

# MITgcm state estimation and forecasts in the Gulf of Mexico

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- ▶ To produce an ocean state estimate by assimilating satellite along-track SSH and gridded SST observations, moored sub-surface velocity, temperature and salinity observations, and Pressure Inverted Echo Sounder (PIES) observations using “strong” constraint four-dimensional variational (MITgcm-4DVAR) assimilation for the Gulf of Mexico (GoM)
- ▶ To examine the deep circulation in the GoM, particularly near the Sigsbee escarpment and Yucatan channel, and to understand the effect of topography on the GoM circulation including loop current (LC) evolution, loop current eddy (LCE) shedding, and the formation of loop current frontal eddies (LCFEs).
- ▶ To understand the circulation in the GoM including LC evolution and LCE separation/re-attachment and shedding
- ▶ To examine the effect of moored subsurface observations, PIES observations, and RAFOS float observations on the LC analysis and prediction by comparing the quality of the ocean state estimates and forecasts using data withholding experiments.

## Model controls

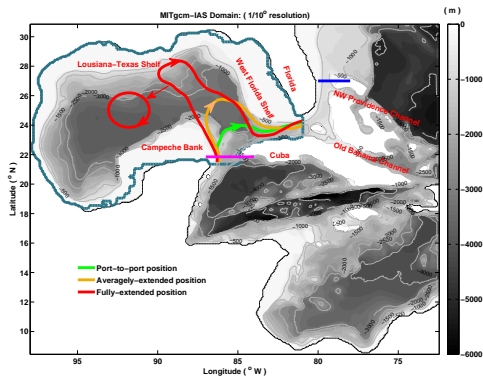
- ▶ Initial conditions for temperature, salinity, and horizontal velocities.
- ▶ Open boundary conditions for temperature, salinity, and horizontal velocities.
- ▶ Atmospheric forcing (bulk formulation: *Large and Pond (1981)*)  
The adjustments to the starting guess controls were penalized in the cost function.

## Observation/Background Uncertainties

- ▶ Daily and spatially bin-averaged along-track SSH observations were separated into time mean and anomalies and were separately fit to the model mean SSH and daily mean SSH anomalies
- ▶ SSH anomaly and geoid uncertainty: 5 cm for Jason-1 and Jason-2, 10 cm for Envisat and ERS-2, and 10 cm for geoid
- ▶ Used high SST observational uncertainty, especially near the coast
- ▶ Velocity uncertainty: linearly varying over depth from 10 cm/s at surface to 5 cm/s at bottom
- ▶ Background uncertainties for the initial condition controls were computed from long-term forward model variability
- ▶ Atmospheric forcing uncertainties were computed from NCEP/NCAR Reanalysis-1 surface winds and fluxes
- ▶ ECCO system enforces 2D and 3D smoothness of control variables following [Weaver (2003)] with a horizontal decorrelation scale of 50 km

# MITgcm-Intra Americas Seas Model

- ▶ ETOPO2 topography
- ▶  $1/10^\circ$  ( $\sim 10$  km) horizontal resolution
- ▶ 40 vertical z-levels ( $\sim 5$  m near surface)
- ▶ NCEP/NCAR Reanalysis-1 surface fluxes/winds: bulk formulation [*Large and Pond (1981)*]
- ▶ HYCOM + NCODA global ( $1/12^\circ$ ) analysis initial and boundary conditions [*Chassignet et al (2007)*],
- ▶ Monthly climatological run-off fluxes



MITgcm-Intra Americas Seas model domain

**GOMEX-Pilot Prediction Project** is an industry/academic collaborative effort focusing on the operational prediction of the circulation of the GoM

The Phase-1 of GOMEX-PPP involved three steps:

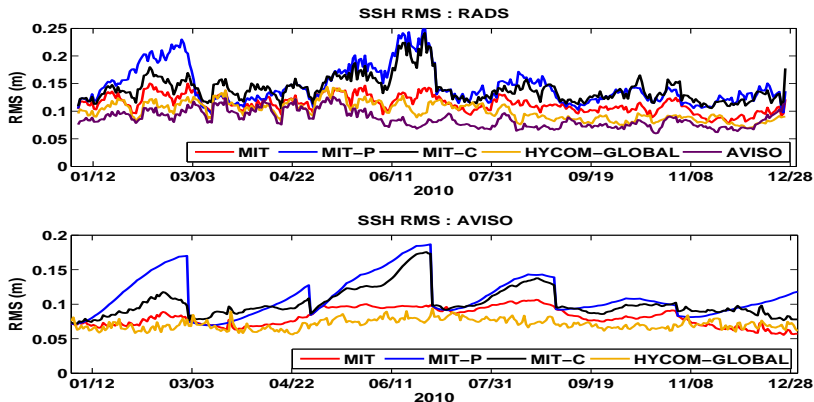
1. Step-1: Retrospective GoM nowcast for 2010
2. Step-2: Twelve 3-month retrospective GoM forecasts for 2010, at monthly intervals
3. Step-3: Seven 3-month GoM forecasts for 2011-2012, at bi-weekly intervals, starting on Sep 16 till Dec 9, 2011.

Eight modeling systems including operational as well as research models participated in this multi-model skill assessment effort organized by Christopher N. K. Mooers, Edward D. Zaron, and Matthew K. Howard.

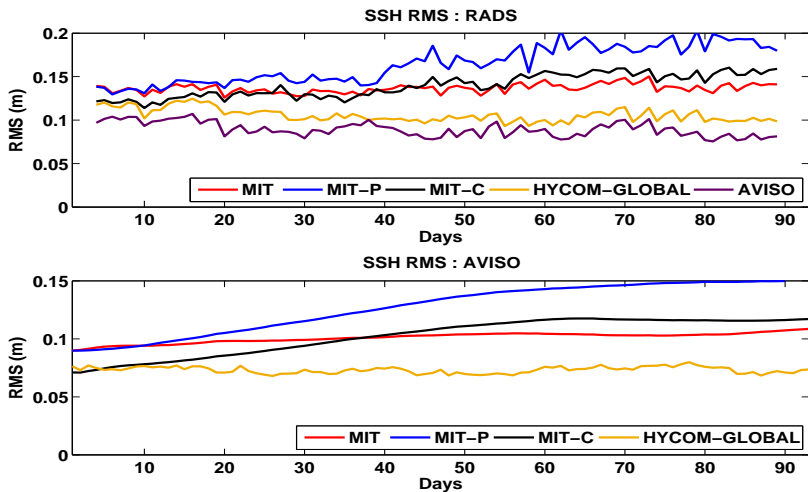
MITgcm-IAS model participated in GOMEX-PPP as academic-research model

(For details refer final report for GOMEX-PPP Phase 1: <http://www.netl.doe.gov/File%20Library/Research/Oil-Gas/deepwater%20technology/08121-280102-final-report-ocean-forecast.pdf>)

