Skill Assessment of Multiple Hypoxia Models in the Chesapeake Bay and Implications for Management Decisions

Isaac (Ike) Irby[1], Marjorie Friedrichs[1], Yang Feng[1], Raleigh Hood[2], Jeremy Testa[2], Carl Friedrichs[1]
[1]Virginia Institute of Marine Science, The College of William & Mary, USA
[2]Center of Environmental Science, University of Maryland, USA
Contact: iirby@vims.edu

INTRODUCTION

Chesapeake Bay and its surrounding watershed play host to an extensive suite of commercial, agriculture, shipping, and tourism industries that have a value upwards of one trillion dollars and home to 16 million people. Ensuring the health of the Bay has become a priority for the six states that make up the watershed. Together they have committed to the implementation of a set of Total Maximum Daily Loads (TMDLs) to improve water quality by decreasing the levels of nutrients and sediment derived from the watershed. A multiple community model implementation approach can be used to gauge uncertainty and elevate confidence in regulatory model projections.

OBJECTIVE

Statistically compare a set of estuarine models of varying biological complexity to the EPA regulatory model in terms of reproducing the mean and seasonal variability of hypoxia related variables in the Chesapeake Bay(Fig. 1).

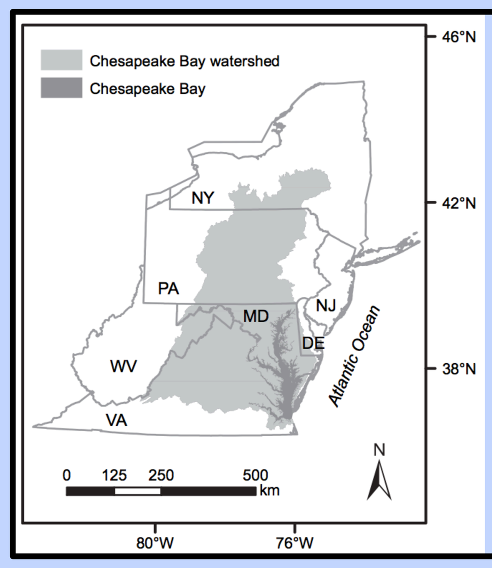


Figure 1. Map of the Chesapeake Bay and its watershed. (Najjar et al., 2010, ECSS, doi10.1016/j.ecss.2009.09.026).

METHODS

- Simulations from the EPA regulatory model and three ROMS-based models were analyzed (Table 1):
  - CH3D – ICM: EPA
  - ROMS – RCA: UMCES
  - ChesNENA: VIMS
  - ChesROMS – BGC: UMCES

Biological Complexity

	CH3D - ICM	ChesNENA	ChesROMS-BGC	ROMS-RCA
Nutrients	N, P, Si	C, N	N	N, P, Si
BGC Sediment	Yes	No	No	Yes
Algal Groups	3	1	1	2
Horizontal Grid	0.25 - 1km^2	~ 1km^2	~ 1km^2	~ 1km^2
Vertical Grid	z: ~ 5ft	σ: 20 layers	σ: 20 layers	σ: 20 layers

Table 1. Characteristics of the individual models.

- Model output was compared to Chesapeake Bay Program monitoring data using a best time match system for roughly 17 cruises at 10 main stem station in 2004 and 2005 (Fig. 2).
- Model ability to reproduce the mean and seasonal variability of each variable was evaluated via Target Diagrams (Fig. 3).

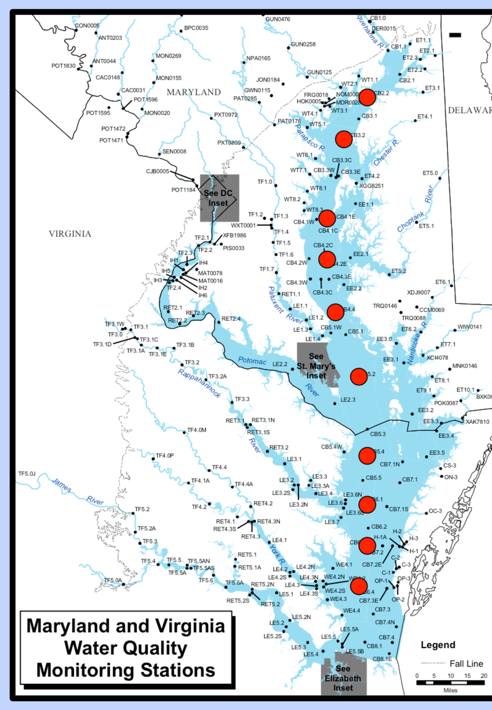


Figure 2. Location of the 10 Chesapeake Bay Program monitoring stations utilized in the study.

