Exploring Fine-Scale Ocean Fronts in the Mississippi Bight Coastal Zone

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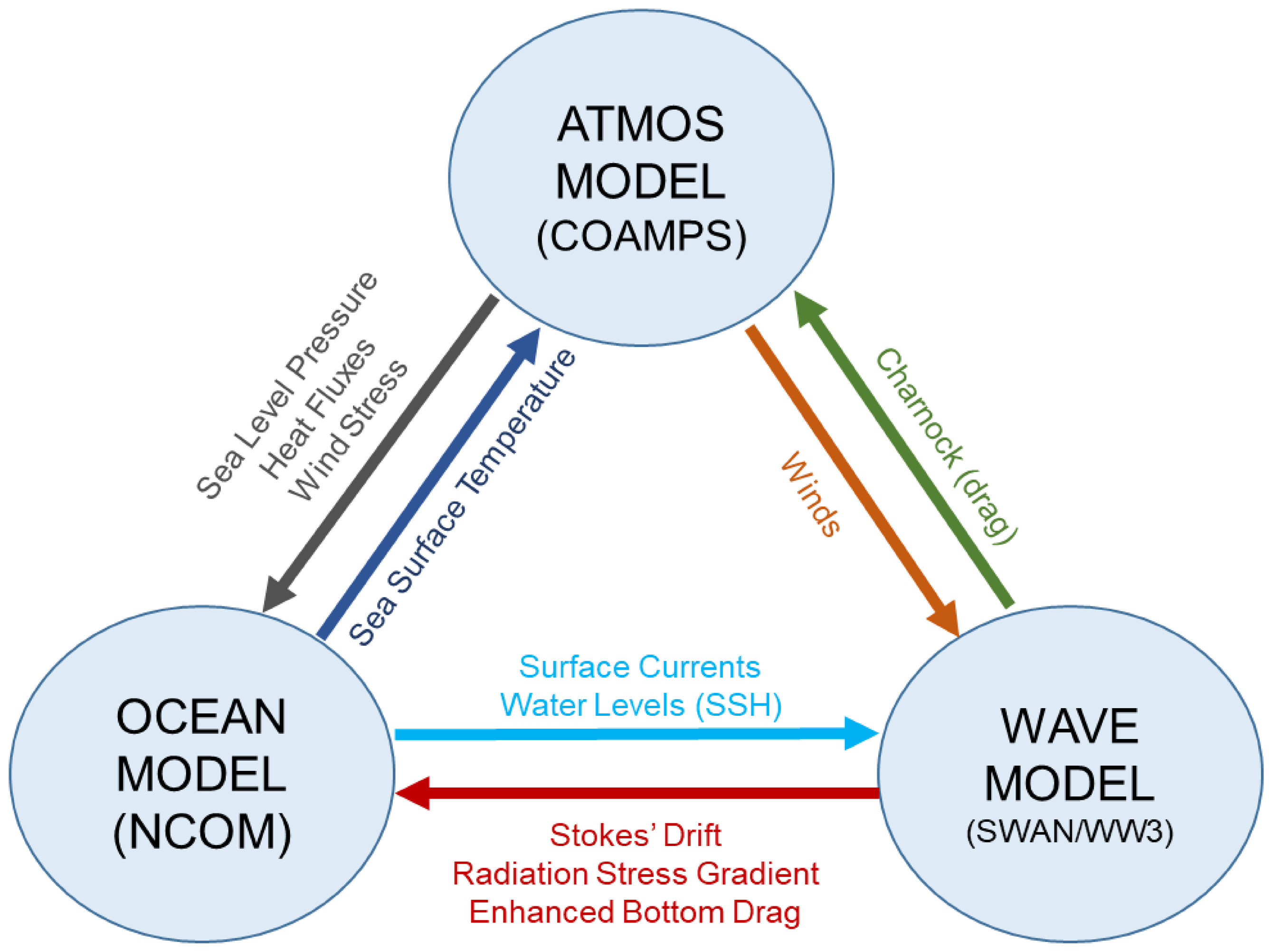
ABSTRACT