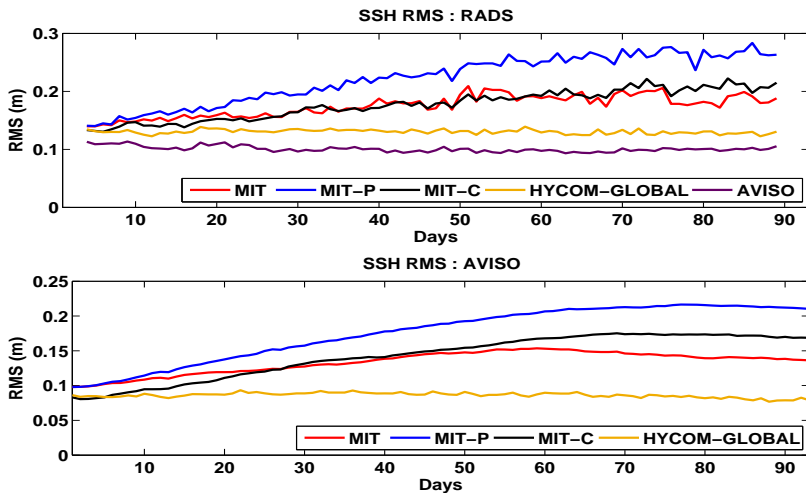
# GOMEX-PPP Results



*Step-1: Spatial averaged SSH rms difference: Top panel shows comparison with RADS along-track data (Jason1/2, Envisat1, and ERS2) where a running 7 day rms difference is used for smoothing, and bottom panel shows comparison with AVISO gridded SSH data. The different lines show model hindcast (MIT), model persistence(MIT-P: keeping the initial state fixed), control model run (MIT-C: "first guess" or iteration-0), HYCOM global analysis (HYCOM-GLOBAL), and AVISO gridded SSH.*



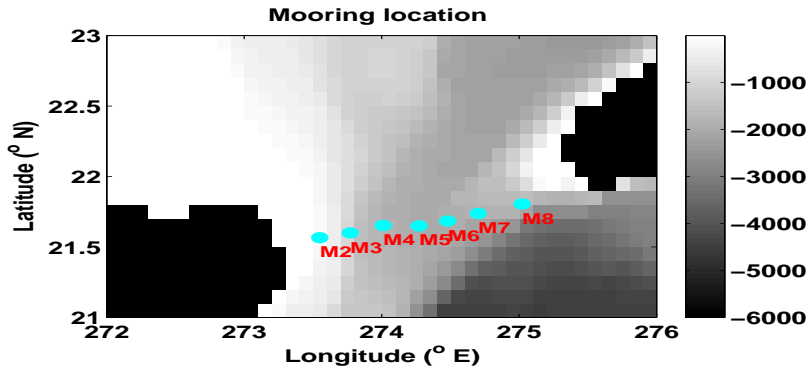
*Step-2: Spatial averaged SSH rms difference similar to Step-1 analysis. Lines represent weighted rms difference over four 3-month Step-2 forecasts (S2-20100301, S2-20100501, S2-20100701, S2-20100901). Model forecasts used climatological forcing and boundary conditions.*



*Step-3: Spatial averaged SSH rms difference similar to Step-1 analysis. Lines represent weighted rms difference over four 3-month Step-3 forecasts (S3-20110916, S3-20110930, S3-20111014, S3-20111028). Model forecasts used climatological forcing and boundary conditions.*



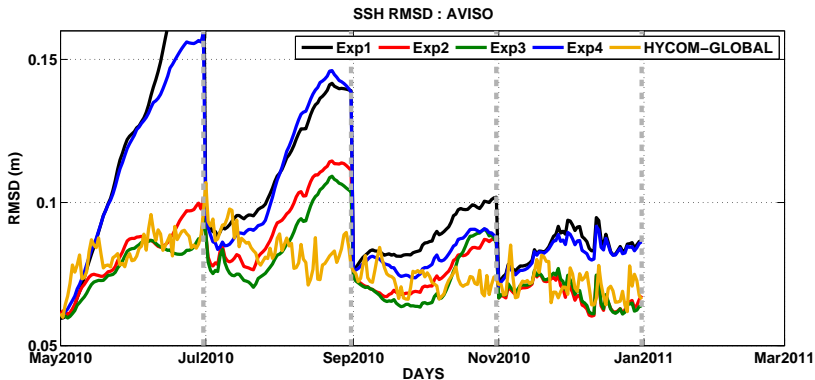
# Moored velocity assimilation in the Yucatan Channel



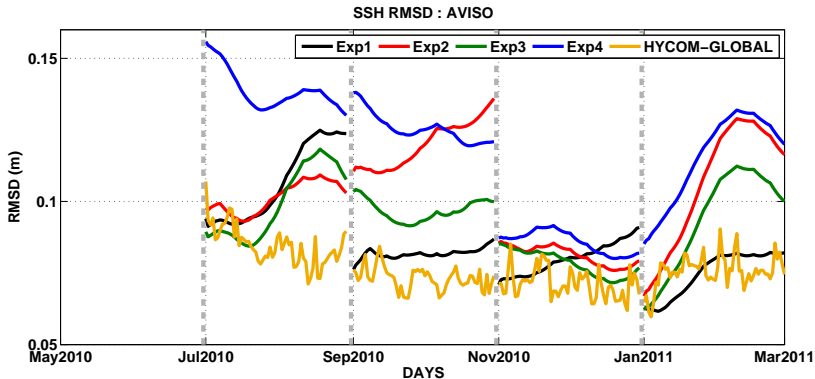
CICESE Mooring location across the Yucatan Channel (Moorings M2 to M8)

