# A 32-Year Run of 1/12$^{o}$ HYCOM in the Gulf of Mexico

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## Outline

1. EM objectives with HYCOM
2. Evaluation of 1/3$^{o}$ and 1/12$^{o}$ original HYCOM in GoM
3. Efforts to improve HYCOM performance in GoM
4. Results of the long-term run
5. Summary

# A 32 -Year Run of 1/12° HYCOM in the Gulf of Mexico

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## Overall Long-term ExxonMobil Objective with HYCOM

- Use HYCOM to simulate currents in deepwater regions that can provide a basis for defining current criteria to the level of wind and wave criteria

## Basic Plan

- Run HYCOM without data assimilation in order to develop a long time history of currents in a region such that reliable estimates of extreme current events can be made
  - precise re-creation of particular strong historical events is not a top priority
  - a long time history which is an unbiased representation (in terms of event location, strength, frequency, duration, etc) of the "current climate" is the goal
  - if a hindcast shows reasonable skill, then for interior improvements needed for engineering applications we may use physical measurements to calibrate simulation results

- Use the Gulf of Mexico as a first case

# *Efforts to Improve HYCOM Model Performance*

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- **Identified Loop Current growth & eddy separation as a critical area for model improvement**
  - Evaluated a 1/3$^{o}$ run and a 1/12$^{o}$ run
  - Studied the effect of spatial resolution, 1/3$^{o}$ *v.s.* 1/12$^{o}$
  - Tested sensitivity of eddy viscosity
  - Tested new bathymetry data
  - Identified the physical mechanisms which govern LC penetration / eddy separation
    - Literature review
    - Process study
  - Ran and evaluated a matrix of cases to test the hypotheses
    - Established a “hybrid boundary condition” method for improving model performance
    - Achieved significant improvements over base case

- **Configured model for a long-term run**
  - Generated hybrid B.C. for a 32-year period of production run
  - Generated wind forcing from NOAA’s WaveWatch3 (WW3) hindcast
  - Ran the 32-year production case

# Model Statistical Measures in the Gulf of Mexico

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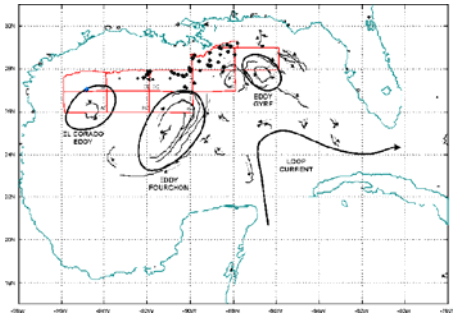
## Measures:

- Gulf Climatology
  1. % occurrence of LCE water by location
  2. eddy generation and paths
  3. eddy translation speeds
  4. 95% non-exceedence surface-layer current
  5. extreme surface-layer speed
  6. GoM temperature structure *
  (7. eddy swirl period)
  (8. eddy size)
- Inflow/Outflow transport

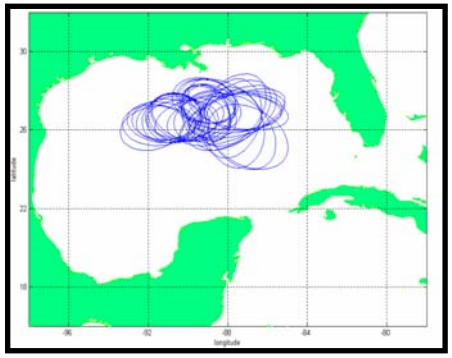



EddyWatch chart with drifting buoys

## Basis for Comparison:

- Gulf Climatology Sources
  1. the Climatology And Simulation of Eddies (CASE) JIP parametric Gulf Eddy Model (GEM)
  2. archived EddyWatch charts
  3. satellite data (primarily altimetry, some AVHRR/ CZCS)

- Inflow/Outflow Sources
  1. “Traditional” Literature
  2. Yucatan Straits inflow experiment



GEM parameterization of an eddy

# Eddy Identification from the Model Simulation

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## Methods

- Traditional pre-ADCP method
  - 15$^{o}$ isotherm at 200*m*
  - 20$^{o}$ isotherm at 125*m*
- Sea-surface height anomaly

