Chesapeake Hypoxia Analysis & Modeling Program (CHAMP):

Predicting impacts of climate change on the success of management actions in reducing Chesapeake Bay hypoxia

Marjorie Friedrichs and Pierre St-Laurent

Virginia Institute of Marine Science

October 5, 2022

CBP Modeling Workgroup, Quarterly Meeting

Chesapeake Hypoxia Analysis & Modeling Program (CHAMP):

Predicting impacts of climate change on the success of management actions in reducing Chesapeake Bay hypoxia

CHAMP PIs:

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Pierre St-Laurent (VIMS)
Ray Najjar (PSU)
Lewis Linker (CBP/EPA)
Gary Shenk (CBP/USGS)
Hanqin Tian (Auburn/Boston Coll.)
Eileen Hofmann (ODU)

CHAMP MTAG:

Don Boesch
Bruce Michael
James Davis-Martin
Beth McGee
Mark Bennett
Dinorah Dalmasy
Dave Montali

Fall 2016 – Fall 2023

Chesapeake Bay Program
Science. Restoration. Partnership.

CHAMP Goal

Develop a multi-model Chesapeake Bay scenario-forecast modeling system to:

- Isolate future impacts on Chesapeake hypoxia of climate change from those due to anthropogenic nutrient inputs
- Determine whether the TMDLs will successfully reduce hypoxia (and meet WQS) under future climate conditions

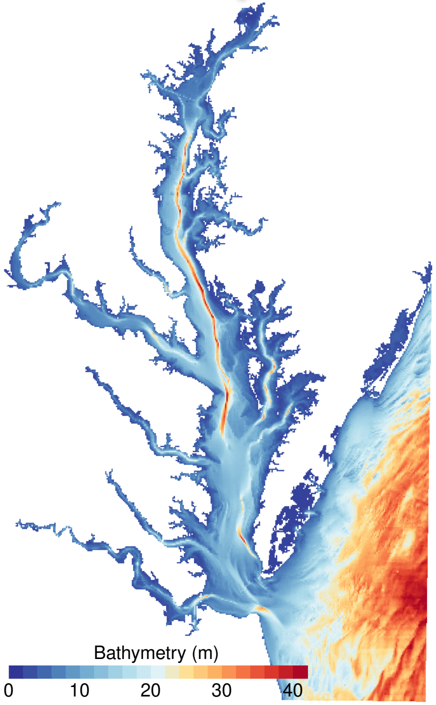
Atmospheric inputs

Estuarine model: ChesROMS-ECB

~600m x 600m
20 vertical levels
Wetting/drying, tides…
BGC cycles: C, N, etc…
Sediment model

ERA5 forcing

Winds
Solar radiation
Temperature
Precipitation



Land inputs

Two Watershed Models:
Phase 6 and DLEM

Coastal inputs

In situ data and NOAA climatology & coastal ROMS model

Bever et al., Env Mod & Software, 2021
St-Laurent et al., BG, 2020

Outline

CHAMP results:

Ike Irby et al., 2018
Pierre St-Laurent et al., 2019
Kyle Hinson et al., 2021
Luke Frankel et al., 2022
Kyle Hinson et al., submitted
Colin Hawes et al., in prep

Ongoing work:

Long continuous run vs. CBP's "delta method"
Higher resolution in the tributaries
Other water quality metrics

Projecting 2050s hypoxia (Irby et al.)

Biogeosciences, 15, 2649–2668, 2018
https://doi.org/10.5194/bg-15-2649-2018

Biogeosciences Open Access EGU

The competing impacts of climate change and nutrient reductions on dissolved oxygen in Chesapeake Bay

Isaac D. Irby, Marjorie A. M. Friedrichs, Fei Da, and Kyle E. Hinson

Virginia Institute of Marine Science, College of William & Mary, Gloucester Point, VA 23062, USA

Correspondence: Isaac D. Irby (isaacirby@gmail.com) and Marjorie A. M. Friedrichs (marjy@vims.edu)

Received: 9 October 2017 – Discussion started: 17 October 2017
Revised: 25 February 2018 – Accepted: 4 April 2018 – Published: 4 May 2018

Projecting 2050s hypoxia (Irby et al.)

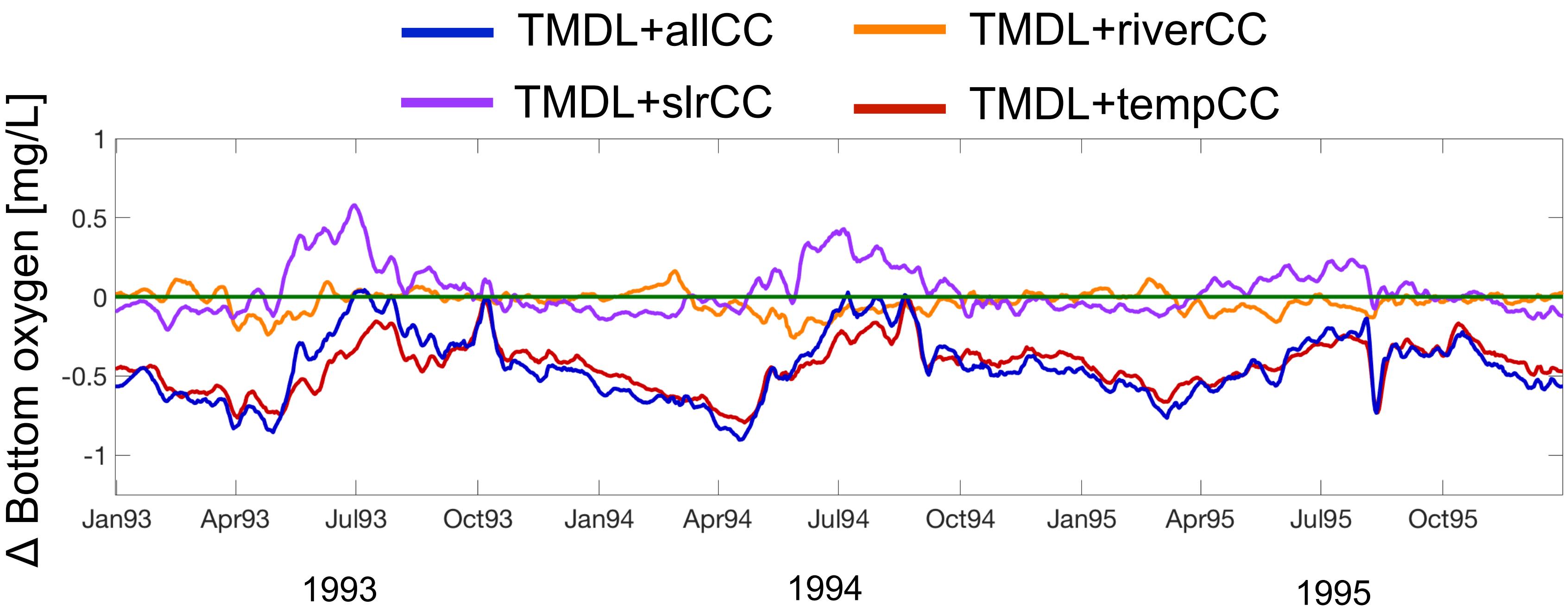
In 2050, relative to 1990s, we assume:

Water Temperature	Sea Level Rise	Watershed/rivers
↑ 1.75°C	↑ 0.5m	↑ ~15% flow

Climate Change Scenarios (with/without TMDL nutrient reductions):

- Temperature
- Sea Level Rise (SLR)
- Watershed/rivers (changing watershed inputs)
- All

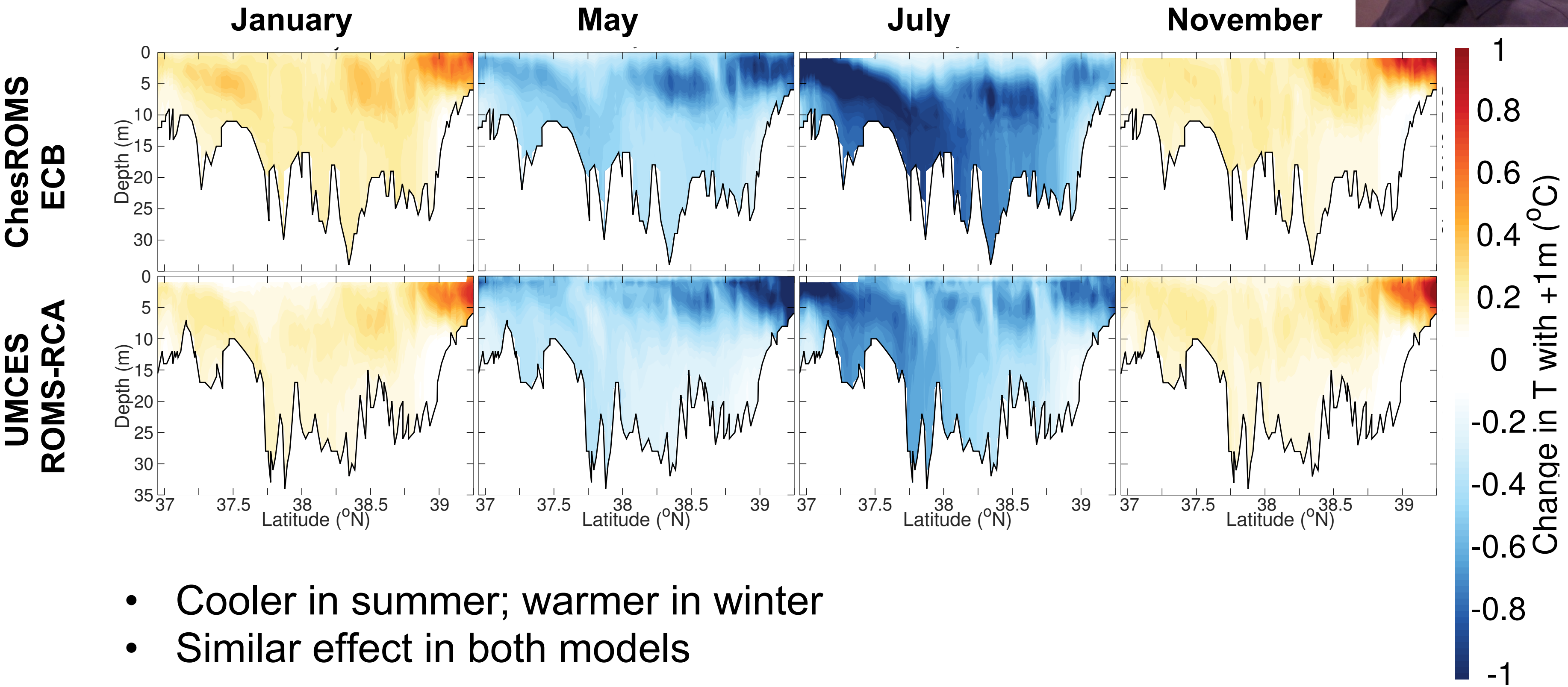
Projecting 2050s hypoxia (Irby et al.)



