Impacts of Sea Level Rise on Hypoxia—progress report

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Overview

We are investigating the impacts of sea level rise (SLR) on hypoxia using different models of the bay.

The experiments assume realistic conditions for the period **1991–1995** and use the same riverine forcing (Phase-6 CXXBASE).
We consider four scenarios:

1. No SLR: base run / control
2. SL raised by 0.17 m at the oceanic model boundary (2025)
3. SL +0.50 m (2050)
4. SL +1.00 m (2100)

Experiments completed / ongoing

Model ChesROMS-ECB:

- Control 1991–2000
- +0.17 m 1991–2000
- +1.00 m 1991–1995 (**ongoing**)

Model UMCES-ROMS (physics) + RCA (biology):

- Control 1991–1995 (physics)
- Control 1991–1995 (biology)
- +0.17 m 1991–1995 (physics)
- +0.17 m 1991–1995 (biology)
- +1.00 m 1991–1995 (physics) (**ongoing**)
- +1.00 m 1991–1995 (biology) (**ongoing**)

Model SCHISM:

- Control 1991–1995 (physics)
- Control 1991–1995 (biology) (**ongoing**)
- +0.17 m 1991–1995 (physics) (**ongoing**)

Questions raised in previous conference calls

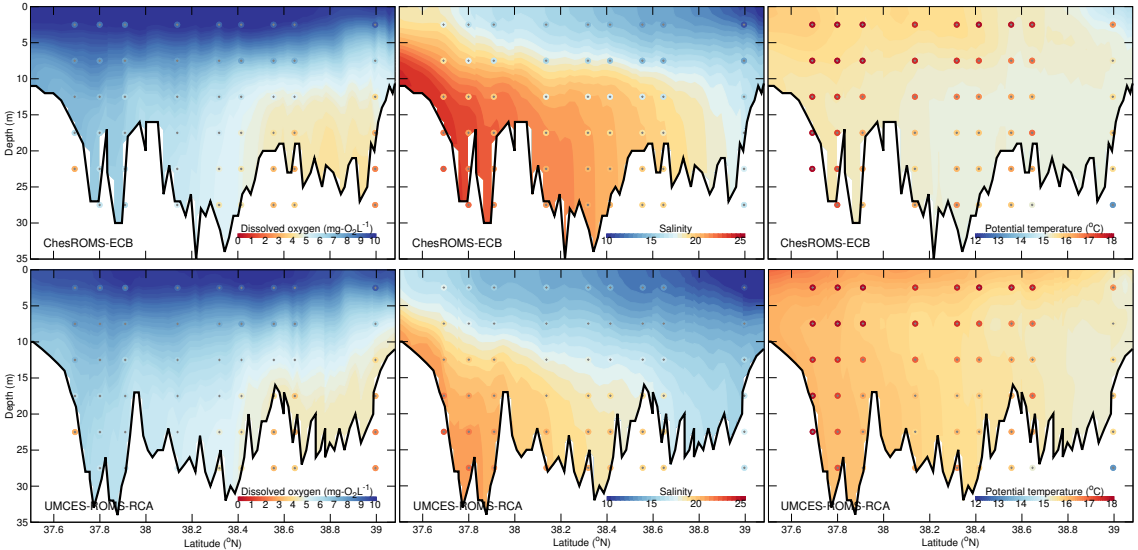
In the previous calls we mostly focused on the dissolved oxygen (DO), salinity (S) and estuarine circulation of the models. However, **temperature** (T) should also be considered given its impact on solubility (as Richard pointed out).

In the next slides we have **model-data comparisons** of DO, S, T for the two ROMS models (ChesROMS-ECB and UMCES-ROMS-RCA). Slide 5 represents an **annual average** over 1991–1995 while Slide 6 is an average over **July** 1991–1995 (month of maximum hypoxia).