ANALYSIS

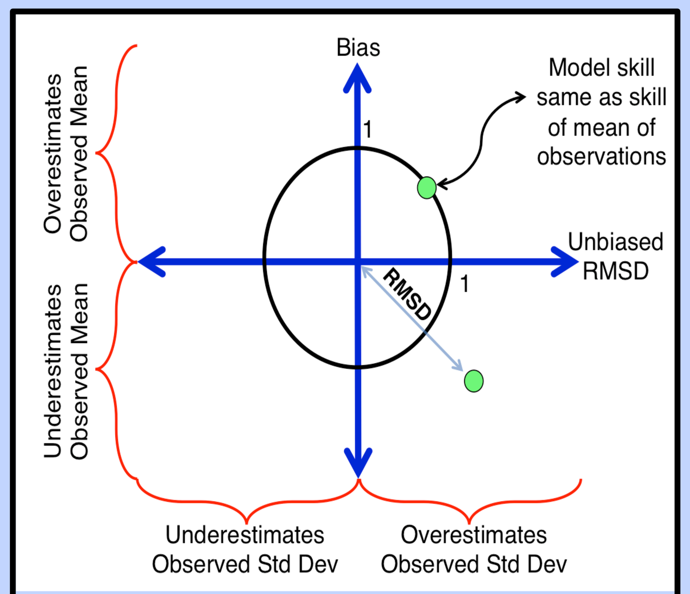


Figure 3. Target Diagram analysis: the total root mean square difference (RMSD) between the observations and the model results, normalized by the standard deviation of the observations. (Jolliff et al., 2009, JMS, doi10.1016/j.jmarsys.2008.05.014).

