

Modeling Biscayne Bay Circulation and Microplastic Fate and Transport: Applications for Improving Canal Conditions

Principal Investigators:

Henry Briceño (FIU), Piero Gardinali (FIU), and Reinaldo Garcia (Hydronia)

Motivation

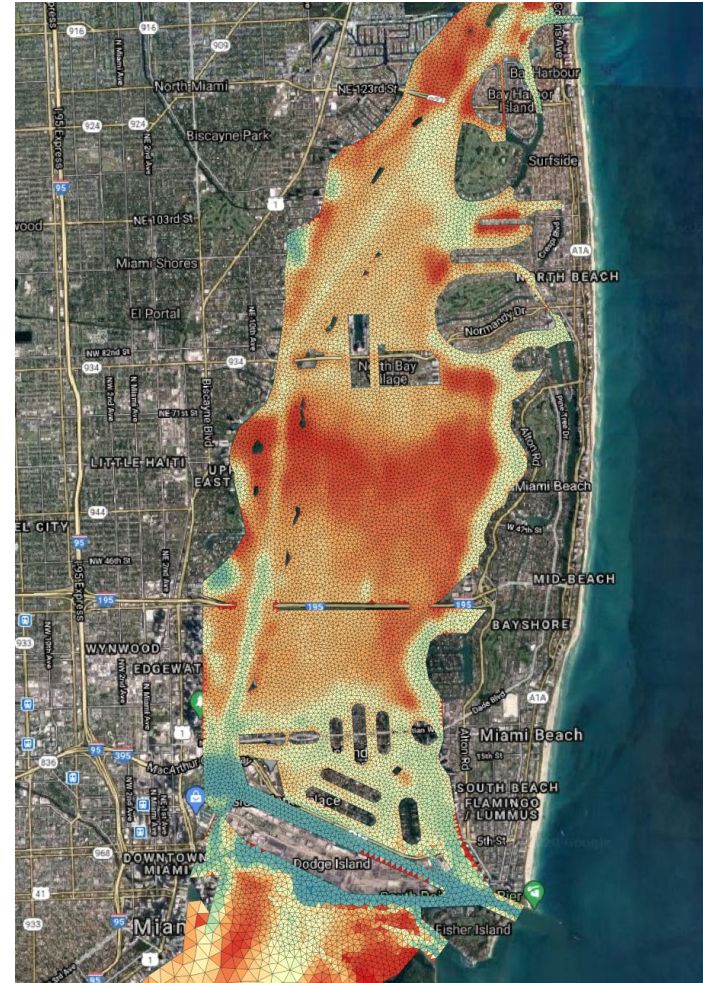
- An estimated 4.8–12.7 million tons of mismanaged plastics have entered the oceans from 192 coastal countries (Jambeck et al., 2015).
- 60–80% of the total marine debris (Derraik, 2002).
- Entanglement in plastic debris poses a major threat to marine wildlife (e.g., Duncan et al., 2017).
- Microplastics (≤ 5 mm) behave as a toxic chemical transport vector.

Hinata et al. *Marine Pollution Bulletin* 152 (2020)



Numerical Model

- RiverFlow2D [Hydronia]
- Shallow water equations in 2D [depth integrated]
 - Flexible mesh
 - GPU parallelization (1000x acceleration)
 - Graphical User Interface
- Components
 - Wind
 - Hydraulic structures
 - Rainfall/Infiltration
- Modules
 - Water Quality
 - Sediment transport
 - Oil Spills on land and water
 - Urban Drainage (SWMM)
 - Plastic Transport



BBOM: Biscayne Bay Operational Model

EPA Funded Project (2019-2023)

A collaborative project between University, Government, and Private Sector.

- Institute of Environment, FIU
- DERM
- Hydronia

BBLAST: Biscayne Bay Plastic Transport Model

EPA Funded Project (2023-2025)

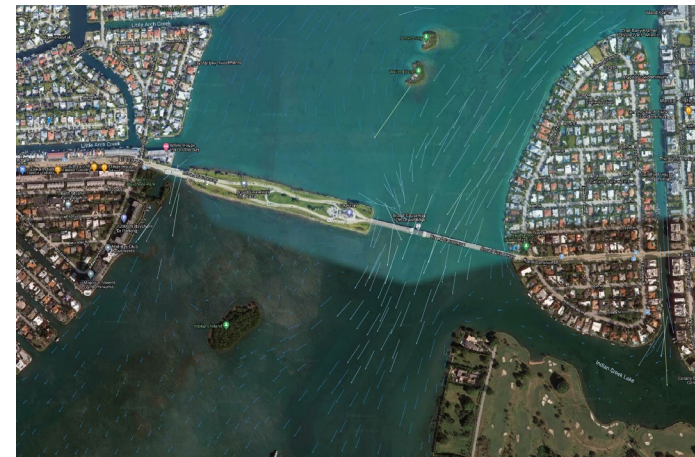
A collaborative project between University, Government, and Private Sector.

- Institute of Environment, FIU
- DERM
- Hydronia
- NBC/Telemundo

BBOM Objectives

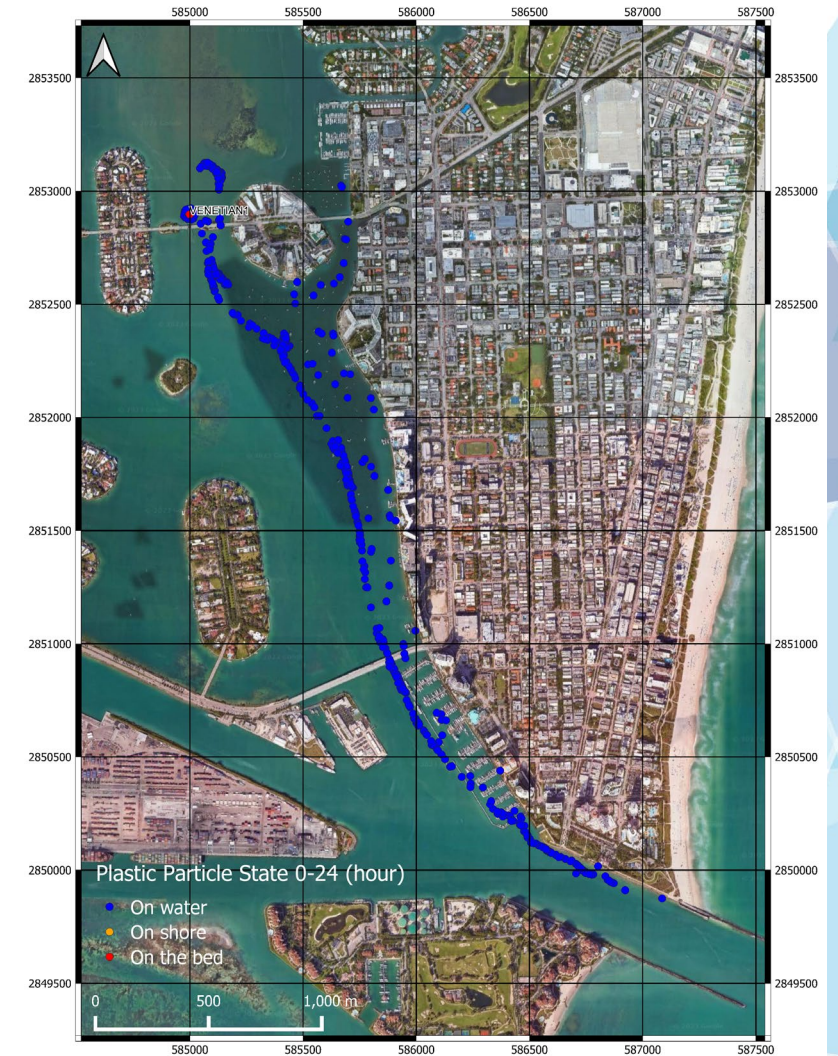
Development of an operational hydrodynamic, sediment transport and water quality model for Biscayne Bay

- Model implementation, calibration and validation
- Measure currents and water quality throughout the bay
- Apply BBOM to optimize monitoring locations
- Bay-wide Assessment of Environmental Status
- Model Requirements
 - Fast to meet operational goals → 2D
 - Flexible mesh
 - Customizable
 - Open use for Agencies, NGO, etc.



BBLAST Objectives

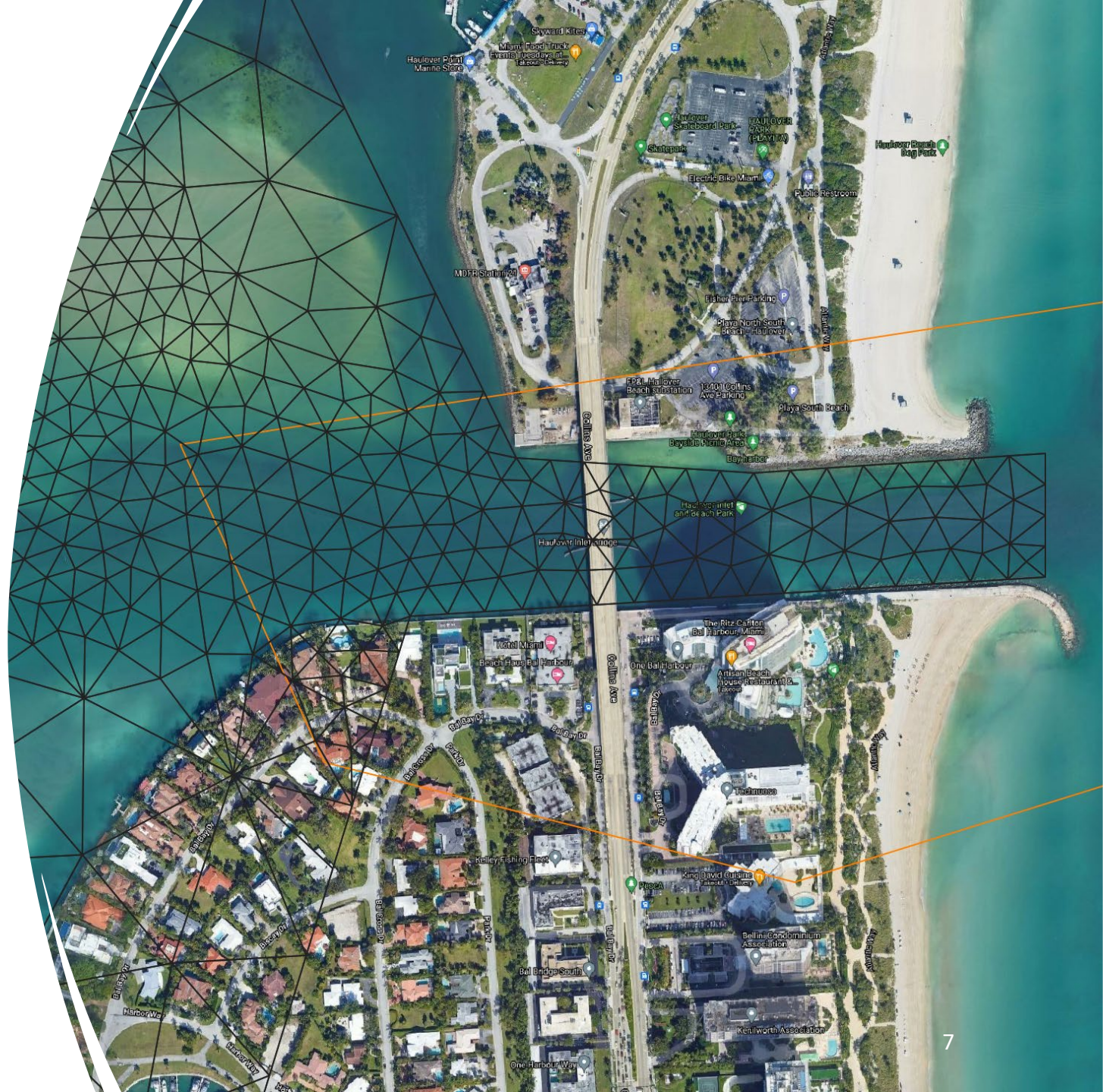
- Enhance the Biscayne Bay Operational Model (BBOM) with a specialized module for simulating the transport and fate of plastics.
- Predict the movement and dispersion of plastics within Biscayne Bay
- Inform local communities and decision-makers on the implications of plastic pollution.



