Modeling a Mobile Ecosystem: Eddies and *Sargassum* in the North Atlantic

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

**Sargassum** is:
- Uniquely holopelagic
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Sargassum is:

• Uniquely holopelagic
• Involved in nutrient cycling and export
**Sargassum** is a keystone species in the Atlantic, Gulf of Mexico, and Caribbean

*Sargassum* is:
- Uniquely holopelagic
- Involved in nutrient cycling and export
- Habitat and forage grounds for commercial and endangered species
Sargassum is a keystone species in the Atlantic, Gulf of Mexico, and Caribbean.
Sargassum varies seasonally across its range

Gower and King 2011
Sargassum varies seasonally across its range

Gower and King 2011
*Sargassum* varies seasonally across its range
Sargassum varies seasonally across its range

Gower and King 2011
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Gower and King 2011
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Methods: Coupled physical-biogeochemical and Lagrangian particle models
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- 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)
- ~120 core hours per model day (~2 minute wall time)
Methods: Coupled physical-biogeochemical and Lagrangian particle models
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- Coupled online with HYCOM physics
- 10 State variables: 3 plankton functional groups, 3 nutrients, 2 detrital pools with variable nutrient stoichiometry.
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- 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
Accounting for physics alone, buoyant particles in this region aggregate in the gyre
Accounting for physics alone, buoyant particles in this region aggregate in the gyre

Law et al. 2010
Eddies and fronts are not sufficient to disperse *Sargassum* particles across the domain

1/4° model resolution

1/12° model resolution

1/12°
Accounting for physics alone, buoyant particles in this region aggregate in the gyre
Seasonally, advection explains up to 60% of observed *Sargassum* distribution at a 60d time scale.

60d old floats in month 10

Match With Observations

- Initial condition from observations
- Random initial condition
Accounting for light and temperature helps constrain boundaries seasonally.

60d old floats in month 10

With criteria
Location only
A *Sargassum* growth model was applied to the particles.
The individual-based model includes light, nutrient, and temperature constraints.
With growth and mortality our model generates realistic *Sargassum* distributions from randomly-seeded particles.
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Sargassum ecology is a key element of the seasonal pattern.
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

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Subregions for Connectivity Analysis:

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- **8**: [Region 8]
- **9**: [Region 9]
- **10**: [Region 10]
- **11**: [Region 11]
- **12**: [Region 12]

Legend:
- **0%**: Light yellow
- **10%**: Yellow
- **20%**: Light orange
- **30%**: Orange
- **40%**: Red
- **50%**: Dark red
- **60%**: maroon
- **70%**: Purple
- **80%**: Blue
- **90%**: Light blue
- **100%**: Light blue
Connectivity between regions highlights major pathways of *Sargassum* transport

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Connectivity between regions highlights major pathways of *Sargassum* transport.
Lagrangian Coherent Structure Analysis

Harrison et al. 2013
Lagrangian Coherent Structure Analysis
Conclusions

• Advection alone can explain between 28-60% of the *Sargassum* distribution at short time scales

• Light and temperature constrain the modeled winter distribution accounting for an additional 15% at that time

• *Sargassum* growth ecology influences the distribution year-round

• The western Gulf of Mexico may be a seed region for *Sargassum*, bounded by differential eddy activity

*Sargassum* wash-up events cost affected countries millions of dollars annually
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.
Mortality suggests potential patterns of export


Fraction of total particles
With growth and mortality our model generates realistic *Sargassum* distributions from randomly-seeded particles
• 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
Backwards particles suggest potential source regions
With growth and mortality our model generates realistic *Sargassum* distributions from randomly-seeded particles.

**Raw particle distribution**

**Sargassum-weighted density**

*November*