## Estimator used

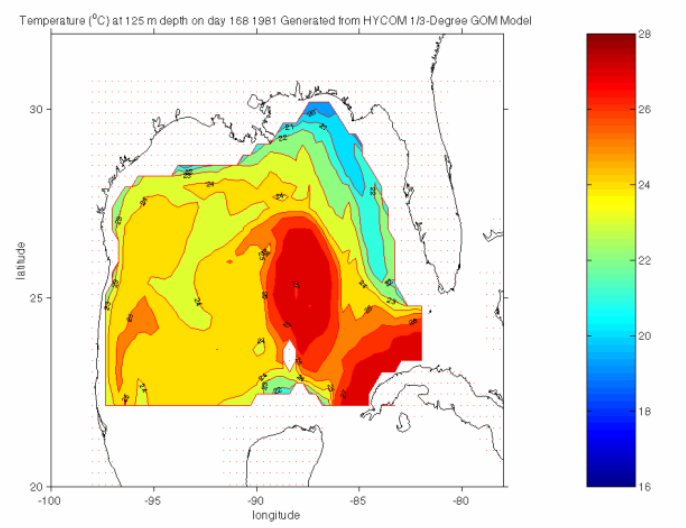
- For 1/3$^{o}$ HYCOM

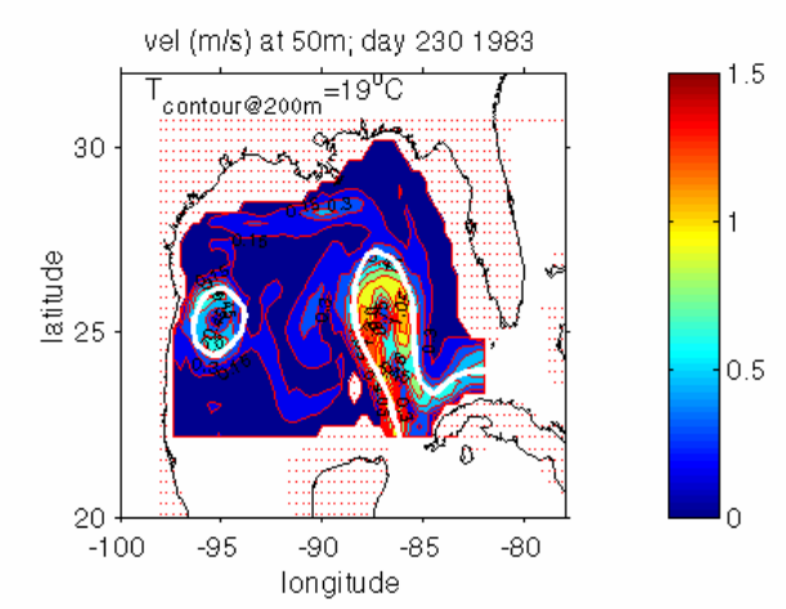
  19$^{o}$ isotherm at 200*m* <u>AND</u> 10*cm* anomaly (based on spatially de-meaned GoM)

  (the 19$^{o}$ isotherm at 200m means the modeled GoM by 1/3$^{o}$ HYCOM is TOO WARM!)

- For 1/12$^{o}$ HYCOM

  15$^{o}$ isotherm at 200*m* <u>AND</u> 9*cm* anomaly



# 16-Year 1/3º HYCOM Atlantic Ocean Run

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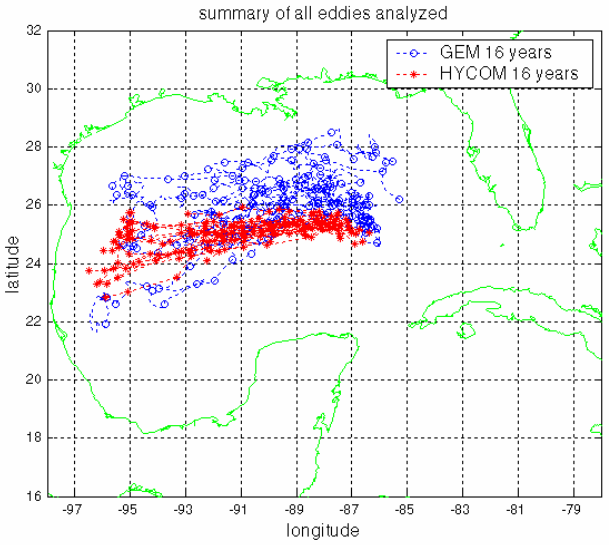
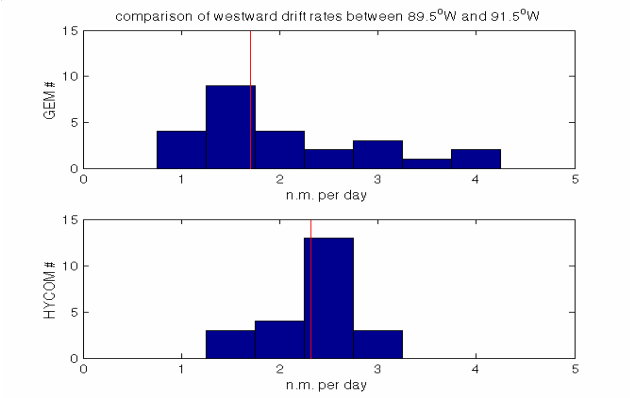
## Eddy Paths

