Simulating Wave-Tide Induced Circulation in Bay St. Louis with a Coupled Hydrodynamic-Wave Model

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Introduction

- ❖ The circulation of Bay-Inlet systems is an important transport mechanism of sediments, pollutants, and biological organisms within the coastal environment.

- ❖ Management of Bay-Inlet systems requires a better understanding of their circulation patterns and the forces that drive them.

- ❖ Development of a shelf-scale coupled hydrodynamic-wave model that can simulate wind, wave, and tidally forced circulation is required to simulate real Bay-Inlet systems.

- ❖ The wave and tidally forced circulation within Bay St. Louis, Mississippi is modeled by coupling the ADCIRC hydrodynamic model and the SWAN wave model.

- ❖ Modeled currents are used to determine the trajectories of passive Lagrangian tracers (sediments, pollutants) within Bay St. Louis.

ADCIRC Hydrodynamic Model

ADCIRC-2DDI: Hydrodynamic Model

- Finite element model (non-uniform grids), Ideal for modeling domains with **complex coastlines**
- Solves shallow water equations in cartesian and spherical coordinates
- 2-D (depth integrated) and 3-D versions
- Barotropic and Baroclinic options
- Wind, wave, river and tidal forcing options

SWAN Wave Model

SWAN: Wave Model (Booij et al. 1999)

- **Phase-averaged multi-spectral** wave model. **2-D finite difference**.
- **Energy-based formulation** allows expedient calculation over large areas.
- **Refraction, shoaling**, reflection, blocking, capable of using sea surface elevation and current fields as input.
- **No diffraction**, only parameterized shallow water nonlinearity, very slow variation assumed.

2-D Wave-Current Interaction Methodology

Two-way coupling using sea surface elevation and currents

Spin-Up Phase

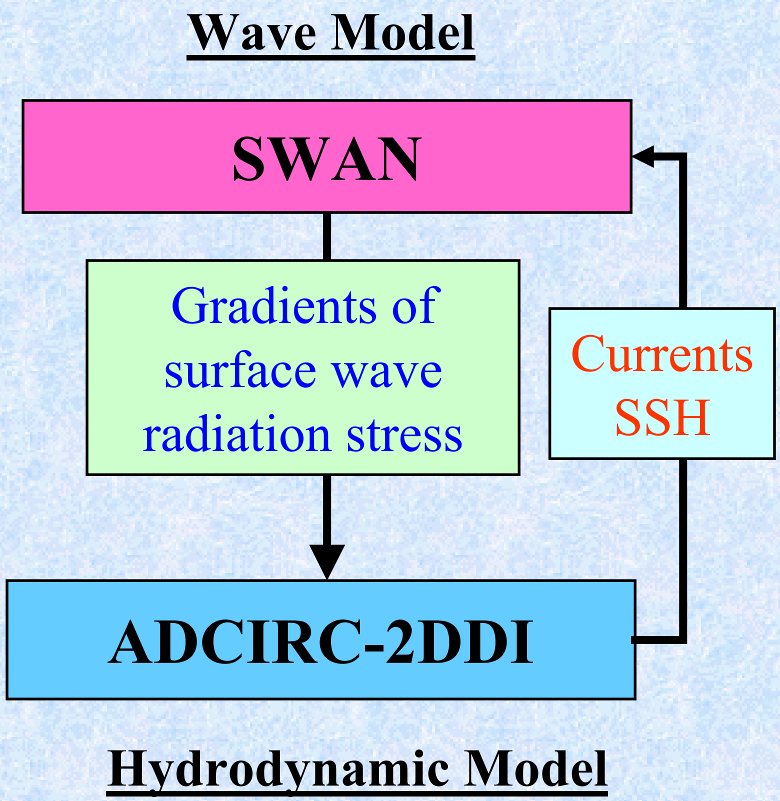
1) **SWAN is run over the computational domain without any circulation input:** **generate initial surface stress forcing** from **radiation stress gradients.**

SWAN parameters chosen to create a narrow banded wave spectrum. Wave field treated as monochromatic with regard to wave height and wave direction for radiation stress calculation.

2) **ADCIRC is run long enough to achieve a steady state solution with the initial surface stress forcing: 5 days for this study**

Coupled Mode

Iteration interval = 1.92 hours
Duration = 23.04 hours



Bay St. Louis, Mississippi

Bay St. Louis: ADCIRC Bathymetry

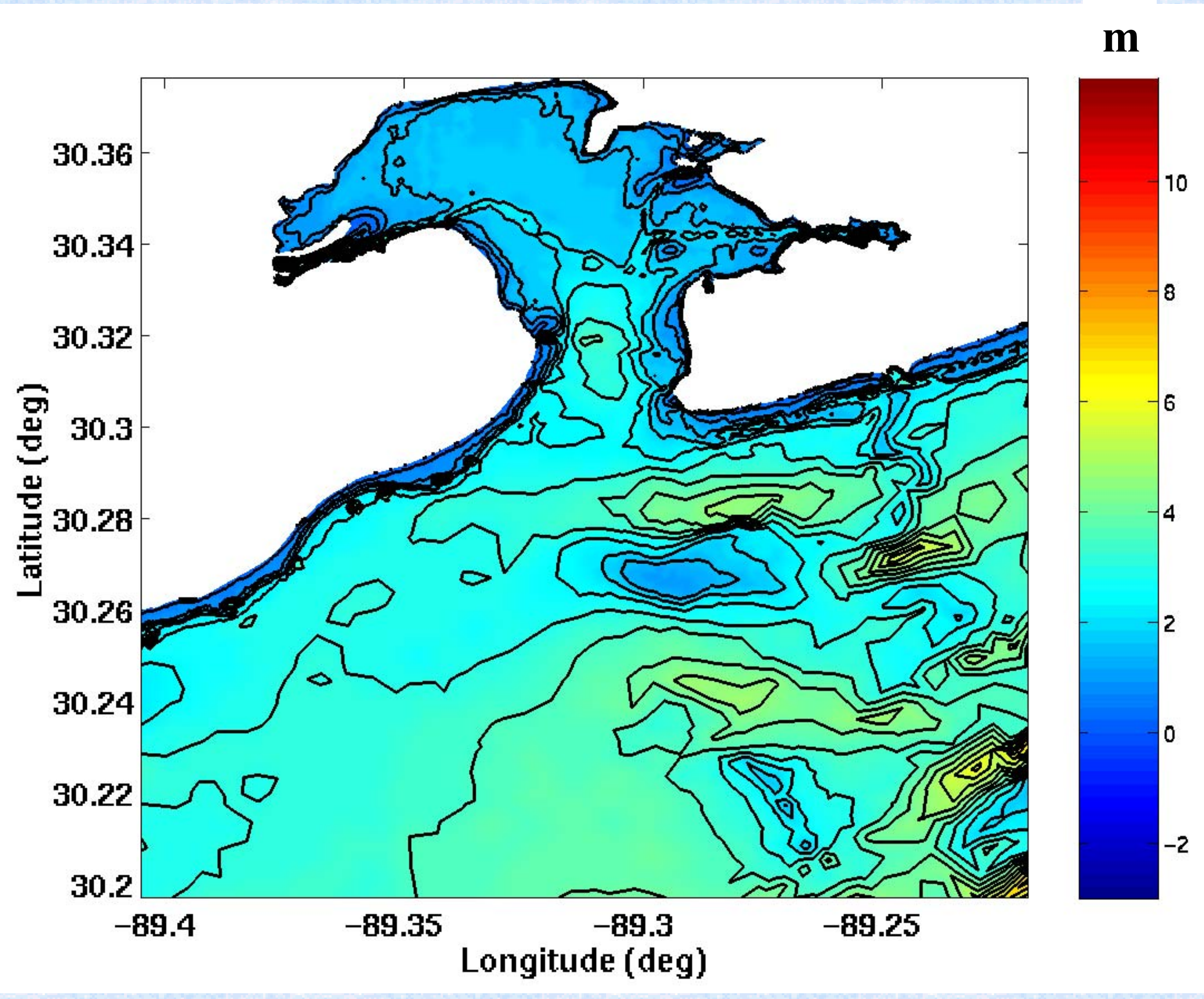
Coastline data: NOAA/NOS Medium Resolution Coastline database
http://rimmer/ngdc.noaa.gov/coast

