Wind and Tide Effects on the Choctawhatchee Bay Plume at Destin Inlet, Florida

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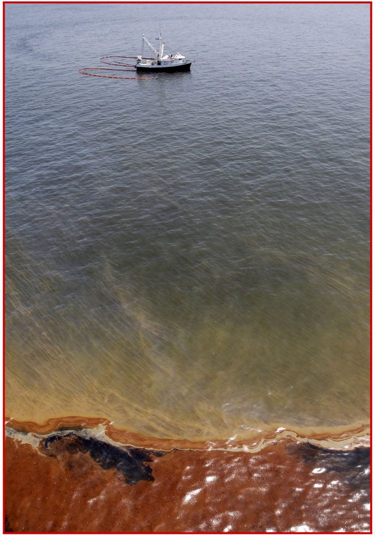
Density Fronts in the Coastal Ocean

Deepwater Horizon Oil Spill (2010)



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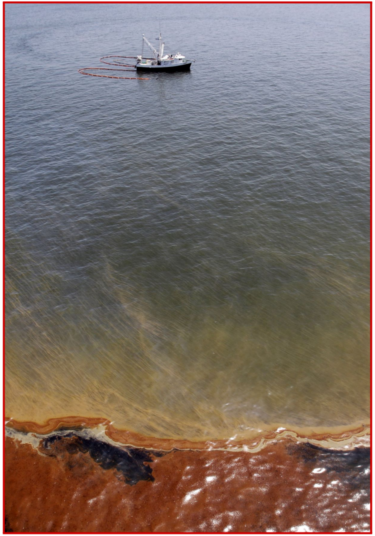
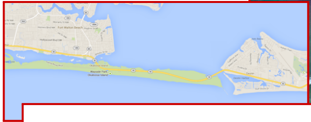


Surfzone Coastal Oil Pathways Experiment (SCOPE)

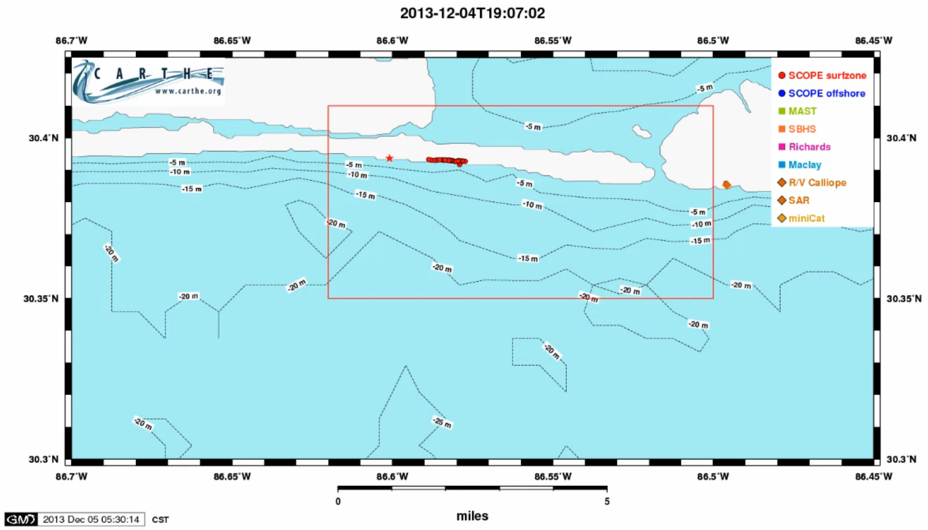
Targeted Field Experiment



- Fort Walton Beach and Destin during 01-17 December 2013
- Led by Ad Reniers (U-Miami) and Jamie MacMahan (NPS)
- Deployed 200 GPS-equipped drifters, unmanned aerial vehicles, helicopters, and pressure and dye sensors

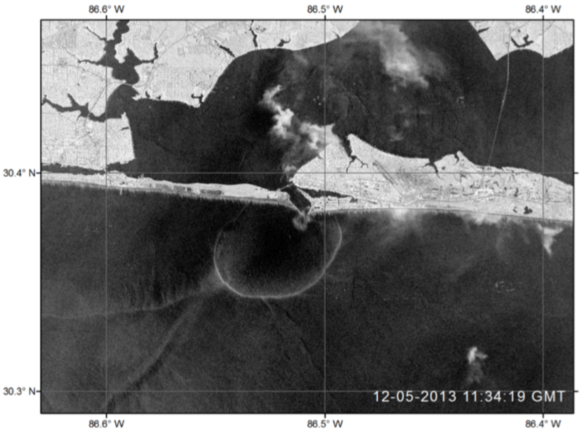
Surfzone Coastal Oil Pathways Experiment (SCOPE)

