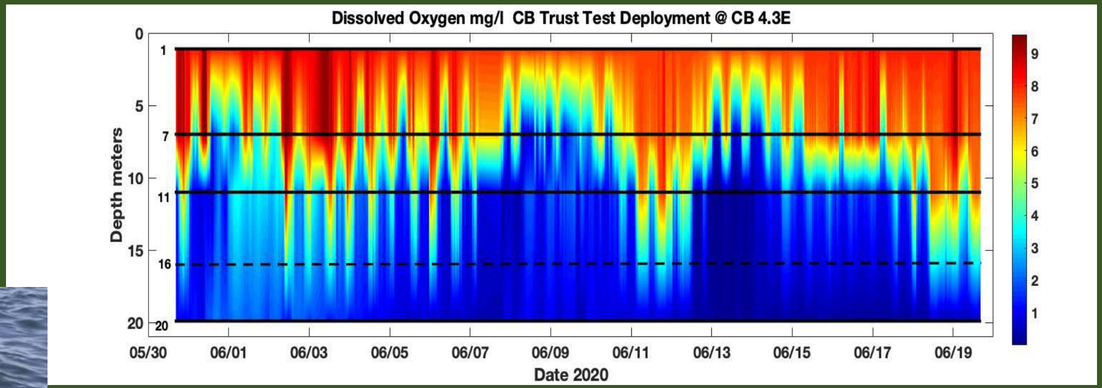
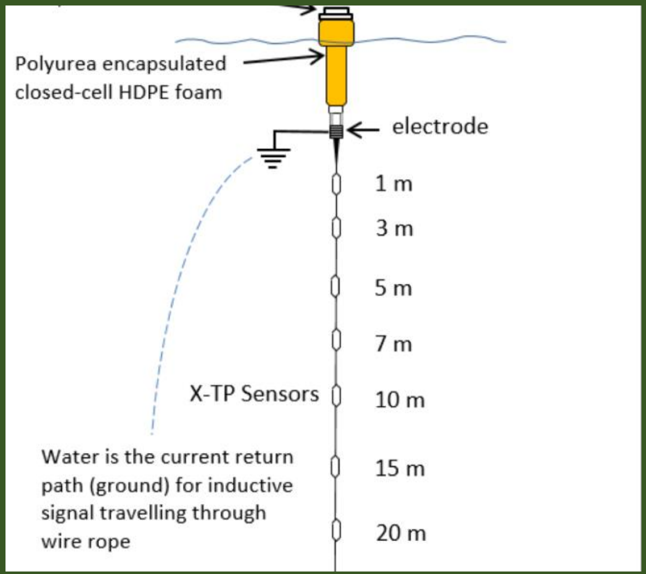
Open Bay Vertical Water Quality Assessments in High Temporal Resolution

An update on sensor arrays and cost considerations

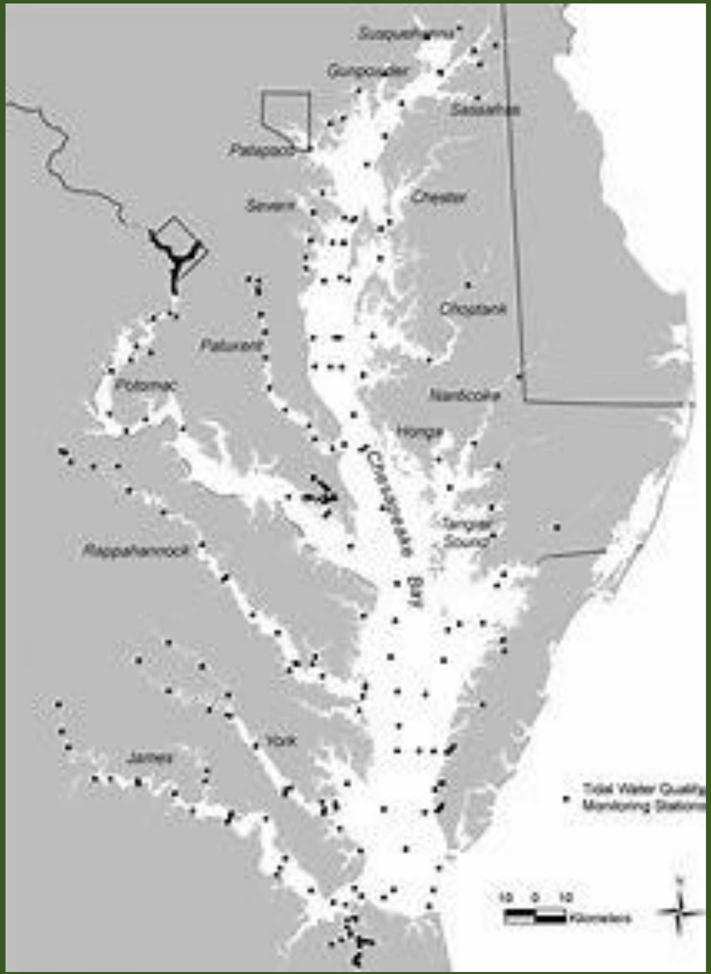




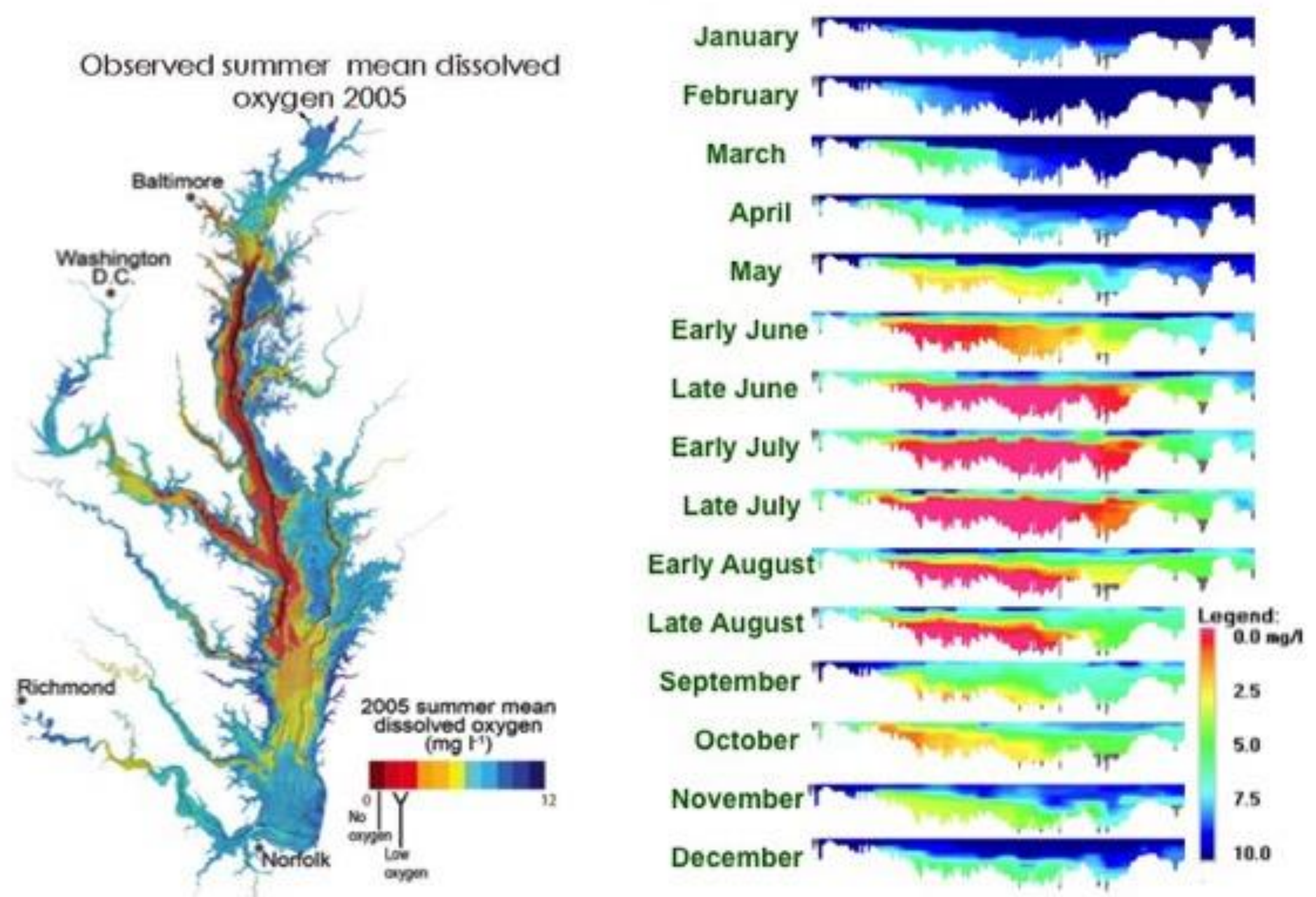
Peter Tango
USGS@CBPO
1-7-2021
Modeling Workgroup Meeting

Chesapeake Bay Long-term Water Quality Monitoring Program sampling design

- 156 stations
- Monthly cruise schedule
- 14-20 cruises per year
- Physical, chemical, biological sampling



1.3. Seasonal variability of dead zone in the Bay



1x per month

2x per month

1x per month

From our Strategic Review System
July 2020 Management Board Meeting presentation

Successes and Challenges

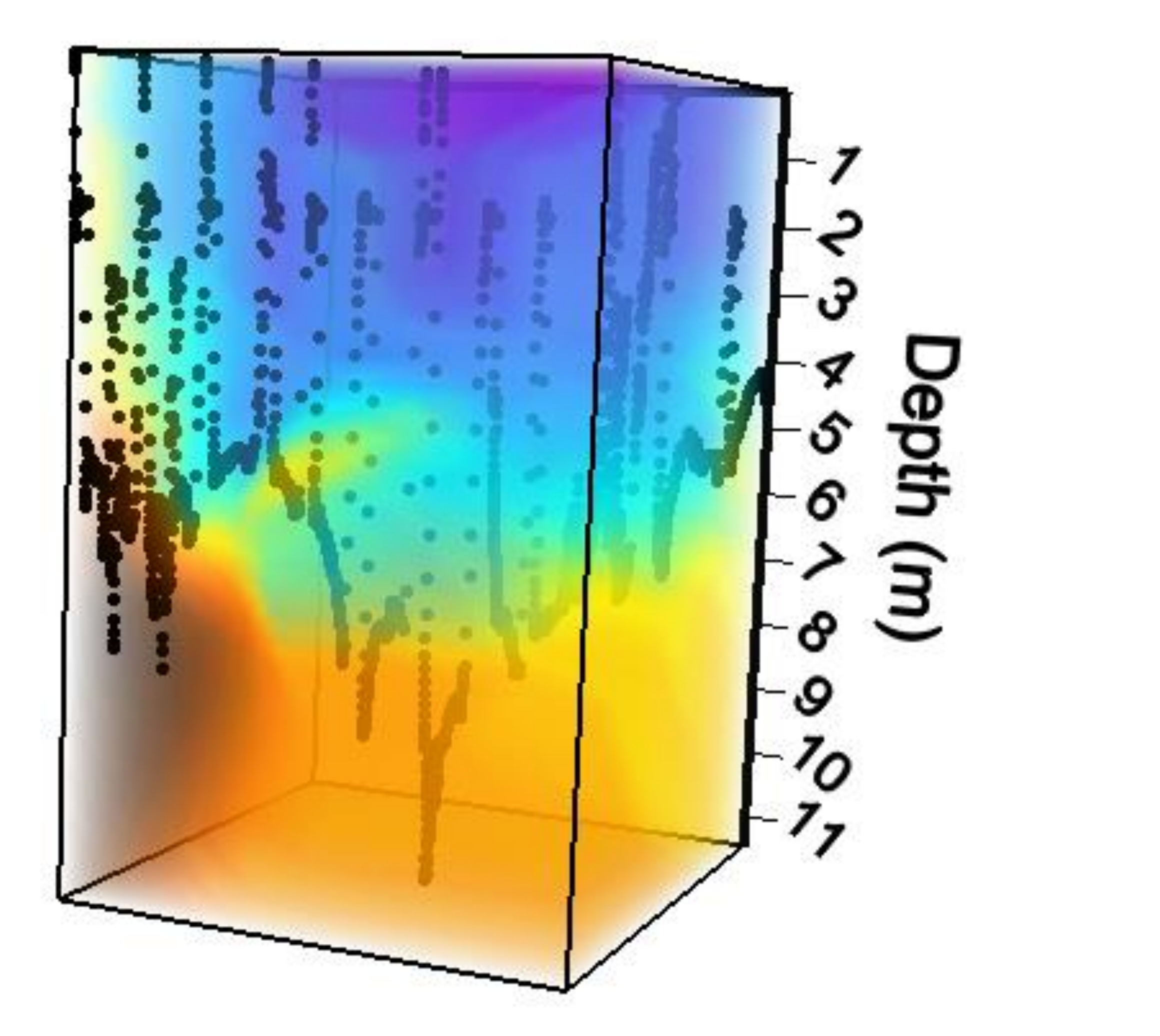
- Unassessed criteria remain a hurdle for delisting decisions of State-adopted water quality standards with our existing framework
- Financial stresses on Bay cruises, SAV aerial survey, NTN
- Contraction of traditional long-term monitoring programming
- Slow pace for expanded assessment of water-quality standards
- Limited non-traditional data use in assessments
- Limited use of new interpretation and interpolation options