The assimilation experiments using combination of data sets are

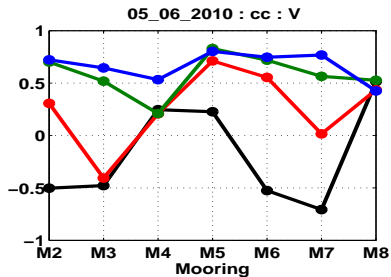
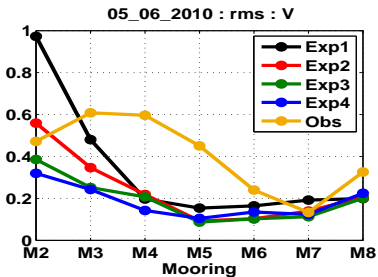
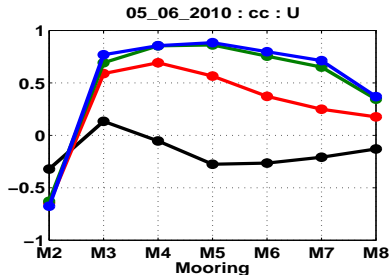
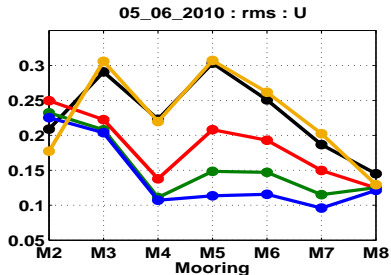
- ▶ Exp1: No assimilation
- ▶ Exp2: SSH + SST data
- ▶ Exp3: SSH + SST + Mooring data (U & V velocities)
- ▶ Exp4: Mooring data (U & V velocities)



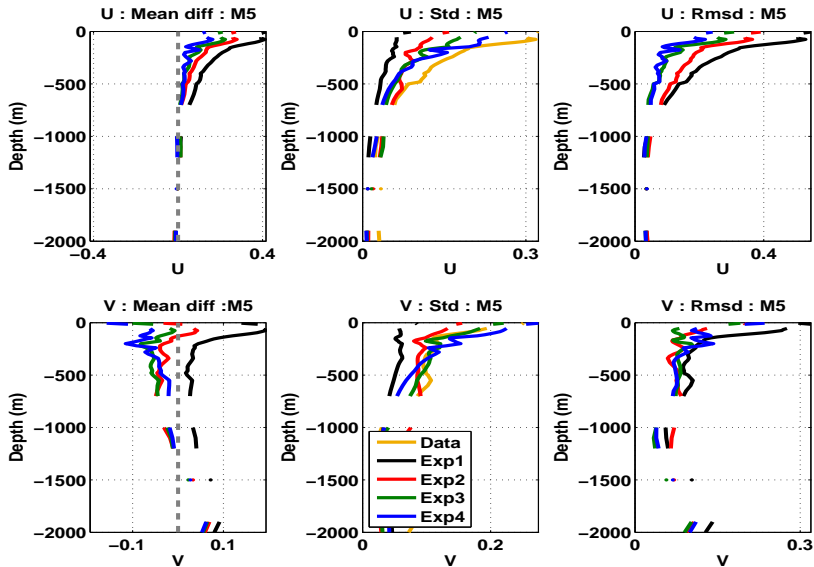
Hindcast: SSH *rmsd* with respect to AVISO gridded SSH averaged in the GoM basin for May - Dec, 2010, from four, two-month state estimates (May - June, July - August, Sep - Oct, and Nov - Dec) separated by vertical dashed gray lines.



