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

Maureen T. Brooks

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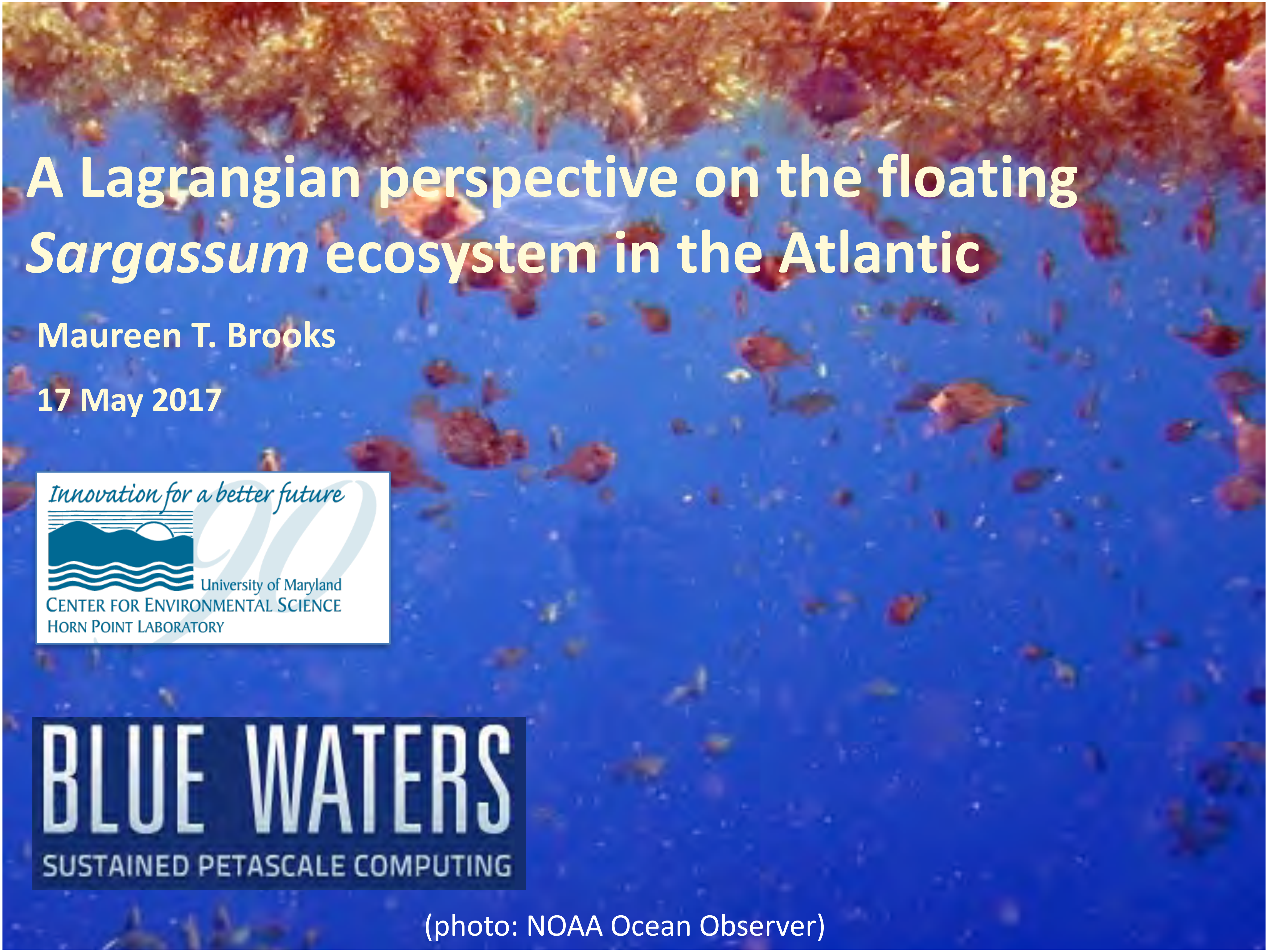
Innovation for a better future
University of Maryland
CENTER FOR ENVIRONMENTAL SCIENCE
HORN POINT LABORATORY

BLUE WATERS
SUSTAINED PETASCALE COMPUTING



(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

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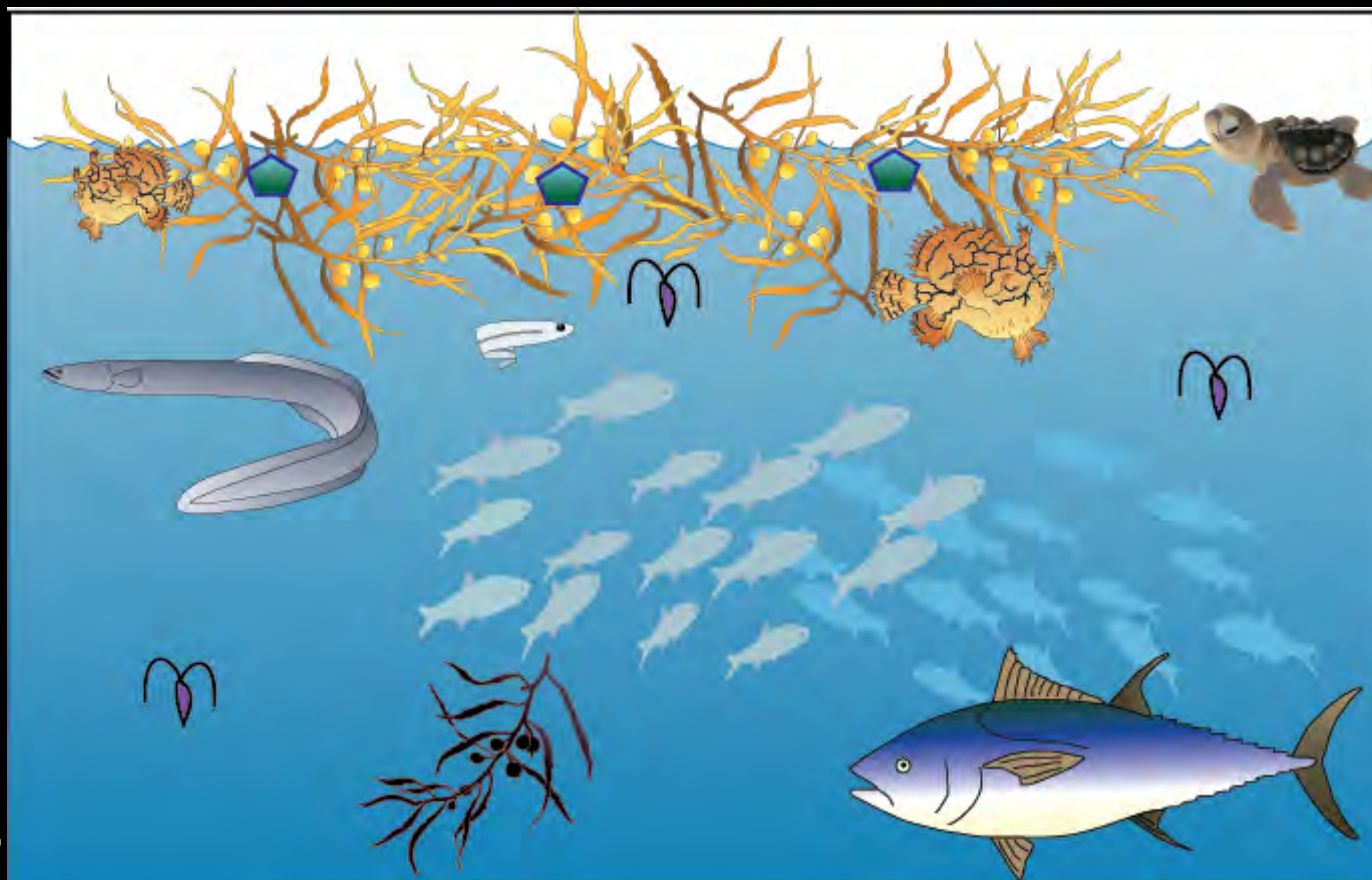
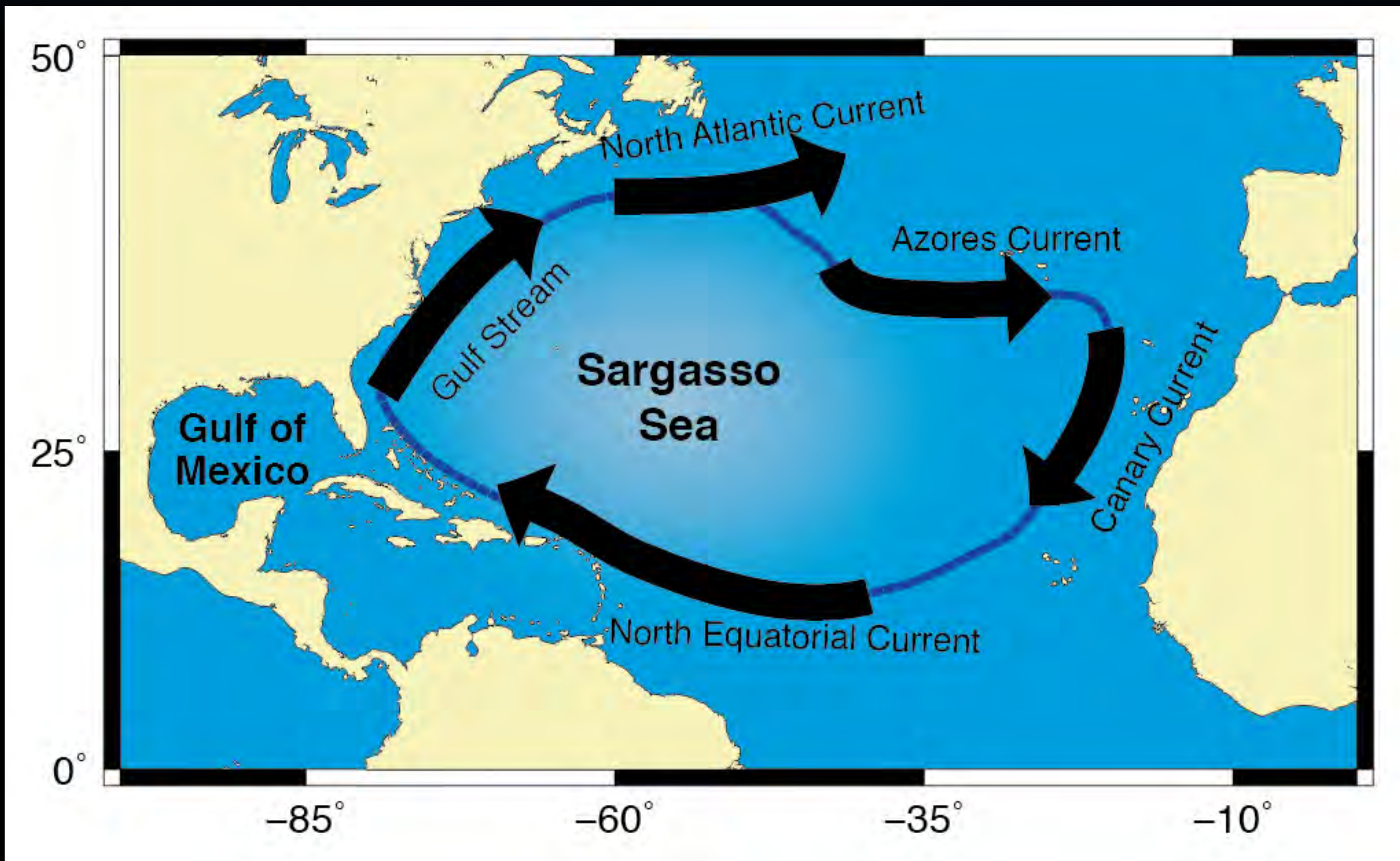
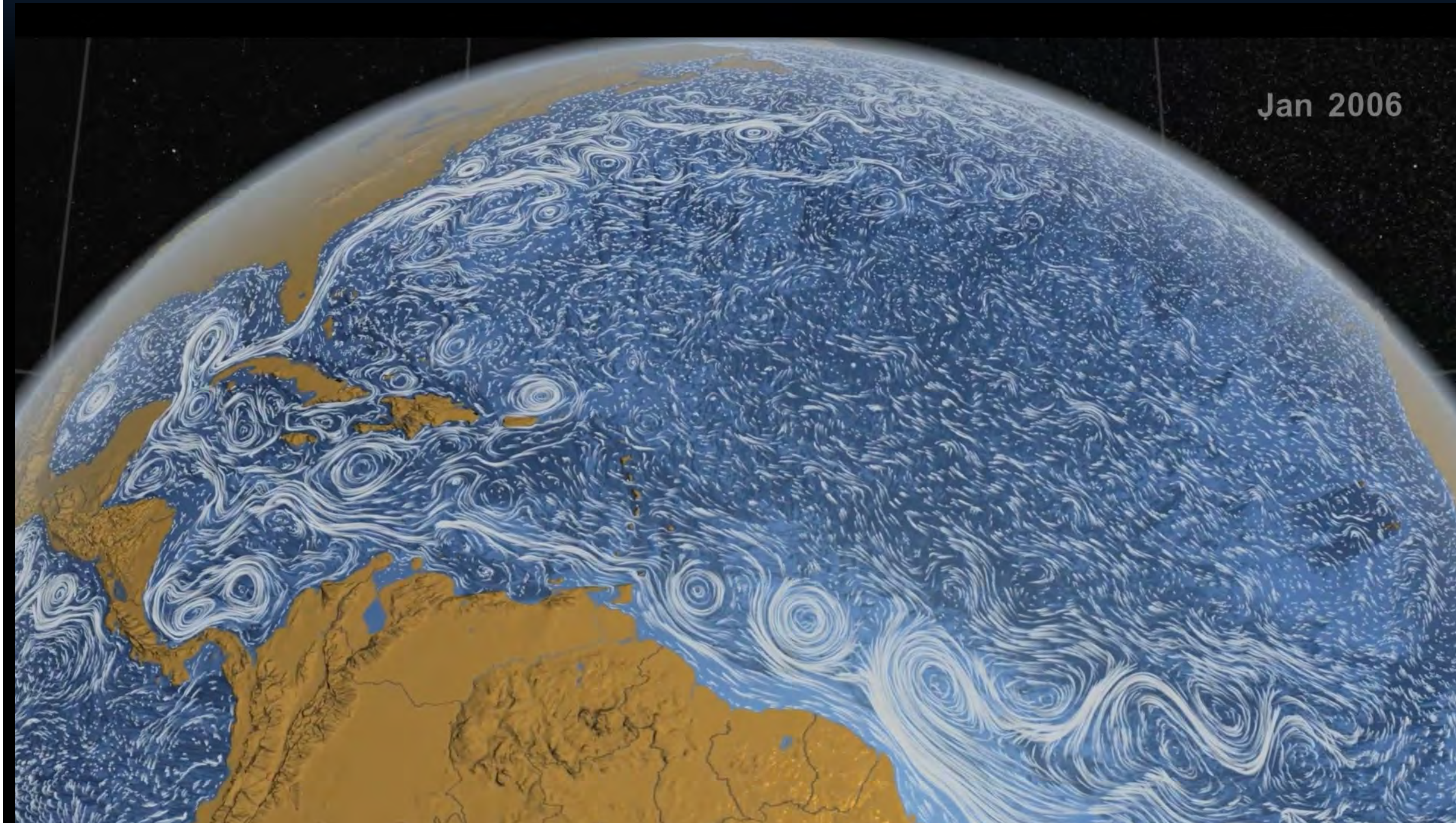


