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Skill Assessment of Multiple Hydrodynamic-Dissolved Oxygen Models in Chesapeake Bay

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INTRODUCTION

The Chesapeake Bay is the largest, most productive, and most biologically diverse estuary in North America, providing crucial habitat and natural resources for a suite of native and migratory species with a watershed serving as a home to over 17 million people. Over the last half-century, anthropogenic impacts, primarily via nutrient export to the Bay from rivers, have dramatically decreased water quality throughout the Bay. Improving the health of the Chesapeake Bay has become a priority for the six states that make up the watershed, and together, they have committed to follow a nutrient reduction plan developed by a modeling system. As water quality models are increasingly used in regulatory applications, it is important to understand the properties and limitations of a model's projections of dissolved oxygen concentrations, the primary indicator used in assessing the health of the Chesapeake Bay. Utilization of a multiple model approach to management decisions regarding dissolved oxygen could enhance confidence in projections and better refine our understanding of uncertainty in those projections, ultimately increasing overall environmental intelligence. Quantitatively assessing model skill by a variety of metrics is necessary to compare the ability of models in a multiple models system.

OBJECTIVE

Statistically compare historical Chesapeake Bay Program monitoring data to a group of coupled hydrodynamic-dissolved oxygen models of varying complexity and to the Chesapeake Bay Program's official regulatory model in order to glean the required environmental intelligence from these modeling efforts.

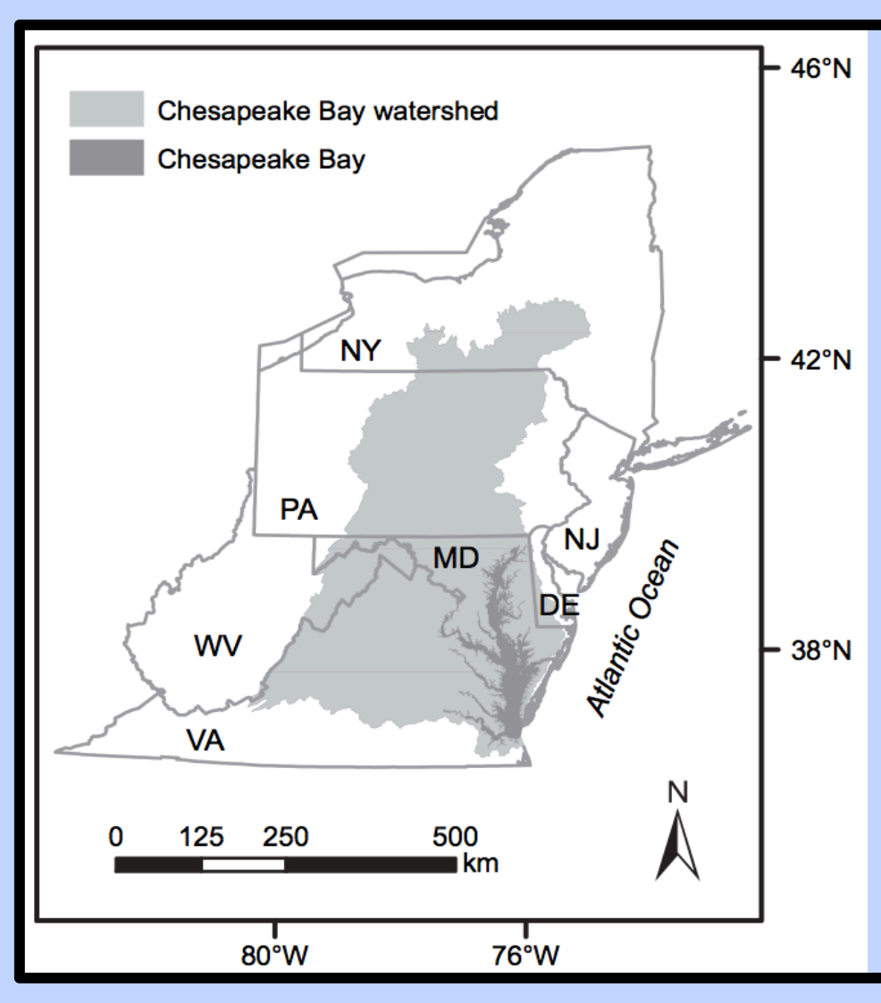

Figure 1. Map of the Chesapeake Bay and its watershed. (Najjar et al., 2010, ECSS, doi10.1016/j.ecss.2009.09.026).