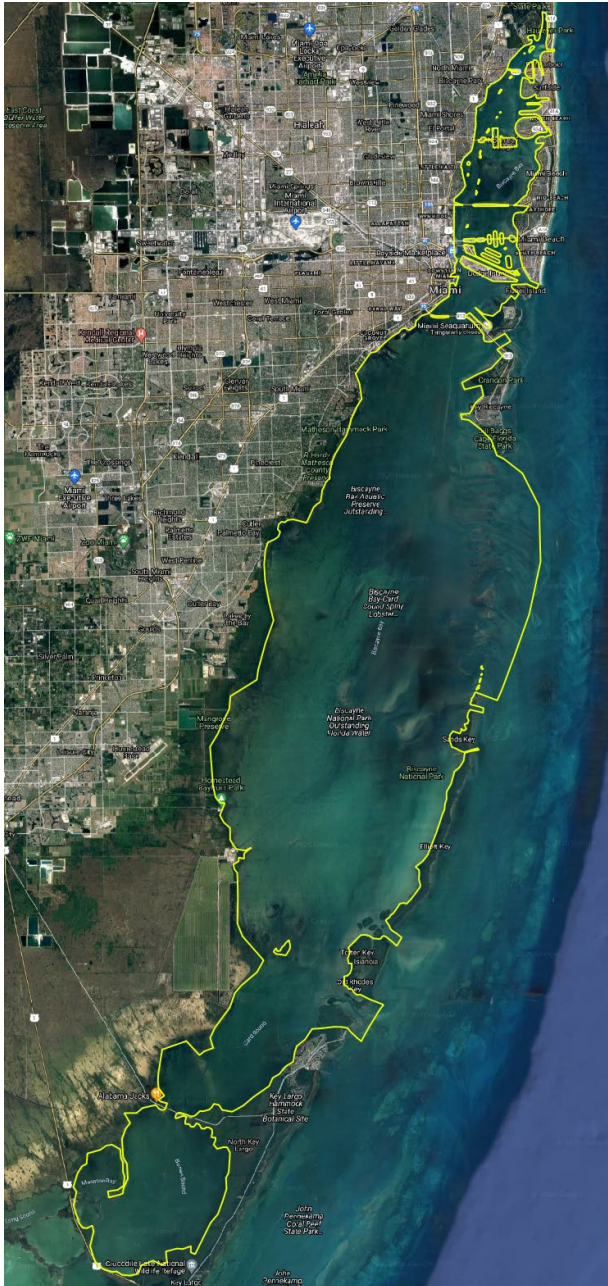
BBOM Implementation

Bathymetric data

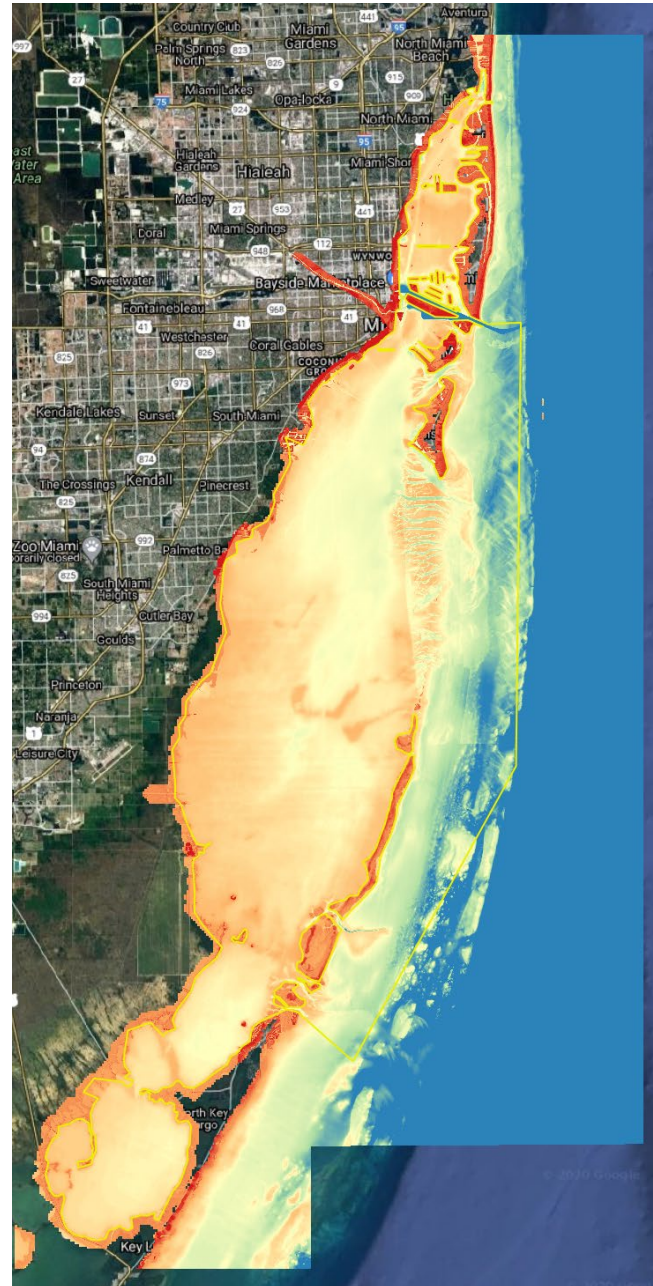
- NOAA Continuously Updated Digital Elevation Model (CUDEM)
—
1/9 Arc-Second Resolution
Bathymetric-Topographic Tiles.
- Updated on 2019-09-03 (BBOM),
2022-03-15 (BBLAST).
- 0.5-3 m resolution.



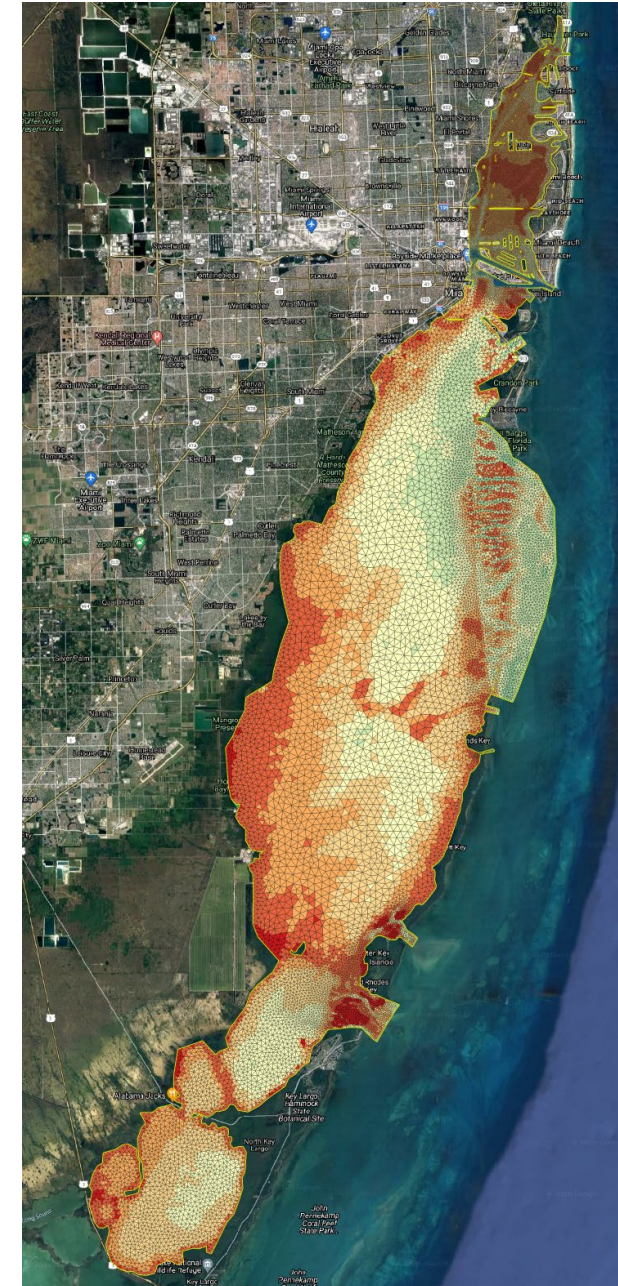
Model area



Topo-bathymetry



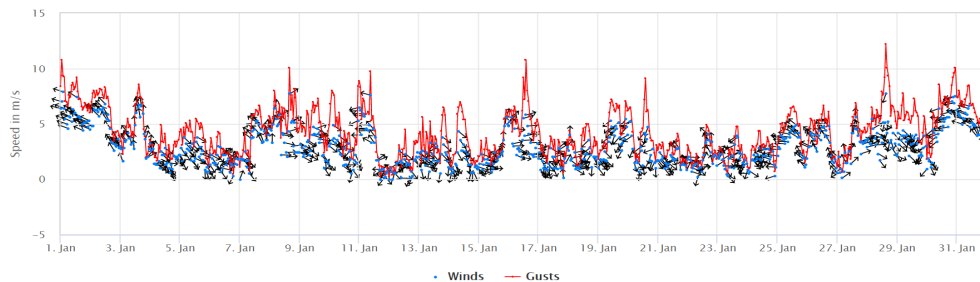
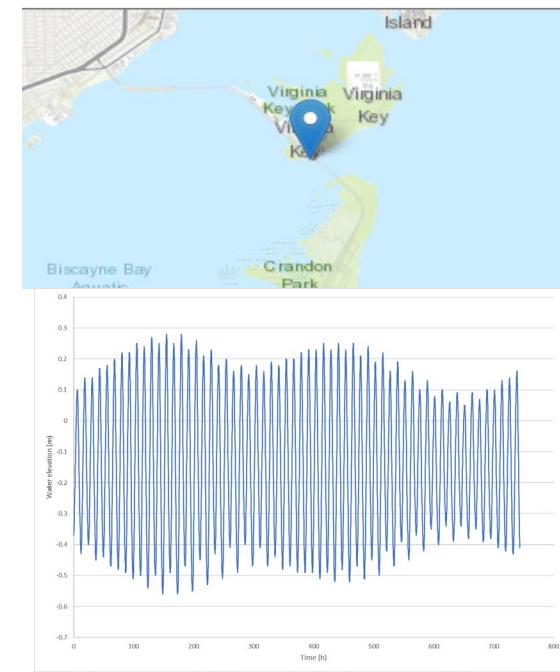
Model mesh



BBOM Implementation

Tides

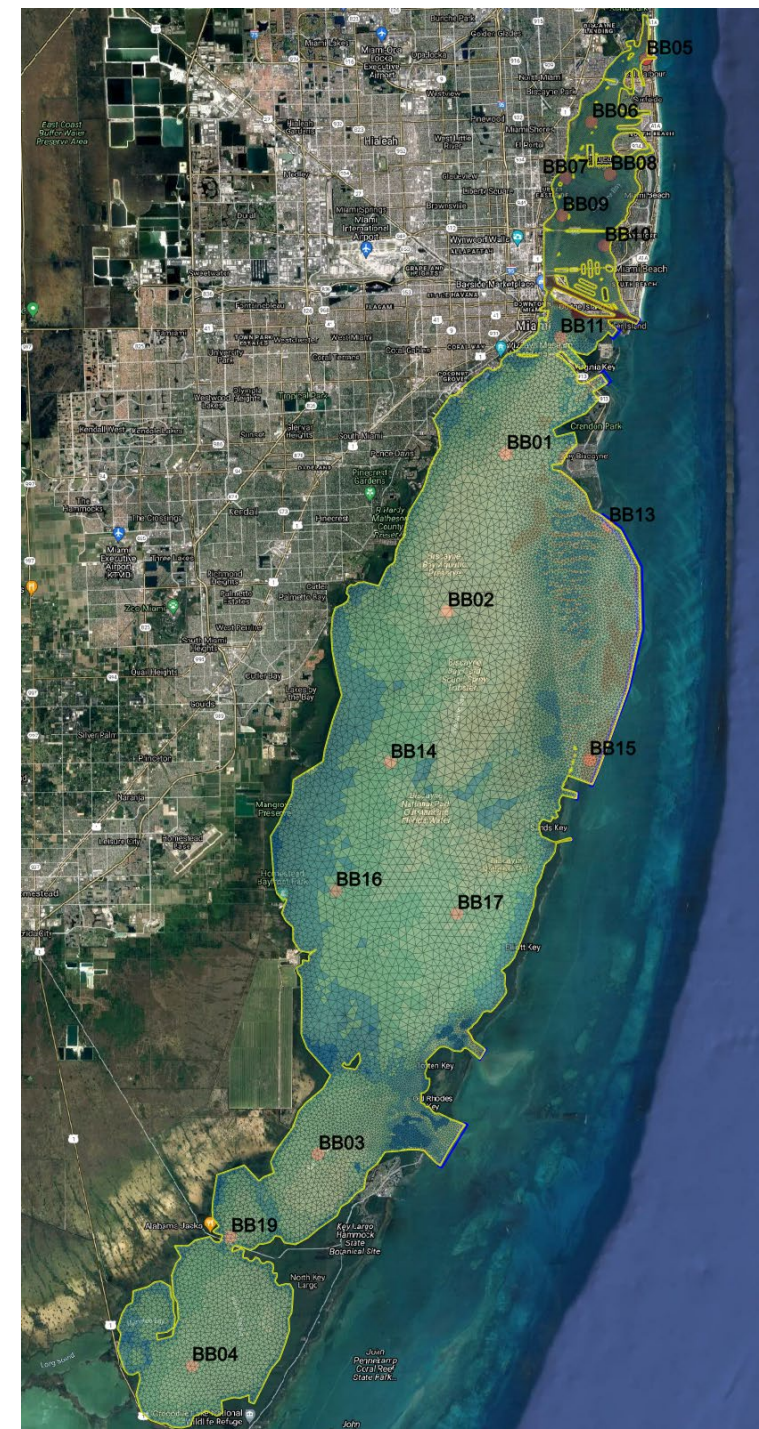
- NOAA Virginia Key station (Station id: 8723214).
- Established on 01/26/1995
- 25° 43.9' N, 80° 9.7' W
- <https://tidesandcurrents.noaa.gov/stationhome.html?id=8723214>
- Measured water elevations at BB05, BB12, and BB13 stations from 1/12/2021 and 1/19/2021.
- Wind speed at NOAA Virginia Key station 8723214 from 1/01/2021 to 1/31/2021. Source: NOAA/NOS/Center for Operational Oceanographic Products and Services.