Ocean currents define *Sargassum's* habitat

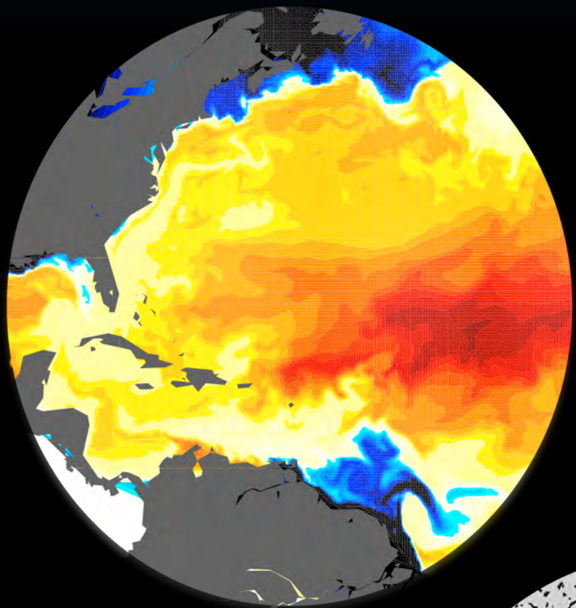
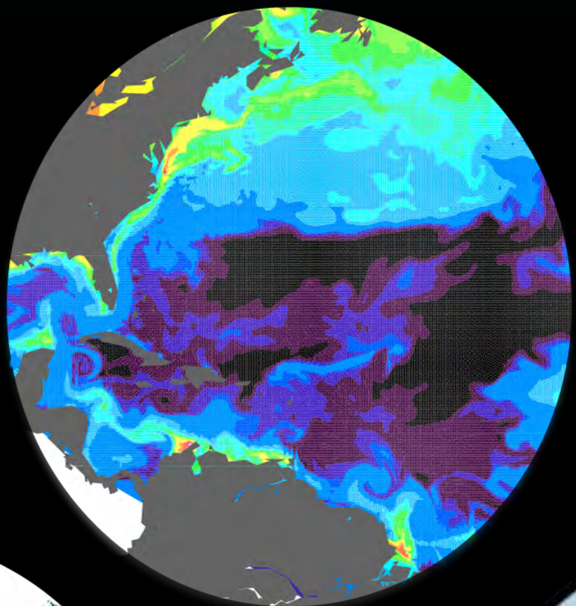
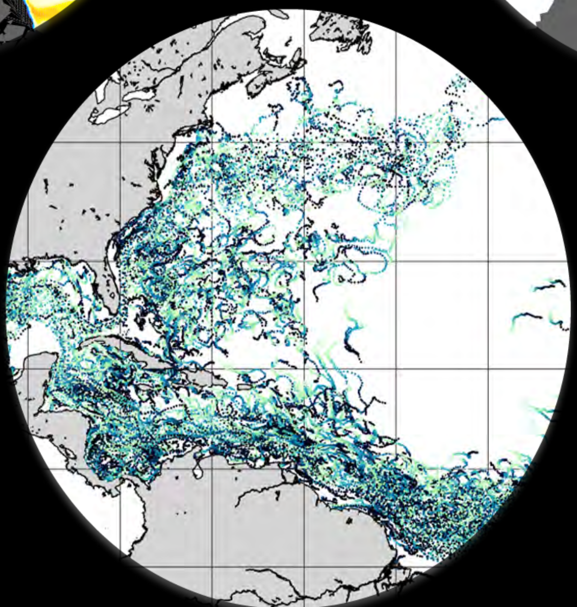


Sargassum experiences more than just the mean circulation

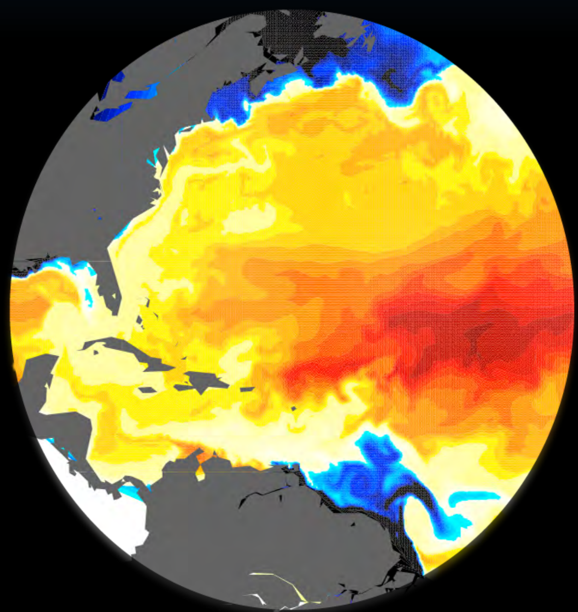


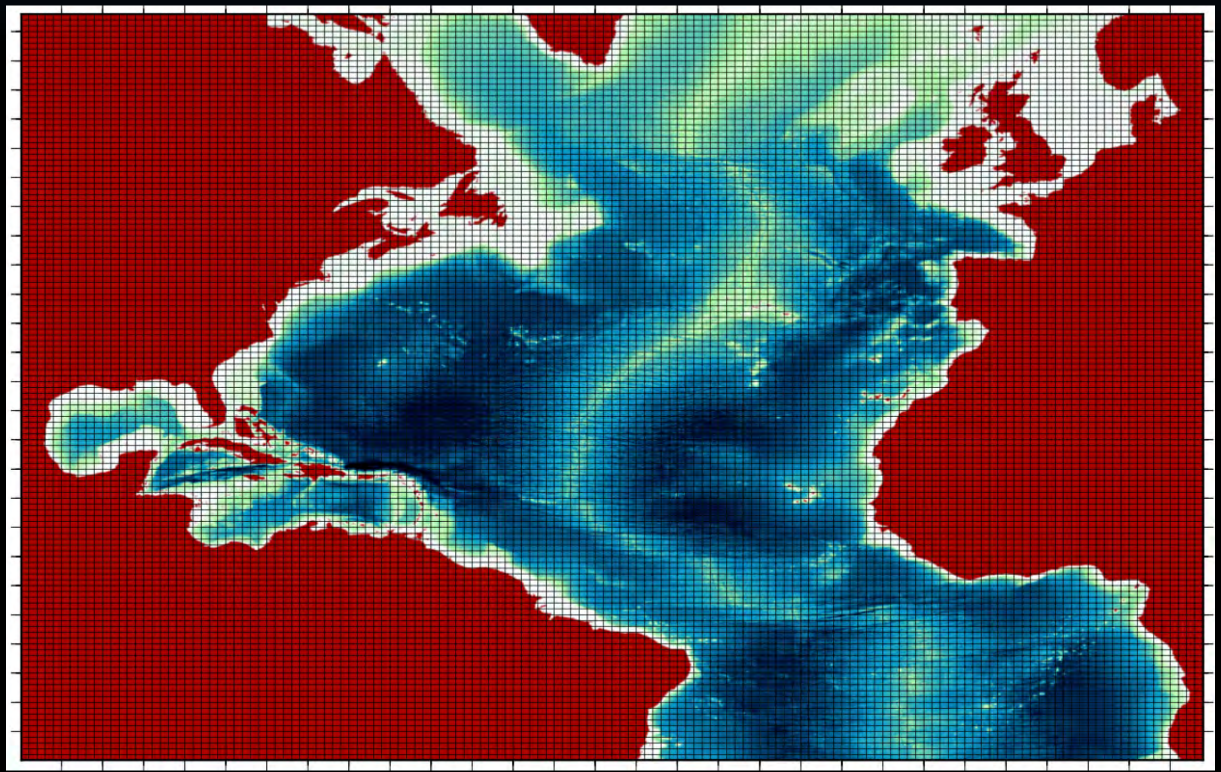
NASA Scientific Visualization Studio

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

$$\frac{dP}{dt} = \mu_P P - g_P Z - m_P P - \tau(Ds + P)P$$

$$\frac{dT}{dt} = \mu_T T - m_T T - \tau_T T^2 - \alpha T$$

$$\frac{dZ}{dt} = g_P \beta Z - l_{BM} Z - l_E \frac{P^2}{k_P + P^2} \beta Z - m_Z Z^2$$

$$\frac{dN}{dt} = -\mu max_P f_P(I) L_P^N P + nA$$

$$\frac{dA}{dt} = -\mu max_P f_P(I) L_P^A P - nA + l_{BM} Z + l_E \frac{P^2}{k_P + P^2} \beta Z + r_{DSN} D_S^N + r_{DLN} D_L^N + \alpha T$$

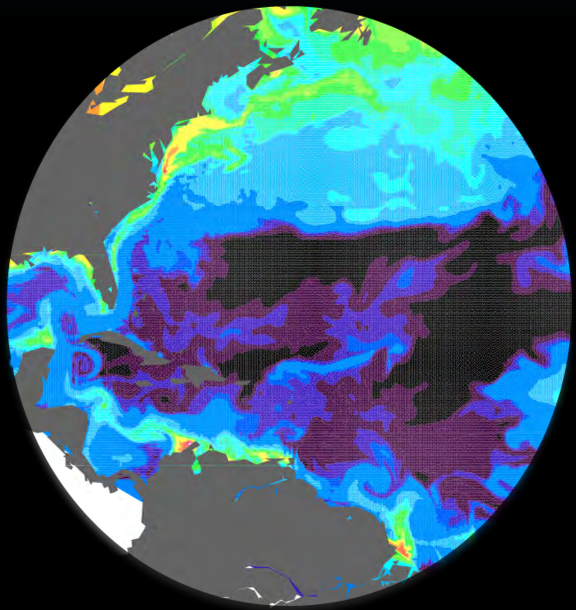
$$\frac{dDIP}{dt} = -\mu max_P f_P(I) L_P^P P - \mu max_T f_T(I) L_T^P T + l_{BM} Z + l_E \frac{P^2}{k_P + P^2} \beta Z + r_{DSP} D_S^P + r_{DLP} D_L^P$$

$$\frac{dD_S^N}{dt} = m_P P + m_T T + m_Z Z^2 - \tau(D_S^N + P) D_S^N - r_{DSN} D_S^N$$

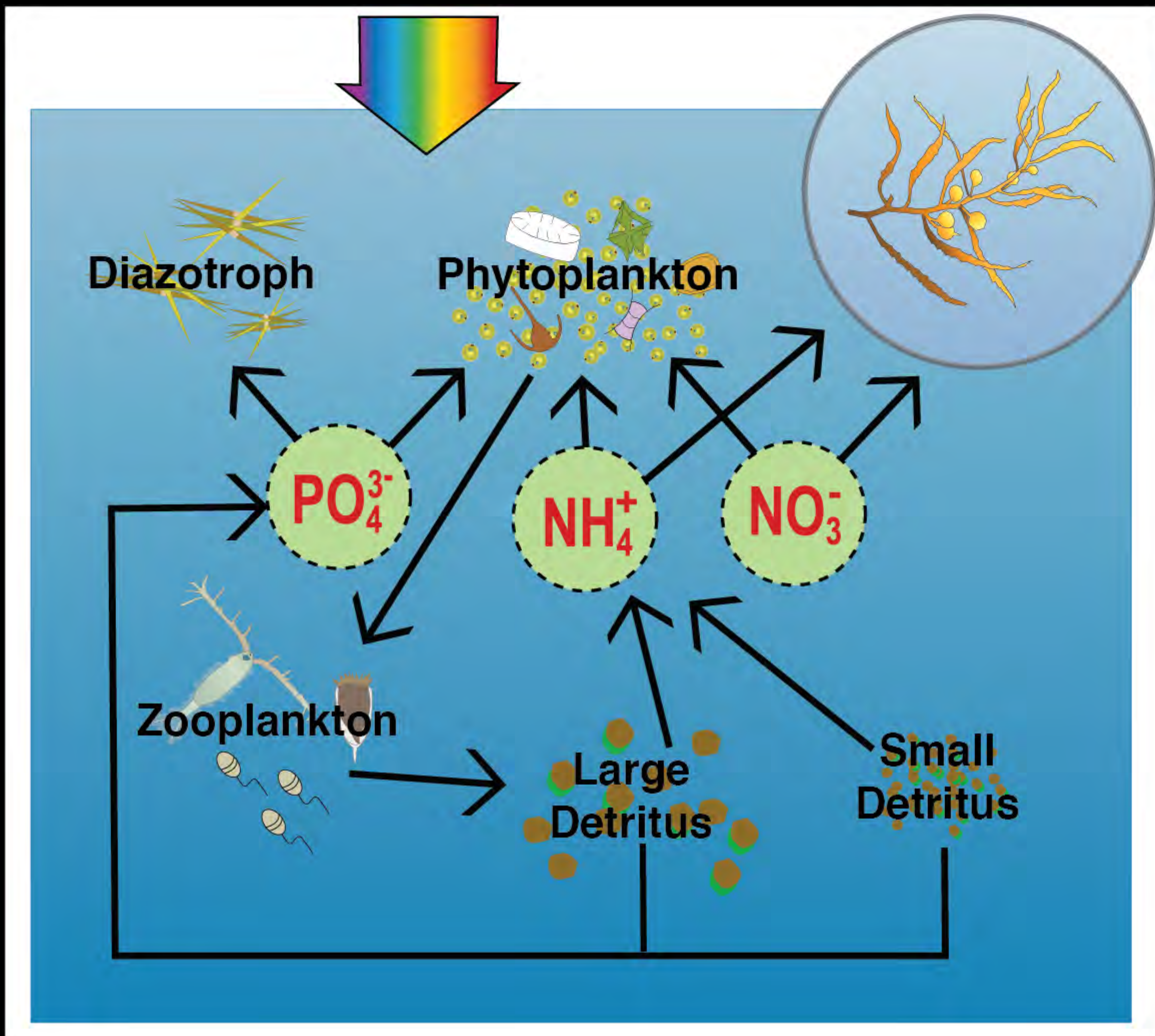
$$\frac{dD_S^P}{dt} = m_P P + m_T T + m_Z Z^2 - \tau(D_S^N + P) D_S^N - r_{DSP} D_S^P$$