- Over 16 years eddies were generated slightly more frequently in HYCOM (26) than has been observed (20) historically
- Eddies in the HYCOM simulation always separated at the southernmost extent of the observed eddy separation region
- There is far less scatter in the tracks of simulated eddies than observed eddies




## Westward Drift Speed

- The westward drift speed of eddies from 89.5ºW to 91.5ºW of HYCOM :
  - shows less scatter than observed
  - faster average drift rate (indicated by vertical red lines)



# 5-Year Original 1/12° HYCOM Run – Base Case

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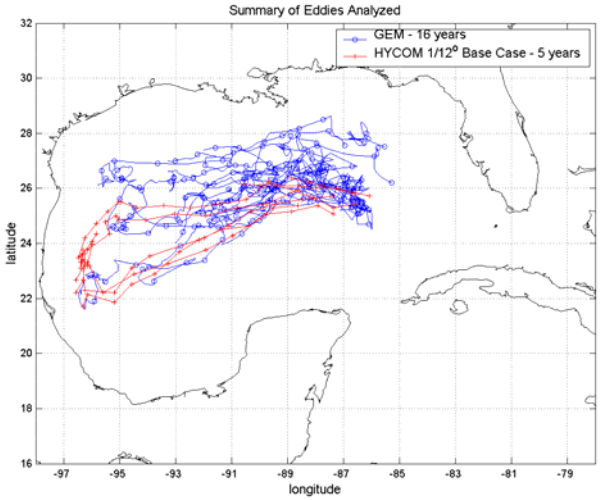
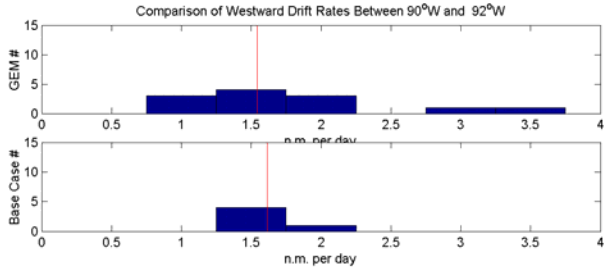
- most tendencies appear to be improved comparing with 1/3° HYCOM
- the warm water bias is less severe in the 1/12° simulation
- within the 5-year simulation
  - the tracks show more scatter, but modeled eddies still “under-penetrate” into the Gulf
  - the westward drift rate of the eddies is near the climatological runs
  - the peak LCE speeds are significantly higher



# Physical Mechanisms & the Test Case Matrix

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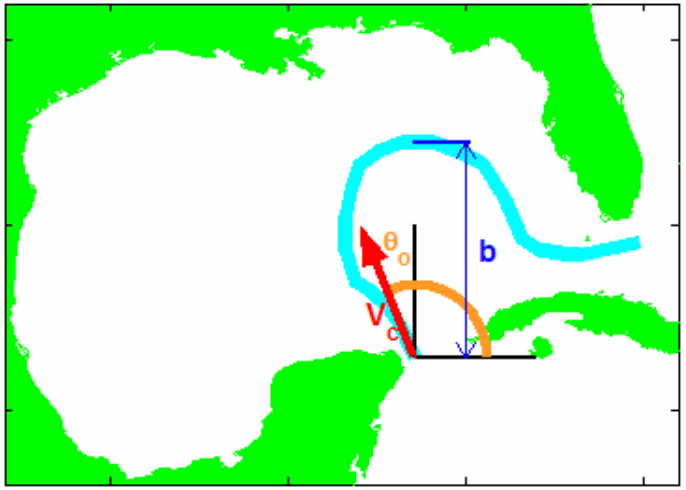
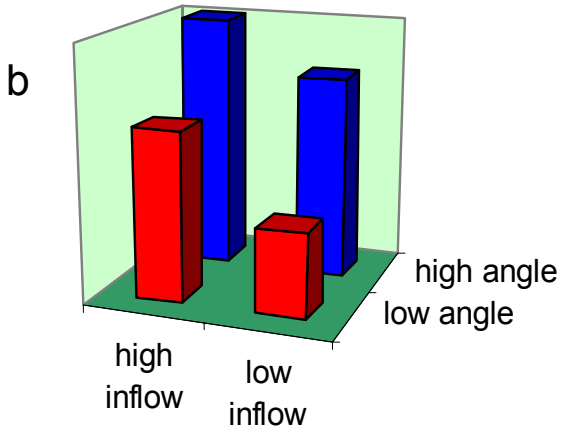
Schematic of Reid model