= Inability to report on standard attainmen

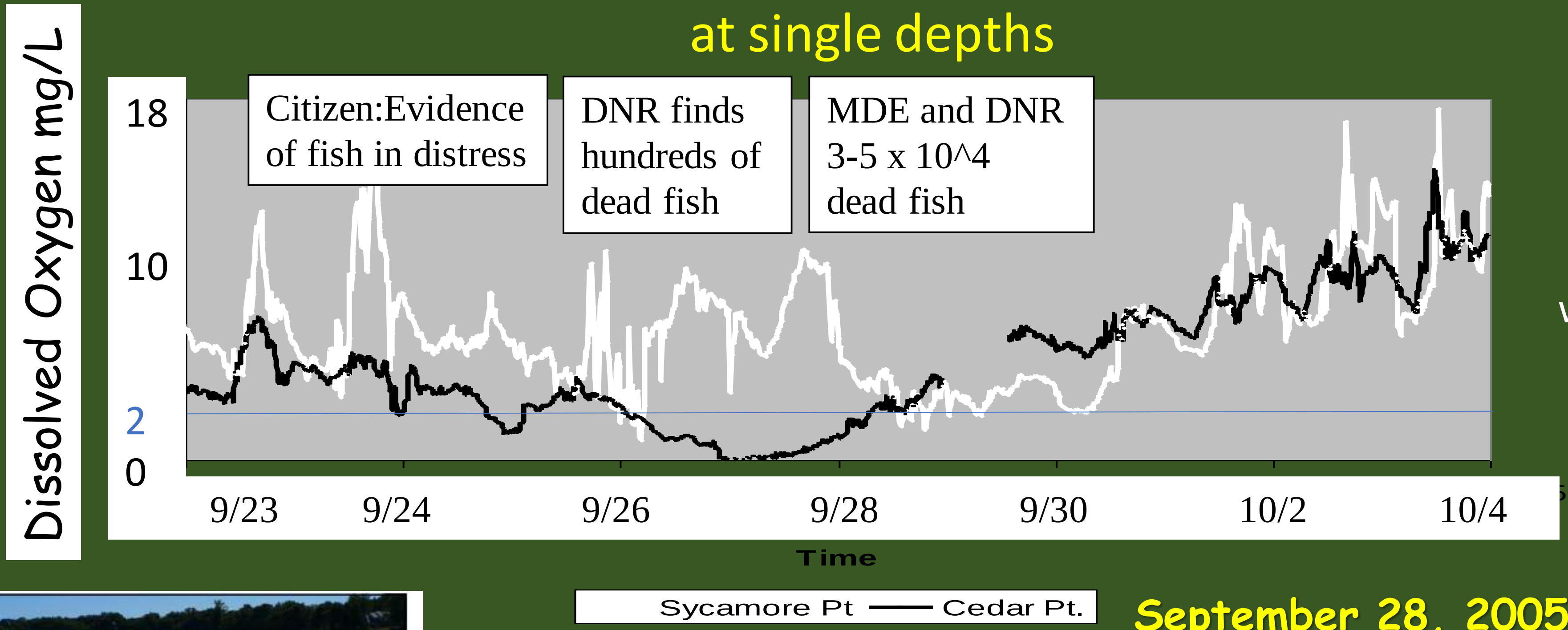
Designated Use	Dissolved oxygen Criteria Concentration/Duration		Temporal Application
Migratory fish spawning and nursery use	7-day mean ≥ 6 mg/L tidal habitats with 0-0.5ppt salinity		February 1 – May 31
	Instantaneous min ≥ 5 mg/L		
	Open water fish & shellfish designated use criteria apply		June 1 – January 31
Shallow water Bay grass use	Open water fish & shellfish designated use criteria apply		Year-round
Open water fish and shellfish use	30-day mean	≥ 5.5 mg/L Salinity: (0-0.5ppt)	Year-round
		≥ 5 mg/L Salinity: >0.5ppt	
	7-day mean	≥ 4 mg/L	
	Instantaneous min ≥ 3.2 mg/L		
Deep-water seasonal fish and shellfish use	30 day mean > 3mg/L		June 1 – September 30
	1-day mean >2.3 mg/L		
	Instantaneous min ≥1.7 mg/L		
	Open water Fish and shellfish designated use criteria apply		October 1-May 31
Deep channel seasonal refuge use	Instantaneous min > 1 mg/L		June 1 – September 30
	Open water F & S applies		October 1 – May 31

We want reliable point estimates in space, through time, at high frequency.

- Improve our understanding of bay dynamics at new resolutions and update relationships with environmental forcing
- Improve our understanding of living resource relationships with bay conditions
- Address regulatory assessment of criteria across the full range of durations address in Chesapeake Bay water quality standards



We have done very well with monitoring nearshore habitats in high frequency at single depths

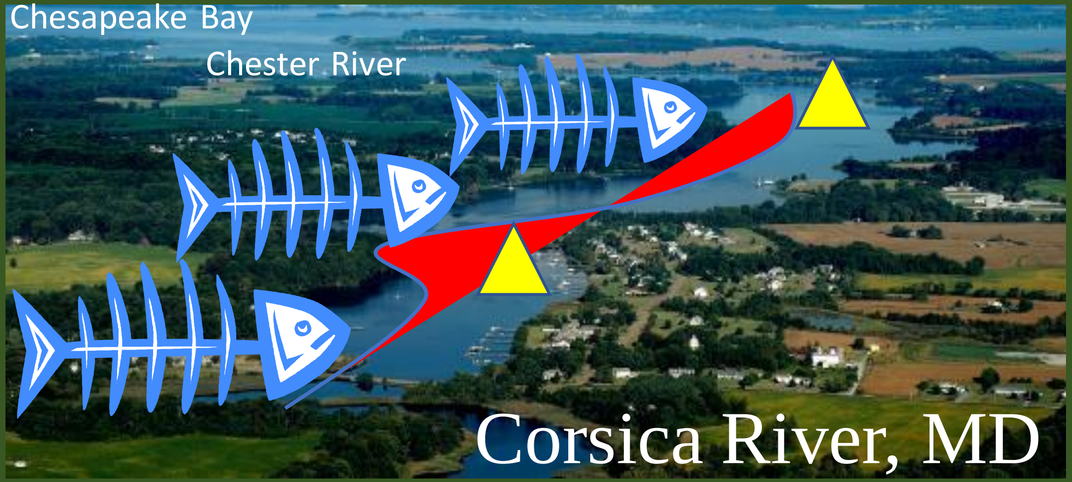


D.O. Dynamics within a 2 week period

Fish Kill in the Corsica

September 28, 2005

Estimated 30,000-50,000 fish dead; 15 species affected



= DNR Continuous Monitoring Stations = Dead fish

USGS science for a changing world

Chesapeake Bay Program A Watershed Partnership

Open Water:
Monitoring needs at high frequency – how much?

JGR Oceans

Research Article | Open Access

Estimating Hypoxic Volume in the Chesapeake Bay Using Two Continuously Sampled Oxygen Profiles

Aaron J. Bever, Marjorie A. M. Friedrichs, Carl T. Friedrichs, Malcolm E. Scully

First published: 27 August 2018 | https://doi.org/10.1029/2018JC014129 | Citations: 3

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Abstract

Low levels of dissolved oxygen (DO) occur in many embayments throughout the world and have numerous detrimental effects on biota. Although measurement of in situ DO is straightforward with modern instrumentation, quantifying the volume of water in a given embayment that is hypoxic (hypoxic volume (HV)) is a more difficult task; however, this information is critical for determining whether management efforts to increase DO are

Volume 123, Issue 9
September 2018
Pages 6392-6407

This article also appears in: The U.S. IOOS Coastal and Ocean Modeling Testbed 2013-2017

Figures References Related Information

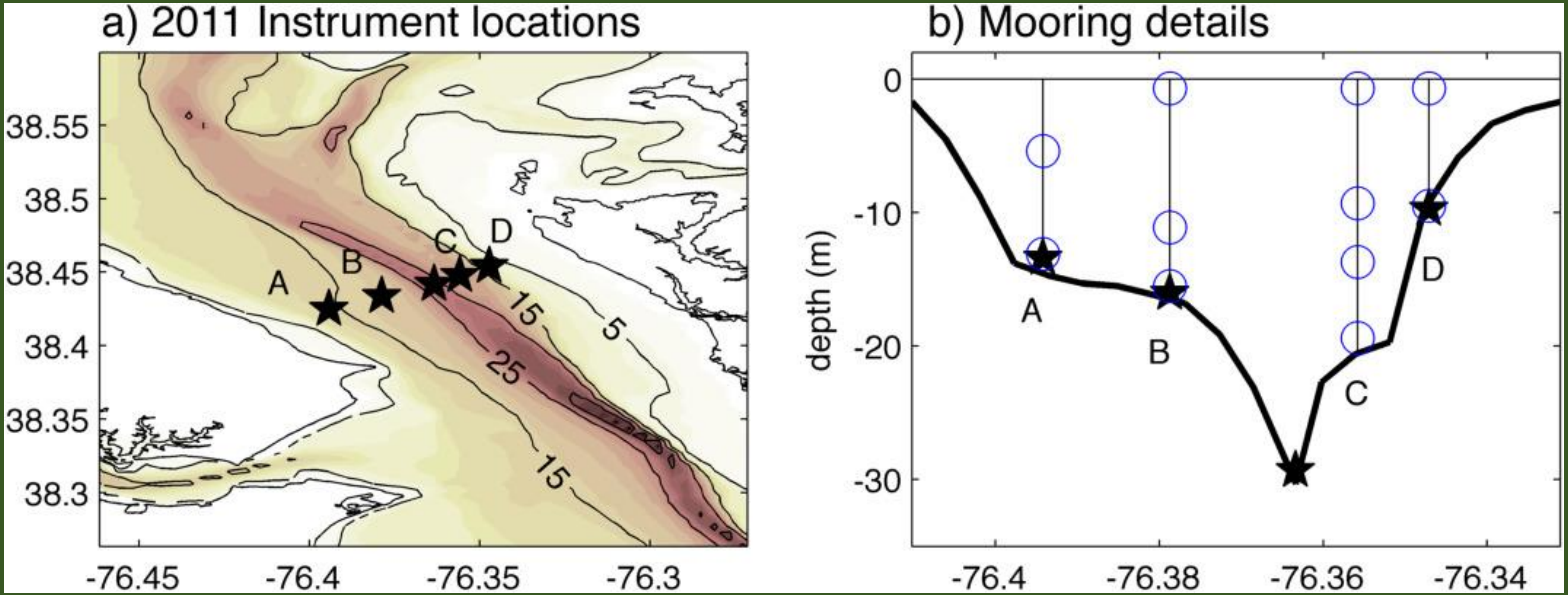
Metrics

Citations: 3

Details

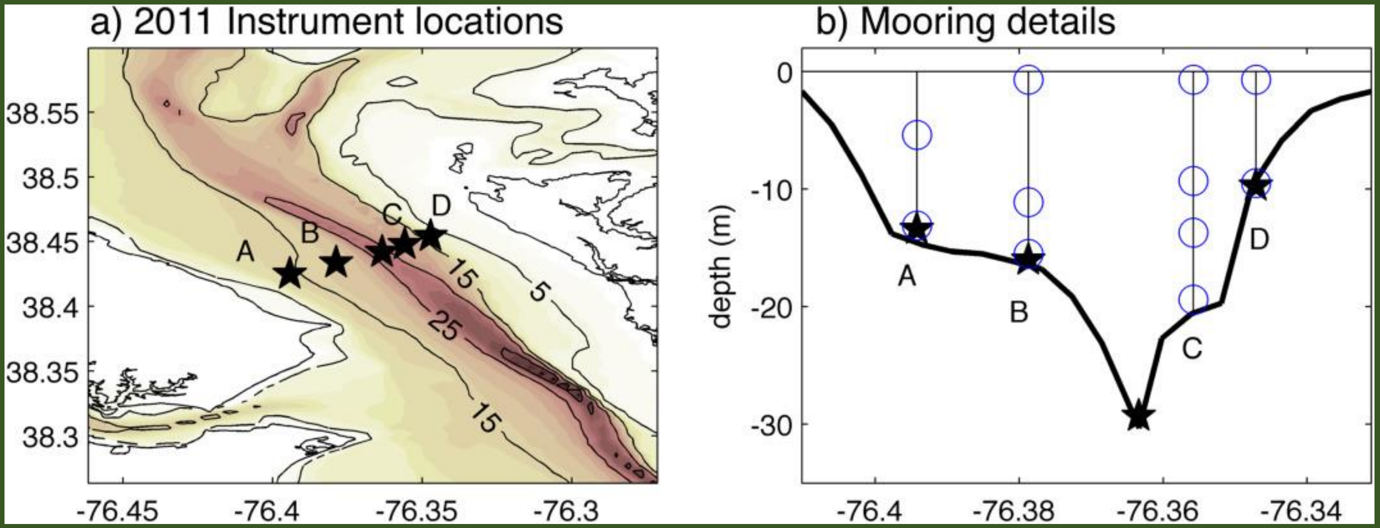
Sensor distribution and sampling design considerations:

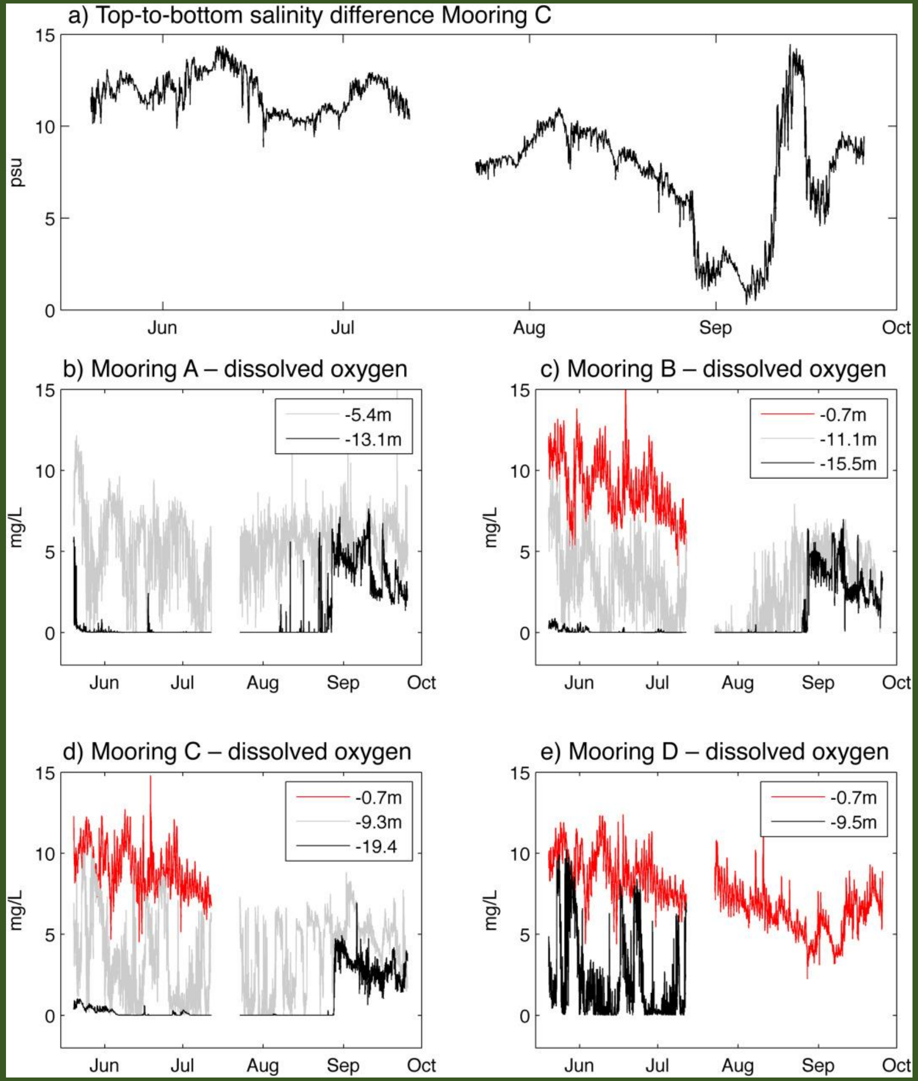
Scully, M. 2016. **Mixing of dissolved oxygen in Chesapeake Bay driven by the interaction between wind-driven circulation and estuarine bathymetry. JGR Oceans**



Vertical Profilers: Mainstem Bay. Precursor work to today.

M. Scully 2016. Mixing of dissolved oxygen in Chesapeake Bay driven by the interaction between wind-driven circulation and estuarine bathymetry





JGR: Oceans, Volume: 121, Issue: 8, Pages: 5639-5654,
First published: 13 July 2016, DOI:
(10.1002/2016JC011924)

Vertical Profilers: Mainstem Bay. Precursor work to today.

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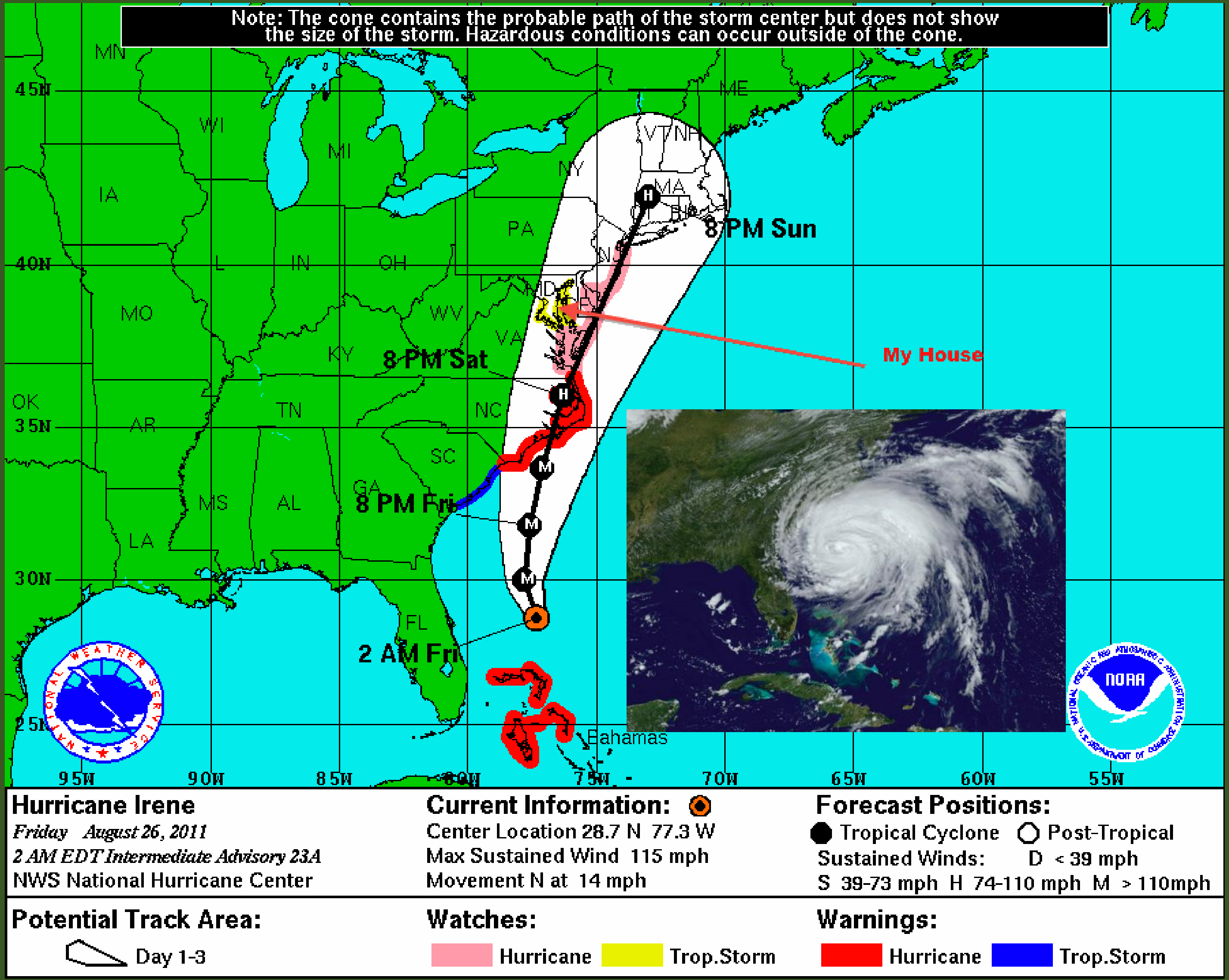
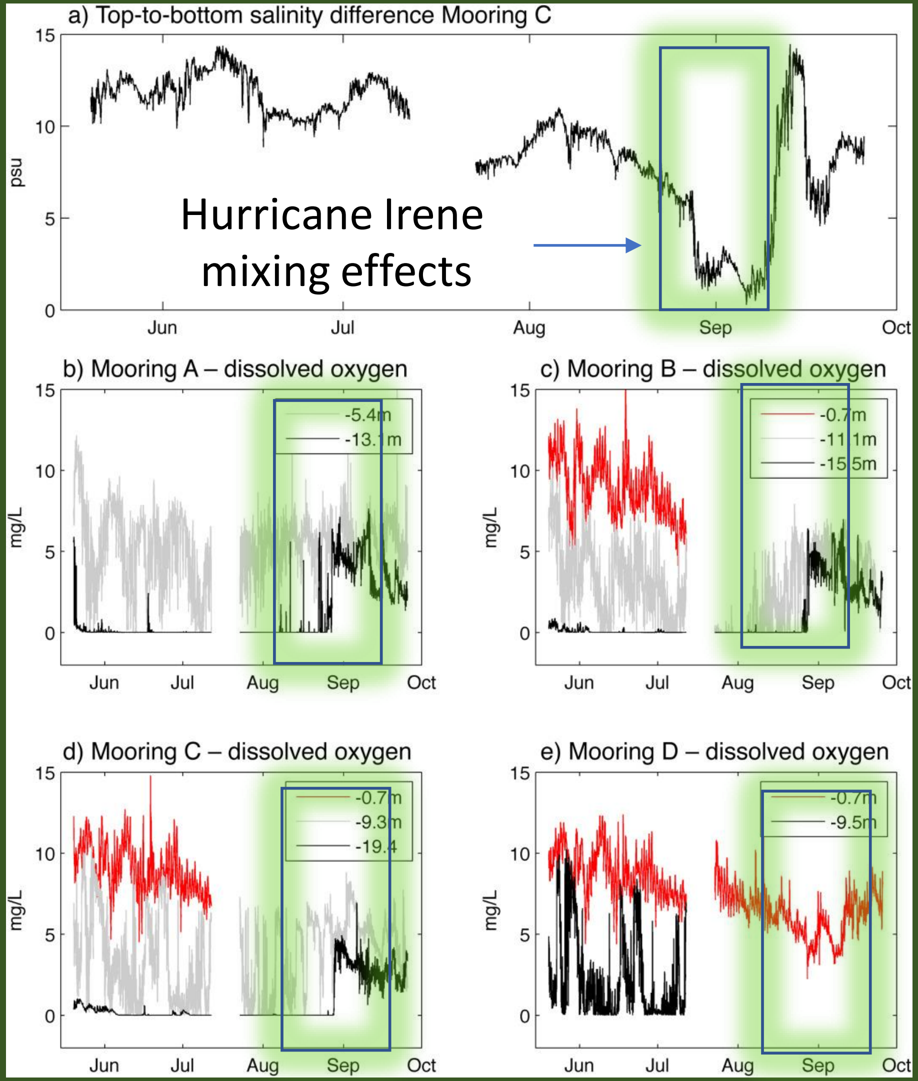
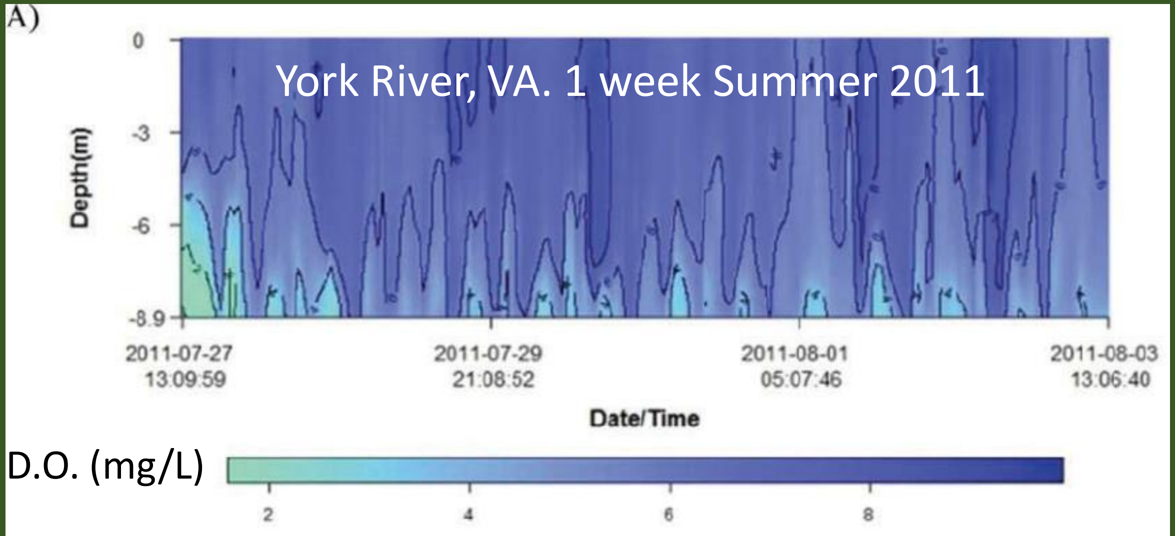
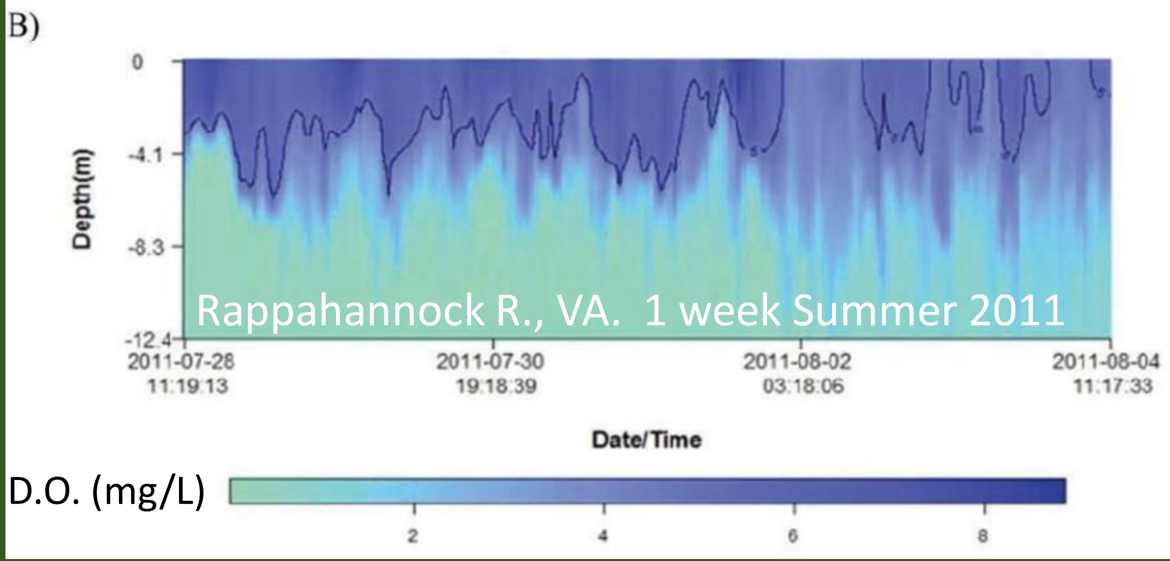