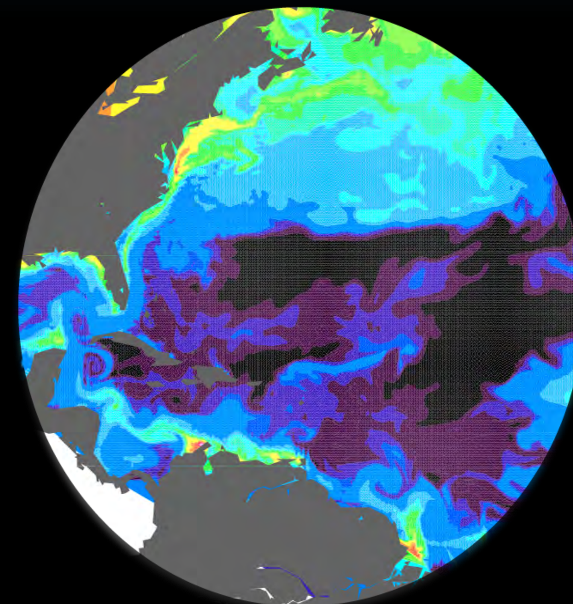
$$\frac{dD_L^N}{dt} = \tau(Ds + P)^2 + \tau_T T^2 - r_{DLN} D_L^N$$

$$\frac{dD_L^P}{dt} = \tau(Ds + P)^2 + \tau_T T^2 - r_{DLP} D_L^P$$

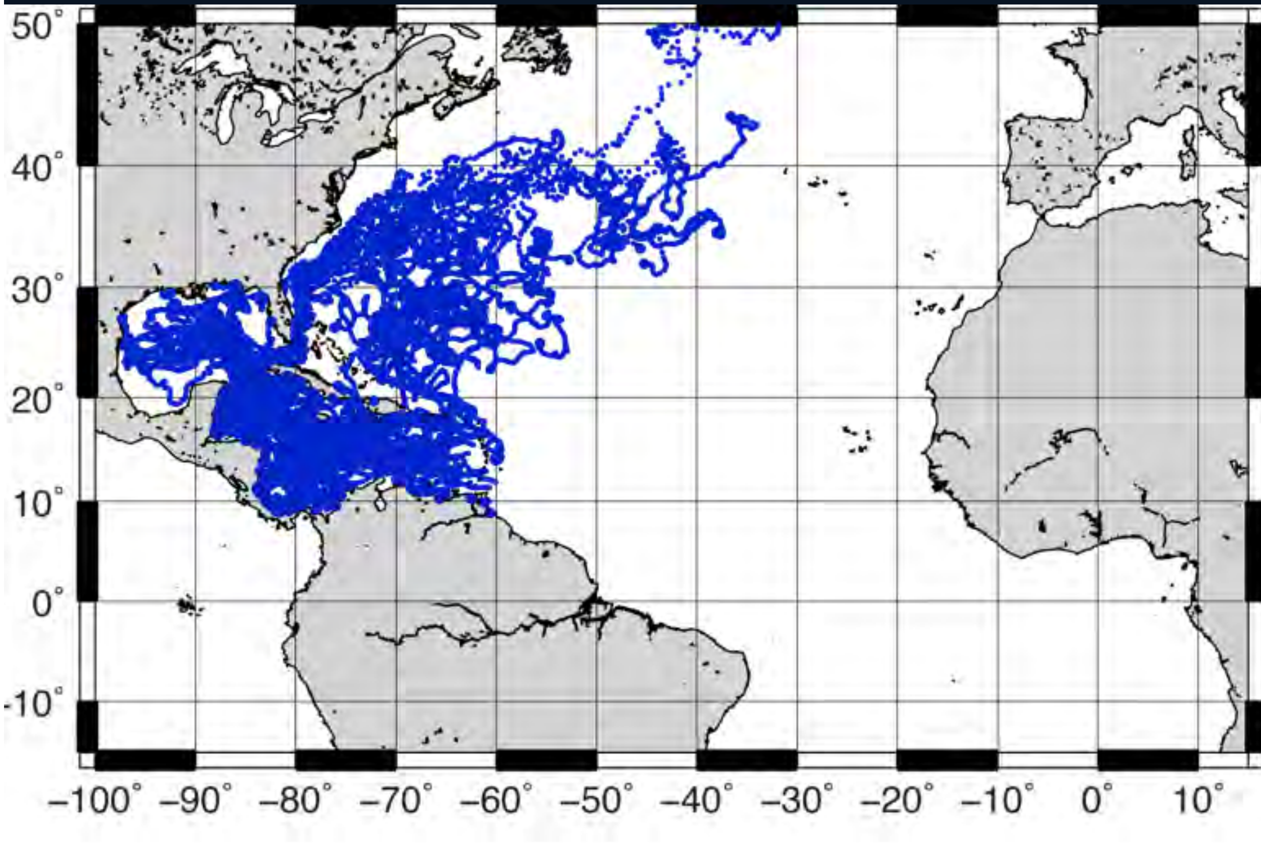


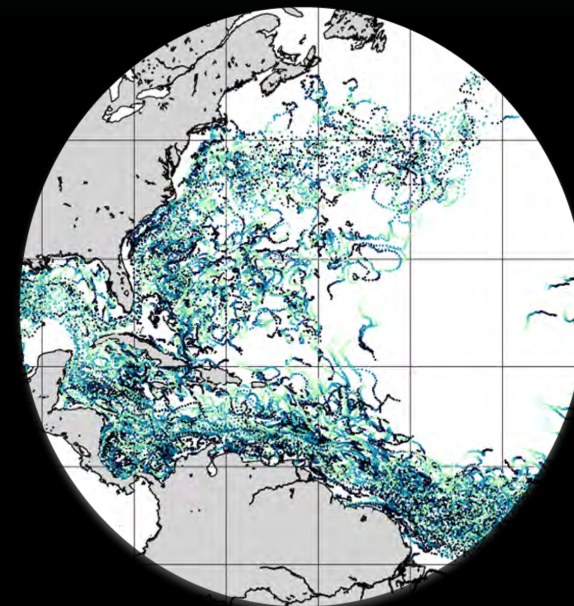
Model System: Biogeochemistry





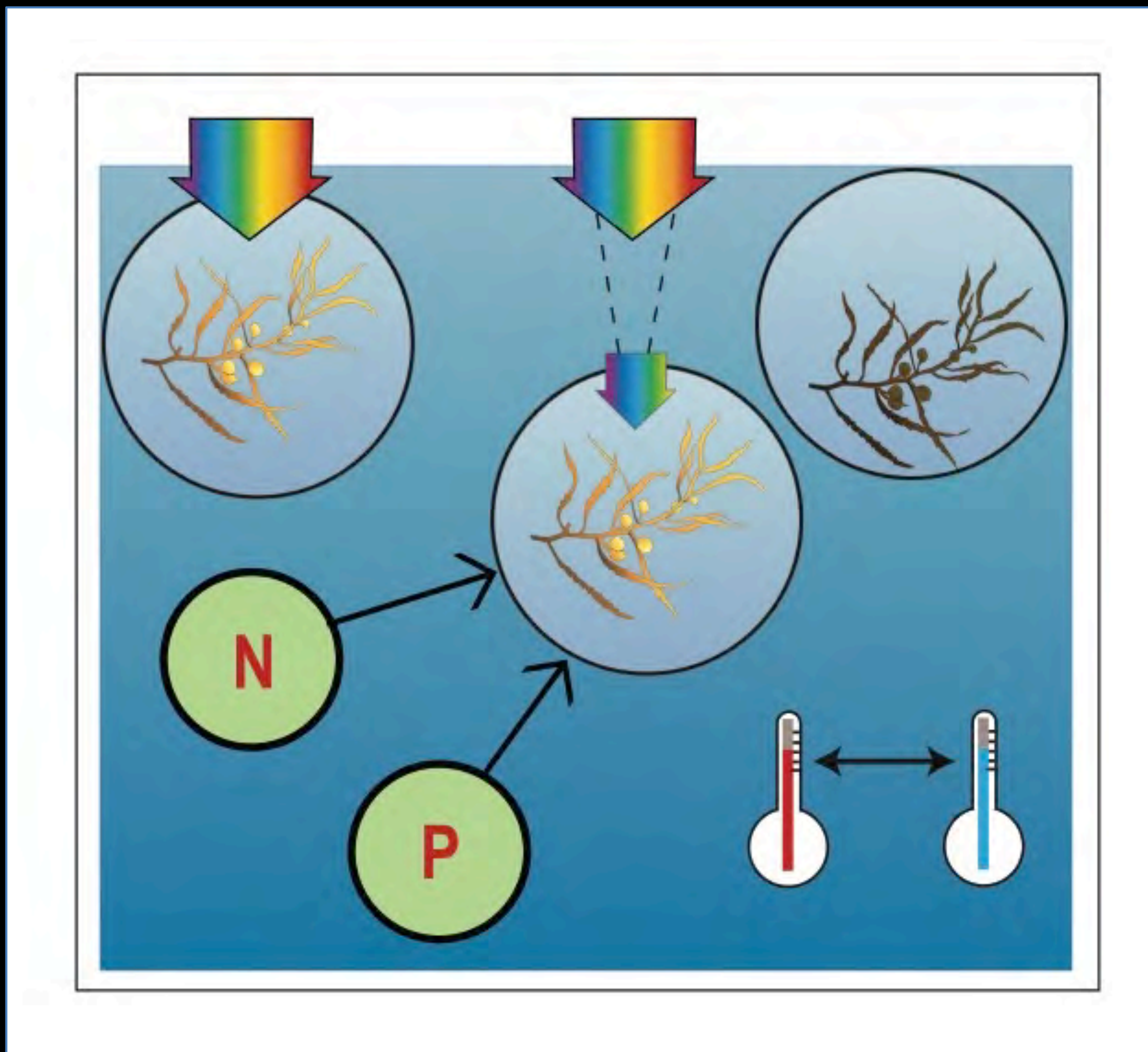
Model System: Lagrangian Particles





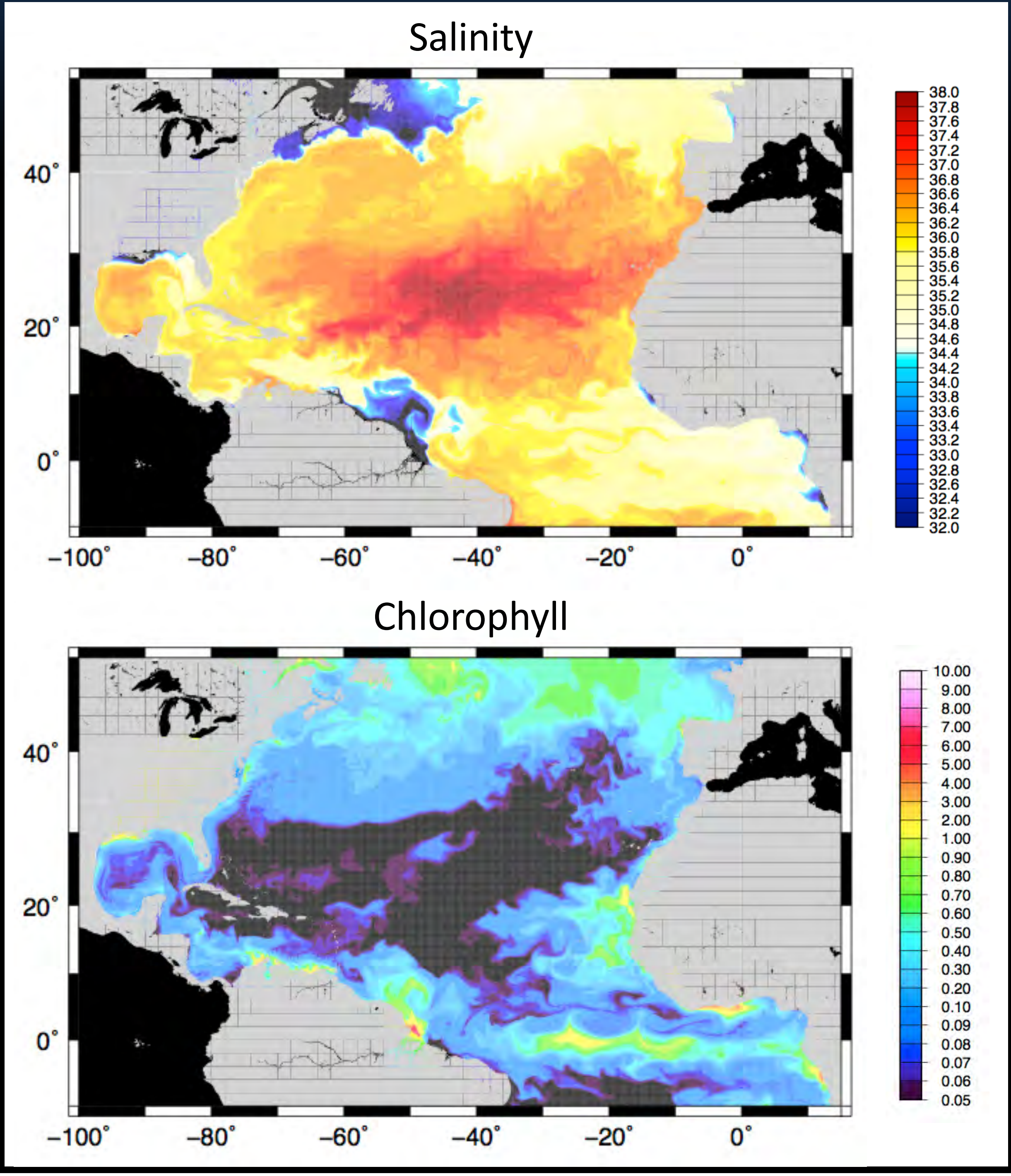
- One-way coupling advects particles with velocities from HYCOM
- Positive buoyancy of 0.1 m/s to simulate buoyant *Sargassum*
- Typical initializations include ~50,000 particles
- Capable of forward- and backward-time simulations
- Samples fields from the biogeochemical model as well as the physics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

Model System: *Sargassum* physiology

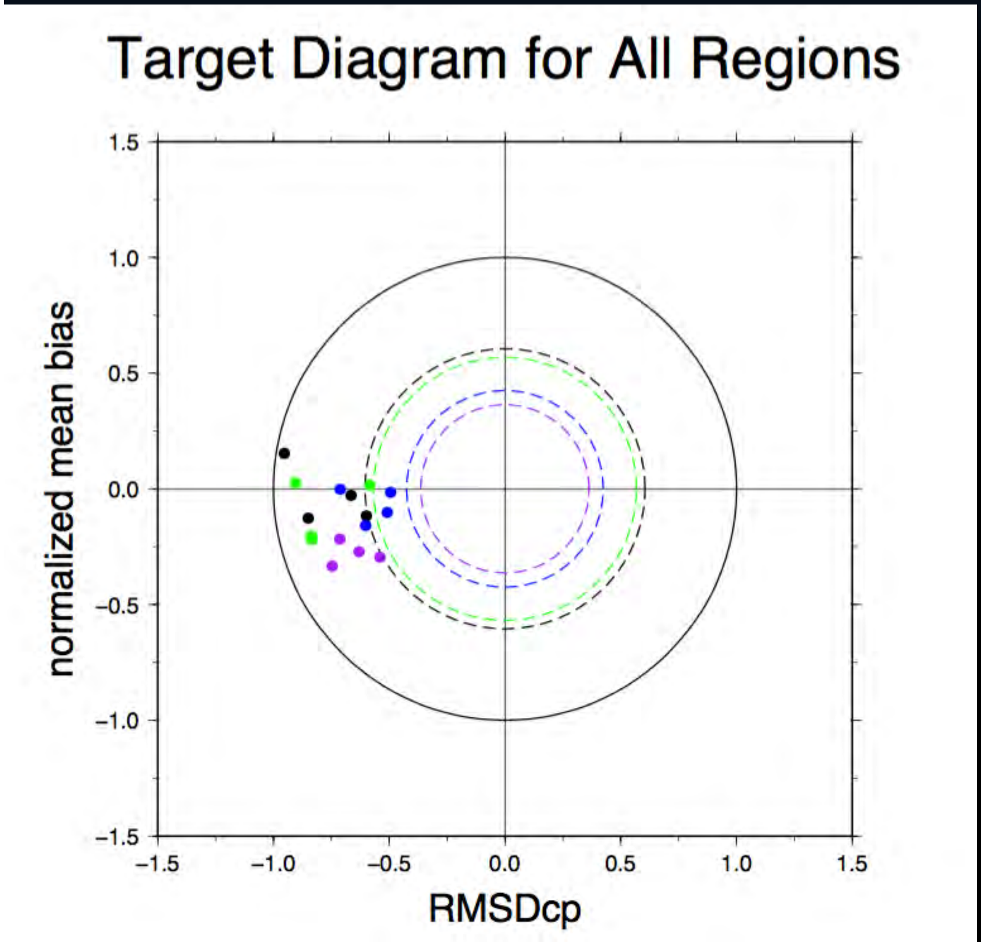


Model System: on Blue Waters

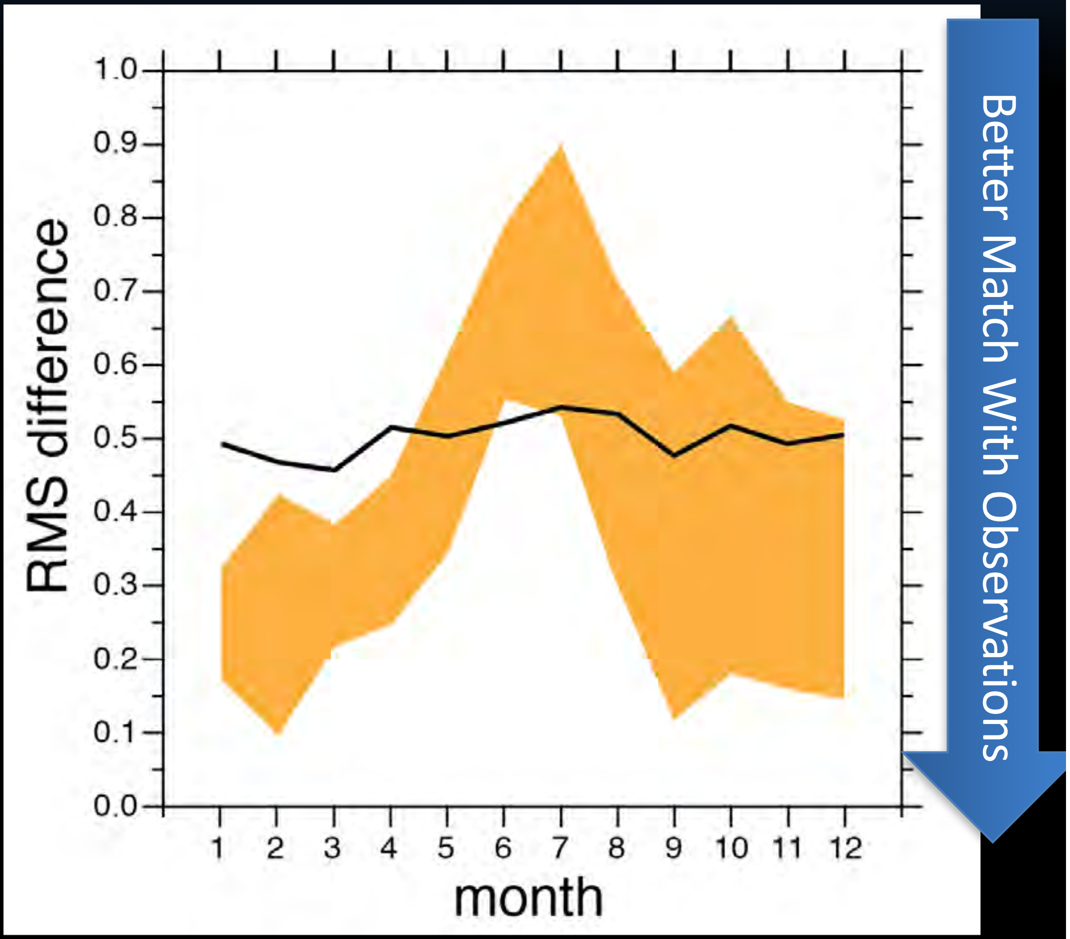
- 4096 tiles
- 128 nodes
- ~120 core hours per model day for physics only
- ~40% higher with biology
- 4GB of output per model day