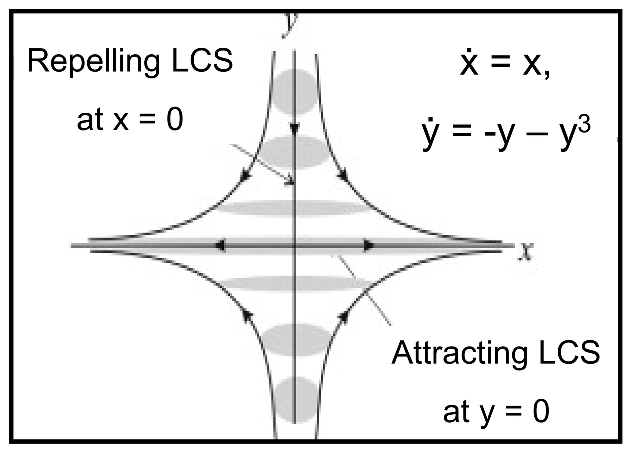
The co-occurrence, intensity, and timing of atmospheric and tidal fronts can combine to reinforce or ameliorate convergence zones near the ocean surface. Thus, atmospheric and tidal fronts further complicate an already complex coastal dynamical and biological/optical picture, although the intensity, extent, and duration of the bio-optical and dynamic alterations they impart are poorly known. Lagrangian Coherent Structures (LCS) calculated from model current fields represent a new way of understanding transport in complex fluid flows, and they are a way of identifying organizing structures in the flow. Although LCS have been used to identify flow features at basin-to-regional scales, few studies have extended LCS studies into coastal regions using the ocean current fields from high-resolution hydrodynamic models, and there has been little work to determine how stable these structures are in coastal zones.

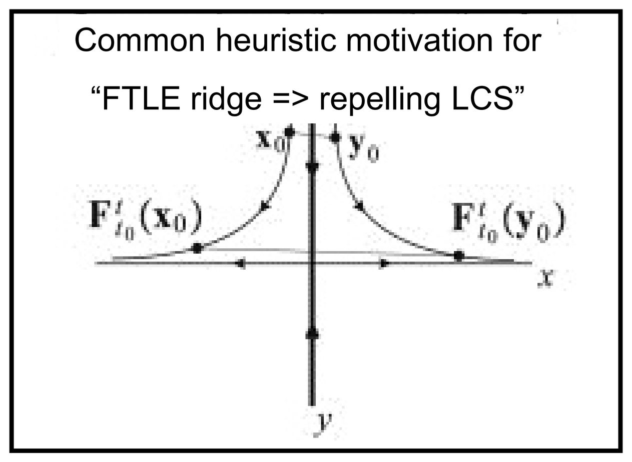
The Naval Research Laboratory has recently extended their mesoscale ocean modeling to include high-resolution coastal zone modeling to address such issues. This study utilizes the COAMPS (Coupled Ocean-Atmosphere Mesoscale Prediction System) coupled atmosphere/ocean model to explore LCS in the Mississippi Bight. The model setup consists of a triple-nested atmospheric domain with 18, 6, and 2 km horizontal resolution. The 2 km atmospheric nest provides two-way coupled atmospheric forcing to both Navy Coastal Ocean Model (NCOM) 2 km, 125 m, and 50 m resolution nested ocean model grids with the latter, very high resolution grid, focusing on the formation of LCS (such as fronts) between Ship and Horn Island just offshore the Mississippi coast.



COAMPS passes variables from one model to the other through the Earth System Modeling Framework. The graphic above depicts the variables being passed to and from each individual model in COAMPS.

Lagrangian Coherent Structures (LCS)





The ocean dynamical equation is given by $\frac{d\mathbf{x}}{dt} = \mathbf{v}(x, y, t)$.

If we follow a particle, integration will provide a flow map, $F(t_0, t)$, such that $\mathbf{x}(t) = F(t_0, t)\mathbf{x}(t_0)$.

