Impacts of Sea Level Rise on Hypoxia—progress report

Pierre St-Laurent[1],
M.A.M. Friedrichs[1]

[1]Virginia Institute of Marine Science

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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.xx m (2100)

Experiments completed / ongoing

Model ChesROMS-ECB:

- Control 1991–2000
- +0.17 m 1991–2000

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

- Control 1991–1995 (physics)
- Control 1991–1995 (biology)
- +0.17 m 1991–1995 (physics) (**completed Feb.13**)
- +0.17 m 1991–1995 (biology) (**completed Feb.17**)

Model SCHISM:

- Control 1991–1995 (physics)
- Control 1991–1995 (biology) (**ongoing**)

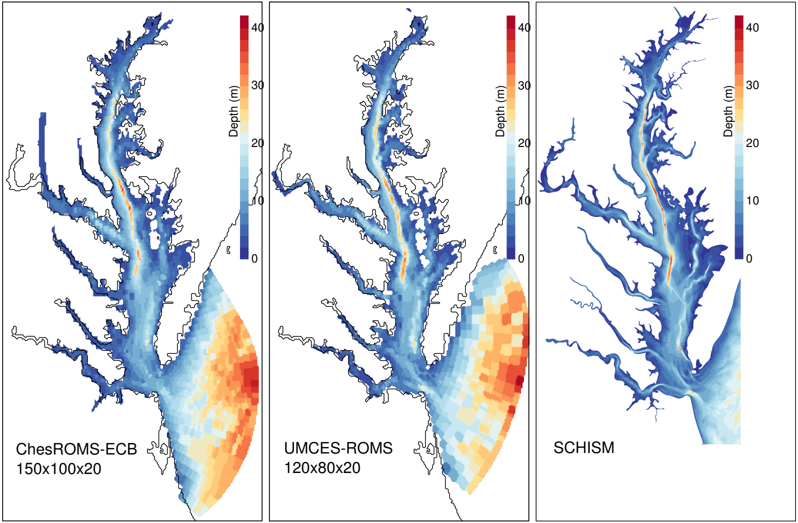
We will analyze the +0.17m scenario fully before moving on to +0.50 m and +1.xx m.

Comparing the model results

In the following slides we compare:

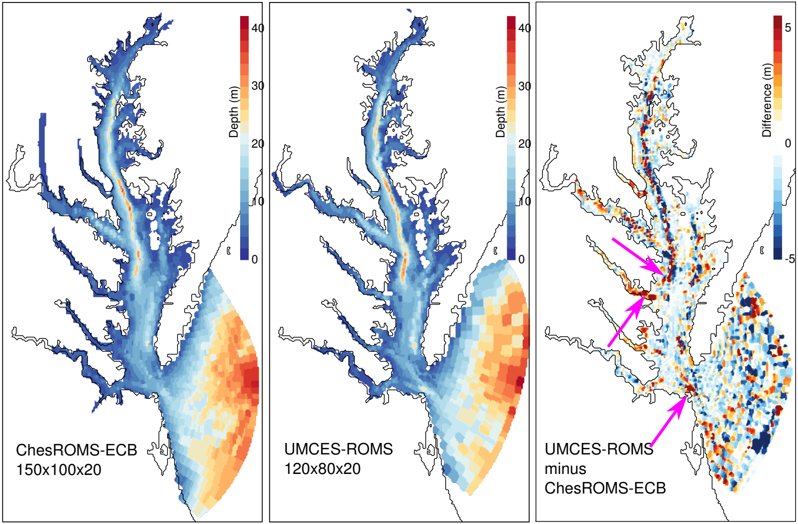
1. Model geometry (grid)
2. Physics, including comparisons with data
3. Dissolved oxygen (DO), including comparison with data
4. Changes in physics caused by SLR of +0.17m (2025)
5. Changes in DO caused by SLR of +0.17m (2025)