- **SLR** slightly *reduces* hypoxia
- **Watershed/rivers** slightly *increases* hypoxia
- **Temperature** causes ***large increase*** in hypoxia

Impact of 1m SLR (St-Laurent et al.)

CBPO Pub: CBP/TRS-329-19



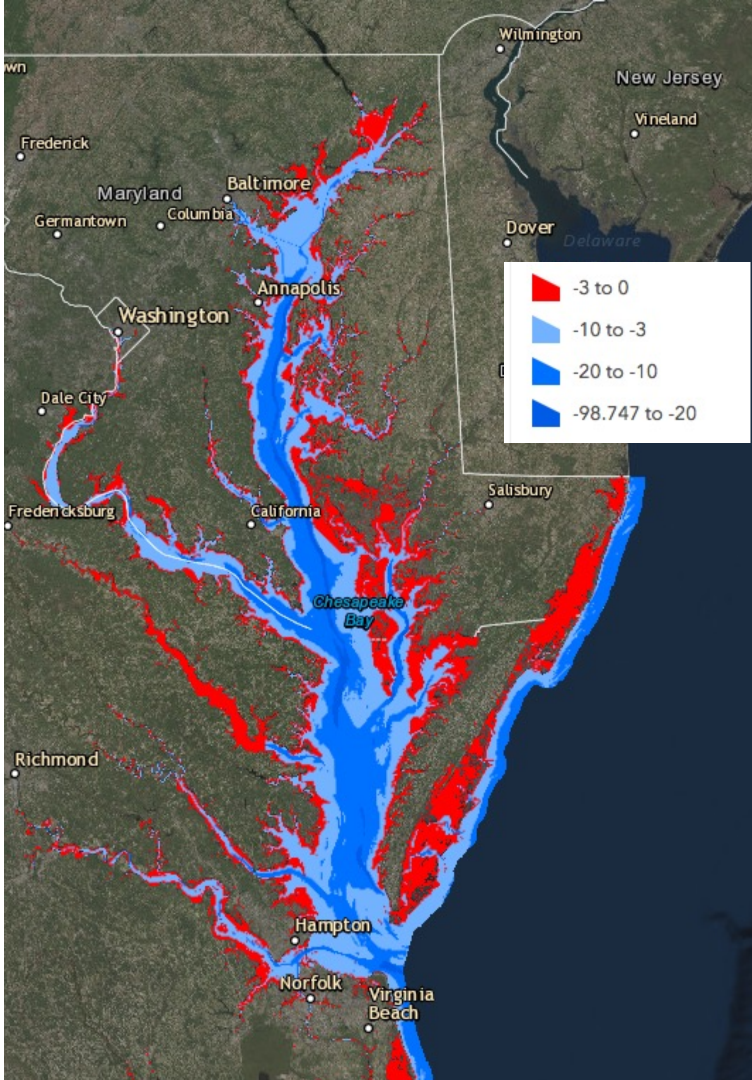
- Cooler in summer; warmer in winter
- Similar effect in both models

Impact of 1m SLR (St-Laurent et al.)

SLR leads to:

→ greater volume of Bay water
→ takes longer to heat up, so cooler in summer
→ decreases summer respiration
→ smaller sink of summer O_2
→ improved hypoxia!

Increases in hypoxia due to warming will likely be partially mitigated by SLR



Chesapeake Bay is Warming!

How much? Where? When? Why? (Hinson et al., 2021)

Kyle Hinson

JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION

AMERICAN WATER RESOURCES ASSOCIATION

Extent and Causes of Chesapeake Bay Warming

Kyle E. Hinson, Marjorie A.M. Friedrichs, Pierre St-Laurent, Fei Da, and Raymond G. Najjar

Research Impact Statement: Since 1985, the Chesapeake Bay has warmed three to four times faster in warmer than cooler months; this has been driven primarily by atmospheric changes and by ocean warming in the lower Bay.

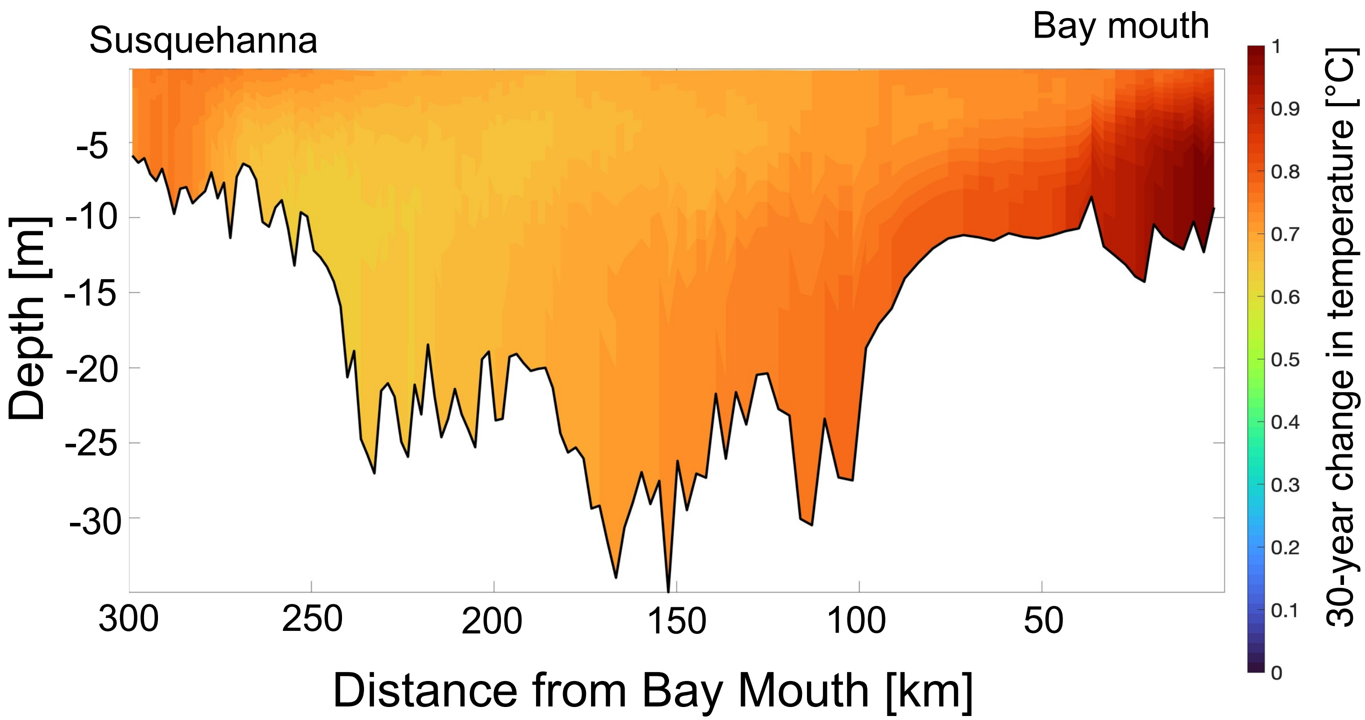
Model Experiments

- Scenarios compared to a realistic 1985-1989 reference run, ***BASE***
- Delta approach (*2015-2019 minus 1985-1989 conditions*) applied
  → All other conditions held constant

Experiment	Ocean Temp	Air Temp	Solar Radiation	River Temp	Sea Level Rise
Combined	BASE +2.19°C	BASE + 0.75°C	BASE + 6.84 W m^{-2}	BASE + 0.84°C	BASE + 0.15m
OceanTemp	BASE + 2.19° C	BASE	BASE	BASE	BASE
AtmTemp	BASE	BASE + 0.75°C	BASE + 6.84 W m^{-2}	BASE	BASE
RiverTemp	BASE	BASE	BASE	BASE + 0.84°C	BASE
SeaLevel	BASE	BASE	BASE	BASE	BASE + 0.15m

Chesapeake Bay is Warming!