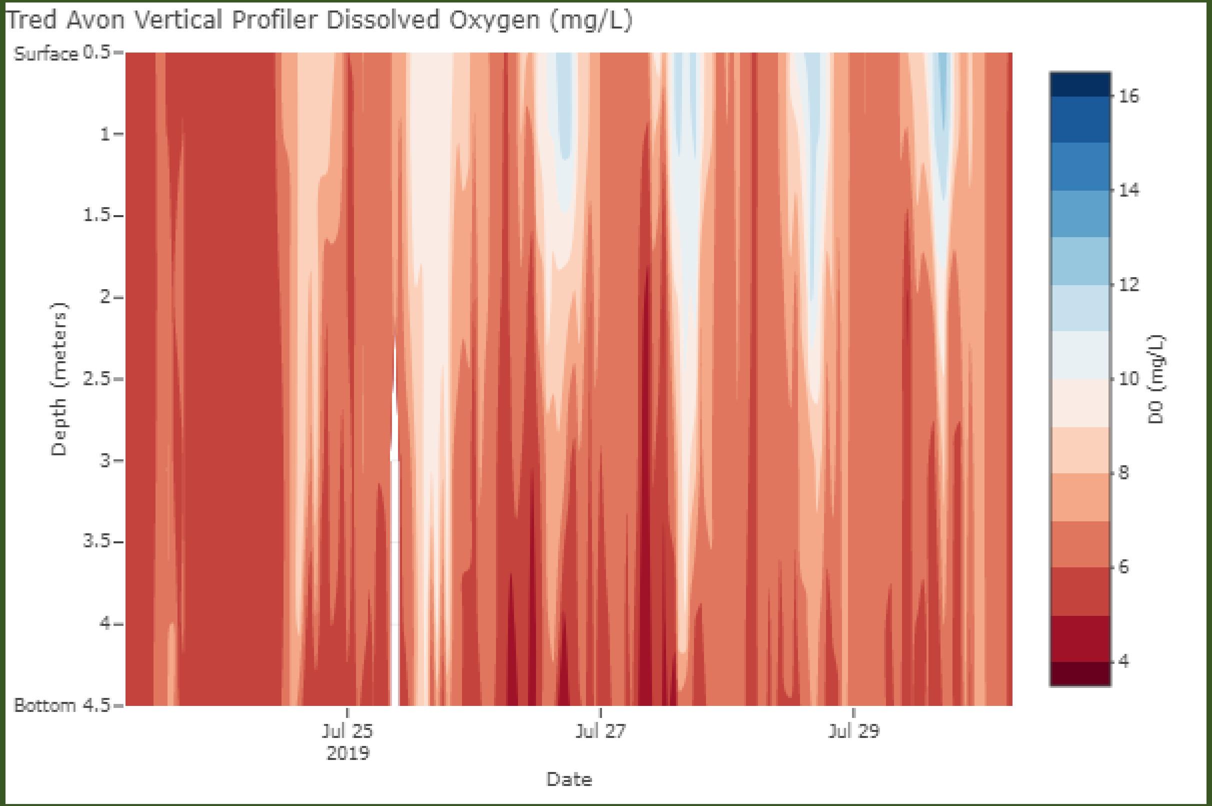


Dissolved oxygen: We have had some success with profilers in shallow river habitats





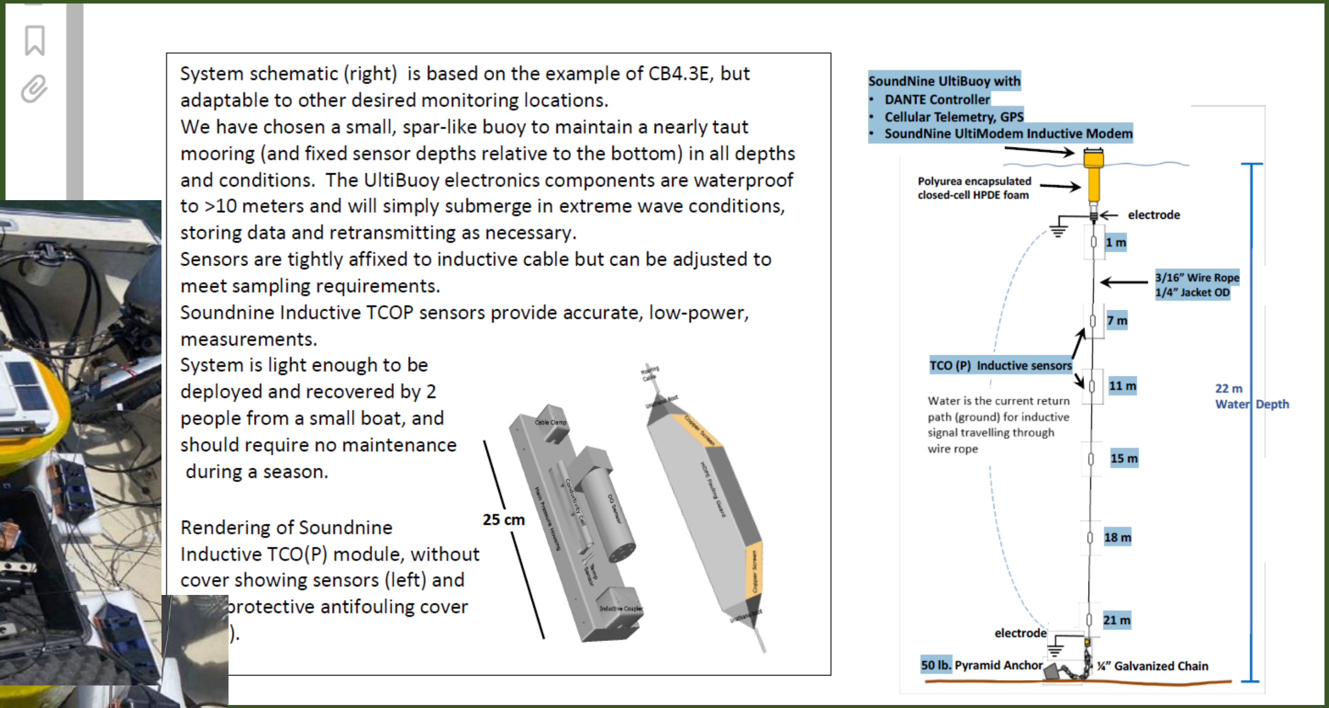
Water Quality Profiler data
(Tuckey and Fabrizio 2016)



MD DNR Water Quality Profiler - hourly
About 1 week, 4.5meter depth, Tred Avon River
July 26- July 30, 2019

M. Trice
MD DNR

2020 GIT Project Goal:
Proof of concept in testing a portable, easily deployable, modest price sensor array for open bay, realtime water quality data collection.



System schematic (right) is based on the example of CB4.3E, but adaptable to other desired monitoring locations.

We have chosen a small, spar-like buoy to maintain a nearly taut mooring (and fixed sensor depths relative to the bottom) in all depths and conditions. The UltiBuoy electronics components are waterproof to >10 meters and will simply submerge in extreme wave conditions, storing data and retransmitting as necessary.

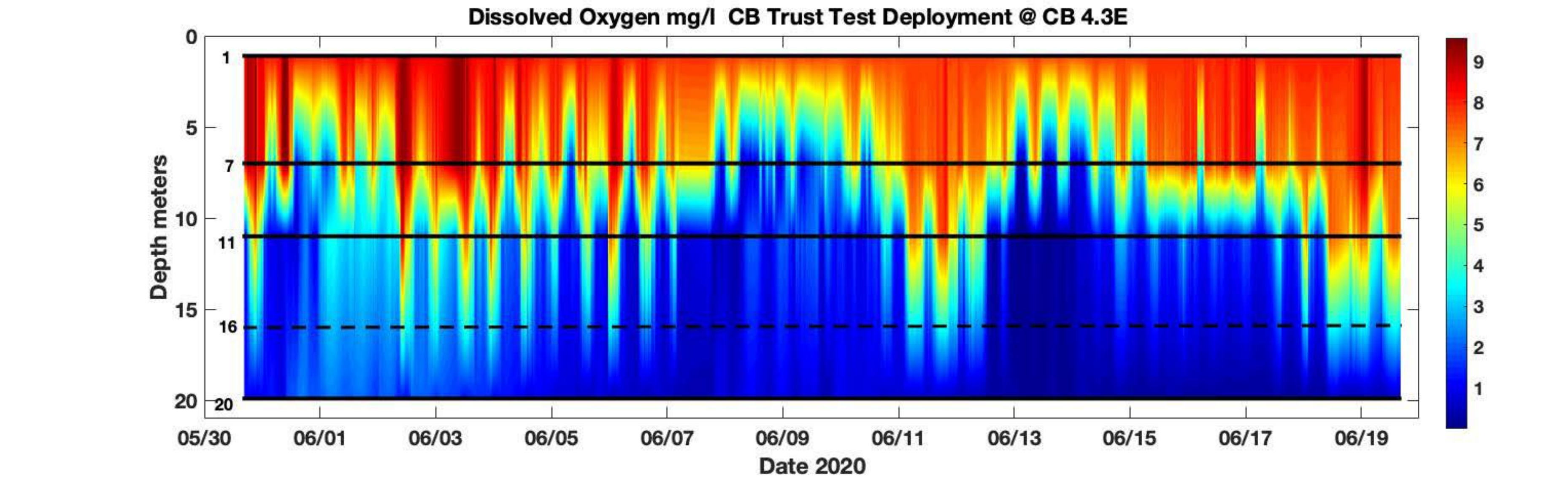
Sensors are tightly affixed to inductive cable but can be adjusted to meet sampling requirements.

Soundnine Inductive TCOP sensors provide accurate, low-power, measurements.

System is light enough to be deployed and recovered by 2 people from a small boat, and should require no maintenance during a season.

Rendering of Soundnine Inductive TCO(P) module, without cover showing sensors (left) and protective antifouling cover).