1. Comparing the model geometry



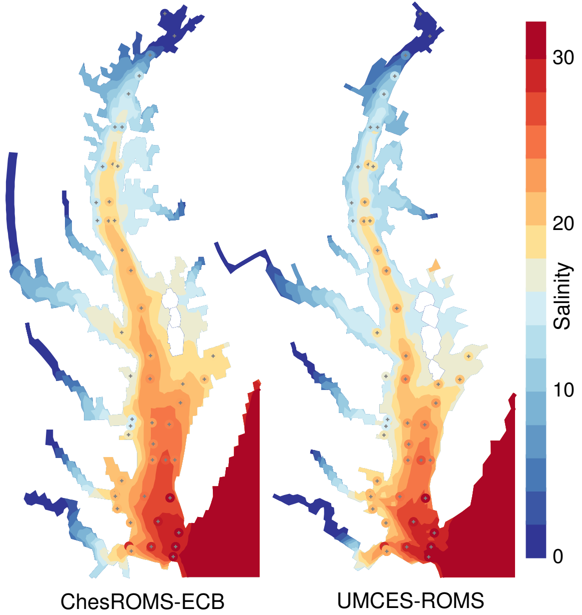
SCHISM distinguishes itself by higher resolution and sharper channels, notably the Rappahannock Shoal channel.

1. Comparing the model geometry



The two ROMS grid are very similar in extent and bathymetry. Differences are mostly noise, with few exceptions.

2. Comparing the model physics: Bottom salinity

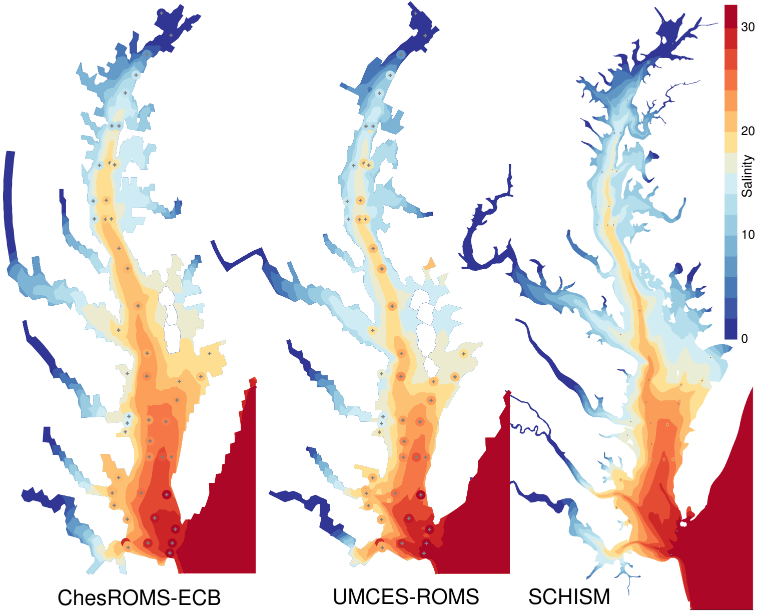


Bottom salinity: Good metric to evaluate stratification and estuarine circulation

Circles with + symbol are WQMP data, averaged over 1991–1995. Ideally the circles blend with modeled fields

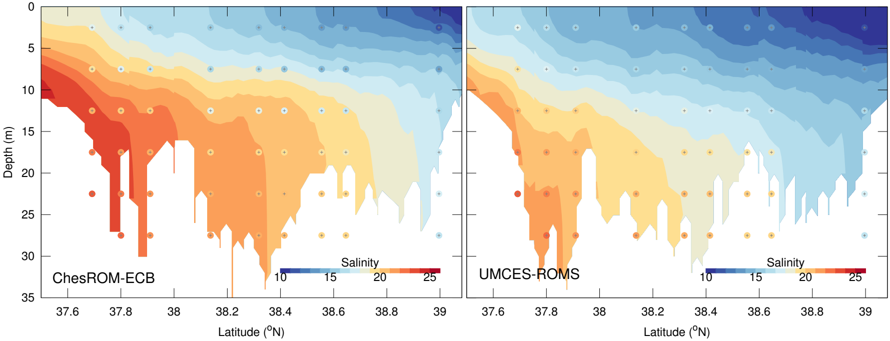
ChesROMS-ECB reproduces bottom *S* well. UMCES-ROMS is 1–2 psu fresher than data in main stem