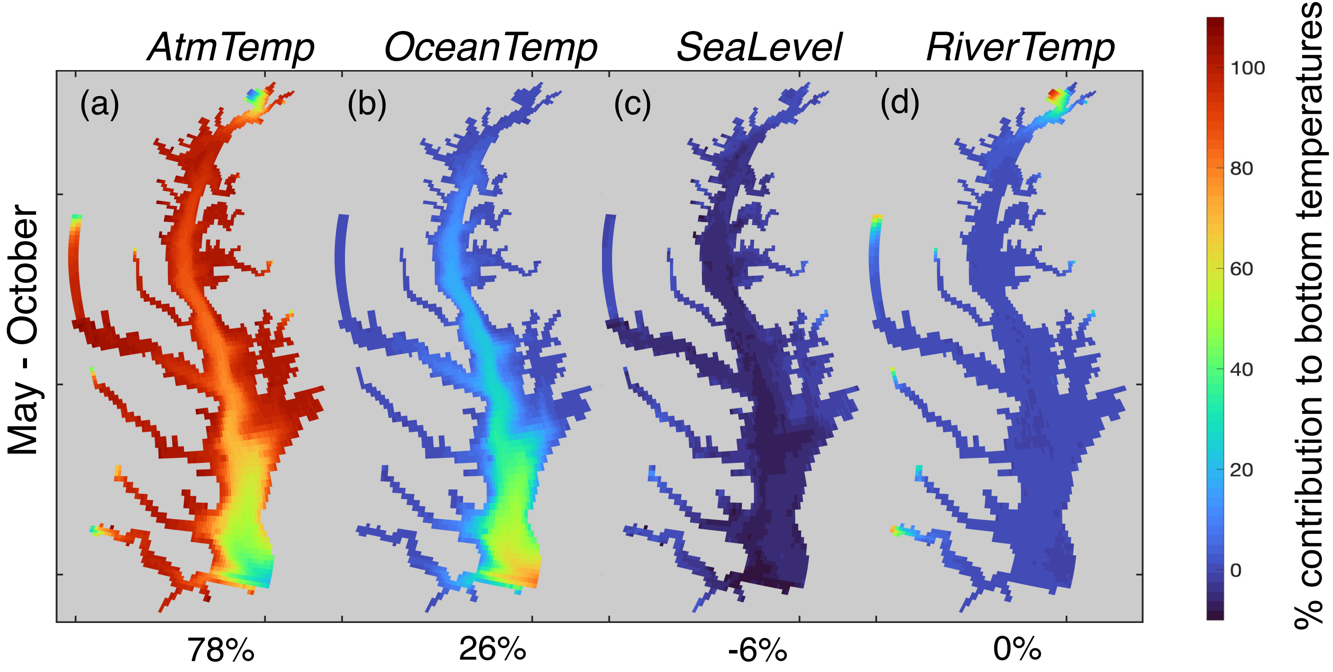
How much? Where? When?



- On average, the Bay has warmed ~0.7ºC over past 30 years
- Similar warming at bottom and surface
- More warming near Bay mouth
- 3-4 times greater warming in warmer months

Chesapeake Bay is Warming!

Why?



- Atmosphere dominates warming
- Ocean is warming VA waters
- SLR cools Bay everywhere
- Rivers only important at heads of tributaries

Have nutrient management efforts been working? (Frankel et al., 2022)

Or…. How bad would Chesapeake Bay hypoxia be if nutrient reductions had *not* taken place over the past 35 years?

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Nitrogen reductions have decreased hypoxia in the Chesapeake Bay: Evidence from empirical and numerical modeling

Luke T. Frankel [a,*], Marjorie A.M. Friedrichs [a], Pierre St-Laurent [a], Aaron J. Bever [b], Romuald N. Lipcius [a], Gopal Bhatt [c,d], Gary W. Shenk [c,e]

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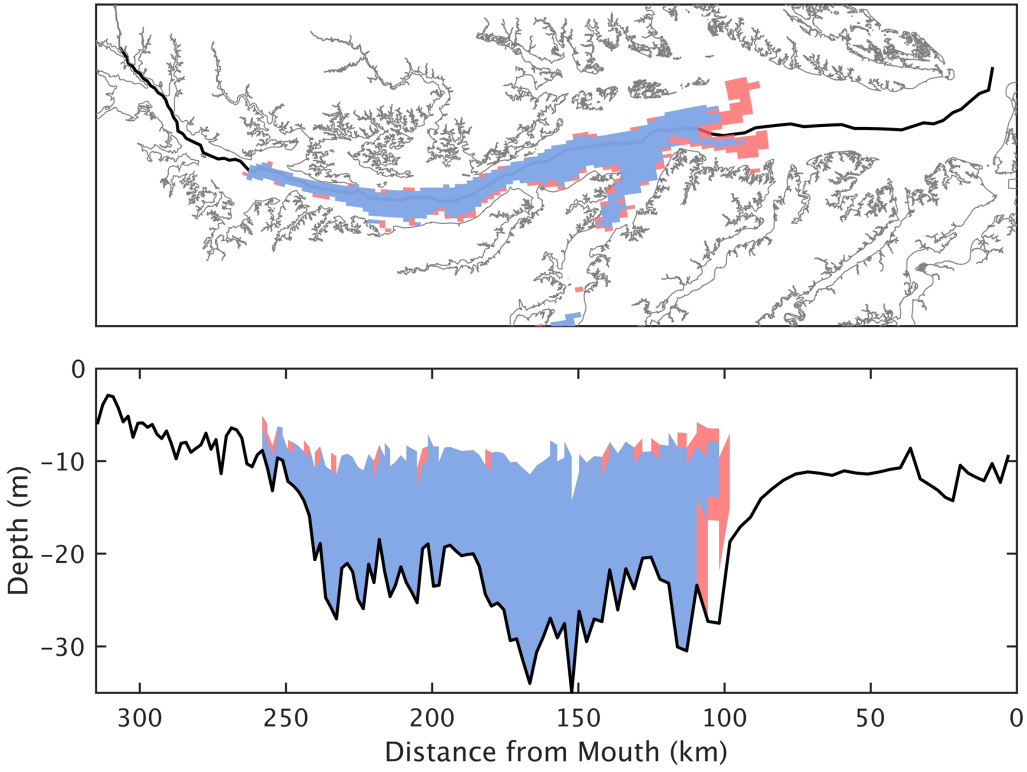
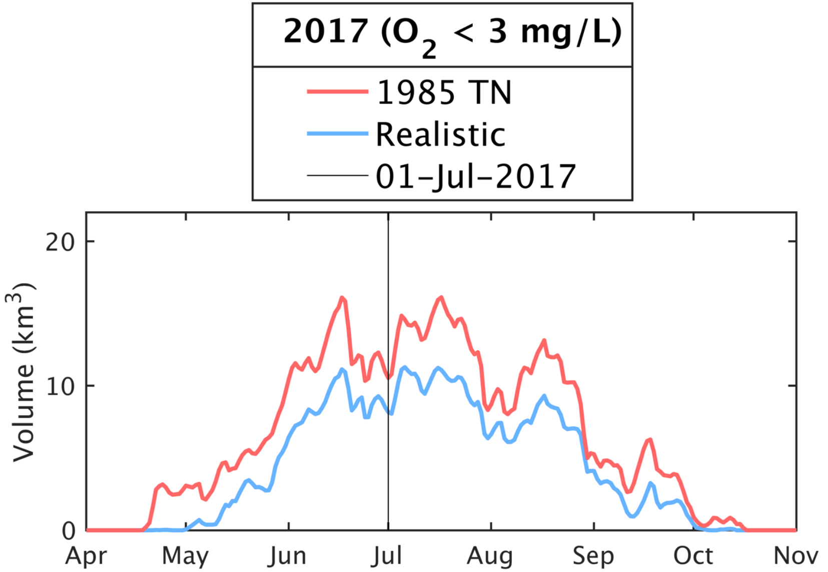
[c] Chesapeake Bay Program Office, 1750 Forest Drive, Suite 130, Annapolis, MD, USA
[d] Department of Civil & Environmental Engineering, The Pennsylvania State University, 212 Sackett Building, University Park, PA, USA
[e] U.S. Geological Survey, Virginia and West Virginia Water Science Center, 1730 East Parham Road, Richmond, VA, USA

Model Experiments

Simulation	Watershed TN Input	Temperature
Realistic	2016-2019	2016-2019
1985 TN	**1985**	2016-2019
1985 Temp	2016-2019	**1985**

