The Importance of Scale in the Simulation of Chesapeake Bay

Modeling Workgroup
Quarterly Review

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Introduction

We have been conducting simulations of the historical period, 1985–Present, with various model configurations. They use the same hydrological (Phase 6) and meteorological forcing (ERA5).

WQMP observations are used to evaluate the model configurations, and determine the improvement associated with each modification.

Outline:

1. Model configurations
2. Model-data comparisons
3. Interannual variability of hypoxia
4. Conclusions & Future work

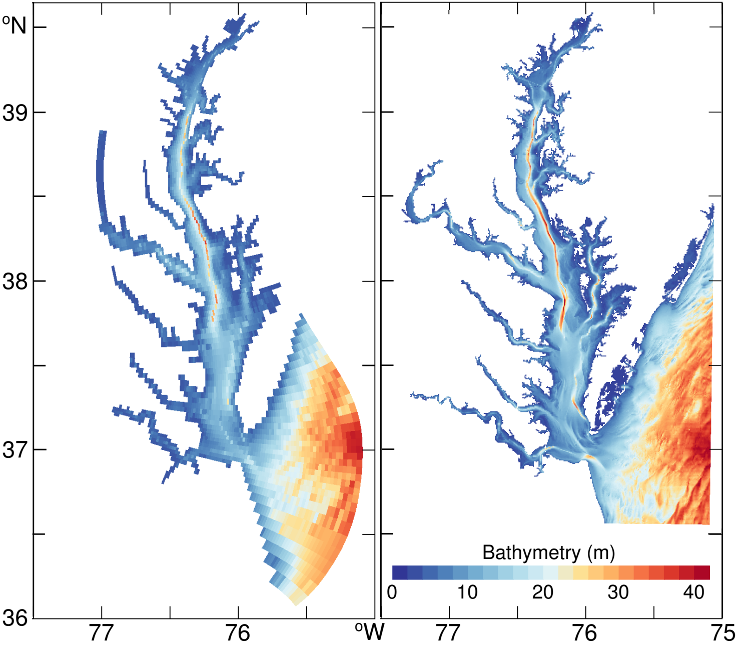
Two model configurations:

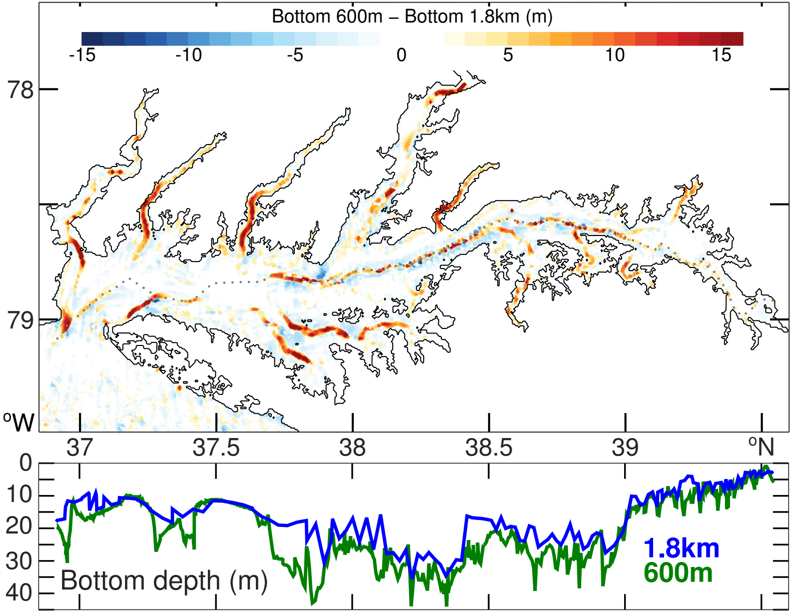
∼**1.8 km** grid versus **600 m** grid.

Key benefits of new 600 m grid:

More realistic coastlines,
Uses the real bathymetry,
Captures the channels inside tributaries and embayments.