Drifter Releases from Destin Inlet



Surfzone Coastal Oil Pathways Experiment (SCOPE)

Behavior of the Choctawhatchee Bay Plume



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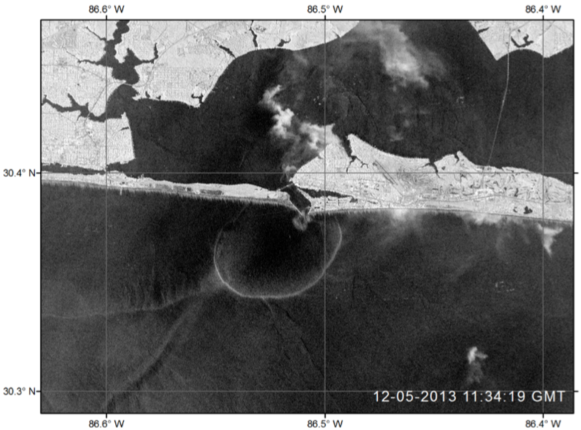

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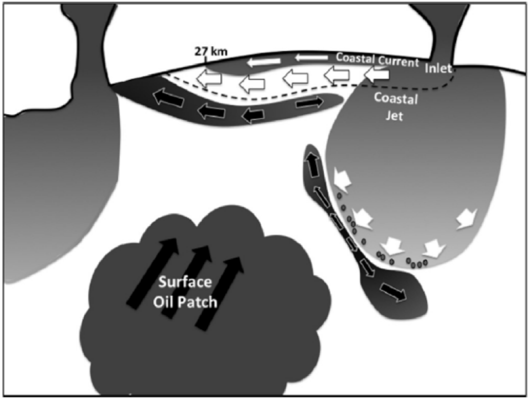


MK Roth, *et al.* (2017). "Observations of inner shelf cross-shore surface material transport adjacent to a coastal inlet in the northern Gulf of Mexico," *Continental Shelf Research*, 137, 142–153.

How does the plume geometry change in response to passing winter cold fronts and neap-to-spring variability in tides?

- **Validate** a three-dimensional, baroclinic, finite-element model for Choctawhatchee Bay
- Investigate the response of the ebb-phase plume at Destin Inlet due to:
  - **Winds –** consecutive days of near-constant tides and variable wind forcing
  - **Tides –** consecutive days of near-constant winds and neap-to-spring variability in tides

We use ADCIRC

- Represents the coastal circulation at high resolution

Solves the generalized wave continuity equation (GWCE) for water levels ζ:

$$\frac{\partial^2 \zeta}{\partial t^2} + \tau_0 \frac{\partial \zeta}{\partial t} + \frac{\partial \tilde{J}_x}{\partial x} + \frac{\partial \tilde{J}_y}{\partial y} - uH \frac{\partial \tau_0}{\partial x} - vH \frac{\partial \tau_0}{\partial y} = 0$$

Solves the shallow-water momentum equations for currents (u, v):

$$\frac{\mathrm{D}u}{\mathrm{D}t} - fu = -g \frac{\partial}{\partial x} \left[\zeta + \frac{p_s}{g \rho_0} - \alpha \eta \right] + \frac{\partial}{\partial x} \left(\frac{\tau_{zx}}{\rho_0} \right) - b_x + m_x$$

$$\frac{\mathrm{D}v}{\mathrm{D}t} + fv = -g \frac{\partial}{\partial y} \left[\zeta + \frac{p_s}{g \rho_0} - \alpha \eta \right] + \frac{\partial}{\partial y} \left(\frac{\tau_{zy}}{\rho_0} \right) - b_y + m_y$$

In horizontal directions (x, y):

- Piecewise-linear, continuous, Galerkin finite elements
  - Values for (ζ, u, v) at every mesh vertex
- Typical minimum mesh spacings of 10 to 50 m

In time:

- Semi-implicit
  - Implicit solution of GWCE using Jacobi Conjugate Gradient (JCG) solver
  - Explicit solution of momentum equations with lumped mass matrix
- Fully explicit
  - Also possible to use lumped mass matrix for solution of GWCE
- Typical time steps of 0.5 to 10 sec

