Intercomparison of 3-D models for estuarine hydrodynamics and hypoxia within the US IOOS Super-Regional Coastal Modeling Testbed

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Intercomparison of 3-D Models for Estuarine Hydrodynamics and Hypoxia

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And the US IOOS Estuarine Hypoxia Testbed Team

24 January 2011
10th Symposium on the Coastal Environment
92nd Annual American Meteorological Society Meeting
Intercomparison of 3-D Models for Estuarine Hydrodynamics and Hypoxia

Overarching Goal:
To help improve process-based, operational and scenario-based modeling of hypoxia in Chesapeake Bay

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Intercomparison of 3-D Models for Estuarine Hydrodynamics and Hypoxia

Outline:

• **Methods:** (i) Models, (ii) observations, (iii) skill metrics

• Results (i): What is the relative hydrodynamic skill of these CB models?

• Results (ii): What is the relative dissolved oxygen skill of these CB models?

• Summary and Conclusions
Methods (i) Models: 5 Hydrodynamic Models (so far)

1. CH3D (L. Linker/C. Cerco, EPA/USACE CBP)
2. EFDC (J. Shen, VIMS)
3. ChesROMS (R. Hood/W. Long, UM CES)
4. UMCES ROMS (M. Li/Y. Li, UMCES)
5. CBOFS2 (L. Lannerolle, NOAA-CSDL)

Additional Candidates:
- ADH
- ECOM
- ELCIRC
- FVCOM
- SELFE
Methods (i) Models (cont.): 5 Dissolved Oxygen Models (so far)

- ICM: CBP model; complex biology
- bgc: NPZD-type biogeochemical model
- 1eqn: Simple one equation respiration (includes SOD)
- 1term-DD: depth-dependent net respiration  
  (not a function of x, y, temperature, nutrients…)
- 1term: Constant net respiration

Methods (i) Models (cont.): 8 Multiple combinations (so far)

- CH3D + ICM
- EFDC + 1eqn, 1term
- CBOFS2 + 1term, 1term+DD
- ChesROMS + 1term, 1term+DD, bgc
Methods (ii) observations: S and DO from Up to 40 CBP station locations

Data set for model skill assessment:

~ 40 EPA Chesapeake Bay stations
  Each sampled ~ 20 times in 2004

Temperature, Salinity, Dissolved Oxygen

Map of Late July 2004
Observed Dissolved Oxygen [mg/L]

(http://earthobservatory.nasa.gov/Features/ChesapeakeBay)
Methods (iii) Skill Metrics: Target diagram

Total $\text{RMSD}^2 = \text{Bias}^2 + \text{unbiased \ RMSD}^2$

Dimensionless version of plot normalizes by standard deviation of observations

Inside unit circle: model does better than mean of data

On unit circle: model-data misfit = variability in data

Bull’s eye: perfect model-data agreement

$y > 0$: overestimates mean

Outside unit circle: model does worse than the mean of the data

$x > 0$: overestimates variability

(modified from M. Friedrichs)
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Results (i): Hydrodynamic Model Comparison

- All models do very well hind-casting temperature.

- All do well hind-casting bottom salinity with CH3D and EFDC doing best.

(a) Bottom Temperature

(b) Bottom Salinity

Inner circle in (a) & (b) = error from CH3D model

Unbiased RMSD [°C] and [psu]

- All underestimate variability of pycnocline depth.
Results (i): Hydrodynamic Model Comparison

- All models do very well hind-casting temperature.
- All do well hind-casting bottom salinity with CH3D and EFDC doing best.
- Stratification is a challenge for all the models.
- All underestimate strength and variability of stratification with CH3D and EFDC doing slightly better.
- CH3D and ChesROMS do slightly better than others for pycnocline depth, with CH3D too deep, and the others too shallow.
- All underestimate variability of pycnocline depth.

(from A. Bever, M. Friedrichs)
Results (i) Hydrodynamics: Temporal variability of stratification at 40 stations

- Model behavior for stratification is similar in terms of temporal variation of error at individual stations

(from A. Bever, M. Friedrichs)
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• Results (i): What is the relative hydrodynamic skill of these CB models?

• Results (ii): What is the relative dissolved oxygen skill of these CB models?

• Summary and Conclusions
Results (ii): Dissolved Oxygen Model Comparison

- Simple models reproduce dissolved oxygen (DO) and hypoxic volume about as well as more complex models.
- All models reproduce DO better than they reproduce stratification.
- A five-model average does better than any one model alone.

(from A. Bever, M. Friedrichs)
Results (ii): Dissolved Oxygen Model Comparison

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Results (ii): Dissolved Oxygen Model Comparison

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(from A. Bever, M. Friedrichs)
Results (ii): Dissolved Oxygen Model Comparison

- A five-model average does better than any one model alone.
- EPA should use multiple models in their scenario forecasts.

(from A. Bever, M. Friedrichs)
Results (ii) Dissolved Oxygen: Top-to-Bottom ΔS and Bottom DO in Central Chesapeake Bay

- All models reproduce DO better than they reproduce stratification.
Results (ii) Dissolved Oxygen: Top-to-Bottom $\Delta S$ and Bottom DO in Central Chesapeake Bay

- All models reproduce DO better than they reproduce stratification.
- So if stratification is not controlling DO, what is?
Results (ii) (cont.): Effect of Physical Forcing on Dissolved Oxygen

ChesROMS-1term model

Hypoxic Volume in km$^3$

Date in 2004

Base Case
Seasonal changes in hypoxia are not a function of seasonal changes in freshwater.
Seasonal changes in hypoxia may be largely due to seasonal changes in wind.

(by M. Scully)
Seasonal changes in hypoxia may be largely due to seasonal changes in wind.

(by M. Scully)
Seasonal changes in hypoxia may be largely due to seasonal changes in wind.

- Since NOAA can forecast wind, NOAA can forecast hypoxia.

(by M. Scully)
Intercomparison of 3-D Models for Estuarine Hydrodynamics and Hypoxia

Summary & Conclusions:

• Available models generally have similar skill in terms of hydrodynamic quantities.

• Simple models reproduce dissolved oxygen (DO) and hypoxic volume about as well as more complex models.

• All models reproduce DO better than they reproduce stratification.

• A five-model average does better than any one model alone.

• Seasonal cycle in DO/hypoxia is due more to wind speed and direction than to seasonal cycle in freshwater input, stratification, nutrient input or respiration.
  
  – Note: This does not mean than inter-annual variation in nutrient input is unimportant.
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- Key guidance for NOAA operational forecasting – Short-term forecasting of hypoxia in Chesapeake Bay built on wind forecasting is likely to work.
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- **Key guidance for NOAA operational forecasting** – Short-term forecasting of hypoxia in Chesapeake Bay built on wind forecasting is likely to work.

- **Key guidance for EPA scenario forecasting** – Long-term scenario forecasting of hypoxia in Chesapeake Bay will be more reliable when averaging multiple models.