Modeling Chesapeake Bay

Raleigh Hood

CSDMS Annual Meeting

May 26, 2015

University of Maryland
CENTER FOR ENVIRONMENTAL SCIENCE
HORN POINT LABORATORY

Some Examples of Some of the Modeling-Oriented Research that Raleigh Hood and Colleagues Have Done in Chesapeake Bay Over the Last 20 Years

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Outline:

- Individual based modeling
- Ecological forecasting
- Modeling hypoxia (Here comes the data)

Theme: Using 3-dimensional, time-dependent hydrodynamic models to provide insight into biogeochemical and ecological processes in Chesapeake Bay.

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Individual Based Modeling

Objectives:

Simulate the impact of 3-dimensional currents and mixing on pelagic organisms in Chesapeake Bay and how these interact with behavior to determine their fate.

- Modeling Particles and Pelagic Organisms in Chesapeake Bay: Convergent Features Control Plankton Distributions (Hood et al., 1999)

- Modeling the Influence of Episodic Events on Transport of Striped Bass Eggs to the Estuarine Turbidity Maximum Nursery Area (North, Hood et al., 2005; 2006)

Modeling Particles and Pelagic Organisms in Chesapeake Bay:

Approach:

$$\frac{\partial \mathbf{x}}{\partial t} = \mathbf{U} + \mathbf{u}$$

U = large scale deterministic velocity vector
u = small scale turbulent velocity vector

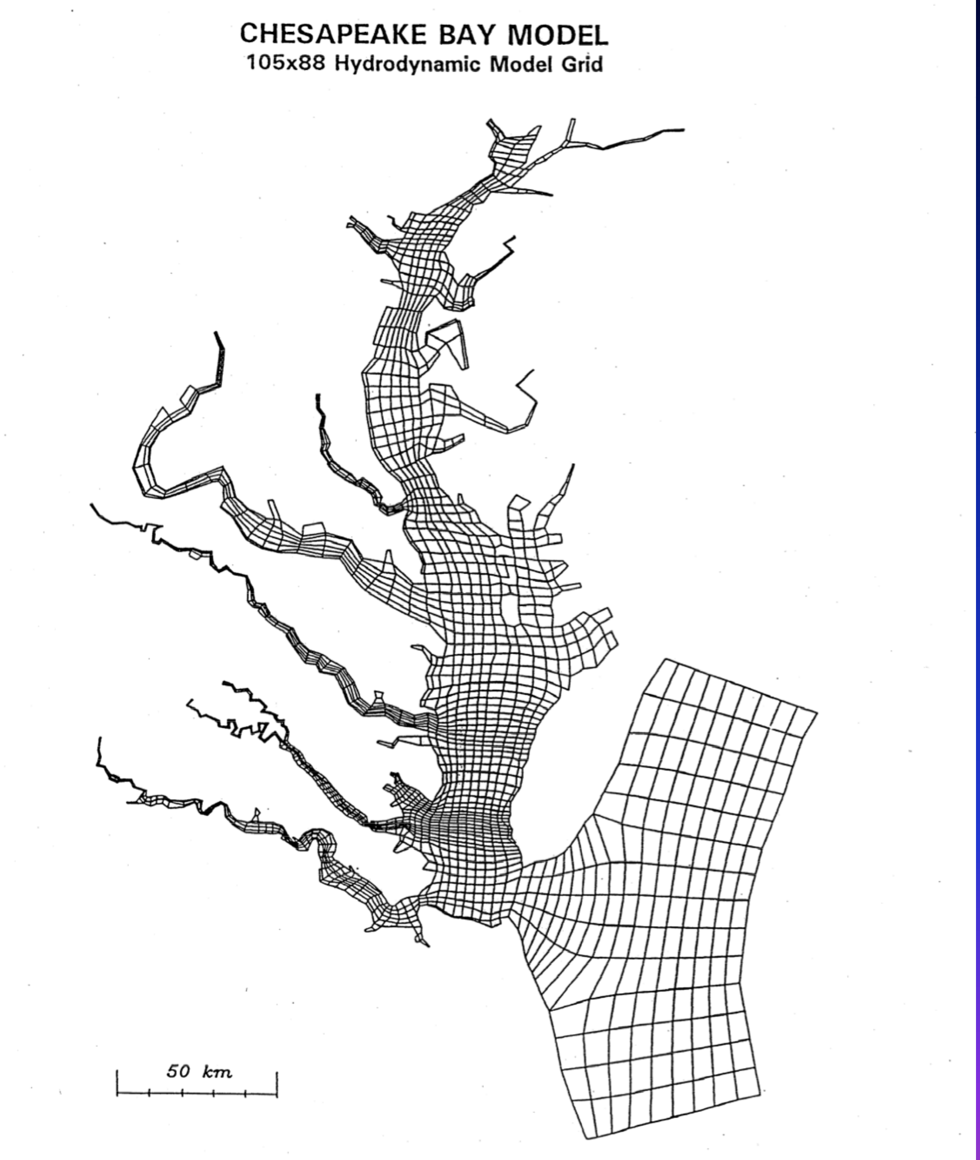
Finite difference: $\Delta x = (U + u)\Delta t$

With sinking or behavior: $\Delta x = (U + u + b)\Delta t$

Hood et al., 1999

Modeling Particles and Pelagic Organisms in Chesapeake Bay:

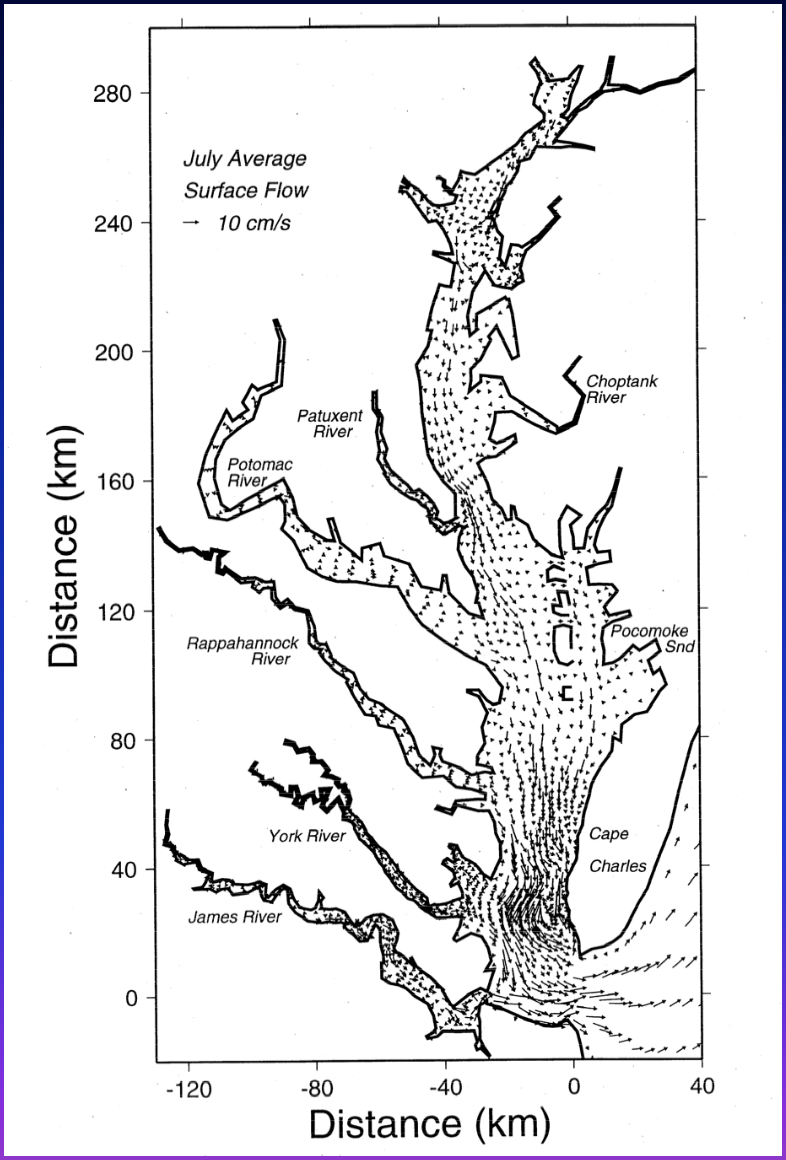
- Earlier version of the Chesapeake Bay hydrodynamic model (CH3D)
- Provides U
- Structured curvilinear grid
- Use a correlated random walk model to specify u