Also includes the Atlantic seaboard, a sediment module, and represents inundation at the coastlines.



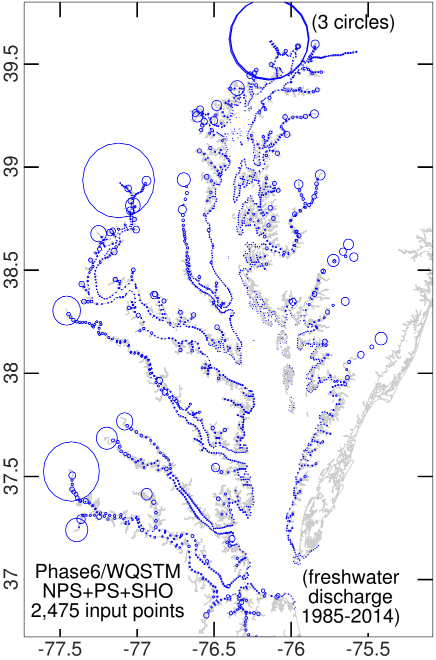


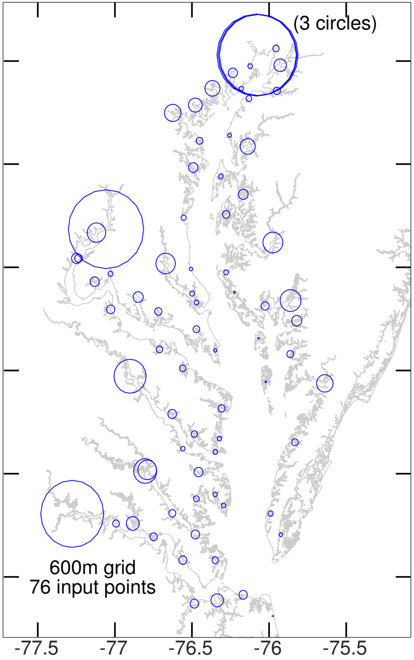
Deep channel of main stem, depths $\geq$ 13m (pycnocline):

$\mathrm{Volume}_{1.8\mathrm{km}} = 3.7\,\mathrm{km}^3$

$\mathrm{Volume}_{600\mathrm{m}} = 4.5\,\mathrm{km}^3$

The 600 m grid can accommodate ~**20%** more hypoxic water than the 1.8 km grid in the same area.



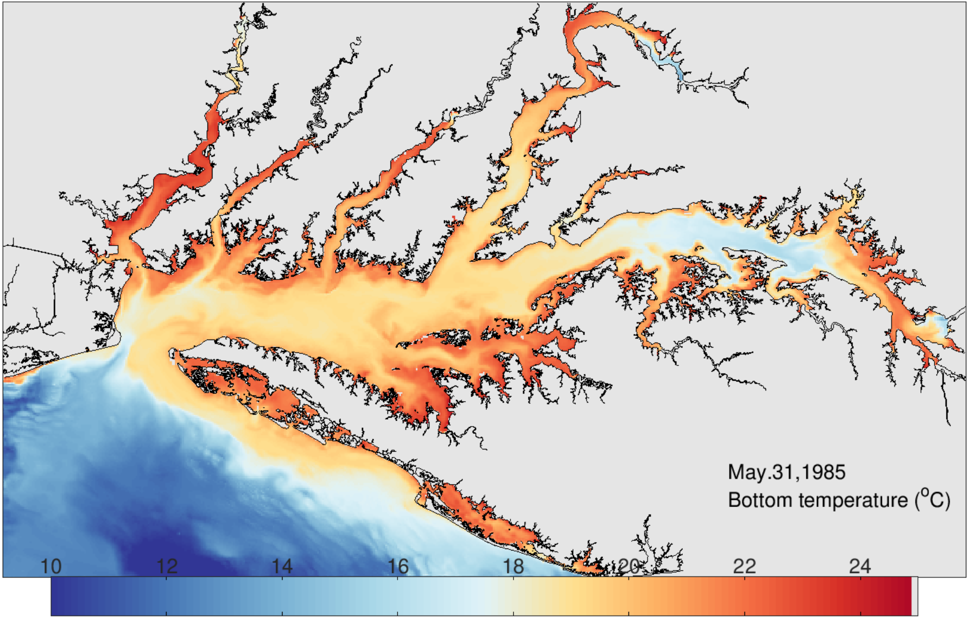


The terrestrial fluxes were also improved following the work of Butler 2019.