2. Comparing the model physics: Bottom salinity



SCHISM stands roughly in between the two ROMS models

2. Comparing the model physics: *S* in main stem



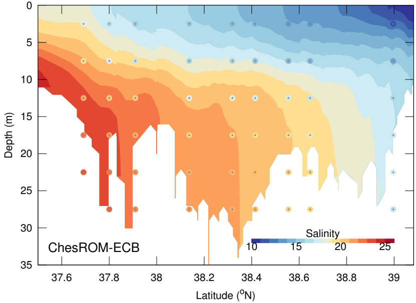
Salinity along main stem, averaged 1991–1995

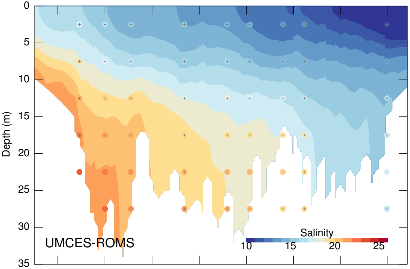
Both ROMS models underestimate bottom depths in main stem (smoothing)

Although ChesROMS-ECB reproduces bottom and surface *S* relatively well, its halocline is too high

UMCES-ROMS reproduces halocline better, but it is 1–2 psu too fresh near bottom/surface

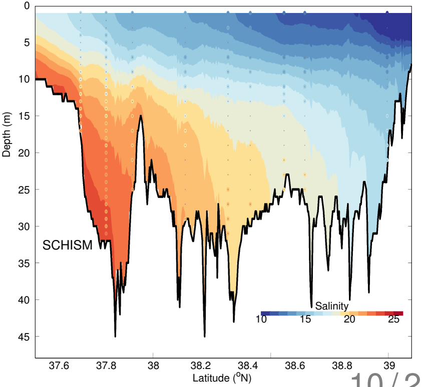
2. Comparing the model physics: *S* in main stem



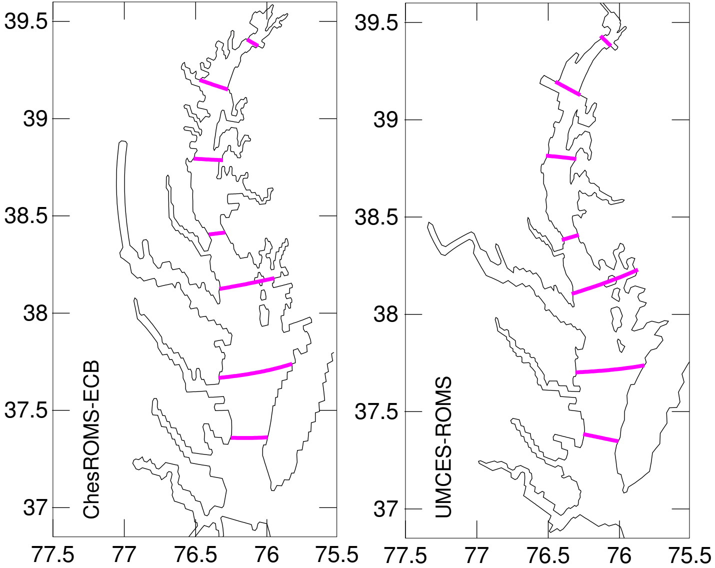


SCHISM reproduces the bathymetry of the main stem more accurately

SCHISM is a bit too salty at 37.8°N, at bit too fresh at 38.6°N.
Overall it is the most accurate of the three models.



