Multiple Model Comparisons in the Chesapeake Bay:
Hydrodynamics and Dissolved Oxygen

Marjy Friedrichs
Virginia Institute of Marine Science

With special thanks for contributions from:
Aaron Bever
Ike Irby
Estuarine Hypoxia Testbed Team PIs
Funding from NOAA

WILLIAM & MARY
VIMS
VIRGINIA INSTITUTE OF MARINE SCIENCE
SCHOOL OF MARINE SCIENCE

- **Lessons learned from the U.S. IOOS Estuarine Hypoxia Testbed model comparison project in the Chesapeake Bay**

- **Recommendations from the STAC sponsored M3.1 workshop, concerning the multiple shallow water model pilot project**

- **Lessons learned from the U.S. IOOS Estuarine Hypoxia Testbed model comparison project in the Chesapeake Bay**

- **Recommendations from the STAC sponsored M3.1 workshop, concerning the multiple shallow water model pilot project**

The U.S. IOOS Testbed Project

PIs:

Rick Luettich (UNC)
Don Wright (SURA)

Four Teams:

Cyberinfrastructure Team
Coastal Inundation Team
Shelf Hypoxia Team (Gulf of Mexico)
Estuarine Hypoxia Team (Chesapeake Bay)

The U.S. IOOS Testbed Project

Estuarine Hypoxia Team:

Marjorie Friedrichs (VIMS)
Carl Friedrichs (VIMS)
Aaron Bever (VIMS)
Jian Shen (VIMS)
Malcolm Scully (ODU)
Raleigh Hood/Wen Long (UMCES)
Ming Li (UMCES)
Kevin Sellner (CRC)

Federal partners

Carl Cerco (USACE)
David Green (NOAA-NWS)
Lyon Lanerolle (NOAA-CSDL)
Lewis Linker (EPA)
Doug Wilson (NOAA-NCBO)

The U.S. IOOS Testbed Project

Overarching Goal of EH Component:

To help improve **operational modeling** of hypoxia in Chesapeake Bay

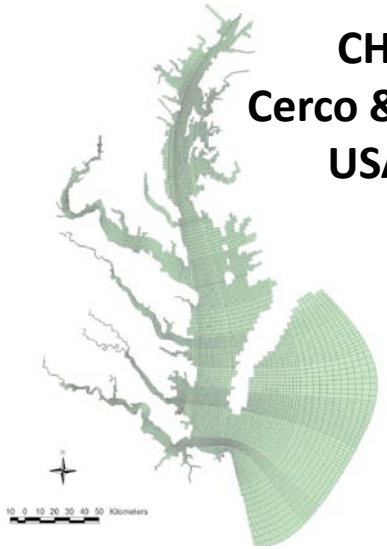
Methods:

- Compare relative skill of various Bay models
- Compare strengths/weaknesses of various models
- Assess how model differences affect water quality simulations

What should a
***"Next Generation Bay Model"* entail?**

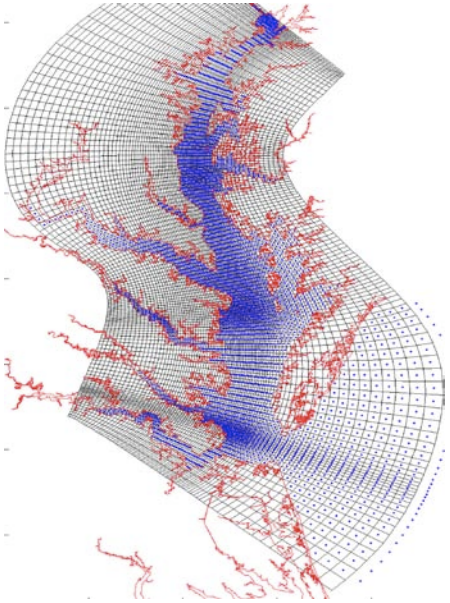
Five Hydrodynamic Models Configured for the Bay

CH3D
Cerco & Wang
USACE

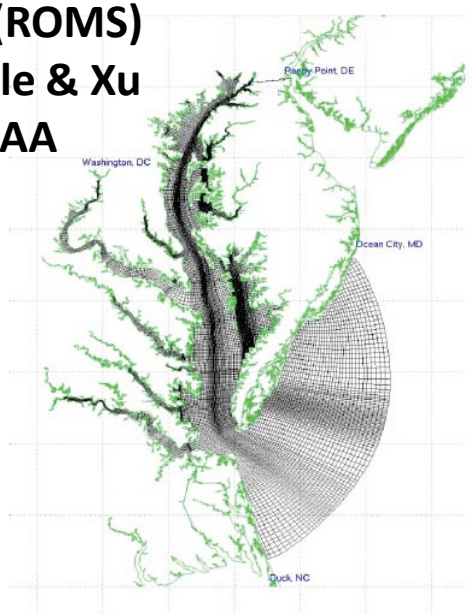


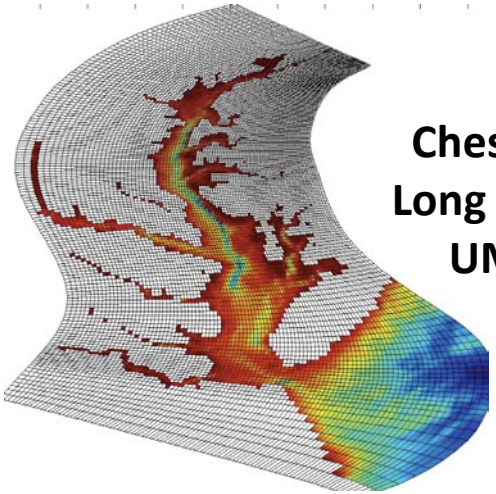
EFDC
Shen
VIMS

UMCES-ROMS
Li & Li
UMCES



CBOFS (ROMS)
Lanerolle & Xu
NOAA





ChesROMS
Long & Hood
UMCES

Five Biological (DO) Models Configured for the Bay

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

Coupled hydrodynamic-DO models

Six combinations:

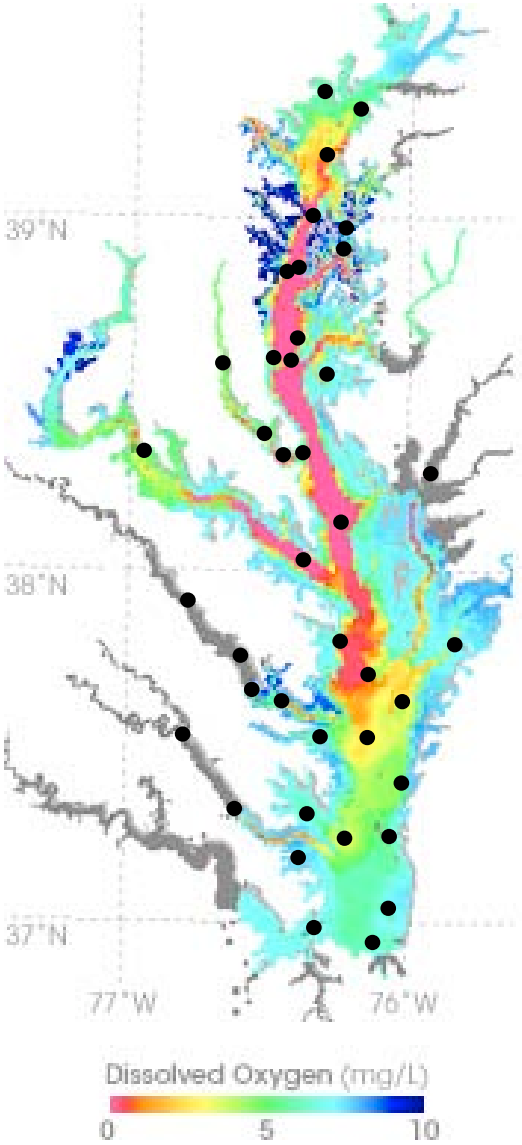
- CH3D + ICM ← **CBP model**
- EFDC + 1eqn
- CBOFS2 + 1term
- ChesROMS + 1term
- ChesROMS + 1term+DD
- ChesROMS + BGC

Physical models are similar; biological/DO models differ dramatically

All models (except CH3D) run using same forcing/boundary conditions, etc…

Model Skill

How well do the models represent the mean and variability of **stratification** and **dissolved oxygen** at ~40 CBP stations in 2004 and 2005?