1.8km grid:
The 2,475 input points of Phase 6 were aggregated into 10 'rivers'.

600m grid: Terrestrial inputs aggregated into *76 rivers*.

(More accurate representation of freshwater and nutrient fluxes.)



Video of 600m grid in action:

Model-data comparisons

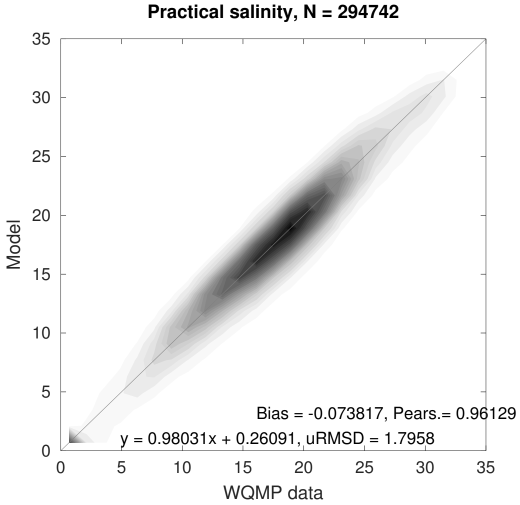
These slides compare the 600m grid against the WQMP data. Model and data are matched in time/location/depth and statistics are computed. Period: 1985–2014.

Salinity bias

Overall bias (*i.e.*, all stations/depths/seasons) is very small, -0.07.

Bias has improved by 1.2 units compared to 1.8km.

Suggests estuarine circulation is well reproduced by 600m grid.



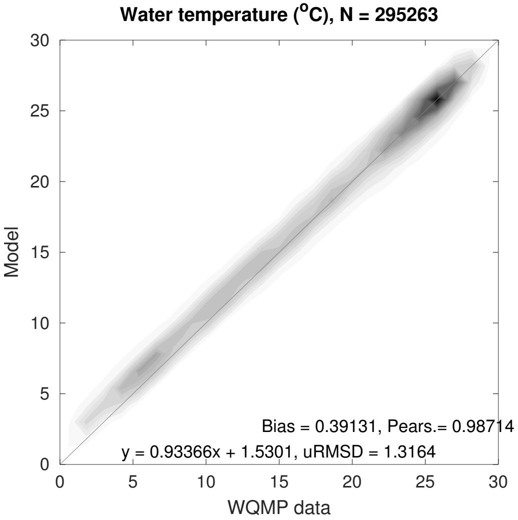
Temperature bias

Overall bias = $+0.39^\circ$C.
Bias has improved by 0.3° C compared to 1.8km grid.

Model is most accurate in summer (during hypoxia).
Warm bias of $\approx +1^\circ$C during winter months.

This warm bias is concentrated in the first decade, 1985–1995.

During this period, the warm bias is apparent at surface, throughout the Bay. Atmospheric forcing (ERA5) is likely to blame.