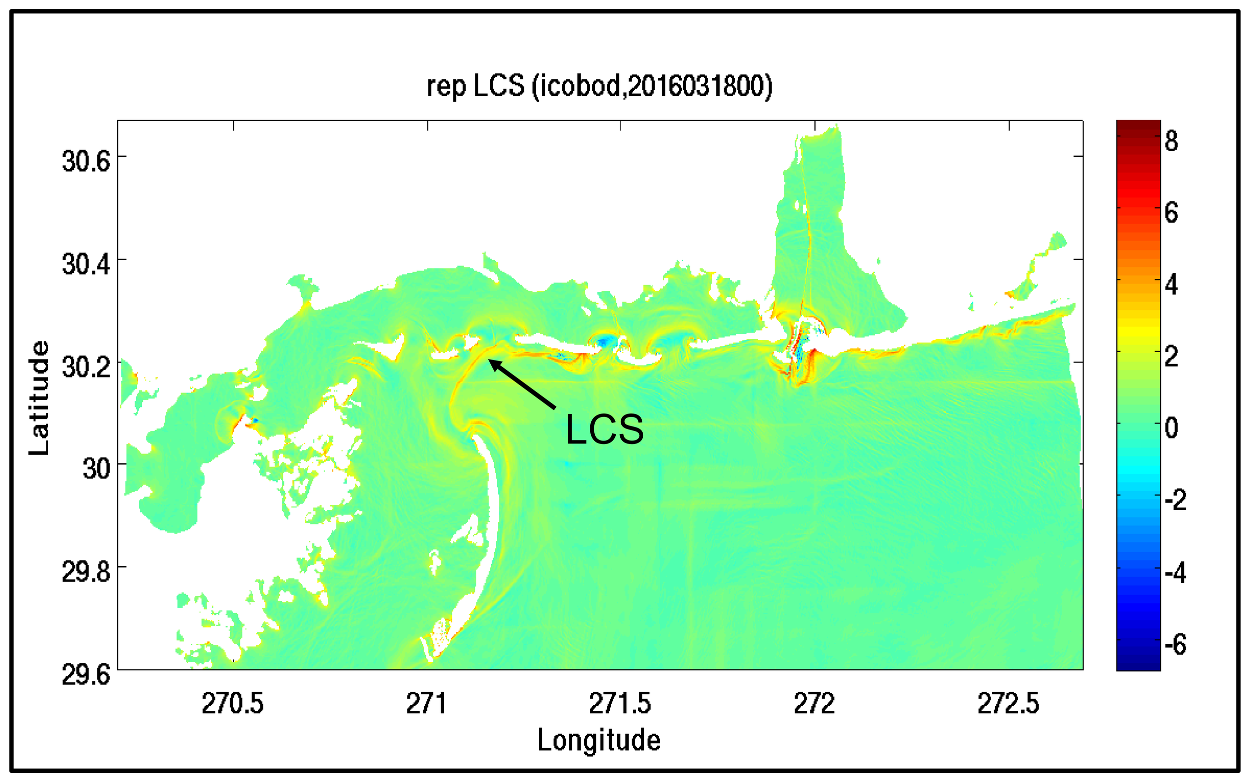
The right Cauchy-Green deformation tensor matrix can be constructed as

$$C = \left(\frac{dF}{d\mathbf{x}}\right)^T \left(\frac{dF}{d\mathbf{x}}\right).$$