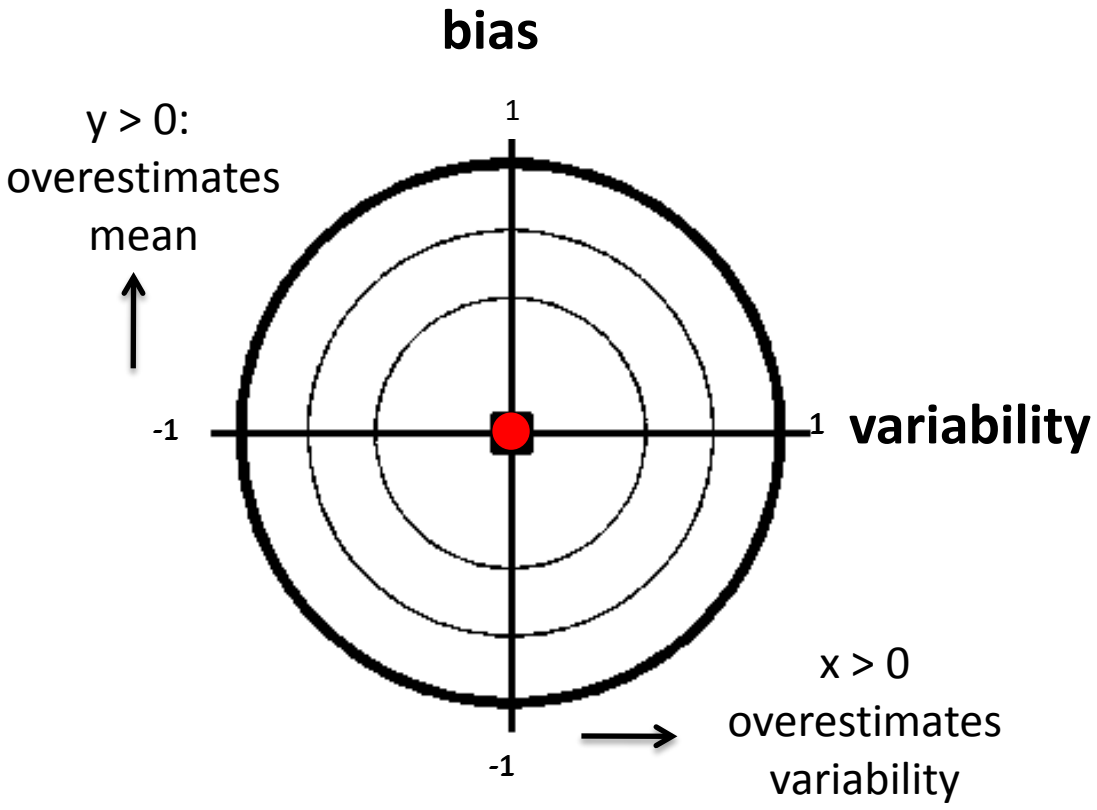


● = ~40 CBP stations used in this model-data comparison

Relative model skill: Target diagrams

Model skill (RMSD) = Distance from Origin

symbol at origin → model fits observations perfectly

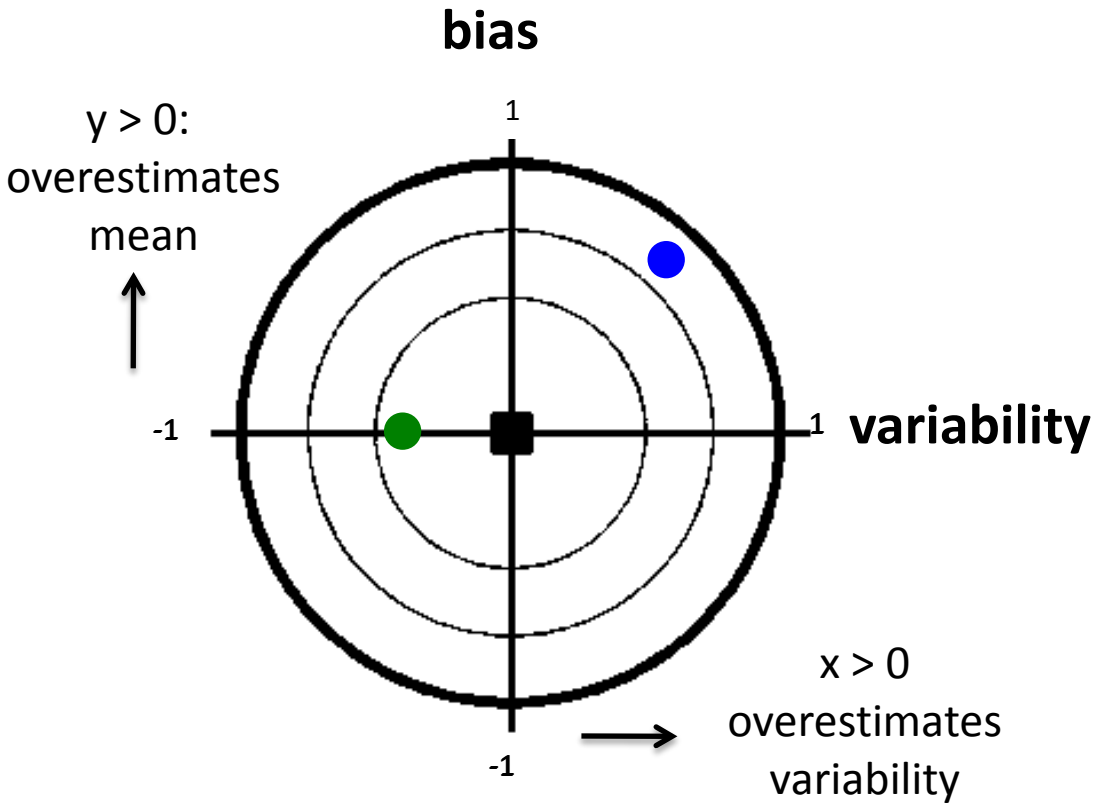


Jolliff et al., 2009

Relative model skill: Target diagrams

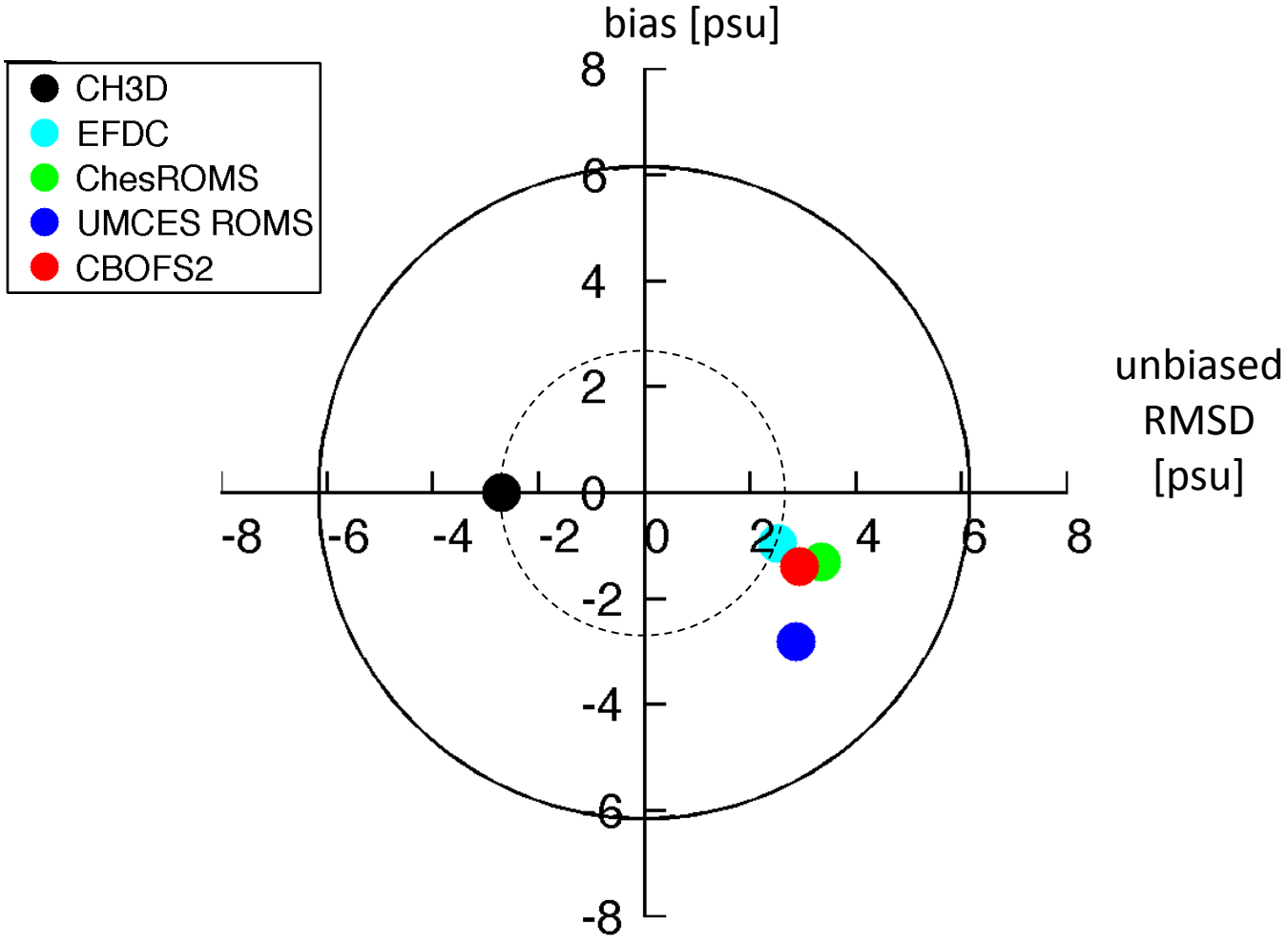
Model skill (RMSD) = Distance from Origin