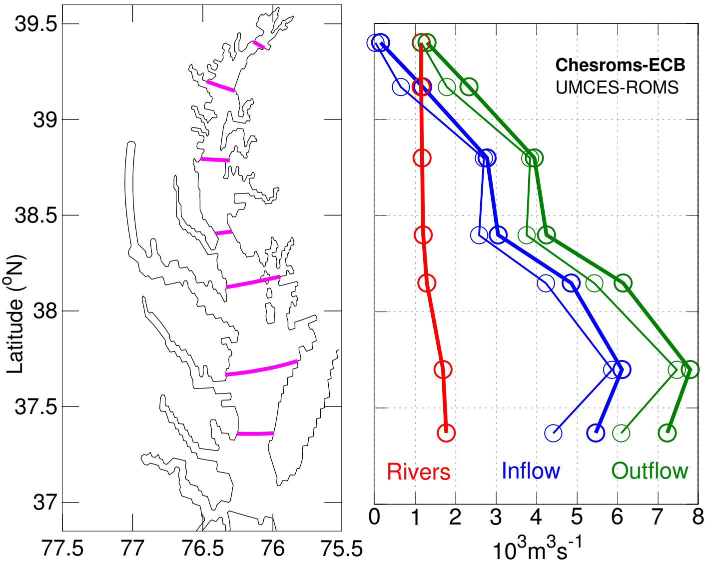
2. Comparing the model physics: Estuarine circ.



To compare the model circulations, we define 7 **sections** aligned with model grid and at same latitudes.

At each section, calculate **Inflow** (northward flow) and **Outflow** (southward flow)

2. Comparing the model physics: Estuarine circ.



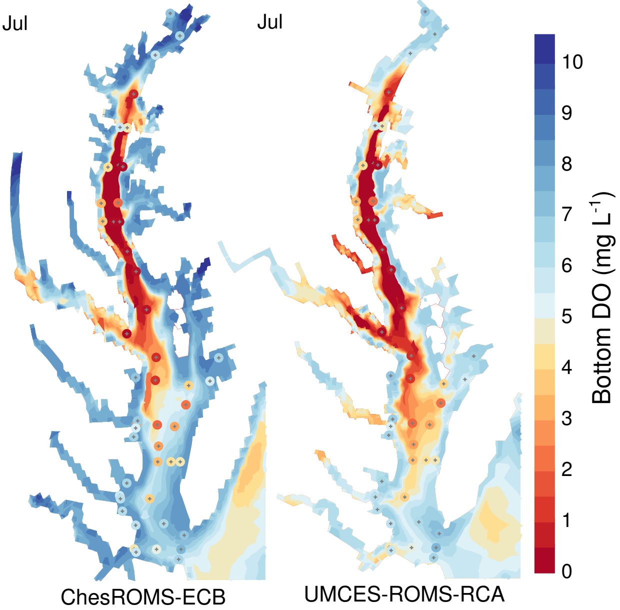
Thick lines: ChesROMS-ECB
Thin lines: UMCES-ROMS (average 1991–1995)

Same river forcing

Similar circulation

Inflow 18% higher in ChesROMS-ECB

3. Comparing dissolved oxygen: Bottom DO



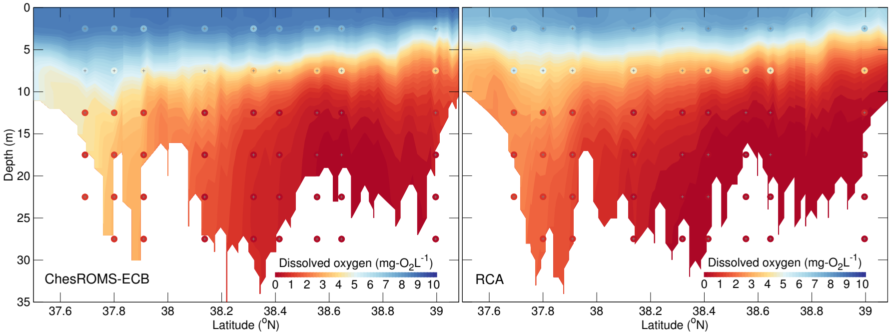
Created monthly climatology for 1991–1995 (models and WQMP data)

