Intercomparison of Hypoxia Models for the Northern Gulf of Mexico

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Introduction

Observations of coastal hypoxia have increased dramatically over the past 50 years likely due to increased anthropogenic nutrient loading. The largest of these hypoxic zones in U.S. coastal waters (15,000 ± 5,000 km^2) forms every summer over the continental shelf in the northern Gulf of Mexico due to nutrient and freshwater input from the Mississippi/Atchafalaya River System. The hypoxic zone varies interannually in terms of both, extent and location, due to variations in spring nutrient load, freshwater discharge, atmospheric forcing and circulation patterns.

Several coupled circulation-hypoxia models are under development for this region in order to improve mechanistic understanding of the primary factors controlling hypoxia formation and to inform nutrient management decisions in the watershed. Here we report on an intercomparsion of hypoxia models for the northern Gulf of Mexico that is being undertaken within the NOAA-funded Coastal & Ocean Modeling Testbed (COMT) project.

Models

Three different circulation models are represented in the intercomparison:

1) the Regional Ocean Modeling System (ROMS),
2) the Finite Volume Coastal Ocean model (FVCOM), and
3) the U.S. Navy's coastal ocean model (NCOM).

ROMS is implemented in two different domains, which we refer to here as the small ROMS domain (Fig. 1a) and the large ROMS domain (Fig. 1b). The geographical extent of the FVCOM domain (Fig. 1c) and the NCOM domain (Fig. 1d) is roughly similar to the small ROMS domain (Fig. 1a).