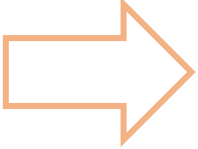
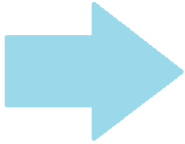
BBOM Implementation

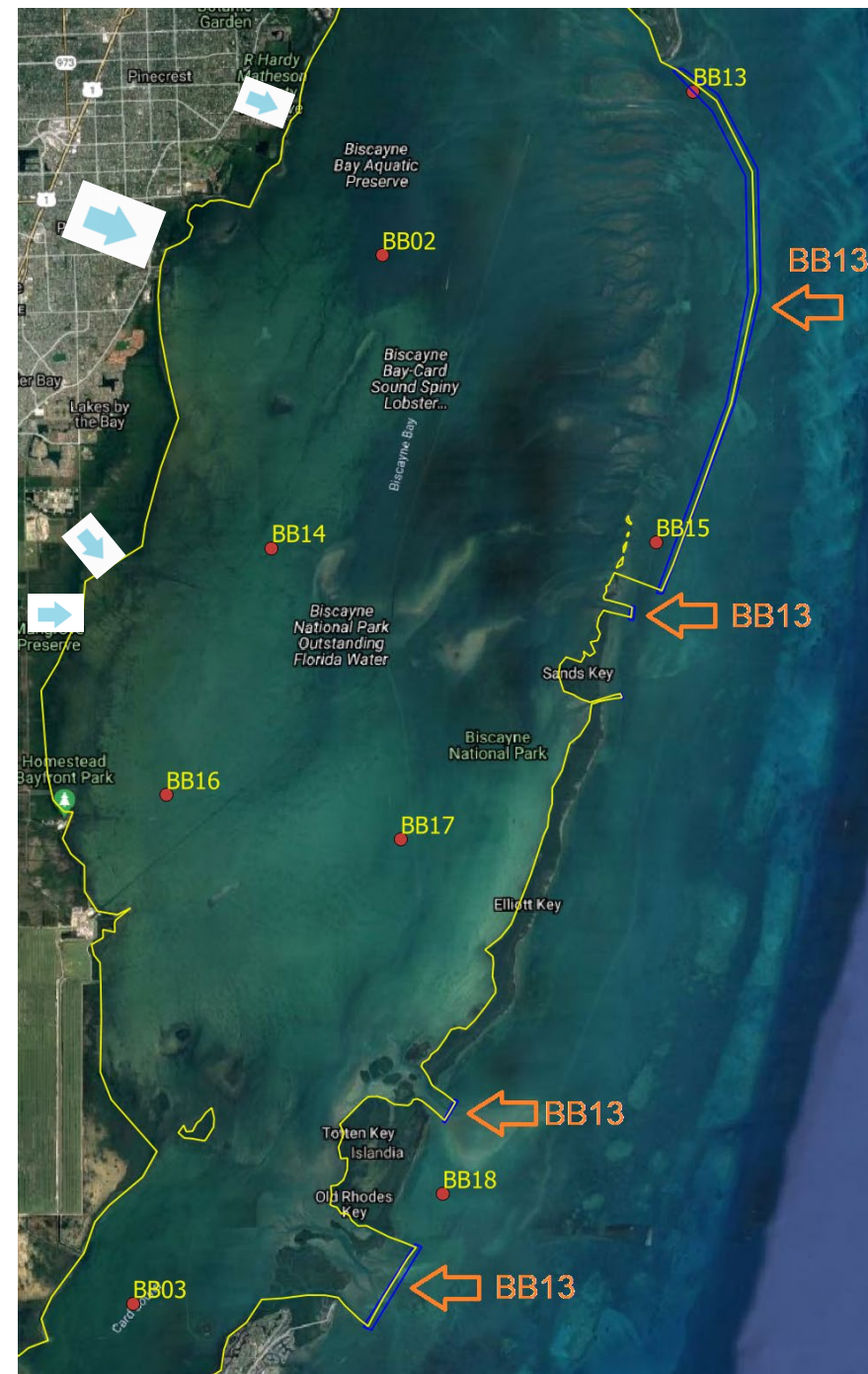
FIU Monitoring Campaigns to collect data for BOM calibration and validation

No.	Measurement campaign time period	
	Start	End
1	2017-10-10	2017-10-17
2	2018-06-20	2018-06-28
3	2019-04-01	2019-04-16
4	2019-10-29	2019-11-13
5	2020-08-19	2020-10-14
6	2021-01-07	2021-01-19



Boundary Conditions

- Tide: WSEL vs time 
- Flowrate Q vs time 
- Flow can enter or leave the mesh through the tidal open boundaries



- Independent data set provided by the South Florida Water Management District (SFWMD).
- Validation period: One year
 - January 2019 and December 2019.
- Depths and salinities collected at 41 stations.



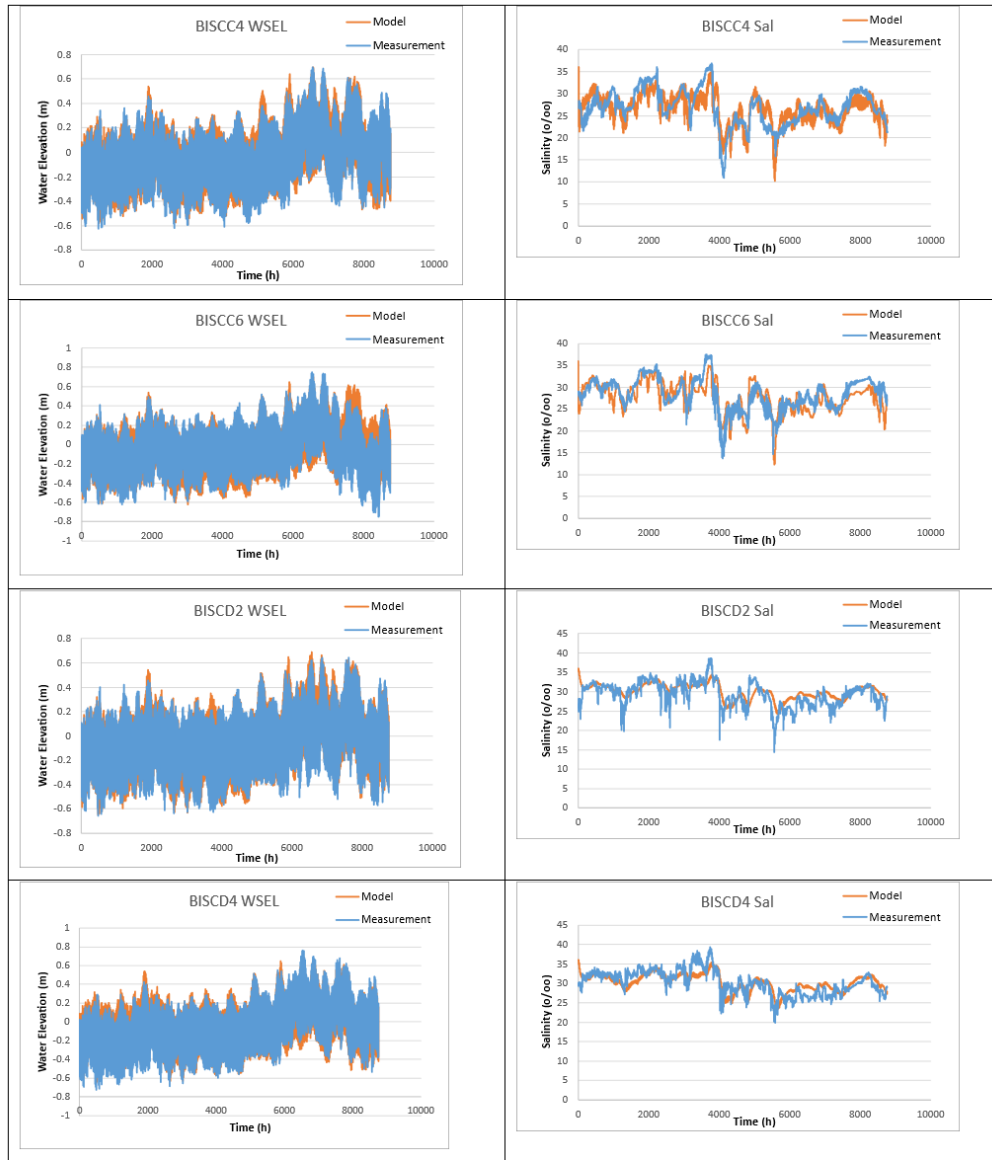


Figure 137 Water Surface elevations and salinities for stations BISCC4, BISCC6, BISCD2, and BISCD4. Comparison of model against measurements.

