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MULTISCALE BIOPHYSICAL INTERACTIONS: INERTIA, GROWTH, AND *SARGASSUM* SEED POPULATIONS

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EXECUTIVE SUMMARY

Sargassum is a macroalgae, or seaweed, that spends its entire life cycle floating on the surface of the Atlantic Ocean. This makes it an ideal model organism for understanding mesoscale biological–physical interactions. It is also of interest because it supports a unique open ocean ecosystem, but also has negative consequences for coastal communities when it washes ashore. This study examines how inertial forces influence the pathways *Sargassum* follows across the Atlantic and its access to nutrients vital for growth. This research uses a coupled model system that bridges scales from nutrient chemistry up through basinwide ocean circulation. Blue Waters resources allowed for model implementation at high spatial and temporal resolution. Results suggest that inertial forces enhance *Sargassum* connectivity between the tropics and the Gulf of Mexico, alter rates of entrainment in eddies, and lead to patchier growth.

RESEARCH CHALLENGE

Pelagic *Sargassum* is unique in the ocean. It is the only macroalgae that does not have a benthic-attached stage in its life cycle. It can be found throughout the tropical and subtropical Atlantic Ocean and serves as a keystone species [1]. In recent years, it has also washed up on beaches in increasing quantities, where it poses economic challenges, causes human health concerns, and can be harmful to wildlife [2]. My previous Blue Waters-supported work has suggested the existence of nursery regions in the Gulf of Mexico and western tropical Atlantic that exert strong influence on the basinwide distribution of *Sargassum*. However, the mechanisms that allow *Sargassum* to be retained in these regions and seed the rest of the basin were not understood.

Recent studies of Lagrangian particles have shown that trajectories can shift when inertial interactions due to particle size and density are considered [3]. Buoyant *Sargassum* rafts are also more likely to become entrained in eddies where they can potentially experience increased nutrient availability due to a shift in the nutricline brought on by eddy pumping. This work compares *Sargassum* growth and trajectories in simulations with and without these inertial interactions to determine their impact on the distribution of *Sargassum* in the Atlantic.

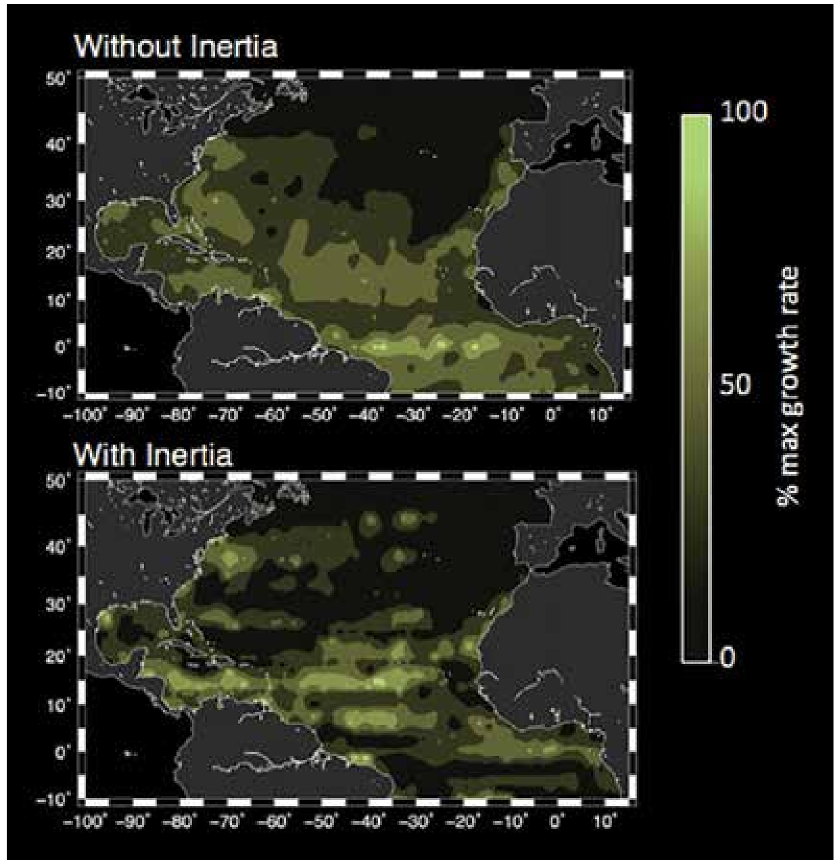

Figure 1: *Sargassum* growth, shown as % maximum growth rate, from model *Sargassum* particles. (a) Control; (b) Inertial experiment. Note patchiness and zonal spreading consistent with entrainment in eddies.