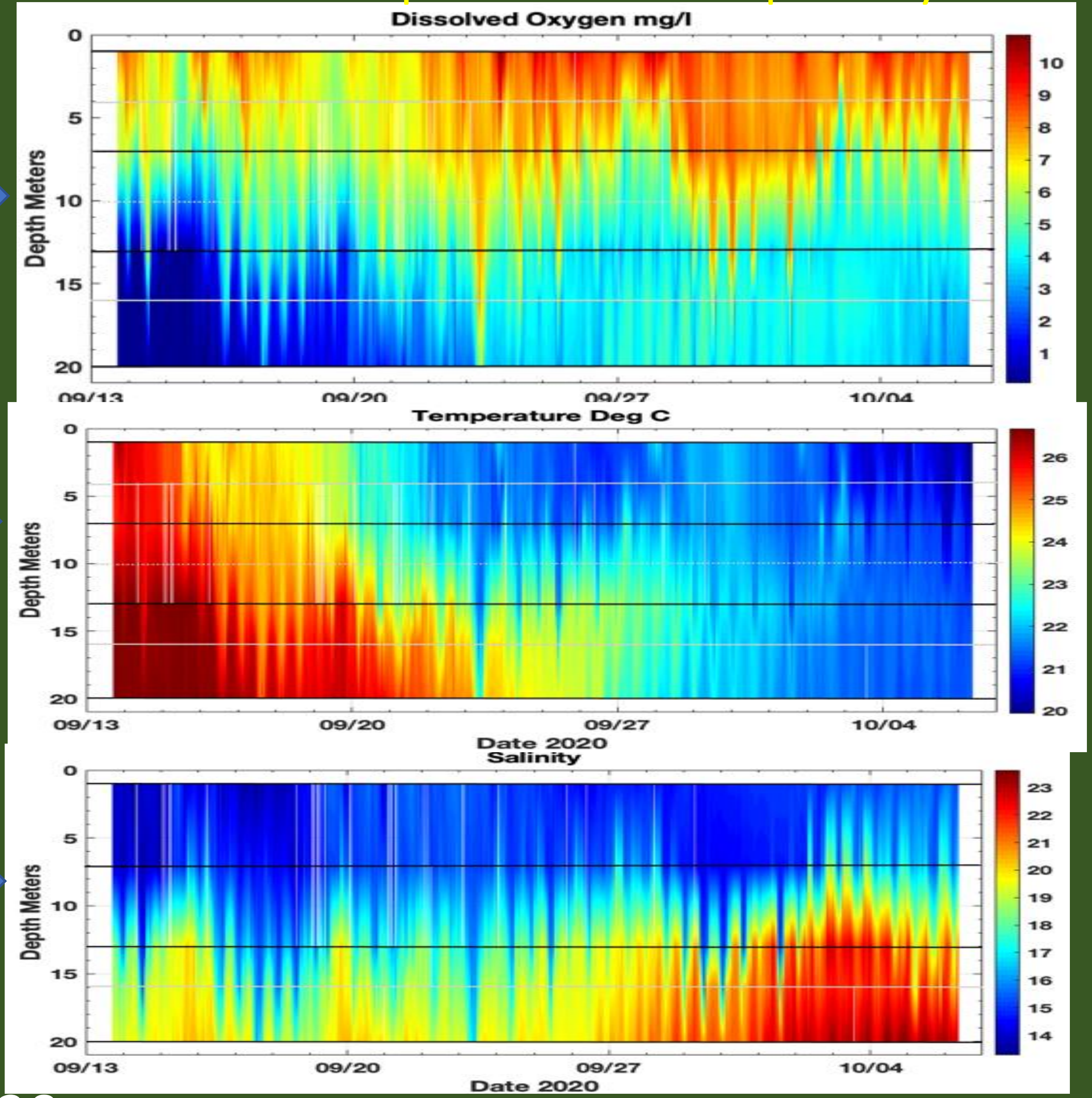
2020. GIT-funded Pilot study on high frequency hypoxia monitoring. Vertical array of open water dissolved oxygen dynamics with vertical profiler data collection at 10-minute intervals.



Summer biweekly monitoring:
*Traditional monitoring program, summer, 1 D.O. profile per 14 days
*Vertical profiler @ 10 minute intervals = 2,016 views of water column D.O. per 14 days

Dissolved oxygen: We have had success with profilers in the open bay habitats

- Dissolved oxygen – water at this station becomes oxygenated
- Temperature stratification is lost and becomes isothermal
- Salinity stratification declines before oxygen rich high salinity water moves into the bottom waters



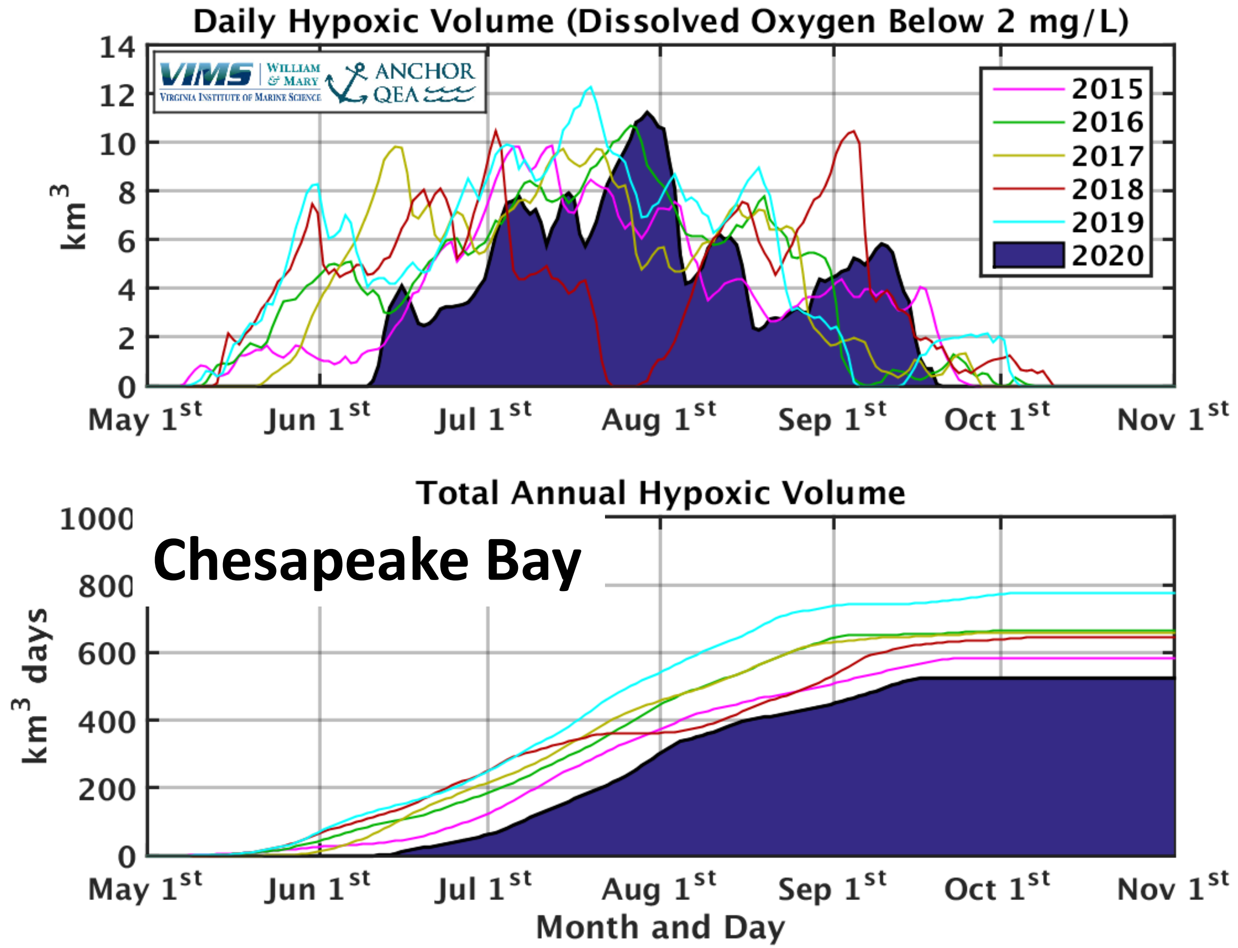
~ $50K Instrument with high data return on investment

4-5K per sensor

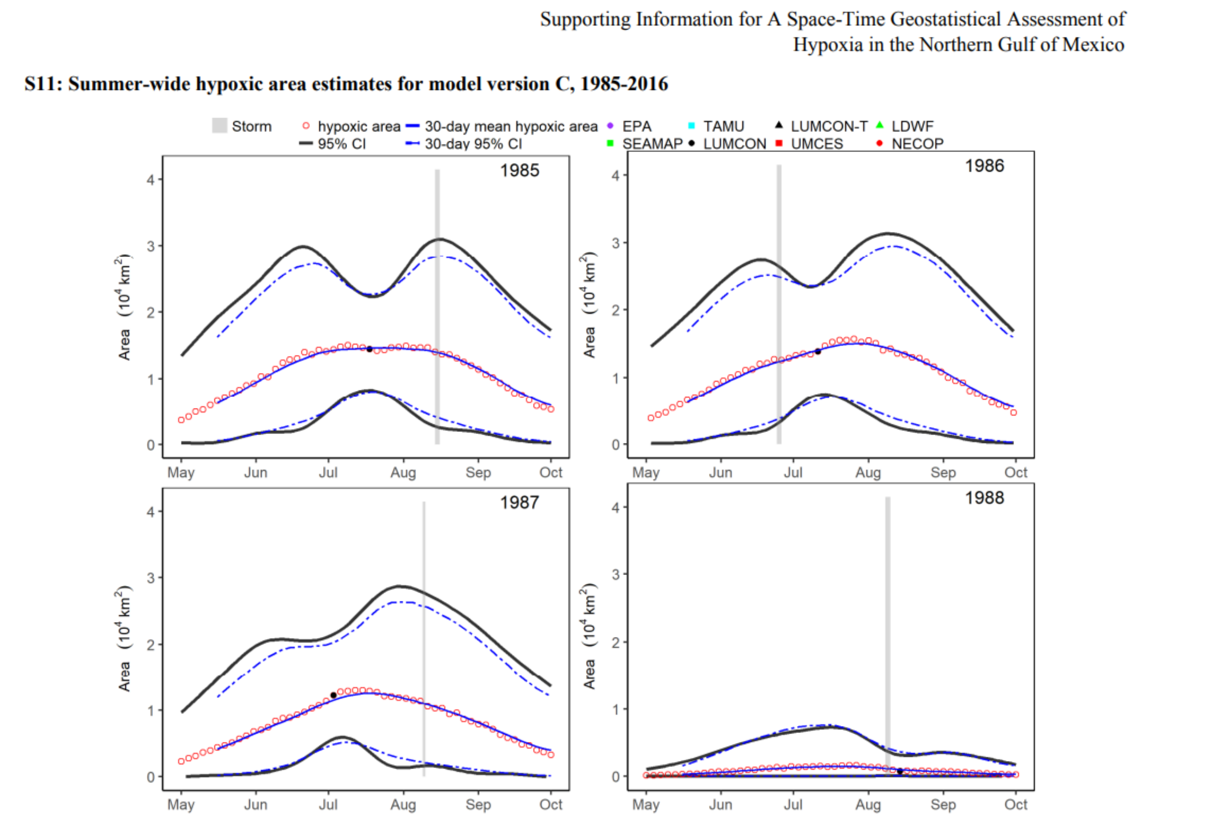
September 2020

D. Wilson 2020. CBT GIT-funded pilot project data

Pushing into real world 4-D Hypoxia tracking – Continuous water quality accounting for 3-D space plus time.