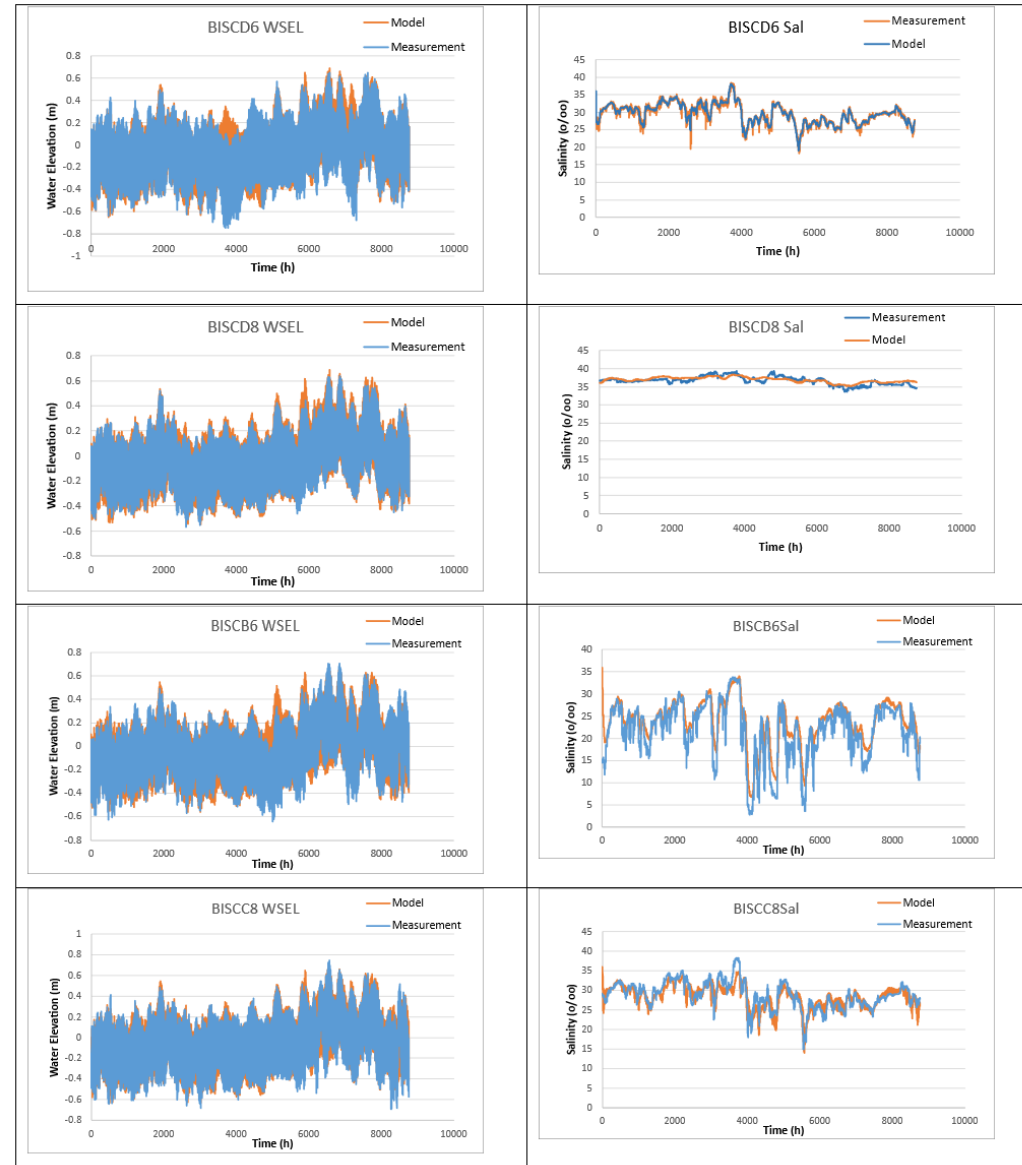
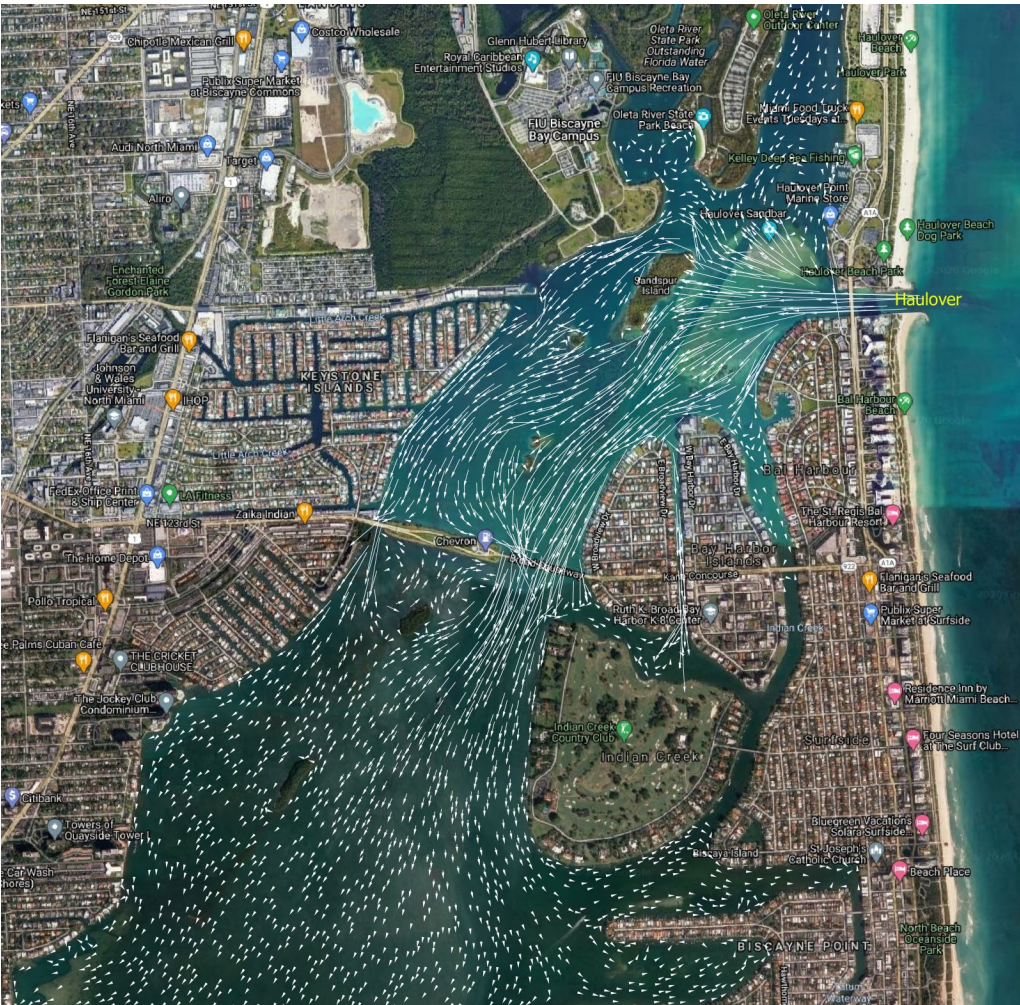


Figure 138 Water Surface elevations and salinities for stations BISCD6, BISCD8, BISCB6, and BISCC8. Comparison of model against measurements.

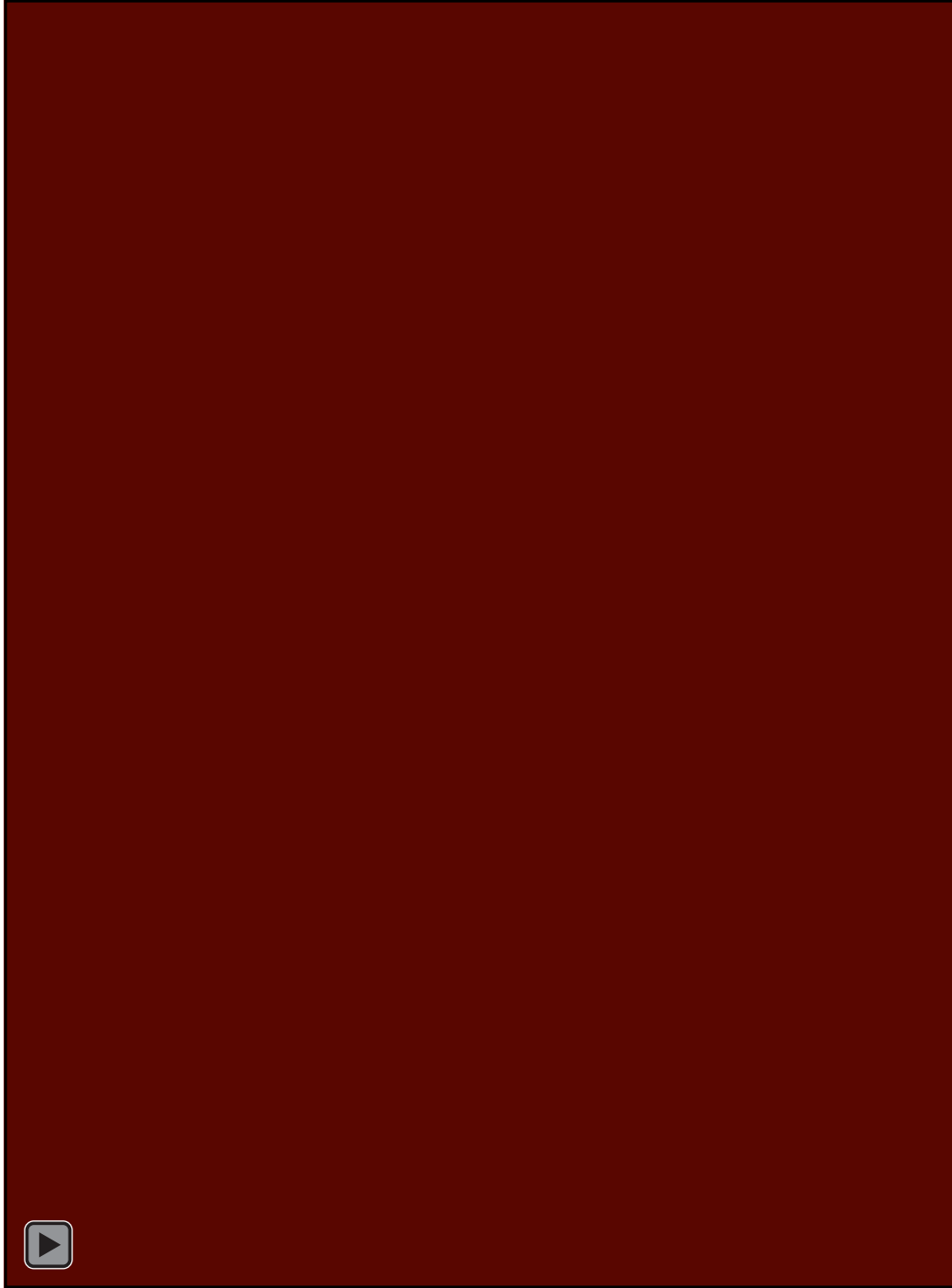
14/35



Velocity field near the northern end of Biscayne Bay. Haulover is the northern open boundary in the model.



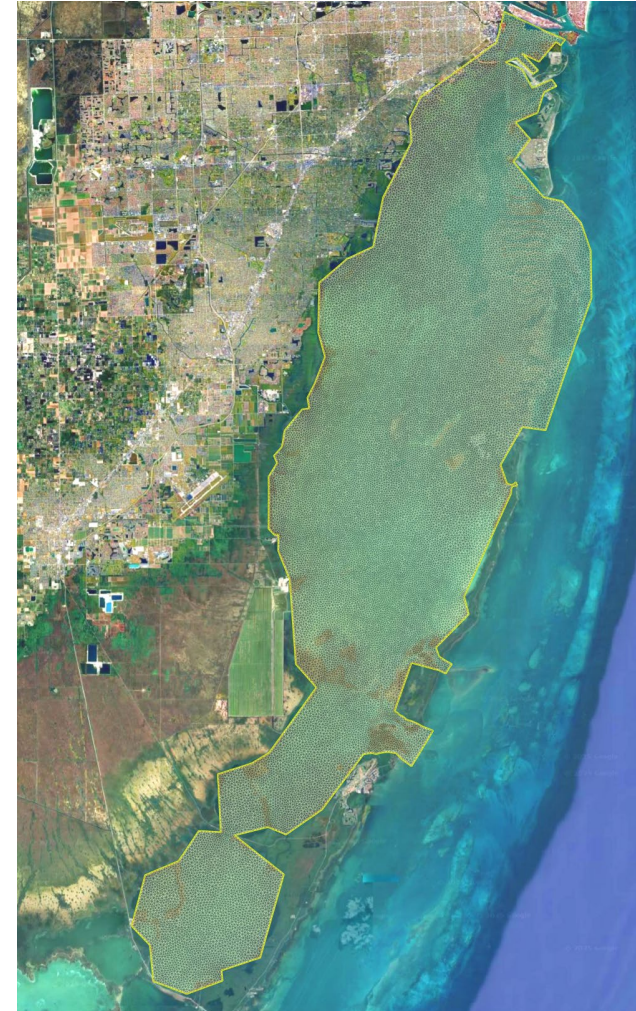
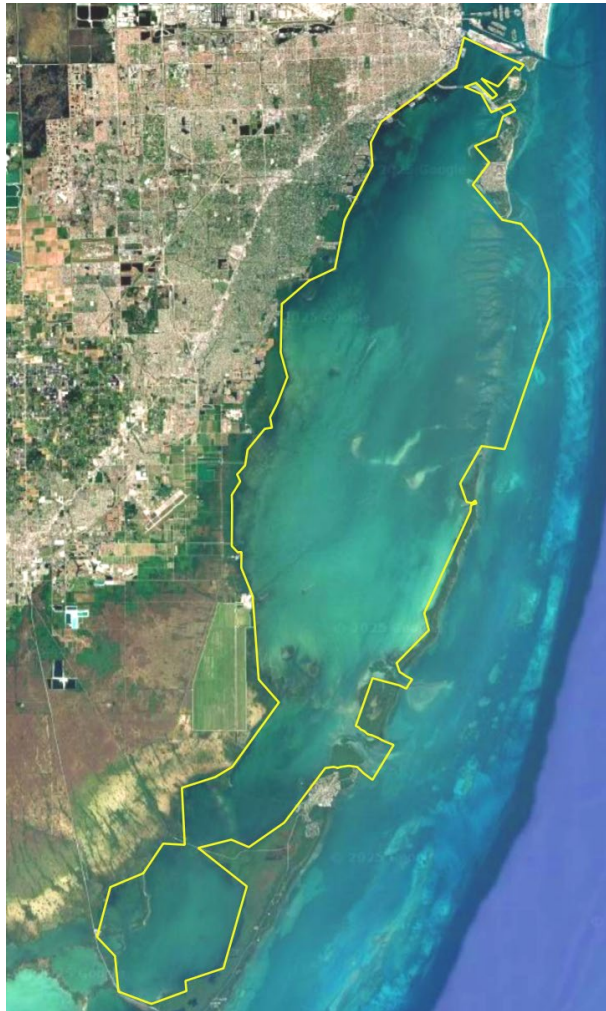
Velocity field between SR 934 and the 195. Note the higher velocities through the 195 bridges and the circulation patterns with large eddies.