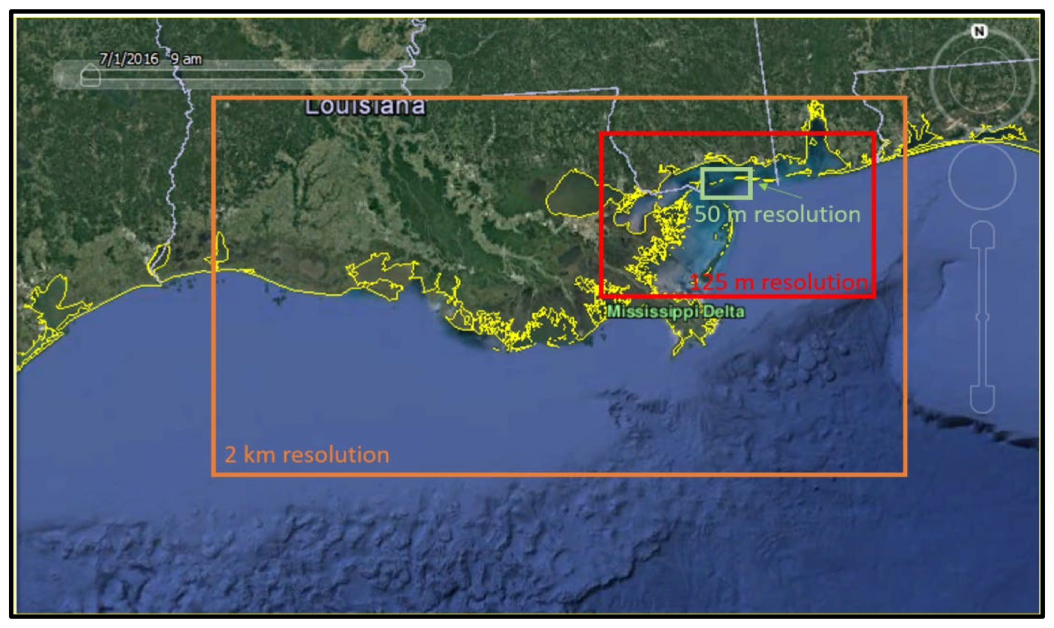
The largest FTLE (finite-time Lyapunov exponent) associated with the trajectory over this time interval is

$$\sigma(\mathbf{x}_0, t_0, \mathbf{x}, t) = \frac{1}{|t - t_0|} \log \sqrt{\lambda_{max}(C)}$$

where $\lambda_{max}(C)$ is the largest eigenvalue of C. The FTLE is the time-averaged maximum exponential stretching about the trajectory. The ridges of the largest FTLE represent the LCS. C is the right Cauchy-Green deformation tensor from the flow map. Forward integration of a set of trajectories generates the repelling LCS at the initial time, while backward integration in time produces the attracting LCS at later time.