Model validation with satellite observations

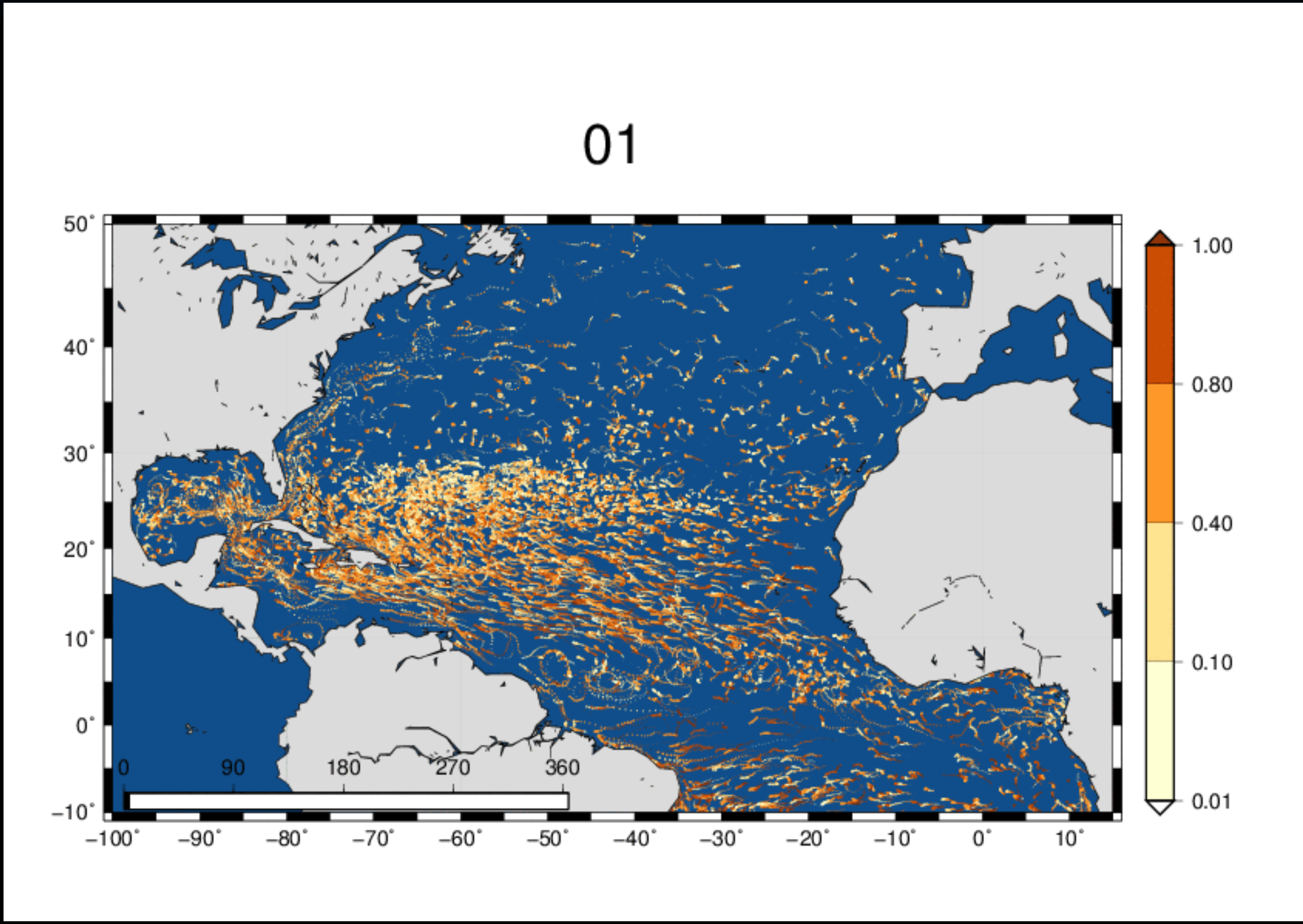


Biogeochemical model

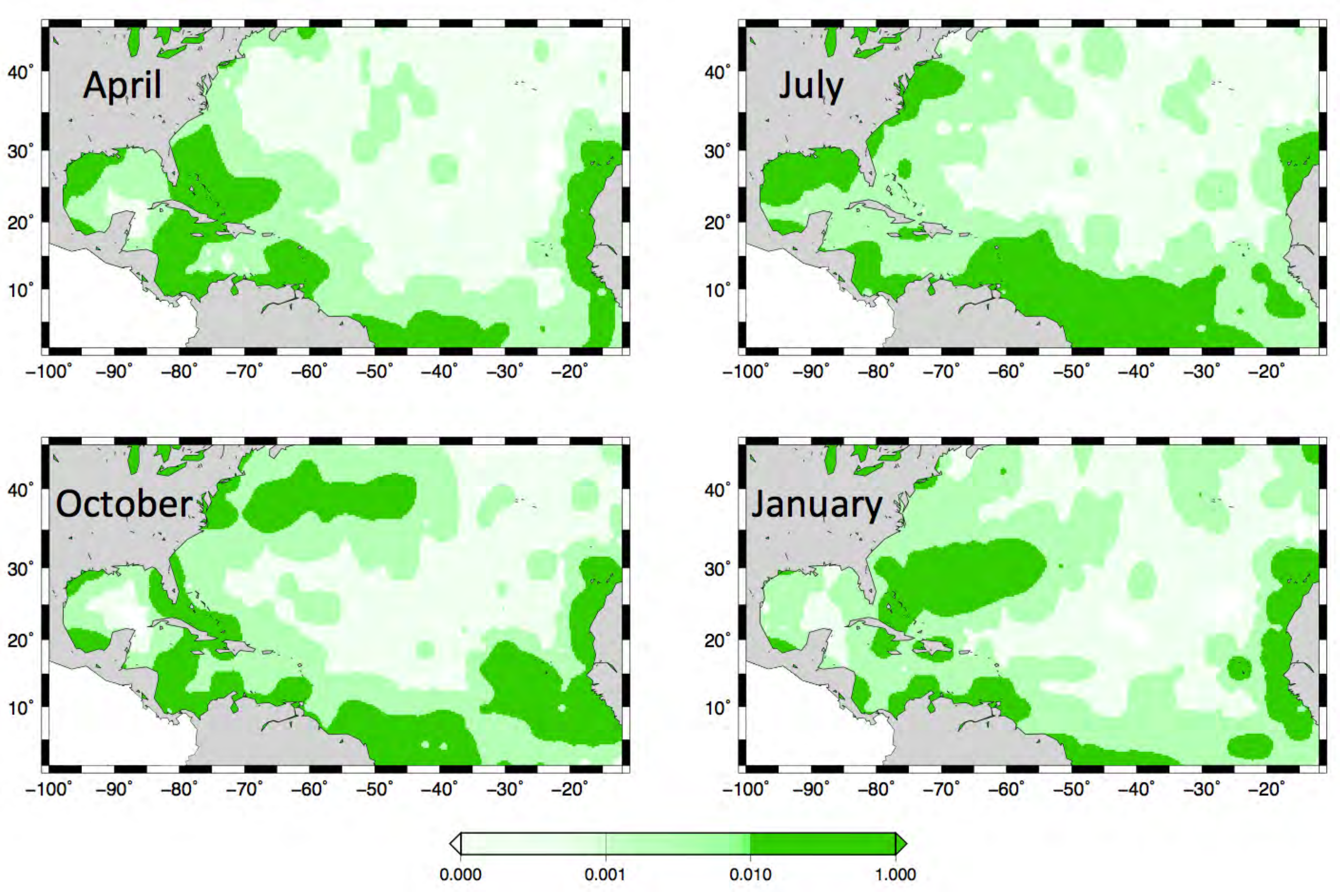


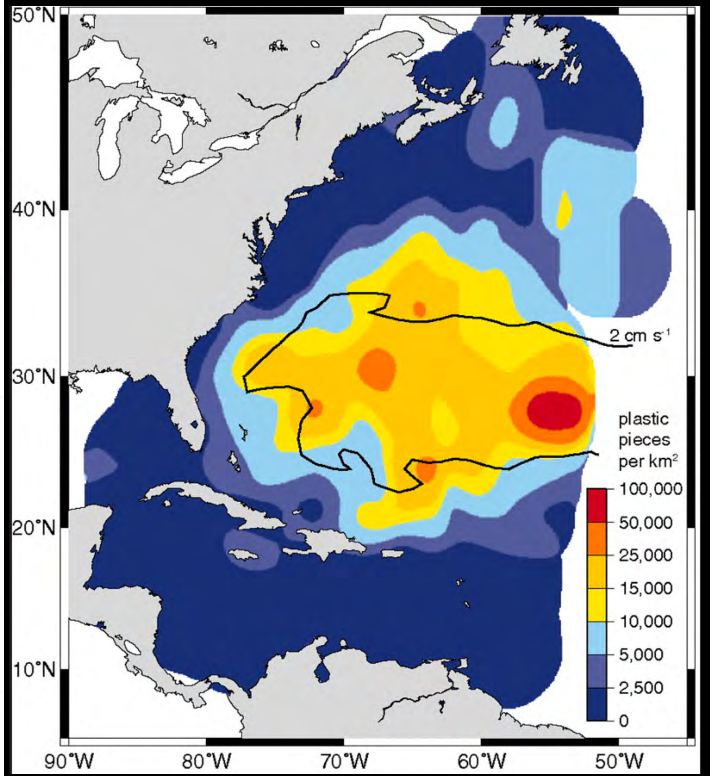
Sargassum model

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?

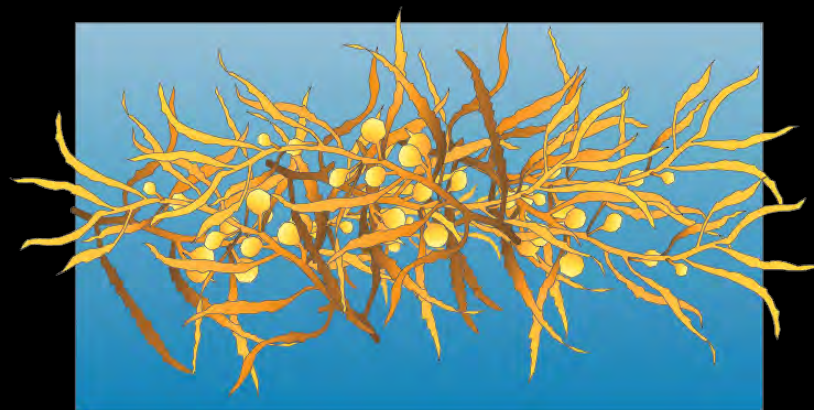




Law et al. 2010

Derived from Gower and King 2011

Hypothesis: Vegetative propagation of *Sargassum* helps maintain its seasonal distribution



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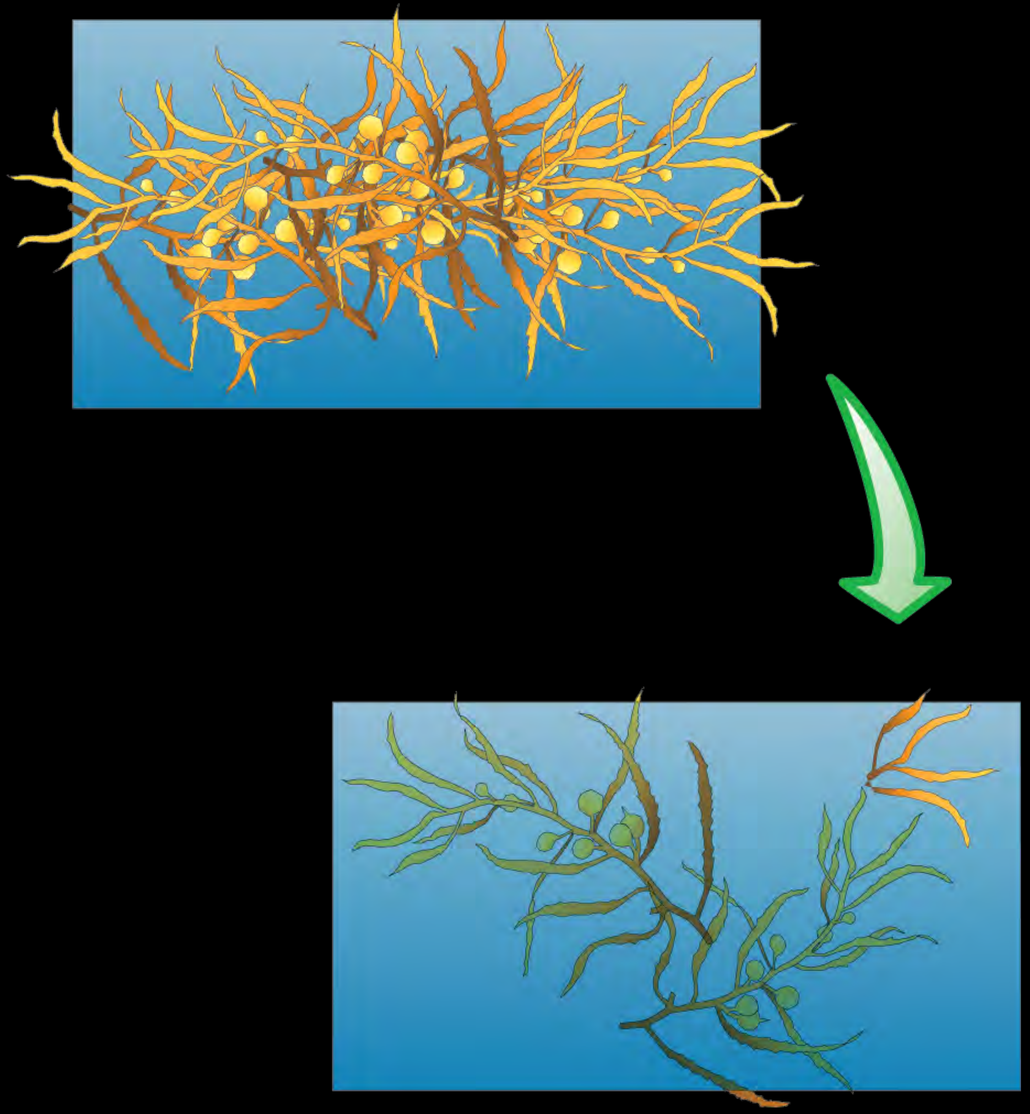