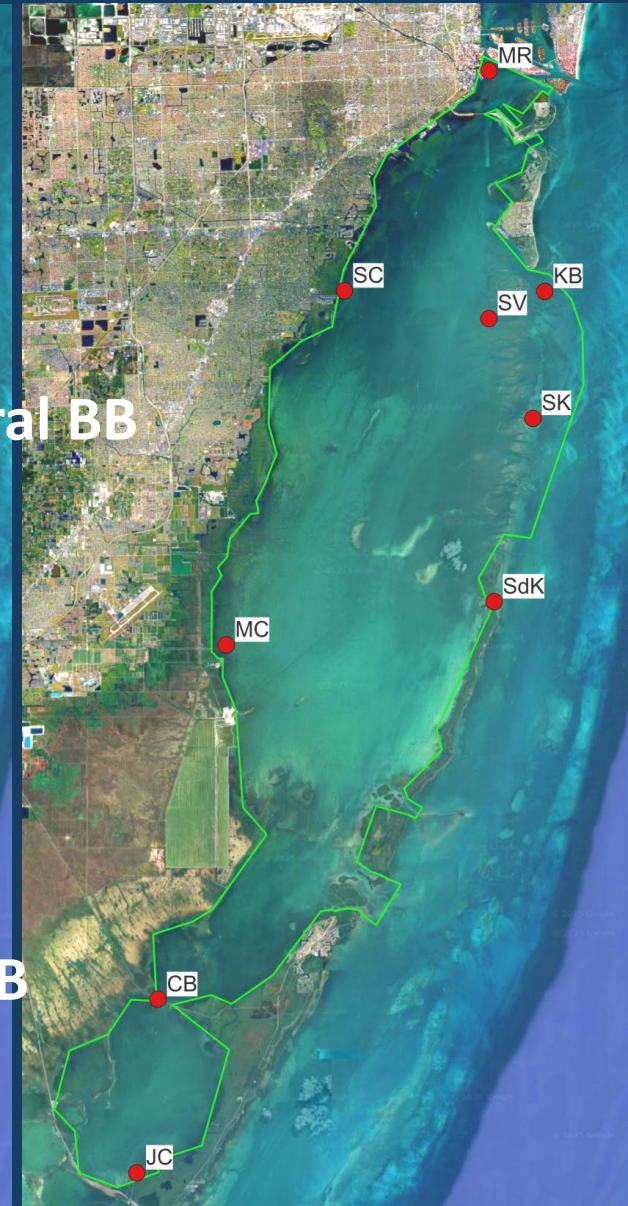
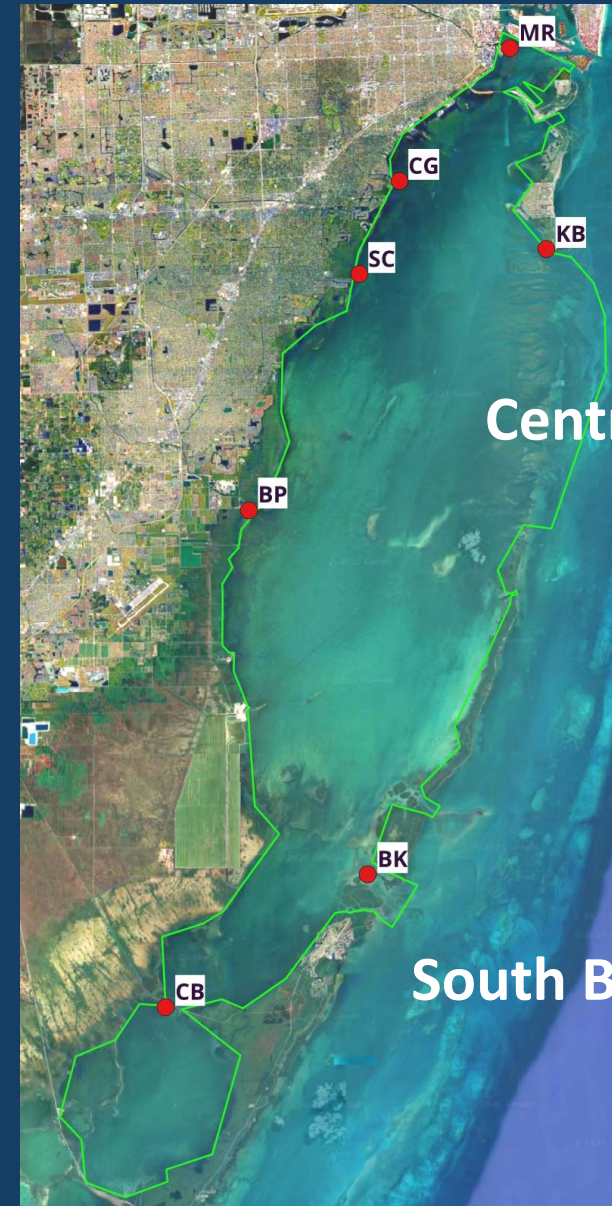
BBOM Results

- The model accurately reproduced water elevations and salinity across Biscayne Bay, achieving high correlation levels with observations.
- Accurate simulations required accounting for freshwater inflows, groundwater, tidal forcing, and wind stress.
- The BBOM system features a flexible triangular-mesh engine with GPU-accelerated performance and a QGIS-based GUI for visualization.

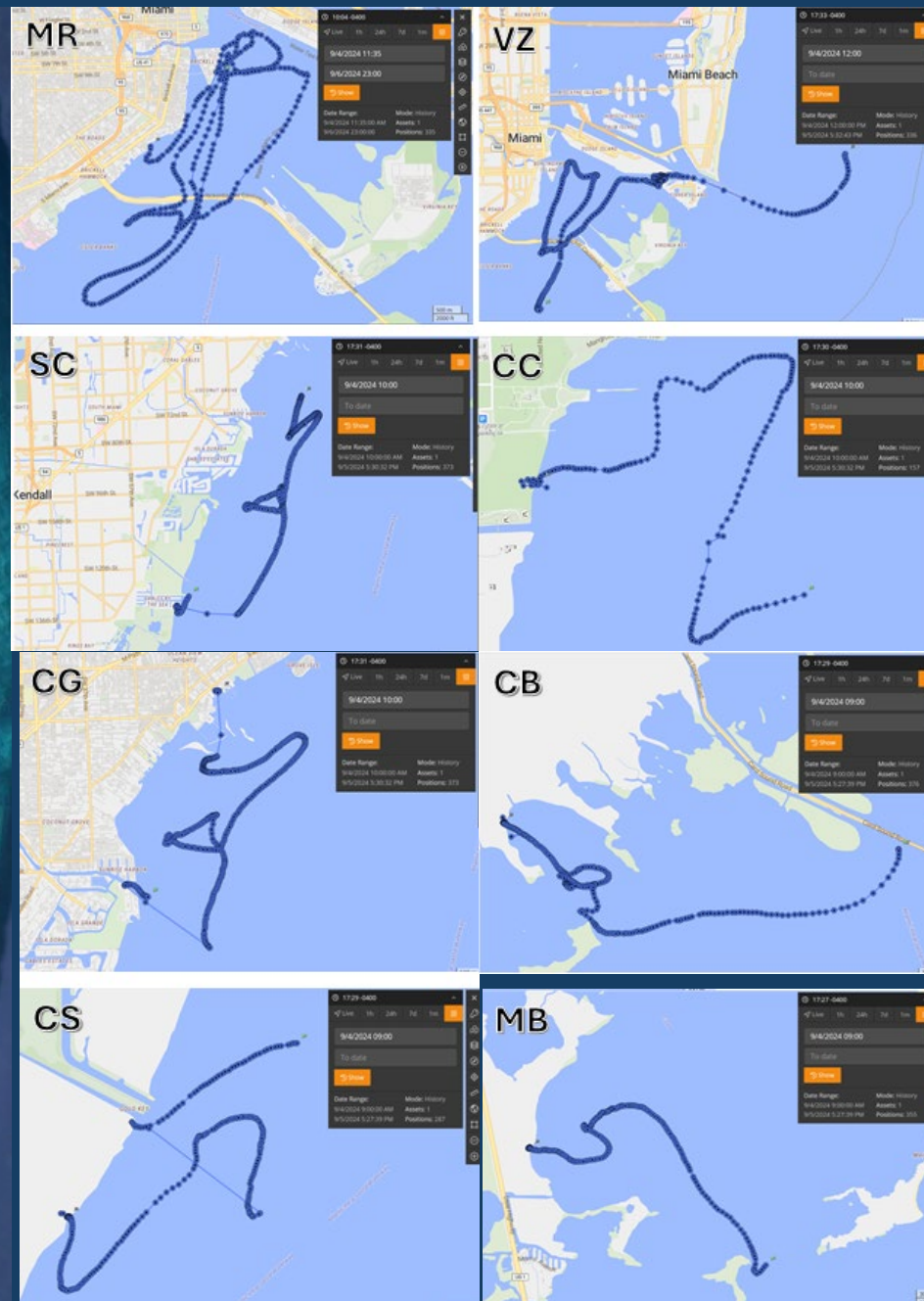
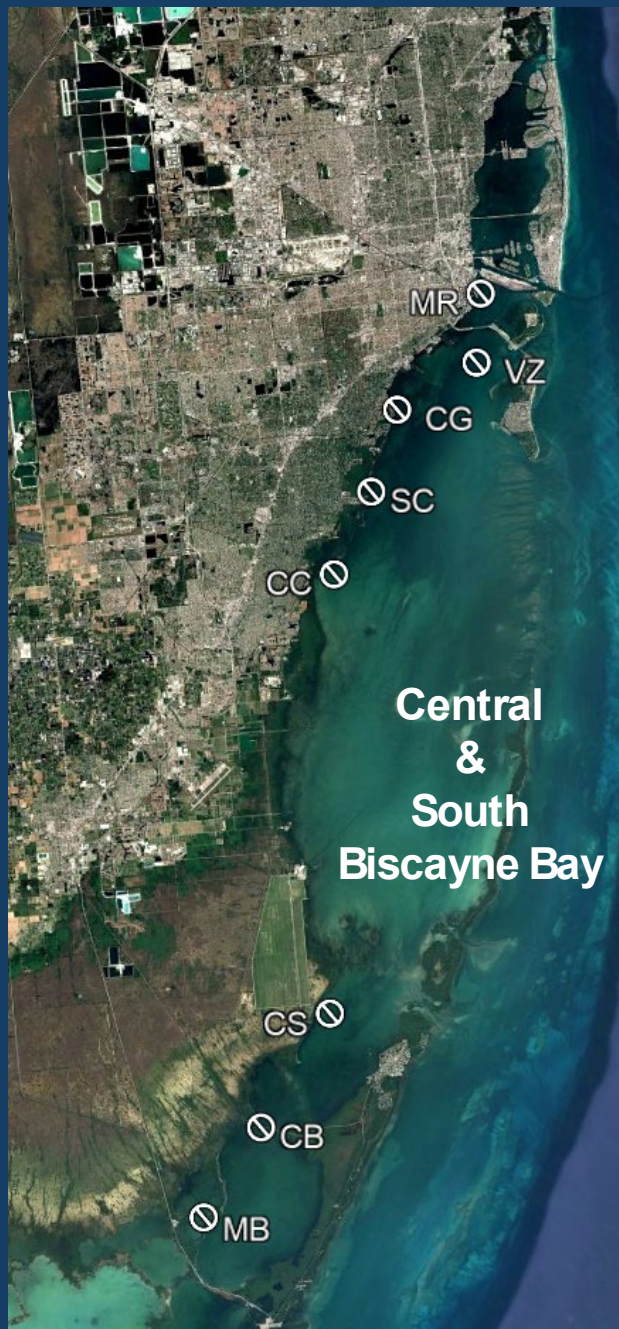
BBLAST Model Implementation