6 second Bathymetry data: Northern Gulf of Mexico Littoral Initiative
(http://128.160.23.41/):

Range of Bathymetry:
11.84 m to -2.99 meters

Note: A smooth transition from sea to land is required for the SWAN wave model in order to have realistic wave breaking.

For this initial study some of the more filamentary coastline structures have been eliminated.



ADCIRC Nodal Grid Structure
Bay St. Louis, MS

Non-uniform Grid is used to reduce computational costs

Finite difference SWAN grid: X and Y spacing = 39.6 m and 39.9 m
<u>This is a rectangular grid surrounding the ADCIRC grid</u>

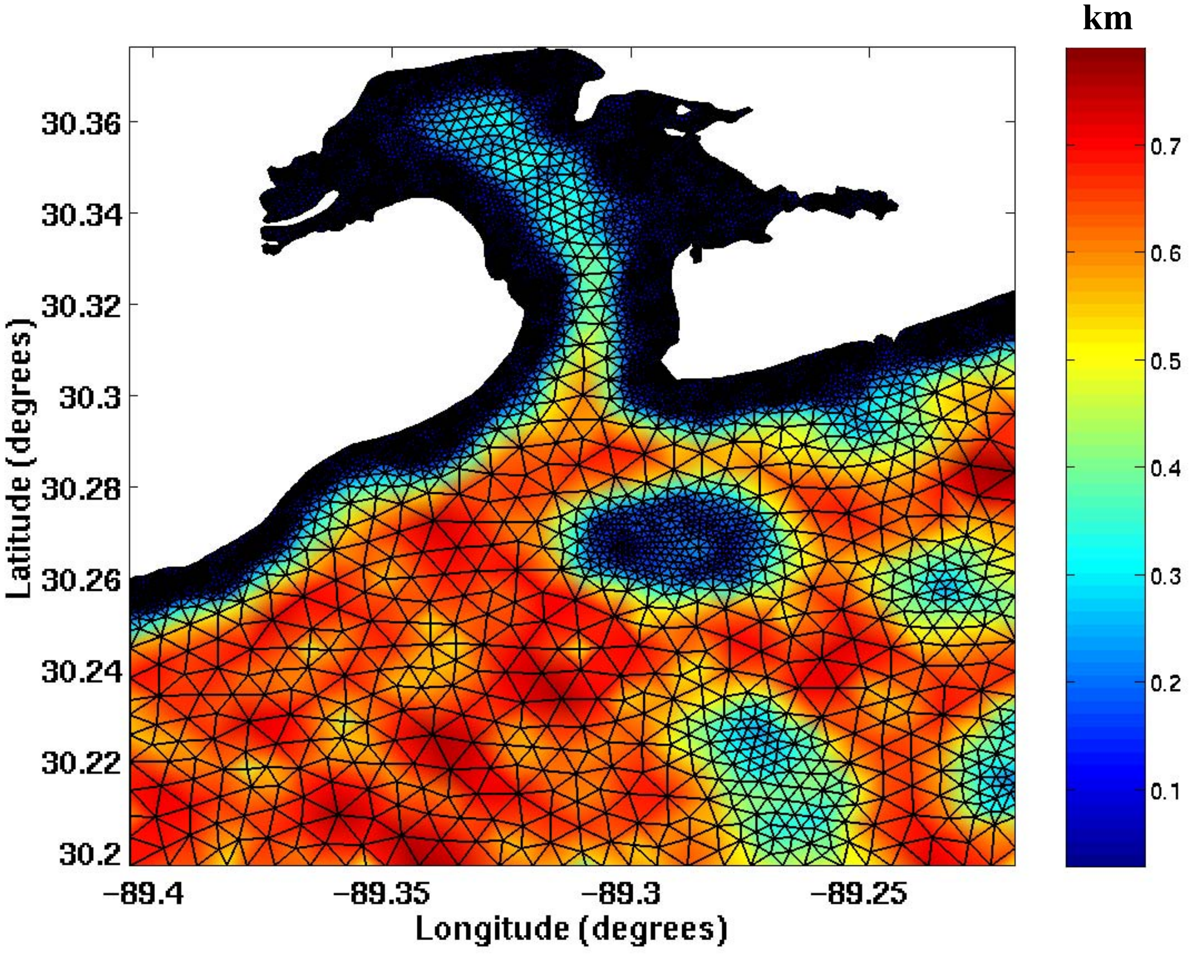
Range of node spacing is 29.1 m to 789.1 m

Increased nearshore ADCIRC resolution:

1) **Required for better hydrodynamic model results in this highly advective region**

2) **Improves interpolation between ADCIRC FE grid and SWAN FD grid: bathymetry, elevation, currents**