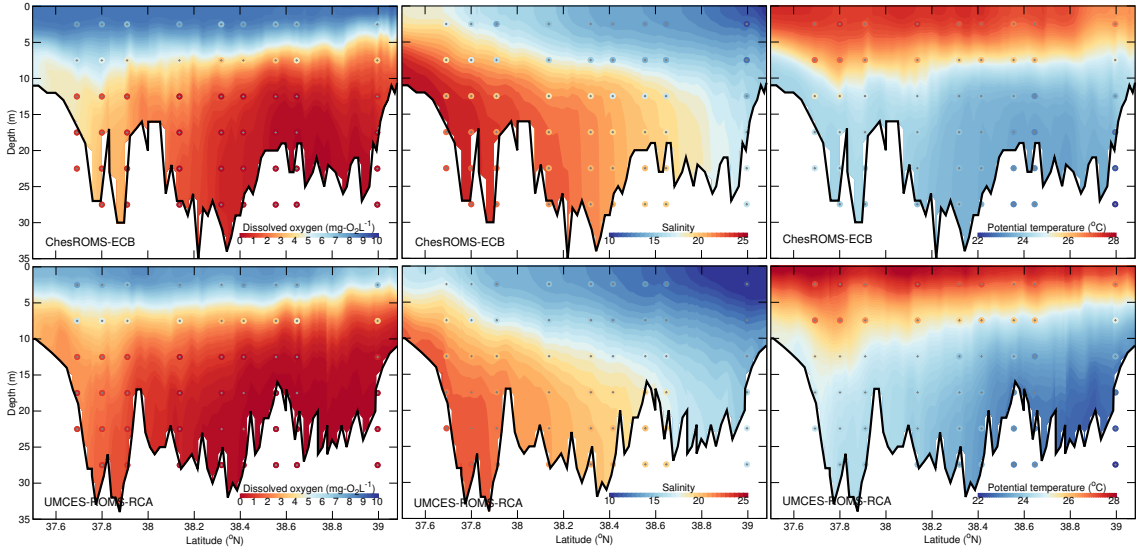
A few things to notice:

(1) Overall, the two ROMS models produce similar results.
(2) The halocline of ChesROMS-ECB is too shallow,
(3) UMCES-ROMS-RCA is a bit too fresh at the surface and bottom (but halocline is more realistic),
(4) ChesROMS-ECB overestimates DO around 37.8°N.