The transport of salinity and temperature is represented by an advection-diffusion equation:

$$\frac{\mathrm{D}c}{\mathrm{D}t} - \mathcal{D}_h\left(c, N_h\right) - \mathcal{D}_v\left(c, N_v\right) = 0$$

in which the transport quantity c can be either salinity or temperature

- Spatial gradients lead to density differences, which drive circulation

In the vertical direction (z), the coordinates are mapped to a terrain-following, σ-coordinate:

$$\sigma = a + \frac{a+b}{H}\left(z - \zeta\right)$$

and thus there can be many vertical layers at every mesh vertex

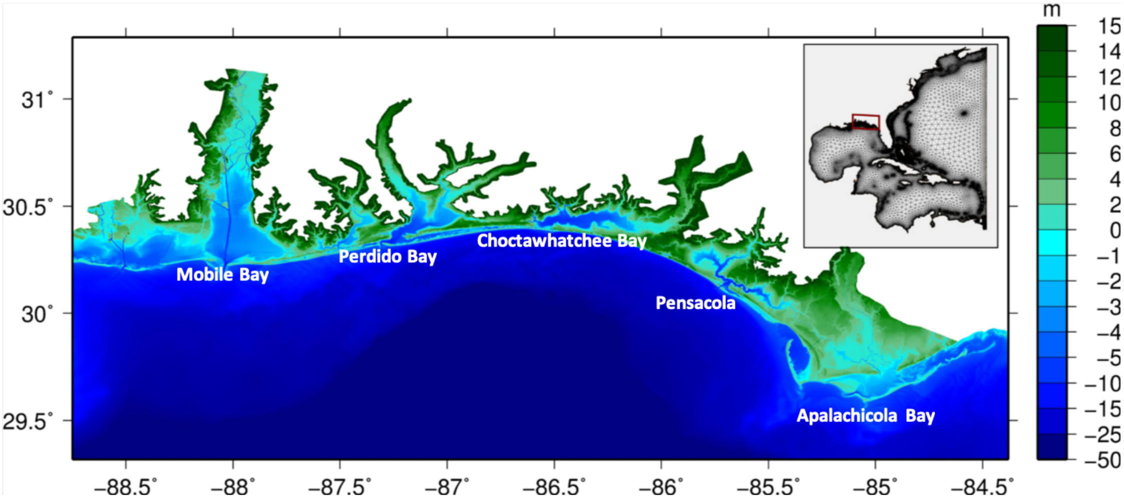
- We use 21 layers in this study

Several improvements to stability:

1. Higher-order interpolation scheme for baroclinic pressure gradient
   - Computed on horizontal z-levels (not σ layers)
   - Now using cubic interpolation onto z-levels
2. Biharmonic operator for viscosity and diffusion coefficients in momentum and transport
   - Replaces a Laplacian scheme, which is known to be overly diffusive
   - WR Holland (1978), Y Zhang, *et al.* (2008)
3. Adaptive filtering of velocity at every time step
   - Weighted average of velocity at neighbors to remove oscillations
   - R Asselin (1972), R Shapiro (1970)
4. Systematic bathymetry smoothing
   - B Barnier *et al.*, (1998), MD Sikiric *et al.*, (2009)

Unstructured Mesh for Choctawhatchee Bay

Focus on Behavior in River-Bay-Inlet-Shelf System



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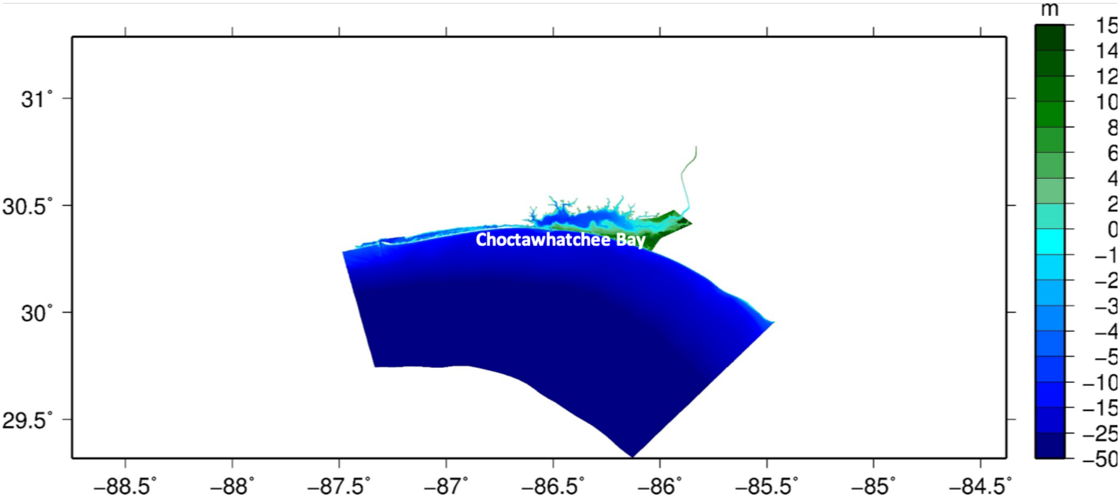