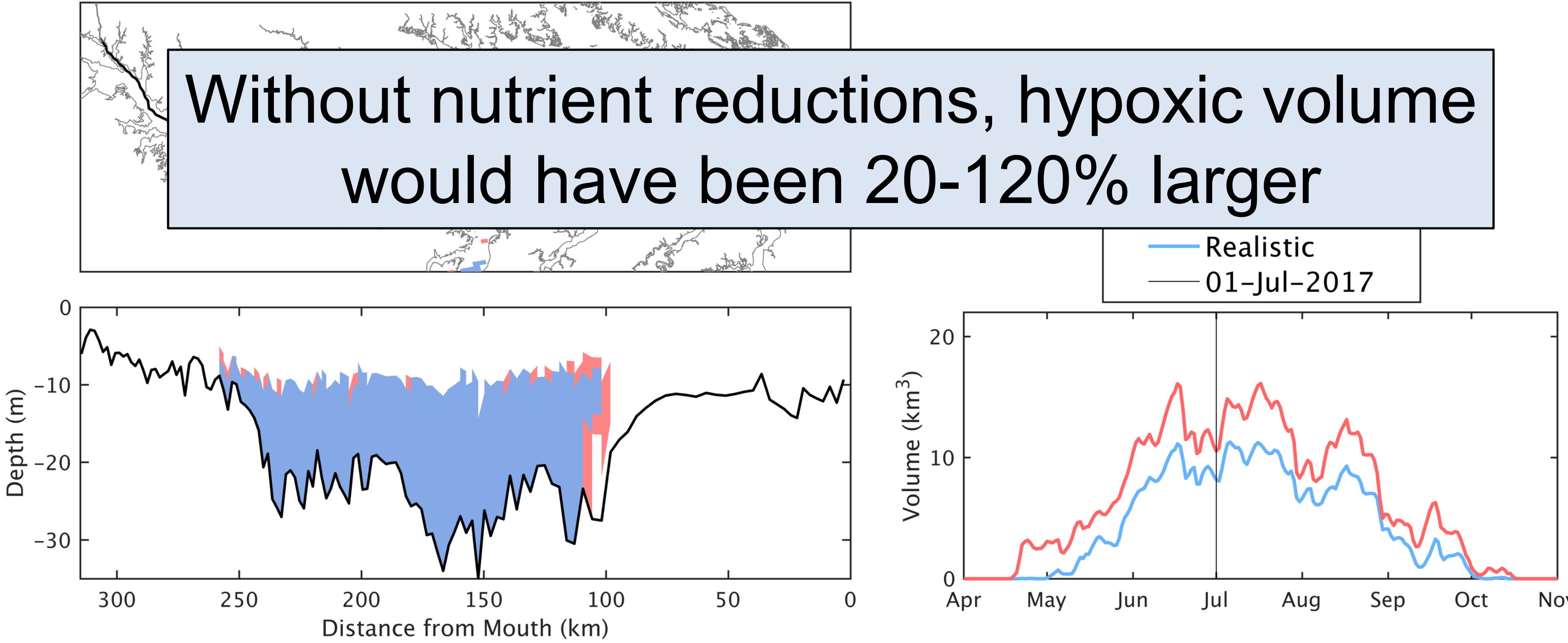
Spatiotemporal Impact of Reductions



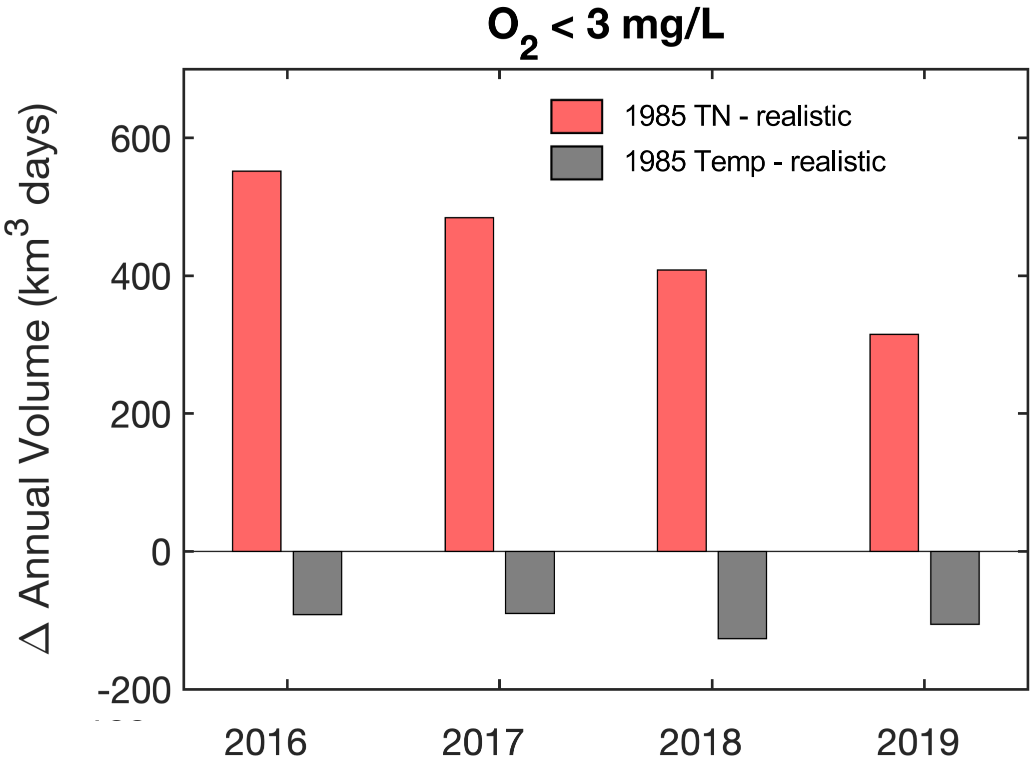


Spatiotemporal Impact of Reductions

Without nutrient reductions, hypoxic volume would have been 20-120% larger



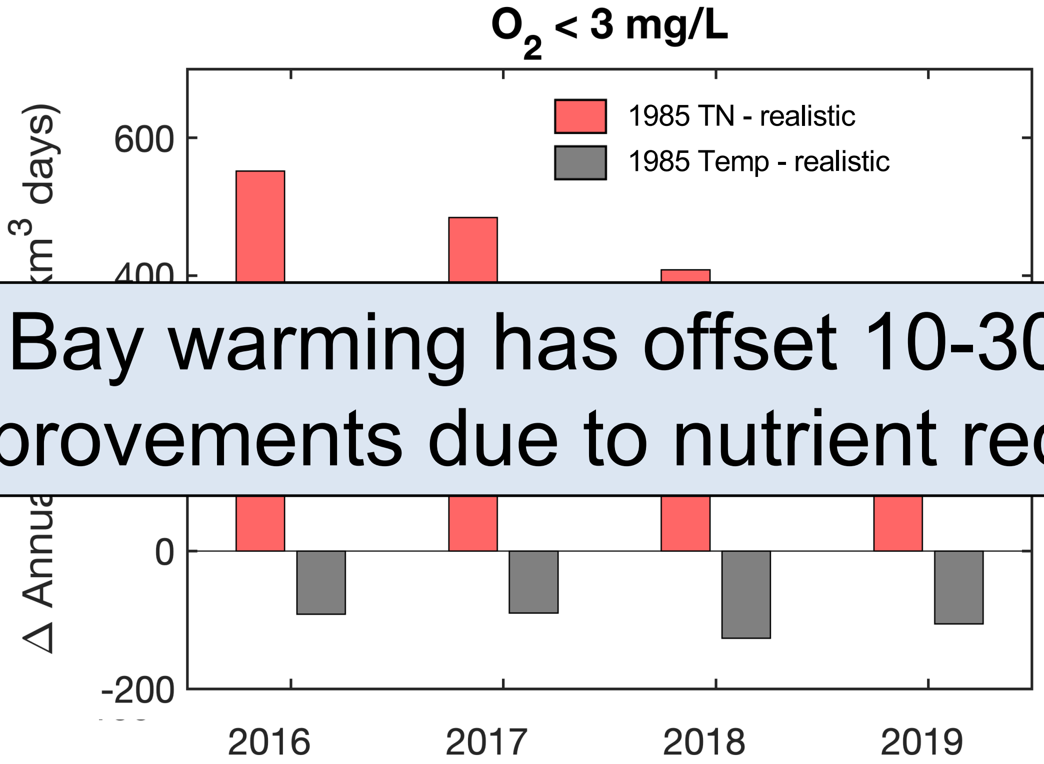
Impact of warming on hypoxia reductions



337 km³ days worse without nutrient reductions

103 km³ days better without atmospheric warming

Impact of warming on hypoxia reductions



Bay warming has offset 10-30% of improvements due to nutrient reductions

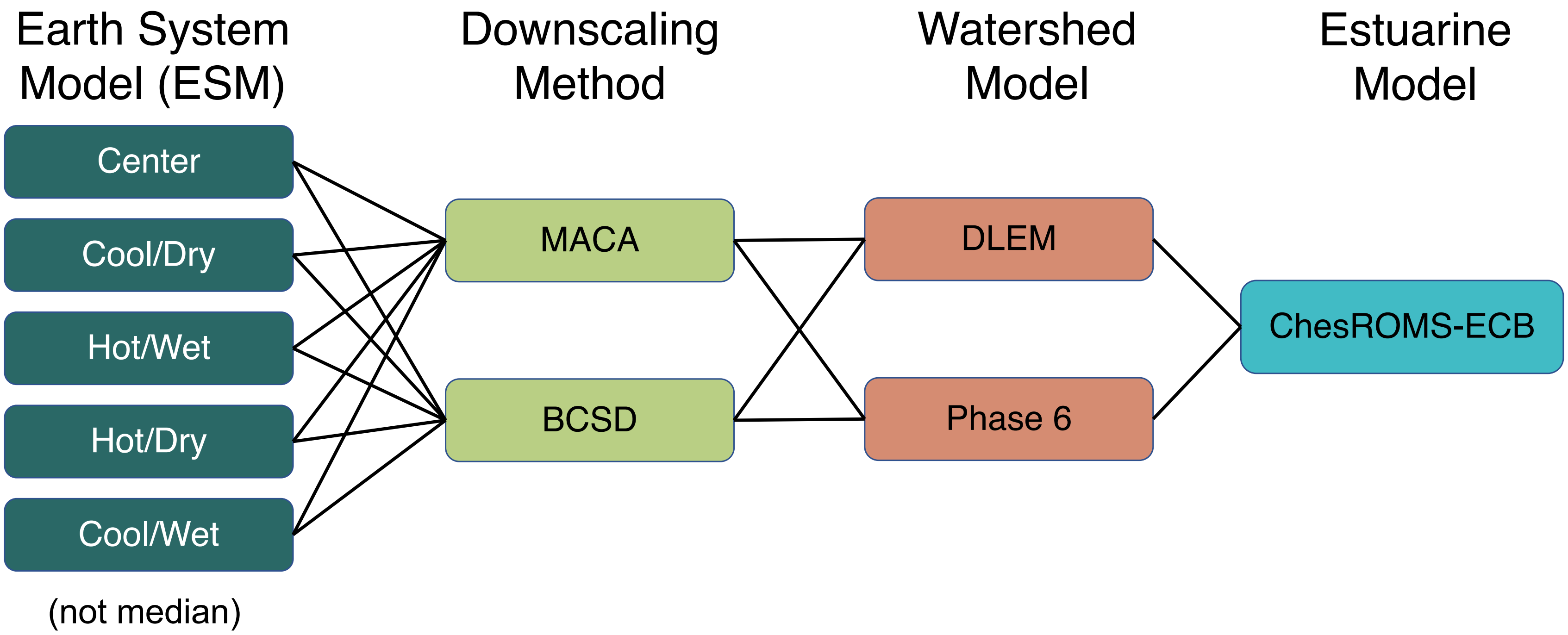
337 km^3 days

103 km^3 days better without atmospheric warming

Future impact of watershed on mid-century hypoxia (Hinson et al., submitted)