Hood et al., 1999

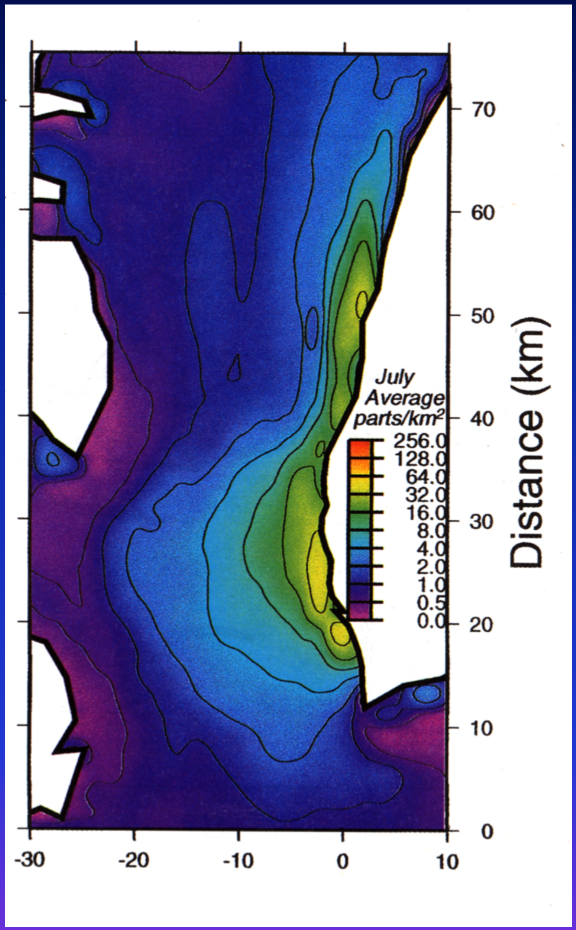
Modeling Particles and Pelagic Organisms in Chesapeake Bay:

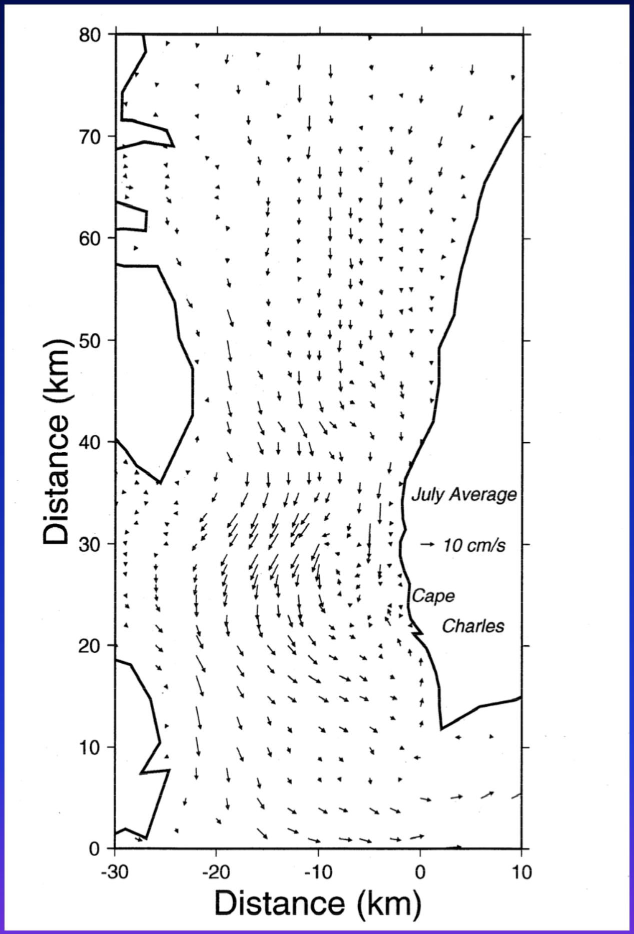
- Residual surface flow in July
- Provides a 2-dimensional velocity field (U)
- For a 2-dimensional application, i.e., bouyant particles on the surface
- Interpolate velocities to particle positions
- Note residual eddy in lower Bay



Hood et al., 1999

Modeling Particles and Pelagic Organisms in Chesapeake Bay:

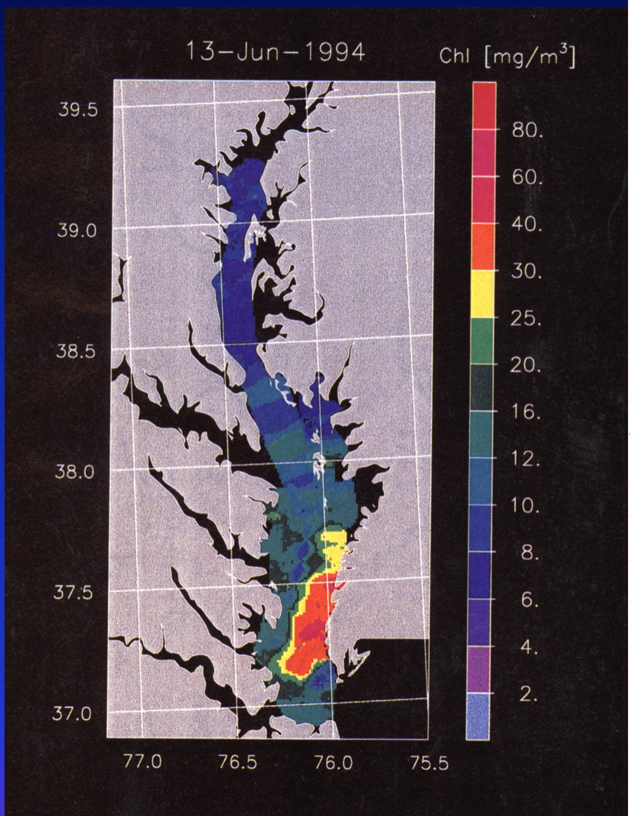




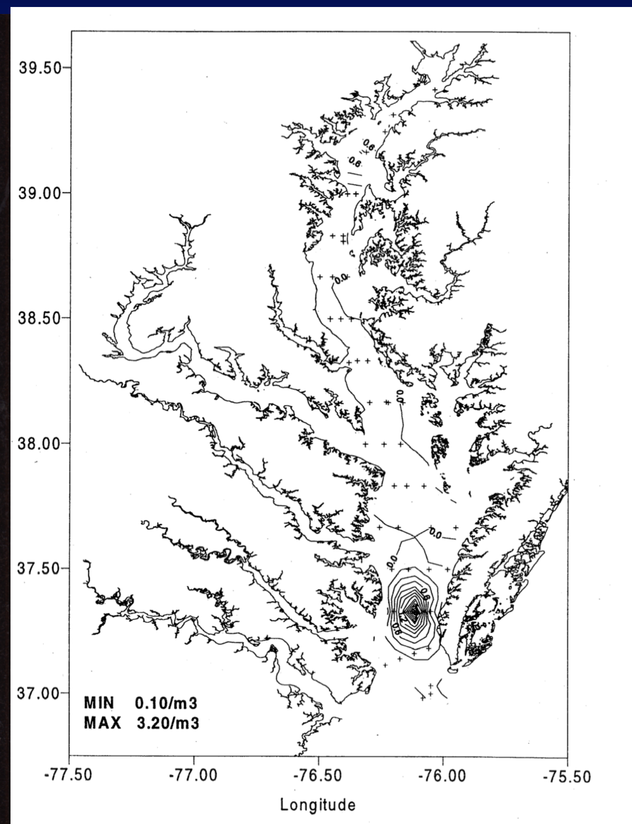
- Model reveals an accumulation zone in the lower bay
- Associated with a downwelling eddy in the residual circulation of the lower Bay

Hood et al., 1999

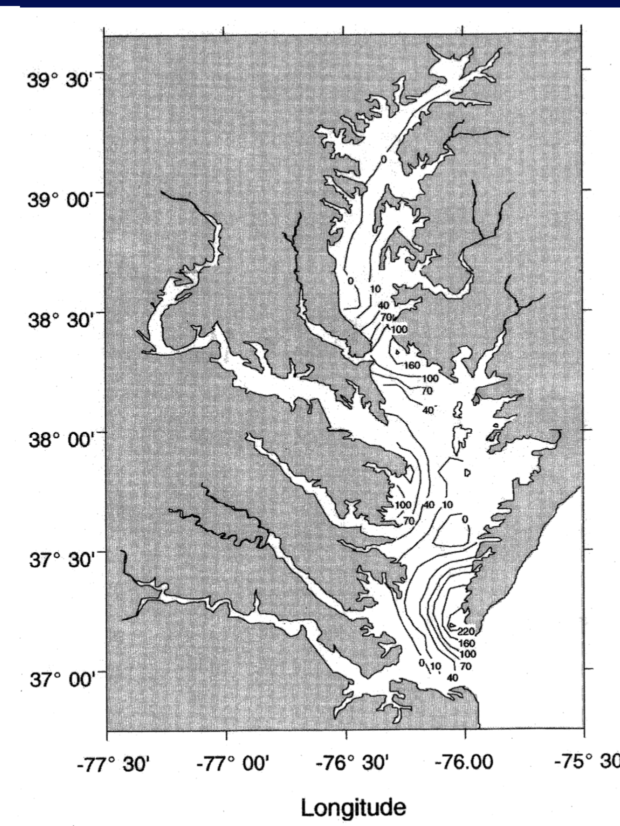
Modeling Particles and Pelagic Organisms in Chesapeake Bay:



Chlorophyll-a



Hydromedusae



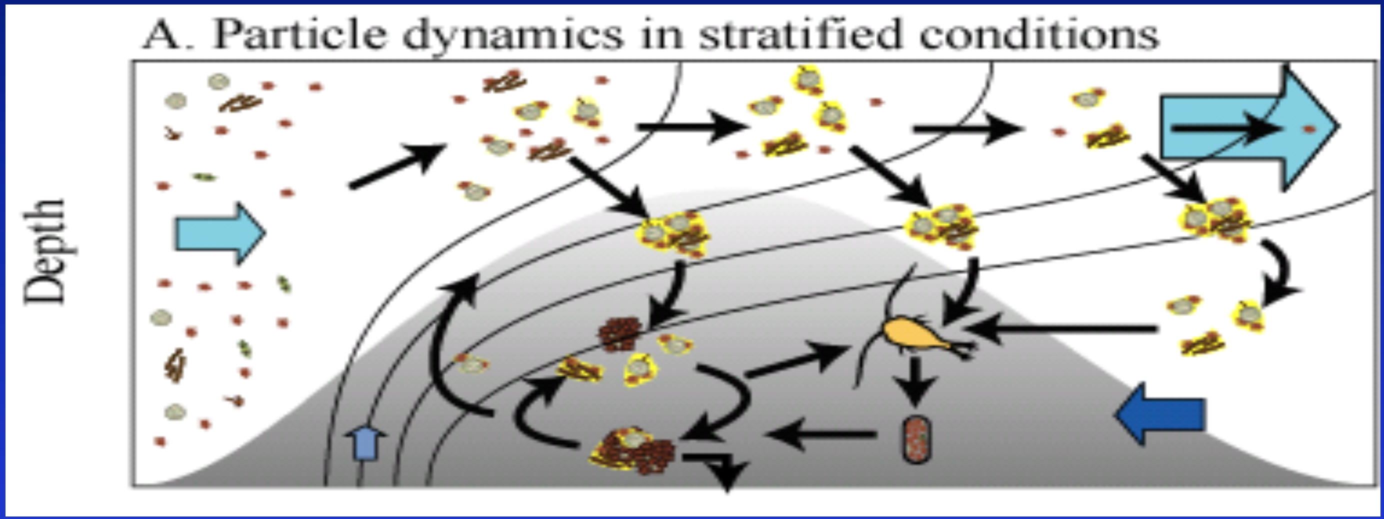
Bay Anchovy

- Which appears to influence chlorophyll concentrations, hydromedusae, Bay anchovy and benthic productivity

Hood et al., 1999

Modeling the Influence of Episodic Events on Transport of Striped Bass Eggs to the ETM

ETM = Estuarine Turbidity Maximum



- Region of an estuary where particles become trapped in a recirculation at the fresh/salt interface
- Leading to high turbidity

North, Hood et al., 2005; 2006

Modeling the Influence of Episodic Events on Transport of Striped Bass Eggs to the ETM

Approach: Same as before…

$$\frac{\partial \mathbf{x}}{\partial t} = \mathbf{U} + \mathbf{u}$$

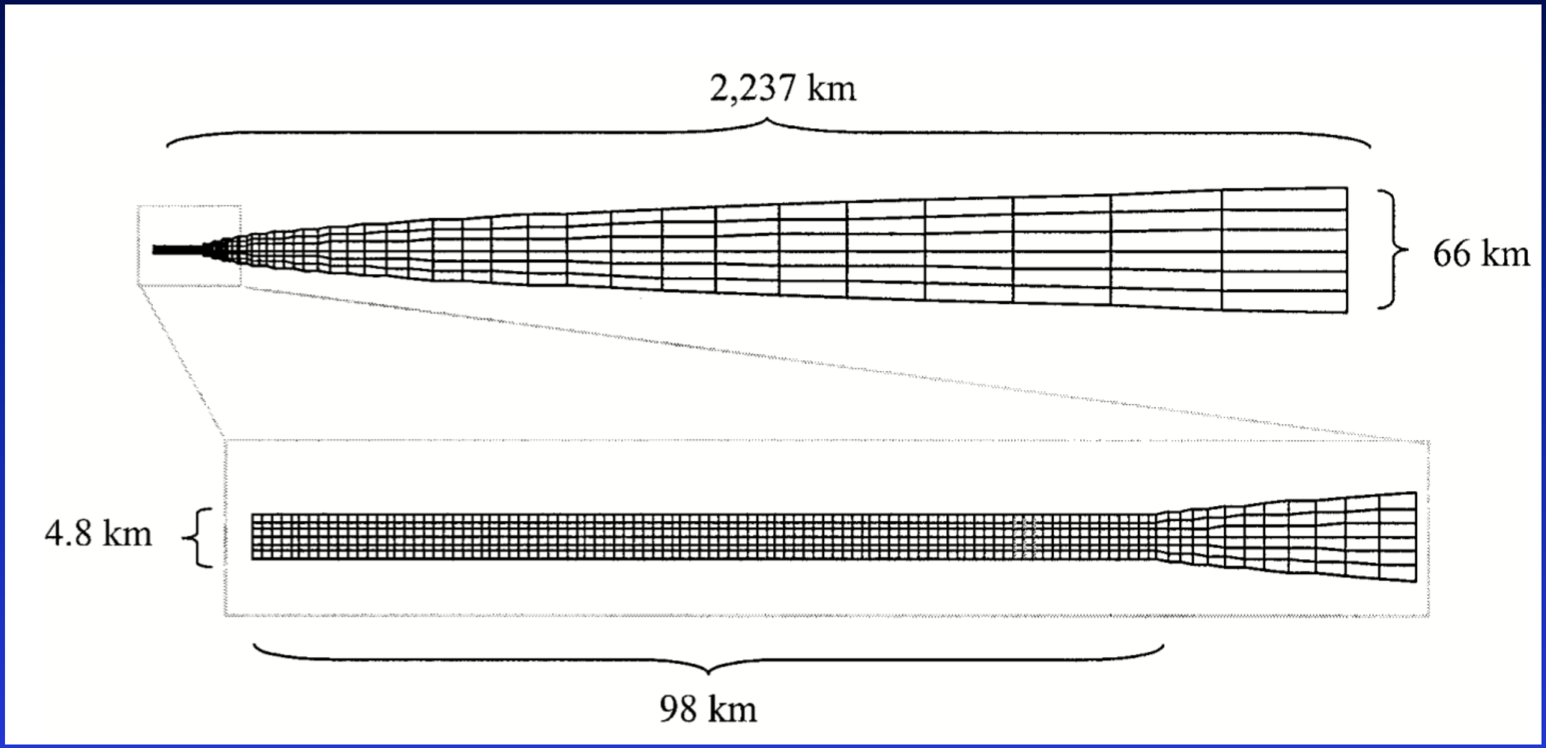
U = large scale deterministic velocity vector
u = small scale turbulent velocity vector