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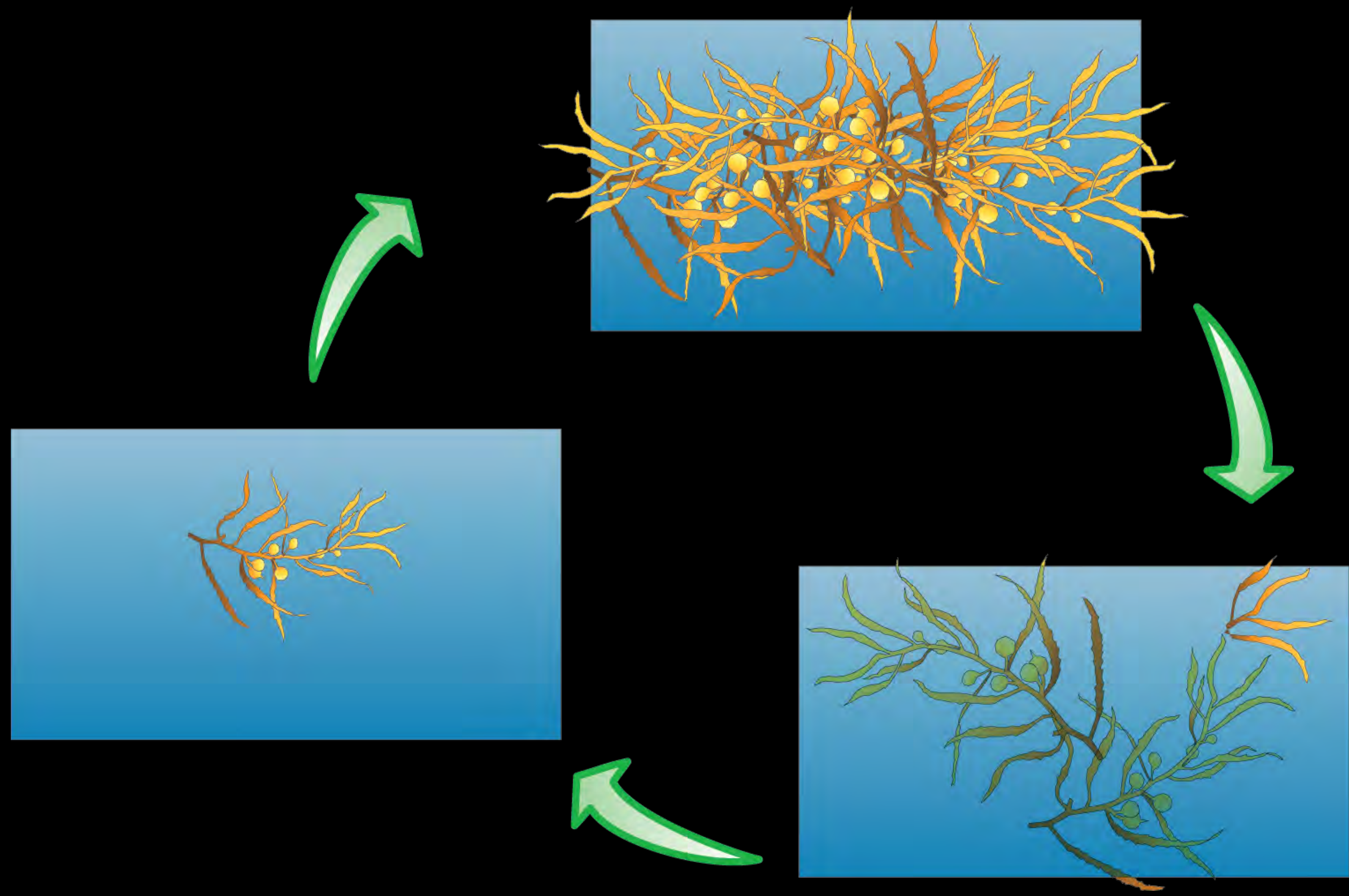
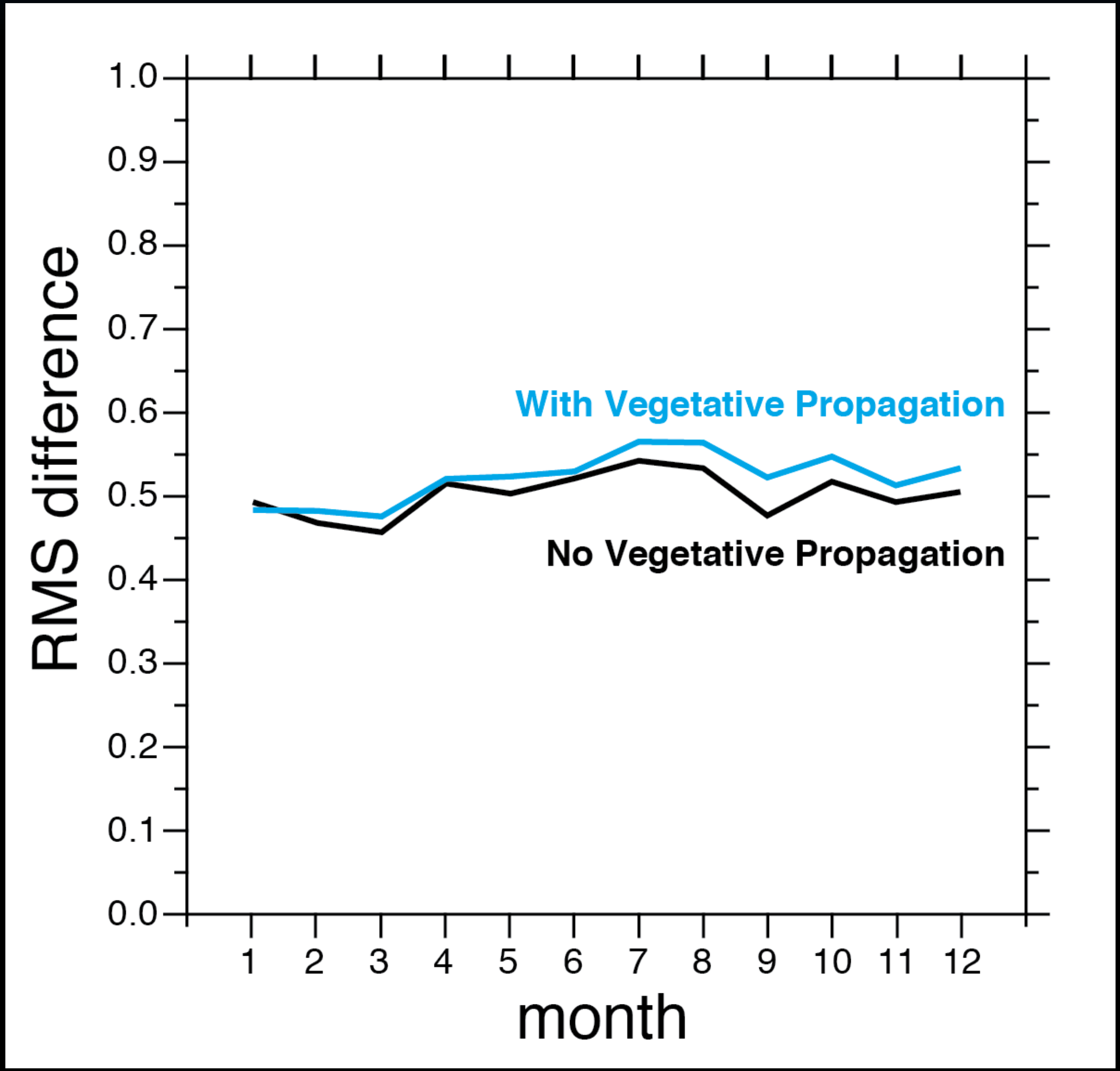
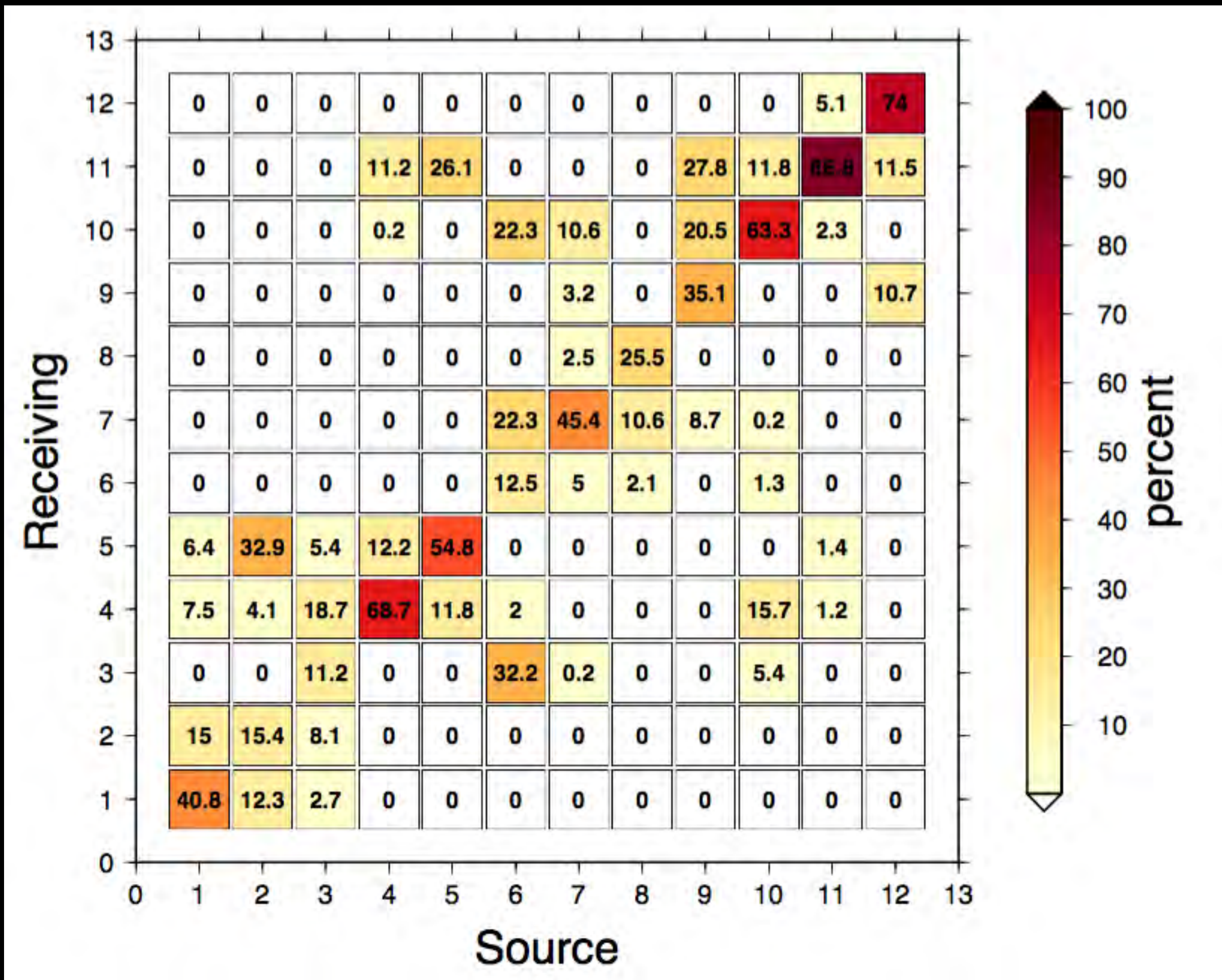


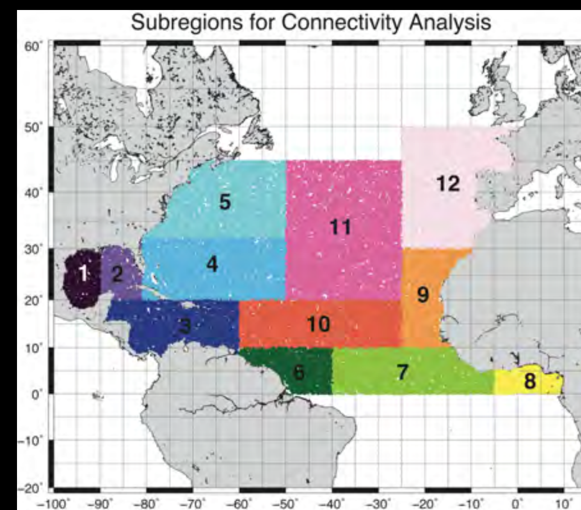
Vegetative propagation doesn't change the seasonal cycle when we are seeding everywhere in the domain



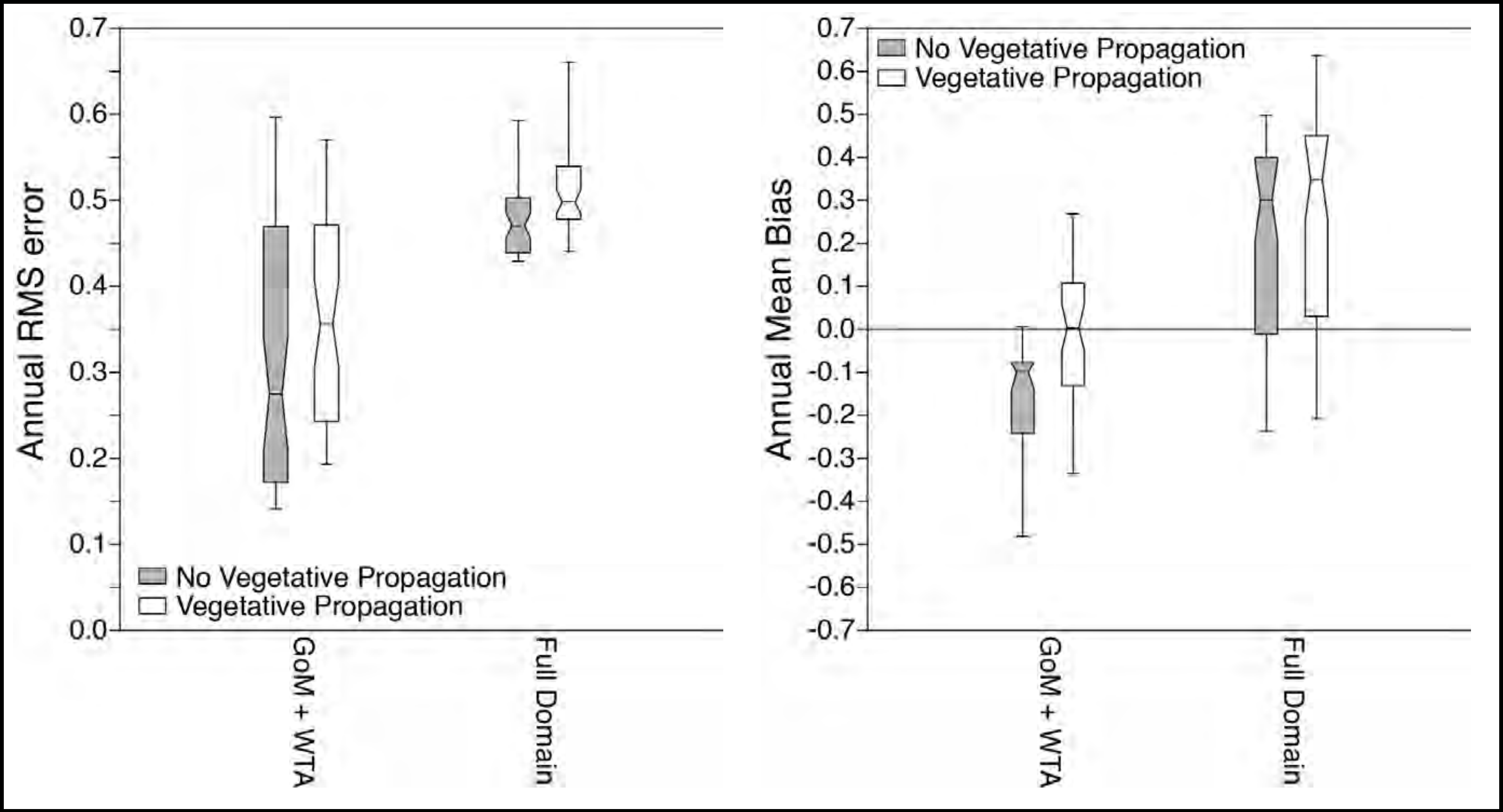
Connectivity between regions highlights major pathways of *Sargassum* transport