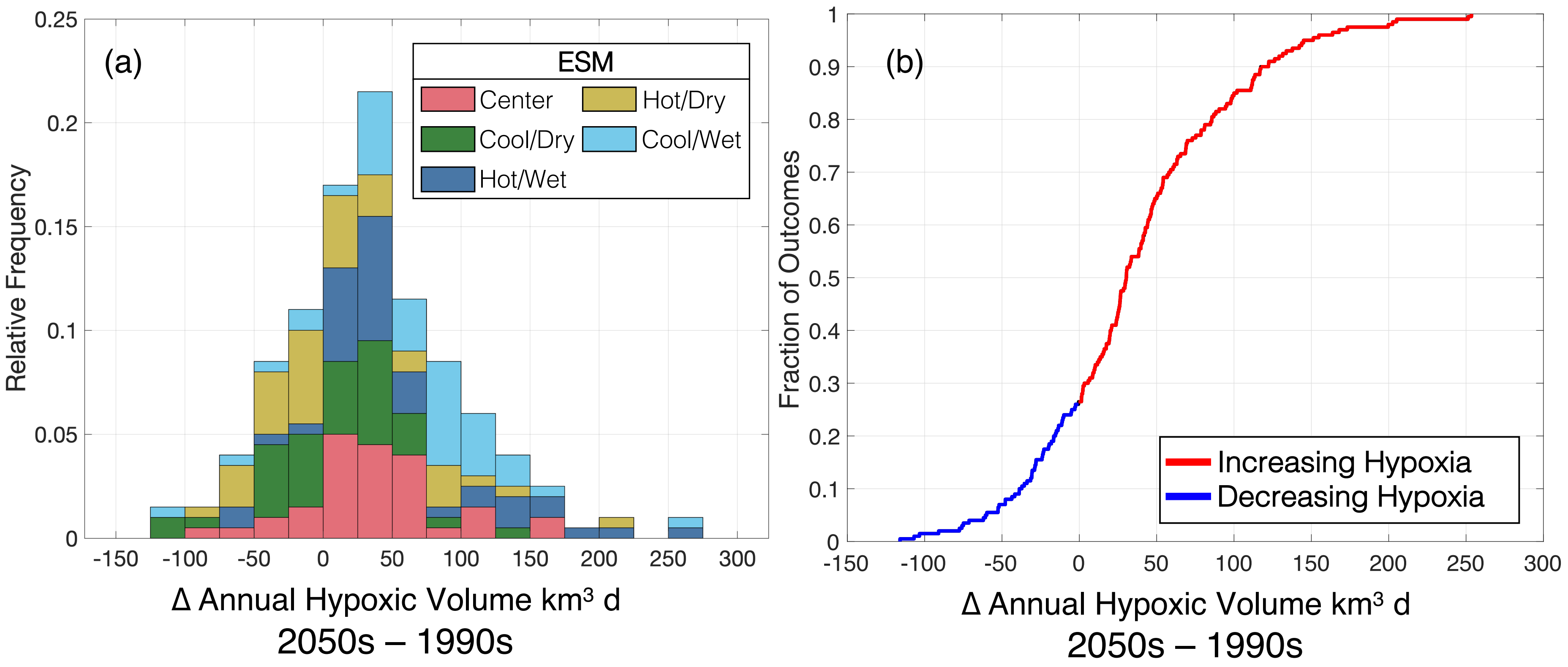
- How will climate change impacts on the watershed affect terrestrial runoff and hypoxia?

- How confident are we in these estimates?
  (i.e. uncertainty quantification)

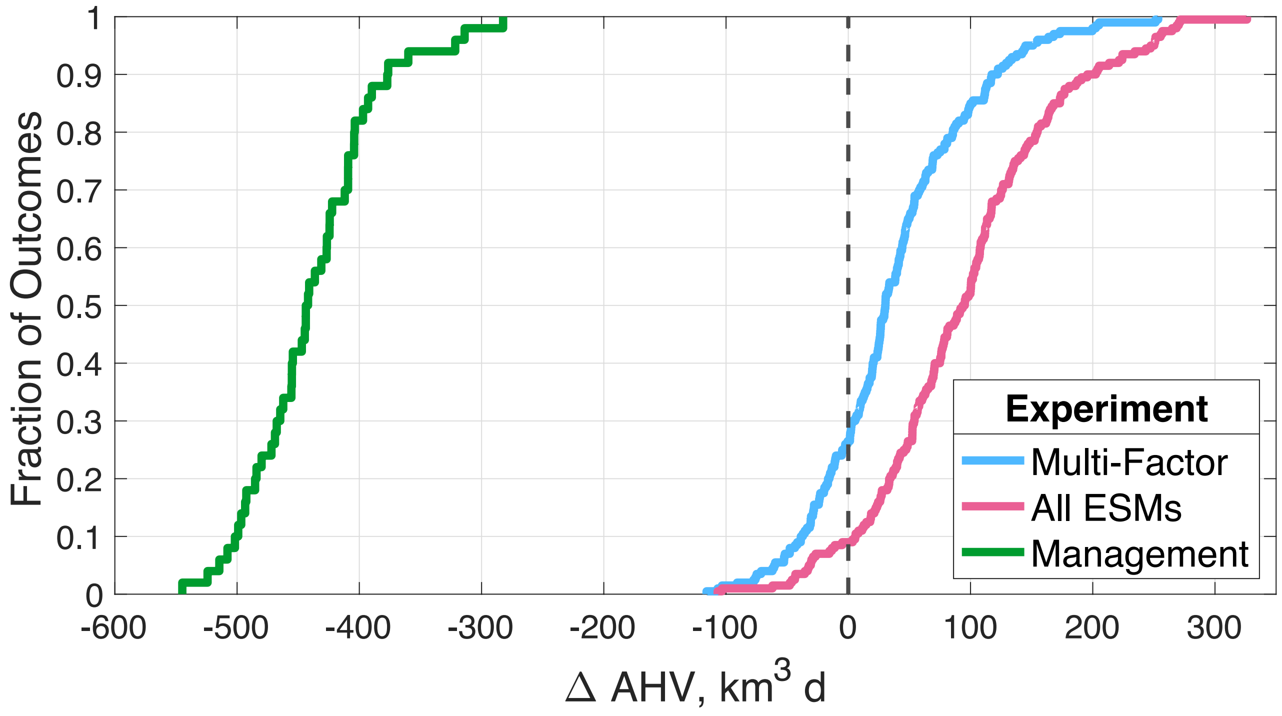


Multiple combinations result in <u>20</u> climate scenarios

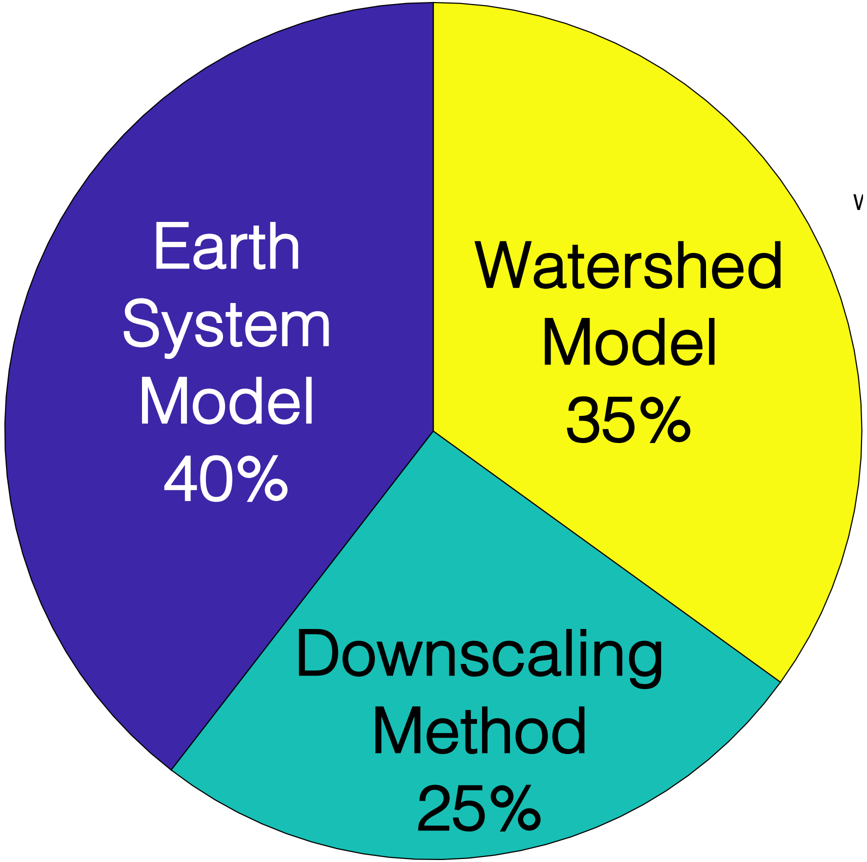
Future hypoxia depends on ESM choice



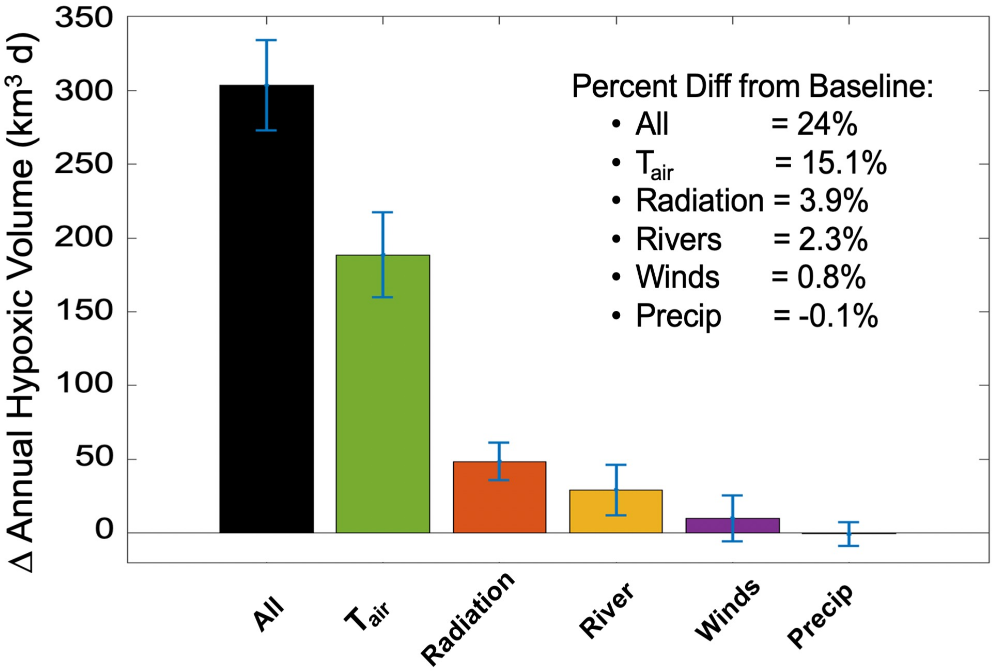
Future hypoxia depends on ESM choice But even more on management actions



Multiple (relatively equal) sources of uncertainty in mid-21st century hypoxia projections



How does the impact of changing watershed inputs, compare to changing atmospheric conditions? (Hawes et al., in prep.)

