MODELING NONLINEAR PHYSICAL–BIOLOGICAL INTERACTIONS: INERTIA AND *SARGASSUM* IN THE NORTH ATLANTIC

Maureen T. Brooks, University of Maryland Center for Environmental Science
2015–2016 Graduate Fellow

EXECUTIVE SUMMARY

The floating seaweed of the genus *Sargassum* serves as critical habitat in the open Atlantic but causes economic harm to coastal communities when it washes ashore in large aggregations. This study links *Sargassum* dispersal and growth to underlying ocean circulation features. A model framework and satellite observations were used to determine how *Sargassum* responds to inertial forces, and the implications for its basinwide distribution. The resources of Blue Waters facilitated model development and allowed implementation at high resolution over the entire *Sargassum* habitat, covering over 4 x 10^7 km^2. This enabled the calculation of *Sargassum's* inertial parameters. Accounting for inertia leads to an increase in *Sargassum* export from the Sargasso Sea, providing a return pathway to the tropics. It also leads to increased retention in the Gulf of Mexico and Caribbean Sea, where the retention can cause management challenges. Including inertial effects in models of *Sargassum* could improve forecasting of coastal inundation events.

RESEARCH CHALLENGE

Floating *Sargassum* supports a diverse ecosystem in an otherwise nutrient-poor region of the ocean, supporting invertebrates, fish, and even sea turtles [1]. However, changes in *Sargassum* abundance and distribution over the past decade have resulted in millions of dollars in economic harm when it washes ashore [2]. Accurate predictions of these beaching events require an understanding of both the ocean currents that transport *Sargassum* and how much it grows along the way. Understanding the effects of inertia is particularly important because that can alter trajectories and potentially change the rate of entrainment in eddies, where growth conditions can differ from the surrounding water. Cyclonic eddies tend to propagate westward and northward in the North Atlantic, which could potentially drive more *Sargassum* to vulnerable coastal areas, while anticyclonic eddies would tend to carry *Sargassum* south toward the equator. The strength of inertial effects determines which of these two scenarios is more likely. Modeling inertial effects on *Sargassum* is difficult because it requires estimates of density and radius, yet *Sargassum* rafts are highly nonspherical. While density can be determined directly from field samples, estimating radius requires a novel approach.

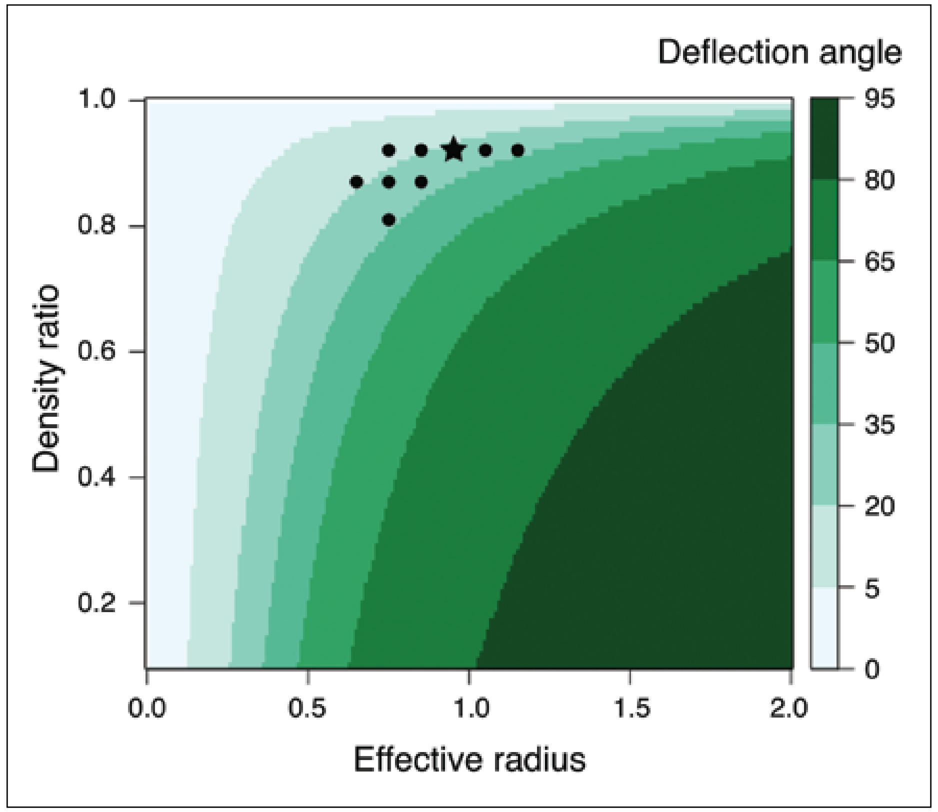

Figure 1: Deflection angle derived from the inertial equations (shading). Density ratio is relative to ambient sea water. Plotted symbols indicate where model and observed deflection angle distributions were most similar. The star indicates the effective radius and density ratio of *Sargassum* determined in this study.