DATA

Historical observation for 2004 from 13 stations along the main stem of the Chesapeake Bay were used to assess model skill for temperature, salinity, dissolved oxygen, nitrate, and chlorophyll. Observation were taken by the Chesapeake Bay Program at each station 17 times throughout the year and at depth intervals of roughly one meter. Stations were sampled twice a month during the summer.

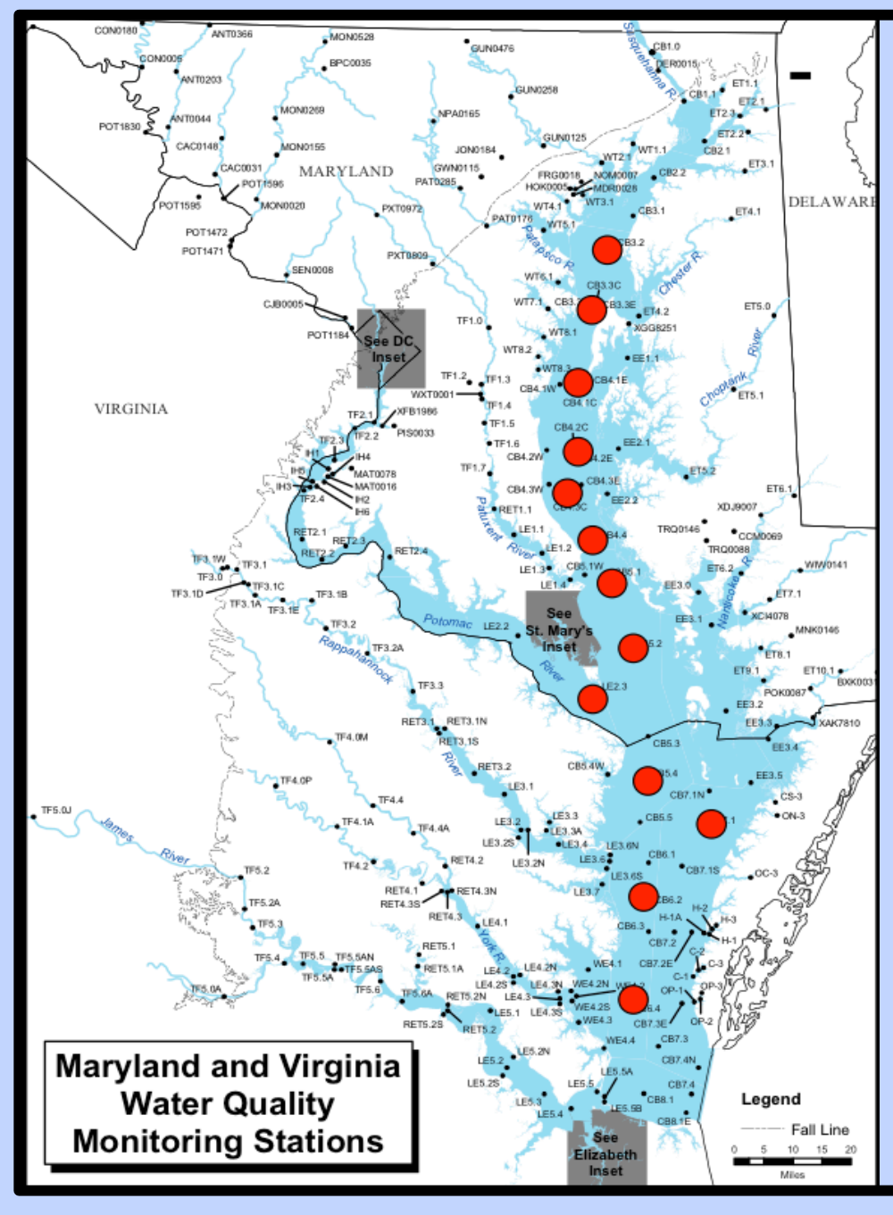

Figure 2. Location of the 13 Chesapeake Bay Program monitoring stations utilized in the study.