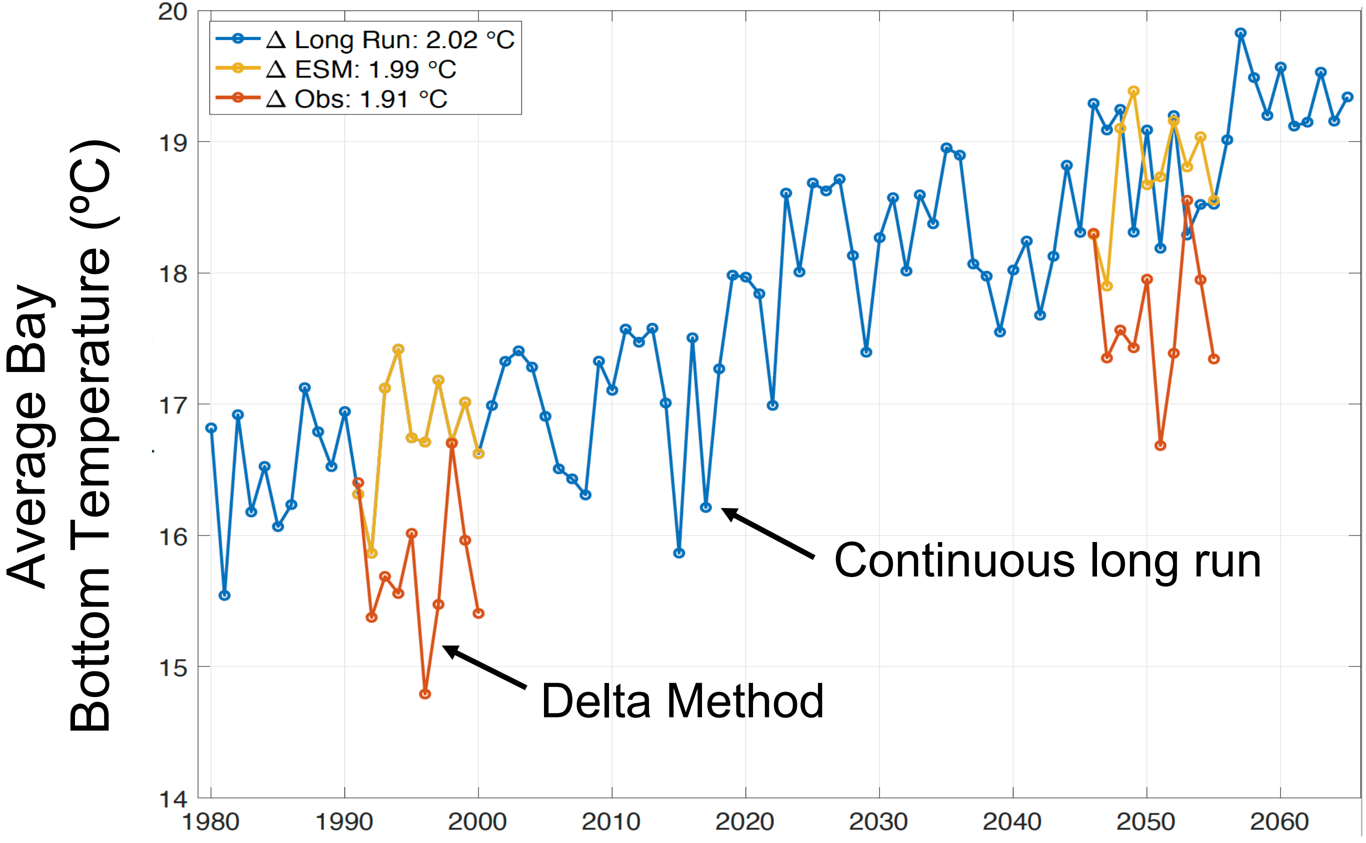


Ongoing CHAMP efforts

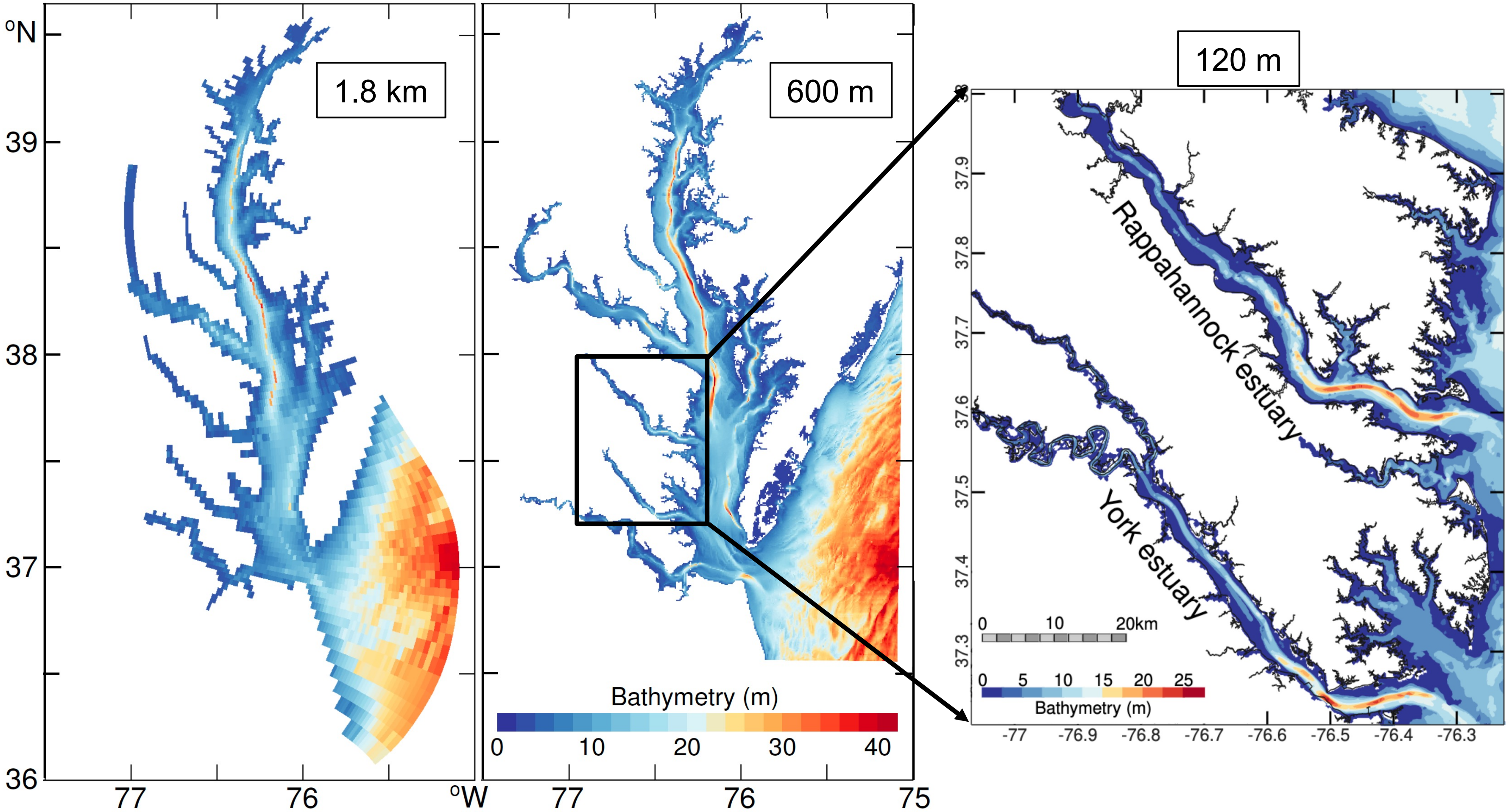
Where are we going from here?

- Continuous future run (1980-2065)
- Increased grid/coastline resolution
- Extending analyses beyond hypoxia

Future/ongoing work – Continuous long run:

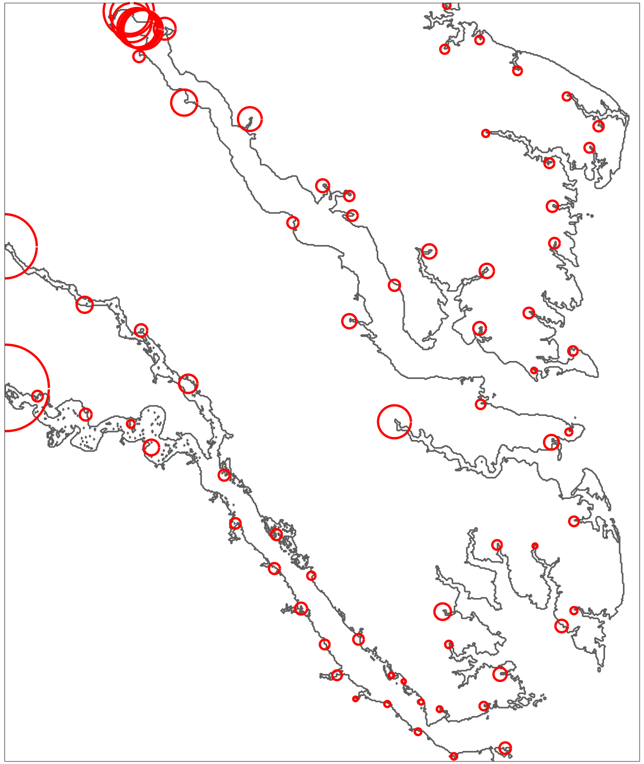


Future/ongoing work – Increased grid resolution:



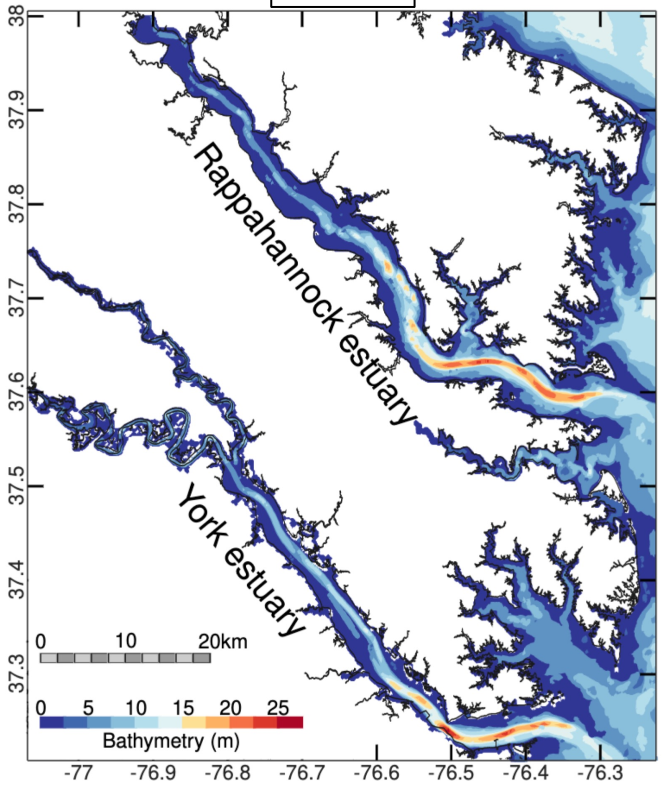
Future/ongoing work – Increased grid resolution:

Increased terrestrial input locations

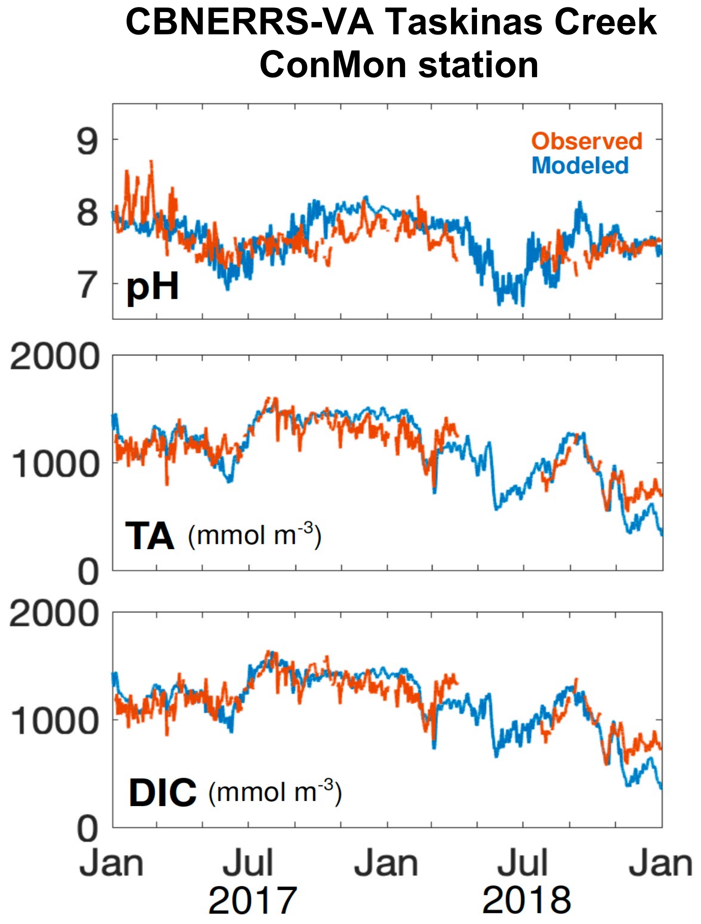


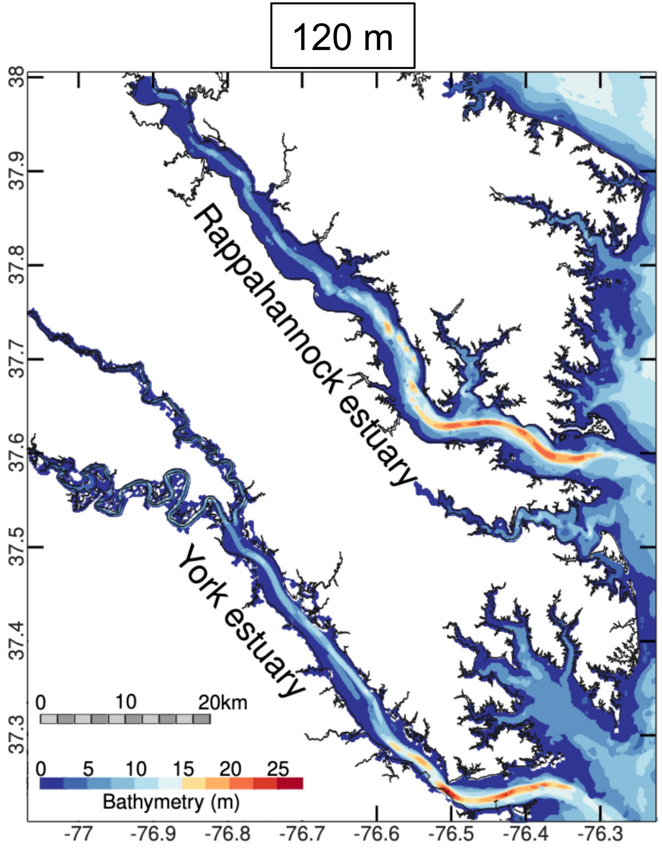
Discharge proportional to circle area

120 m



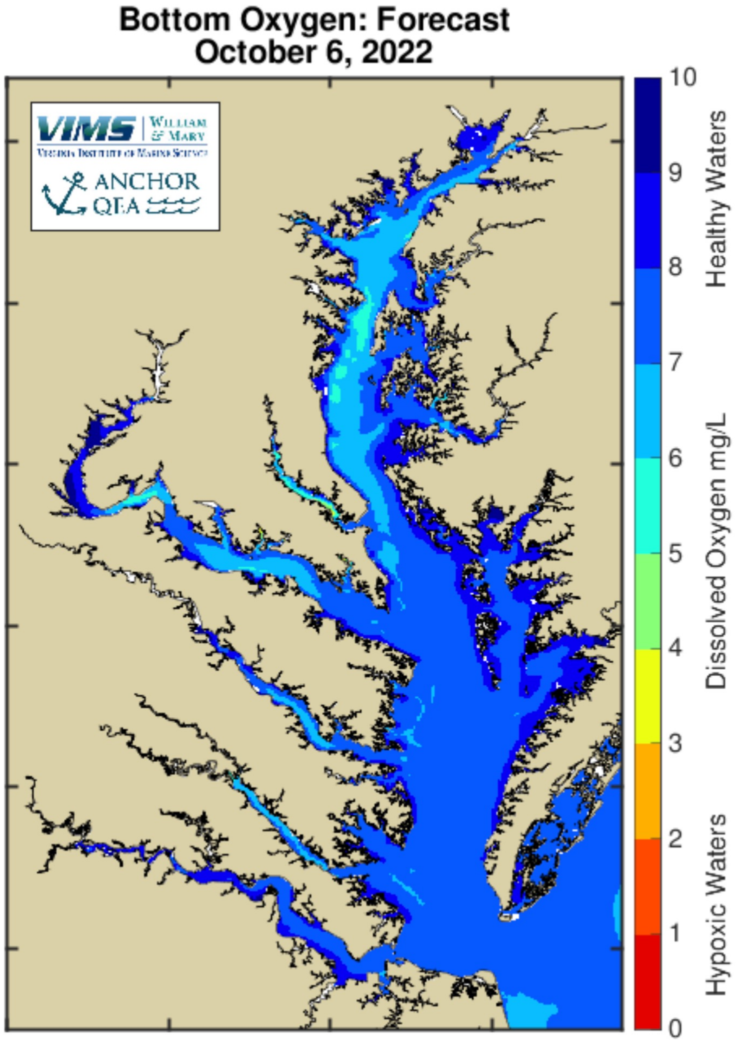
Future/ongoing work – Beyond hypoxia:





Thanks!