3) **SWAN points outside ADCIRC grid are given -0.01 m depths**



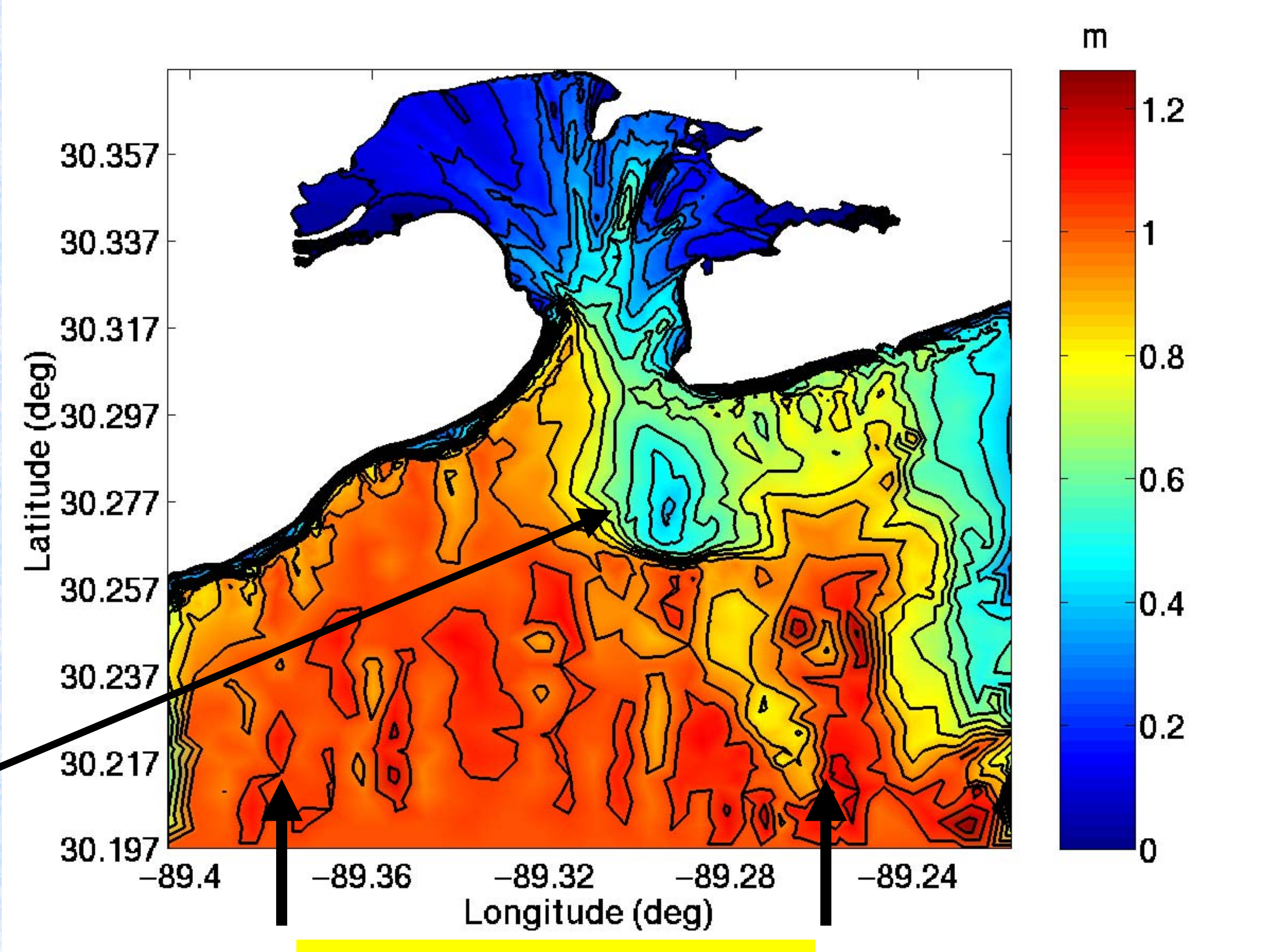
SWAN Wave Field: Spin-Up Phase

Incident wave significant height = 1.0 m
Wave height range = 0 to 1.32 m
Incident wave Peak frequency = 10 seconds

Default JONSWAP spectrum employed for incident waves at the boundary

JONSWAP spectrum is made narrow in order to produce an approximately monochromatic incident wave field