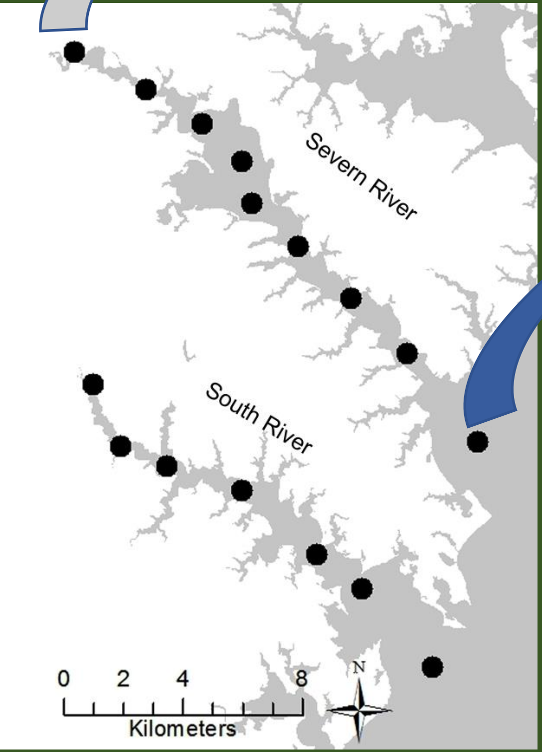


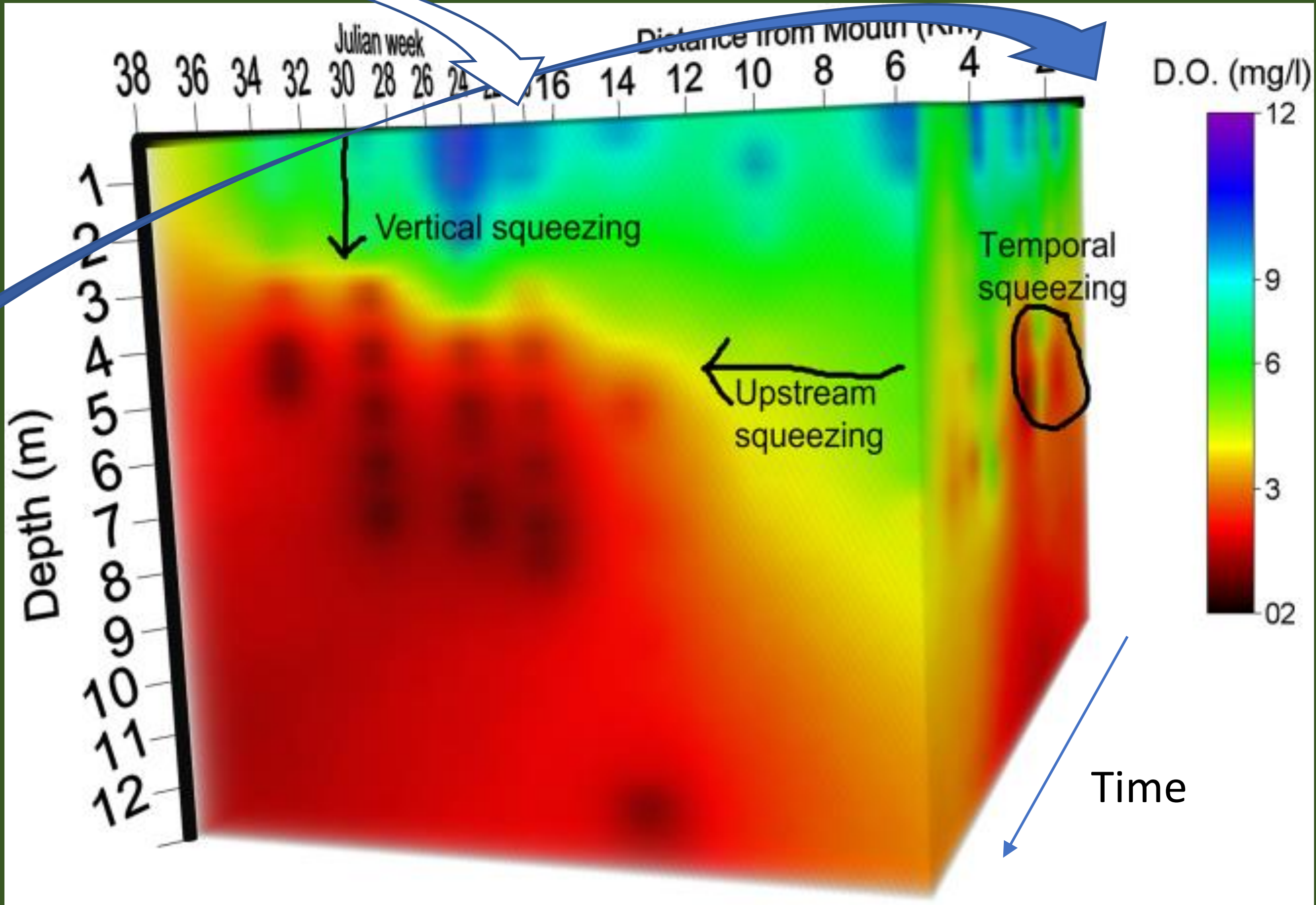
Gulf of Mexico
Matli et al. 2018



VIMS: Realtime Hypoxia Tracking
https://www.vims.edu/research/topics/dead_zones/forecasts/cbay/hypoxic-volume/index.php

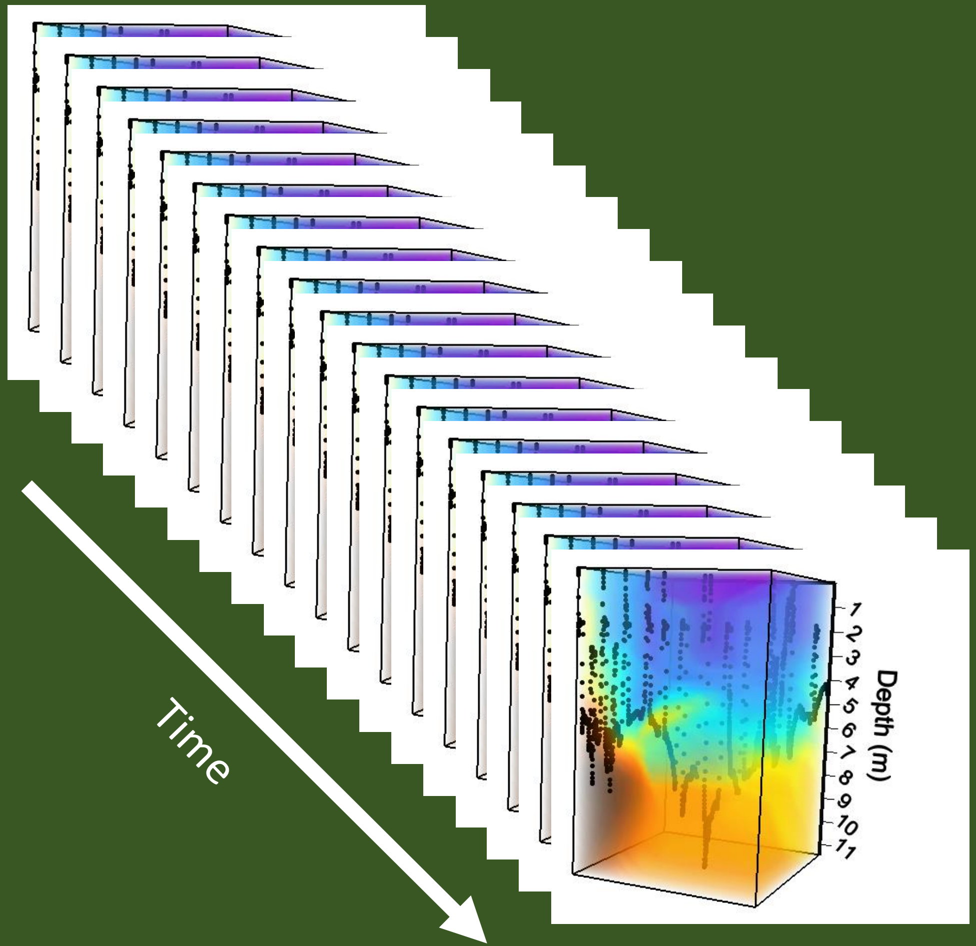
We want to integrate high frequency deep water data profiles with nearshore continuous monitoring for 4-dimensional habitat assessment





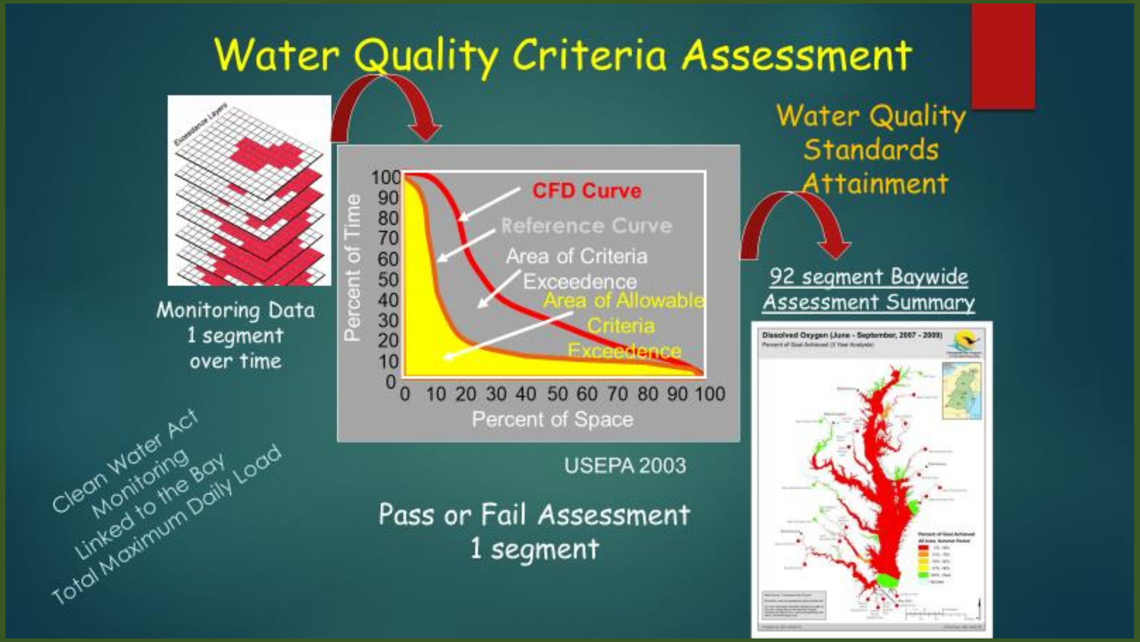
Severn River time series. Muller and Muller, Heliyon, 2016.

We need more than total hypoxia. We need reliable point estimates in 3D-space, through time, at high frequency.

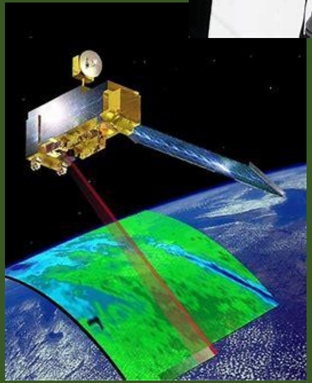


Shape of habitat volume

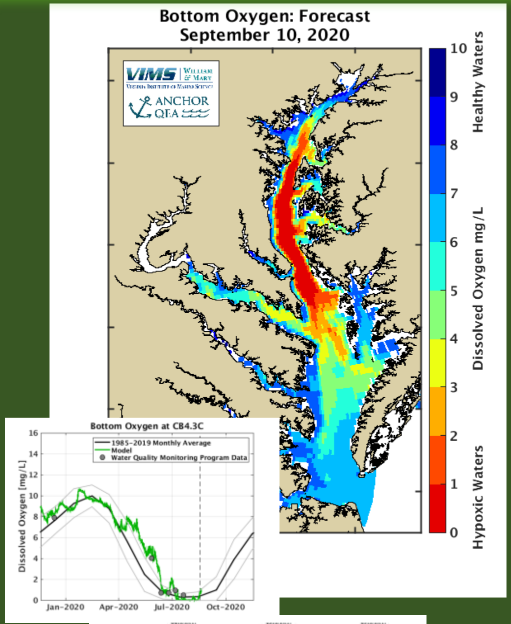
- Improved estimate of hypoxic volume
- Improved understanding of location of hypoxia in space, through time that living resources are navigating

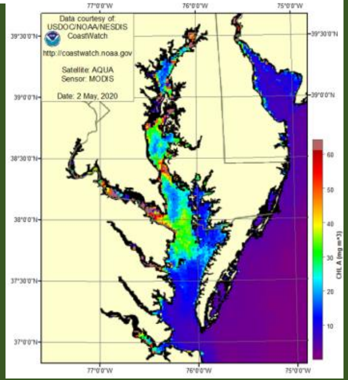


We need 2 things:
1. Integrated monitoring to address time and space resolution
2. 4-D interpolator for continuity in habitat characterization



Update integrated monitoring approach





Update analytical and assessment approaches

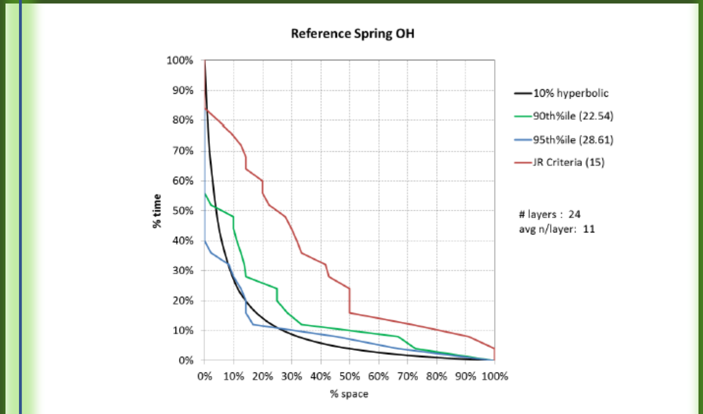


Figure 4b. Spring oligohaline CFD curves for chlorophyll *a* from reference water quality conditions.