MODELS

Six models were used in this study that all couple a hydrodynamic component to a biogeochemical (BGC) component of varying degrees of complexity. CH3D-ICM is the regulatory water quality model used by the EPA's Chesapeake Bay Program. The other five models, including CBOFS (Chesapeake Bay Operational Forecasting System, NOAA-CSDL), have hydrodynamic components built upon the community-based Regional Ocean Modeling System (ROMS). ChesROMS-ECB, ROMS-RCA, and ChesROMS-BGC include a full suit of biogeochemical interactions throughout the water column. CBOFS and ChesROMS-1term both only include dissolved oxygen as a tracer based on a constant respiration rate. CBOFS has higher horizontal resolution than the other ROMS models.

	CH3D-ICM	ChesROMS-ECB	ChesROMS-1term	ROMS-RCA	CBOFS-1term	ChesROMS-BGC
Institution	EPA	VIMS	WHOI	UMCES	NOAA	UMCES
BGC	Yes	Yes	No	Yes	No	Yes
XY - Grid	0.25 - 1km^2	~ 1km^2	~1km^2	~ 1km^2	~ 0.3km^2	~ 1km^2
Z - Grid	z: ~ 5ft	σ: 20 layers	σ: 20 layers	σ: 20 layers	σ: 20 layers	σ: 20 layers

Table 1. Characteristics of the individual models.