Note bathymetry induced change in the wave heights



Normally Incident Waves

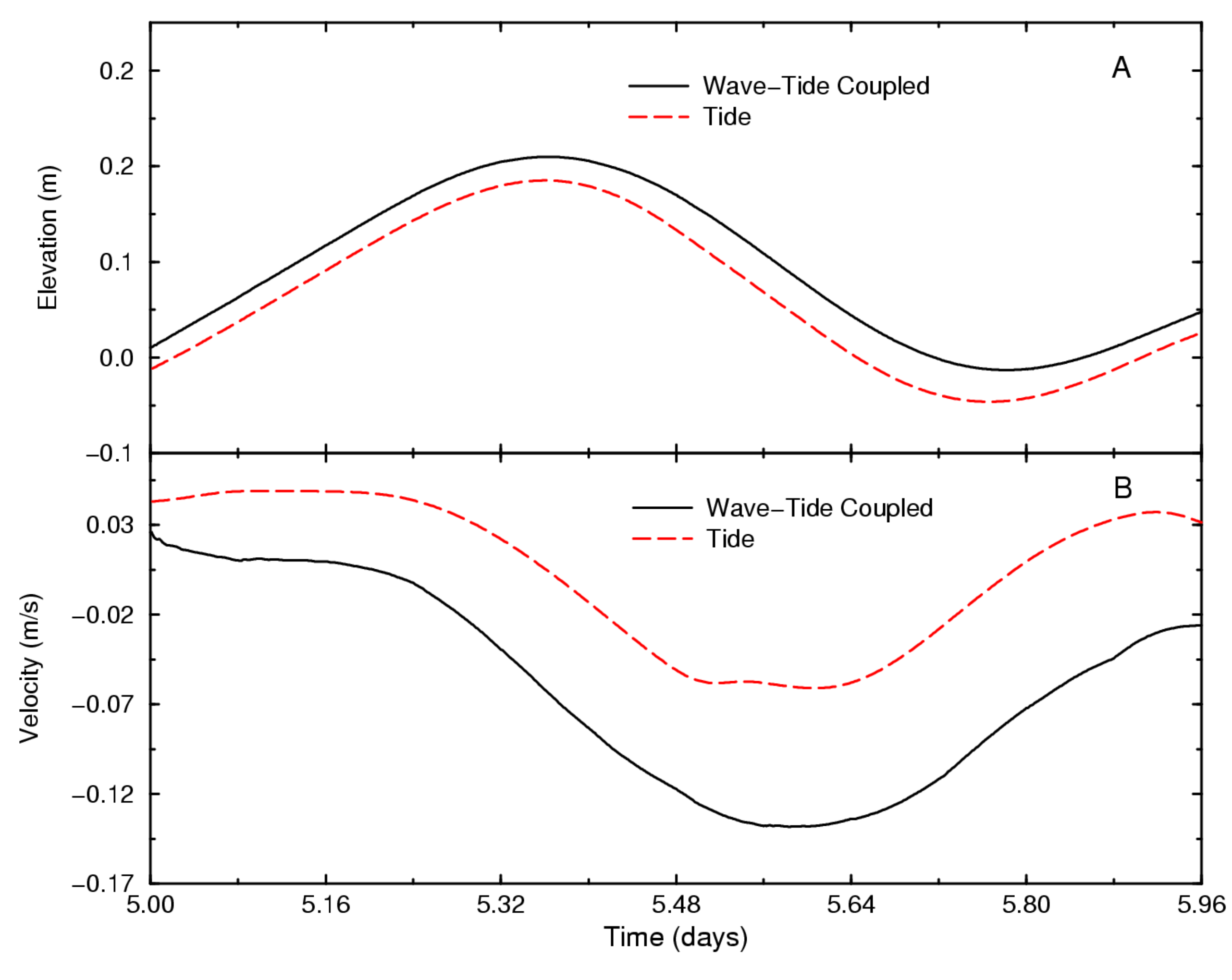
ADCIRC Simulations

Time step = 4 seconds
Lateral mixing coefficient = 1.0 m^2/s
Nonlinear bottom friction coefficient = 0.008
Tidal forcing on <u>open boundary</u>: K_1, O_1, P_1, Q_1, M_2, N_2, and S_2
No flow boundary with lateral slip along land and island boundaries

Location: inlet entrance (-89.31, 30.32 degrees)

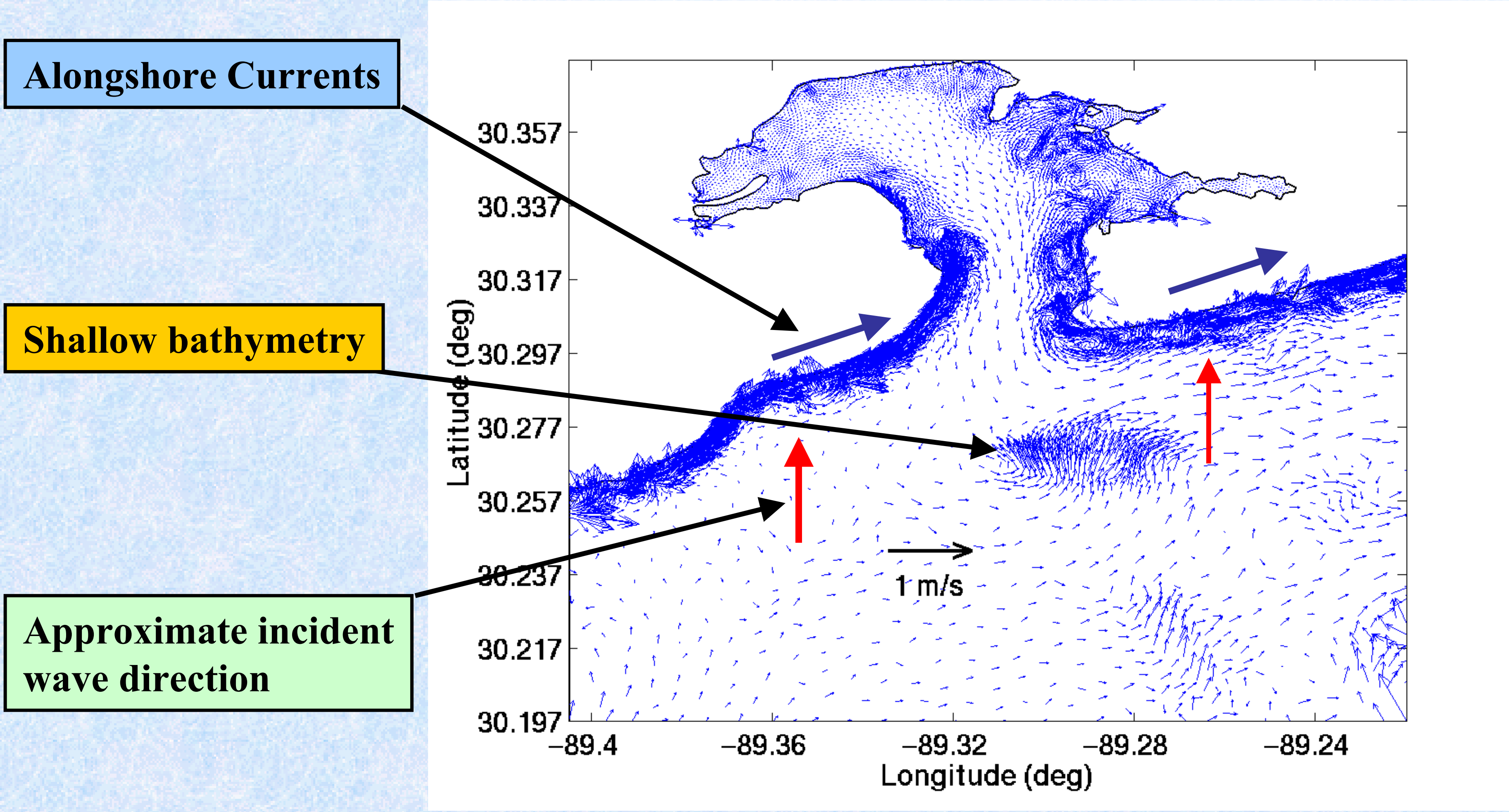
<u>Diurnal</u> Components dominate inlet region of Bay St. Louis.

Wave-Current interaction enhances elevation and increases the magnitude of the out-flowing current.