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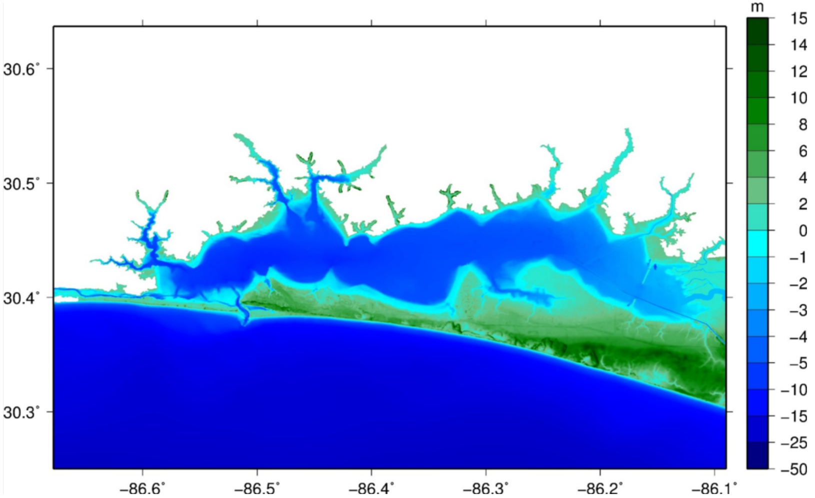
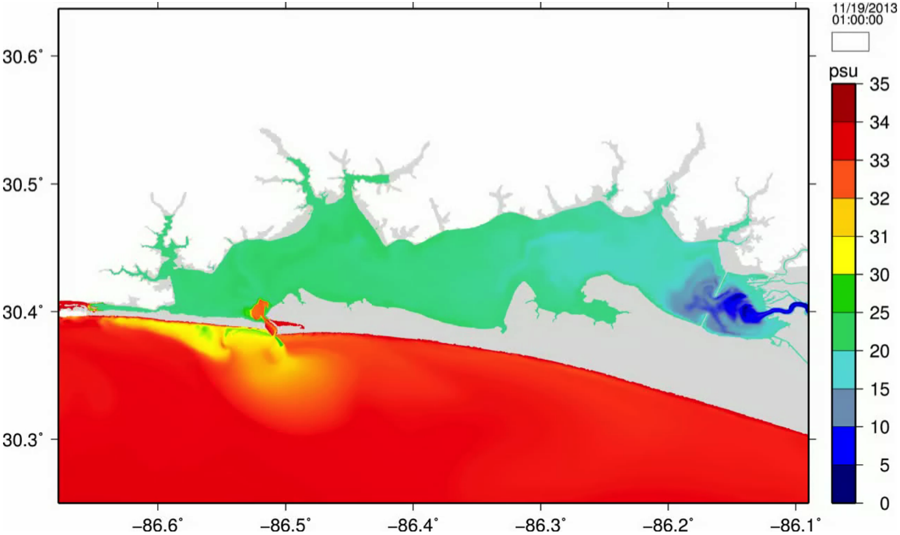


Coupling with the HYbrid Coordinate Ocean Model (HYCOM)

- NRL operates a high-resolution forecast system for the Gulf
  - Horizontal resolution of $1/25^\circ$ (about 3.5km) with 20 vertical surfaces
  - Navy Coupled Ocean Data Assimilation (NCODA)
    - Satellite altimeter observations
    - Satellite and in situ sea surface temperatures
    - In situ vertical temperature and salinity profiles
  - Model results are available for download from `hycom.org`
    - Hourly output containing temperature, salinity, 3D currents, etc.
    - Output at standard Levitus depths (so fixed vertical layers in output)
- How are we coupling with HYCOM?
  - Initial conditions – Salinities, temperatures
  - Surface boundary conditions – Heat fluxes
  - Open ocean boundary conditions – Sea surface heights, salinities temperatures