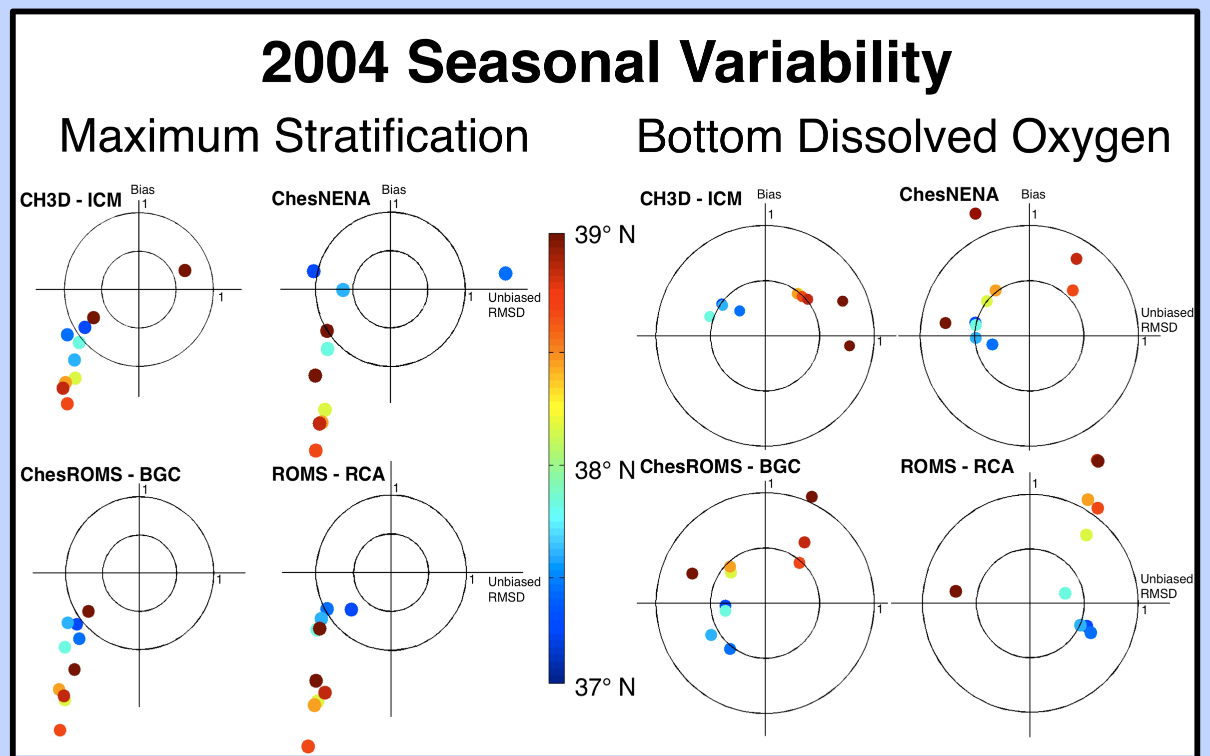


Figure 4. Normalized target diagrams showing how well the models reproduce the observed mean and seasonal variability at 10 main stem stations. Colors represent latitude. Stratification is defined as the maximum value of dS/dz in the water column.

2004 / 2005	CH3D - ICM	Ches NENA	ChesROMS - BGC	ROMS - RCA
Temp Surface	0.14 / 0.11	0.09 / 0.09	0.18 / 0.11	0.09 / 0.11
Temp Bottom	0.21 / 0.15	0.33 / 0.30	0.21 / 0.17	0.19 / 0.20
Salinity Surface	0.23 / 0.23	0.31 / 0.40	0.43 / 0.18	0.36 / 0.23
Salinity Bottom	0.33 / 0.32	0.51 / 0.36	0.53 / 0.48	0.82 / 0.60
Max Strat	1.11 / 1.07	1.36 / 1.12	1.34 / 1.18	1.33 / 1.20
DO Surface	0.71 / 0.54	0.51 / 0.53	0.74 / 1.30	0.66 / 0.54
DO Bottom	0.46 / 0.41	0.52 / 0.63	0.77 / 0.65	0.48 / 0.51
Chl-a Surface	1.17 / 1.10	1.25 / 0.98	1.70 / 1.61	2.08 / 1.67
Chl-a Bottom	0.88 / 0.89	1.05 / 1.07	1.28 / 1.11	1.54 / 1.12
Nitrate Surface	0.76 / 0.65	0.61 / 0.54	1.49 / 2.14	0.43 / 0.52
Nitrate Bottom	0.72 / 0.61	0.51 / 0.44	1.98 / 3.55	0.54 / 0.50

Table 2. Total normalized RMSD computed for multiple variables of each model using observations from cruises in 2004 (top value) and 2005 (bottom value) at 10 main stem stations shown in Figure 2. White font indicates model results that perform worse than the mean of the observations.