Finite difference: $\Delta x = (U + u)\Delta t$

With sinking: $\Delta x = (U + u + s)\Delta t$

North, Hood et al., 2005; 2006

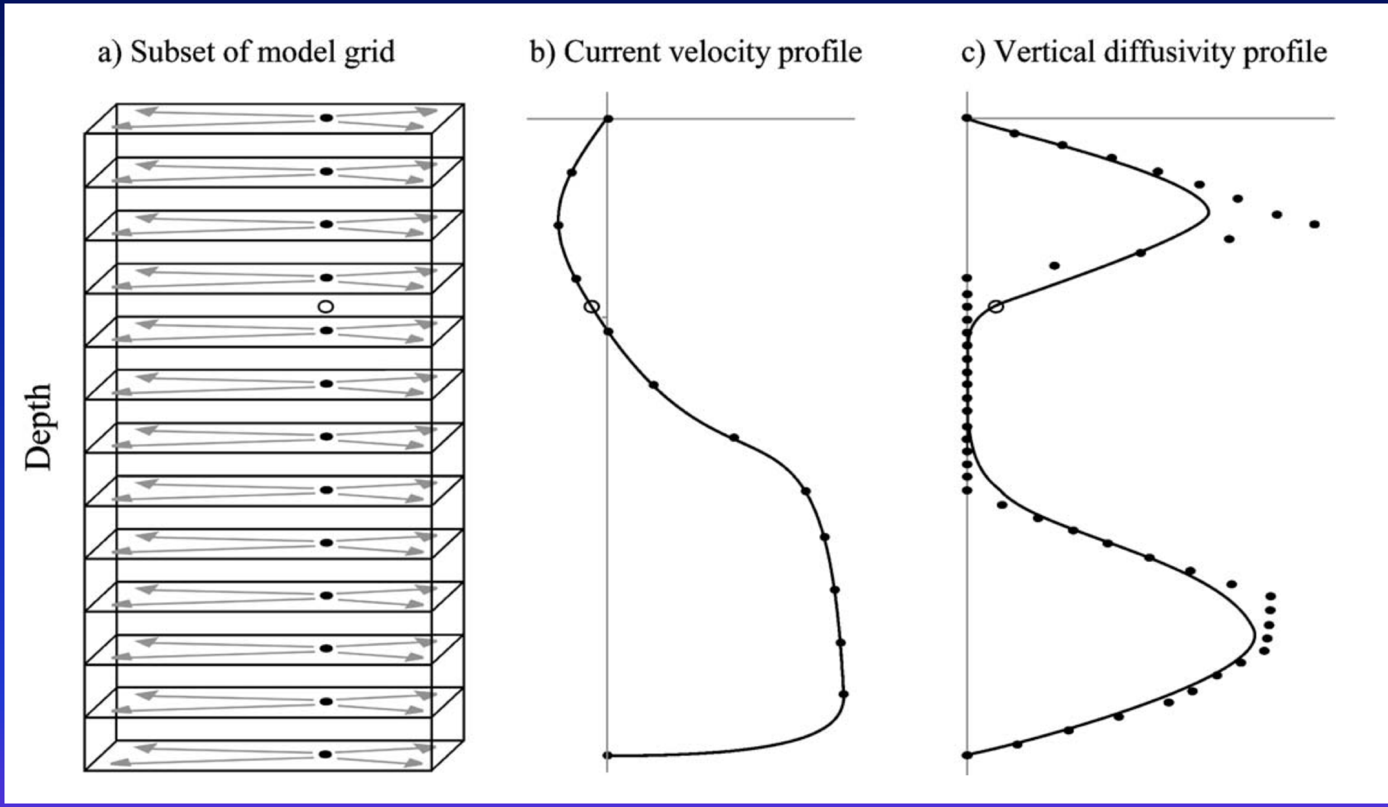
Modeling the Influence of Episodic Events on Transport of Striped Bass Eggs to the ETM



- Idealized hydrodynamics and sediment transport simulated with the Princeton Ocean Model (POM)
- Structured horizontal grid
- 12 sigma coordinates in the vertical (3-dimensional)

North, Hood et al., 2005; 2006

Modeling the Influence of Episodic Events on Transport of Striped Bass Eggs to the ETM

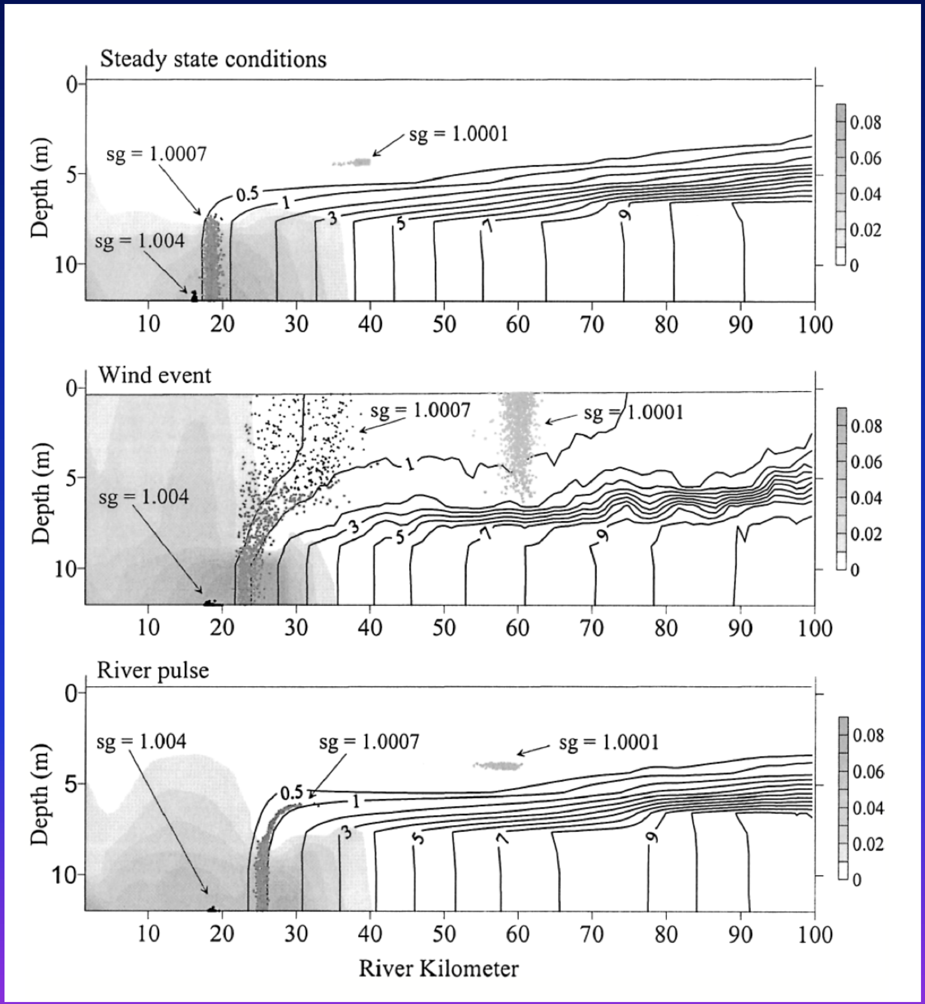


- 3-dimensional application
- Interpolate modeled velocities and diffusivities to the particle location
- Use diffusivities to scale u
- Then add sinking

North, Hood et al., 2005; 2006

Modeling the Influence of Episodic Events on Transport of Striped Bass Eggs to the ETM

- Realistic Striped bass egg specific gravities resulted in optimal retention in the ETM nursery area.
- Wind events and river pulses can significantly alter egg retention in the ETM.
- Eggs transported to the ETM nursery area decreased when particles were released before and during wind and river pulse events.
- Spawning after river flow events may promote early-stage survival by taking advantage of improved transport, enhanced turbidity refuge, and elevated prey production that may occur after river pulse events.



North, Hood et al., 2005; 2006

Outline:

- Individual based modeling
- Ecological forecasting
- Modeling hypoxia (Here comes the data)

Ecological Forecasting

Objectives:

Provide nowcasts and short-term (3-day) forecasts of Sea Nettle, HAB, pathogen and also physical and biogeochemical properties for research, management and public uses in Chesapeake Bay.

Approach:

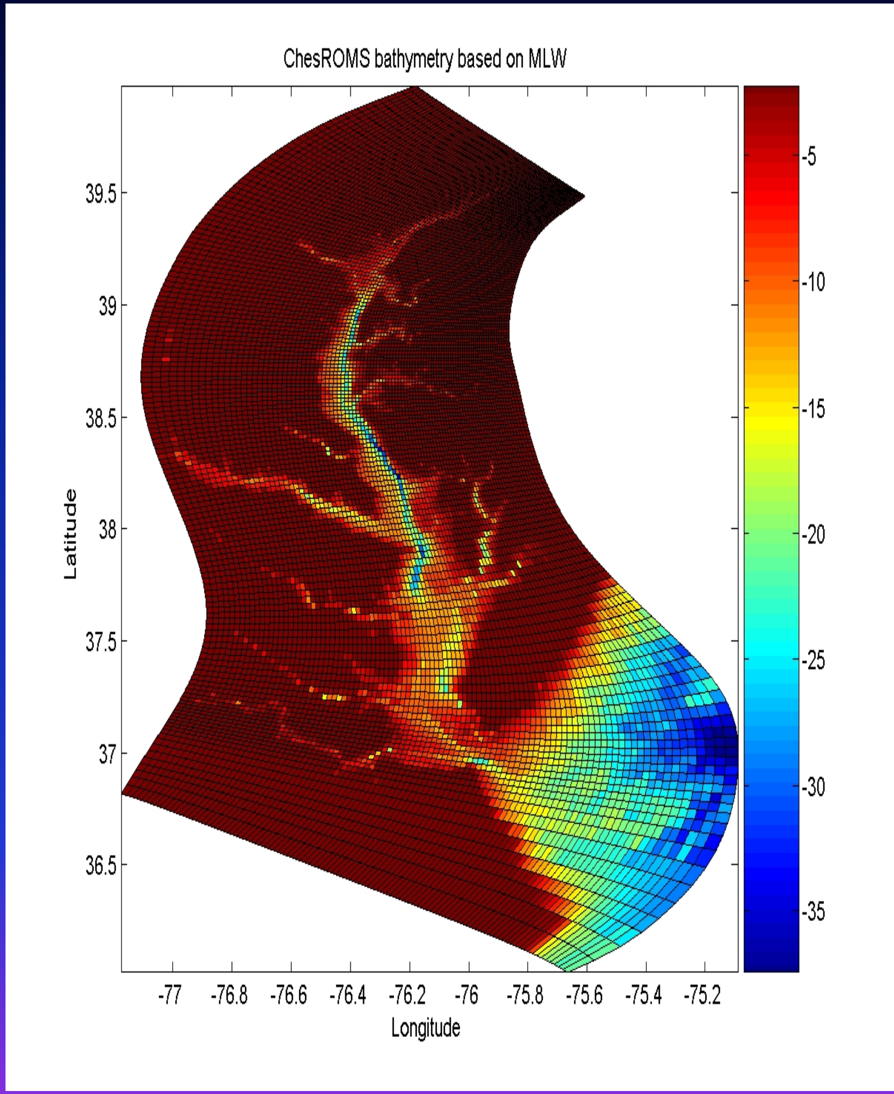
Use mechanistic hydrodynamic and biogechemical models to force empircal habitat models that predict likelihood of an organisms presence.