Please visit us at
www.vims.edu/cbefs



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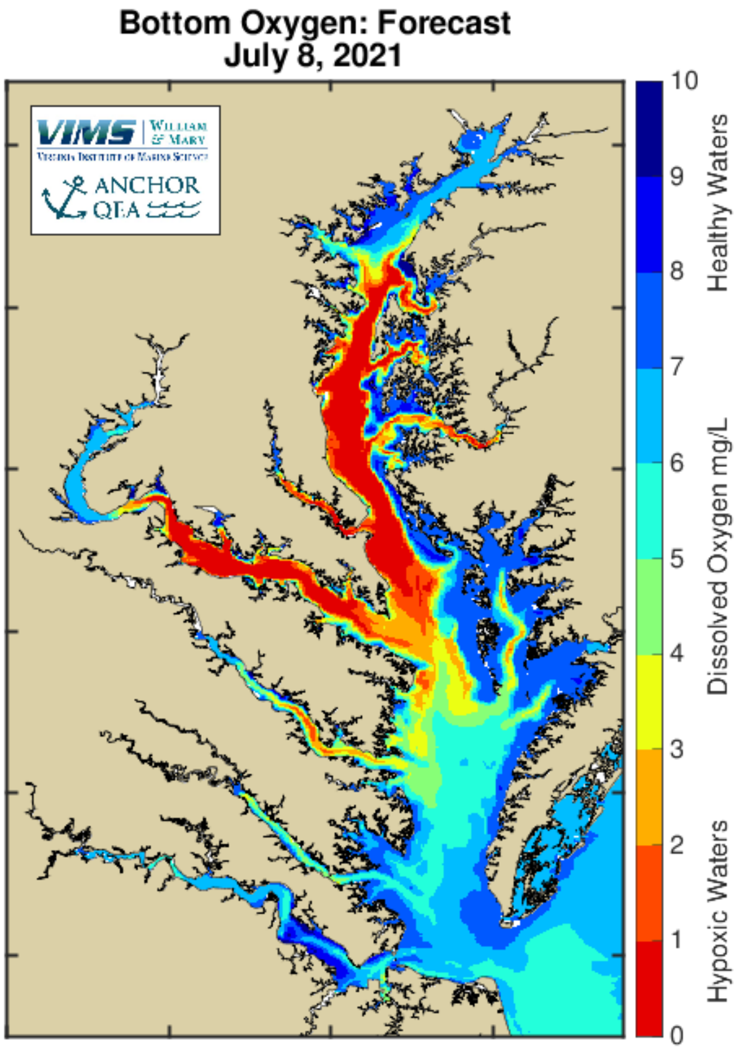
Extra Slides



Chesapeake Bay Environmental Forecast System (CBEFS)

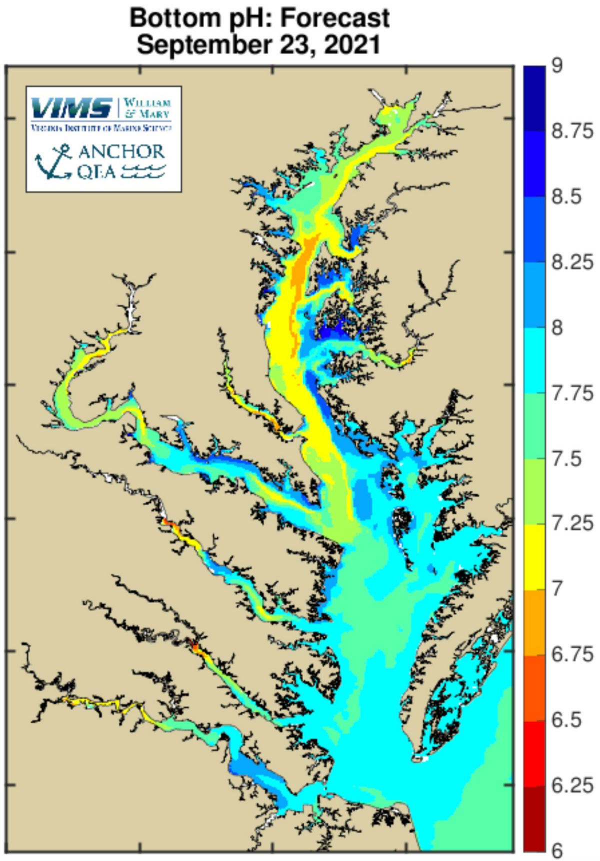
www.vims.edu/cbefs

Blues → High bottom oxygen
= Good bottom water
= Bottom fish and crabs

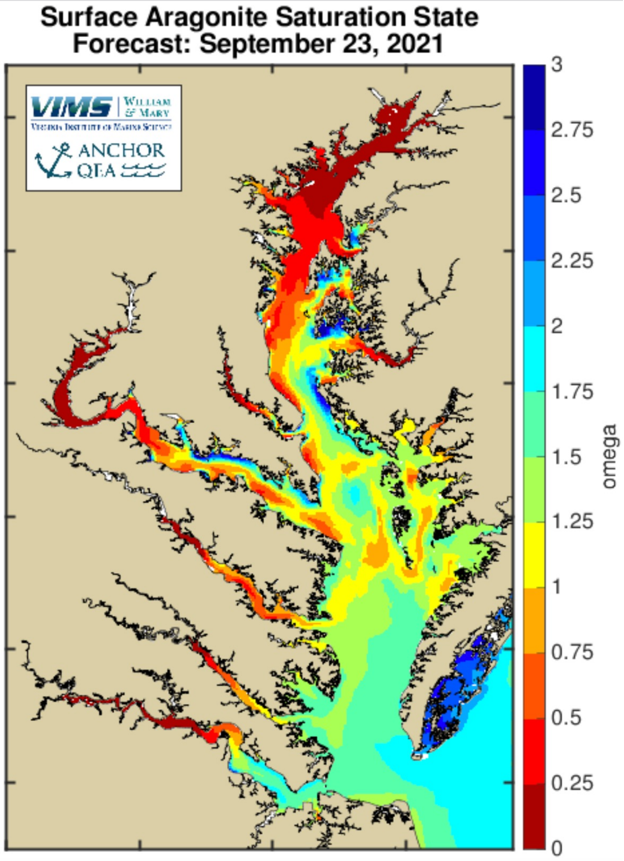
Yellow/green → Moderately low oxygen
= Poor bottom water
= Fewer bottom fish and crabs

Red → Very low bottom oxygen
= Bad bottom water
= No bottom fish or crabs

Bottom pH Forecast *(Sept. 23)*



Surface Ω_{AR} Forecast *(Sept. 23)*



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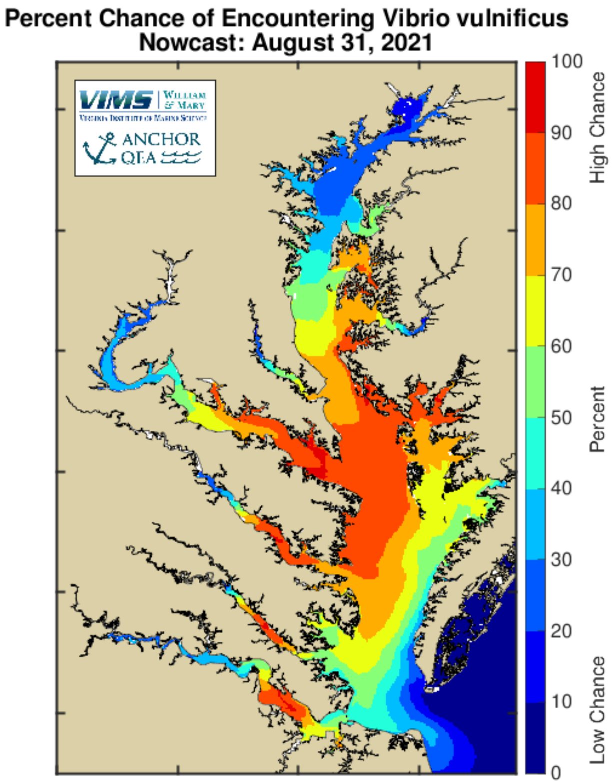
% Chance of Encountering Vibrio

August Forecast



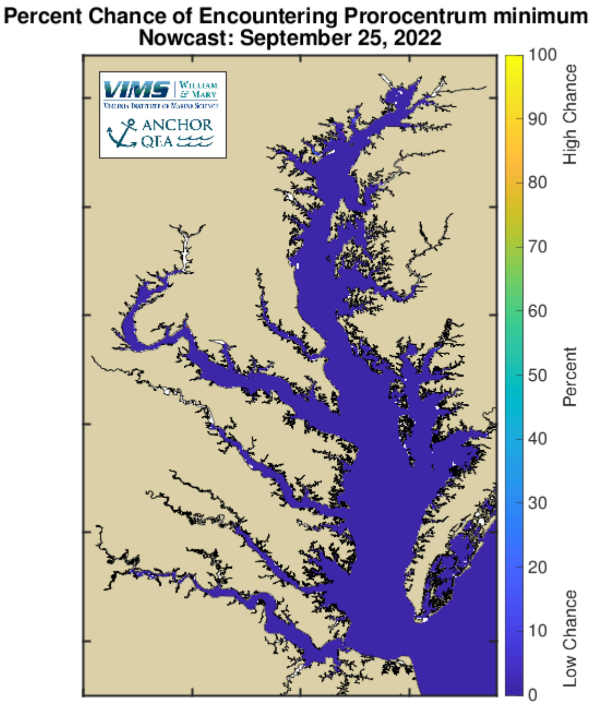
www.vims.edu/cbefs

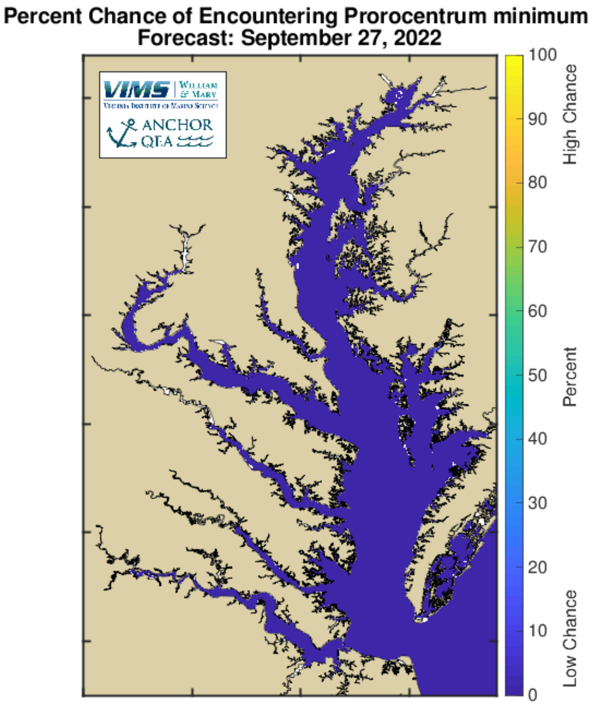
Blues → Low chance (0-30%)

Greens → Moderate chance

Oranges → High chance (70-100%)

The VIMS Chesapeake Bay Environmental Forecast System (www.vims.edu/cbefs)
is now providing information on *Prorocentrum minimum* forecasts (other HABS to follow)





https://www.vims.edu/research/products/cbefs/harmful_algal_blooms/index.php