Model-data comparisons: Annual average 1991–1995



Model-data comparisons: July 1991–1995

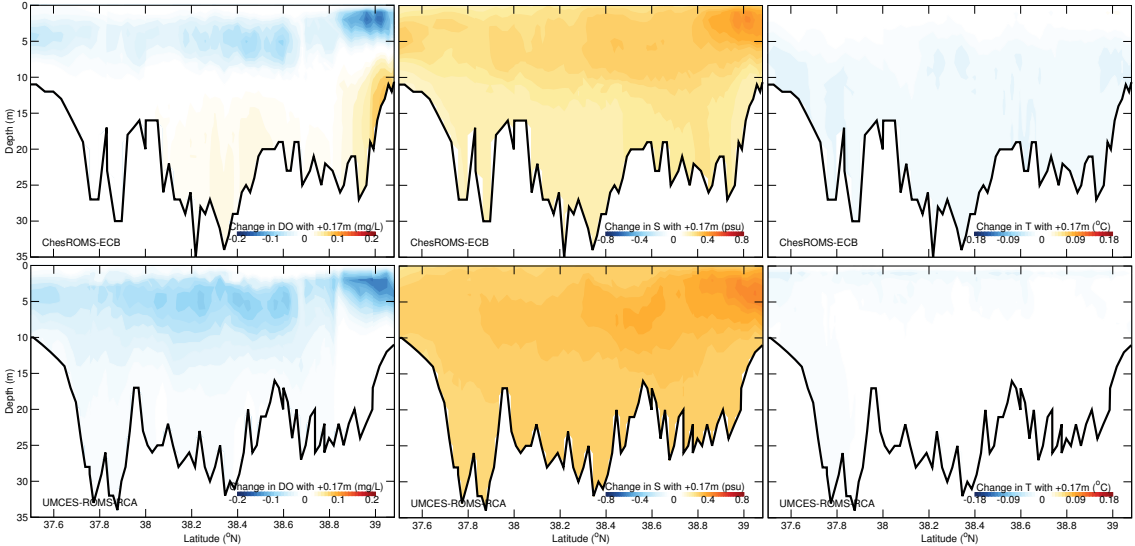


Response to ΔSL = +0.17m

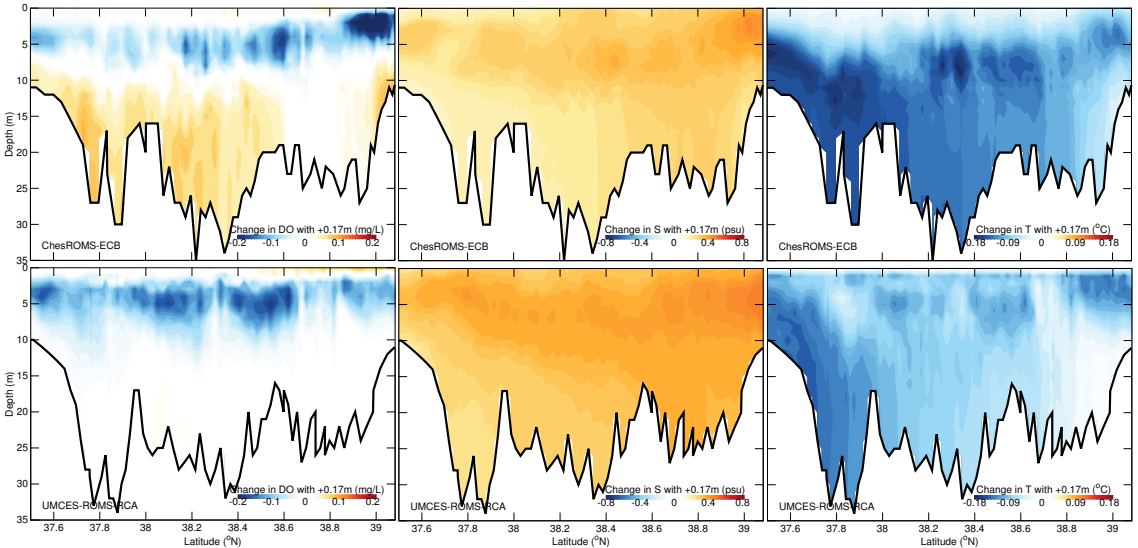
Slides 8,9 show the response to an increase in sea level rise of +0.17 m for the two ROMS models. A few things to notice:

1. Both models show an upward displacement of the pycnocline, causing a band of $\Delta\text{DO} < 0$ and $\Delta S > 0$ around ~ 5 m depth.
2. Both models predict enhanced landward intrusion of salty/cold seawater (similar to Hilton et al. 2008, Hong & Shen 2012). The change in T is most apparent in July (when the water column is thermally stratified).
3. The main difference between the models is the presence/absence of an improvement in July's bottom DO.

Response to ΔSL = +0.17m (average 1991–1995)



Response to ΔSL = +0.17m (July 1991–1995)



Questions raised in previous conference calls

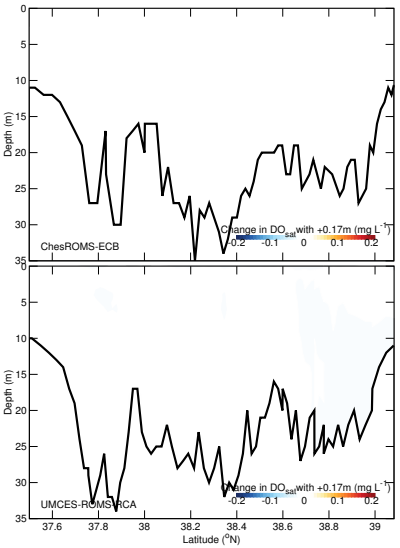
Could ΔT,ΔS contribute to the ΔDO through solubility?