ANALYSIS

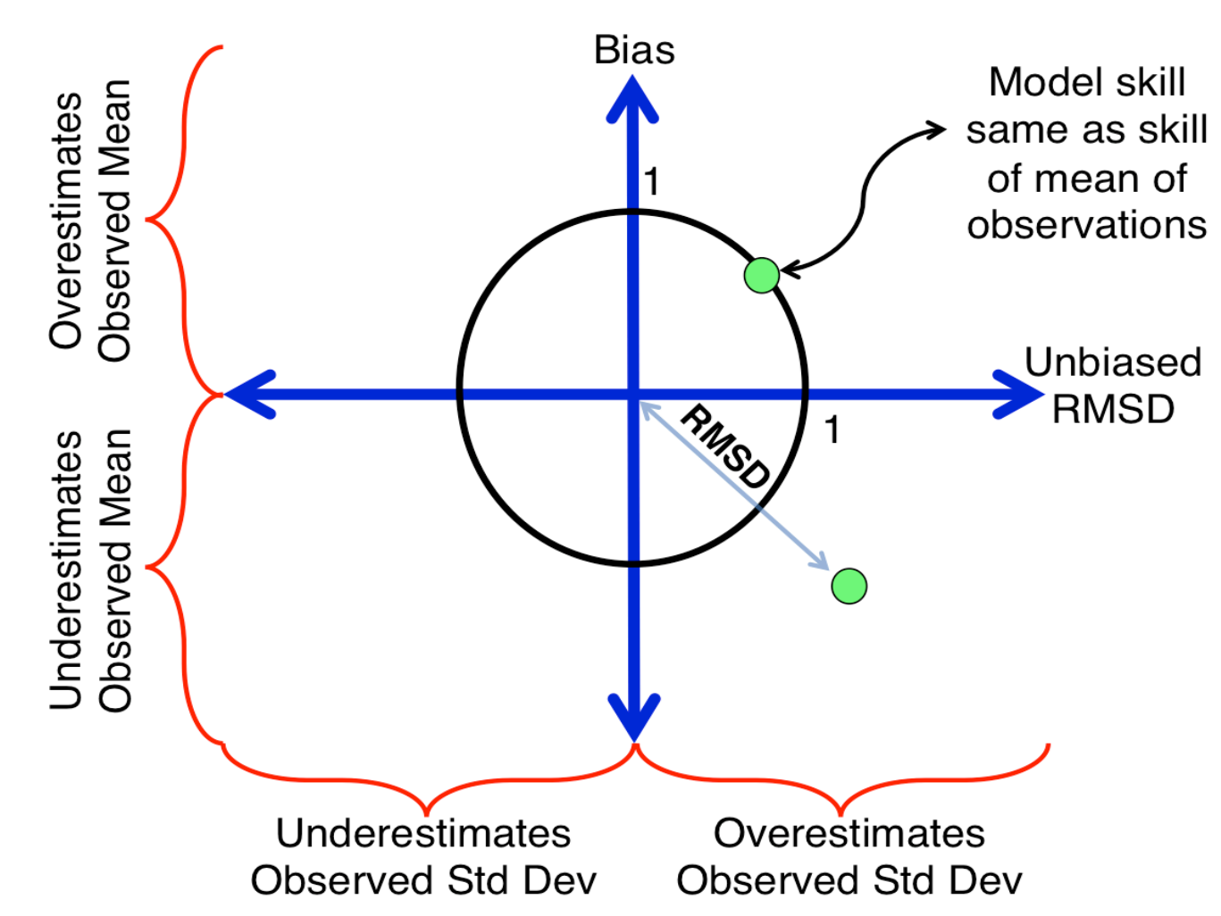

Figure 3. Target Diagram illustrate the total root mean square difference (RMSD), bias and unbiased RMSD between the observations and the model results, normalized by the standard deviation of the observations. (Jolliff et al., 2009, JMS, doi10.1016/j.jmarsys.2008.05.014).