symbol at origin → model fits observations perfectly



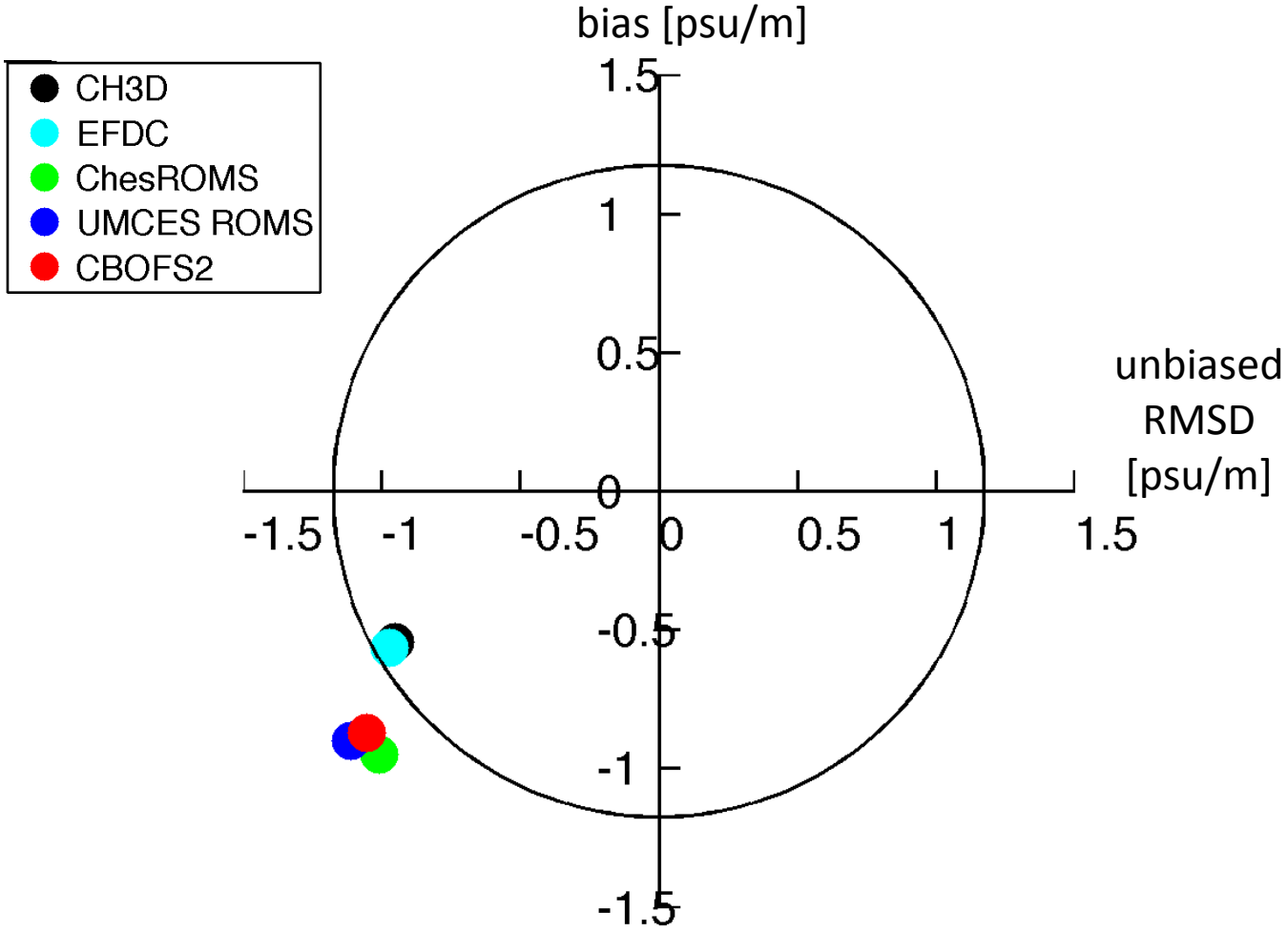
Jolliff et al., 2009

2004 Bottom Salinity



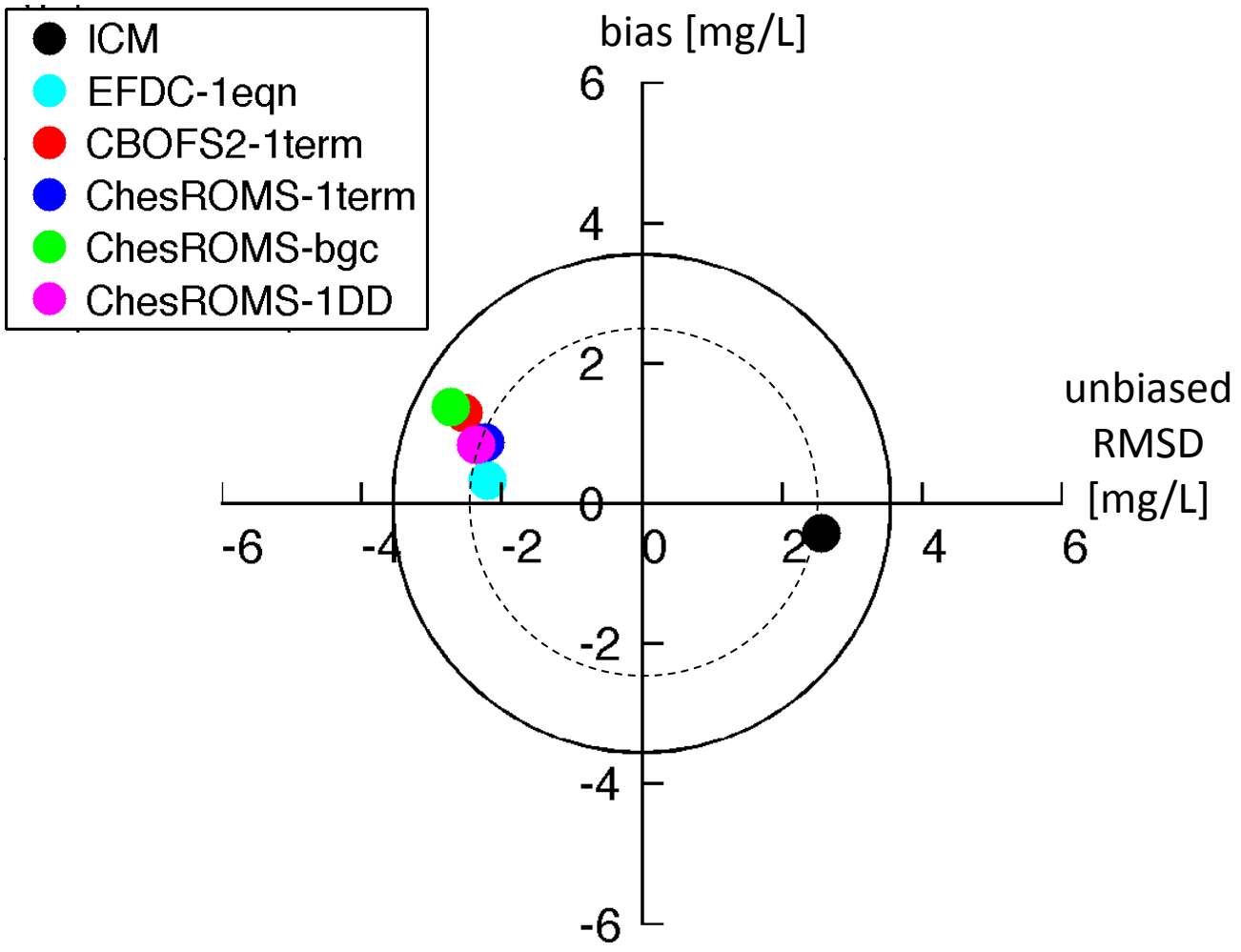
CH3D, EFDC reproduce bottom salinity best

2004 Stratification



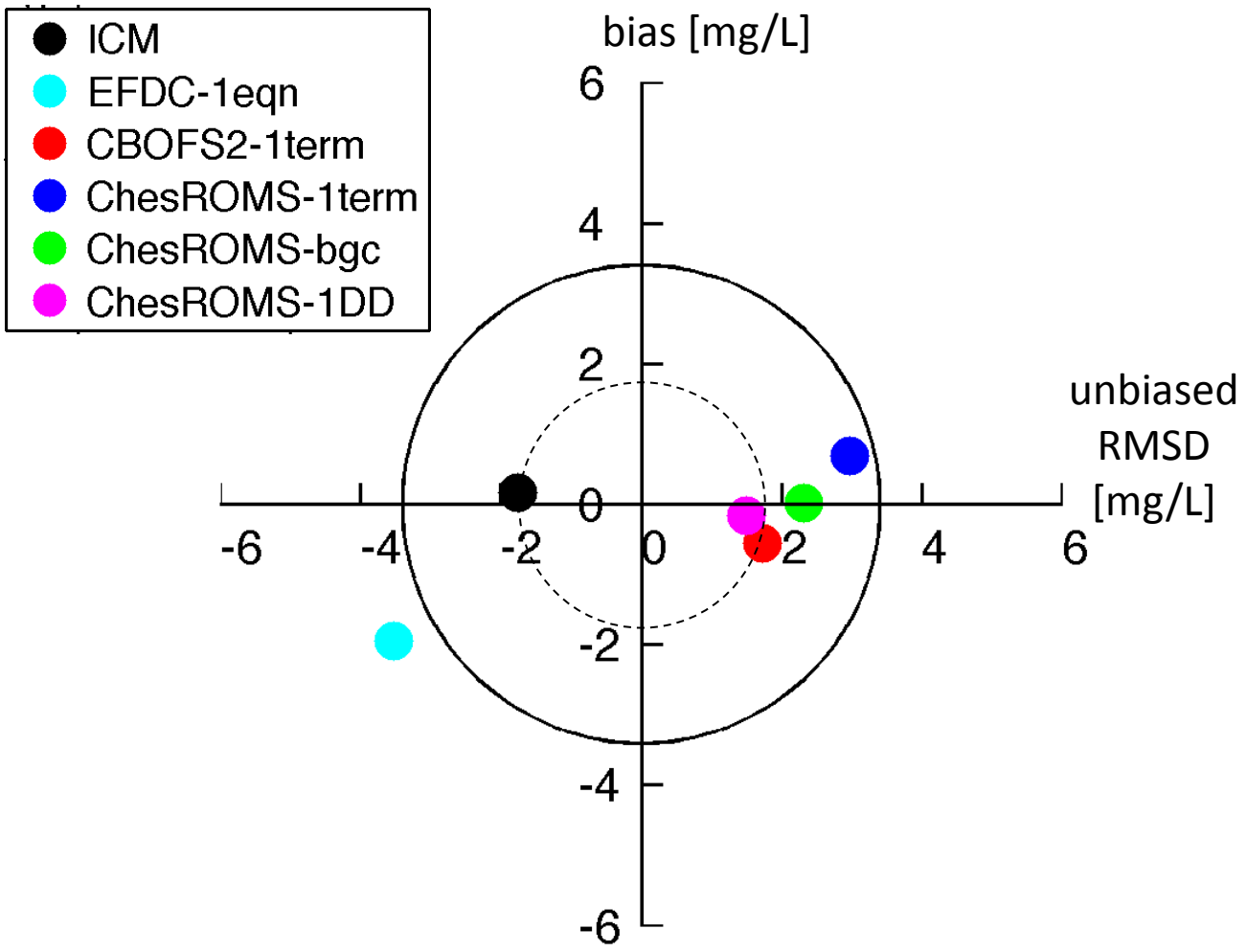
CH3D reproduces hydrodynamics better than the ROMS models: the multiple model comparison has increased our confidence in the CBP model