Forecast: SSH *rmsd* with respect to AVISO gridded SSH averaged in the GoM basin. A 60-day forecast was initialized using optimized state starting from the end of each two-month state estimate, marked by vertical dashed gray lines.



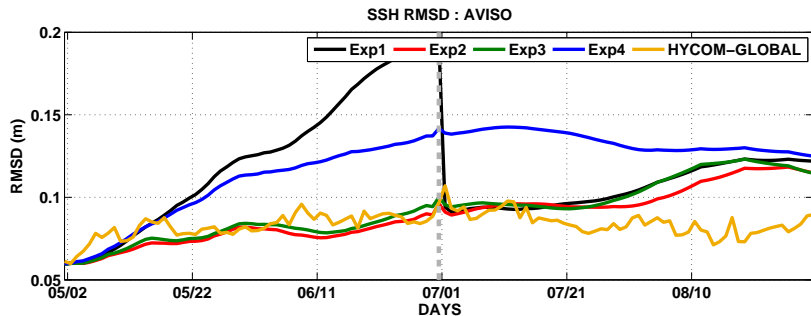
Hindcast: data - model comparisons for May - June, 2010, for all moorings, for experiments 1 to 4. Left panels show the *rms* and the right panels show the cross-correlation for U (top panels) and V (bottom panels).



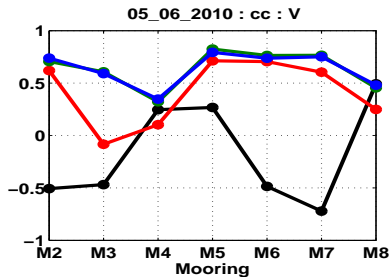
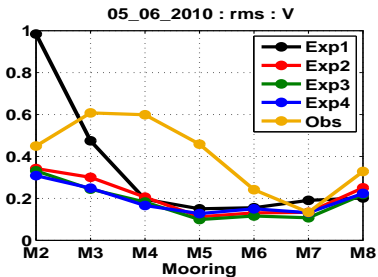
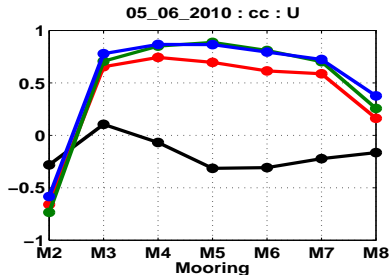
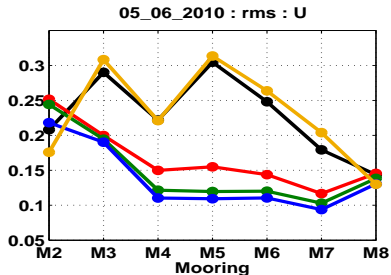
Hindcast: data - model comparisons for May - June, 2010, for Mooring-5. Left panels show mean difference, middle panels show standard deviation, and right panels show *rmsd* for U (top panels) and V (bottom panels).

- ▶ ETOPO2 topography
- ▶  $1/10^\circ$  ( $\sim 10\text{ km}$ ) Horizontal resolution
- ▶ Increased vertical resolution to 80 vertical z-levels ( $\sim 2.5\text{m}$  near surface)
- ▶ NCEP/NCAR Reanalysis-1 surface forcing/fluxes: bulk formulation [*Large and Pond (1981)*]
- ▶ HYCOM + NCODA global ( $1/12^\circ$ ) analysis initial and boundary conditions [*Chassignet et al (2007)*],
- ▶ Monthly climatological run-off fluxes

## Moored velocity assimilation in the Yucatan Channel: High-resolution vertical grid



Hindcast/Forecast: SSH *rmsd* with respect to AVISO gridded SSH averaged in the GoM basin for May - June, 2010

