Challenges associated with modeling low-oxygen waters in Chesapeake Bay: a multiple model comparison

I.D. Irby
Virginia Institute of Marine Science

M.A.M. Friedrichs
Virginia Institute of Marine Science

Carl Friedrichs
Virginia Institute of Marine Science

COMT Estuarine Hypoxia Team

Follow this and additional works at: https://scholarworks.wm.edu/presentations

Part of the Environmental Sciences Commons

Recommended Citation
Challenges associated with simulating low-oxygen waters in Chesapeake Bay: a multiple model comparison

Isaac (Ike) Irby
Ph.D./M.P.P. Candidate

Marjorie Friedrichs
Carl Friedrichs
Aaron Bever
Coastal Ocean Modeling Testbed: Chesapeake Hypoxia Team
Modelers involved in study:

P. Wang, L. Linker
Y. Feng
R. Hood, H. Wang
J. Testa
M. Xia
M. Scully
L. Lanerolle
J. Shen

CH3D-ICM
ROMS-ECB
ROMS-BGC
ROMS-RCA
FVCOM-ICM
ROMS
CBOFS
EFDC
Chesapeake Bay

- Historical Water Quality Issues
- Regulatory Actions
  - Dissolved Oxygen
- Modeling Efforts
  - Government
  - Academia
Motivating Question

How can we improve model simulations of low-oxygen conditions in the Chesapeake Bay?
Models Evaluated in Study

8 Different Models

- 5 full BGC models of varying complexity and resolution
- 3 constant respiration models of varying resolution

- 2 models used by government agencies
- 6 models used by academia
- Not all focused on water quality

8 Different Models + Model Ensemble Mean = 9 Total Models
Methods: Observations

- 13 Observation Stations
- 2004 – 2005
- 1-2 times a month
- *Seasonal Variability

Variables:
- Temperature
- Salinity
- Dissolved Oxygen (DO)
- DO Stratification
- Oxycline
- MLDo
- Chlorophyll
- Nitrate
Methods: Observations

- 13 Observation Stations
- 2004 – 2005
- 1-2 times a month
- *Seasonal Variability
Methods: Observations

- 13 Observation Stations
  - 2004 – 2005
  - 1-2 times a month
  - *Seasonal Variability

- Variables
  - Temperature
  - Salinity
  - Dissolved Oxygen (DO)
  - Chlorophyll
  - Nitrate
  - Stratification
    - Oxycline
    - MLD0
Methods: Stratification

Station CB4.1C

WINTER

SUMMER

Depth (m)

DO (mg L\(^{-1}\))

DO Observations

MLDo

0  2  4  6  8  10  12  14

0  2  4  6  8  10  12  14

DO (mg L\(^{-1}\))
Methods: Skill Assessment

Target Diagram

Taylor Diagram

Bias

Model skill same as skill of mean of observations

Unbiased RMSD

Total RMSD

RMSD = Root mean square difference

Correlation Coefficient

Standard Deviation

2

1

0

0

1

2
Methods: Skill Assessment

Target Diagram

- Bias
- Total RMSD
- Unbiased RMSD

Model skill same as skill of mean of observations

Taylor Diagram

- Correlation Coefficient
- Standard Deviation
- RMSD

RMSD = Root mean square difference
Methods: Skill Assessment

Target Diagram

- Bias
- Total RMSD
- Unbiased RMSD
- Model skill same as skill of mean of observations

Taylor Diagram

- Correlation Coefficient
- RMSD
- Standard Deviation

RMSD = Root mean square difference

*Normalized
All models, regardless of biogeochemical complexity, do well.
Dissolved Oxygen

The model mean performs better than any single model.
Variables Driving DO Variability

- A: Temp at Bottom
- B: Salinity at Bottom
- C: DO at Bottom
- D: Chl at Bottom
- E: Nitrate at Bottom
- F: Obs
- G: M
- H: Obs
- M: Unbiased RMSD

Normalized Standard Deviation

Normalized Bias

Correlation Coefficient

0 0.2 0.4 0.6 0.8 0.9 0.99
Variables Driving DO Variability

Models simulate temperature the best. Models simulate bottom DO better than salinity, chl, and NO$_3$. 
Oxygen Stratification

![Diagram showing normalized bias and correlation coefficient](image)

- **MLDo**: Maximum depth of oxygen depletion
- **Max dO/dz**: Maximum gradient of oxygen concentration

Legend:
- A
- B
- C
- D
- E
- F
- G
- H
- M
- Obs

Normalization and Standard Deviation Plots

- Normalized Bias
- Unbiased RMSD
- Normalized Standard Deviation
- Correlation Coefficient
Oxygen Stratification

Models underestimate degree and variability of vertical gradient. Models place MLDo too high in water column and miss variability.
Oxygen Stratification

But we already established that the models resolve DO well throughout the water column.