2004 Bottom DO



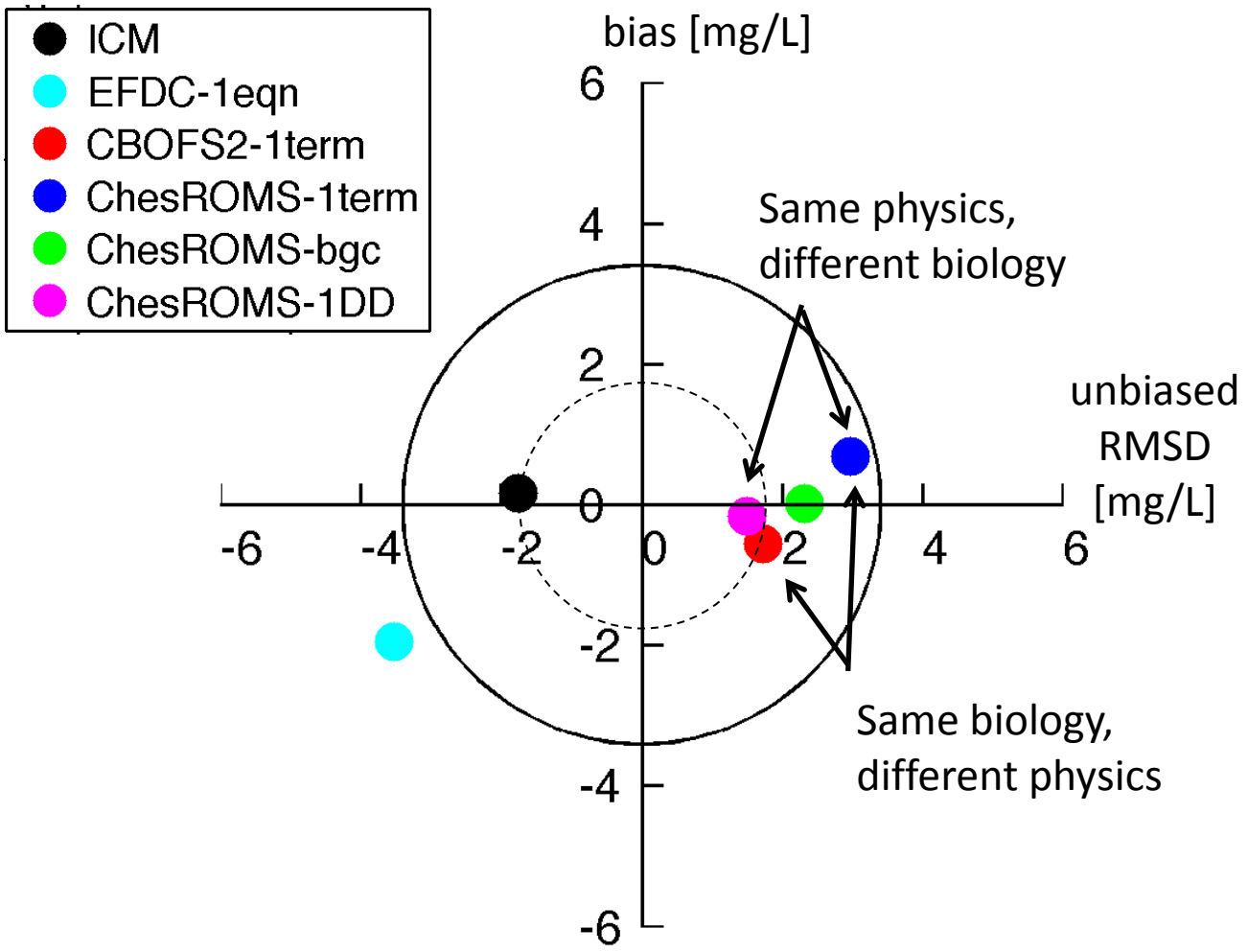
CBP model does well, but other models do equally well, even though they were not as skillful in terms of stratification

2004 Hypoxic Volume



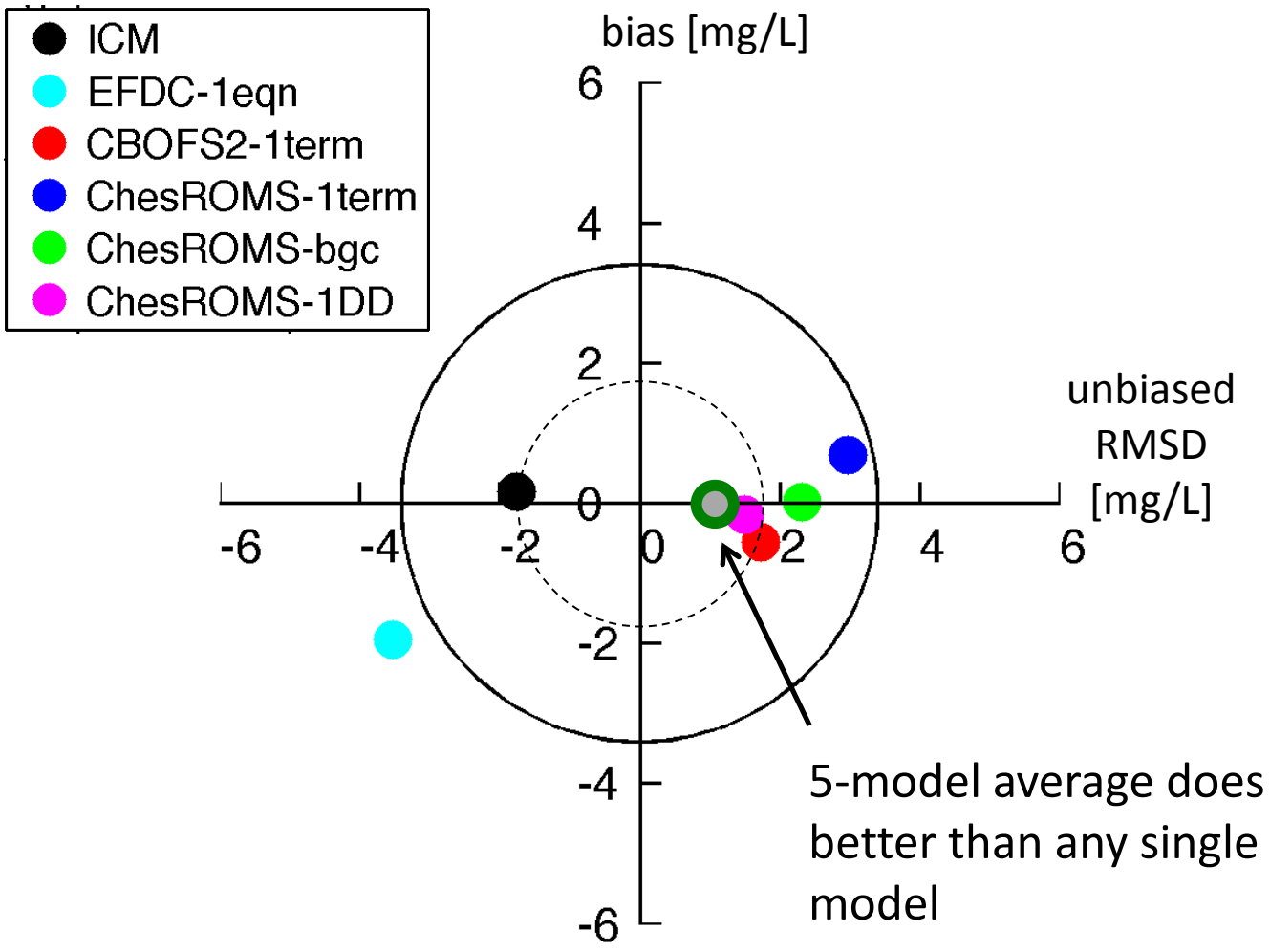
Again, CBP model does well, but other community models are rapidly improving; some now do equally well