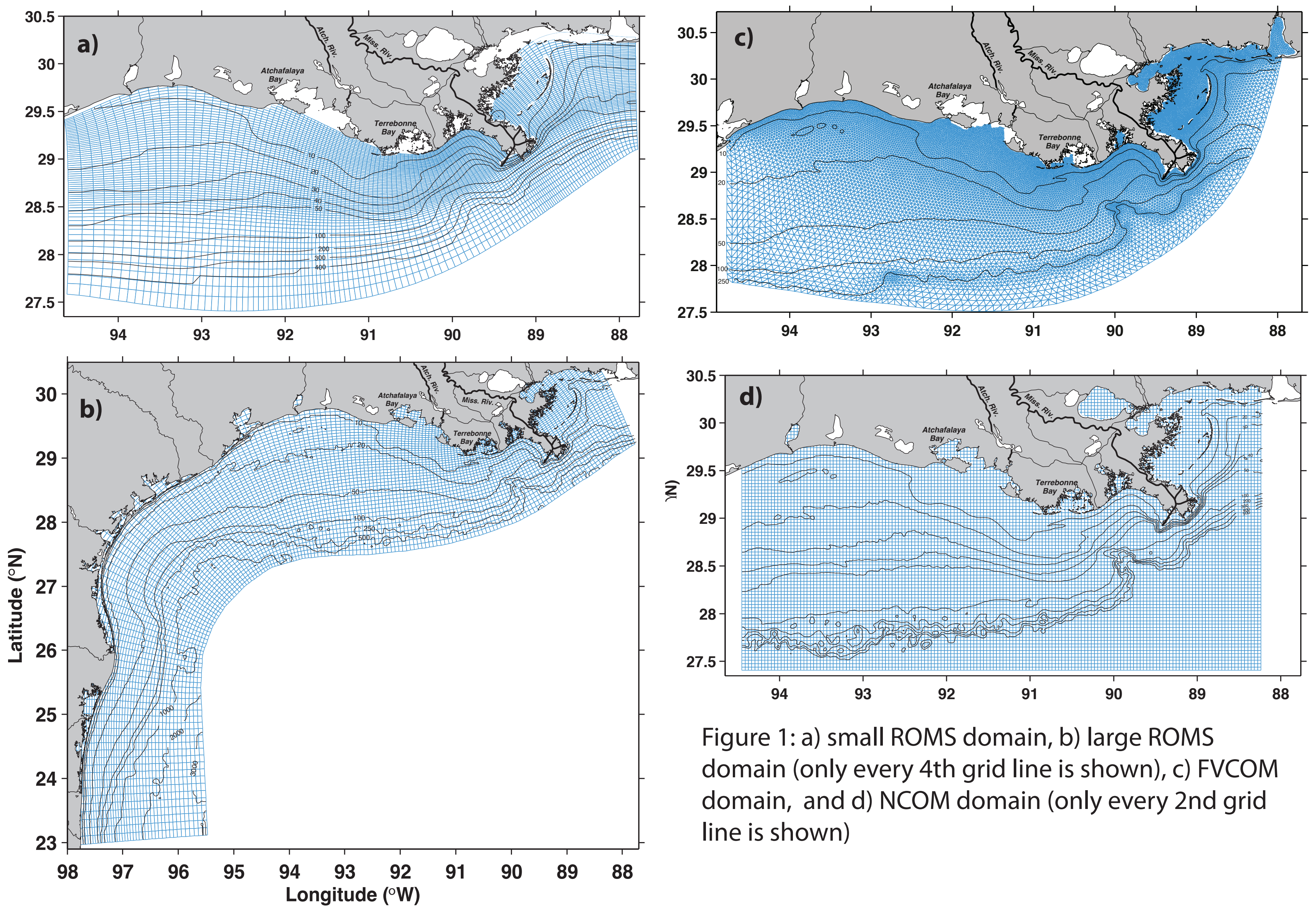

Figure 1: a) small ROMS domain, b) large ROMS domain (only every 4th grid line is shown), c) FVCOM domain, and d) NCOM domain (only every 2nd grid line is shown)

We consider two different categories of hypoxia models: a simple oxygen consumption parameterization that is applied identically in all physical models, and NPZD-type biological models with explicit representations of dissolved oxygen, which differ between the different physical models.

The simple oxygen consumption parameterization includes a horizontally and vertically constant oxygen consumption term in the water column that is applied inside of the 20 m isobath (and ramps down to zero at the 30 m isobath), a parameterization of sediment oxygen consumption that depends on bottom water temperature and oxygen concentration only (Hetland & DiMarco, 2008), and air-sea gas exchange. We henceforth refer to this oxygen parameterization as the ***simple oxygen model***.

The NPZD-type models, which we henceforth refer to as the ***full models***, differ between physical models: in both ROMS domains we use the model of Laurent & Fennel (2014), while in the FVCOM domain we use the model of Justic & Wang (2014). A full model for the NCOM domain will be included in the future. The full ROMS model has two different parameterizations for sediment oxygen consumption: instanteneous remineralization (IR), which assummes that the organic matter reaching the bottom is instanteneously remineralized, and the parameterization of Hetland & DiMarco (H&D), which is also used in the simple oxygen model.

Model comparisons

Among the **simple oxygen models** NCOM generates a notably smaller hypoxic area than the ROMS models, while both ROMS models give very similar results in this case (Fig. 2, top row). Simulated bottom water oxygen concentrations are higher in NCOM compared to the ROMS models; however, the timing of variations in bottom oxygen matches closely between both, NCOM and ROMS (Fig. 3, top row). Since these models use the same simple oxygen model, differences must be due to different model physics.

Among the **full models** FVCOM and the ROMS version with H&D sediment parameterization predict very similar hypoxic areas (Fig. 2, bottom panel) and very similar bottom water oxygen concentrations except near the Mississippi Delta where FVCOM's bottom water oxygen is higher than that of ROMS (Fig. 3, bottom row). The ROMS version with sediment oxygen consumption (SOC) according to IR predicts a smaller hypoxic area than the other two models shown (Fig. 2, bottom panel) likely because SOC is smaller (Fig. 4).