Bottom layer of main stem in July: $T \sim 24°\text{C}$, $S \sim 21$ psu
$\Delta\text{SL} = +0.17$ m causes $\Delta T \sim -0.1°\text{C}$, $\Delta S \sim +0.3$ psu

$\text{DO}_{\text{sat}}(T, S) = 7.465$ mg L^{-1}
$\text{DO}_{\text{sat}}(T + \Delta T, S) = 7.478$ mg L^{-1}
$\text{DO}_{\text{sat}}(T, S + \Delta S) = 7.452$ mg L^{-1}

Changes in T,S offset each other (mostly).
$\Delta\text{DO}_{\text{sat}}$ is much smaller than the ΔDO seen in previous slides (see figure $\rightarrow$ with same scale as previous slide)

Solubility alone would not explain the ΔDO of the models (nor their differences).



Budget for DO

The goals of the DO budget are to:

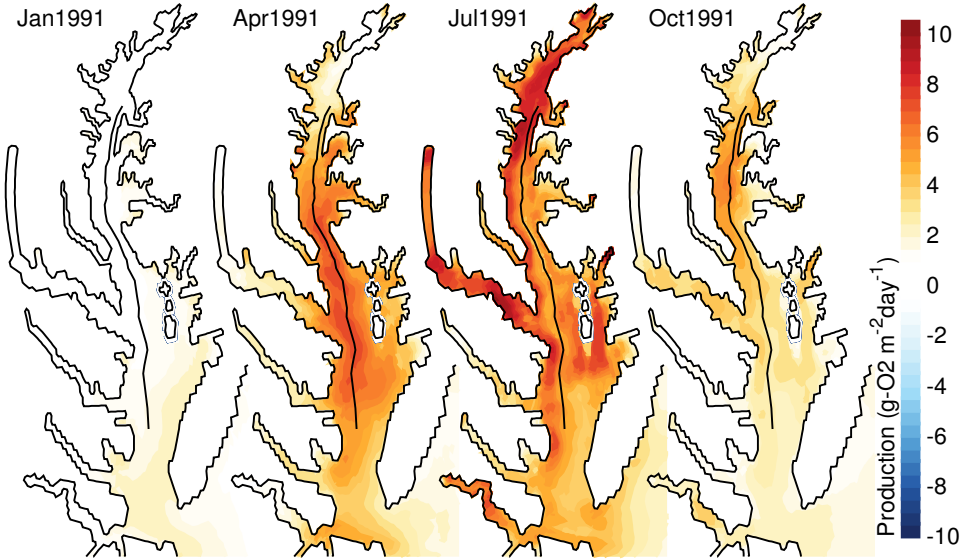
1. Determine the relative importance (magnitude) of the physical and biogeochemical processes/terms influencing DO and hypoxia,
2. Determine in what ways these terms change with ΔSL,
3. Identify which term(s) are responsible for the improvement (or lack of improvement) in July's bottom DO,
4. Determine whether these results are valid year after year (or if they change with, e.g., wet/dry years).

Equation for vertically-integrated DO budget (bottom to surface):

$$\frac{\partial}{\partial t}\iiint \mathrm{DO}\, dV = Prod - Resp + Hadv + AirSea, \tag{1}$$

(not too different from, e.g., Li, Li & Kemp 2015.)
Budget only available for ChesROMS-ECB at this point but UMCES-ROMS-RCA will follow.