2004 Hypoxic Volume



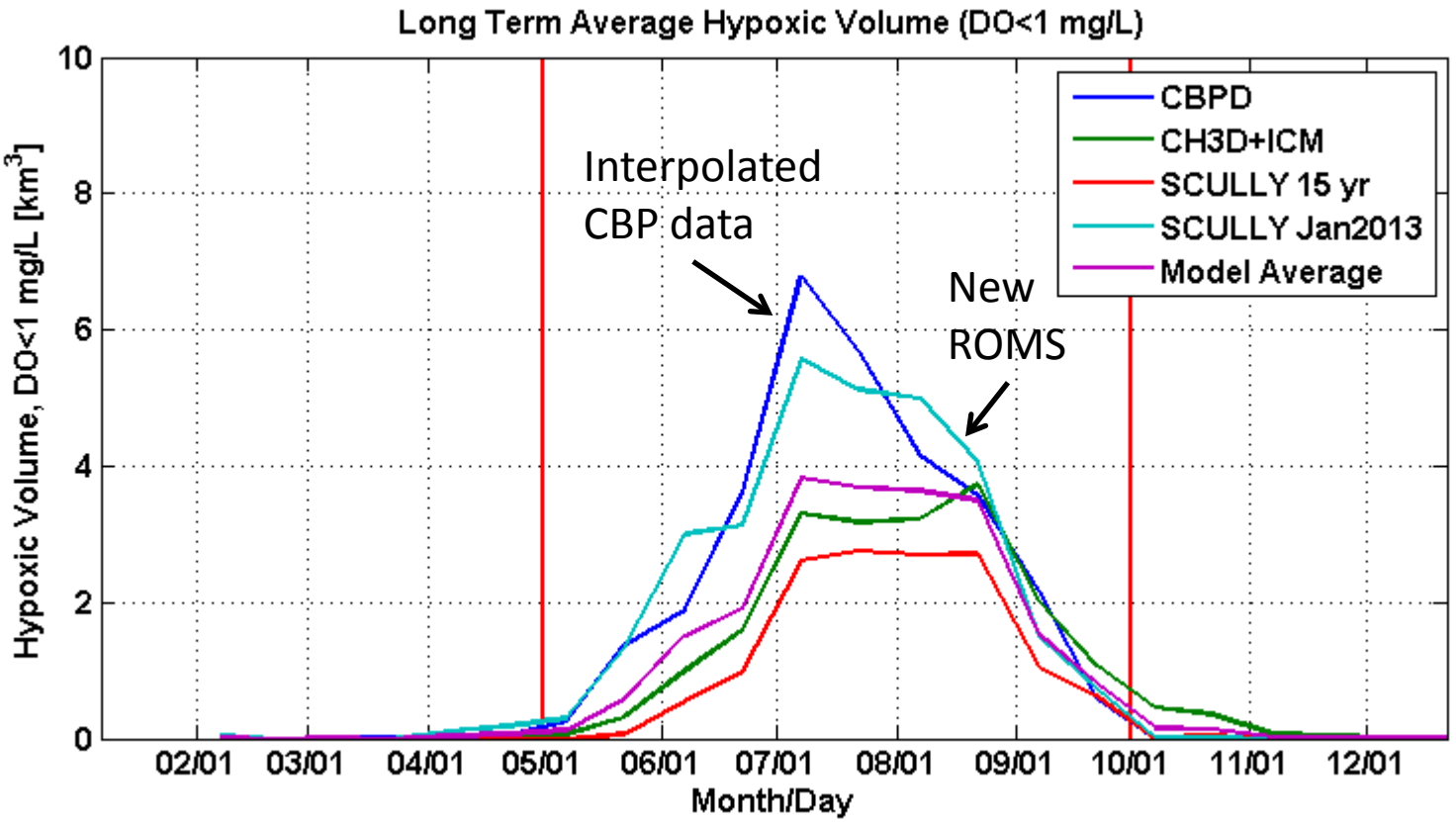
Multiple model comparison demonstrates that improving the physical model can be just as important as improving the biological model

2004 Hypoxic Volume



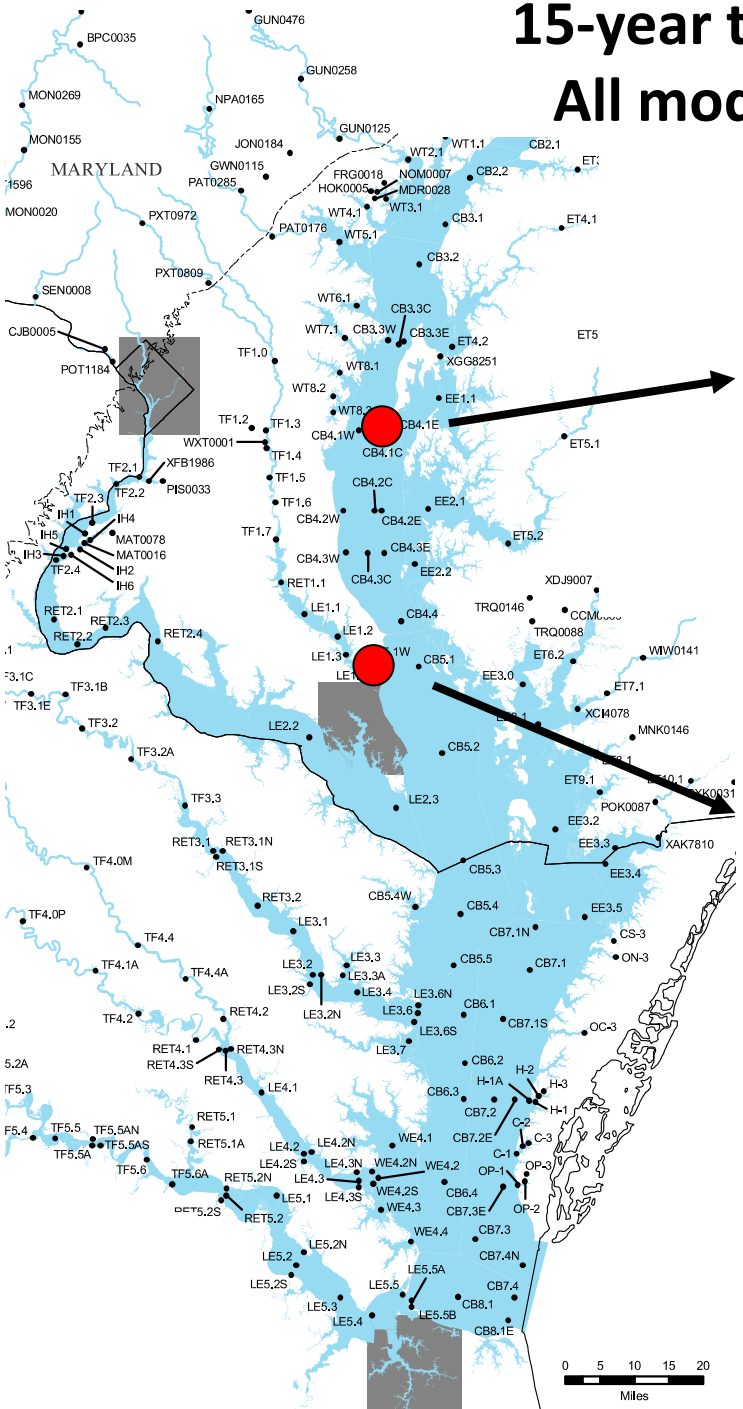
What about other years, besides 2004?

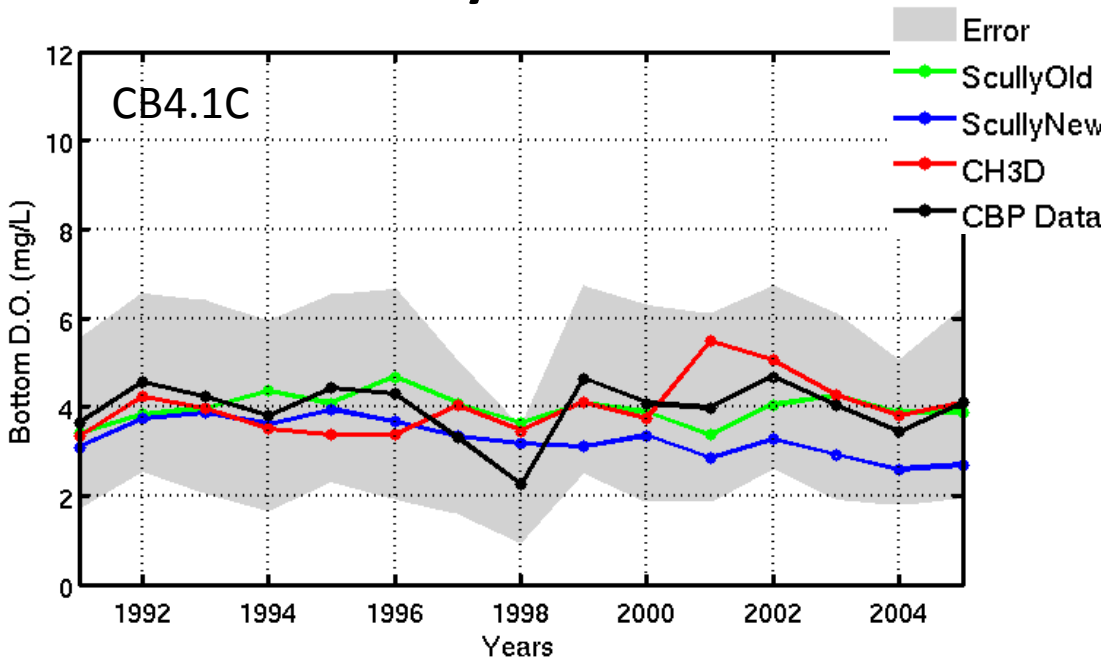
15-year Climatological Hypoxic Volume

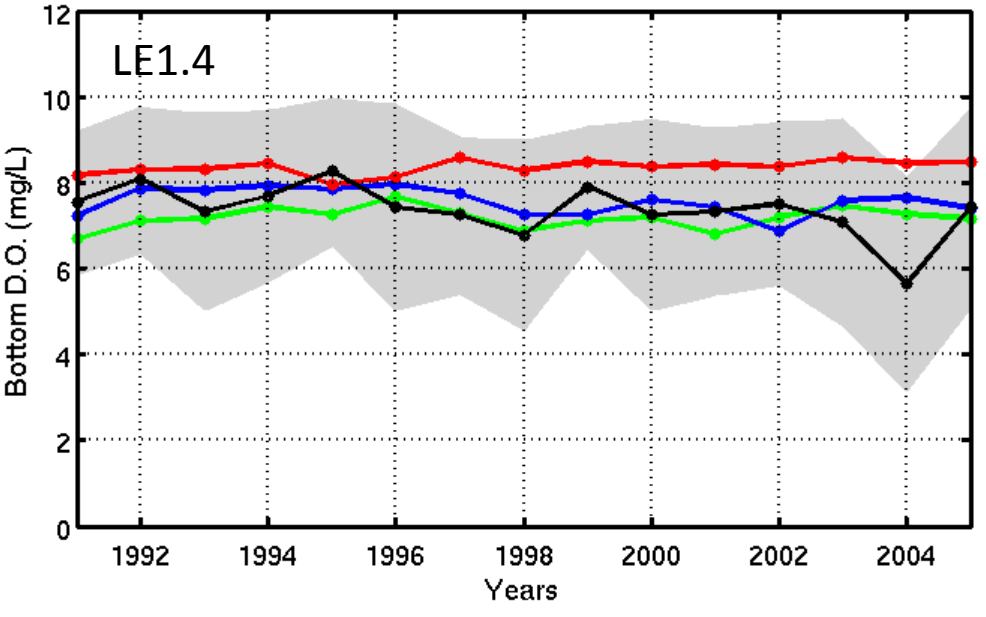


By adjusting the advection scheme in ROMS, the HVs now agree better with the data; maybe an adjustment to the advection in CH3D could result in a similar improvement?