Models underestimate degree and variability of vertical gradient. Models place MLDo too high in water column and miss variability.
How can models simulate DO well throughout the water column while missing the maximum value of the oxycline and the MLDo?
Observation Station CB4.1C

**Bottom DO**

**DO at MLD**

**MLD**

---

*Observations*
Models simulate DO better than MLD₀ primarily due to the pronounced seasonal cycle.
Does it matter that the models do not simulate the MLDo well?
In summer, the water column fills with low-DO water up to MLD₀.
This has major implications for habitat compression throughout the Chesapeake Bay.
Important to get MLD0 correct for management.
Motivating Question

How can we improve model simulations of low-oxygen conditions in the Chesapeake Bay?
Models simulate DO concentrations well.

Models do not simulate the MLDo well.
Models simulate DO concentrations well.

Models do not simulate the MLDo well.

*Increased biogeochemical complexity does not seem to solve this issue*
Models simulate DO concentrations well.

Models do not simulate the MLDo well.

*Increased biogeochemical complexity does not seem to solve this issue*

So how do we move forward?

Mixed Layer Depth

Observations at all 13 Stations: 1998-2006

Mixed Layer Depth

Maximum Vertical Gradient

The mixed layer depths have a much stronger relationship than the actual degrees of stratification.
The mixed layer depths have a much stronger relationship than the actual degrees of stratification. It is not the vertical gradient*, but the location of the MLD that is important.
Stratification

![Graph showing stratification with symbols A to E representing different variables.]

- A: MLDρ
- B: Max dρ/dz
- C: MLDϕ
- D: Max dO/dz
- E: Obs

Symbols:
- ★ A
- ▲ F
- ★ B
- ▲ G
- ◆ C
- ▲ H
- ■ D
- ● M
- ▼ E
- X Obs

Axes:
- Normalized Bias
- Unbiased RMSD

Correlation Coefficient
- 0.2
- 0.4
- 0.6
- 0.8
- 0.9
- 0.99

Normalized Standard Deviation
- 0
- 0.5
- 1
- 1.5
- 2

Variables:
- MLDρ
- Max dρ/dz
- MLDϕ
- Max dO/dz
- Obs
Stratification

Increased skill of $\text{MLD}_\rho \rightarrow$ increased skill of $\text{MLD}_O$
Conclusions

• All models do well in terms of bottom DO
  • Independent of biogeochemical complexity
  • Model Mean performs best
Conclusions

• All models do well in terms of bottom DO
  • Independent of biogeochemical complexity
  • Model Mean performs best
• Models do not simulate MLDo well
  • Important to management because of its impact on habitat compression
Conclusions

- All models do well in terms of bottom DO
  - Independent of biogeochemical complexity
  - Model Mean performs best
- Models do not simulate MLDo well
  - Important to management because of its impact on habitat compression
- Better physics is needed to solve the issue
  - The location of the density mixed layer depth is more important to correctly simulate than the degree of the vertical gradient
Challenges associated with modeling low-oxygen waters in Chesapeake Bay: a multiple model comparison

I. D. Irby\textsuperscript{1}, M. A. M. Friedrichs\textsuperscript{1}, C. T. Friedrichs\textsuperscript{1}, A. J. Bever\textsuperscript{2}, R. R. Hood\textsuperscript{3}, L. W. J. Lanerolle\textsuperscript{4,5}, M. E. Scully\textsuperscript{6}, K. Sellner\textsuperscript{7}, J. Shen\textsuperscript{1}, J. Testa\textsuperscript{8}, M. Li\textsuperscript{8}, H. Wang\textsuperscript{3}, P. Wang\textsuperscript{9}, L. Linker\textsuperscript{10}, and M. Xia\textsuperscript{11}

\textsuperscript{1}Virginia Institute of Marine Science, College of William & Mary, P.O. Box 1346, Gloucester Point, VA 23062, USA

\textsuperscript{2}Anchor QEA, LLC, 130 Battery Street, Suite 400, San Francisco, CA 94111, USA

\textsuperscript{3}Horn Point Laboratory, University of Maryland Center for Environmental Science, P.O. Box 775, Cambridge, MD 21613, USA

\textsuperscript{4}NOAA/NOS/OCS Coast Survey Development Laboratory, 1315 East–West Highway, Silver Spring, MD 20910, USA

\textsuperscript{5}ERT Inc., 14401 Sweitzer Lane Suite 300, Laurel, MD 20707, USA

\textsuperscript{6}Woods Hole Oceanographic Institution, Applied Ocean and Engineering Department, Woods Hole, MA 02543, USA

\textsuperscript{7}Chesapeake Research Consortium, 645 Contees Wharf Road, Edgewater, MD 21037, USA

\textsuperscript{8}Chesapeake Biological Laboratory, University of Maryland Center for Environmental Science, P.O. Box 38, Solomons, MD 20688, USA

\textsuperscript{9}VIMS/Chesapeake Bay Program Office, 410 Severn Avenue, Annapolis, MD 21403, USA

\textsuperscript{10}US Environmental Protection Agency Chesapeake Bay Program Office, 410 Severn Avenue, Annapolis, MD 21403, USA

\textsuperscript{11}Department of Natural Sciences, University of Maryland Eastern Shore, MD, USA
Bottom Dissolved Oxygen

Observation Station CB4.1C

- 95% Confidence Interval
- Observations
- Individual Models
- Model Mean

Date

DO Concentration (mg L⁻¹)