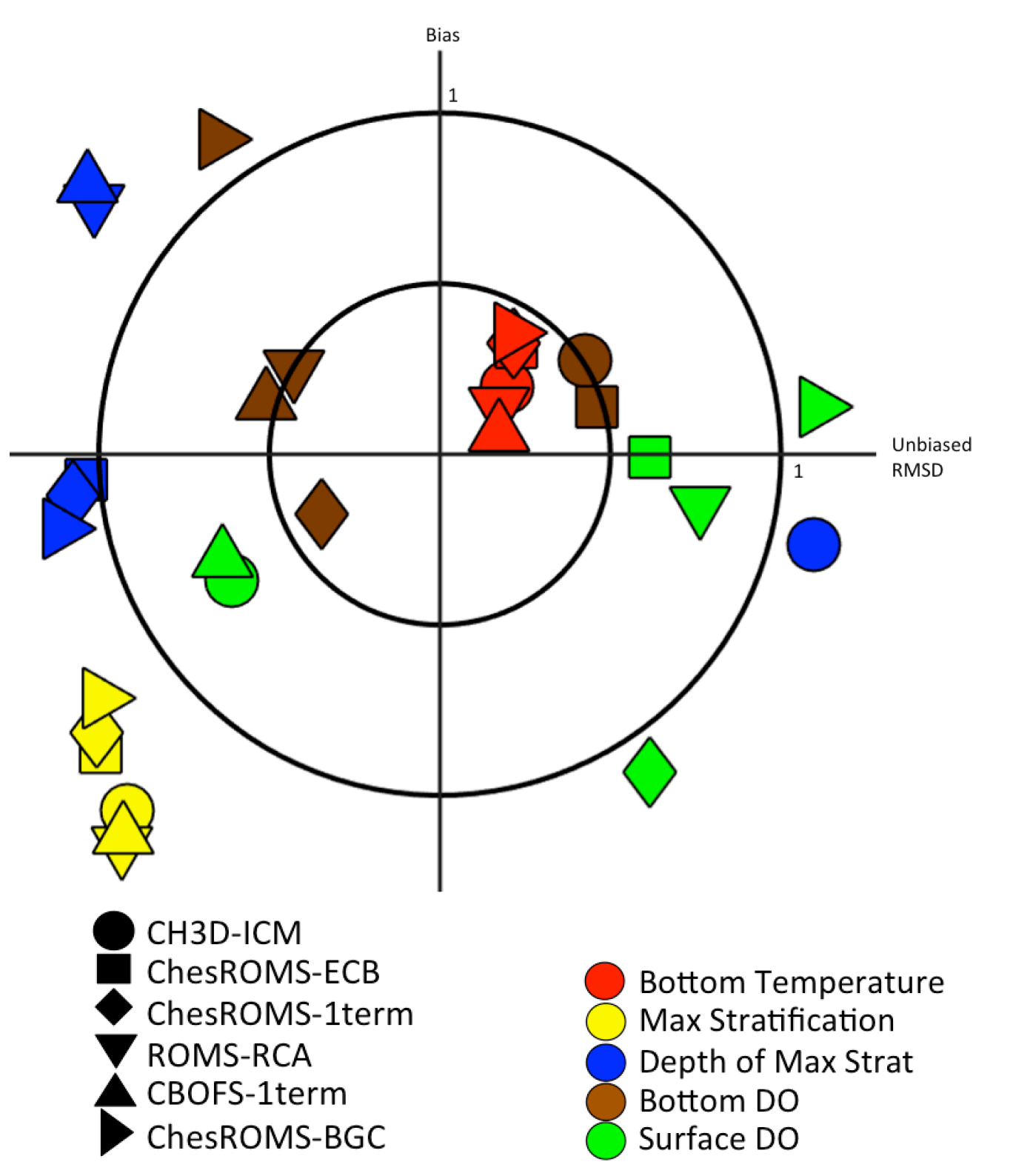

Figure 4. Normalized target diagram for 2004 illustrating how well the six models perform in terms of reproducing the observed means and combined spatial and seasonal variability for six water quality variables.