Bay-Inlet Circulation: Ebb phase (5.53 days)

1) Large scale circulation is dominated by tidal forcing: Eastward flow
2) Wave-induced circulation is very intense near the shoreline

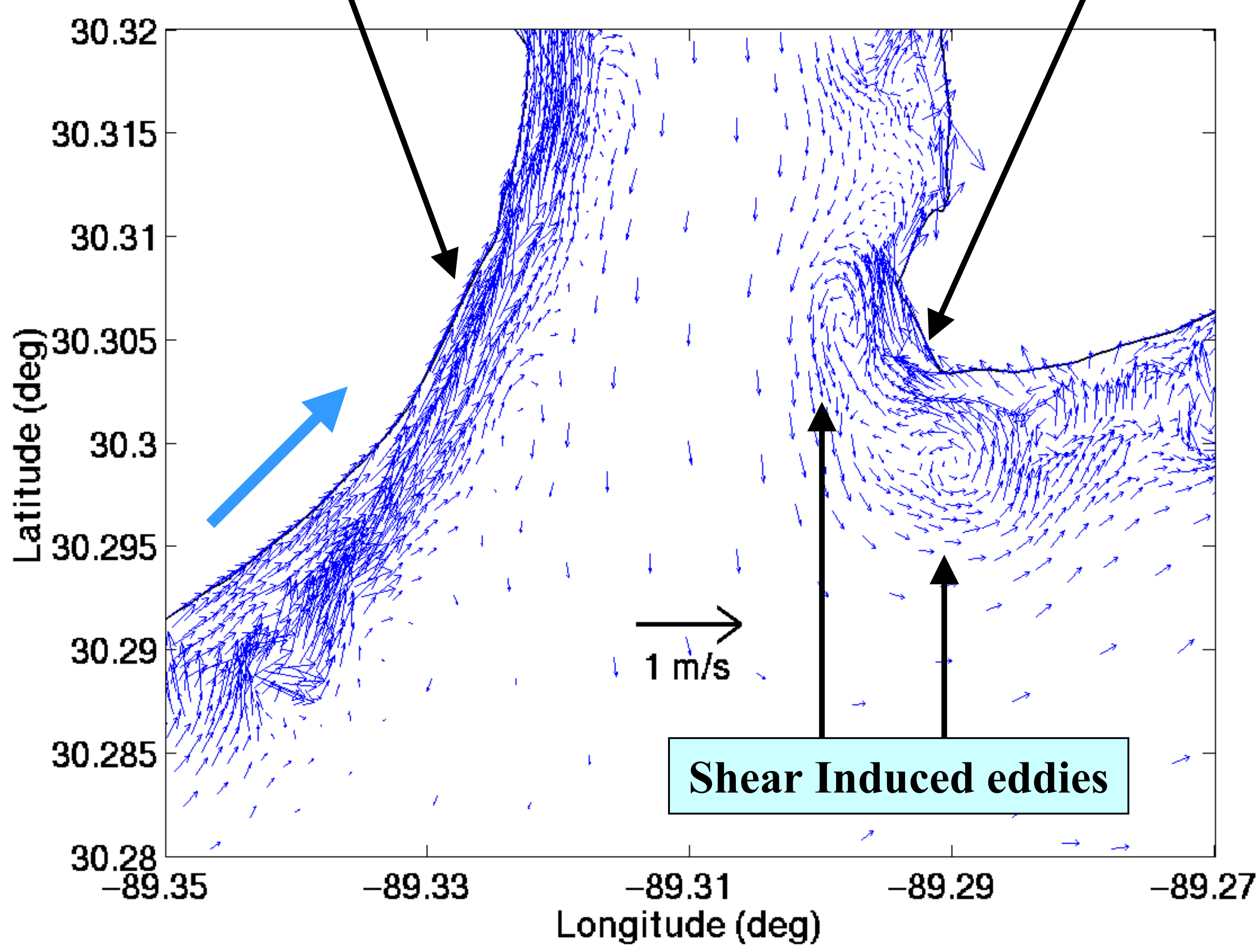


Bay-Inlet Circulation: Ebb phase (5.53 days)

Strong inflowing alongshore currents during all phases of the tidal cycle

Tidally induced currents are typically less (~50%) then wave-induced alongshore currents in the vicinity of the inlet.

Wave-induced circulation generates a strong out-flowing current in the middle of the inlet in addition to the tidally forced circulation.