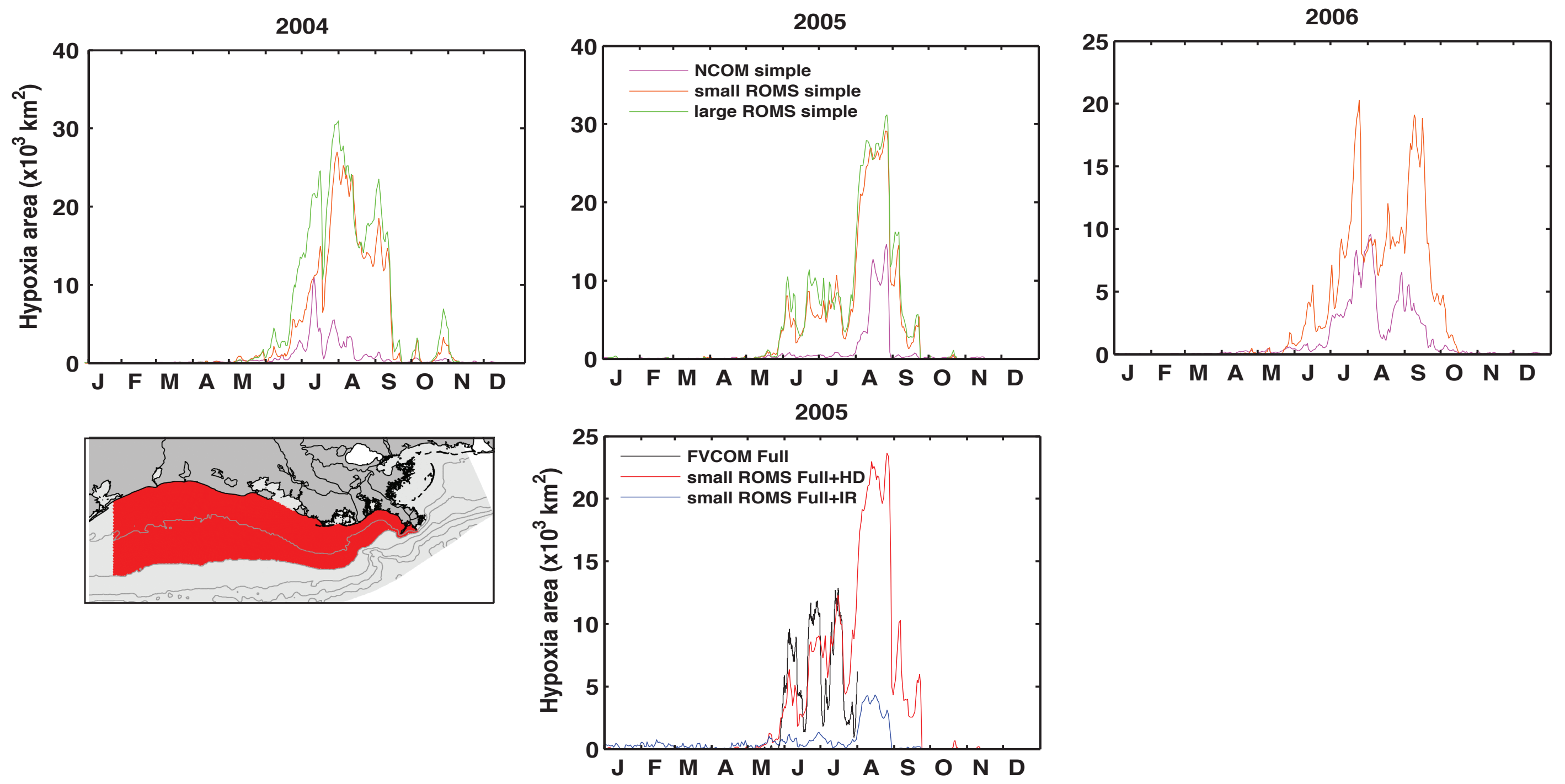

Figure 2: Simulated hypoxic area from 2004 to 2006 for the simple oxygen models is shown in the top row. The bottom panel shows the simulated hypoxic area in 2005 for the full models. The hypoxic area was calculated only for the region indicated in red in the map.

