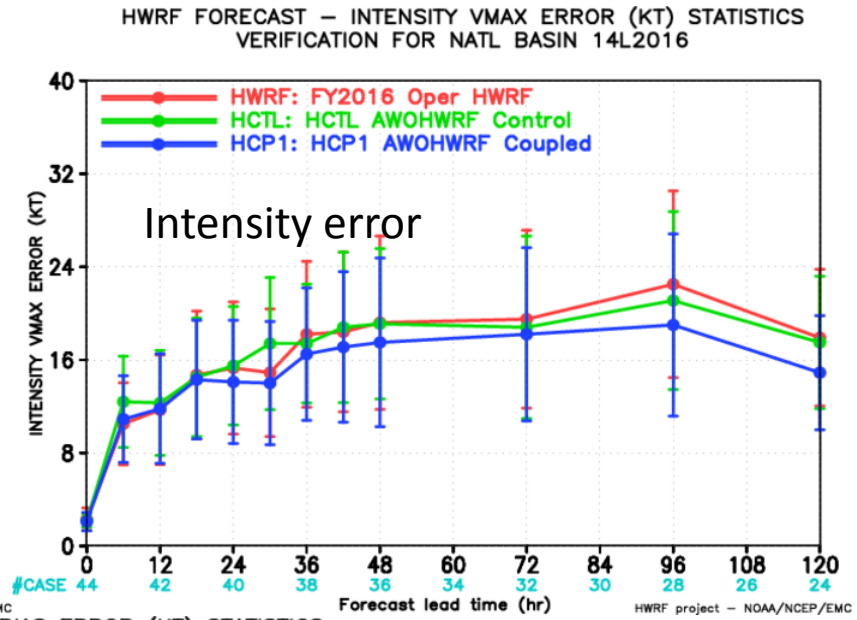


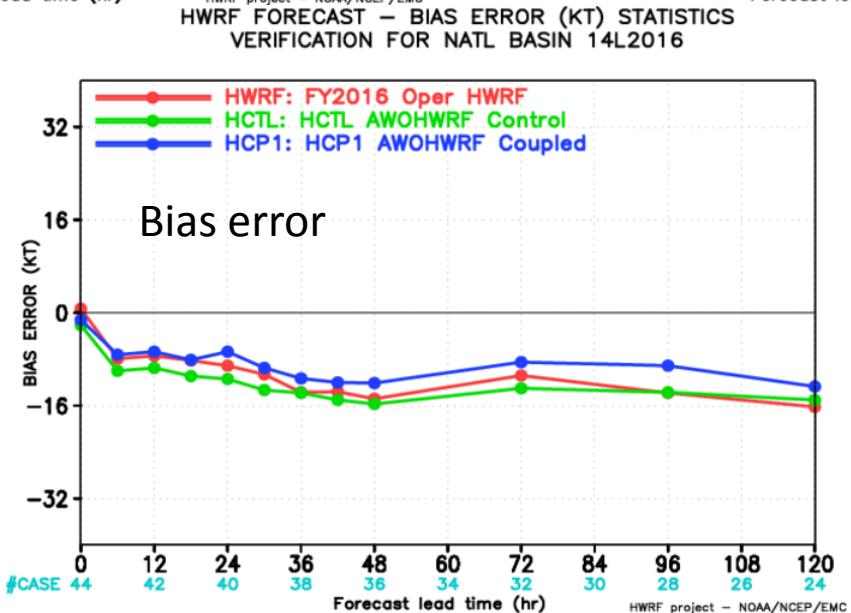


Operational HWRF
Control
Coupled

III. AWO coupling for Matthew







Operational HWRF
Control
Coupled

III. Conclusions

- Storm intensities are better predicted by including
  - Reduced drag coefficients
  - Sea-state dependent coupling processes
- Future work:
  - Full three year study
  - Study impact of different mixing schemes for ocean coupling. Add wave model boundary conditions

Summary

- Ocean hindcasts with NCODA + HYCOM are being produced in near real-time for the Gulf of Mexico. Preliminary work has been started for ocean hindcasts in the global domain

- Strong tropical cyclones for the North Western and Eastern Pacific are better predicted with a coupled ocean-atmospheric model with realistic ocean initialization

- A coupled Wave-Ocean-Atmospheric system resulted in improvement in storm intensity predictions due to reduced high wind drag coefficient and sea-state dependent coupling processes.