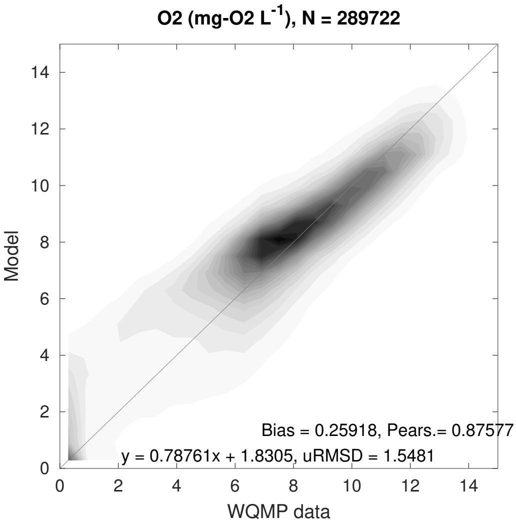
Dissolved O_2 bias

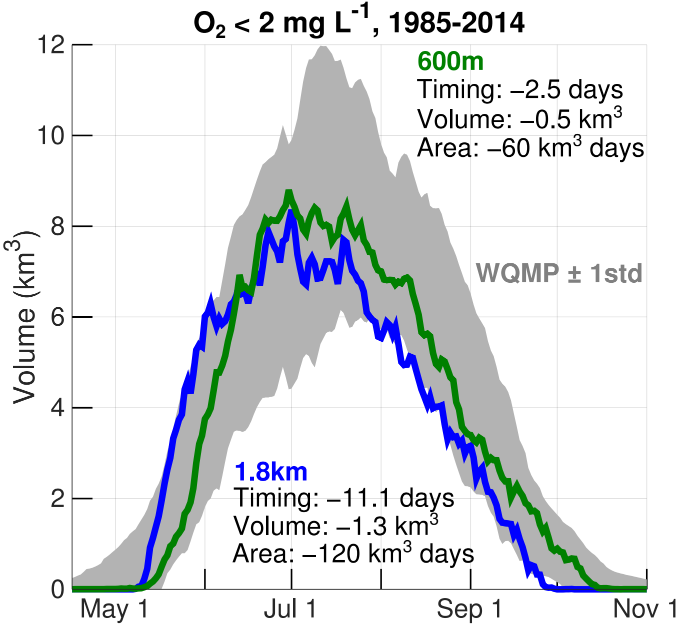
Overall bias = +0.26 mg L^{-1}.

Overall bias is comparable between
the two model configurations,
was slightly lower in 1.8km (by 0.05 mg L^{-1}).

The positive bias is concentrated in Jul–Aug,
at the surface in the upper Bay,
and at the bottom in the lower Bay.

What about hypoxia?





Three metrics:

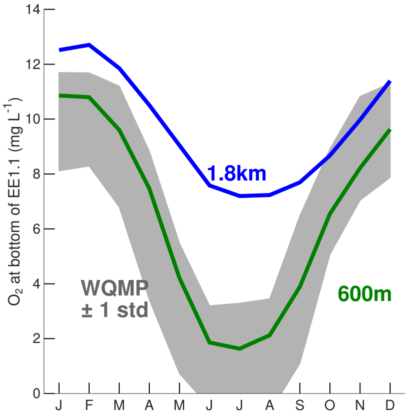
- Timing of peak hypoxia,
- Volume at peak hypoxia.
- Area under the curve.

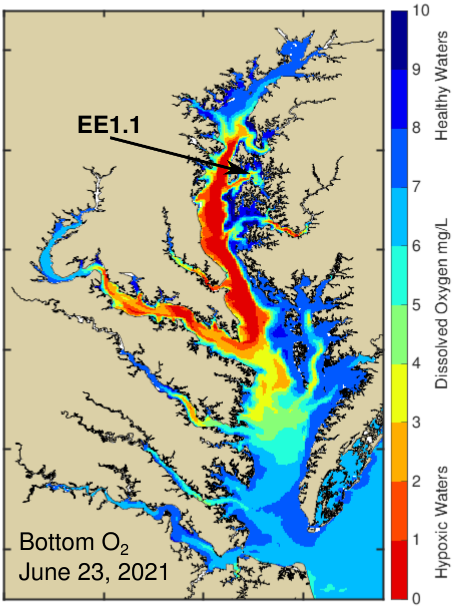
WQMP computed as in Bever et al. 2013.