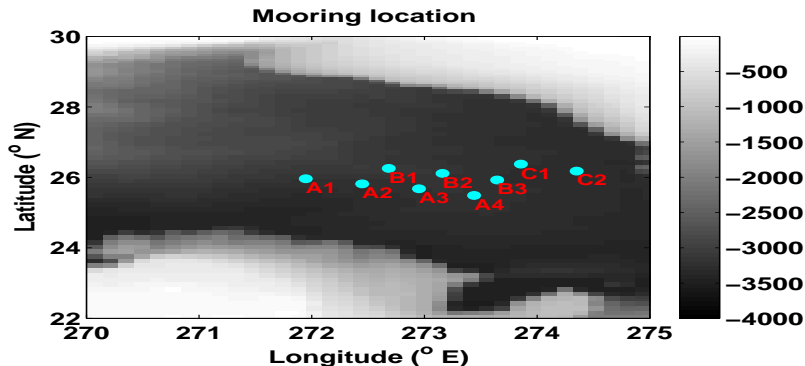


Hindcast: data - model comparisons for May - June, 2010, for all moorings, for experiments 1-4. Left panels show the *rms* and the right panels show the cross-correlation for U (top panels) and V (bottom panels).



- ▶ GoMRI topography in the GoM basin and ETOPO2 topography near the boundaries.
- ▶  $1/20^\circ$  ( $\sim 5\text{ km}$ ) horizontal resolution in the Deep Gulf, telescoping to  $1/10^\circ$  ( $\sim 10\text{ km}$ ) horizontal resolution near boundary.
- ▶ 80 vertical z-levels ( $\sim 2.5\text{m}$  near surface)
- ▶ NCEP/NCAR Reanalysis-1 surface forcing/fluxes: bulk formulation [*Large and Pond (1981)*]
- ▶ HYCOM + NCODA global ( $1/12^\circ$ ) analysis initial and boundary conditions [*Chassignet et al (2007)*],
- ▶ Monthly climatological run-off fluxes
- ▶ Added initial horizontal velocity controls (U0 & V0), in addition to other model controls: Initial conditions for Temperature, Salinity (T0 & S0), Open boundary conditions for Temperature, Salinity, and horizontal velocities, and Atmospheric forcing.

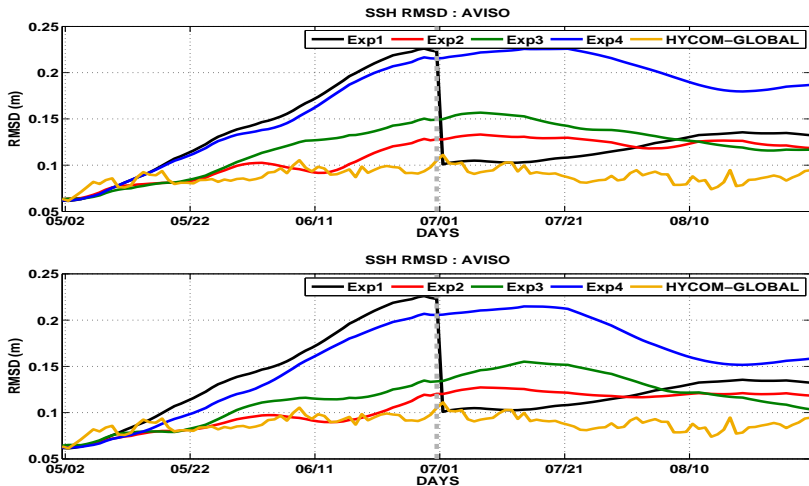
# Moored velocity assimilation in the Deep Gulf



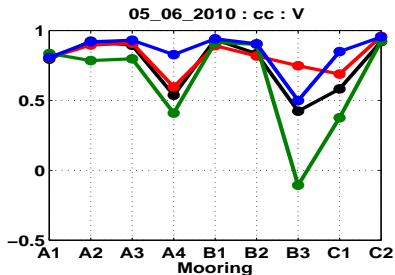
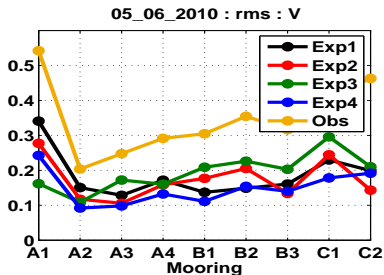
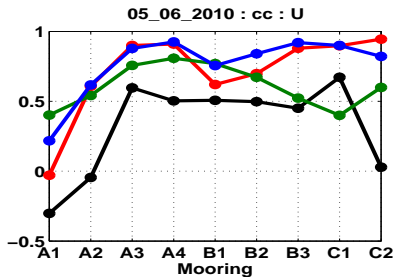
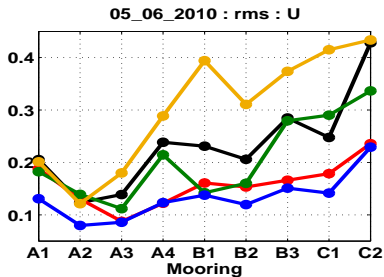
LEIDOS mooring location in the Deep Gulf