Connectivity after 90 days for *Sargassum* seeded in May

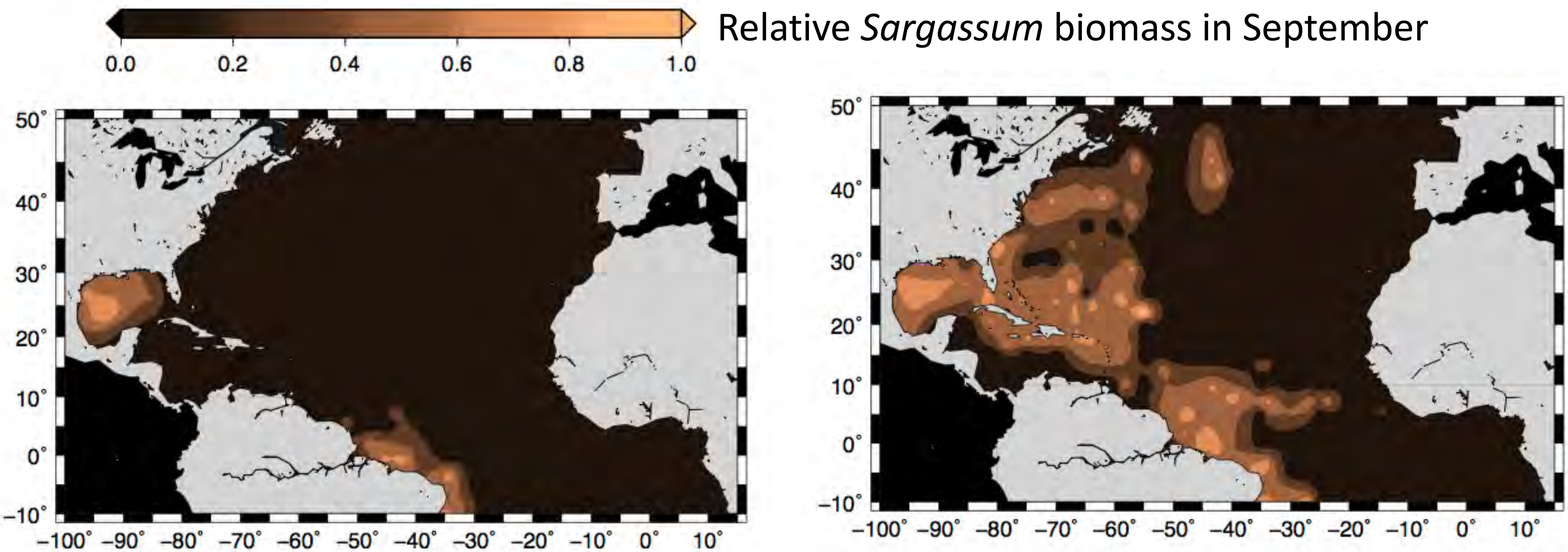




Seeding in GoM and WTA with vegetative propagation gives most realistic results



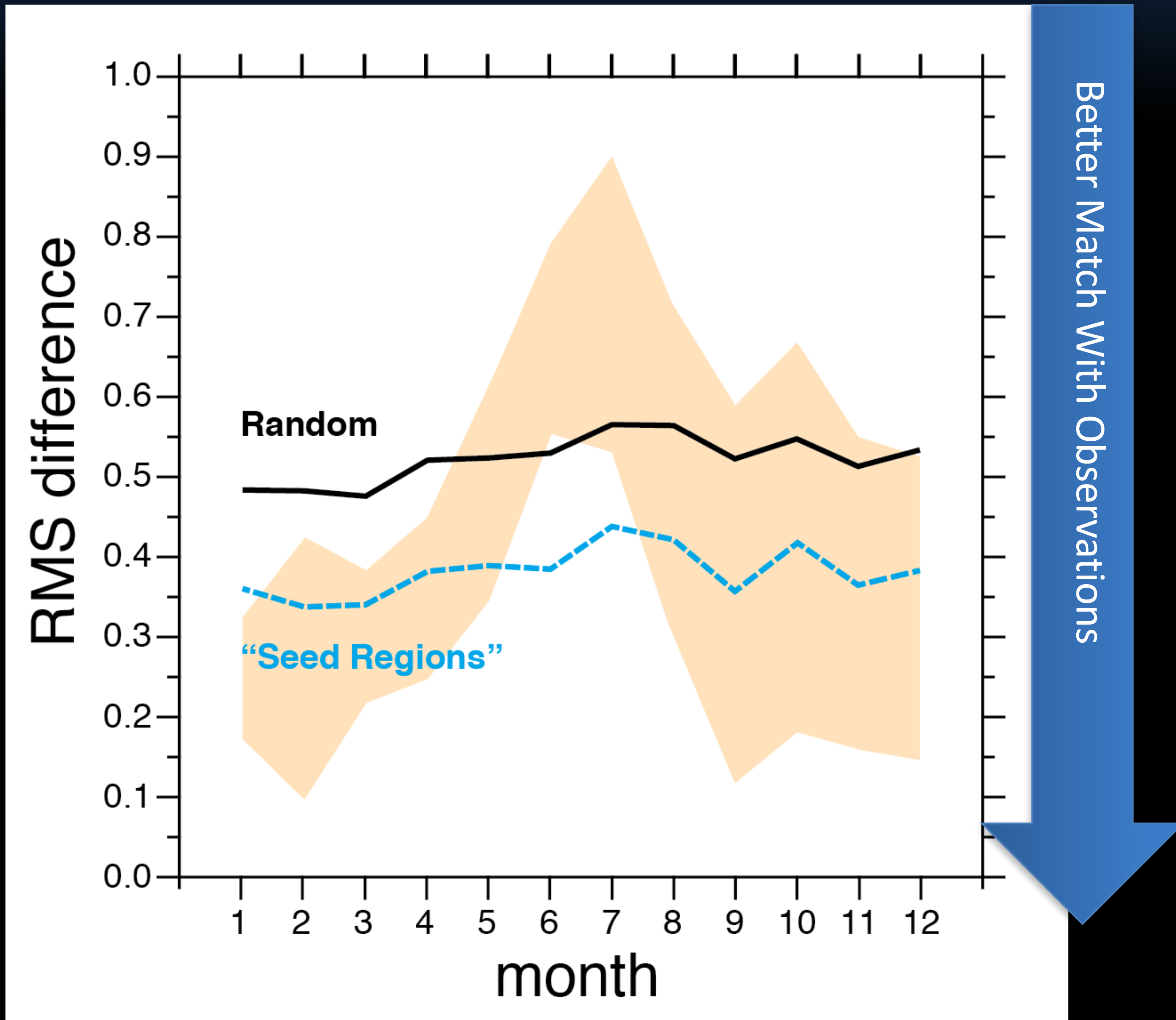
Including both vegetative propagation and seeding in key regions better reproduces the observed distribution



Without vegetative propagation

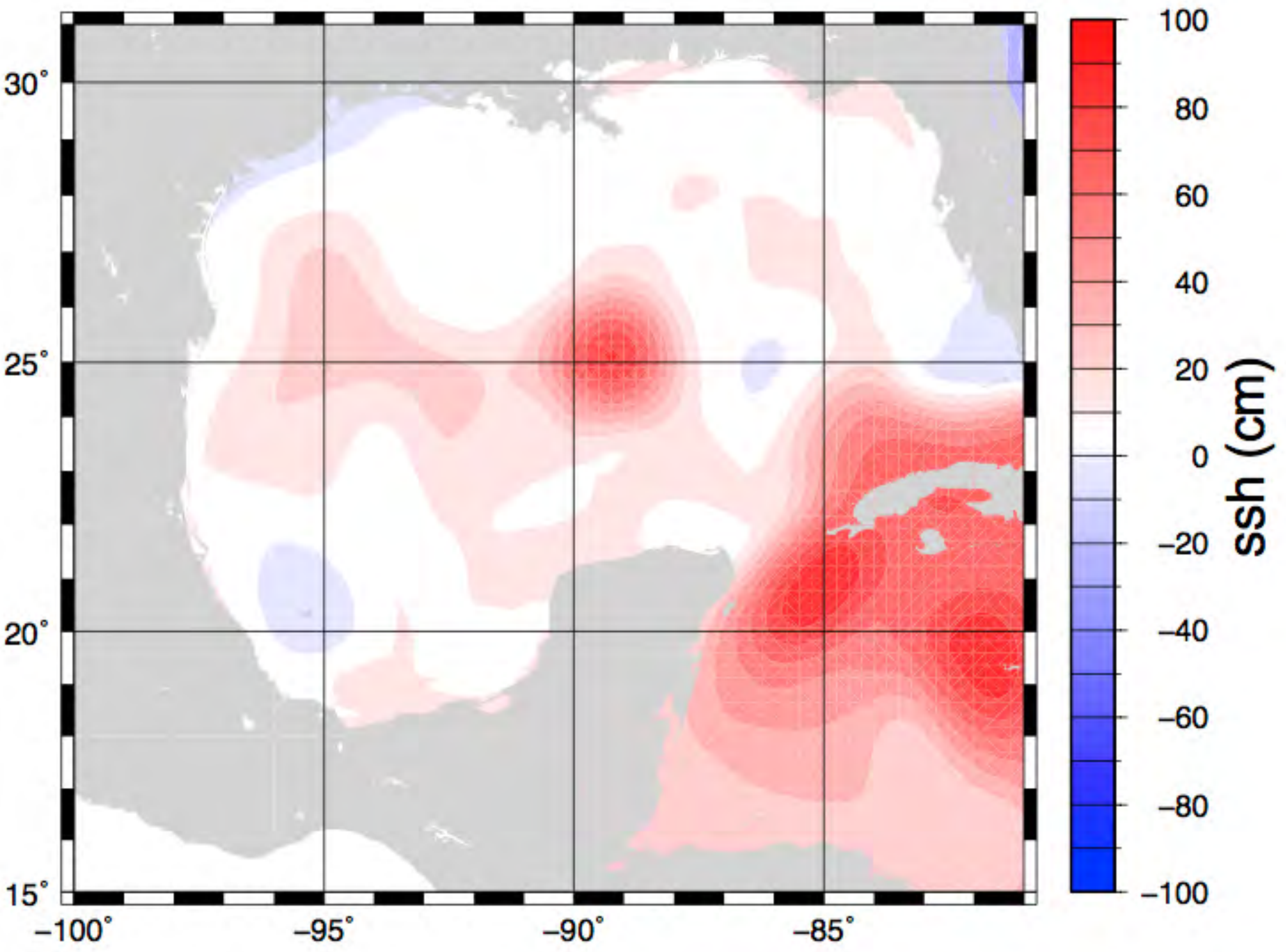
With vegetative propagation

This model paradigm functions well over the seasonal cycle



With vegetative propagation

How do physics and biology interact in the Gulf of Mexico?



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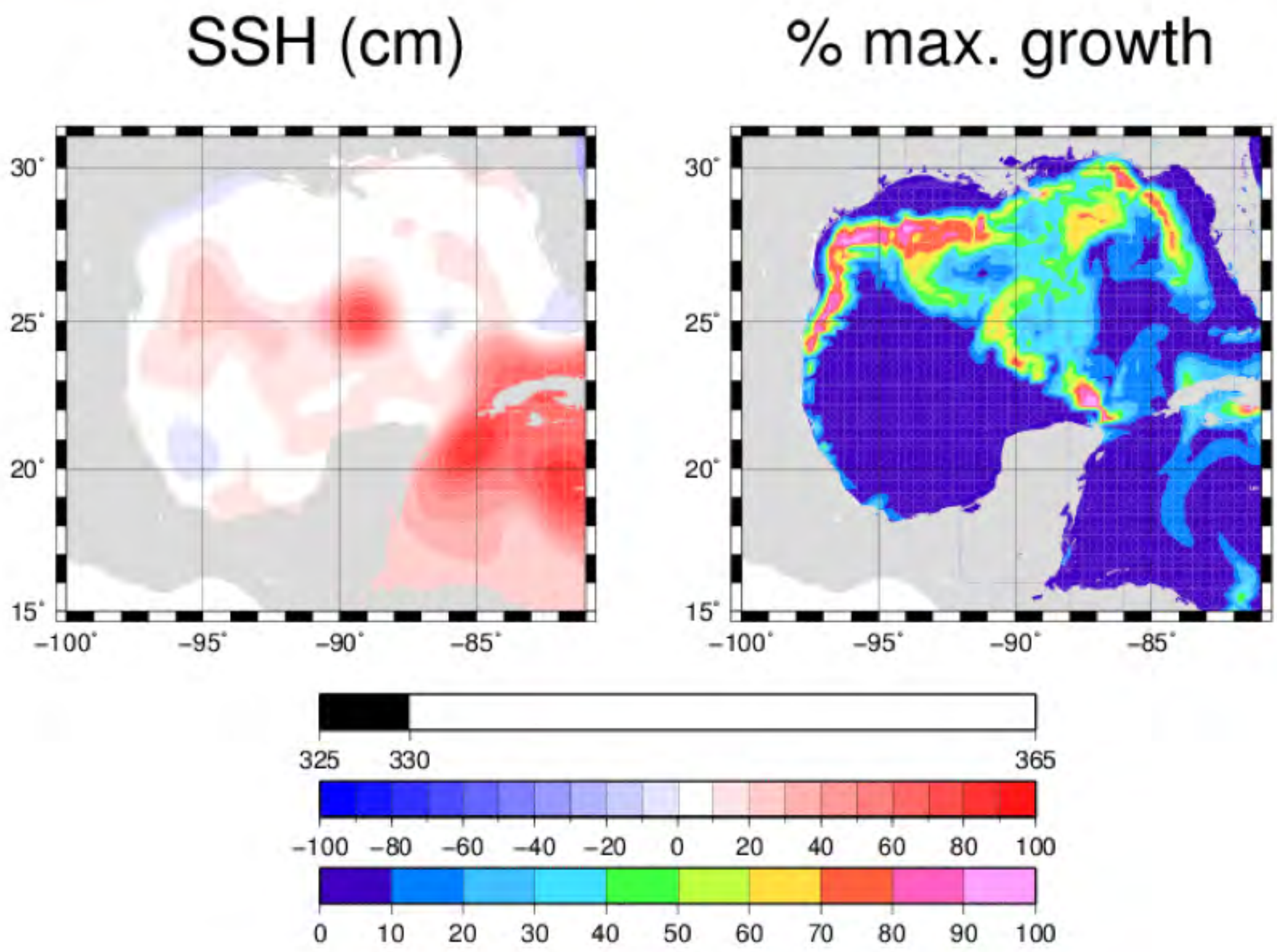