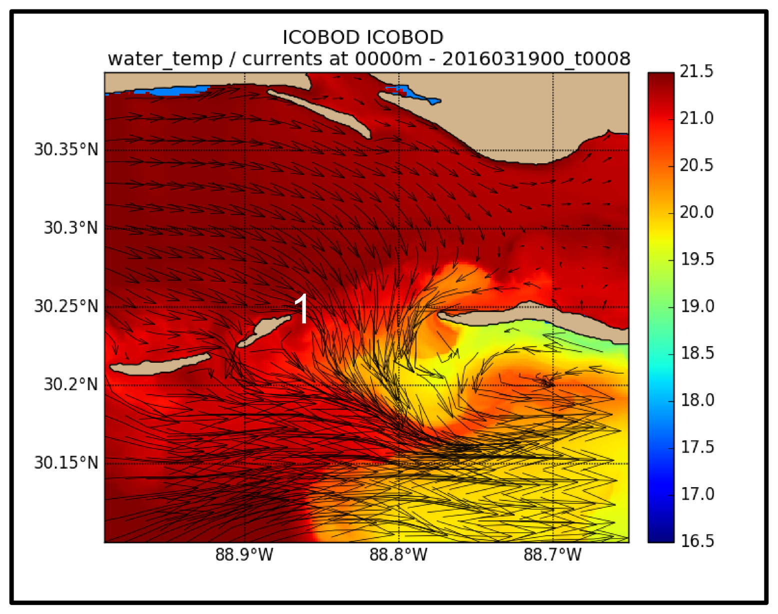


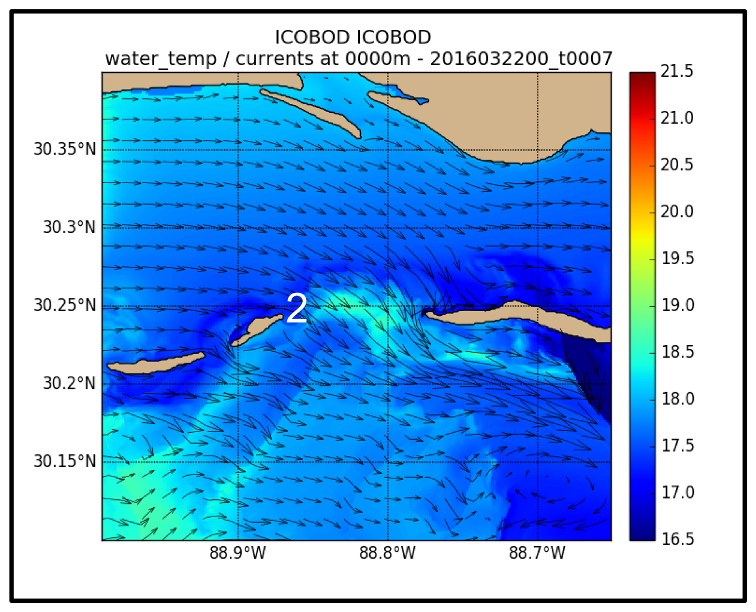
Calculations of the surface FTLE show areas in which Lagrangian Coherent Structures in the ocean flow may exist. Red and orange colors represent larger values of repelling LCS structures.

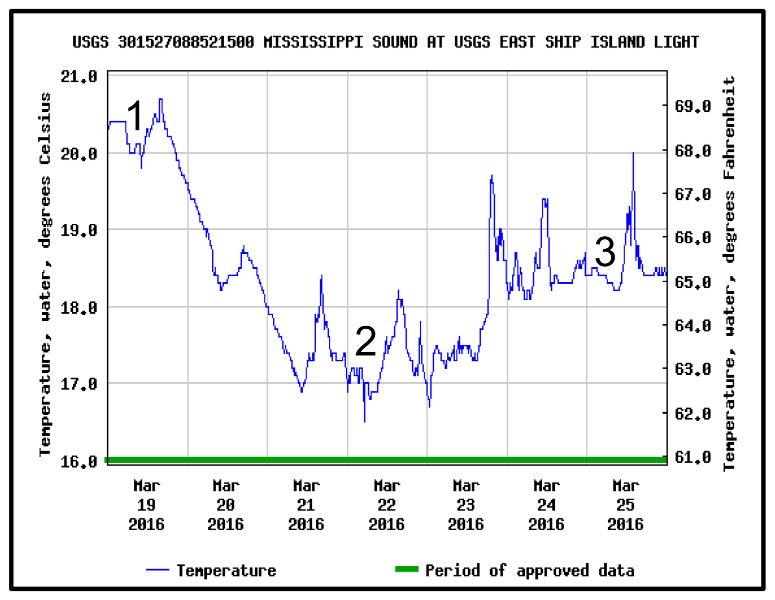


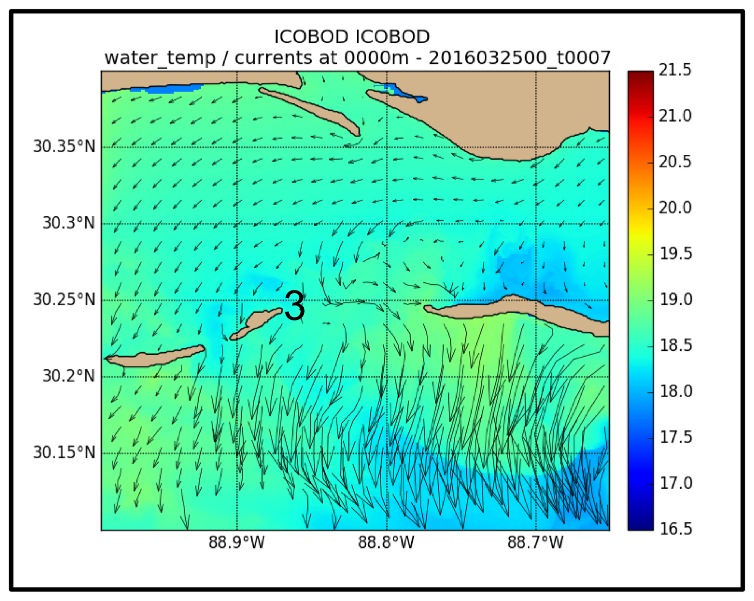
COAMPS ocean model nests (NCOM) at 2 km, 125 m, and 50 m resolution for the Mississippi Bight.