Nominal Test Matrix




## Loop Current Penetration Issue

•HYCOM runs did not show sufficient penetration of the Loop Current into the Gulf of Mexico

•We need to ensure the model has realistic Loop penetration, eddy separation & eddy propagation

## Literature Review

•In 1972 R. Reid presented a simplified model based on conservation of potential vorticity

$$b = \left\{ \left( \frac{2V_c}{\beta} \right) (1 - \cos\theta_o) \right\}^{1/2}$$

•Oey (2003) assumes a fixed inflow angle and gives a similar relation in terms of relative vorticity and inflow velocity

•Our HYCOM test matrix probes the parameter space of inflow strength and “vorticity”

## Process Studies

•Isolate important physical mechanisms by using

- •constant inflow
- •no wind stress

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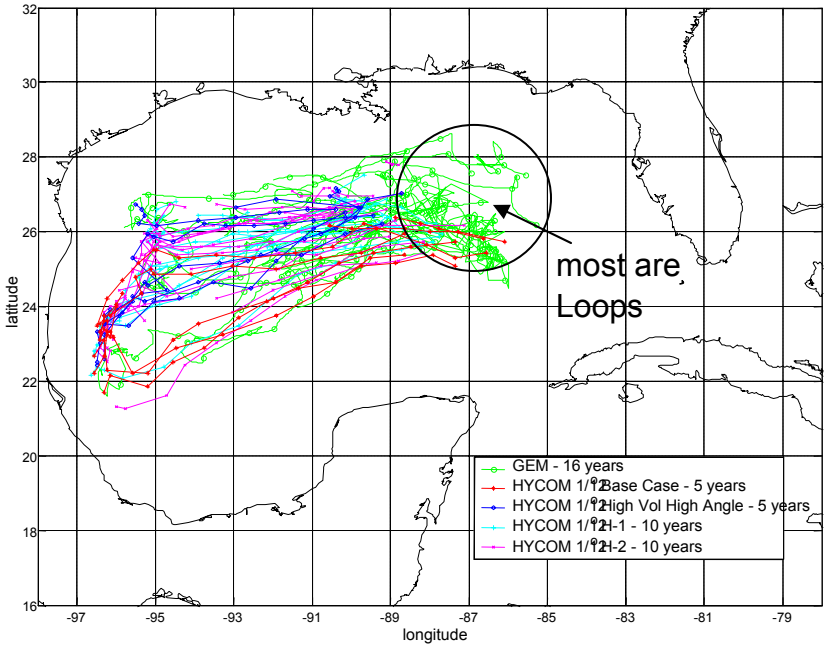
## Hybrid Boundary Conditions

(hybrid b.c.) = $\alpha$ (high volume/high angle)
+ (1-$\alpha$) (base case)

We have tested 4 cases:

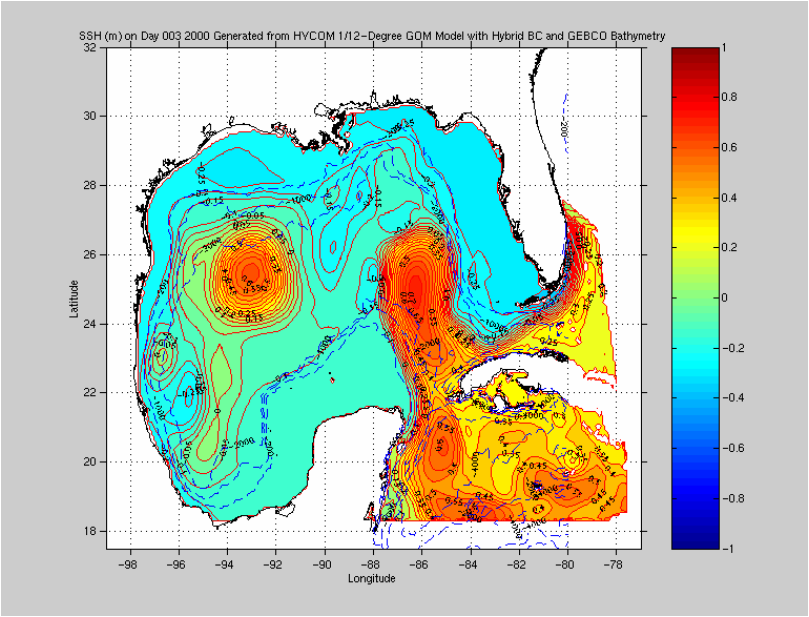
- α=1.00 high volume / high angle (5-year)
- α=0.75 hybrid 1 case (10-year)
- α=0.50 hybrid 2 case (10-year)
- α=0.00 base case (5-year)

Four Test Cases:

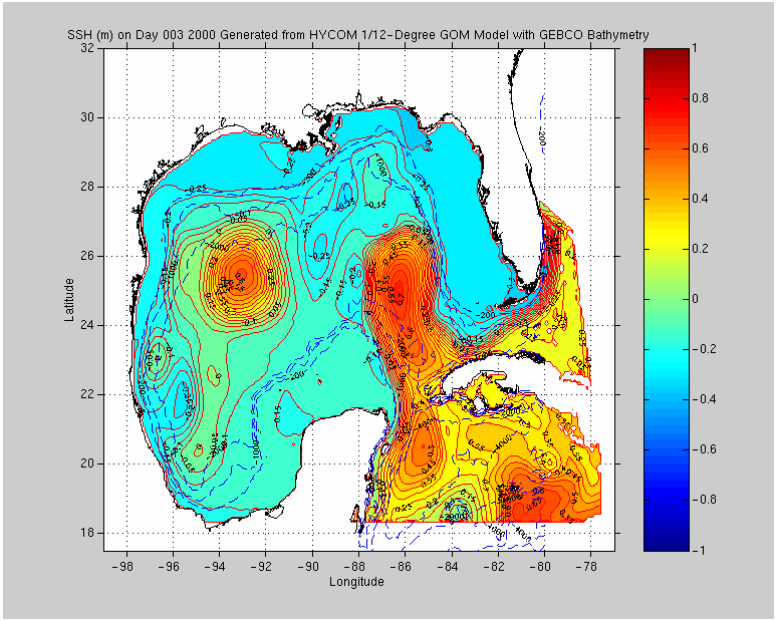


## Comparison Two Extreme Test Cases

- With low inflow angle the model does not generate deep penetration or even eddies
- With high inflow angle and high volume the model creates excessively deep penetrations