TCM1 current meter and HOBOS salinity, depth sensors

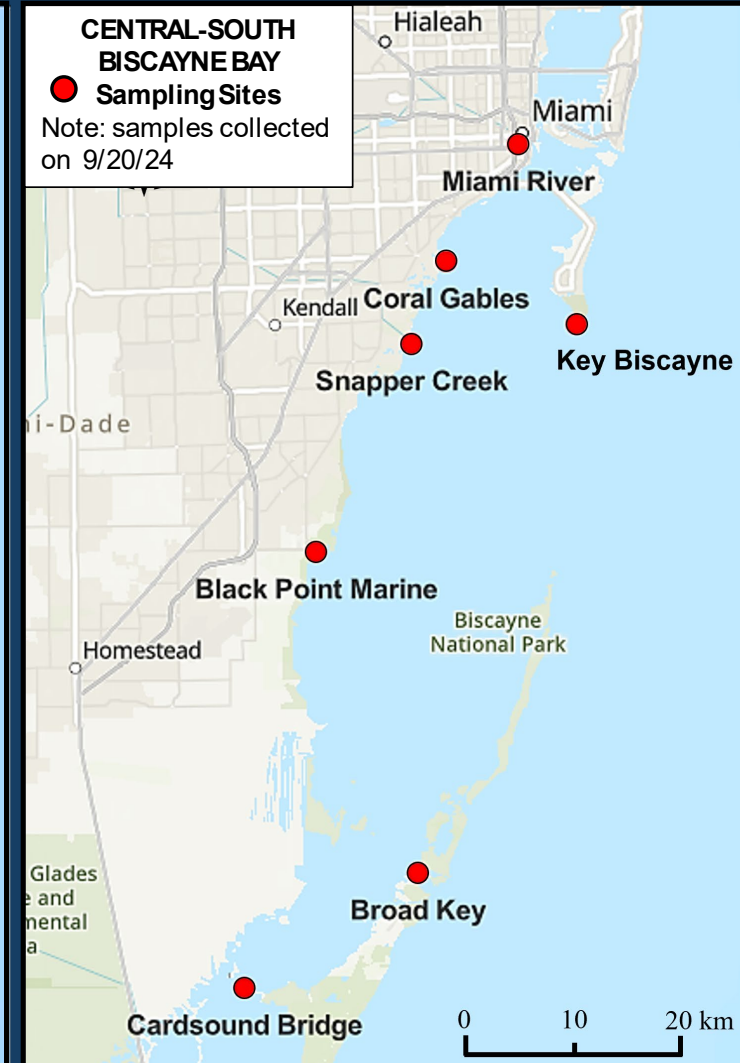
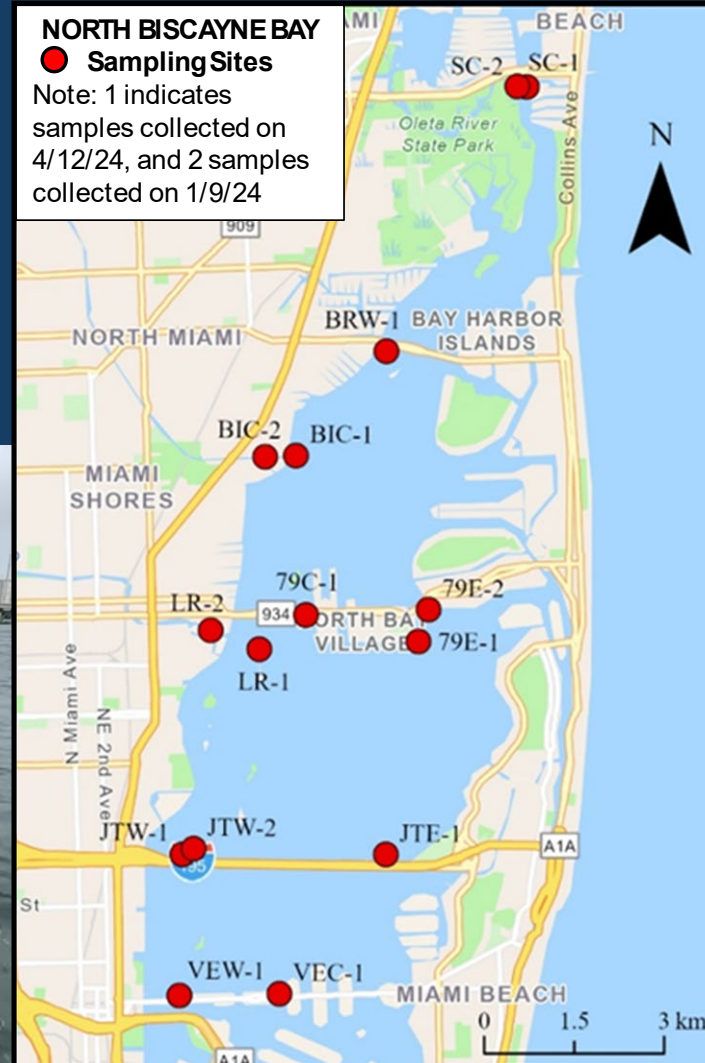
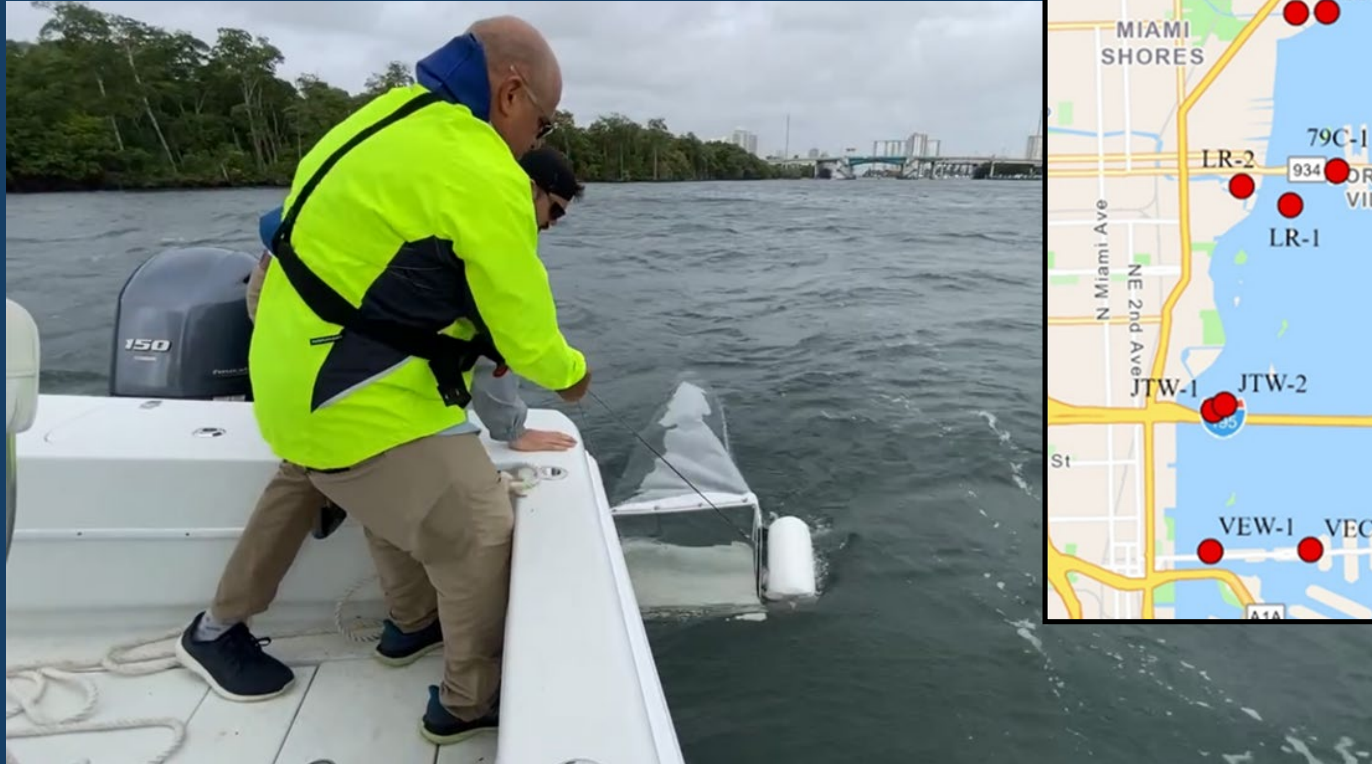