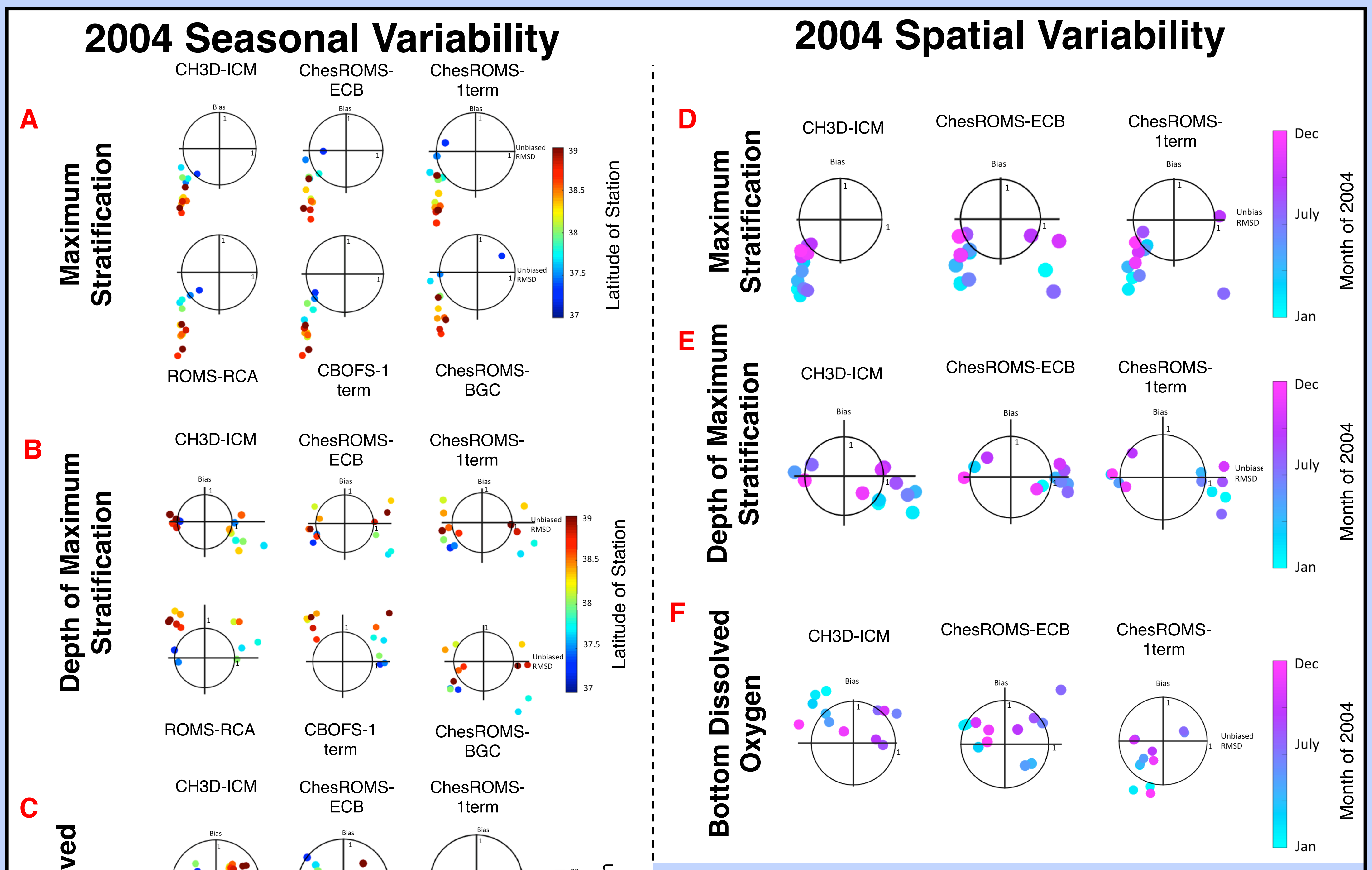

Figure 5. Normalized target diagrams showing how well the models reproduce the observed mean and variability at 13 main stem station for 2004. A) Seasonal variability of maximum stratification (dS/dz). Colors represent station latitude. B) Seasonal variability of the depth of maximum stratification. Colors represent station latitude. C) Seasonal variability of bottom (deepest layer or observation) dissolved oxygen. Color represents station latitude. D) Spatial variability of maximum stratification (dS/dz). Colors represent month of the year. E) Spatial variability of the depth of maximum stratification. Colors represent month of the year. F) Spatial variability of bottom (deepest layer or observation) dissolved oxygen. Color represents month of the year. All models tend to represent bottom dissolved oxygen and depth of max strat variability better than max stratification.

RESULTS & CONCLUSIONS

- All models perform similarly well for temperature, most perform well for bottom and surface DO and depth of maximum stratification, but all consistently underestimate both the mean and standard deviation of maximum stratification (Fig. 4).
- While the models perform uniformly poorly in terms of stratification, the generally perform better in terms of depth of maximum stratification and bottom DO in both seasonal and spatial variability (Fig. 5).
- The observed extent of water column hypoxia (DO < 2 mg/L) is limited by the depth of stratification (Fig. 6).
- For most models, the depth of the 2 mg/L contour is highly variable, but is also tied to the depth of stratification in summer months (Fig. 6).

Hypoxia is controlled by a mix of influencing variables. This study suggests that a key factor for resolving hypoxic conditions throughout the water column is the ability to adequately resolve the depth of stratification, which is correlated to the depth of the maximum change in dissolved oxygen. While all of the models have difficulty resolving the degree of stratification, they resolve depth of stratification fairly well. This is critical because the observations show that during hypoxic events, low dissolved oxygen water will fill the water column up to where stratification limits further vertical movement. This effectively cuts off waters below stratification for the majority of Bay species during the summer months in areas that experience hypoxia.