Animation of the current for the case of High Volume/Low Inflow Angle




Animation of the current for the case of High Volume/High Inflow Angle

# HYCOM 32-Year Run

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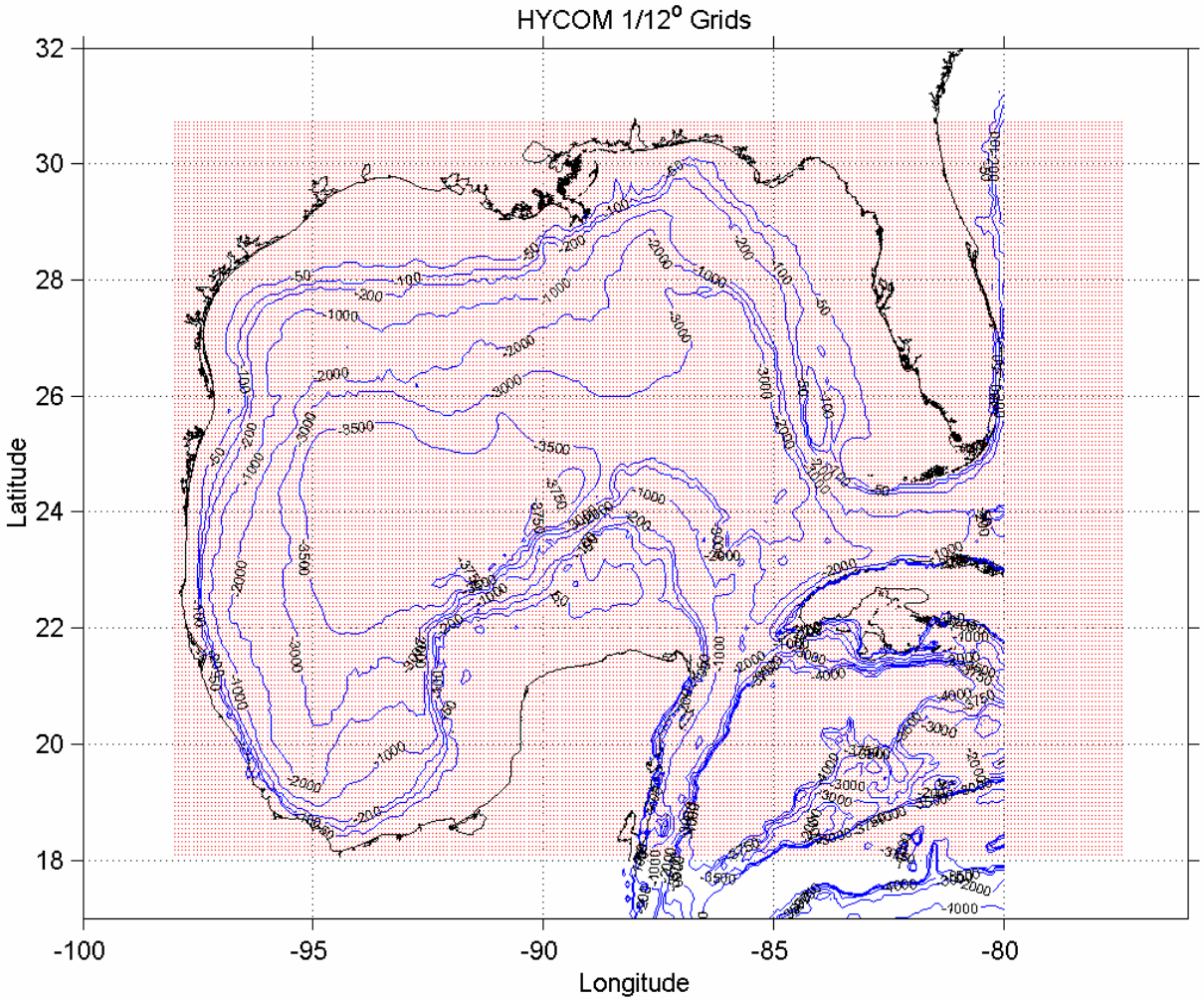
## Model Input:

- B. C.: hybrid 2, *i.e.*, α=0.50
- wind forcing: NOAA's WW3 hindcast

## Model Output:

- array size: 258x175
- vertical layer: 20
- output interval: every day
- model period: 32 years



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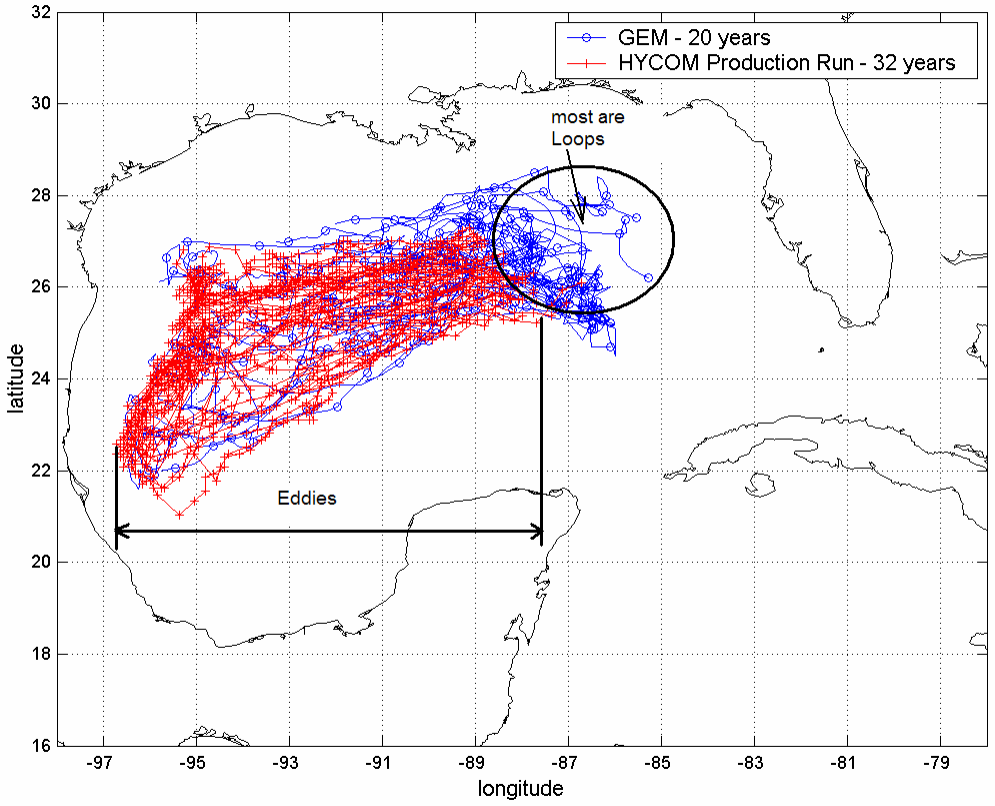
## Eddy Path