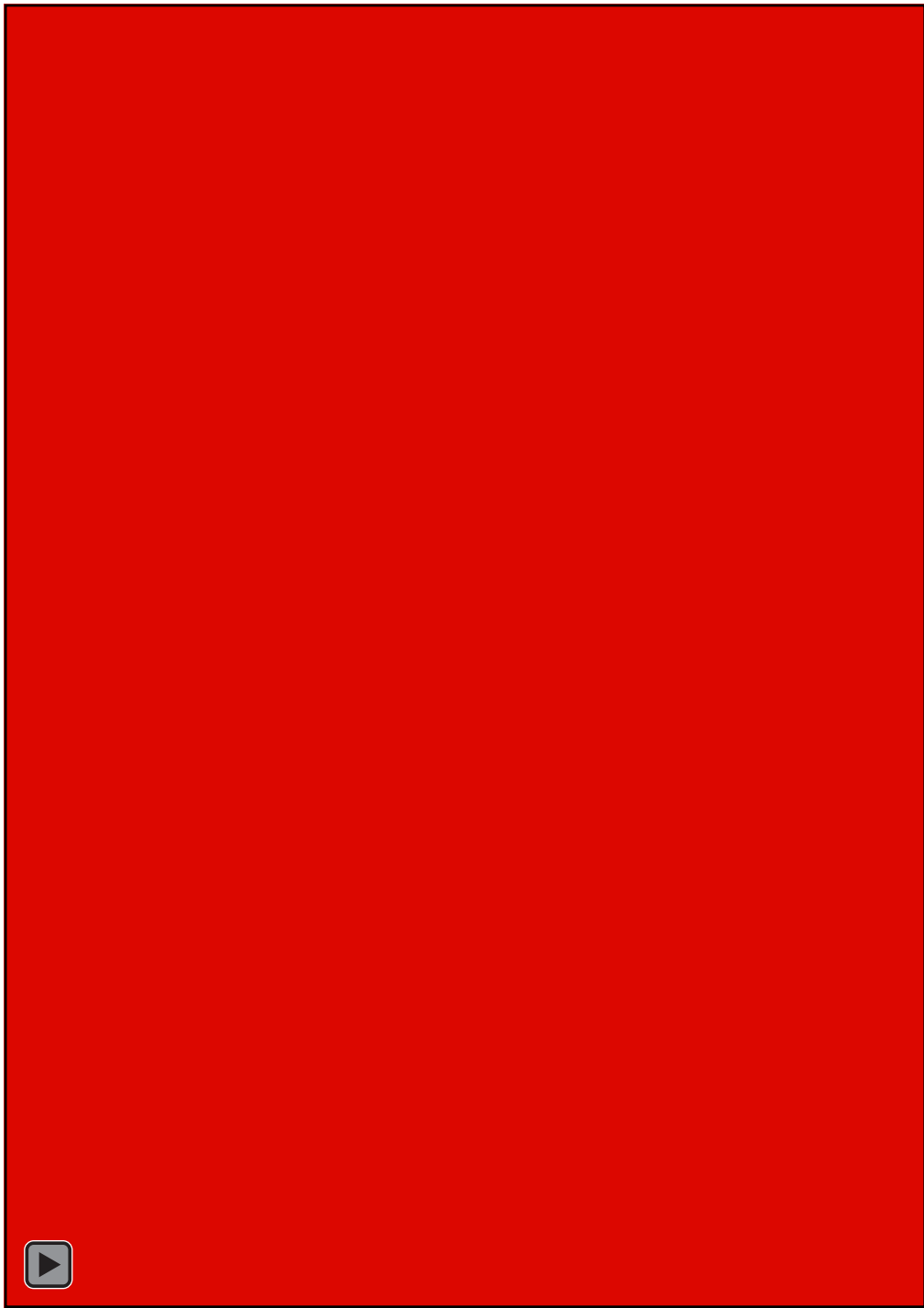
Drifter deployment

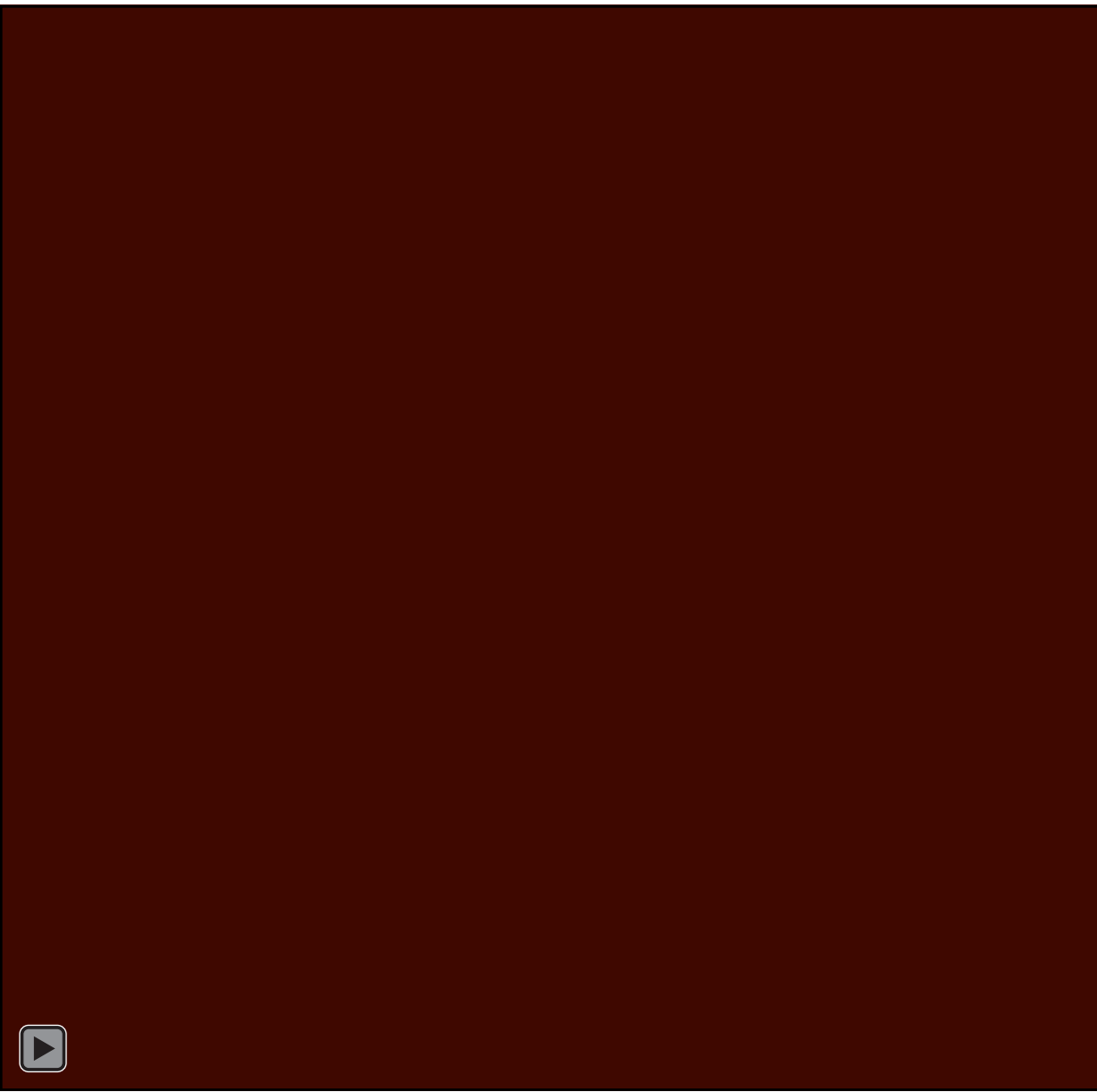


BBLAST04
All Drifters
10/25/2024 –
10/31/2024

μplastics sampling







Microplastic
Dispersion entering
from canals into
North Biscayne Bay



BBLAST Project Conclusions

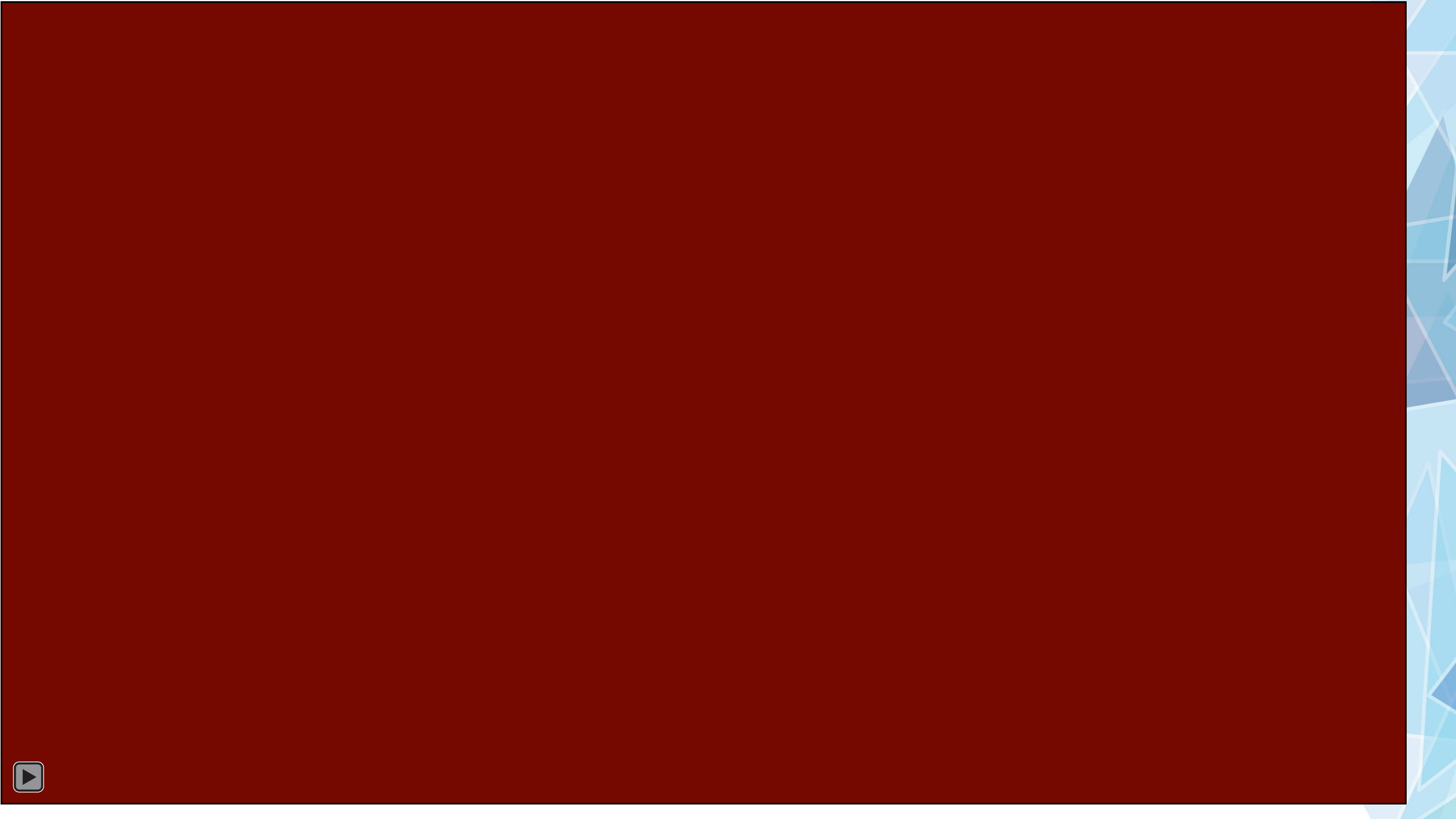
- Models successfully reproduced large-scale circulation patterns and supported microplastic transport analysis, though they showed some limitations in shallow coastal areas and underrepresented fine-scale variability due to limited wind data.
- Results improved understanding of retention zones and internal exchanges, providing a strong foundation for operational coastal management tools and highlighting the need for sustained monitoring infrastructure.

Potential Applications in the Florida Keys

Simulating Pollutant Dispersion in Canals of the Florida Keys

- Investigate complex water and pollutant exchange between canals and open waters in the Florida Keys using numerical modeling.
- Take advantage of the data collected by FIU





Questions / Comments

Henry Briceño bricenoh@fiu.edu

Piero Gardinali gardinal@fiu.edu

Reinaldo Garcia rey@hydronia.com





What do we want to know?

- How do the water velocities affect the trajectory of plastics?
- Determine the trajectories of plastics
- What are the main areas of plastic accumulation?
- Estimate the probable original spill location of plastics



RiverFlow2D Model Formulation

$$\frac{\partial \mathbf{U}}{\partial t} + \frac{\partial \mathbf{F}(\mathbf{U})}{\partial x} + \frac{\partial \mathbf{G}(\mathbf{U})}{\partial y} = \mathbf{H}(\mathbf{U}) + \mathbf{R}(\mathbf{U}) + \mathbf{D}(\mathbf{U})$$

$$\mathbf{U} = (h, q_x, q_y, h\phi_i)^T$$

$$\mathbf{F} = \left(q_x, \frac{q_x^2}{h} + \frac{1}{2}gh^2, \frac{q_x q_y}{h}, h\phi_i u \right)^T, \quad \mathbf{G} = \left(q_y, \frac{q_x q_y}{h}, \frac{q_y^2}{h} + \frac{1}{2}gh^2, h\phi_i v \right)^T$$

$$\mathbf{H} = (0, gh(S_{0x} - S_{fx}), gh(S_{0y} - S_{fy}), 0)^T$$

$$\mathbf{R} = (0, 0, 0, -Kh\phi_i)^T$$

$$\mathbf{D} = \left(0, 0, 0, \vec{\nabla}(Dh\vec{\nabla}\phi_i) \right)^T$$

i

- h : depth
- q_x, q_y : unit discharge in x and y ($q_x = u h, q_y = v h$)
- u, v : velocity vector components in x, y .
- ϕ_i : i Pollutant concentration

- S_{0x}, S_{0y} : bed slope in x, y .
- S_{fx}, S_{fy} : energy slope in x, y .
- K : First-order reaction rate matrix.
- D : Dispersion coefficient vector.





Motivation

- An estimated 4.8–12.7 million tons of mismanaged plastics, have entered the oceans from 192 coastal countries (Jambeck et al., 2015).
- Accounts for 1.8–4.7% of the global plastic production in 2010.
- 60–80% of the total marine debris (Derraik, 2002).
- Entanglement in plastic debris poses a major threat to marine wildlife (e.g., Duncan et al., 2017).
- Microplastics (≤ 5 mm) behave as a toxic chemical transport vector with the aid of their hydrophobicity and small size.

Hinata et al. Marine Pollution Bulletin 152 (2020)

BBOM Implementation

Bathymetric data

- NOAA Continuously Updated Digital Elevation Model (CUDEM) – 1/9 Arc-Second Resolution Bathymetric-Topographic Tiles.
- Updated on 2019-09-03 (BBOM), 2022-03-15 (BBLAST).
- 0.5-3 m resolution.





Macro-plastic Trajectories in Central-South Biscayne Bay



Macro-plastic Trajectories in North Biscayne Bay



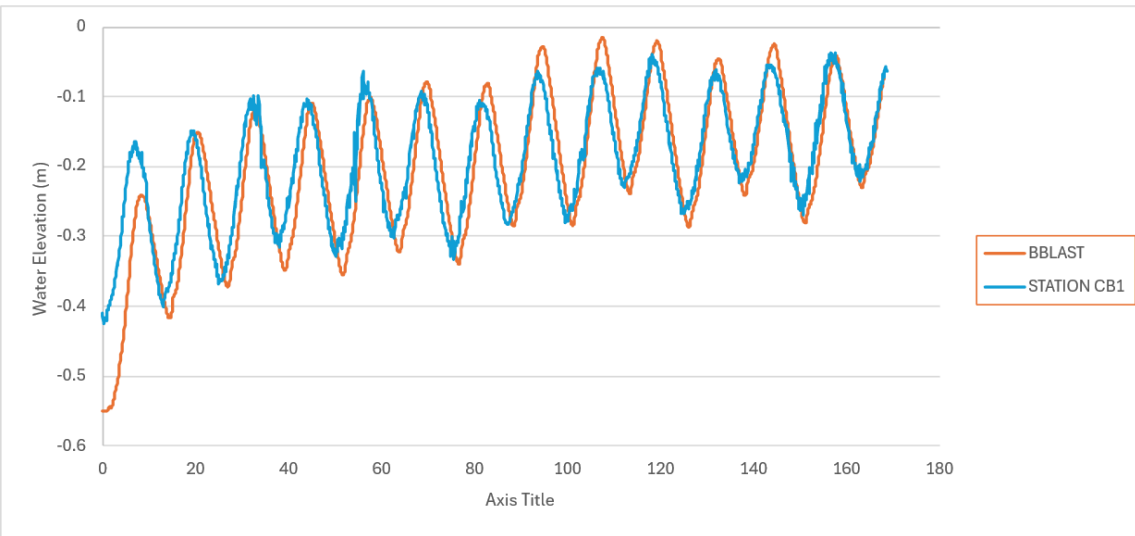


Figure 29 Comparison of BBLAST Water Surface Elevation results with Data from Station CB.

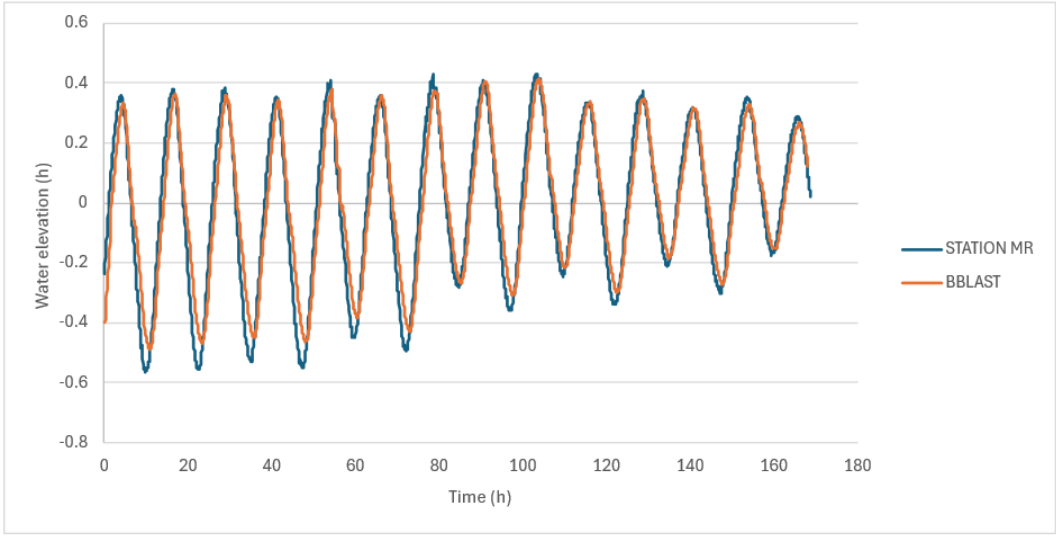


Figure 36 Comparison of BBLAST Water Surface Elevation results with Data from Station MR.