Designated Use	Dissolved oxygen Criteria Concentration/Duration		Temporal Application
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		≥ 5 mg/L Salinity: >0.5ppt	
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Deep channel seasonal refuge use	Instantaneous min > 1 mg/L		June 1 – September 30
	Open water F & S applies		October 1 – May 31

Dissolved Oxygen Criteria

Measured

Unmeasured

Improved capacity

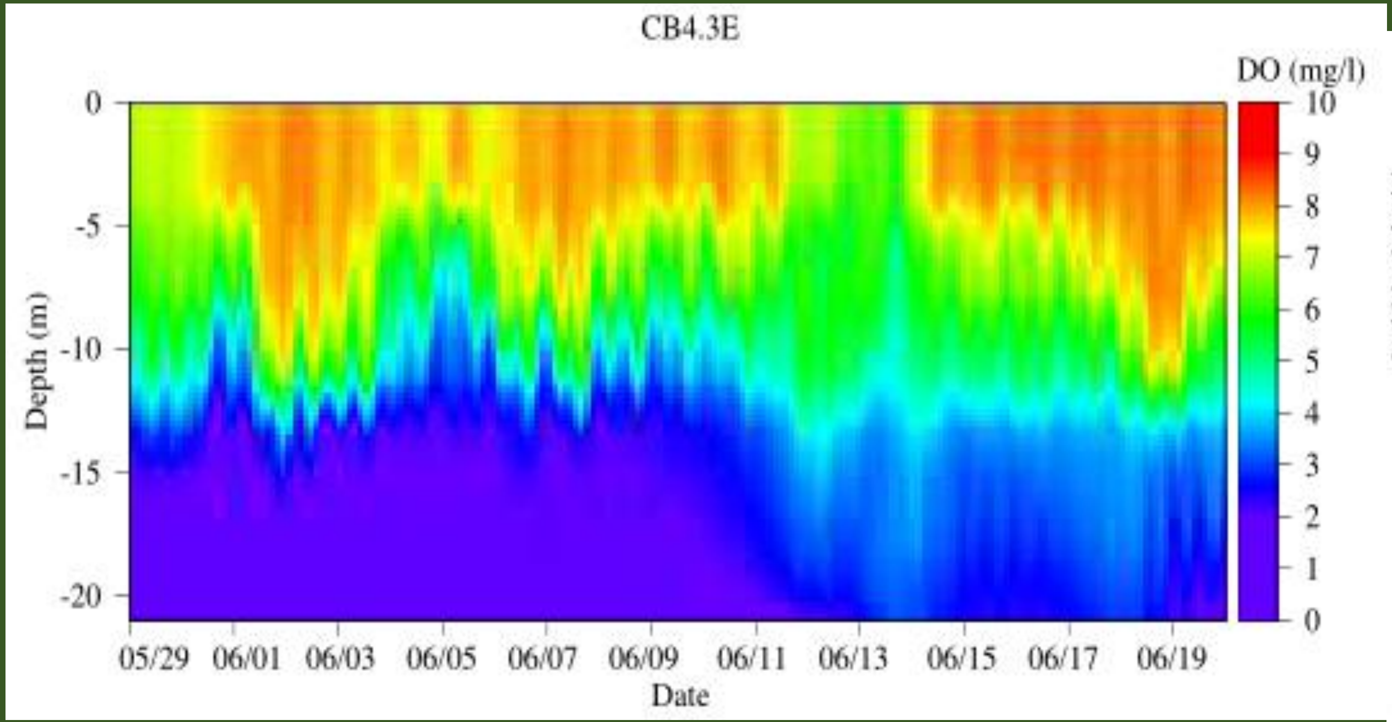
Fill Habitat Assessment Gaps

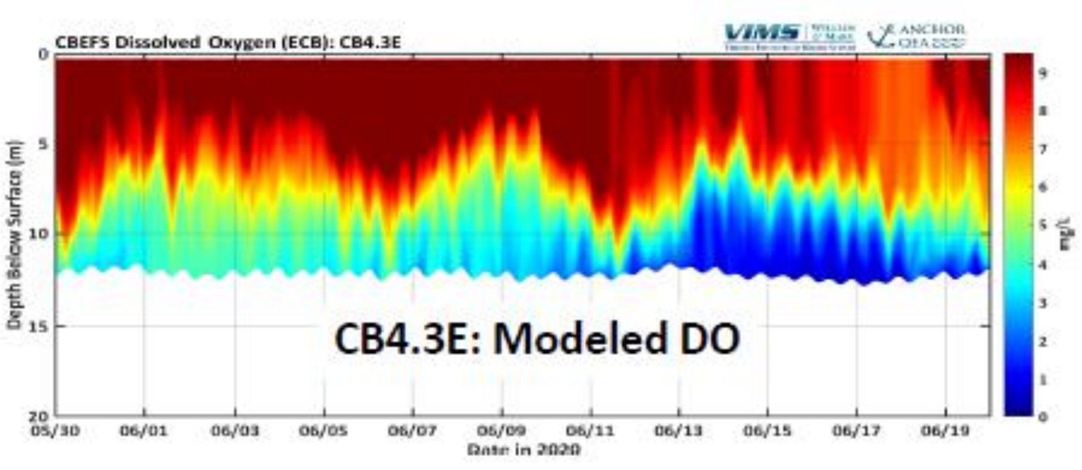
Targeting Dissolved Oxygen Assessment needs, questions for the group:

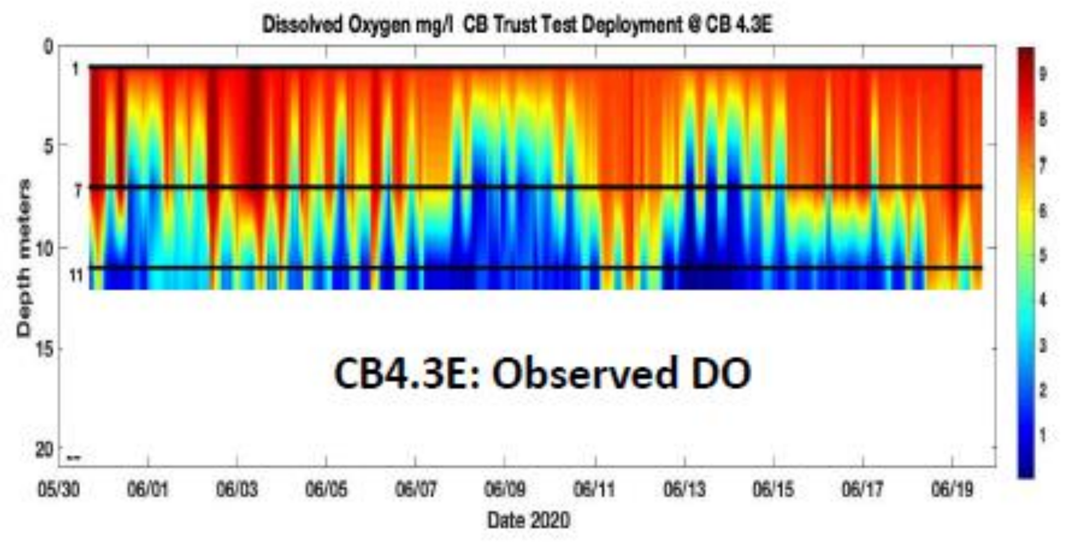
- Build out network of vertical measures: minimum 2 suggested, more? (DO, Temp and Salinity are necessary sensors here)
-
- Does "more" mean addressing lateral conditions of the mainstem? Can we get what we need with a network of bottom sensors if we have 2+ vertical realtime monitors in the mainstem?
- Vertical sensor array – minimum number, distribution? Do we mimic long term monitoring depth profile distributions (place a lot of sensors in the water) needed for defining AP, P, BP habitats?