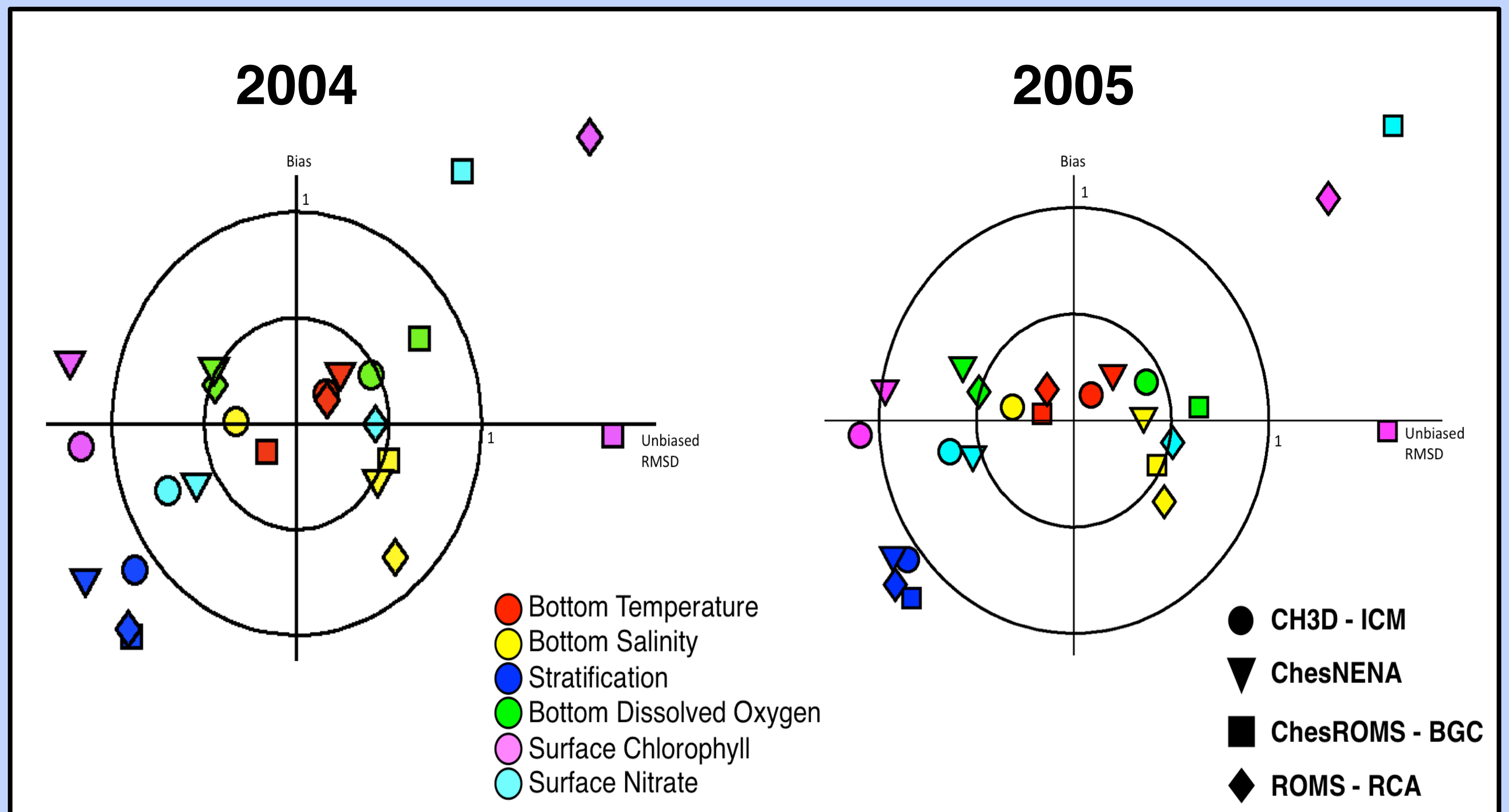


Figure 5. Normalized target diagrams for 2004 and 2005 illustrating how well the four models perform in terms of reproducing the observed means and spatial and seasonal variability for six variables.