- Based upon Xu and Hood (2006); Decker, Brown, Hood et al. (2007); Xu et al. (2011), Brown, Hood et al., 2013, Feng et al. (2015), Wiggert, Hood et al. (in prep.)

Ecological Forecasting

ChesROMS

- ChesROMS is the hydrodynamic engine for our ecological forecasting.
- It is a Chesapeake Bay implementation of the Regional Ocean Modelling System (ROMS version 3.0).
- Curvilinear horizontal grid (100 * 150).
- Includes all major tributaries.
- Both hindcast and *operational* implementations at UMCES.
- Open Source (SourceForge).



Xu et al. (2011)

Four Empirical Habitat Models for Ecological Forecasts

- Sea Nettles (Decker et al, 2007)

  logistic regression model, based on T and S

- *Karlodinium veneficum* (Brown et al. 2013)

  Neural Network based on T and S, and time of year

- *Vibrio cholera* (Constantin de Magny et al., 2010)

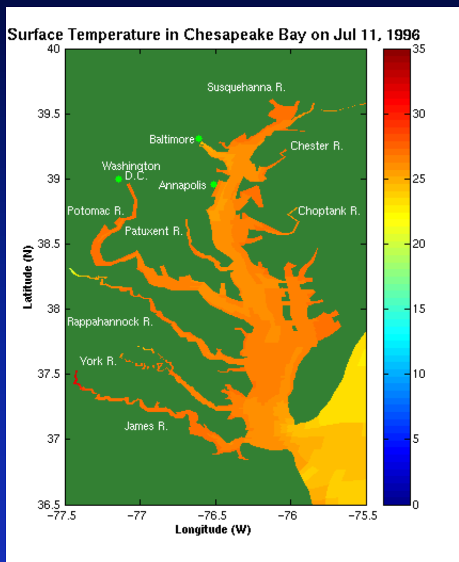
  logistic regression model, based on T and S

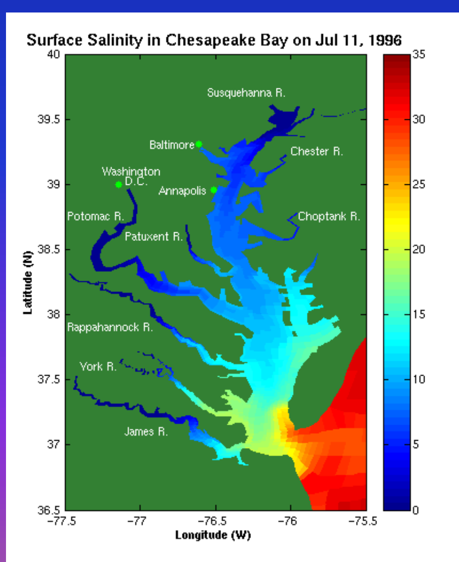
- *Vibrio vulnificus* (Jacobs et al., 2010; 2014)

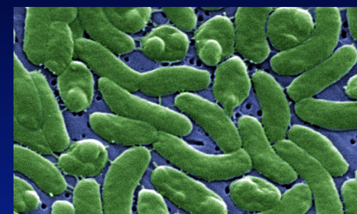
  logistic regression model, based on T and S

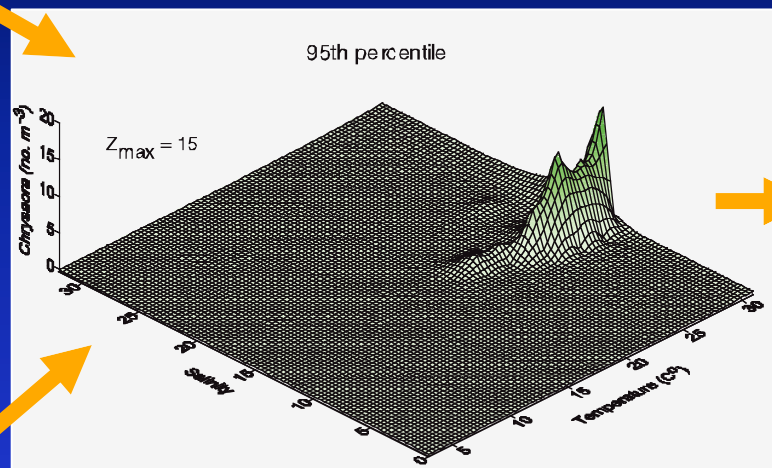
Ecological Forecasting

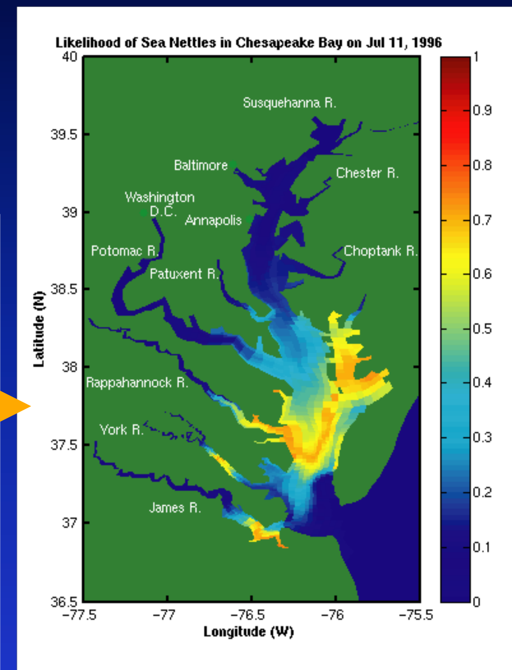
(Sea Nettles and *V. vulnificus*)