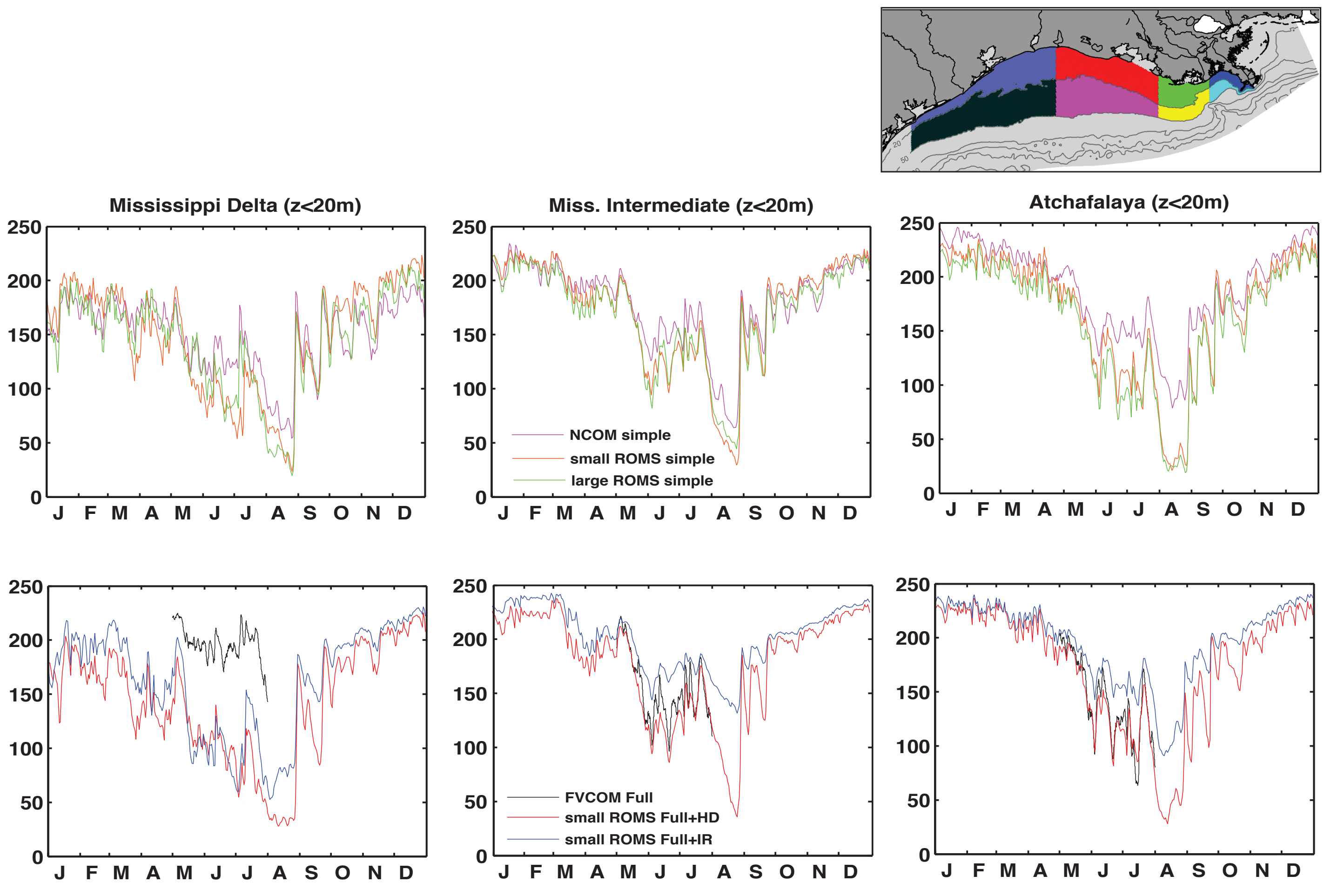

Figure 3: Seasonal evolution of spatially averaged bottom water oxygen concentration in 2005 for the simple oxygen models is shown in the top row. The bottom row is for the full models. The averaging areas are shown in the map (Mississippi Delta (z < 20 m) in blue, Mississippi Intermediate (z < 20 m) in green, Atchafalaya (z < 20 m) in red).

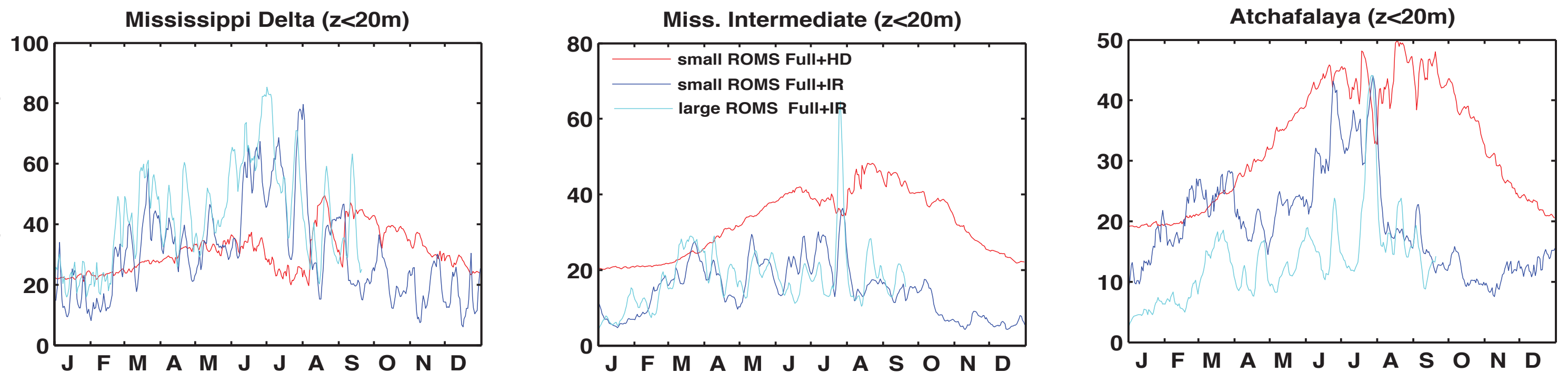

Figure 4: Spatially averaged Sediment Oxygen Consumption (SOC) in 2005 is shown for the full models.