METHODS & CODES

A system of four coupled models was developed to simulate *Sargassum* growth and transport. A 1/12°-resolution Hybrid Coordinate Ocean Model (HYCOM) [4] implementation was run over an Atlantic domain from 15°S to 64°N and 100°W to 15°E. The vertical structure includes 28 hybrid-coordinate layers that can transition between sigma- and z-coordinates, with increased resolution near-surface to better capture dynamics relevant to *Sargassum* physiology. A biogeochemical model adapted from the work of Fennel [5] captures planktonic ecosystem dynamics and biologically mediated nutrient cycling.

A Lagrangian particle model tracks the trajectories of individual *Sargassum* colonies, and a *Sargassum* physiology model calculates growth and mortality within each particle. For this study, I have modified the HYCOM particle-tracking code to allow for buoyant *Sargassum* and to sample and interpolate the physical and biological parameters from the circulation and biogeochemical models that are necessary for calculating *Sargassum* growth. Inertial effects were implemented using a simplified Maxey–Riley equation applicable for a quasigeostrophic flow [3]. Lagrangian particle motion accounts for finite particle size and the difference in density between the *Sargassum* particles and ambient seawater.

The *Sargassum* physiology model uses light, temperature, and nutrient availability to determine growth rate. Model *Sargassum* reproduces via vegetative propagation, where a new *Sargassum* particle can be initialized in place when conditions are favorable. The coupled model estimates of *Sargassum* biomass were validated using monthly satellite climatologies derived from 10 years of observations [6].

RESULTS & IMPACT

Model experiments comparing *Sargassum* growth and distribution in inertial versus noninertial particles highlight several new biological–physical interactions. Including inertial forces due to the size and density of individual rafts significantly alters the pathways by which *Sargassum* moves between regions of the Atlantic. Connectivity analysis showed year-round reductions of almost 50% in transport from the tropics to the Sargasso Sea. Instead, *Sargassum* that started in the tropics either remained there or was transported into the Caribbean and Gulf of Mexico. This is consistent with previous work that showed the strong influence of the western tropics and Gulf of Mexico on the overall *Sargassum* distribution.

Analysis of the *Sargassum* physiology also yielded new insights. When modeled as noninertial water parcels, *Sargassum* experiences moderate growth conditions across most of its range (Fig. 1a). In contrast, accounting more realistically for the physical properties of *Sargassum* rafts yields patchier growth rates as the rafts get entrained in eddies. It also leads to local conditions of higher growth in the western Gulf of Mexico, the Caribbean, and the tropics.

Together, these results point to the tropics as the major potential source for the *Sargassum* responsible for inundation events in the Caribbean and give an additional mechanism leading to the high biomass that makes them so difficult to manage. Understanding this pathway and the oceanographic conditions that drive it is key to being able to predict and eventually mitigate these costly events.

WHY BLUE WATERS

The scope of this project is reliant on Blue Waters. This study combines high-resolution ocean circulation with ocean biogeochemistry, Lagrangian particle tracking, and individual-based organism physiology across orders of magnitude of spatial scales. Blue Waters' performance helped accommodate the high computational cost of running this complex system of models. In addition, the responsiveness and professionalism of the NCSA staff has been of great value in implementing this code on Blue Waters.

PUBLICATIONS & DATA SETS

Brooks, M., et al., Factors controlling the seasonal distribution of pelagic *Sargassum*. *Mar. Ecol. Prog. Ser.*, in revision (2018).

Maureen T. Brooks is in the fifth year of a Marine–Estuarine–Environmental Sciences PhD program, working under the direction of Victoria Coles at the University of Maryland Center for Environmental Science Horn Point Laboratory. She plans to complete her degree in 2018.