Seasonal cycle very similar between models (not shown)

← Max hypoxia (July)

Similar patterns, but ChesROMS-ECB overestimates DO in lower bay

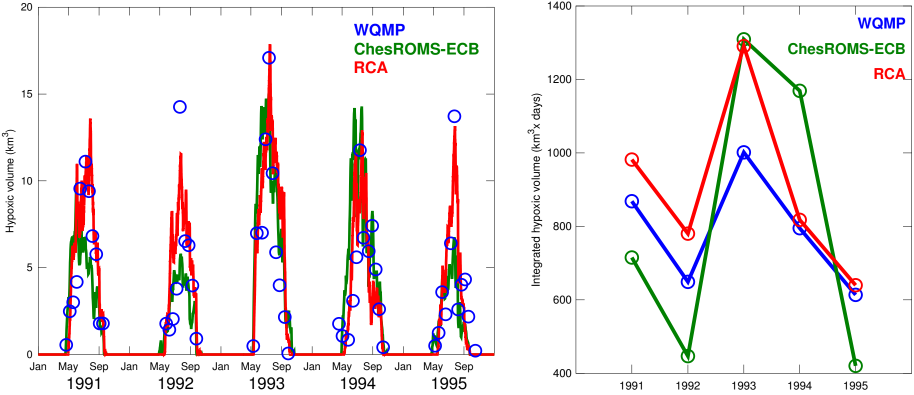
3. Comparing dissolved oxygen: Main stem



Dissolved oxygen along main stem, July (max hypoxia)

Both models underestimate bottom depths in main stem (smoothing)
Similar spatial distributions with minimum DO in upper main stem (38.8°N)
Oxycline is too high in RCA
ChesROMS-ECB overestimates DO in lower bay

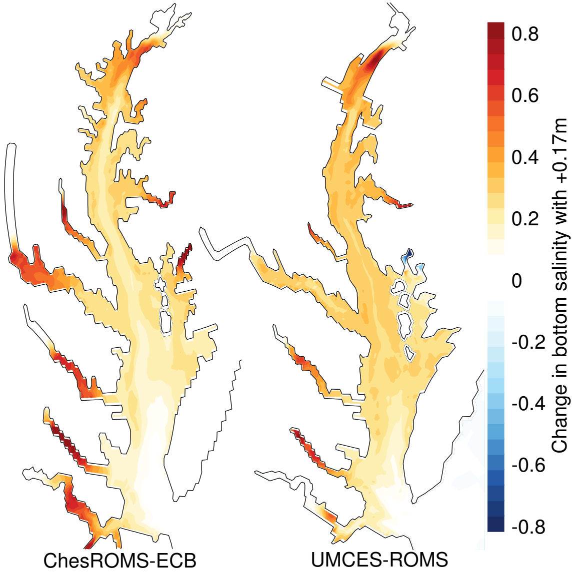
3. Comparing dissolved oxygen: Hypox. volume



(Left) Models reproduce timing of hypoxia and hypoxic volume relatively well

(Right) Annually-integrated hypoxic volume
High/low years are reproduced qualitatively, but models exaggerate year-to-year variations (especially ChesROM-ECB)

4. Changes in physical fields with SLR = +0.17m



Change in **bottom salinity** (average 1991–1995)

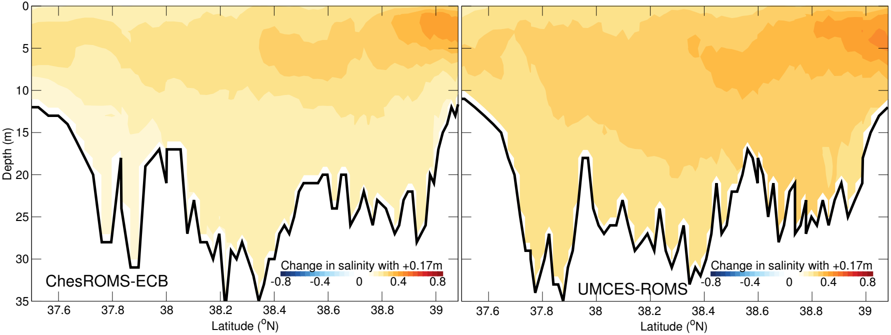
(Left) $\Delta S \sim 0.3\,\text{psu}$
(Right) $\Delta S \sim 0.35\,\text{psu}$
for +0.17 m