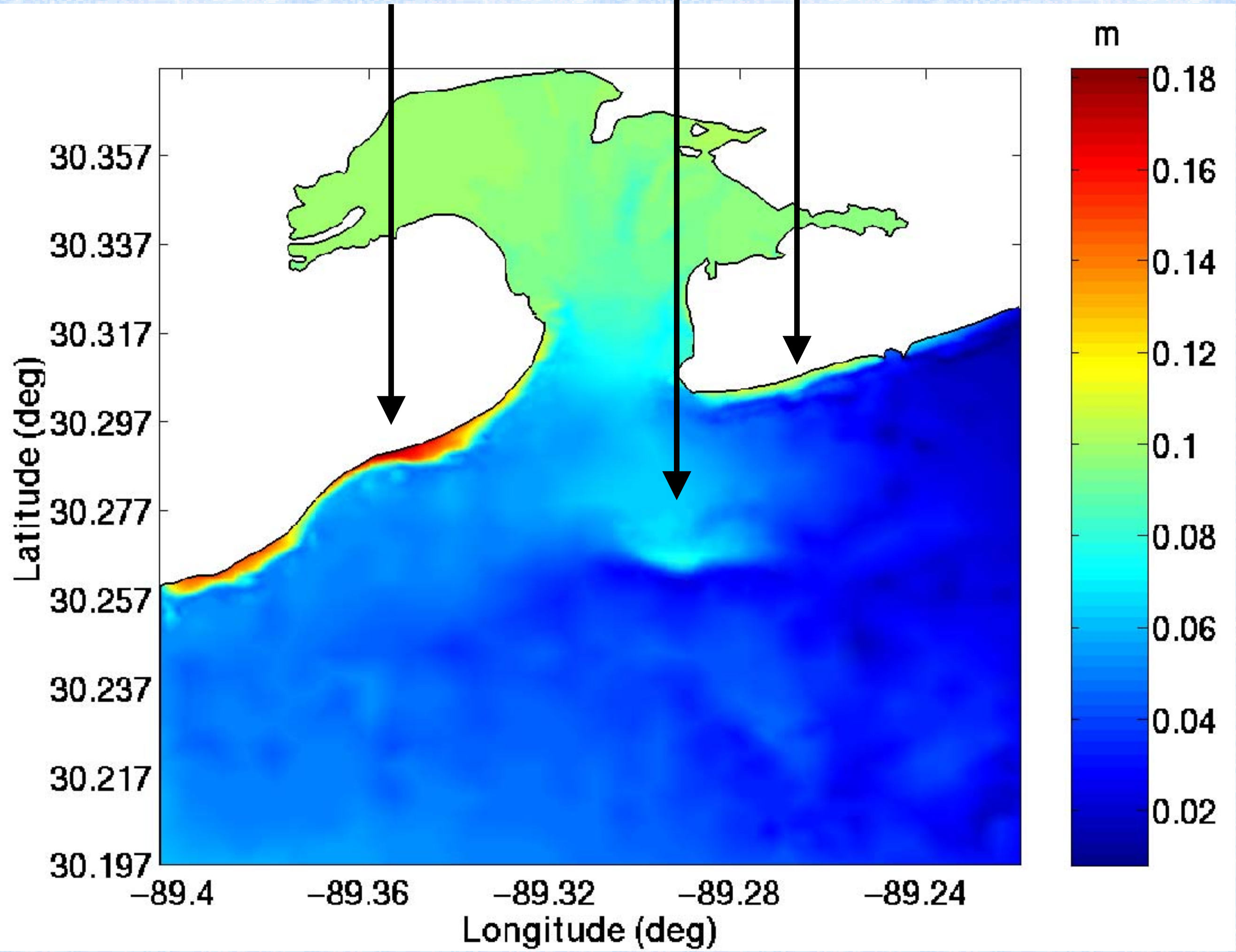


Shear Induced eddies

Bay-Inlet Sea Surface Elevation: <u>Ebb phase (5.53 days)</u>

Because of the deeper bathymetry the left side of the coastline receives much more intense waves and larger set-up

Shallow offshore bathymetry leads to wave breaking and less intense waves on the right side of coastline



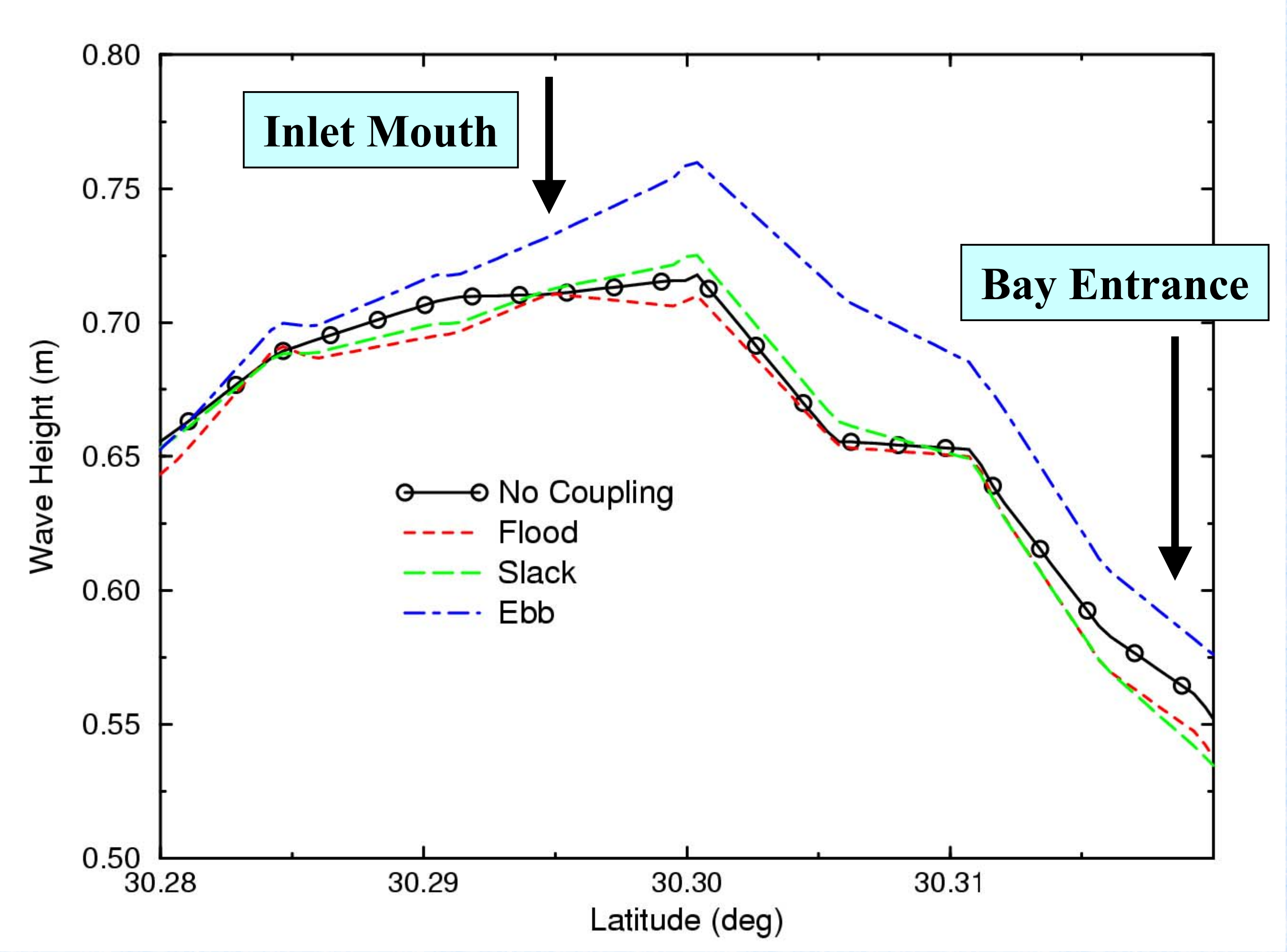
Wave Heights: Wave-Current Interaction

The no-coupling, flood, and slack wave heights are quite similar.

Only the ebb phase wave heights are significantly different. The ebb current is much more intense due to addition of the wave and tidally induced circulation.

Opposing current leads to significant shoaling of the incident waves during the ebb phase.