METHODS & CODES

This research uses a system of four coupled models to simulate *Sargassum* growth and transport. A Hybrid Coordinate Ocean Model (HYCOM) [3] domain was implemented at 1/12° (< 10 m) resolution with 28 hybrid vertical layers, encompassing the known *Sargassum* distribution from 15°S to 64°N and 100°W to 15°E. Coupled to this is a biogeochemical model adapted from the work of Fennel [4], which includes nitrogen and phosphorus, phytoplankton, zooplankton, and detritus to effectively capture the dynamics of biologically mediated nutrient cycling in the upper ocean. *Sargassum* rafts are modeled using an individual-based physiology model embedded within a Lagrangian particle model. The particle model is modified from the HYCOM Lagrangian particle package to allow for *Sargassum* buoyancy, inertial effects, reproduction (particle splitting), and sampling of the underlying nutrient availability to allow for growth.

The effective radius of a modeled *Sargassum* raft was determined via an inverse method. Lines of visible *Sargassum* from satellite remote sensing [5] were compared with the finite-size Lyapunov exponent field to determine the deflection angle. A total of 91 *Sargassum* lines were measured from four dates in 2018 when there was high abundance. These angles were compared with angles calculated from model simulations with varying particle radius. An Anderson–Darling *k*-sample test was used to compare model and observed probability density functions and determine the *Sargassum* effective radius. This parameter was then applied to the *Sargassum* particles in the coupled model system to examine the effects of inertia on growth and distribution.

RESULTS & IMPACT

This multiscale modeling project provides the first estimates of *Sargassum* parameters for implementing inertial effects. Although the size of *Sargassum* rafts can vary from centimeters up to aggregations spanning kilometers, they respond to inertia comparably to a sphere with a radius of 0.95 m and a density of 92% of ambient sea water (Fig. 1). Accounting for these inertial properties changes how *Sargassum* moves and grows. Inertial *Sargassum* is entrained in eddies much more frequently, with 61% entrainment compared to 12% entrainment of noninertial particles. *Sargassum* is 48% more likely to be retained in the Western Gulf of Mexico and 36% more likely to be retained in the Caribbean Sea than noninertial particles. Finally, there is a seasonal increase in export of up to 20% out of the Sargasso Sea, which helps explain how the seasonal pattern of *Sargassum* distribution can restart every year.

These inertial effects and changes in trajectories also have implications for *Sargassum* growth. Although simulations did not show significant differences in growth for *Sargassum* inside versus outside of eddies, there were differences in overall growth between inertial and noninertial *Sargassum* particles. The annual mean biomass is 8% higher when inertia is accounted for, growth rates more frequently approach their theoretical maximum, and survival time is increased. This is owing to higher transport into and retention within regions with optimal growing conditions. Accounting for these physical and biological consequences of inertia can help improve predictions of *Sargassum* beaching events and allow coastal communities to better mitigate their harmful effects.

WHY BLUE WATERS

The resources of Blue Waters have made the scale and scope of this project possible. High-resolution ocean circulation modeling alone has a high computational cost. By utilizing Blue Waters, this was accomplished along with coupling it with ocean biogeochemistry, Lagrangian particles, and individual organism physiology at temporal and spatial scales that span orders of magnitude. The NCSA staff has also been key to the success of this project. Their responsiveness and expertise was critical to implementing and running this code on Blue Waters.

PUBLICATIONS & DATA SETS

M. T. Brooks, V. J. Coles, R. R. Hood, and J. F. R. Gower, "Factors controlling the seasonal distribution of *Sargassum*," *Mar. Ecol. Prog. Ser.*, vol. 599, pp. 1–18, Jul. 2018, doi: 10.3354/meps12646.

M. T. Brooks, V. J. Coles, and W. C. Coles, "Inertia influences pelagic *Sargassum* advection and distribution," *Geophys. Res. Lett.*, vol. 46, pp. 2610–2618, Mar. 2019, doi: 10.1029/2018GL081489.

Maureen T. Brooks received a Ph.D. in marine–estuarine–environmental sciences in 2019, working under the direction of Victoria Coles at the University of Maryland Center for Environmental Science Horn Point Laboratory.