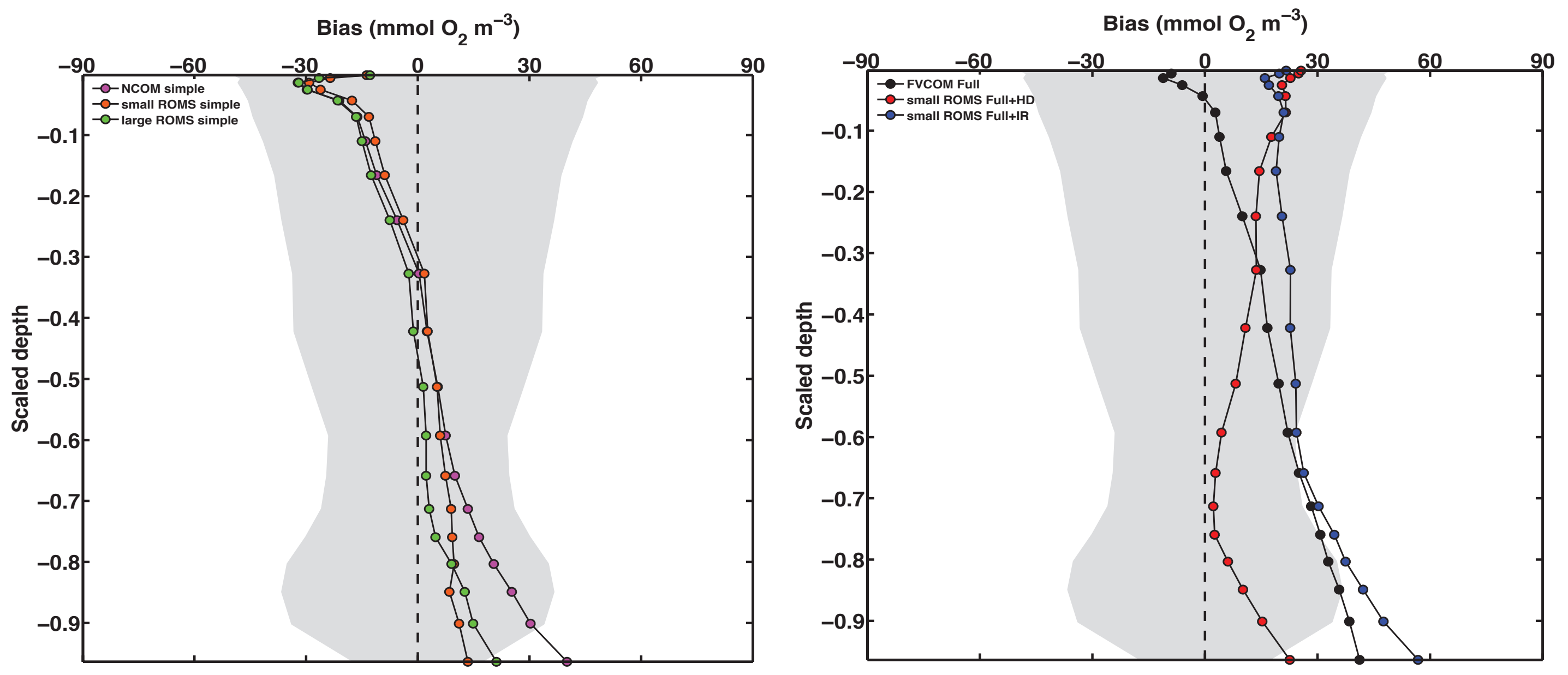

Figure 5: Bias (model - observations) in vertical oxygen distribution calculated from 496 profiles measured between May and July of 2005. The simple oxygen models are shown on the left, the full models on the right. The grey area indicates plus/minus one standard deviation of the observations.