Budget for DO: Production



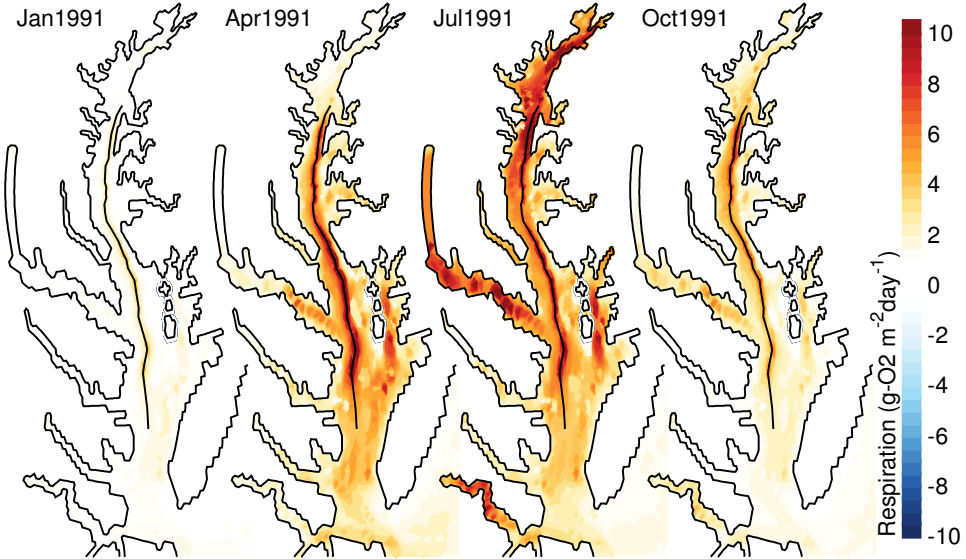
Main terms are *Prod*, *Resp* and *Hadv*.

These three terms $\sim$ balance each other.

$\partial/\partial t$ and *AirSea* play a lesser role.

Figure shows 1991; similar pattern in other years.

Budget for DO: Respiration

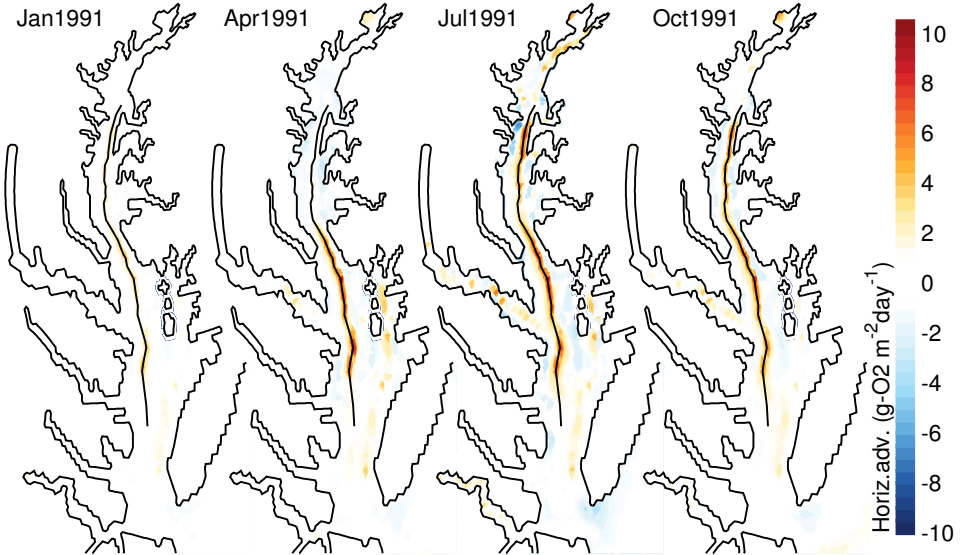


Resp is primarily taking place in the water column.

Sediments play a lesser role (same as in Li, Li & Kemp 2015).

Lots of respiration along main stem (black line).