Transect along the middle of the inlet (longitude = -89.31°)

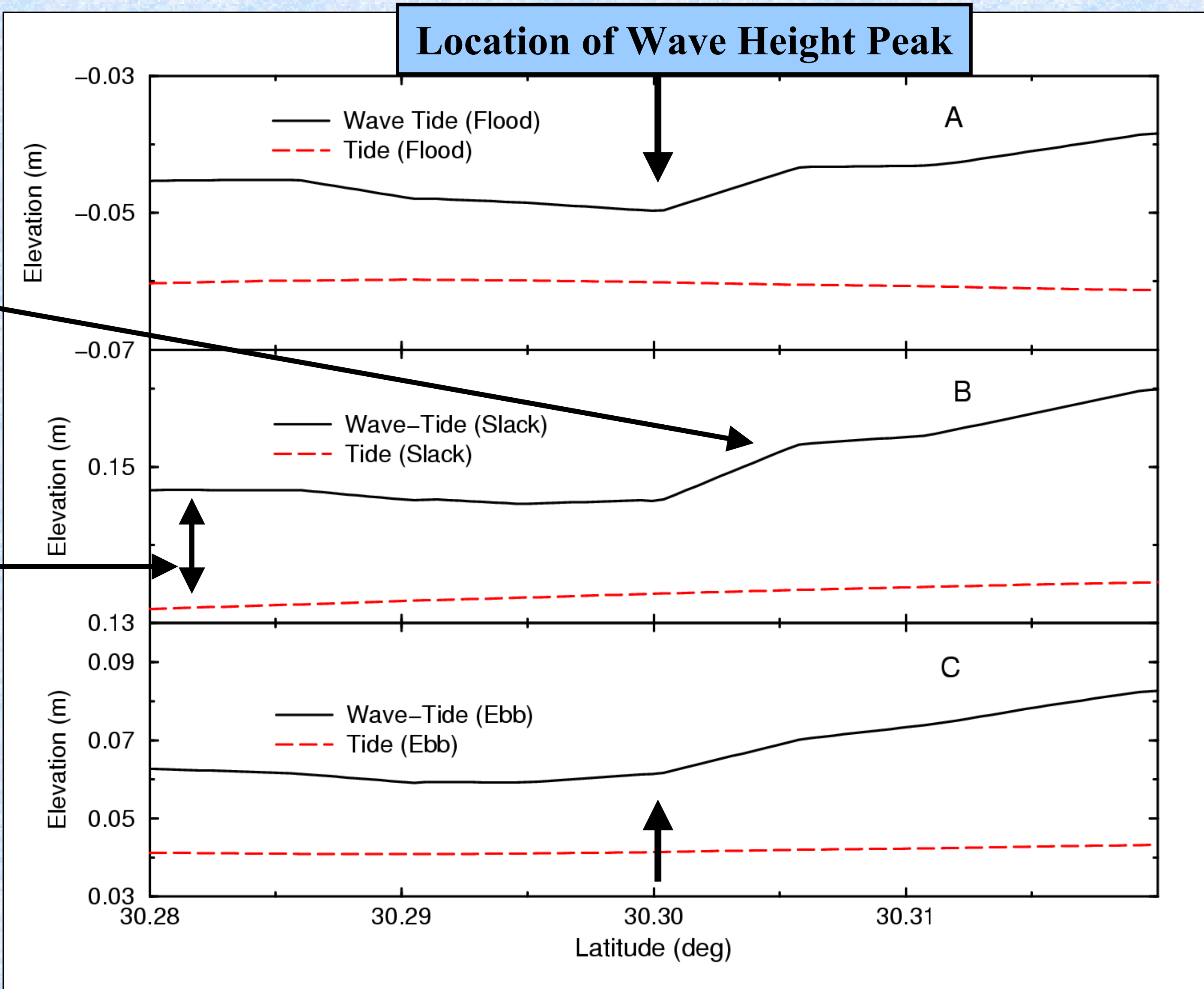


Sea Surface Elevation: ADCIRC

Transect along the middle of the inlet (longitude = -89.31^{O})
Flood, Slack, and Ebb phases

Wave-induced set-up and set-down are imposed on the tidally induced sea surface elevation.

Wave-induced shift in sea surface elevation :approx. 0.02 m.



Current Velocity: ADCIRC

Transect along the middle of the inlet (longitude = -89.31^{O})

Flood, Slack, and Ebb phases

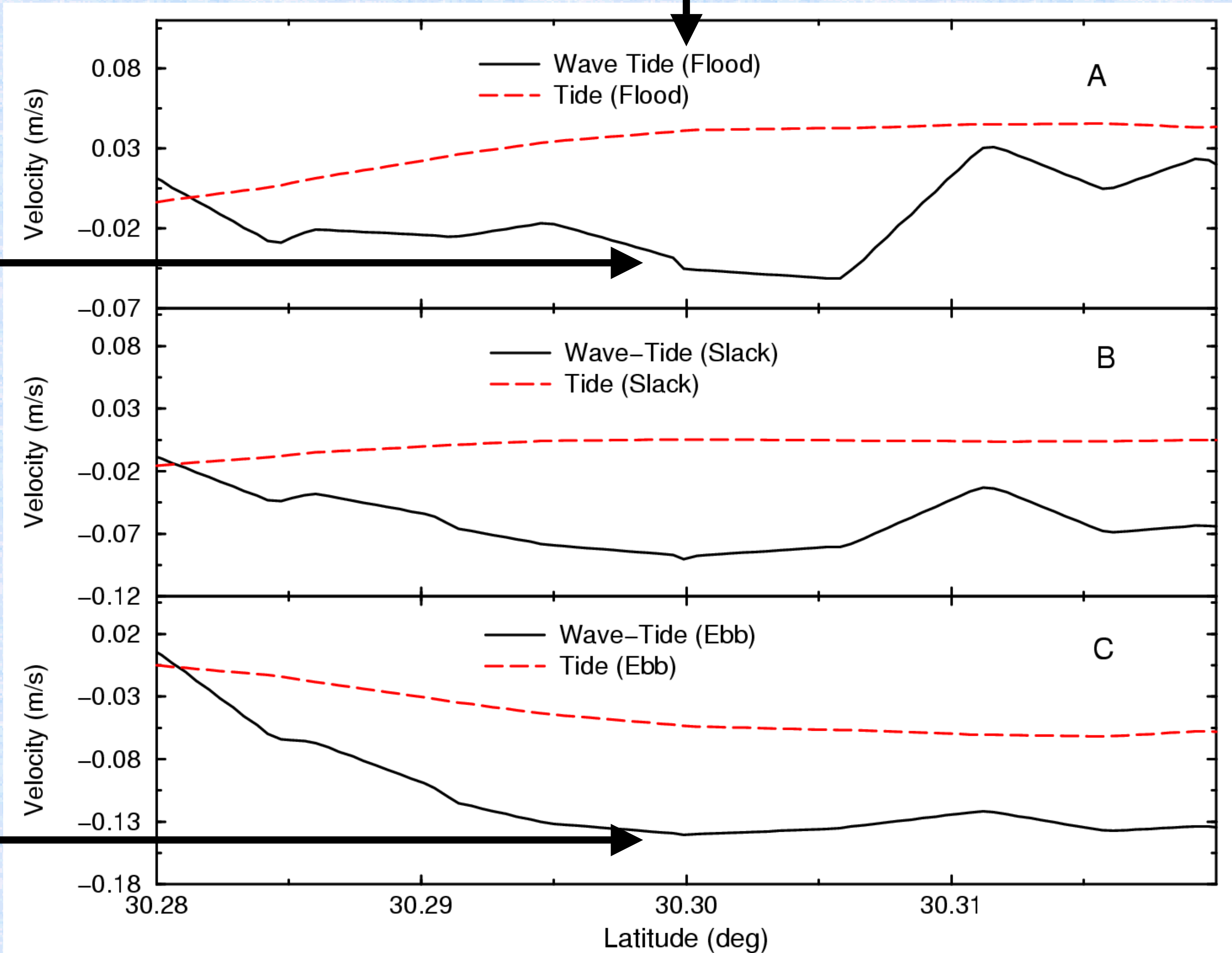
An out-flowing current is present in all phases of tidal cycle.