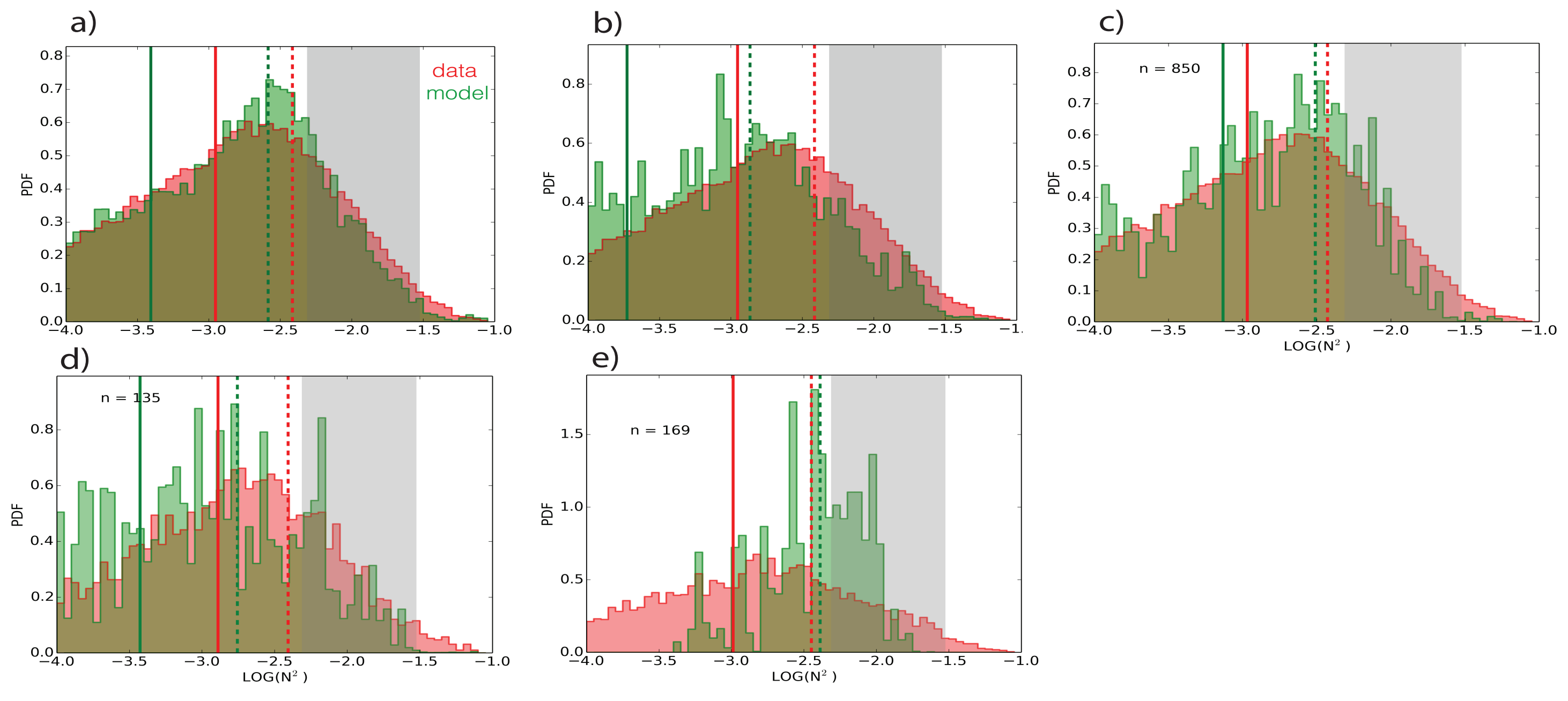

Figure 6: Histograms of vertical stratification strength (log(N2)) from observed profiles (red) and simulations (green) for three long simulations in the top row: a) the large ROMS domain, b) the small ROMS domain, and c) NCOM. The bottom row shows the same comparison for shorter simulations with d) the large ROMS domain and f) FVCOM.

The bias plots (Fig. 5) show that all models represent the vertical distribution of dissolved oxygen well (within one standard deviation of the observations) except near the bottom, where most models overestimate oxygen slightly.

The density comparisons indicate that stratification tends to be underestimated during times of strong stratification in NCOM and the ROMS simulation in the small domain, while stratification is more accurately predicted in the large ROMS domain (Fig. 6, top row). Short simulations are difficult to assess because the histograms are noisy in these cases (Fig. 6, bottom row).

Next Steps

Next steps will include expanding the comparison by including an FVCOM simulation with the simple oxygen model, an NCOM simulation with a full model, more detailed comparisons against oxygen observations and comparisons against observed primary production, water column respiration and sediment oxygen consumption.

References:

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Justić, D. & Wang, L. Assessing temporal and spatial variability of hypoxia over the inner Louisiana–upper Texas shelf: Application of an unstructured-grid three-dimensional coupled hydrodynamic-water quality model, Continental Shelf Research 72:163-179, 2014.

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