- Loop penetration was identified as a major shortcoming
- A first quality check of the production run is to compare eddy center paths versus historical observations
- The model results show paths with realistic
  - penetration distances
  - path variability
- Some shortcomings may remain
  - no observed shedding on east side of Loop (an infrequent occurrence in nature)
  - note: GEM paths east of 89°W may be part of Loop Current. HYCOM results are only for separated eddies



# Evaluation of Production Run Results – Eddies (continued)

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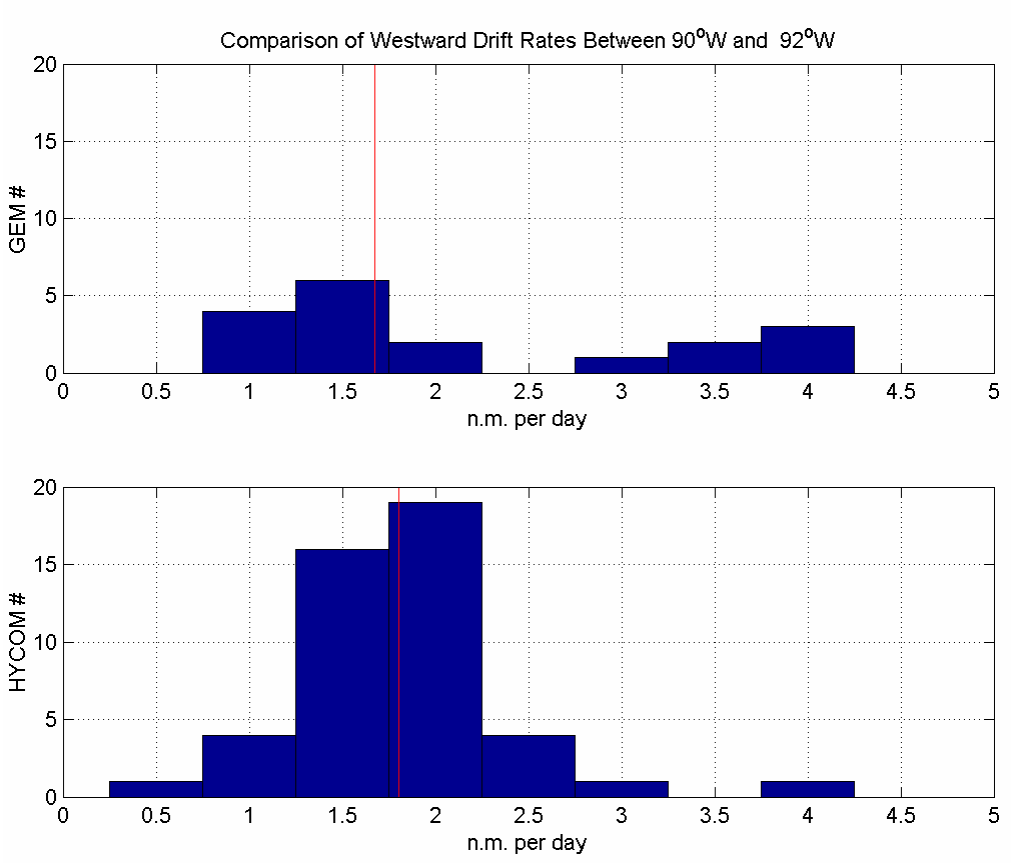
## Eddy Shedding Rate