Hong & Shen 2012:
$\Delta S \sim 0.5\,\text{psu}$ for +0.30 m

Hilton et al. 2008:
$\Delta S \sim 0.5\,\text{psu}$ for +0.20 m

Consistent with literature

4. Changes in physical fields with SLR = +0.17m

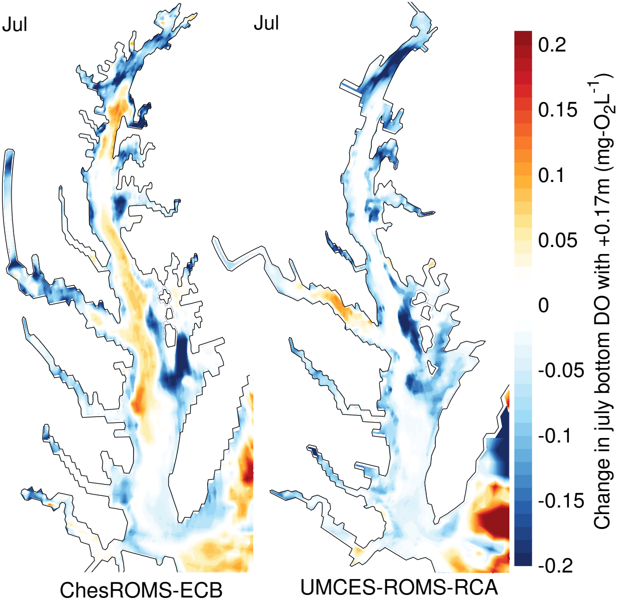


Change in **salinity along main stem**, average 1991–1995

(Left) $\Delta S \sim 0.3\,$psu, mostly uniform with depth
(Right) $\Delta S \sim 0.35\,$psu, also $\sim$uniform with depth
(i.e., similar to previous slide showing bottom salinity)

Maximum changes occur within the halocline (depth $\sim 5\,$m)

5. Changes in DO with SLR = +0.17m



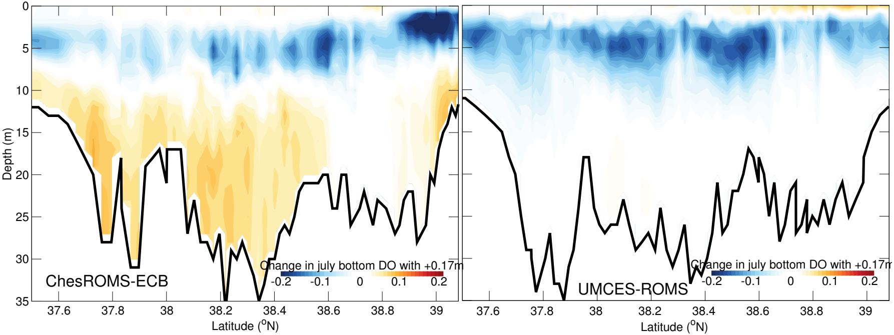
Change in **bottom DO** (average July 1991–1995)

Both ↗ and ↘ over the bay,
Mostly ↘ in shallow water & tributaries

ChesROMS-ECB suggests that DO increases in the main stem by ~ 0.05 mg L^{-1}

RCA does not show any increase in the main stem (white)

5. Changes in DO with SLR = +0.17m



Change in **DO along main stem**, average July 1991–1995

Both models predict ↘ in the pycnocline (5 m depth)

Below 10 m depth, the models show a qualitatively different response (even though they used the same rivers, they simulated the same exact years, and their physical response to SLR (ΔS) was similar (see slide 17).)