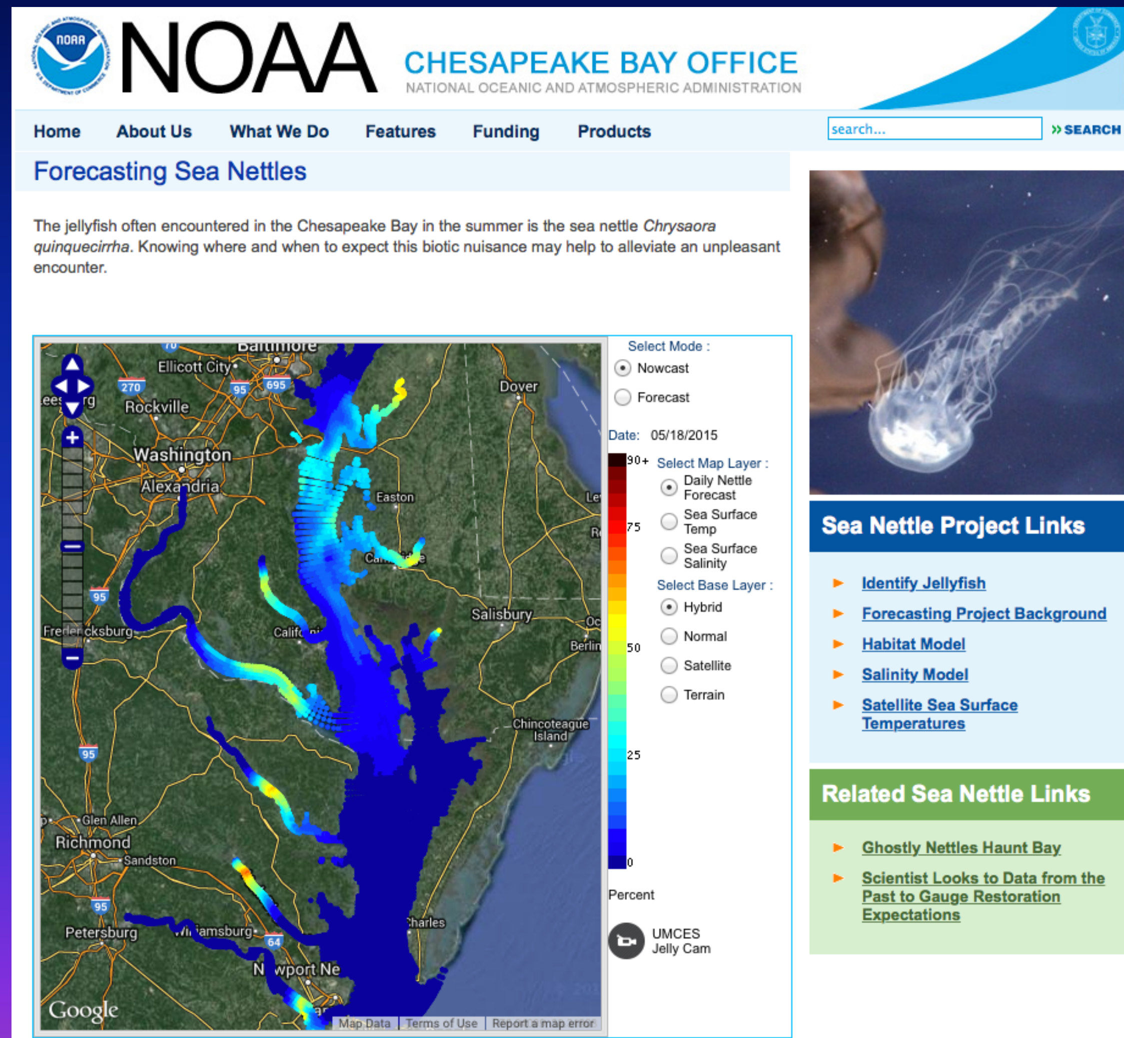


- Sea Nettles (*Chrysaora quinquecirrha*) can become very abundant in Chesapeake Bay during summer and they sting people.
- *Vibrio vulnificus* also becomes abundant during summer and infection is a potential human health threat.
- T and S strongly constrain sea nettle and *V. vulnificus* distributions.
- Estimate (nowcast and forecast) T and S using ChesROMS.
- Provides input to empirical logistic regression models that predicts probability of sea nettle and *V. vulnificus* occurrence.

Nowcasting/Forecasting Sea Nettles:

http://chesapeakebay.noaa.gov/forecasting-sea-nettles

- ➢ Nettle maps generated daily and posted on the WWW.
- ➢ *V. vulnificus* maps are also generated but not currently posted publicly on the WWW.
- ➢ Nowcasts.
- ➢ 3 day forecasts.
- ➢ Probabilities are increasing for Sea Nettles and *V. vulnificus* (still a bit cold).
- ➢ High probabilities are shifted up-river (dry conditions).



May 18th, 2015 nowcast

Outline:

- Individual based modeling
- Ecological forecasting
- Modeling hypoxia (Here comes the data)

Modeling Hypoxia

Objective:

Assess the readiness/maturity of a suite of existing estuarine community models for determining past, present and future hypoxia events within the Chesapeake Bay, in order to accelerate the transition of hypoxia model formulations and products from "academic research" to "operational" centers.

Friedrichs, Hood, Scully et al. (in progress)

Modeling Hypoxia

Fundamental questions:

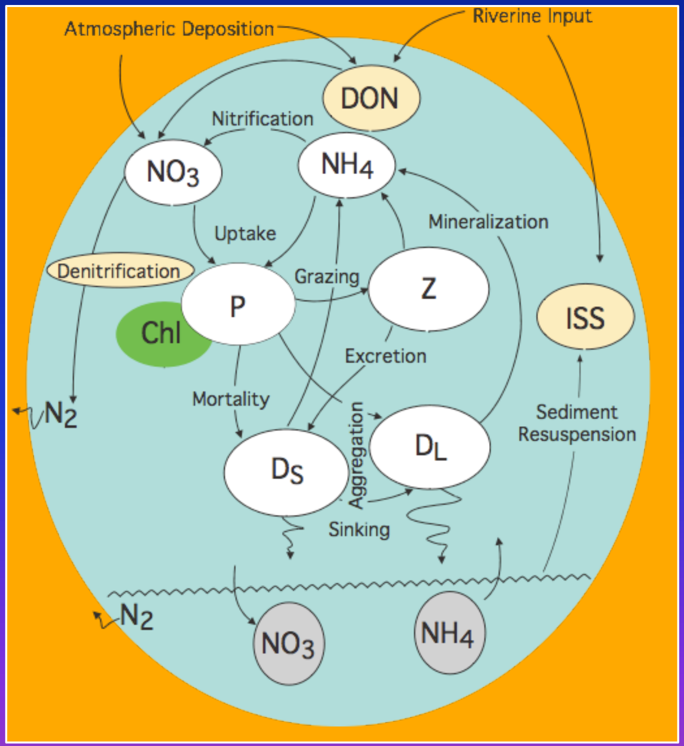
- How well do simple (1-term, constant respiration) models work compared to full biogeochemical models?
- Can they be used for operational applications?

1-term constant respiration model

Equation for conservation of oxygen:

$$\frac{\partial O_2}{\partial t} + \nabla \cdot O_2 = \frac{\partial}{\partial z} K_z \frac{\partial O_2}{\partial z} - R$$

Full biogeochemical model



Friedrichs, Hood, Scully et al. (in progress)

Modeling Hypoxia

Time scales of interest:

- Intraseasonal (weeks/months)
- Interannual (~20-30 years):

Friedrichs, Hood, Scully et al. (in progress)

Modeling Hypoxia

Intraseasonal Comparisons

Assess the relative skill of a suite of Chesapeake Bay hypoxia models on seasonal time scales:

- Statistically comparing output from six Chesapeake Bay models for 2004 (and 2005):
  - Five ROMS models with varying biological complexity:
    ChesROMS-ECB, ChesROMS-BGC, ROMS-RCA
    ChesROMS-1term, CBOFS-1term (constant biology)
  - EPA regulatory/operational biologically sophisticated model:
    CH3D-ICM

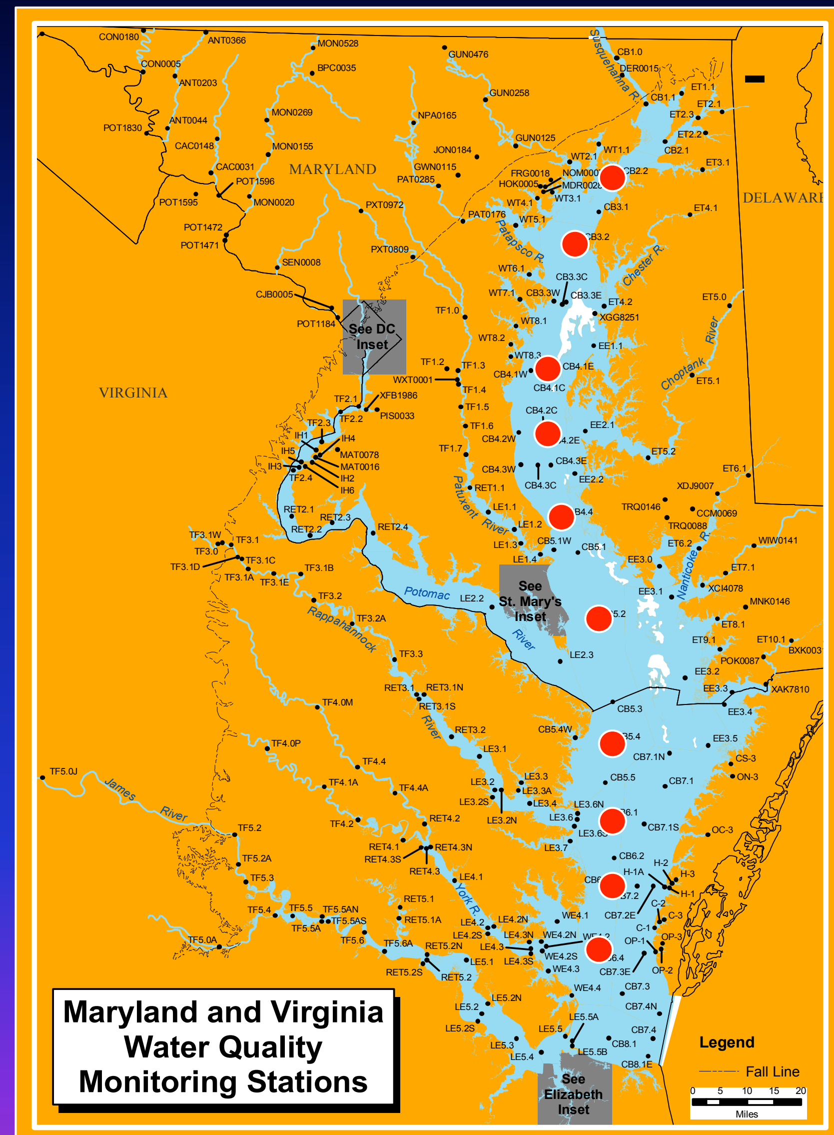
- Examining how well they reproduce the mean and spatial/ seasonal variability of:
  - temperature, salinity, stratification, dissolved oxygen (DO), chlorophyll-a, and nitrate