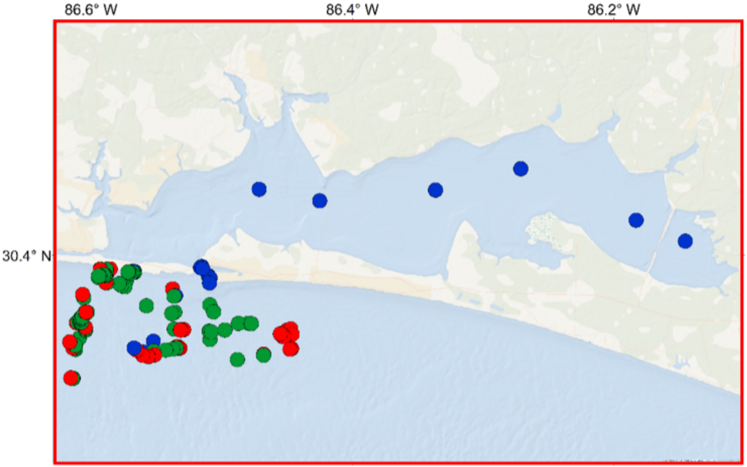
Salinity

Surface Evolution



Salinity

Vertical Profiles



Salinity

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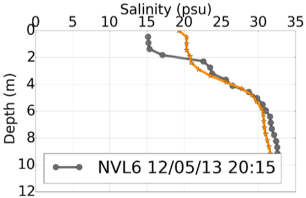

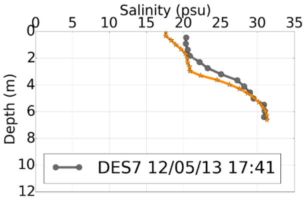

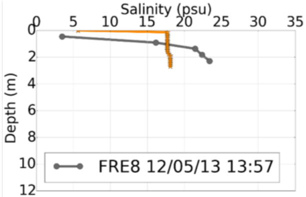

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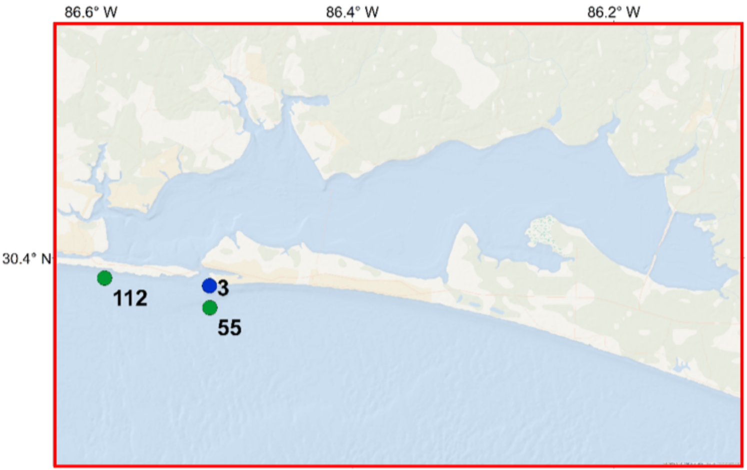