Next steps

- UMCES-ROMS-RCA: Analyze the case with +0.17 m (completed Feb.17) in more detail and compare with ChesROMS-ECB
- DO budgets for the main stem, to understand how the modeled DO responds to SLR (and why)
- Simulate the cases +0.50 m and +1.xx m (2050 and 2100, resp.)
- Investigate the linearity of the response to SLR
(and potential complications)
- SCHISM: Follow-up with Joseph's team once their runs are completed

Appendix

slides from CHAMP meeting in Annapolis (Nov.13, 2018)

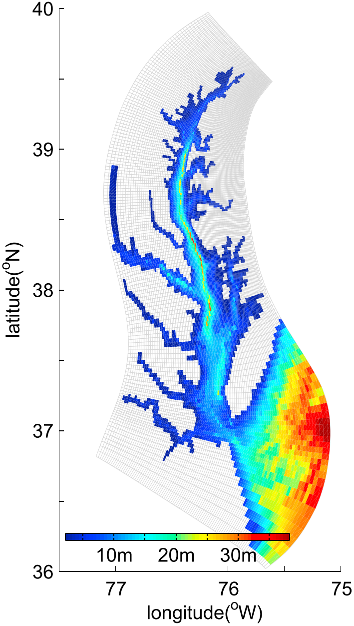
Sensitivity experiment: $\Delta SL = +0.17\,\text{m}$, 1991–1995

In the next slides I will present results from a sensitivity experiment where the sea level was increased by 0.17 m at the oceanic boundary of the model $\rightarrow$

$\Delta SL = +0.17\,\text{m}$ is the estimated change between 1995 and 2025. We use Phase-6 (CXXBASE) as the riverine dataset.

We provide a 5-year period to the model (1986–1990) for it to acclimate to the higher SL, and then analyze the next 5 years (1991–1995).

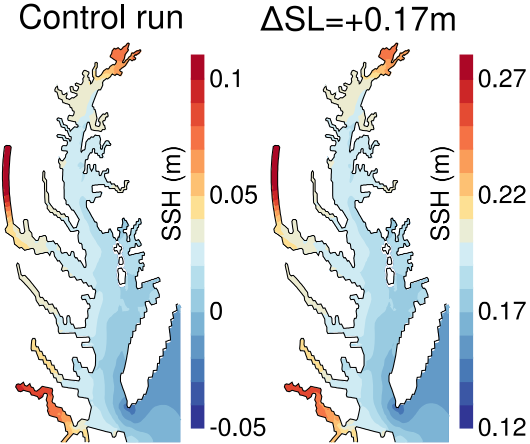
Note that the model setup prescribes monthly climatological S, T, $DO_{sat}(S, T)$ at the oceanic boundary. The same climatology is used in all model runs.



Sensitivity experiment: $\Delta SL = +0.17\,\mathrm{m}$, 1991–1995

These experiments do not attempt to predict the loss of land associated with ΔSL. They assume that the coastlines are armored and unchanged.

The model's response to ΔSL at the oceanic boundary is simply an offset in SL throughout the bay. The gradients in SL and the barotropic circulation are largely unaffected $\rightarrow$



Sensitivity experiment: $\Delta SL = +0.17\,\mathrm{m}$, 1991–1995

Changes in annual volume are small, $\pm 18\%$ at most, and largest for case $DO < 0.2\,\mathrm{mg\ L^{-1}}$

Less hypoxia in most years, but not all years (see 1994)

Daily timeseries (below): volume is $\sim$always smaller during 1991,1992,1995.
Years 1993,1994: both + and $-$

Table: Change in annual vol. (AV) caused by $\Delta SL = +0.17\,\mathrm{m}$ ($DO < 2\,\mathrm{mg\ L^{-1}}$)

Year	AV km^3 day	ΔAV km^3 day	ΔAV %
1991	715	-18	-3
1992	447	-32	-7
1993	1309	-4	0
1994	1169	$+11$	+1
1995	420	-13	-3

Change in volume caused by SL=+0.17m (DO < 2 mg L^{-1})