600m grid shows a major improvement in all three metrics.

600m also shows hypoxia inside certain tributaries or small embayments (the coarser grid didn't.)

WQMP data of 1985–2014 confirm that this prediction is correct and is an improvement over the **1.8km**:





(Better resol.⇒ better bathymetry⇒ better bottom O_2.)

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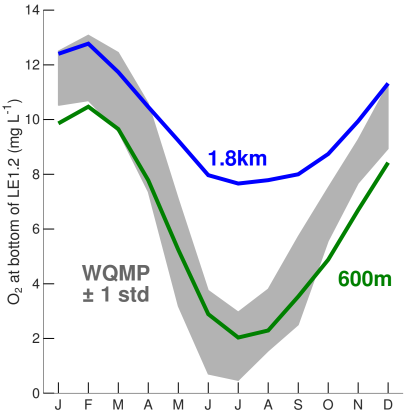

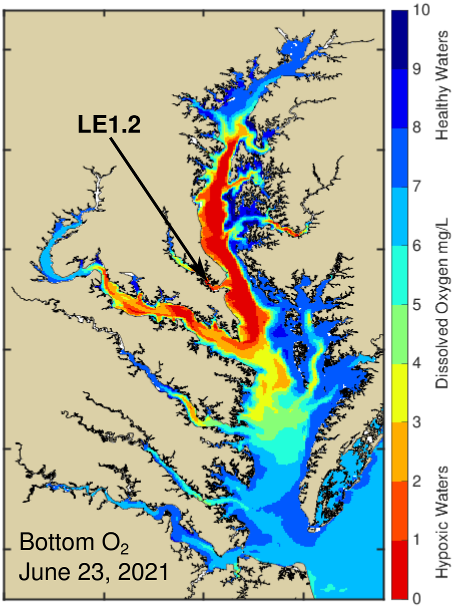

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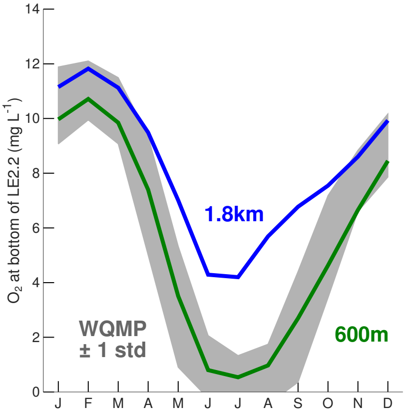

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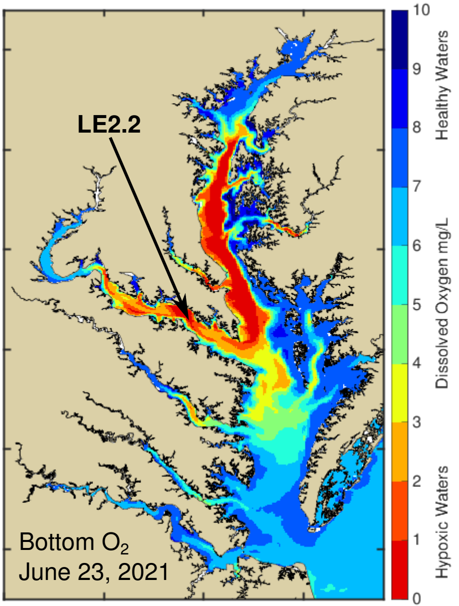

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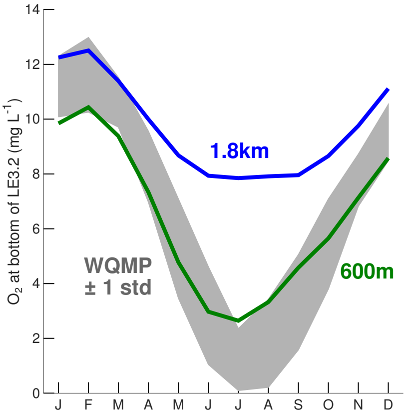