The assimilation experiments using combination of data sets are

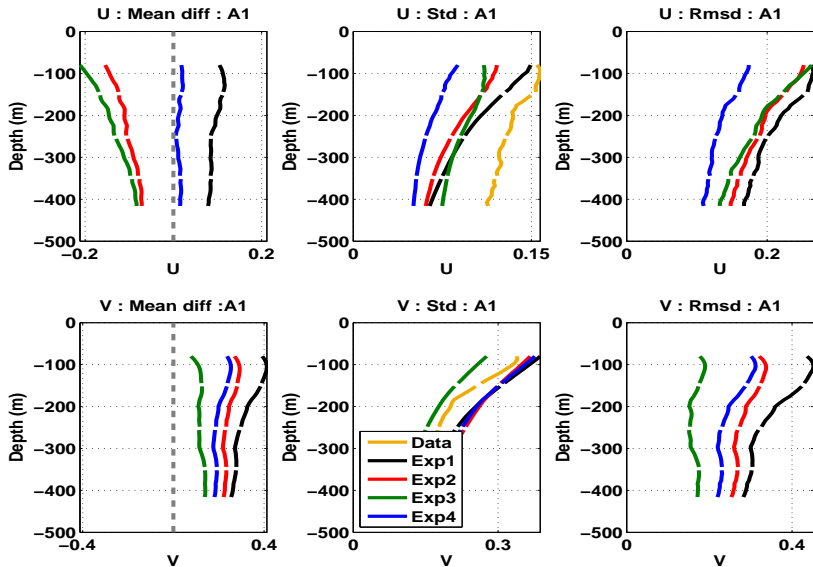
- ▶ Exp1: No assimilation
- ▶ Exp2: SSH + SST data
- ▶ Exp3: SSH + SST + Mooring data (used only horizontal velocities from A1-A4, B1-B3, and C1-C2 moorings)
- ▶ Exp4: Mooring data



Hindcast/Forecast: SSH *rmsd* with respect to AVISO gridded SSH averaged in the GoM basin for May - June 2010, using only T0 and S0 control (Top panel) and using T0, S0, U0 and V0 control (Bottom panel)



Hindcast: data - model comparisons for May - June, 2010, for all moorings, for experiments 1-4, using T0, S0, U0 and V0 control. Left panels show the *rms* and the right panels show the cross-correlation for U (top panels) and V (bottom panels).



Hindcast: data - model comparisons for May - June, 2010, for Mooring-A1. Left panels show mean difference, middle panels show standard deviation, and right panels show *rmsd* for U (top panels) and V (bottom panels).

- ▶ Extending state estimation experiments for 2010 using high-resolution MITgcm-GoM grid, assimilating SSH, SST, and LEIDOS mooring observations in the Deep Gulf.
- ▶ Offline particle trajectory experiments using three-dimensional estimated velocities, and compare model trajectories with RAFOS trajectories.
- ▶ Computing drifter velocities based on RAFOS float observations and assimilating them into MIT-GoM model
- ▶ Assimilating PIES observations into the MIT-GoM model
- ▶ Providing/sharing model hindcast with other groups for process studies

- ▶ Several data sources: the Radar Altimetry Database System (RADS), AVISO, NCEP/NCAR Reanalysis-1, the HYCOM consortium, Remote Sensing Systems, Inc, and the ECCO consortium, including MIT, JPL, and the University of Hamburg

Thank You



## Extra Slides