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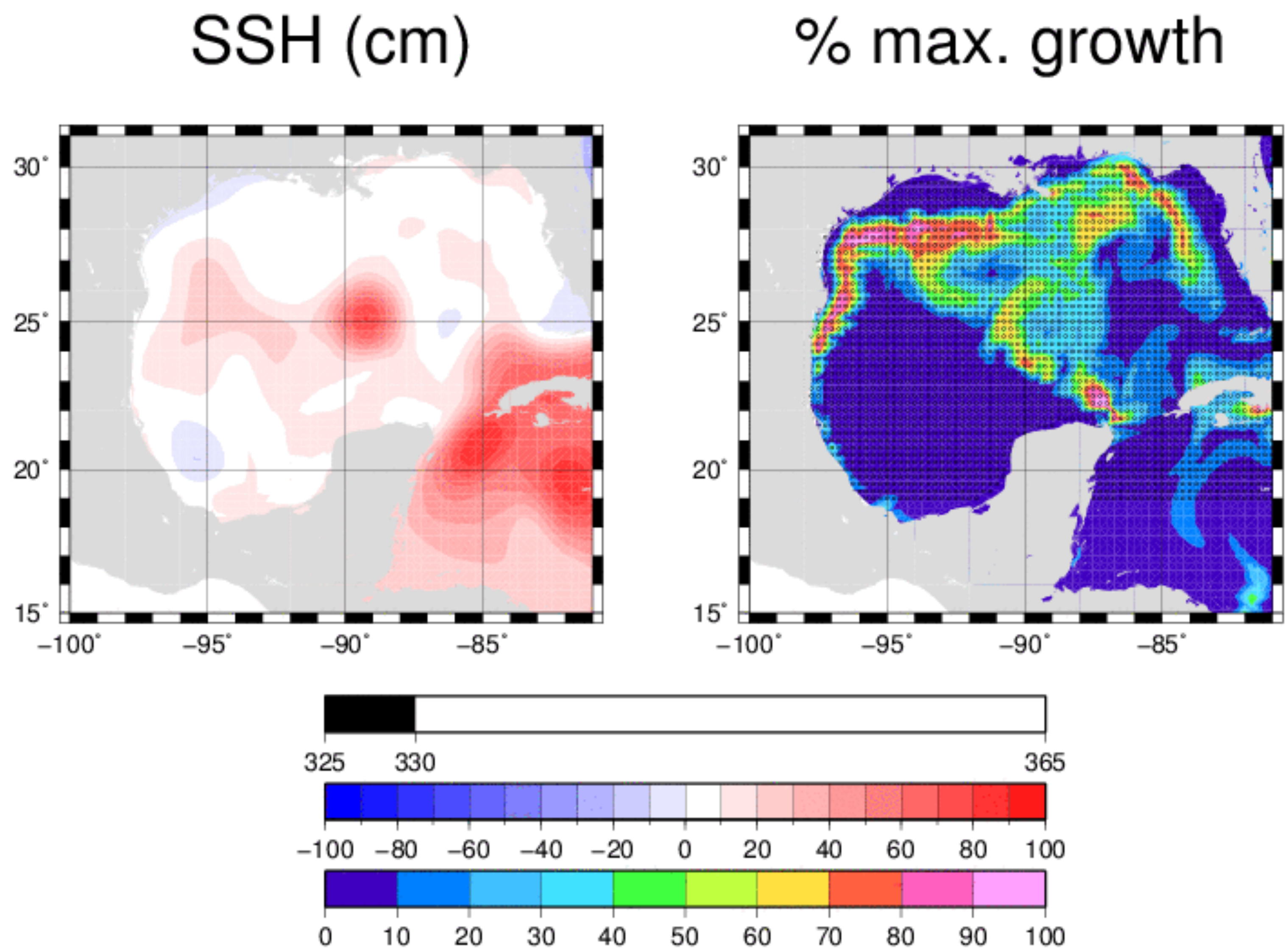

Conclusions

- 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

Mariana C. León

mbrooks@umces.edu

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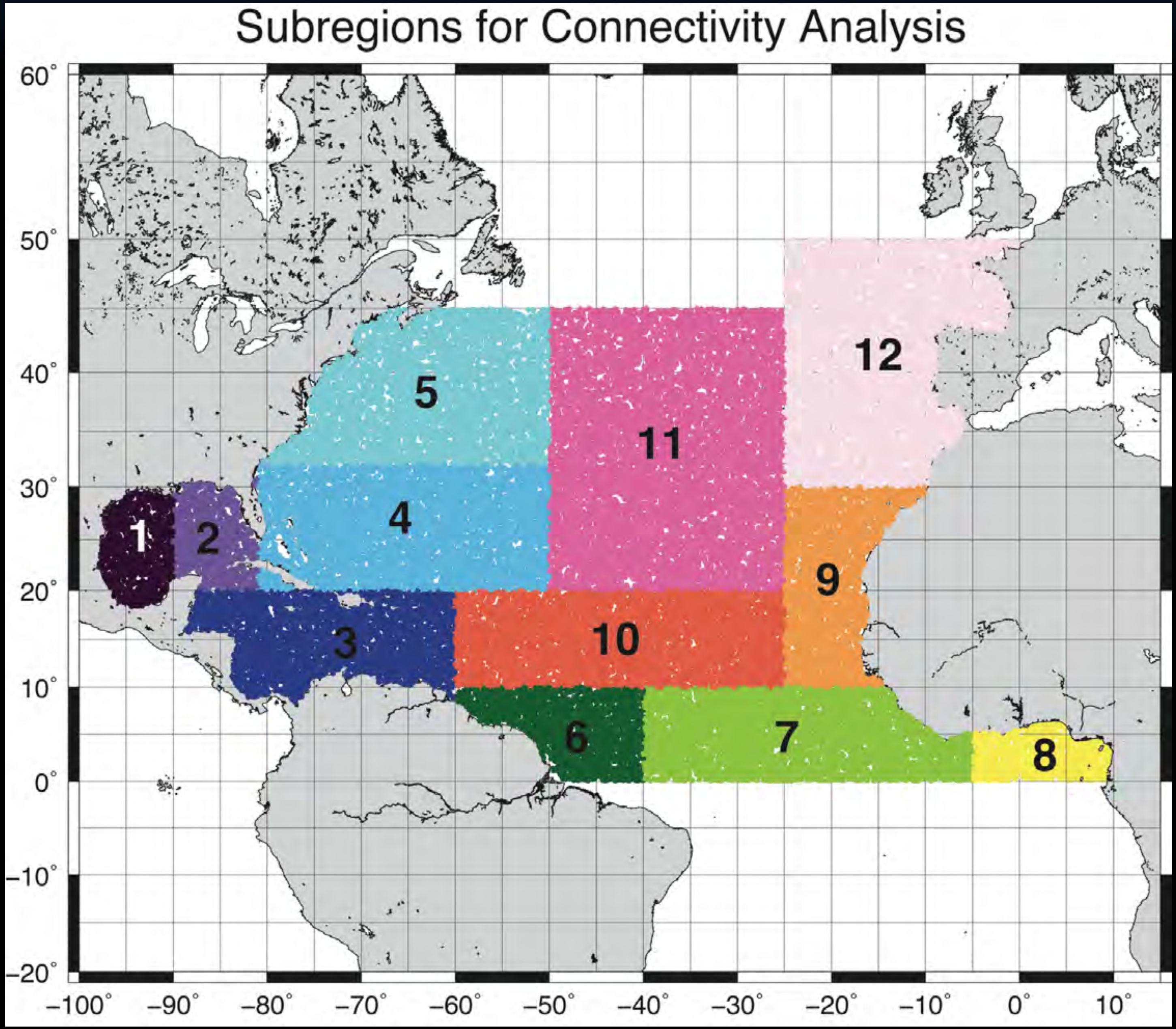
Connectivity between regions highlights major pathways of *Sargassum* transport



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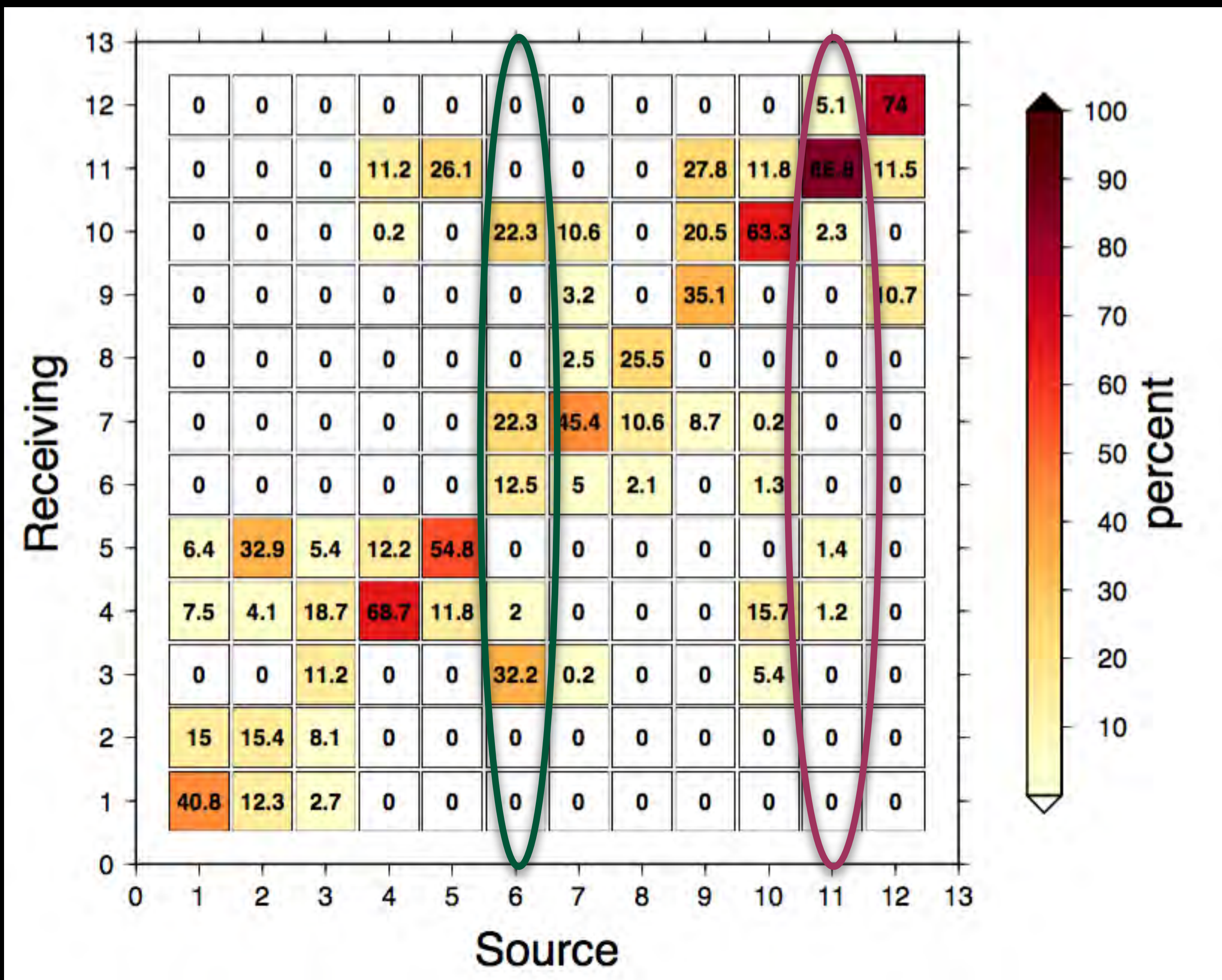
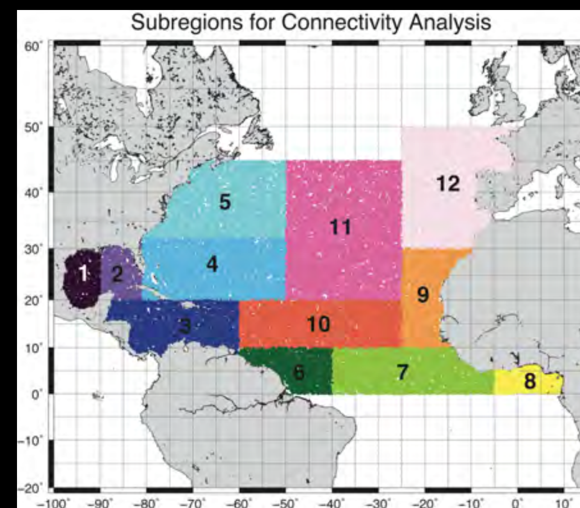
Connectivity after 90 days for particles launched in May