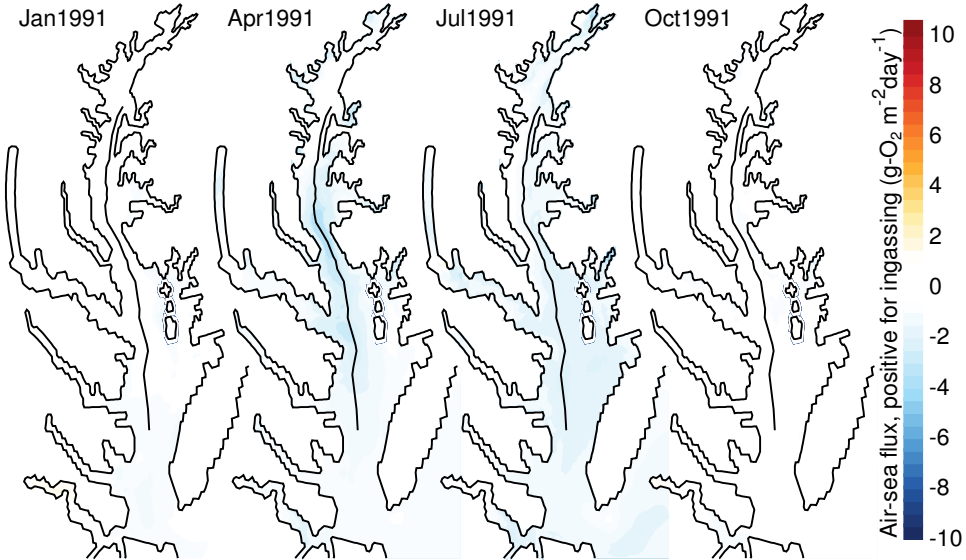
Budget for DO: Horizontal advection



Flow is northward in deep layer (Li et al. 2005) and gradually decreases as one moves toward north.

Hadv is > 0 along main stem, i.e. circulation contributes to oxygenating the main stem.

Budget for DO: Air-sea flux



Air-sea flux is primarily outgassing during spring & summer (next slide shows a monthly timeseries)

Weak spatial variations (although temporal averaging contributes to smoothness)

Budget for DO: Seasonal cycle in main stem (clim. 1991–1995)

Control volume over main stem (isobath 13 m)

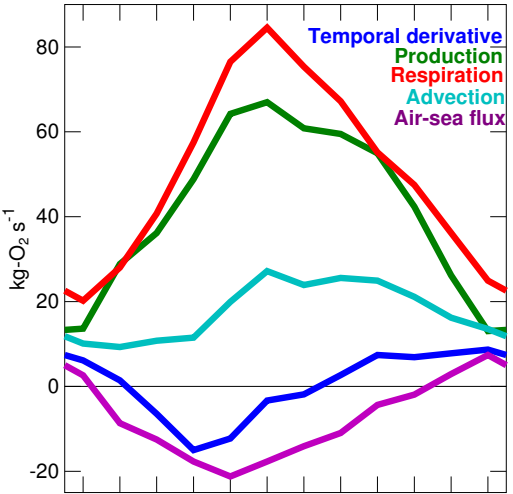
Production and respiration dominate the budget

Strong seasonality influenced by T (accelerates production & respiration)

Respiration $>$ Production in main stem

Advection relatively steady over year; oxygen is outgassed in spring/summer

DO decreases from March to July, then recovers over Sep–Jan.



$\frac{\partial}{\partial t} \iiint \mathrm{DO}\, dV = Prod - Resp + Hadv + AirSea$

Budget for DO: Changes caused by $\triangle$SL = +0.17 m

The effect of ΔSL = +0.17 m on the budget terms is **small**, a few % at most.

The effect can be positive or negative depending on seasons and on regions. More analyses are necessary to clarify how SLR affects production, respiration, advection and air-sea fluxes.

ChesROMS-ECB relies on temperature-dependent rates for production and respiration (Lomas et al. 2002). It is possible that the ΔT associated with SLR drives substantial changes in production/biomass, respiration, and in turn, hypoxia.

Next steps

- Continue the analysis of the DO budget of ChesROMS-ECB, and compute a similar budget using UMCES-ROMS-RCA.
- One difficulty noted today was the smallness of the changes associated with $\Delta\text{SL} = +0.17\,\text{m}$.
  The experiments with $\Delta\text{SL} = +1.00\,\text{m}$ (ongoing) should lead to larger anomalies and may help with the interpretation of the case $\Delta\text{SL} = +0.17\,\text{m}$.
- We may also conduct additional experiments to test specific hypotheses, e.g., the role of ΔT on biological rates.
- Investigate the linearity of the response to SLR by adding the case +0.50 m.
- SCHISM: Follow-up with Joseph's team once their runs are completed.