High-Resolution COAMPS Modeling (50 m)

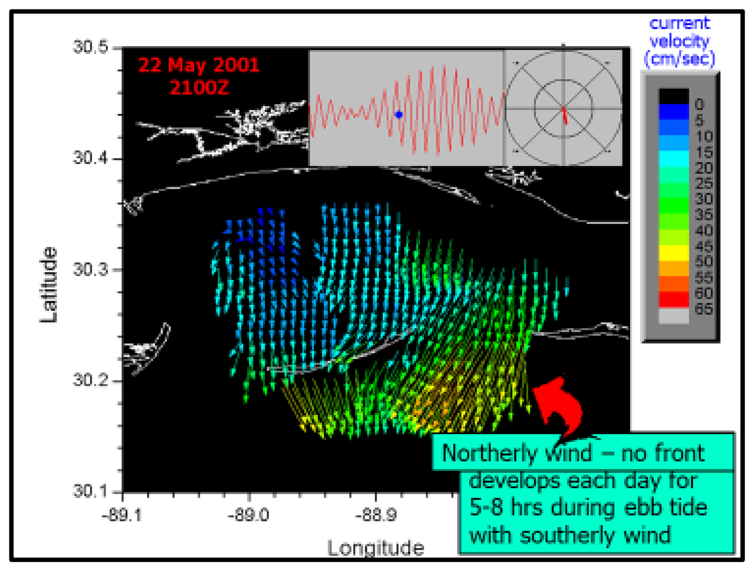


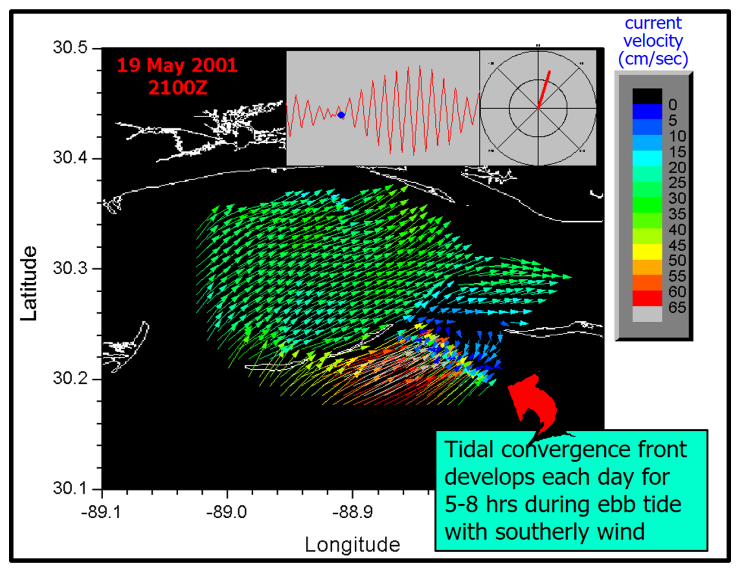


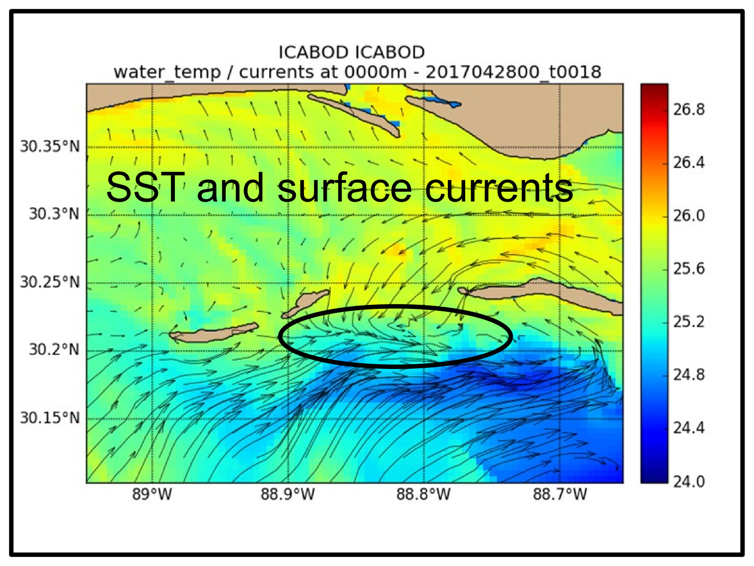


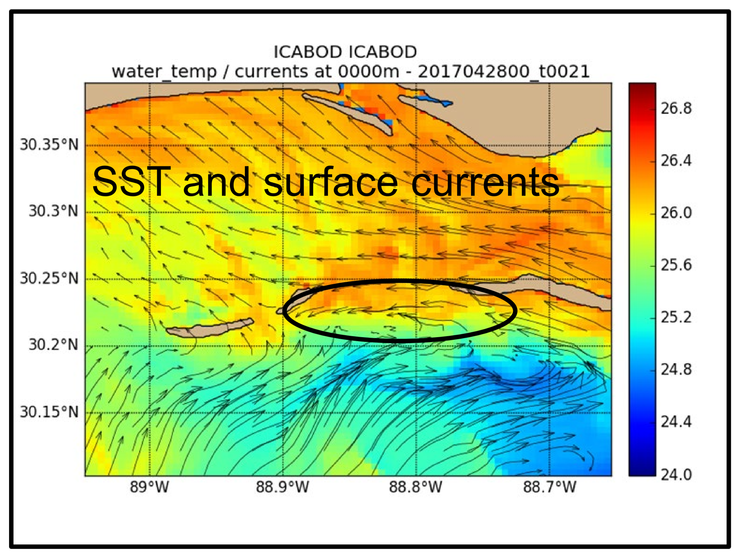


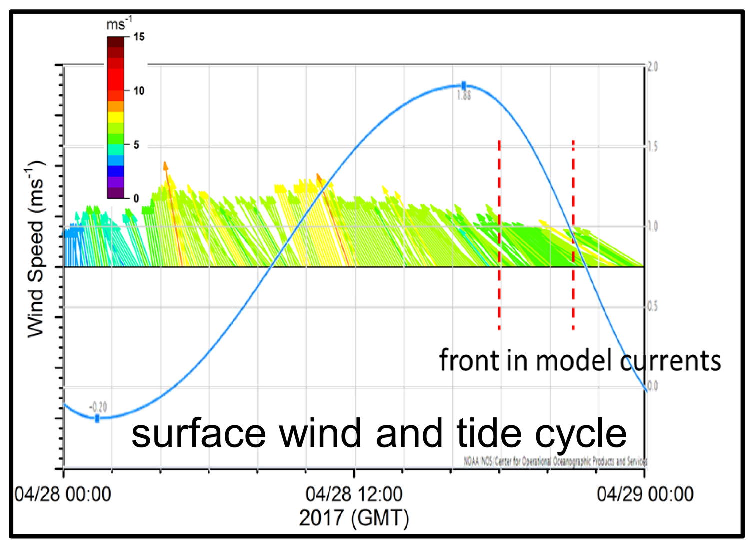
Validation of the 50 m resolution NCOM nest shows excellent agreement in the sea surface temperatures (SST) during the period 19-25 March 2016. SST observations were observed just offshore of east Ship Island (offshore of the Mississippi Coast). The nested ocean model correctly shows the fluctuation of SST during the period. For comparison, the corresponding numbers on each SST model plot are indicated on the SST time series to show the progression of SST during the period.