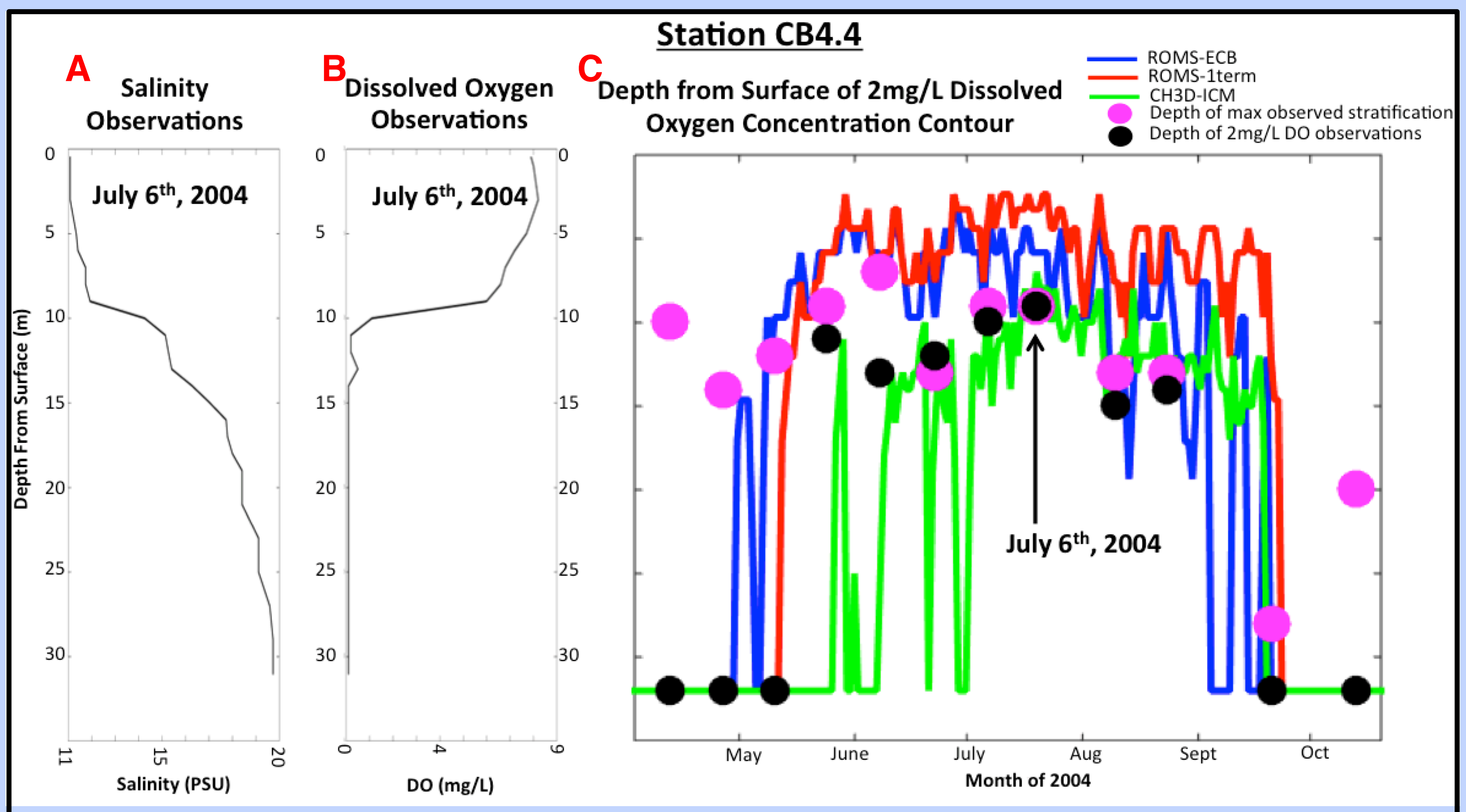

Figure 6. Salinity (A) and dissolved oxygen (B) observation profiles for a mid-Bay station (CB4.4) on July 6th, 2004. (C) is a time series of depth of the 2 mg/L oxygen contour from the observations (black dots) and the models: ROMS –ECB (blue), ROMS-1term (red), and CH3D-ICM (green). Pink dots represent the depth of maximum observed stratification. The arrow indicates the July 6th observations where depth of observed maximum stratification equals the depth of the 2mg/L dissolved oxygen observation. This is the date shown in profiles (A) and (B).

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