Flood phase: part of the out-flowing current must be due to wave-induced circulation.

The tidally induced inflowing current is opposing the wave induced out-flowing current.

Strong wave-tide ebb current

Location of Wave Height Peak



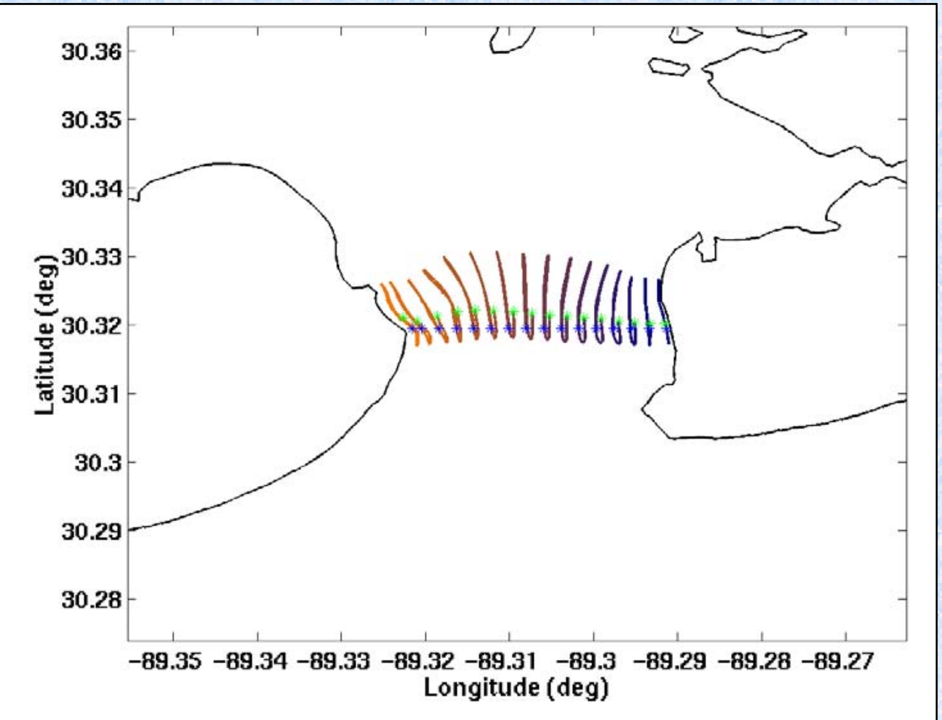
Lagrangian Tracers

Paths of tracers are determined over a time period of <u>0.96 days</u> during <u>coupled phase</u> of simulation.

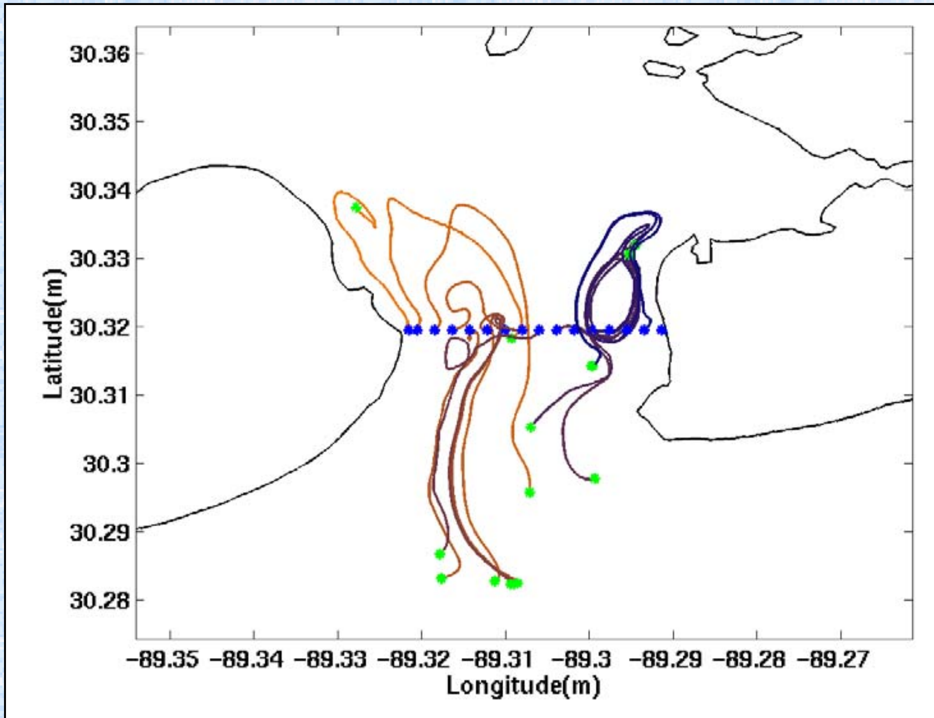
Tidally driven circulation: Tracers return to the vicinity of their starting point. The role of residual currents requires further investigation.

Wave-driven circulation: Tracers move along the complex wave-tide circulation patterns. Depending on location some enter the bay while others are transported to the outer ocean region.

Tidally-driven currents



Wave-driven currents



Conclusion

I. Successful implementation of a shelf-scale coupled hydrodynamic-wave model using ADCIRC and SWAN wave models.

II. This initial study indicates that wave-current interaction can be a significant effect in tidally driven inlets.

III. This study also demonstrates that wave-induced circulation can play an important role in the overall circulation of a tidally forced inlet.

IV. Lagrangian tracers indicate that passive particle transport of wave-tide and tidally forced inlets is dramatically different.

V. Elevation, current, and wave field data are required to benchmark the performance of the coupled model scheme.

VI. Future studies will focus on using multi-spectral radiation stress as well as wind and river forcing. In addition, 3-D simulations will be performed.