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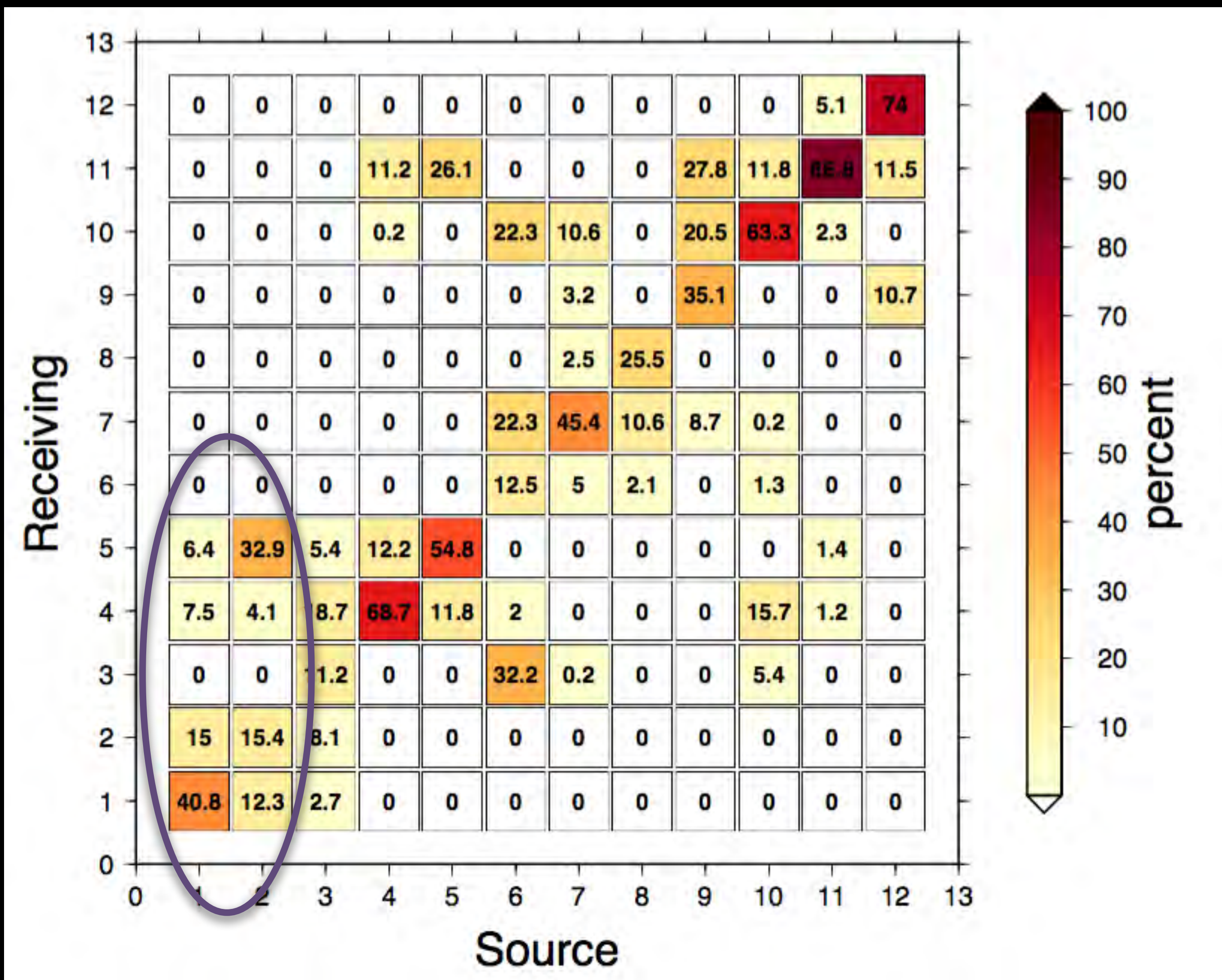
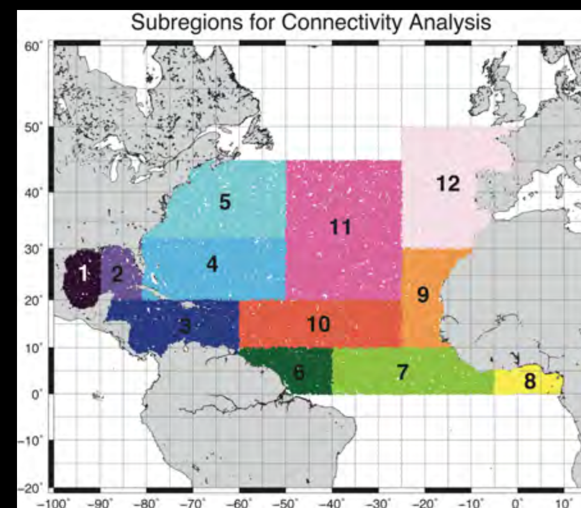
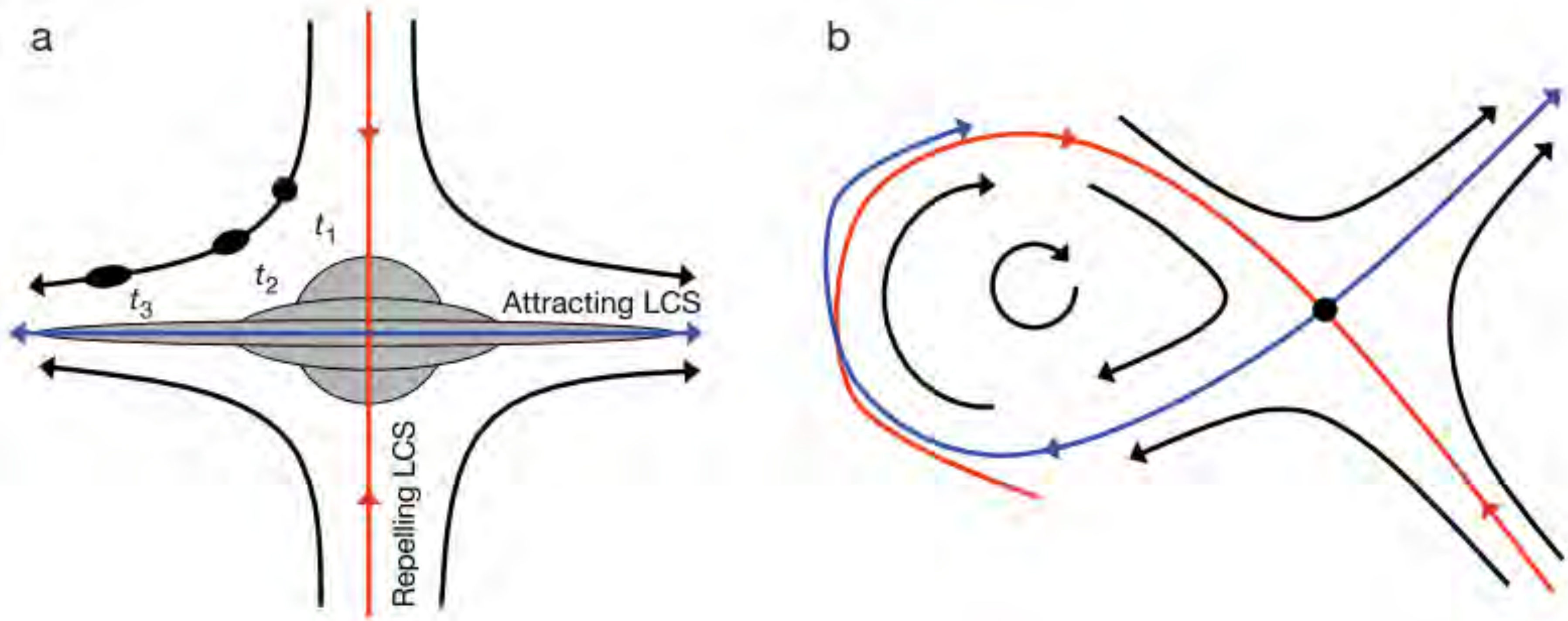


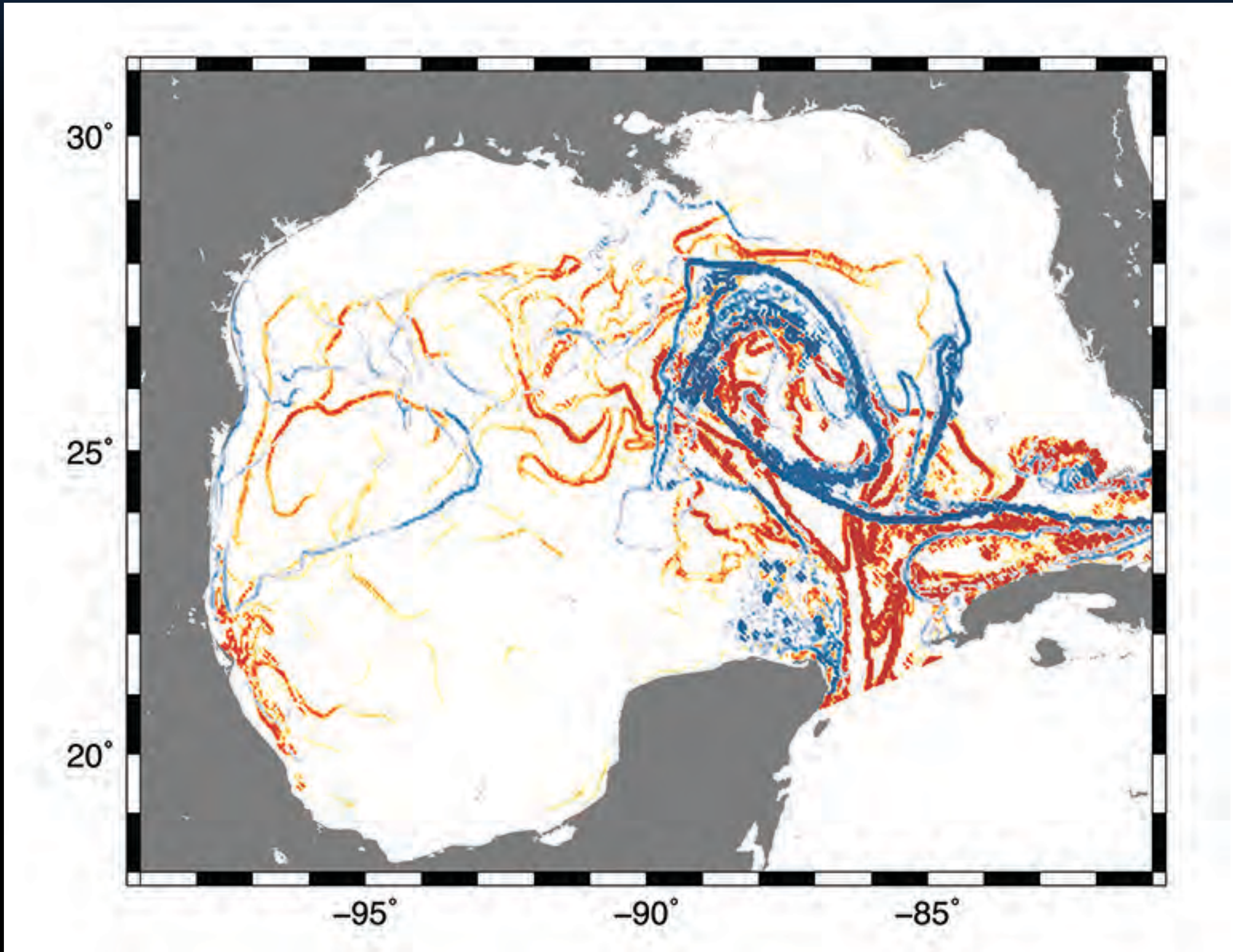


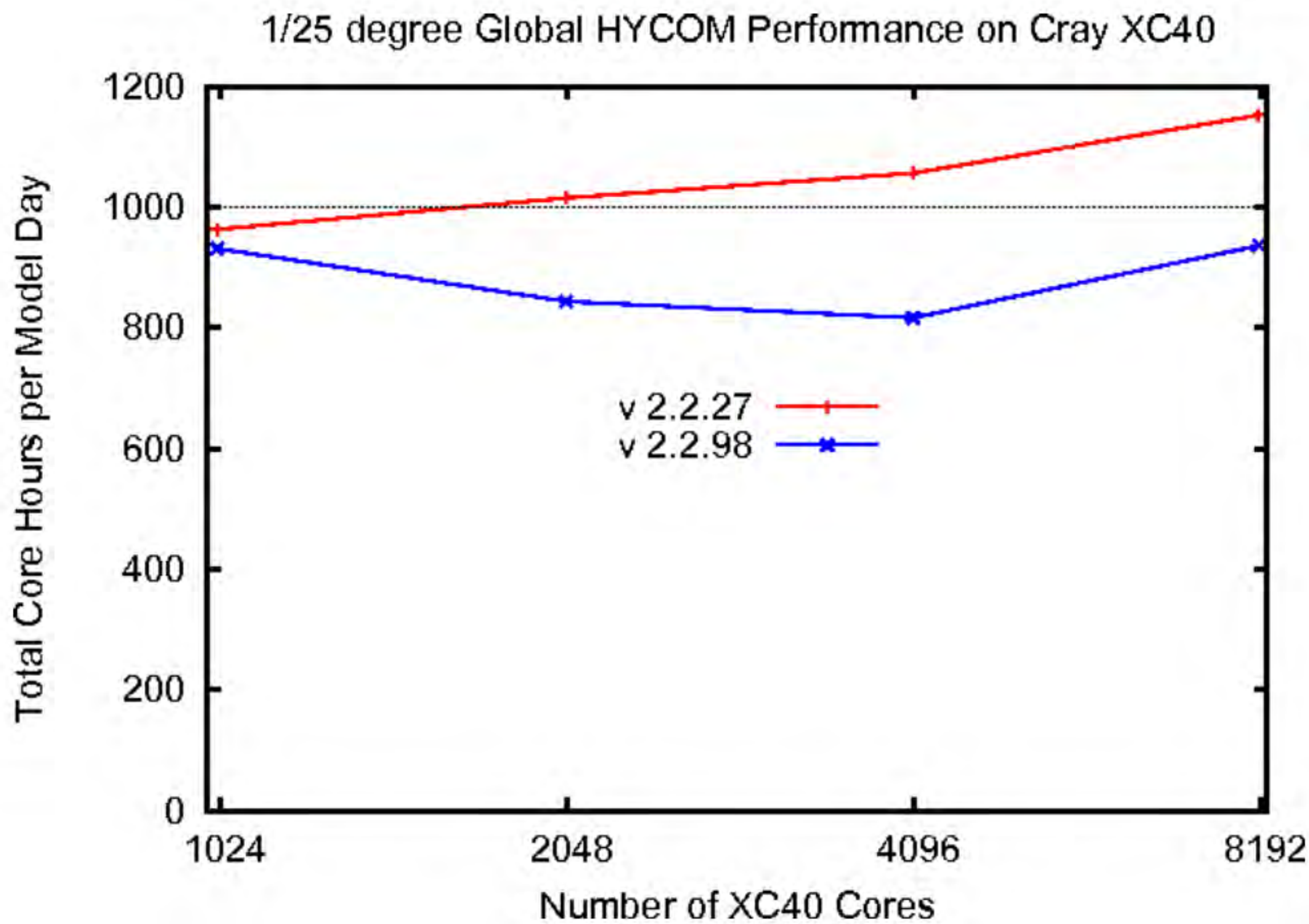
Lagrangian Coherent Structure Analysis



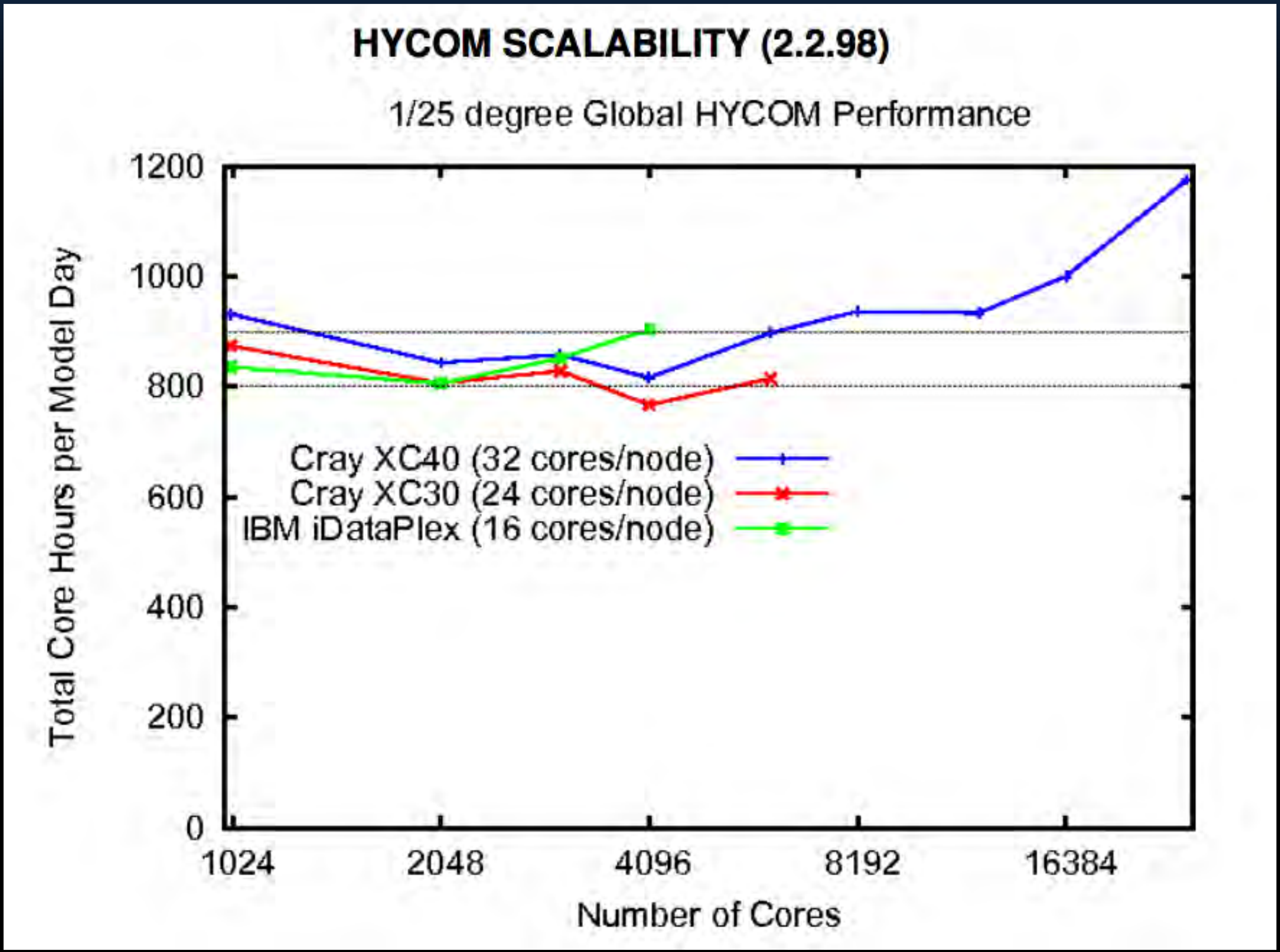
Harrison et al. 2013

Lagrangian Coherent Structure Analysis





- **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
0
200
400
600
800
1000
1200
1024
2048
4096
8192
16384
Cray XC40 (32 cores/node)
Cray XC30 (24 cores/node)
IBM iDataPlex (16 cores/node)