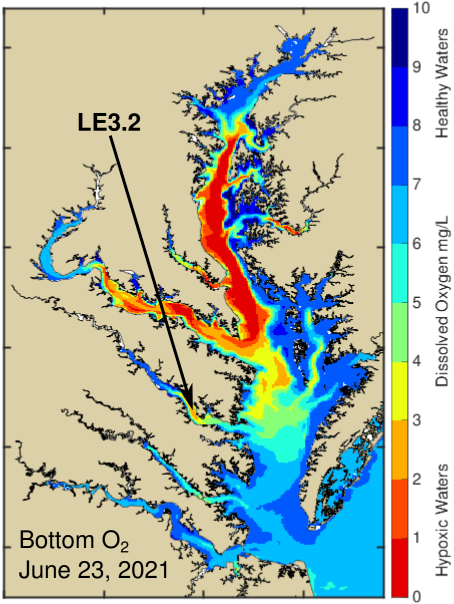

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Interannual variability of hypoxic volume

Two metrics:

- **July hypoxic volume**(*year*), in km^3
- **annual hypoxic volume**(*year*), in $km^3 \times$ days

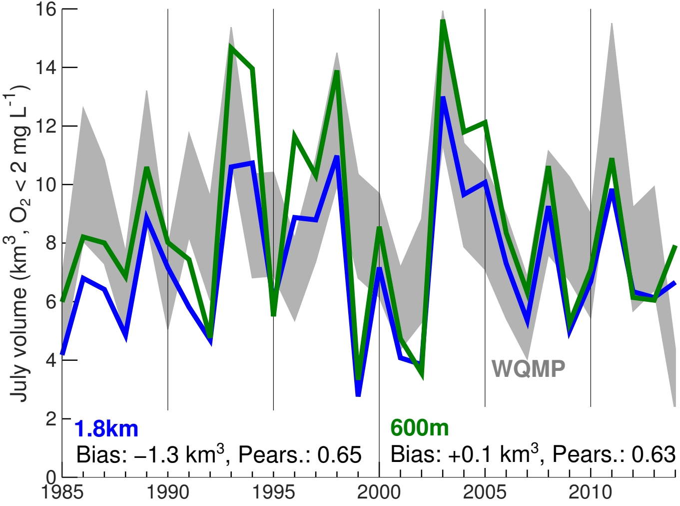
July volume is well constrained by WQMP observations,
useful to evaluate which of the 600m/1.8km configurations is more accurate.

Annual volume reflects the duration+severity of hypoxia.

We expect the two configurations to show substantial differences given the changes in:

- grid resolution,
- bathymetry,
- realism of physical circulation (salinity),
- distribution of terrestrial inputs, etc.

July hypoxic volume

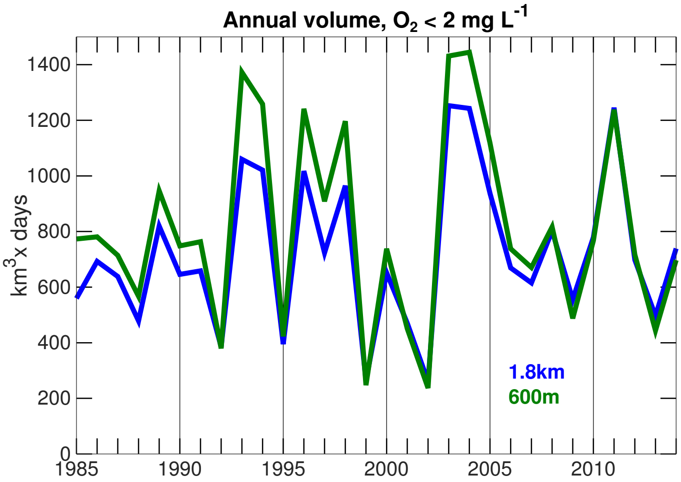


For the *interannual variability*, the two model configurations show nearly the same skill (0.65 versus 0.63).