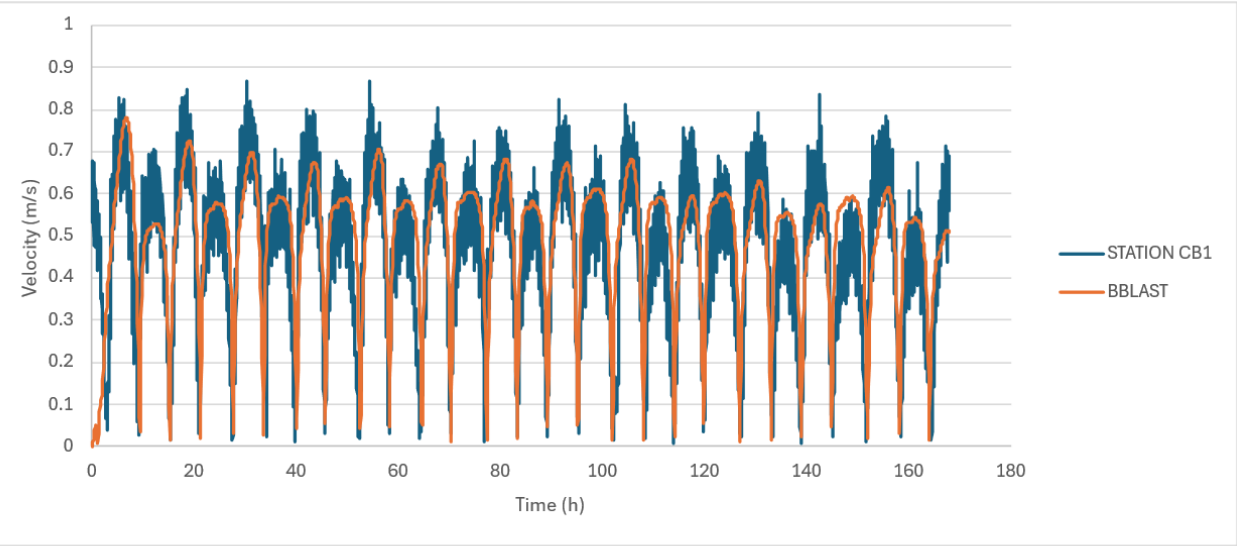


Figure 30 Comparison of BBLAST velocity results with Data from Station CB.

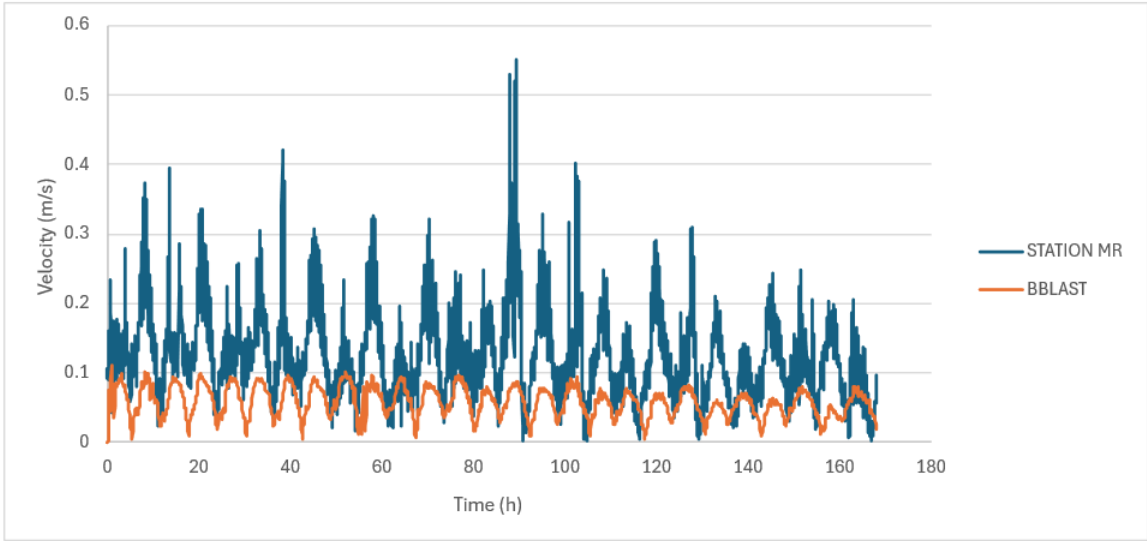


Figure 37 Comparison of BBLAST velocity results with Data from Station MR.

Drifter Trajectories (Observed vs BBLAST)

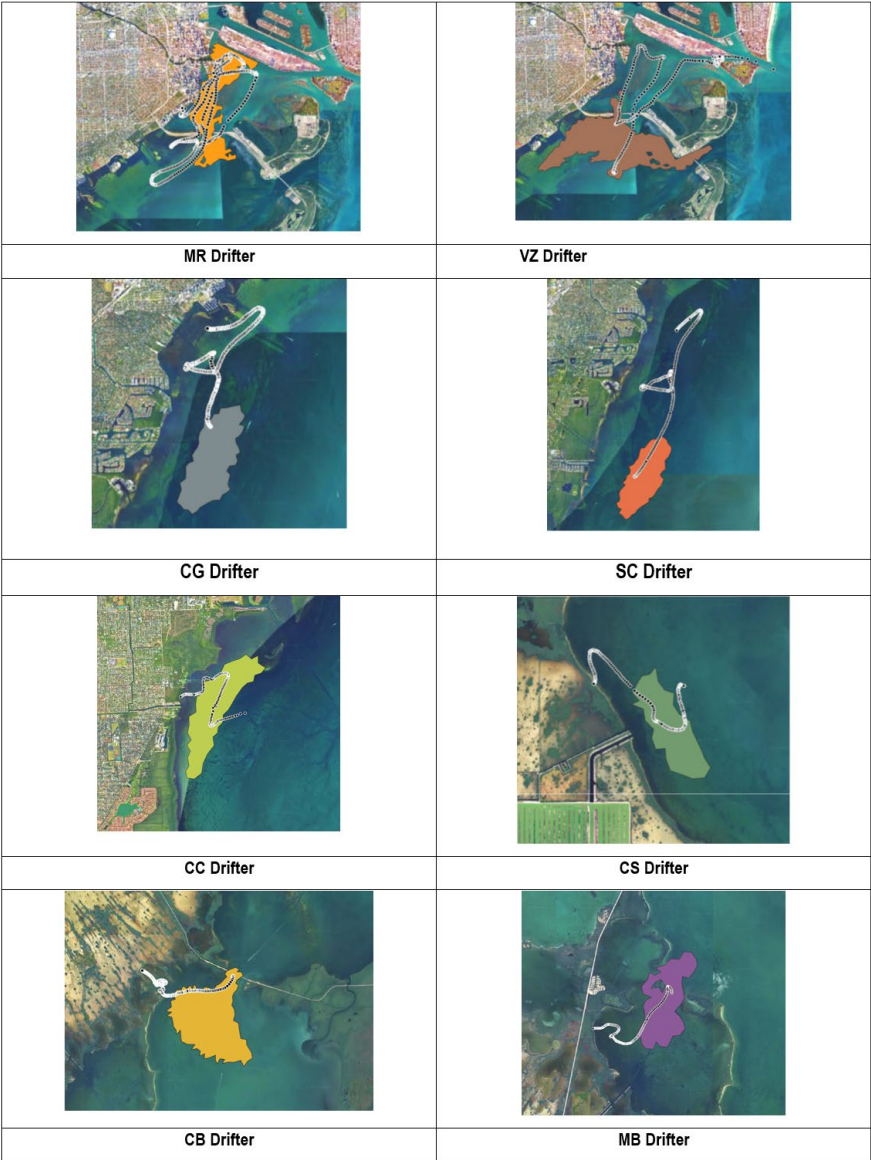


Figure 55 Comparison of the observed drifter trajectories during the BBLAST 03 campaign with the impacted area simulated by BBLAST.

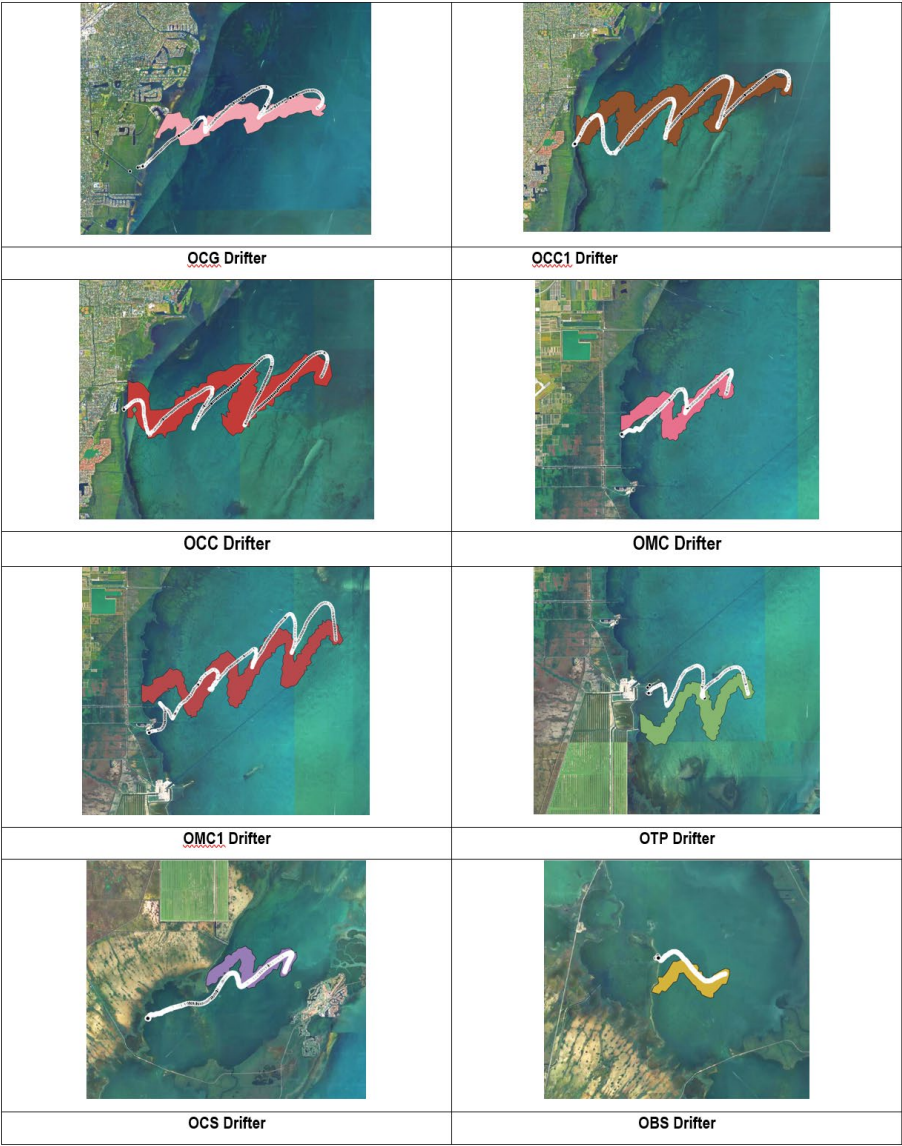


Figure 56 Comparison of the observed drifter trajectories during the BBLAST 04 campaign with the impacted area simulated by BBLAST.

BBLAST Project Conclusions

- The BBLAST project combined high-resolution hydrodynamic models with observational data (GPS drifters and in situ measurements) to study Biscayne Bay circulation and microplastic dispersion.
- Models successfully reproduced large-scale circulation patterns and supported microplastic transport analysis, though they showed some limitations in shallow coastal areas and underrepresented fine-scale variability due to limited wind data.
- Results improved understanding of retention zones and internal exchanges, providing a strong foundation for operational coastal management tools and highlighting the need for sustained monitoring infrastructure.