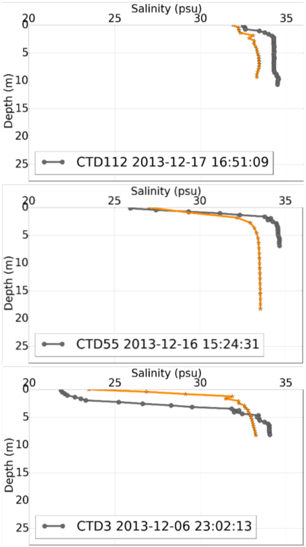

Salinity

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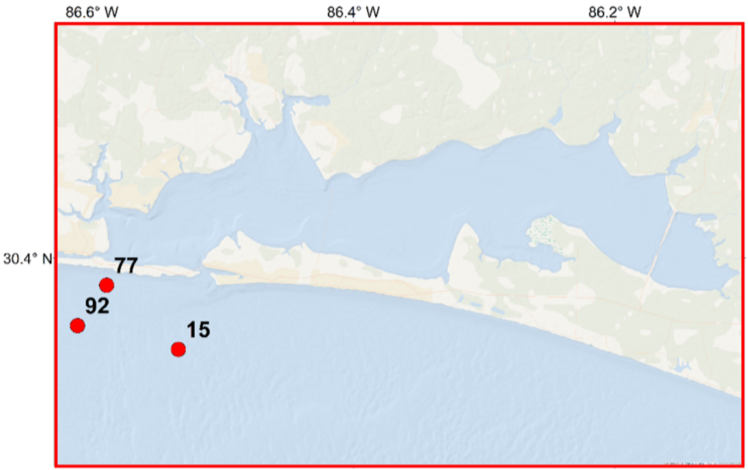
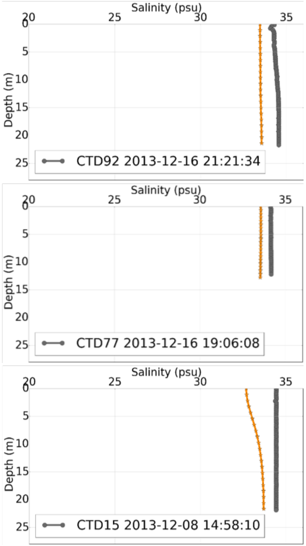
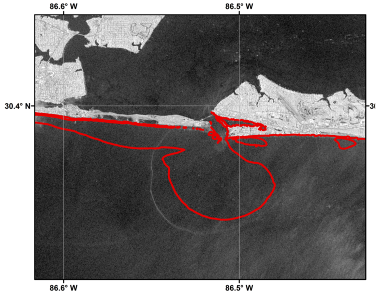




Plume

Satellite Imagery



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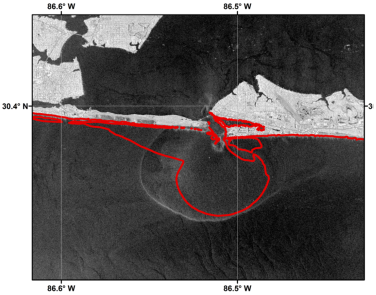

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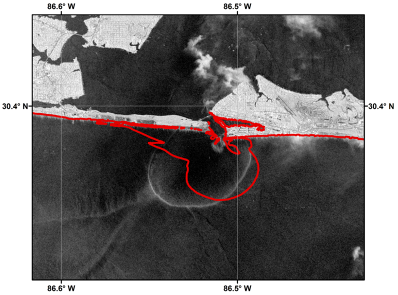

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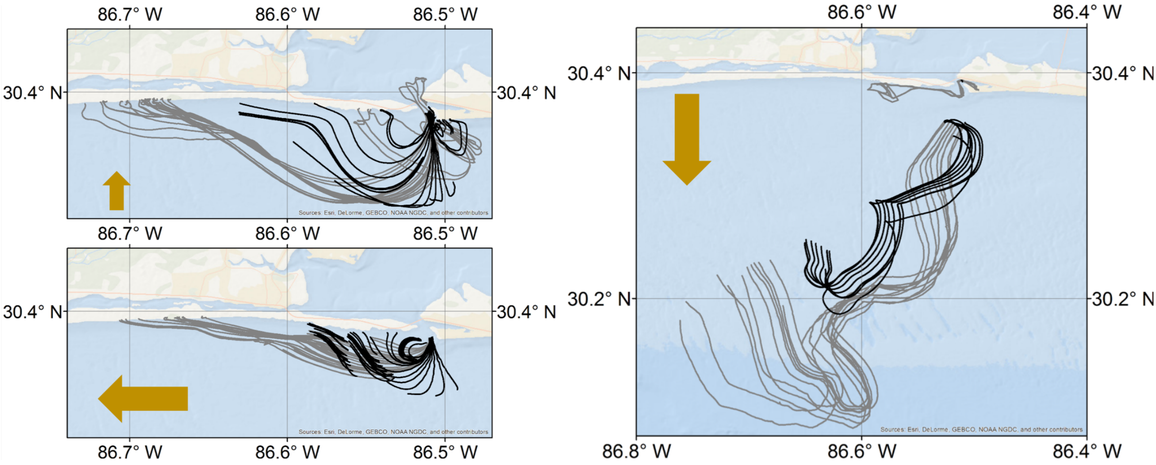
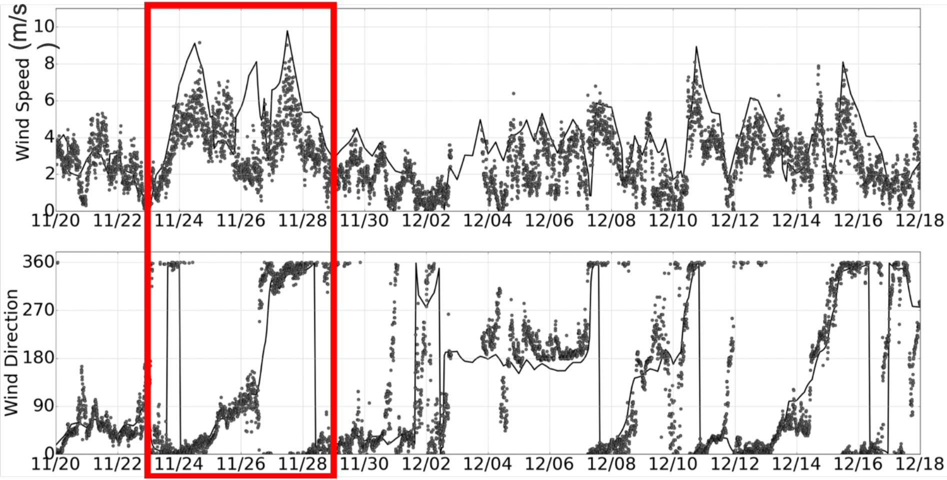
Plume