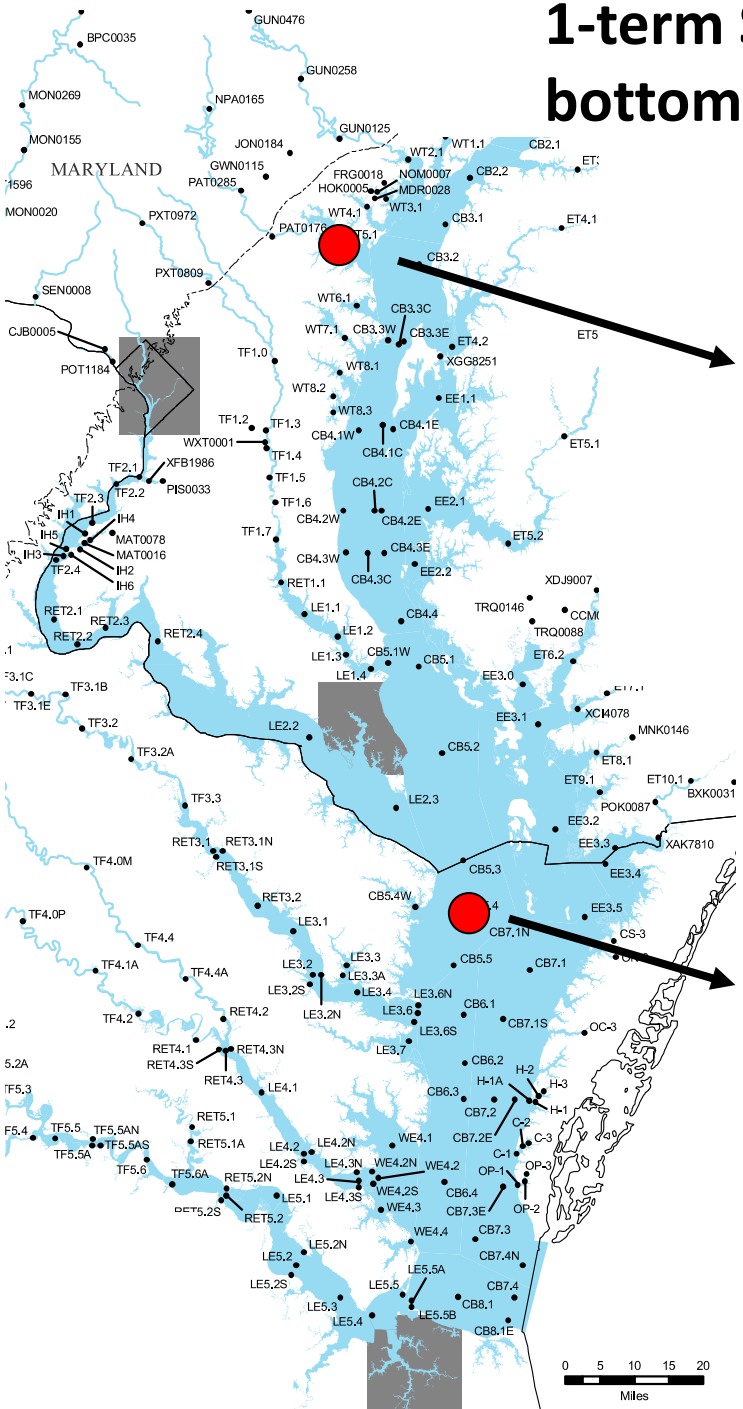
15-year time series (1991-2005) mean bottom DO
All models do well at many of the CBP stations