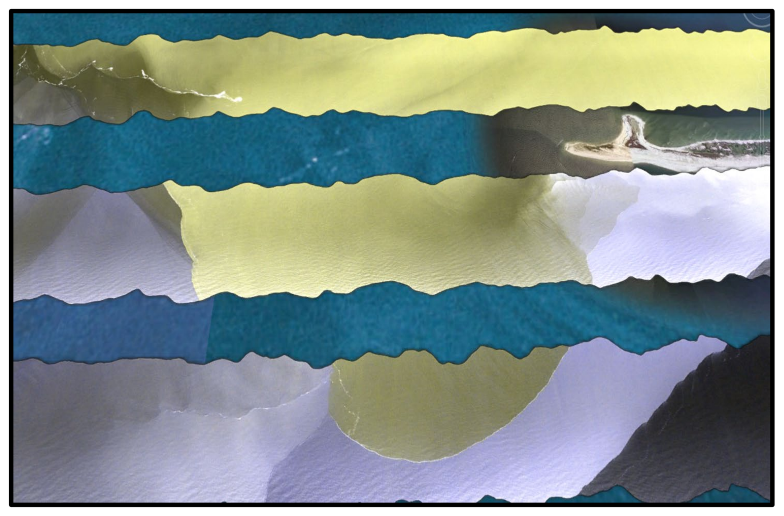


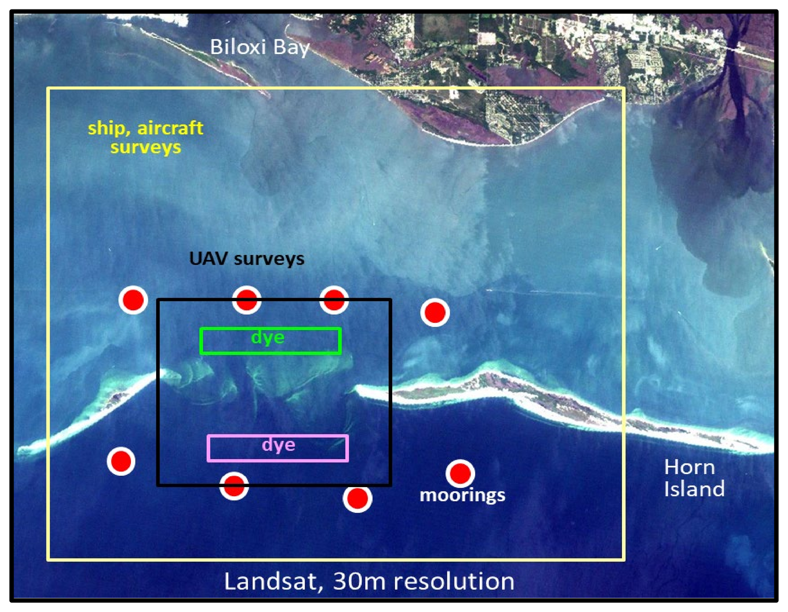






COAMPS 50 m resolution modeling (two figures above) indicates the development of a surface frontal boundary (circled) during ebb tide and within a period of southerly wind flow (figure to the left) on 28 April 2017. These fronts do not typically develop during a period of northerly wind flow. High-resolution modeling will further our understanding of the development of these mesoscale fronts and determine other acoustical, biological, and thermodynamic properties of these structures.





Thermal and optical imagery (above left) taken in March 2016 clearly show the development of a distinct frontal boundary within the Mississippi Bight. The yellow color indicates differing thermal properties when compared to the surrounding waters. A ship-release dye experiment (left) from the R/V Wilson (above) is set to occur in March and April 2018 to detect and record the development and dissipation of an ocean frontal boundary between Ship and Horn Island offshore the Mississippi Coast. This observational data will aid in modeling these frontal boundaries in a high-resolution coastal model.

DISCUSSION

High-resolution modeling of the Mississippi Bight has allowed for further research and examination of the development of mesoscale frontal boundaries in the northern Gulf of Mexico. Such high-resolution modeling is necessary to diagnose the development of Lagrangian Coherent Structures (LCS) which can alter physical, acoustical, and biological processes over short periods of time. The field work to take place in March and April 2018 will further enhance our knowledge of these frontal boundary structures, and lead to better understanding of these structures in the coastal zone.

ACKNOWLEDGEMENTS

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