Friedrichs, Hood, Scully et al. (in progress)

Modeling Hypoxia

Chesapeake Hypoxia Model Comparisons

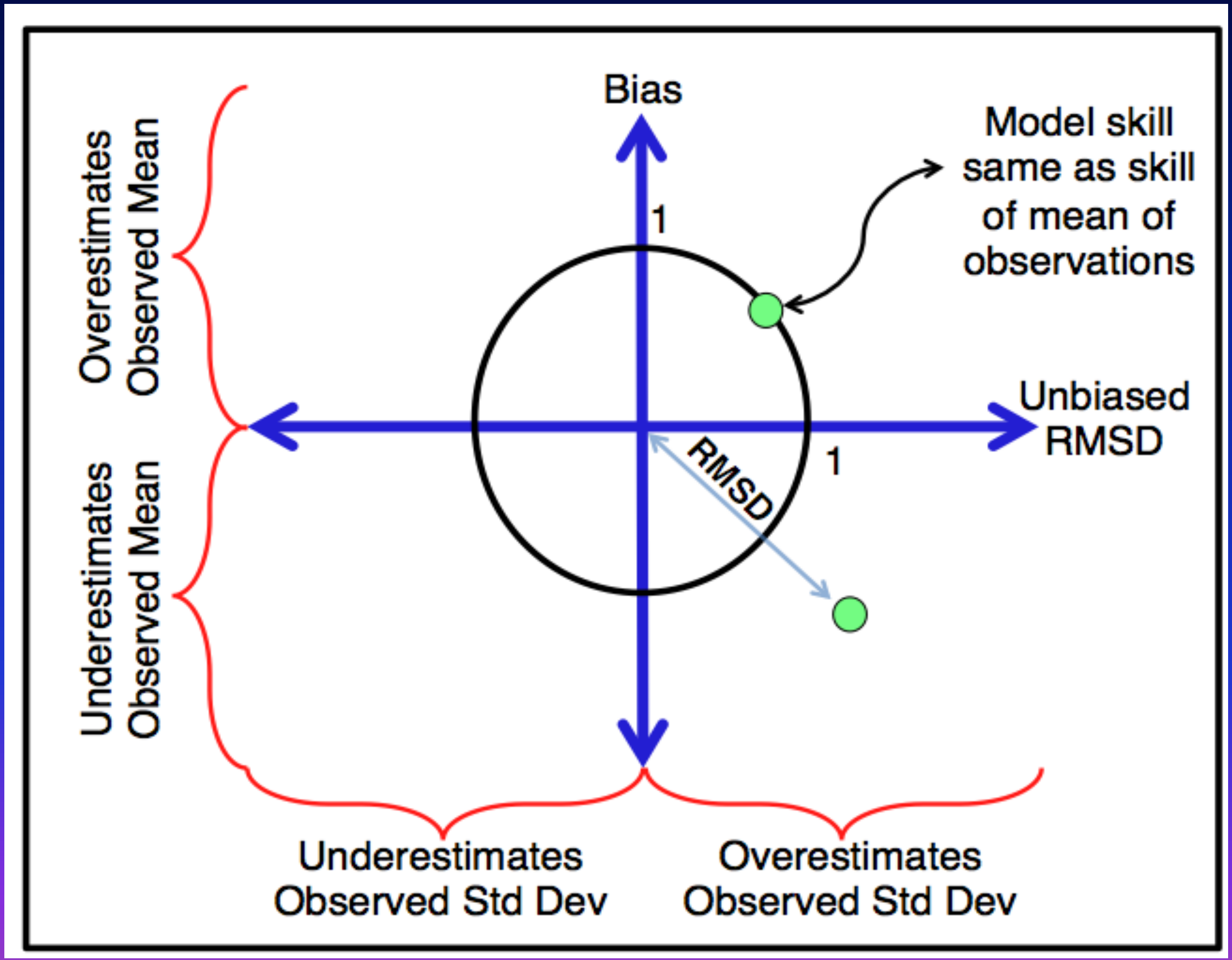
- Compare simulations to observations at 10 main stem stations for ~16 cruises in 2004 (and 2005)



Friedrichs, Hood, Scully et al. (in progress)

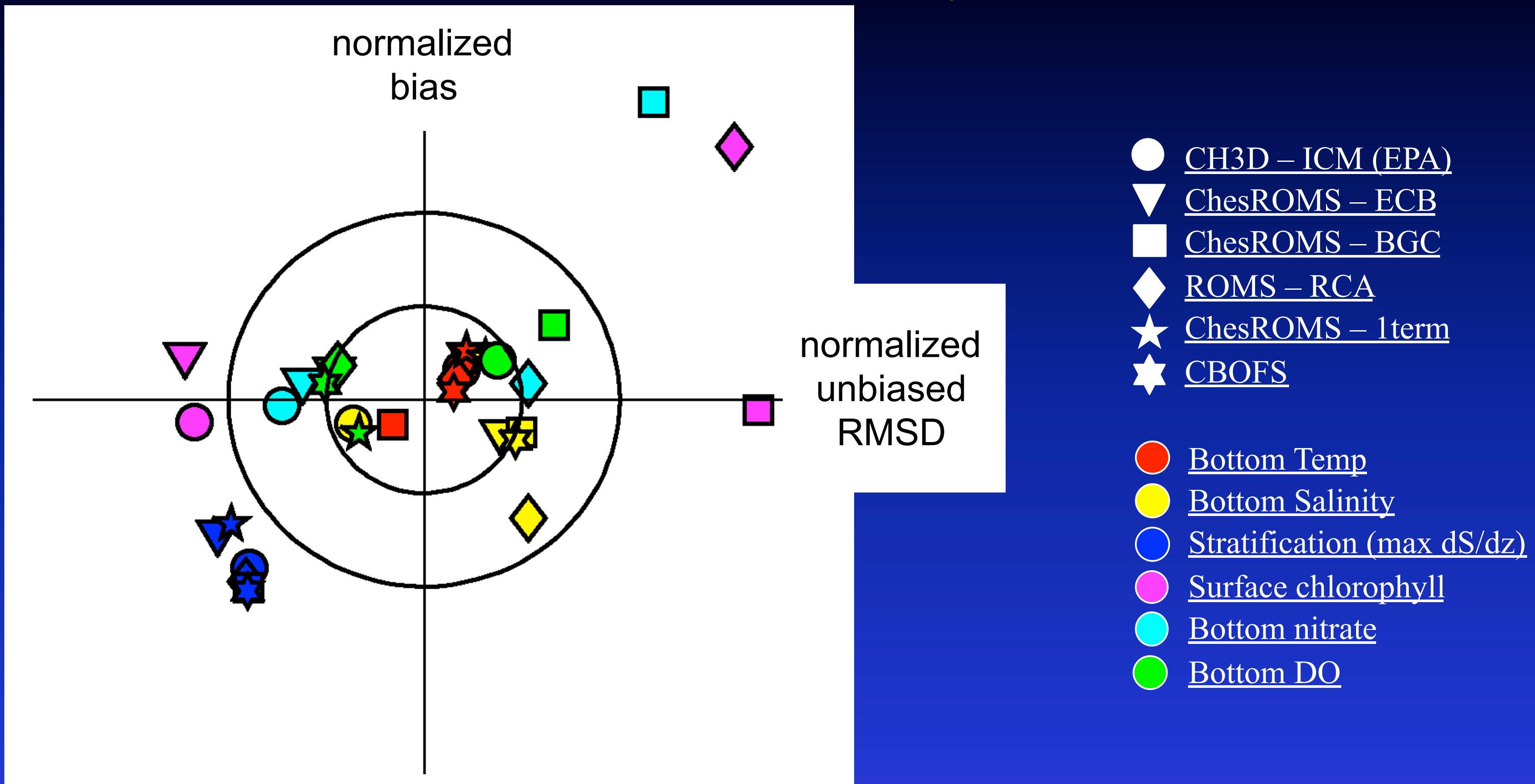
Modeling Hypoxia

Model Skill Assessment via Target Diagrams



Friedrichs, Hood, Scully et al. (in progress)