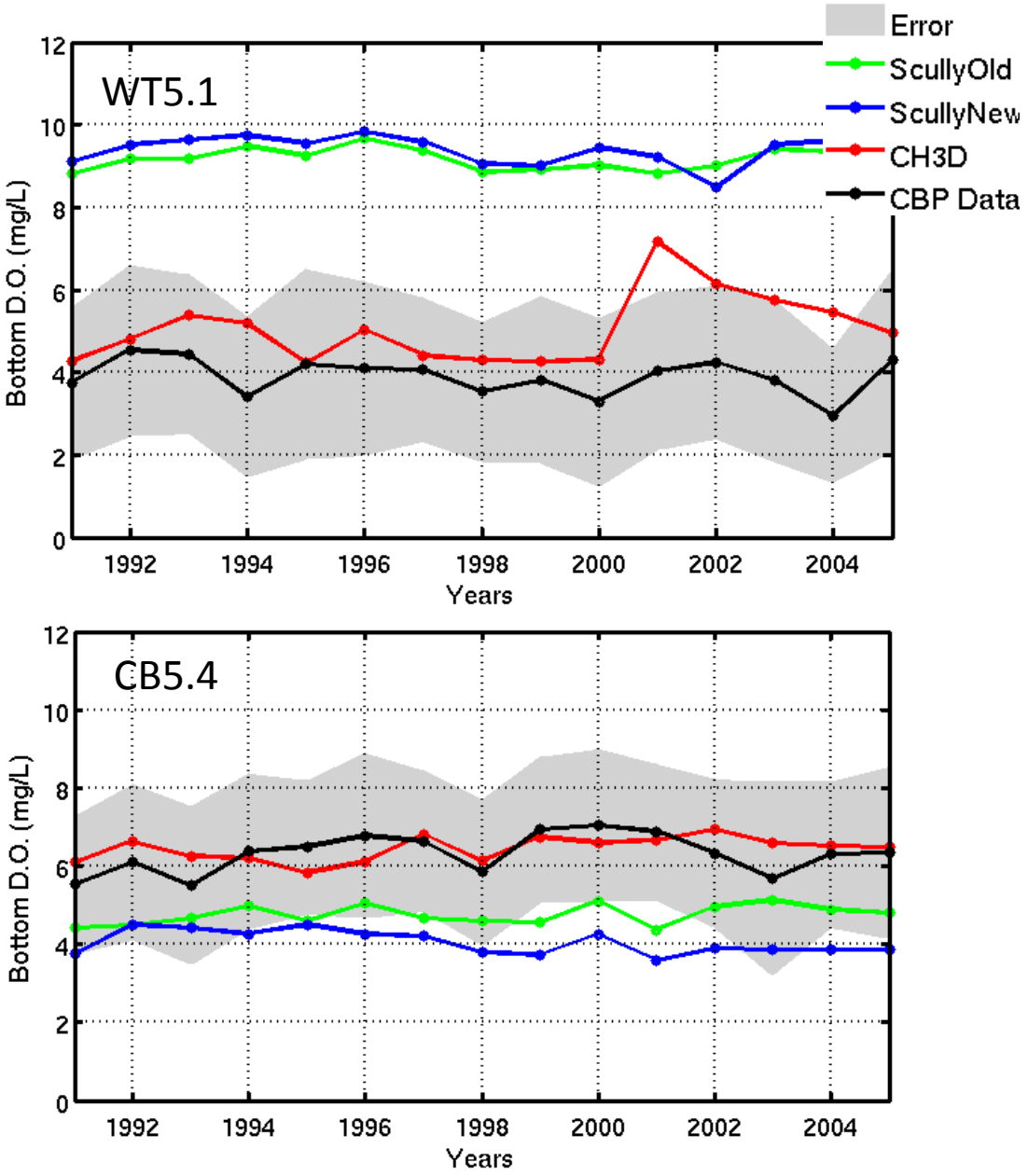




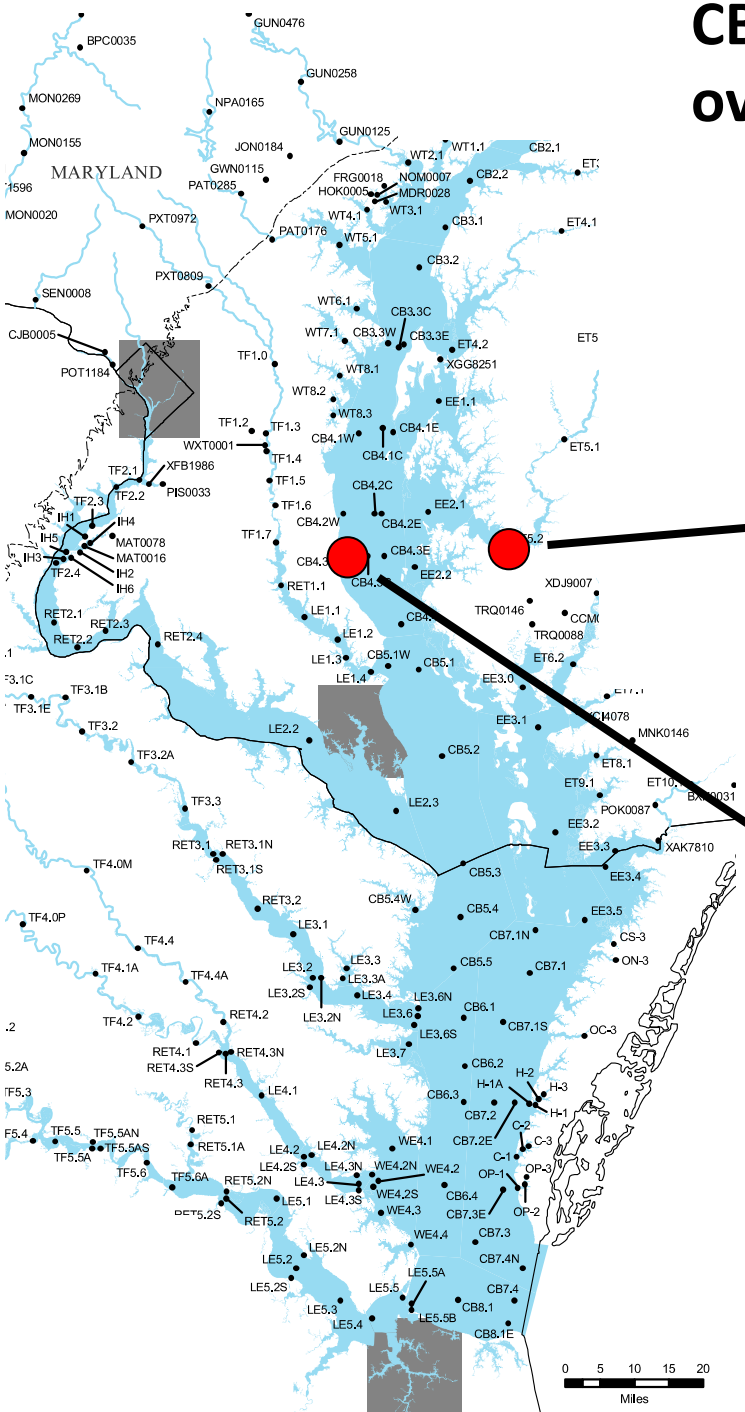


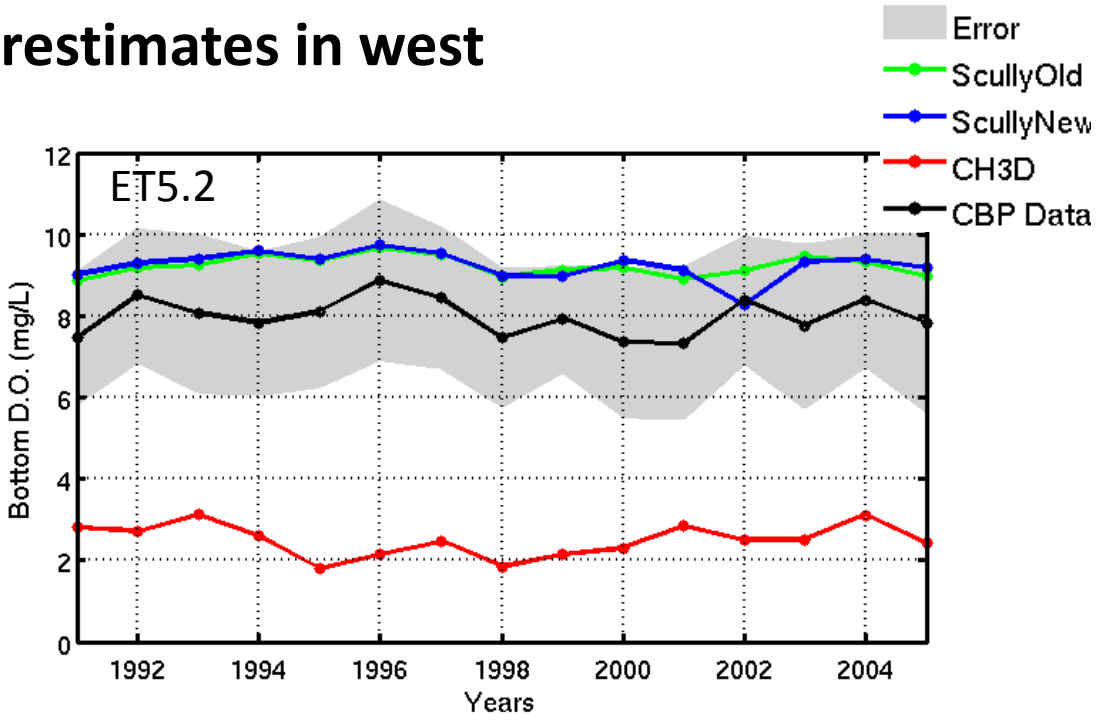
1-term Scully models overestimate annual mean bottom DO in north and underestimate in south

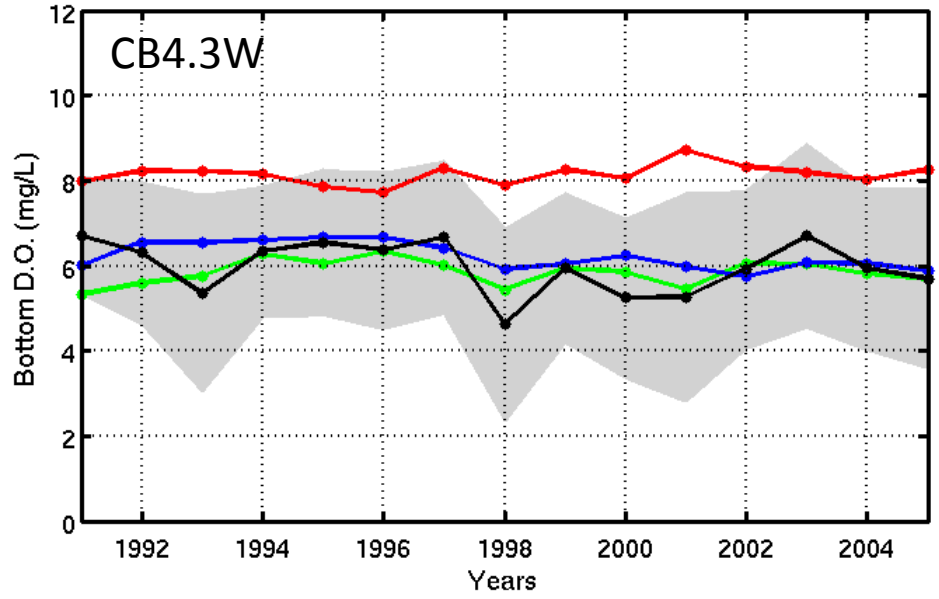




CBP model underestimates in east; overestimates in west







What have we learned from the U.S. IOOS multiple modeling effort?

Specifically…

- Multiple hydrodynamic+DO models exist for the Bay
- CBP model does very well!
  - Increased academic confidence in and support for the CBP model
- Other models do nearly as well, especially in terms of reproducing DO
  - Even though they are not reproducing stratification as well as CBP model, they can still reproduce DO fields
- Simple constant net respiration rate models reproduce mean and variability of DO surprisingly well
- Averaging output from multiple models provides better hypoxia hindcasts than relying on any individual model alone
- New ROMS with improved advection scheme shows great promise

What have we learned from the U.S. IOOS multiple modeling effort?

More generally…

Critical importance of:

- quantitatively assessing model skill
- multiple open source, community models
- large group of people from multiple institutions, all collaborating on CB modeling issues

Recommendation for CBP modeling program (from STAC):

- use a multiple modeling strategy
- begin with a multiple shallow water model pilot project

- **Lessons learned from the U.S. IOOS Estuarine Hypoxia Testbed model comparison project in the Chesapeake Bay**

- **Recommendations from the STAC sponsored M3.1 workshop, concerning the multiple shallow water model pilot project**

M3.1 Workshop
Virginia Institute of Marine Science
April 26-27, 2012

- **Overall Recommendation:**

A multiple shallow water model pilot project is key to the advancement of the CBP modeling program and should begin as soon as possible.

Workshop report (Friedrichs, Sellner & Johnston, 2012) available online at:
http://www.chesapeake.org/pubs/291_Pyke2012.pdf

Pilot Project Rationale

- **Need for <u>multiple modeling</u> efforts:**

  - Help determine whether the regulatory model is as skillful as other models of the Bay
  - Build scientist, management and stakeholder confidence in the model at a time when confidence in the regulatory model is low
  - Excellent opportunity for the CBP to heed recommendations suggested in several recent CBP reports and reviews

Pilot Project Rationale (cont.)

- **Need for <u>new shallow water modeling</u> efforts:**

  - Modeling WG has identified limitations to existing model in the shallowest, most productive part of Bay
  - Because DO & water clarity are criteria that must be met to delist the Bay, the Modeling WG has suggested that additional modeling approaches need to be considered in these waters

Pilot Project Outcomes

- **Project Outcome:**

  - Identification of new model for the shallow waters and/or suggested improvements to existing model
  - Confidence estimates for CBP shallow water simulations
  - Demonstration of utility of using multiple CB models, in response to recommendations of previous NRC/STAC reports/reviews

Pilot Project Methods

- **Methods:**

  - Shallow water hydrodynamic+water quality modelers will be sought for participation in a 1-2 yr pilot project

  - Each modeling team will:
    - Use common forcing to implement 3-5 year base case runs at specified times and sites
    - Provide daily distributions of variables relevant for SAV (T, S, DO, light, nutrients)
    - Provide results as above after forcing model with specified nutrient reduction scenarios

Pilot Project Methods

- **Methods (cont.):**

  - A separate model comparison team will:
    - Use daily distributions from each model as input to a specified empirical SAV model
    - Use state-of-the-art metrics to assess the relative skill of the participating simulations
    - Compare results of the modeled nutrient change scenarios
    - Analyze causes and impacts of differences among models

M3.1 Workshop
Virginia Institute of Marine Science
April 26-27, 2012

- **Overall Recommendation:**

A multiple shallow water model pilot project is key to the advancement of the CBP modeling program and should begin as soon as possible.