The two modeled curves are highly correlated together (0.97) despite differences in model configurations.

What about the other metric, the annual hypoxic volume?

Annual hypoxic volume



The two timeseries are even closer in appearance, and highly correlated (0.97) together.

Only difference is that 600m values are slightly higher during years of high hypoxia.

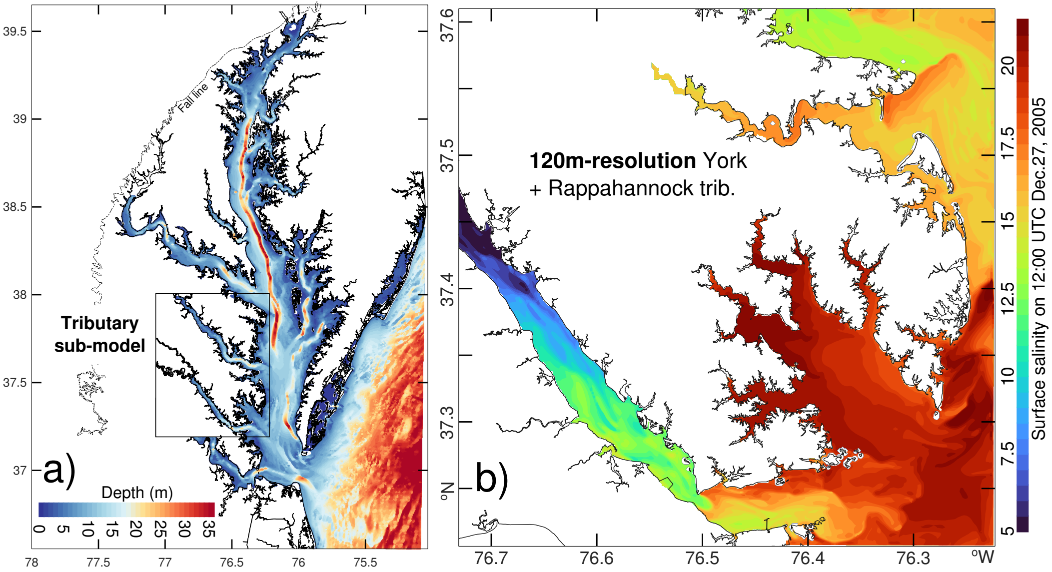
(Same conclusion with different thresholds; $O_2 < 1$ or $3\,\text{mg L}^{-1}$.)

Discussion

1. Similarities between 1.8km and 600m suggest there are **external factors** dictating the interannual variability (and overshadowing the improvements of the 600m grid).
2. (a) Nutrient availability. Empirical models of hypoxia, such as Scavia *et al*. 2006, have their interannual variability driven by riverine inputs of TN. They have substantial success in reproducing observed hypoxic volumes.

   Li *et al*. 2016 also conclude that nut. loadings drive interannual hypoxia in their 3-D model.
3. (b) Physical forcings (winds, temperature) may also drive the interannual variability, independently of nutrient availability. See Scully 2013, Hong & Shen 2013, Du & Shen 2015.
4. 1.8km and 600m used the same nutrient loadings (Phase 6) and the same winds (ERA5), which would explain their similar year-to-year variability.
5. **On smaller spatial/temporal scales, the 600m remains a major improvement**, notably in tributaries (Patuxent, Potomac. . .) and shallow embayments.

Beyond 600m—Resolving the shorelines



Ongoing work

We are improving the modeled primary production during the months when PO_4^{3-} is limiting. We implemented a simple representation of phosphorus in the water column, based on Laurent *et al.* 2012.

At the sediment-water interface, PO_4^{3-} is relaxed toward climatological concentrations from the WQMP data.
It mimics the net effect of all sediment-water PO_4^{3-} fluxes, without modeling them explicitly.

Phosphorus is not conserved with this approach (in contrast to N,C) but it is a simple way to implement PO_4^{3-} limitation on production.