Drifter Trajectories



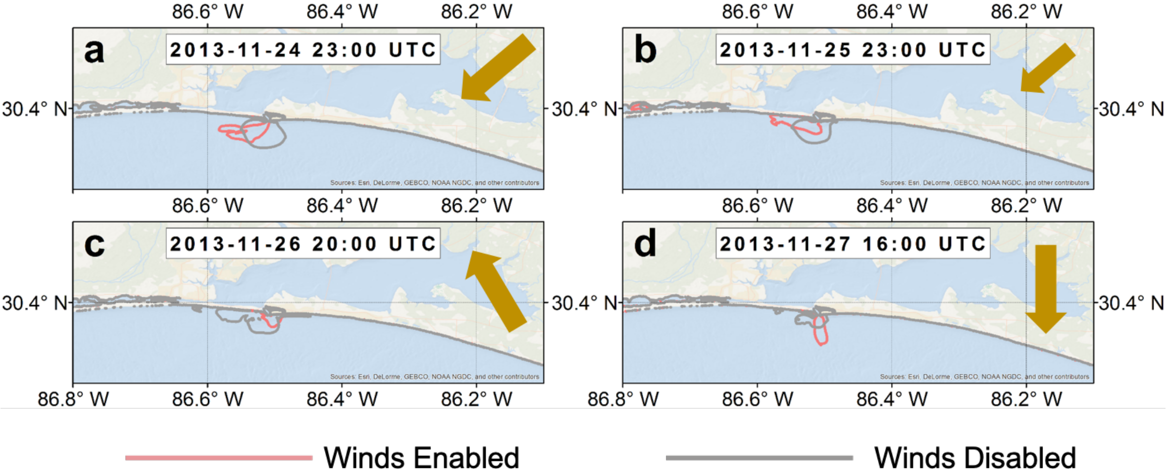
Wind Effects

Variability in Wind Directions



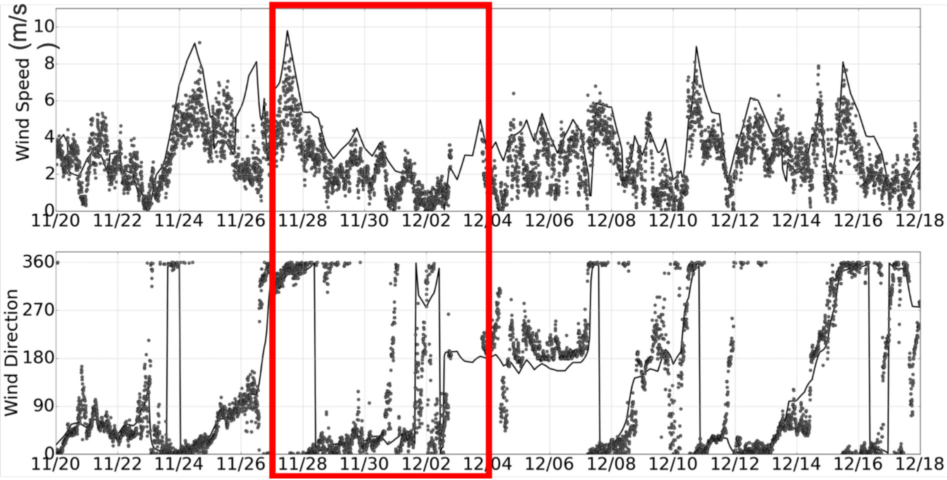
Wind Effects

Plume Response to Passing Cold Front



Tide Effects

Variability in Tidal Forcing



Tide Effects

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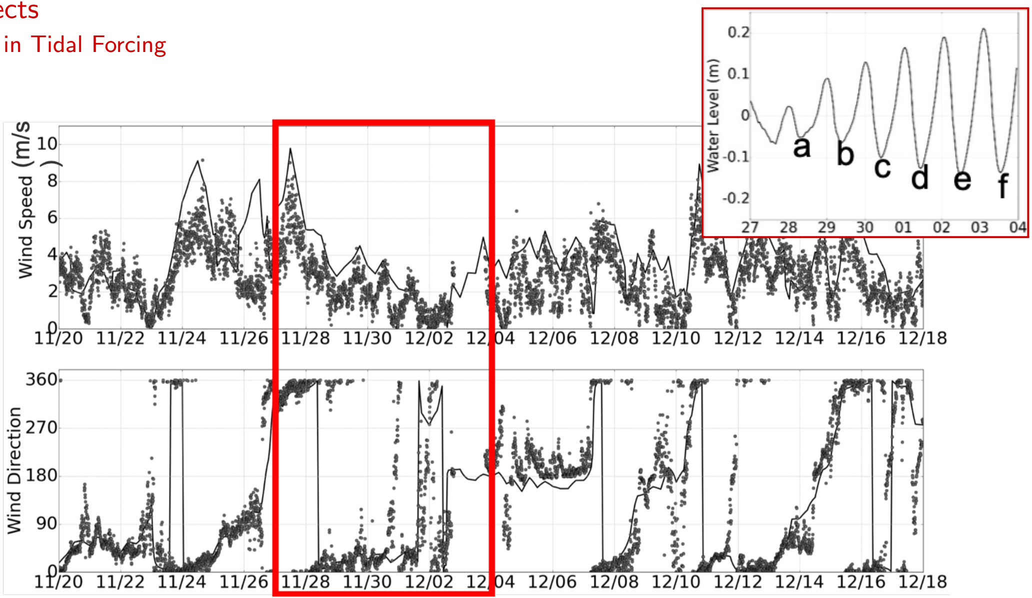
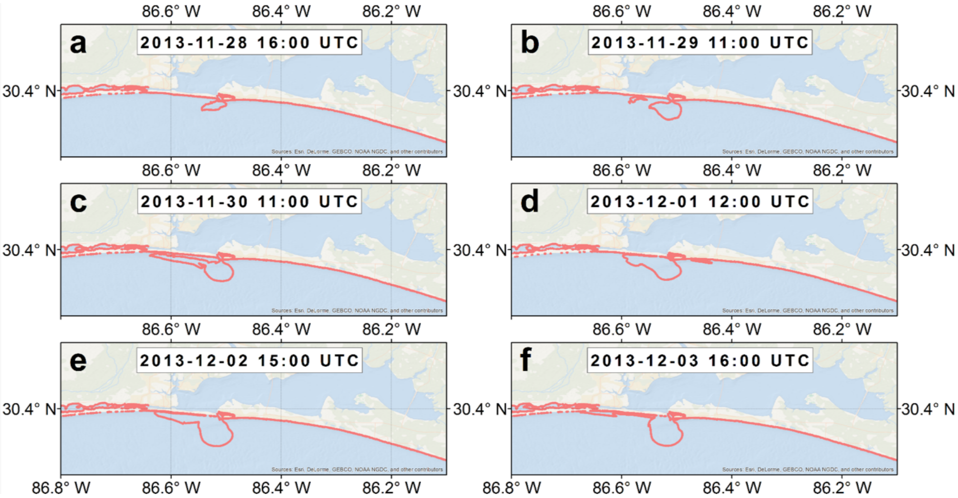


Tide Effects

Plume Response to Neap-to-Spring Tides



Summary

Wind and Tide Effects on the Choctawhatchee Bay Plume at Destin Inlet, Florida

Model development and validation:

- Baroclinic ADCIRC model applied to represent shelf-estuarine circulation
- Model validation efforts demonstrate ability to represent key features of the circulation and salinity transport

Plume dynamics:

- Plume geometry changes due to changes in wind and tidal forcing
- Northerly winds enhance offshore expansion, and vice versa
- Plume expands west along the coastline under prevailing easterly winds
- When wind forcing is disabled, the plume expands radially

Future work:

- Apply a range of different river discharges and investigate bay salinities