Workshop report (Friedrichs, Sellner & Johnston, 2012) available online at:
http://www.chesapeake.org/pubs/291_Pyke2012.pdf

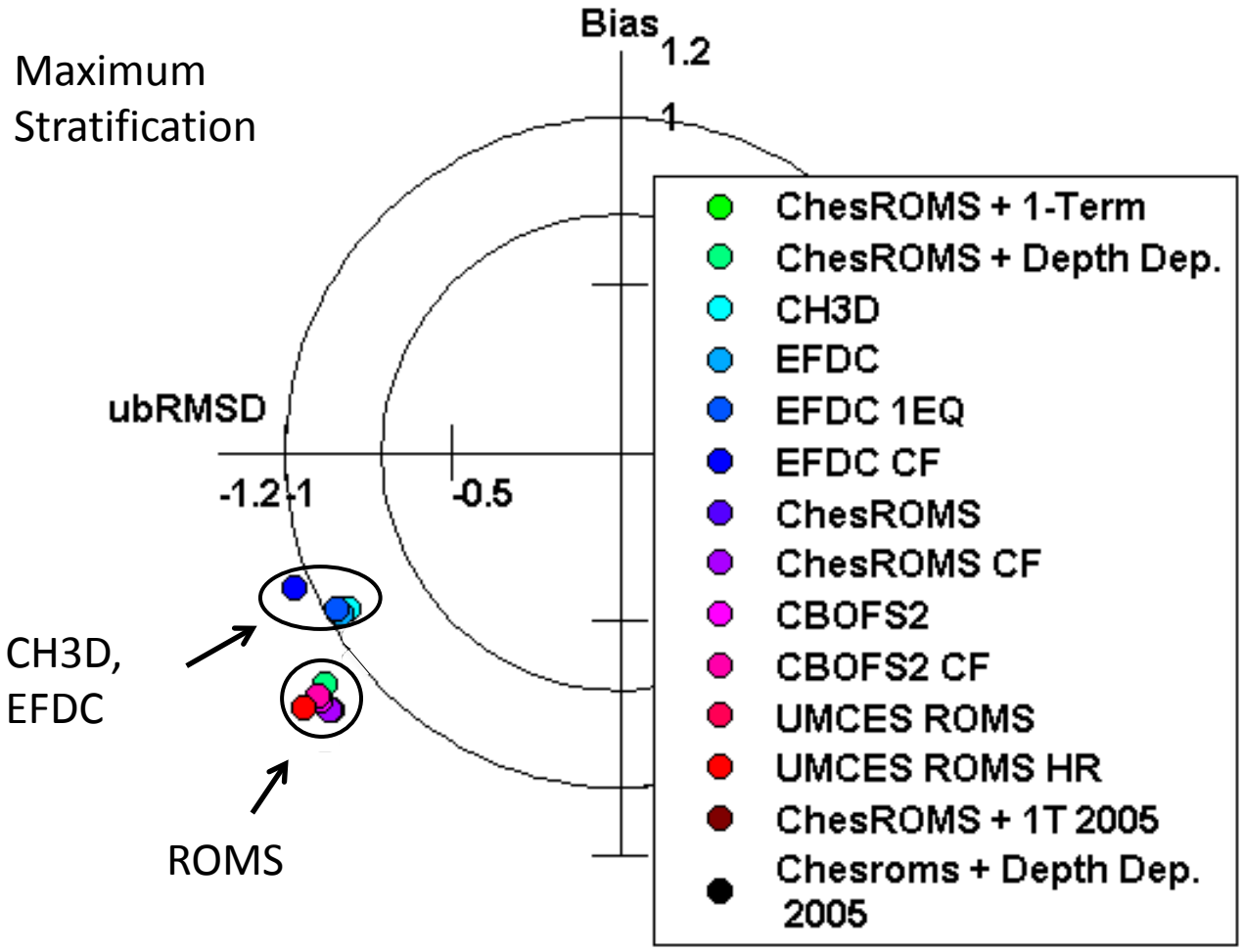
Extra Slides

Sensitivity Experiments

Use ROMS and EFDC to test sensitivity of hydrodynamic skill to:

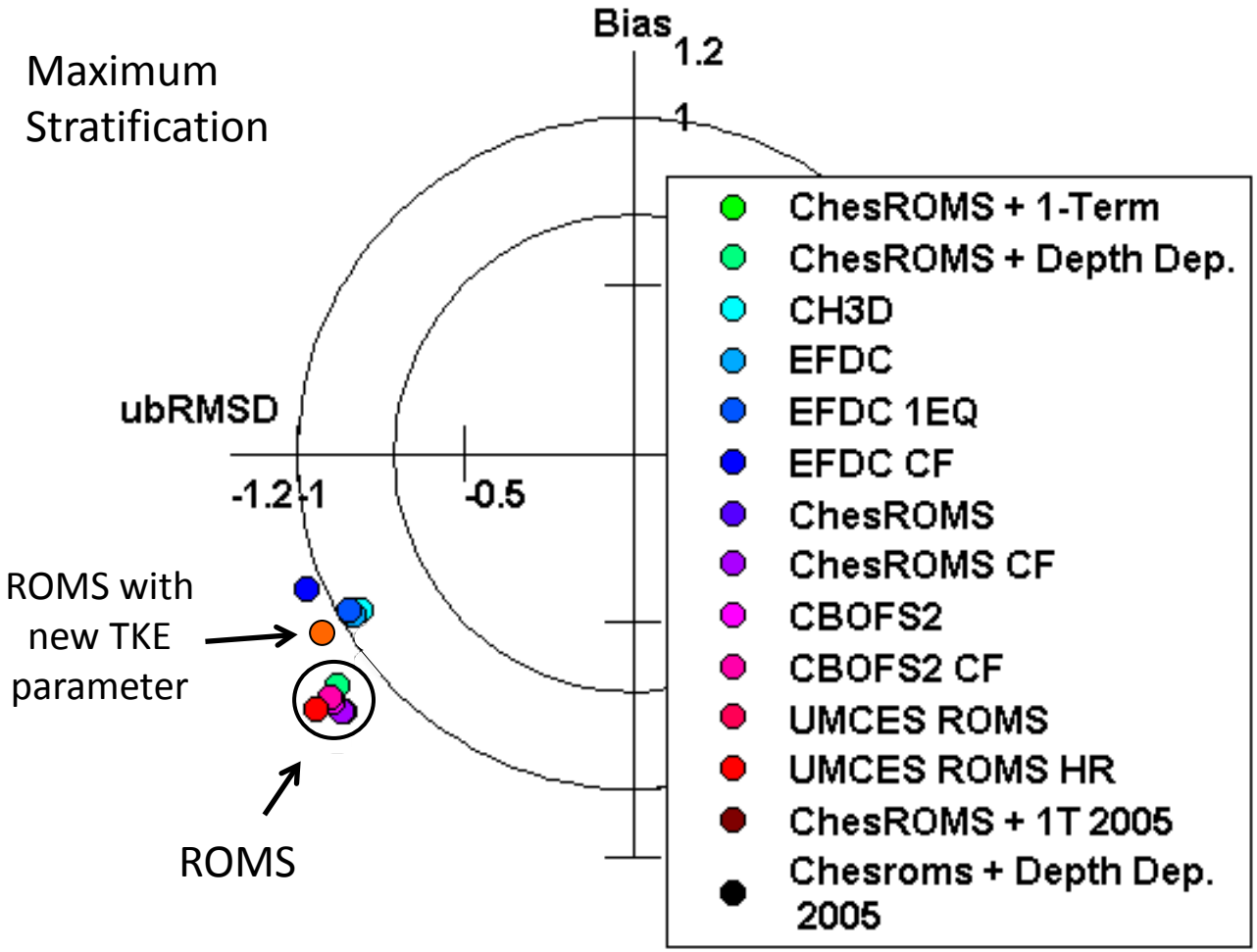
- Vertical grid resolution
- Horizontal grid resolution
- Vertical advection scheme
- Atmospheric forcing – winds
- Freshwater inflow
- Coastal boundary condition
- Mixing/turbulence closure

Sensitivity Experiments



Stratification is insensitive to horizontal/vertical grid resolution, freshwater inflow, coastal boundary, atmospheric forcing

Sensitivity Experiments



Stratification is insensitive to horizontal/vertical grid resolution, freshwater inflow, coastal boundary, atmospheric forcing

What have we learned from the IOOS testbed CB model sensitivity experiments?

Modeled stratification **is not highly sensitive** to:

- choice of wind forcing
- choice of river flow
- grid resolution
- coastal boundary condition

Modeled stratification **is most sensitive** to:

- turbulence closure parameterizations
- advection scheme

Pilot Project Funding & Timeline

- **Funding:**
  - ~100K per modeling team per year, depending on # of sites
  - Significant advantages for a multi-year project
  - Must have mechanism to ensure participation of governmental research scientists
  - Cost sharing must not be required

- **Timeline:**
  - Because of upcoming 2015 implementation deadline for the Modeling WG, the pilot project should begin as early in 2013 as possible

Pilot Project Site Selection

- **Site Selection Criteria:**

  Most importantly, contrasting, representative sites with data (3-5 years) available:

  - SAV present vs. absent
  - Fresh vs. salty
  - Sandy vs. muddy environment
  - Tidally vs. wave dominated
  - Eutrophic vs. oligotrophic

Perhaps one Virginia site (e.g. York River) and one Maryland site (e.g. upper Potomac)

Note: Workshop SC could provide document outlining specific optimal locations