GEM: 28 eddies in 20 years = 1.4/year

HYCOM: 49 eddies in 32 years = 1.5/year

## Eddy Westward Translation Speed



## Maximum Current Extreme Comparison:

| | HYCOM (cm/s) | GEM (cm/s) | difference (cm/s) (HYCOM-GEM) |
|---|---|---|---|
| 95% nx | 147 | 133 | 14 |
| 1-yr | 212 | 159 | 53 |
| 5-yr | 217 | 200 | 17 |
| 10-yr | 228 | 218 | 10 |
| 20-yr | 237 | 232 | 5 |
| 50-yr | 249 | 260 | -11 |
| 100-yr | 258 | 269 | -11 |
| 200-yr | 266 | 279 | -13 |
| Overall Time Series | 288 | 266 | 22 |

Note: For extremes, HYCOM and GEM were compared over the same GEM area; for time series, the area for HYCOM is the whole gulf.

# Examine Bottom Currents in the Sigsbee Escarpment Area

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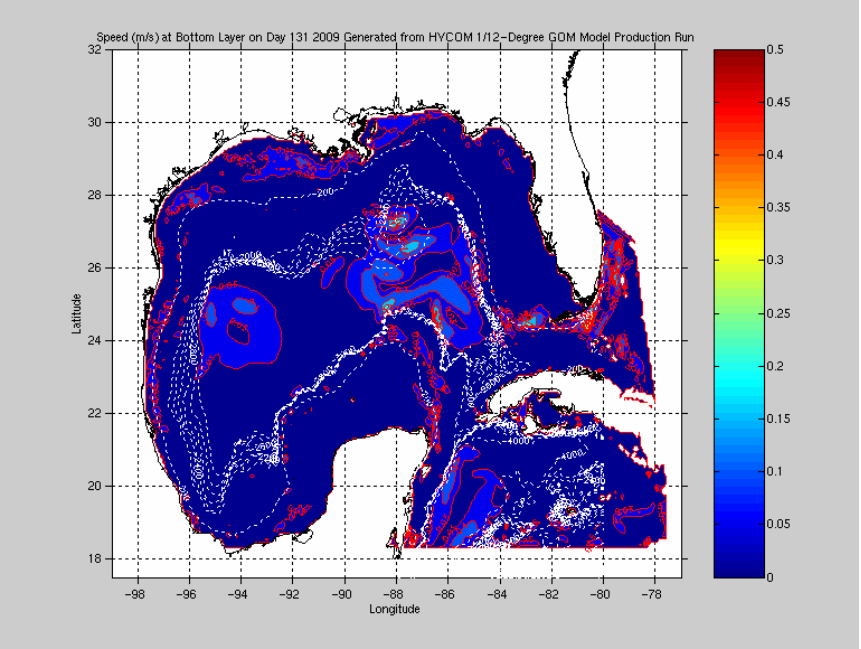
**Observation indicates that strong currents occur occasionally in the bottom layer, main features of the current events are:**

- Event Occurrence rate: ~1 event/year
- Magnitude: > 1m/s
- Duration: ~ a couple of days
- Depth: ~bottom several hundreds meters
- Bottom Topographic Wave (BTW) propagates from east to west along the Escarpment




Animation of the bottom current for a BTW event in model year 2009

**Statistics from model output show that the characteristics of bottom current events match observations, however, magnitude of model current event is lower than observation.**

# Application of Model Results in the GoM

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- Apply the model results for current criteria for sites with insufficient field data in the Gulf
  - Result provides a continuous time series of currents which may be useful for operational criteria or fatigue assessments
  - Result may provide initial estimates beyond extent of existing measurements

- Considering re-run the 32-year production run with finer vertical resolution to better simulate the bottom currents
  - if success with a moderate effort, we will get the full value of the model results
  - it is very important for pipeline design and installation and also for riser analysis with full water column currents

# Summary

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- HYCOM capabilities are impressive
- Details in domain and at the boundaries are important
  - Further effort before model can provide results with reliability needed for engineering application
  - Some applications will need further improvement through water column
- All users will benefit from further HYCOM improvement
  - For the GoM example, where we have extensive data, HYCOM results can be calibrated to match observations. For other regions, such data is not always available. Therefore, it is desirable for HYCOM to be stand-alone without calibration