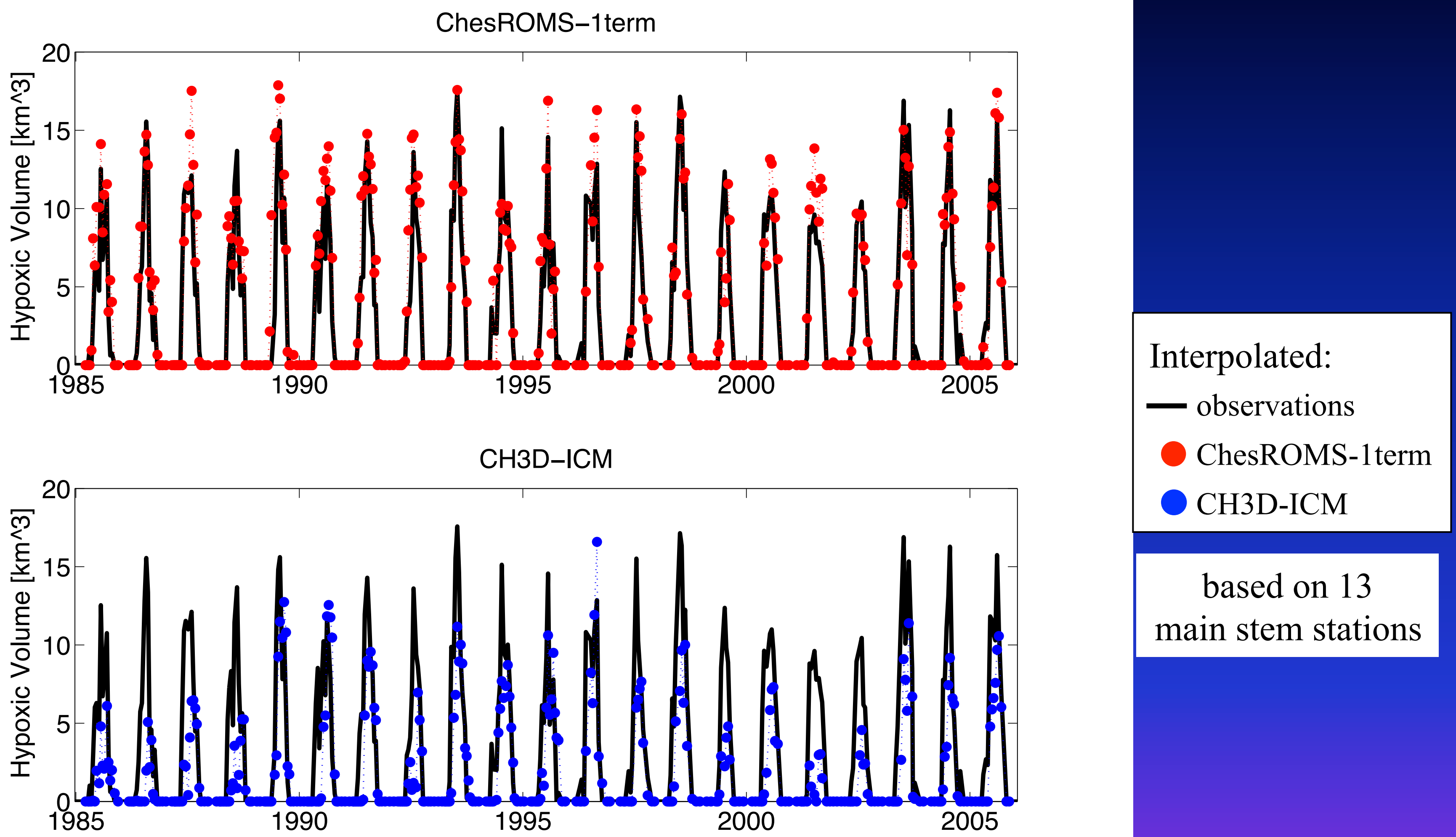
2004 Model Comparison



Overall skill of all models (temporal + spatial variability):

- **High** in terms of **bottom T and S**
- **Lower** in terms of **stratification AND chlorophyll, nitrate**
- **High for DO**
- **Models can reproduce seasonal DO without correct stratification & biology**
- **Simple 1-term model works as well as more complex models**
- **Hypoxia forecasting is possible with simple biological formulations (for < 1 year)**

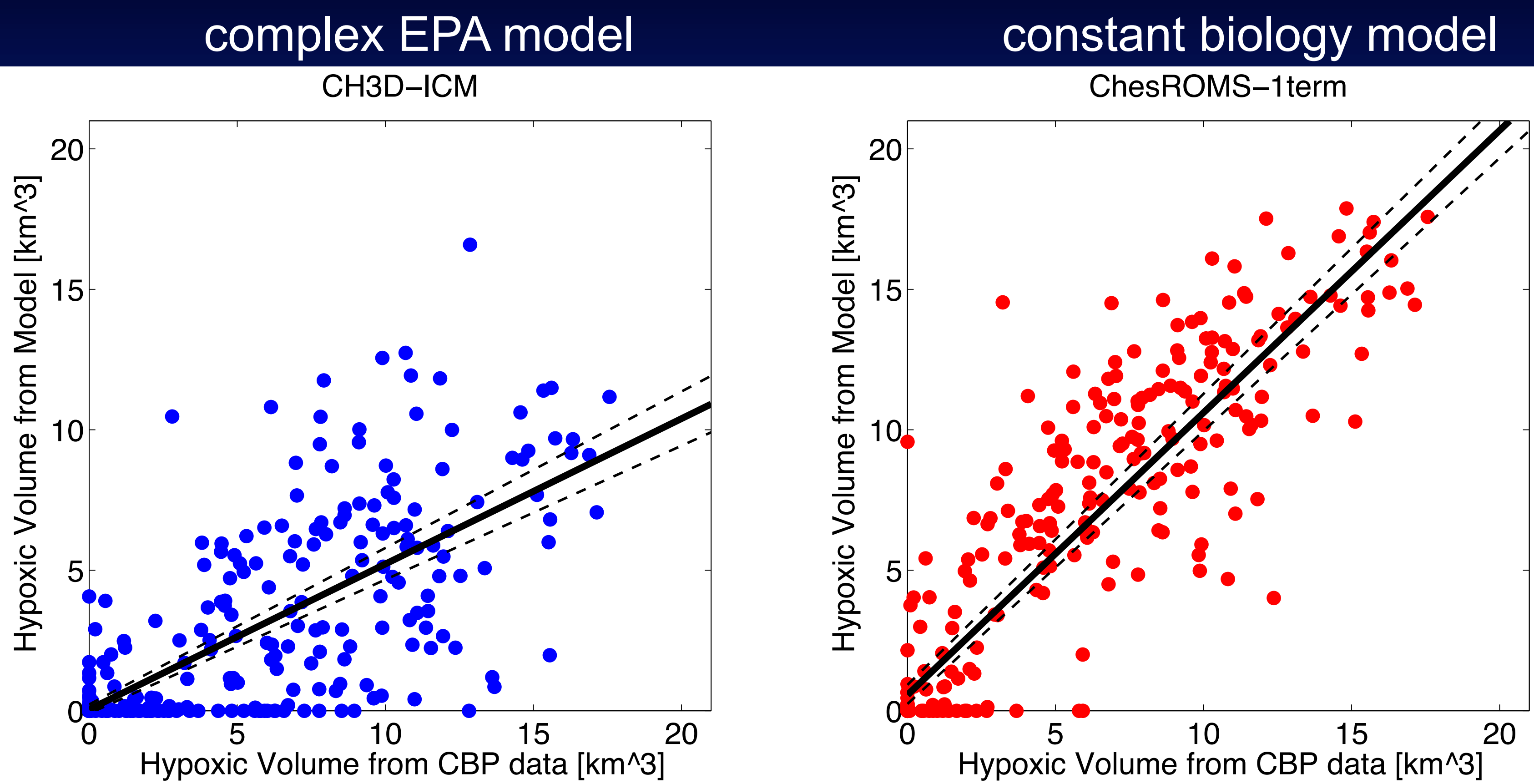
20-year Hypoxic Volume comparison



based on 13 main stem stations

What about at interannual timescales?

20-year Hypoxic Volume comparison



- On interannual time scales, constant biology (1-term) model does significantly better than the complex regulatory model in terms of reproducing our best estimate of hypoxic volume!
- Suggest that physical processes are more important than biological processes in driving hypoxic volume variability.

Summary

These modeling approaches provide powerful tools for:

- Simulating the impact of 3-dimensional currents and mixing on pelagic organisms in Chesapeake Bay and how these interact with behavior to determine fate. There are many applications related to fish and invertebrate (e.g., oyster) larval transport and fate and also plankton with relevance to management.

- Nowcasting and forecasting Sea Nettle, HAB, pathogen and also physical and biogeochemical properties for research, management and public uses in Chesapeake Bay. This technique can be expanded to any marine organism for which the habitat can be defined and can also be used to forecast potential invasive species.

- Assessing the skill of estuarine community models for determining past, present and future hypoxia events within the Chesapeake Bay. This work will ultimately provide ability to do operational oxygen modeling in Chesapeake Bay (e.g., oxygen weather forecasts). The approach can be extended to any biogeochemical property.

Thank You