RESULTS

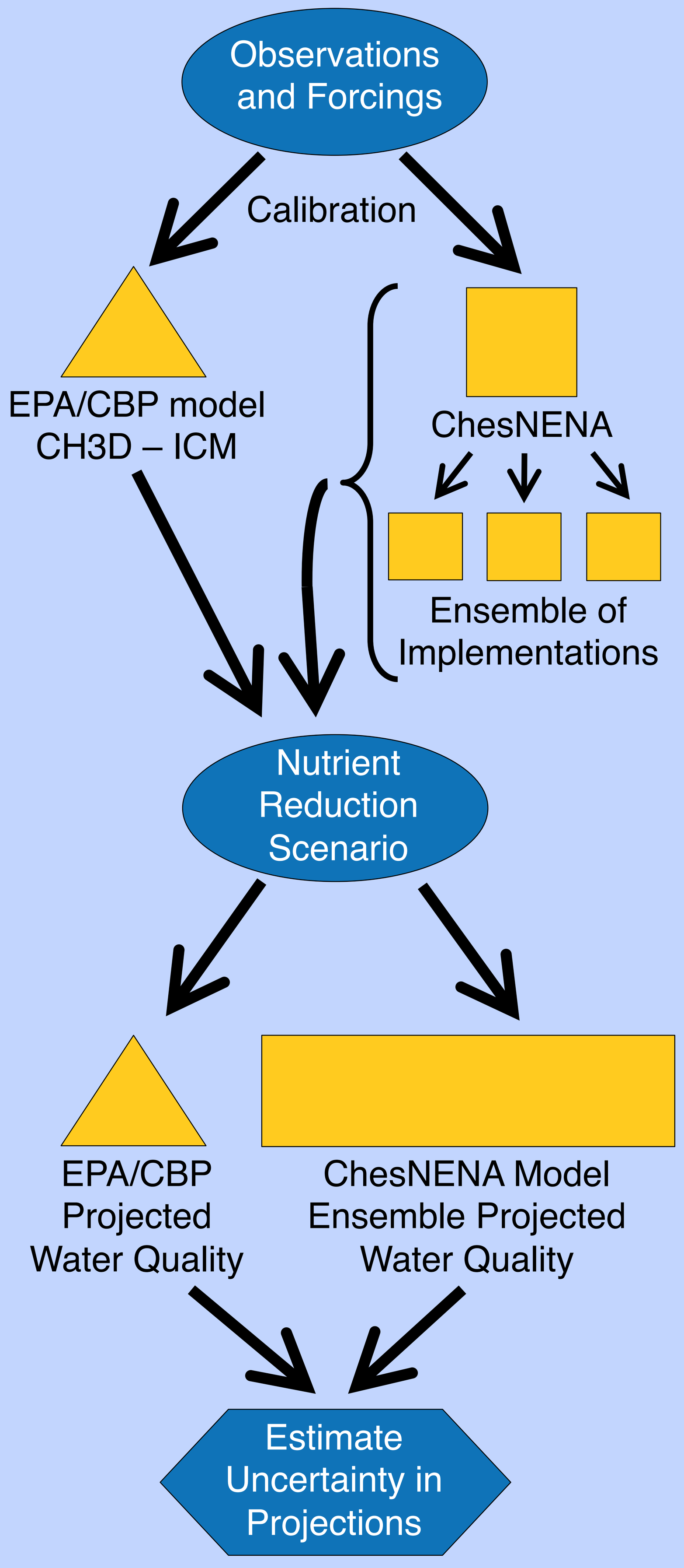
- All models consistently underestimate both the mean and standard deviation of stratification but perform well in terms of surface and bottom temperature, salinity, and DO (Fig. 4, Table 2).
- All models consistently perform better in the southern portion of the Bay (Fig. 4).
- The skill of all four models are similar to each other in terms of temperature, salinity, stratification, and DO (Fig. 5, Table 2).
- Model skill for Chl-a and nitrate is inconsistent between the models (Fig. 5).
- **All models reproduce bottom DO better than the primary influencing variables on DO: stratification, Chl-a, and nitrate (Table 2).**

CONCLUSIONS

- Overall, models with lower biological complexity and lower resolution achieve similar skill scores as the EPA regulatory model in terms of seasonal variability along the main stem of the Chesapeake Bay.
- All four models do substantially better at resolving bottom DO than they do at resolving its primary influences due to DO's sensitivity to temperature as a result of the solubility effect.
- Modeled DO simulations may be very sensitive to any future increases in Bay temperature.
- **In terms of TMDL development, these findings offer a greater confidence in CH3D – ICM predictions of DO seasonal variability since a model does not necessarily need to perform well in terms of stratification, chlorophyll, or nitrate in order to resolve the mean and seasonal variation of DO.**

FUTURE WORK

- Examine the skill of these models in terms of interannual variability for a 25 year period.
- Generate a multiple model ensemble from ChesNENA.
- **In cooperation with the CBP, evaluate the EPA nutrient reduction scenarios used in TMDL development in parallel with CH3D – ICM.**
- **Utilize the suite of projected water quality simulations to define the uncertainty in EPA/CBP estimates of estuarine response to reduced nutrient loads.**



ACKNOWLEDGEMENTS

This work was funded by the NOAA NOS IOOS as part of the Coastal Modeling Testbed (NA13NOS0120139) and the NASA Interdisciplinary Science Program as part of the USECoS project (NNX11AD47G). Special thanks to Aaron Bever and Ping Wang.