A Lagrangian perspective on the floating *Sargassum* ecosystem in the Atlantic

Maureen T. Brooks

17 May 2017

(photo: NOAA Ocean Observer)
Sargassum is a keystone species in the Atlantic, Gulf of Mexico, and Caribbean

**Sargassum is:**
- Unique
- Involved in nutrient cycling and export
- Habitat and forage grounds for commercial and endangered species
- Good and bad for beaches

(SAFMC)
**Sargassum** is a keystone species in the Atlantic, Gulf of Mexico, and Caribbean

**Sargassum** is:

- Unique
- Involved in nutrient cycling and export
- Habitat and forage grounds for commercial and endangered species
- Good and bad for beaches
Ocean currents define Sargassum’s habitat
Sargassum experiences more than just the mean circulation
Model System: Four coupled models
Model System: Ocean Circulation

- HYCOM (Hybrid Coordinate Ocean Model)
- 1/12° grid scale (~10 km resolution), 28 vertical layers
- >1.8 million grid cells partitioned into 4096 equal-area tiles for parallelization
- 6 State variables: Temperature, Salinity, Density, Velocity (u, v, w)
- 17 term equation of state
Model System: Biogeochemistry

\[
\begin{align*}
\frac{dP}{dt} &= \mu_p P - g_P Z - m_P P - \tau(D_S + P) P \\
\frac{dT}{dt} &= \mu_T T - m_T T - \tau T^2 - \alpha T \\
\frac{dZ}{dt} &= g_P \beta Z - l_B Z - \frac{P^2}{k_p + p_z} \beta Z - m_z Z^2 \\
\frac{dN}{dt} &= -\mu_{max}(l_T) l_T^2 P + nA \\
\frac{dA}{dt} &= -\mu_{max}(l_T) l_T^2 P - nA + l_B Z + \frac{P^2}{k_p + p_z} \beta Z + r_{DSN} D_S^N + r_{DLN} D_L^N + \alpha T \\
\frac{dD_P}{dt} &= -\mu_{max}(l_T) l_T^2 P - \mu_{max}(l_T) l_T^2 T + l_B Z + \frac{P^2}{k_p + p_z} \beta Z + r_{DSP} D_S^P + r_{DLP} D_L^P \\
\frac{dD_S^N}{dt} &= m_P P + m_T T + m_z Z^2 - \tau(D_S^N + P) D_S^N - r_{DSN} D_S^N \\
\frac{dD_S^P}{dt} &= m_P P + m_T T + m_z Z^2 - \tau(D_S^N + P) D_S^N - r_{DSP} D_S^P \\
\frac{dD_L^N}{dt} &= \tau(D_S + P)^2 + \tau T^2 - r_{DLN} D_L^N \\
\frac{dD_L^P}{dt} &= \tau(D_S + P)^2 + \tau T^2 - r_{DLP} D_L^P
\end{align*}
\]
Model System: Biogeochemistry
Model System: Lagrangian Particles

- One-way coupling advects particles with velocities from HYCOM
- Positive buoyancy of 0.1 m/s to simulate buoyant Sargassum
- Typical initializations include ~50,000 particles
- Capable of forward- and backward-time simulations
- Samples fields from the biogeochemical model as well as the physics
- “online” and “offline” modes allow more experiments with HYCOM and BGCM output
Model System: *Sargassum* physiology
Model System: on Blue Waters

- 4096 tiles
- 128 nodes
- ~120 core hours per model day for physics only
- ~40% higher with biology
- 4GB of output per model day
Model validation with satellite observations

Target Diagram for All Regions

Biogeochemical model

Sargassum model

Better Match With Observations
How does this pattern of biomass get maintained?
How is the *Sargassum* population sustained when the circulation tends to aggregate floating particles in the central gyre?

Derived from Gower and King 2011

Law et al. 2010
Hypothesis: Vegetative propagation of *Sargassum* helps maintain its seasonal distribution.
Hypothesis: Vegetative propagation of *Sargassum* helps maintain its seasonal distribution.
Hypothesis: Vegetative propagation of *Sargassum* helps maintain its seasonal distribution
Vegetative propagation doesn’t change the seasonal cycle when we are seeding everywhere in the domain.
Connectivity between regions highlights major pathways of *Sargassum* transport

Connectivity after 90 days for *Sargassum* seeded in May
Seeding in GoM and WTA with vegetative propagation gives most realistic results
Including both vegetative propagation and seeding in key regions better reproduces the observed distribution.
This model paradigm functions well over the seasonal cycle.

With vegetative propagation, the model better matches with observations.
How do physics and biology interact in the Gulf of Mexico?
How do physics and biology interact in the Gulf of Mexico?
How do physics and biology interact in the Gulf of Mexico?
Conclusions

• The Gulf of Mexico and Western Tropical Atlantic are key to sustaining the *Sargassum distribution*

• Vegetative propagation also contributes

• Eddies and fronts in the GoM can improve growth conditions but the experience of any individual *Sargassum* colony is variable
This research is part of the Blue Waters sustained-petascale computing project, which is supported by the National Science Foundation (awards OCI-0725070 and ACI-1238993) and the state of Illinois. Blue Waters is a joint effort of the University of Illinois at Urbana-Champaign and its National Center for Supercomputing Applications.
Connectivity between regions highlights major pathways of *Sargassum* transport
Connectivity between regions highlights major pathways of *Sargassum* transport

Connectivity after 90 days for particles launched in May
Connectivity between regions highlights major pathways of *Sargassum* transport

Connectivity after 90 days for particles launched in May

![Connectivity Matrix](image)

![Subregions for Connectivity Analysis](image)
Lagrangian Coherent Structure Analysis

Harrison et al. 2013
Lagrangian Coherent Structure Analysis
1/25 degree Global HYCOM Performance on Cray XC40

- DoD HPCMP benchmark case, 1 model day with standard I/O
  - 2.2.27: static memory allocation, land via do-loops
  - 2.2.98: dynamic memory allocation, land via masks
HYCOM SCALABILITY (2.2.98)

1/25 degree Global HYCOM Performance

- Total Core Hours per Model Day
- Number of Cores

- Cray XC40 (32 cores/node)
- Cray XC30 (24 cores/node)
- IBM iDataPlex (16 cores/node)