First look model comparisions…

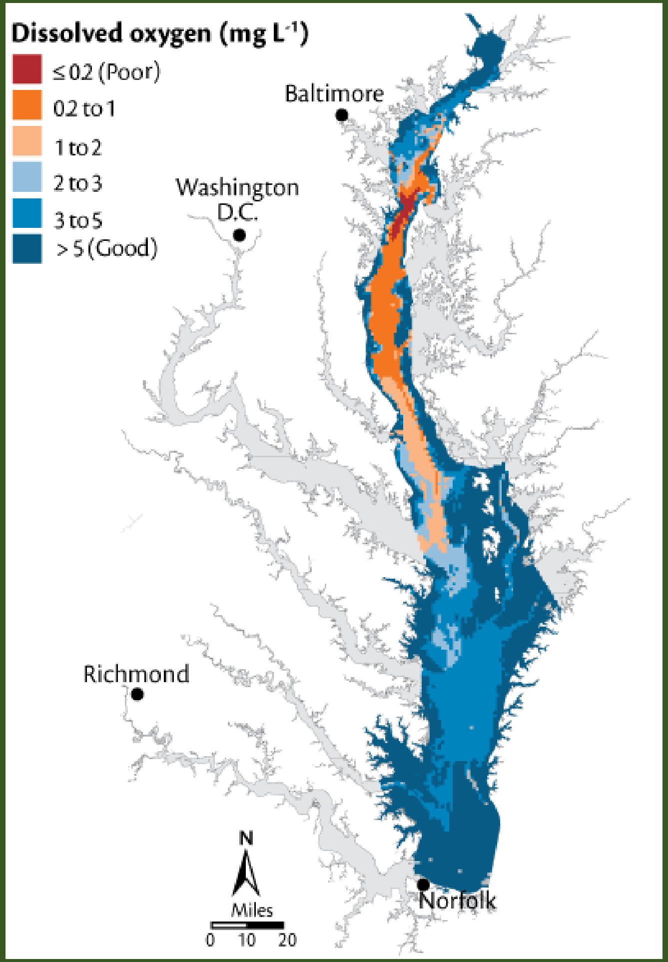
CB3D-ICM 1994

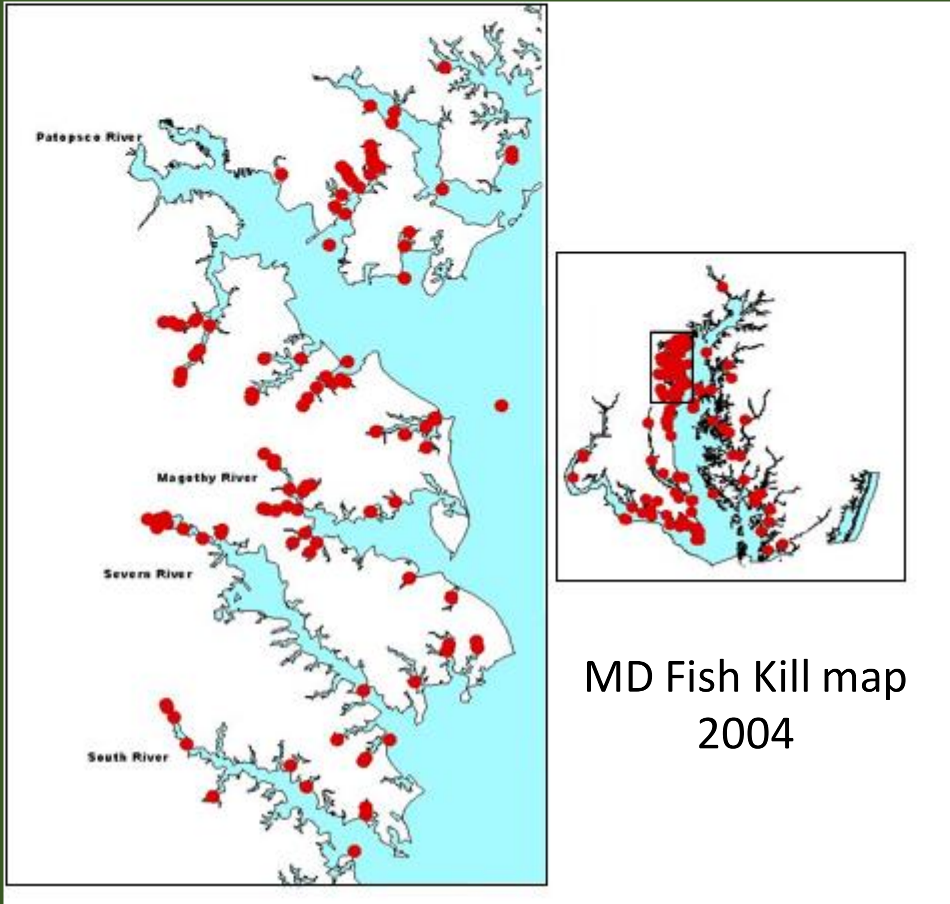






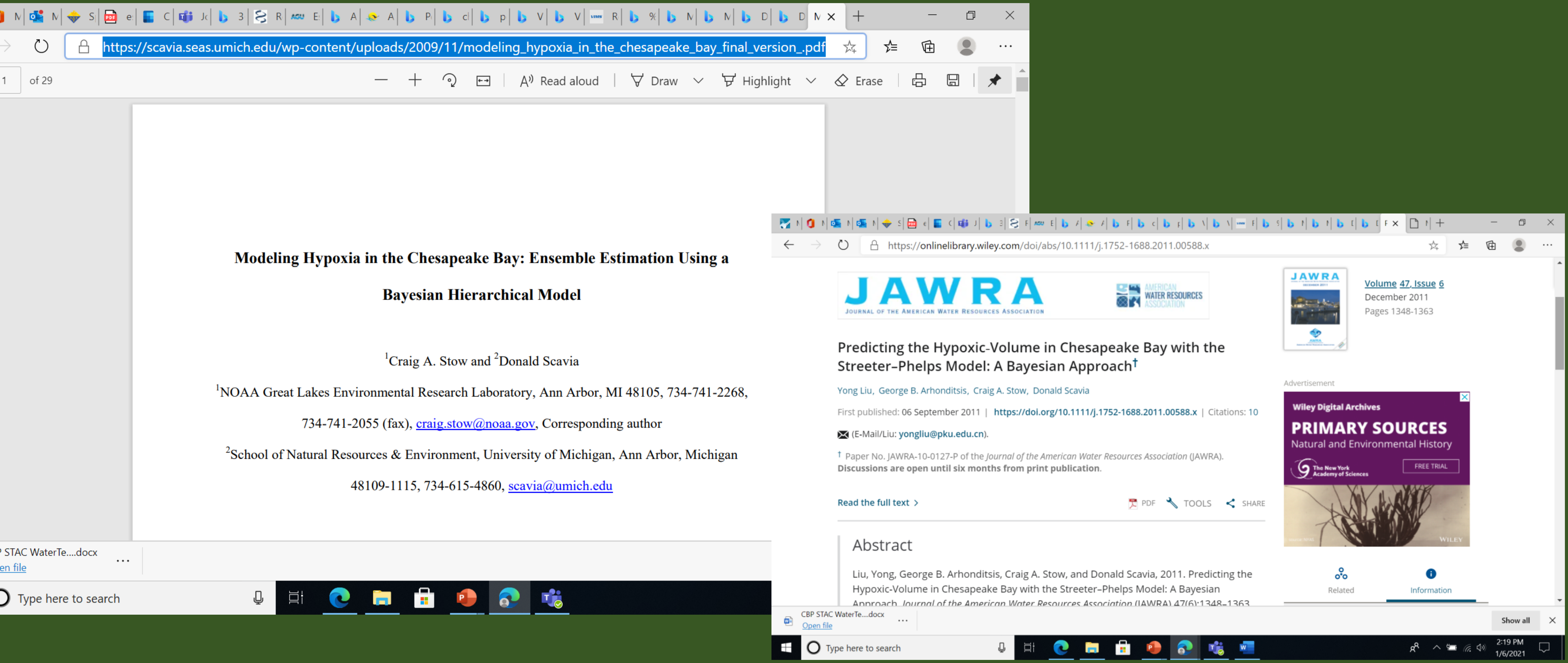
Shallow water is important too: Over 24% of Chesapeake Bay is <2m deep





Deep water hypoxia is important…

…but fish kills tend to be shallow water phenomenon


https://scavia.seas.umich.edu/wp-content/uploads/2009/11/modeling_hypoxia_in_the_chesapeake_bay_final_version_.pdf

Modeling Hypoxia in the Chesapeake Bay: Ensemble Estimation Using a Bayesian Hierarchical Model

[1]Craig A. Stow and [2]Donald Scavia

[1]NOAA Great Lakes Environmental Research Laboratory, Ann Arbor, MI 48105, 734-741-2268, 734-741-2055 (fax), craig.stow@noaa.gov, Corresponding author

[2]School of Natural Resources & Environment, University of Michigan, Ann Arbor, Michigan 48109-1115, 734-615-4860, scavia@umich.edu

https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1752-1688.2011.00588.x

JAWRA
JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION

Volume 47, Issue 6
December 2011
Pages 1348-1363

Predicting the Hypoxic-Volume in Chesapeake Bay with the Streeter–Phelps Model: A Bayesian Approach†

Yong Liu, George B. Arhonditsis, Craig A. Stow, Donald Scavia

First published: 06 September 2011 | https://doi.org/10.1111/j.1752-1688.2011.00588.x | Citations: 10

(E-Mail/Liu: yongliu@pku.edu.cn).

† Paper No. JAWRA-10-0127-P of the *Journal of the American Water Resources Association* (JAWRA). **Discussions are open until six months from print publication.**

Read the full text

Abstract

Liu, Yong, George B. Arhonditsis, Craig A. Stow, and Donald Scavia, 2011. Predicting the Hypoxic-Volume in Chesapeake Bay with the Streeter–Phelps Model: A Bayesian Approach. *Journal of the American Water Resources Association* (JAWRA) 47(6):1348–1363

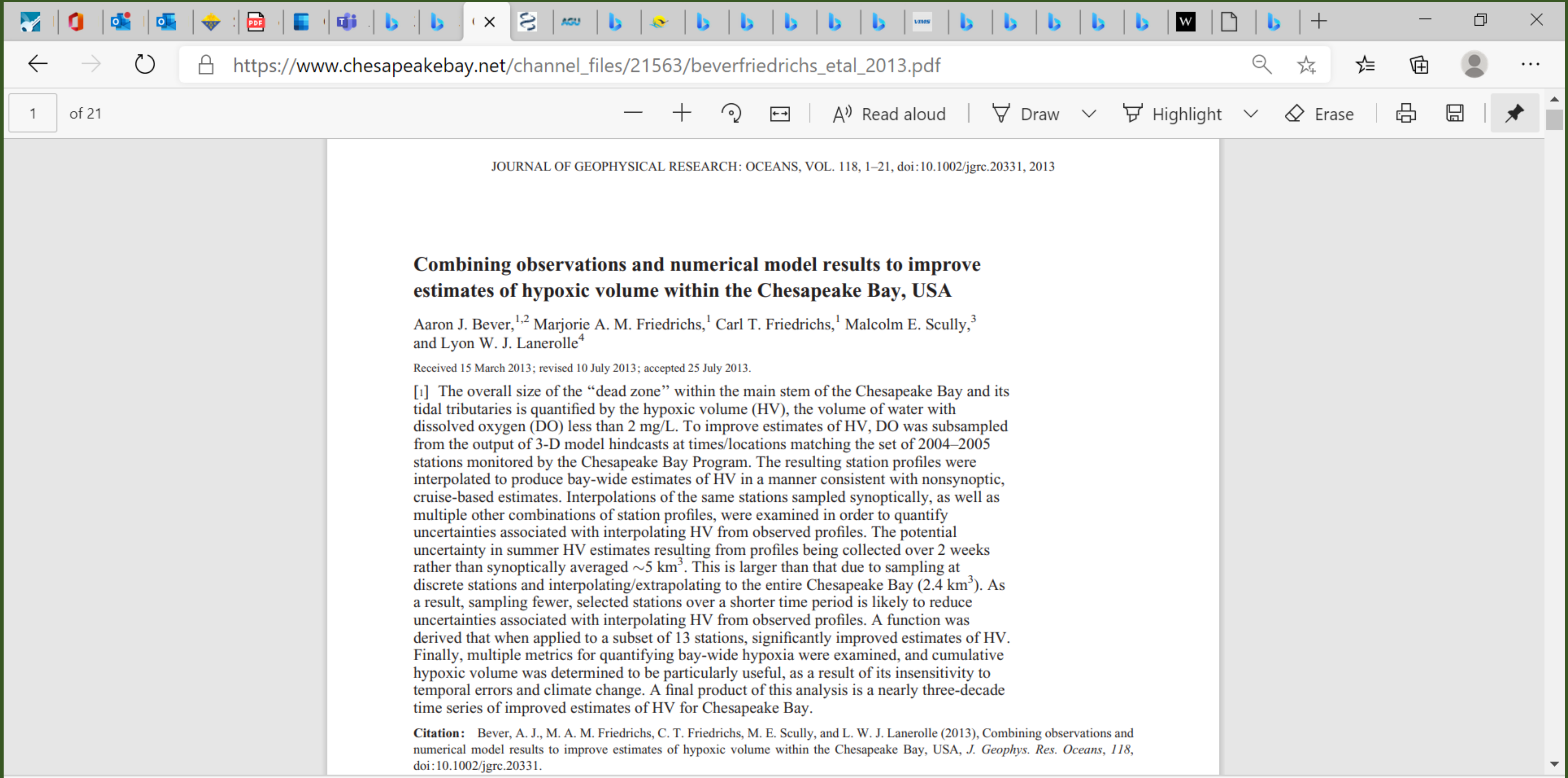
Table 3.1. A short list of recent articles comparing the precision of IDW to a subset of other possible interpolation methods.

Authors	Methods Compared	Variables Manipulated	Conclusions
Kravchenko (2003)	Inverse Distance Weighting (IDW), Ordinary Kriging (OK)	spatial structure and sample grid spacing	IDW better than OK unless sample sizes were fairly large
Dille, et al. (2002)	IDW, OK, Minimum Surface Curvature (MC), Multiquadric Radial Basis Function (MUL)	neighborhood size, spatial structure, power coefficient in IDW, sample grid spacing, quadrat size	No interpolator appears to be more precise than another. Sample grid spacing and quadrat size were deemed more important.
Valley, et al. (2005)	IDW, OK, Non-parametric Detrend + Splines	spatial structure, sample size, quadrat size	OK tended to be more precise but IDW was very similar
Lloyd (2005)	moving window Regression (MWR), IDW, OK, simple kriging with locally varying mean (SKlm), kriging with external drift (KED)	spatial structure, sample size	KED and OK best
Reinstorf, et al. (2005)	IDW, OK, KED + deterministic chemical transport models	single dataset was analyzed	OK best
Zimmerman, et al. (1999)	2 types of IDW, UK, OK	spatial structure, sampling pattern, population variance	UK and OK better than IDW

3.3 Non-parametric Interpolation Methods

http://www.chesapeake.org/pubs/cfd_stac_final.pdf

Technique directions: Combining observations and model results



JOURNAL OF GEOPHYSICAL RESEARCH: OCEANS, VOL. 118, 1–21, doi:10.1002/jgrc.20331, 2013

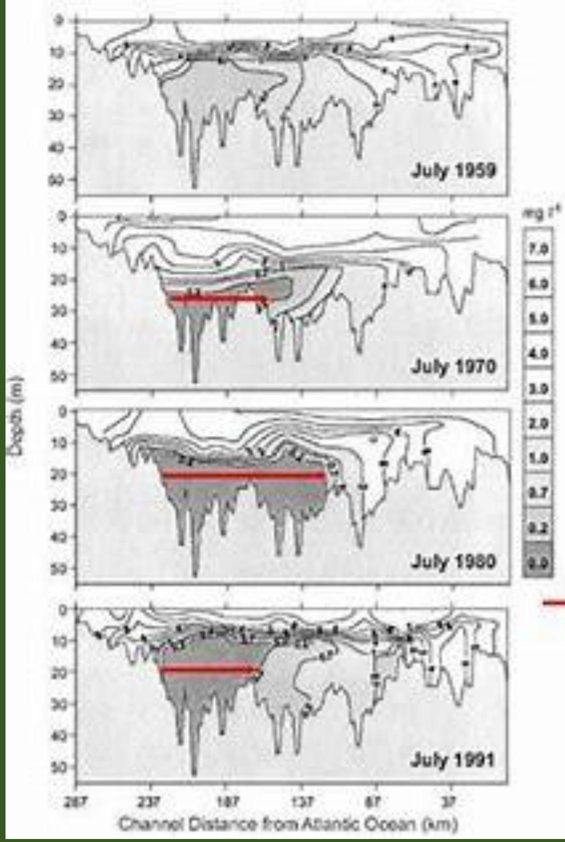
Combining observations and numerical model results to improve estimates of hypoxic volume within the Chesapeake Bay, USA

Aaron J. Bever,[1,2] Marjorie A. M. Friedrichs,[1] Carl T. Friedrichs,[1] Malcolm E. Scully,[3] and Lyon W. J. Lanerolle[4]

Received 15 March 2013; revised 10 July 2013; accepted 25 July 2013.

[1] The overall size of the "dead zone" within the main stem of the Chesapeake Bay and its tidal tributaries is quantified by the hypoxic volume (HV), the volume of water with dissolved oxygen (DO) less than 2 mg/L. To improve estimates of HV, DO was subsampled from the output of 3-D model hindcasts at times/locations matching the set of 2004–2005 stations monitored by the Chesapeake Bay Program. The resulting station profiles were interpolated to produce bay-wide estimates of HV in a manner consistent with nonsynoptic, cruise-based estimates. Interpolations of the same stations sampled synoptically, as well as multiple other combinations of station profiles, were examined in order to quantify uncertainties associated with interpolating HV from observed profiles. The potential uncertainty in summer HV estimates resulting from profiles being collected over 2 weeks rather than synoptically averaged ~5 km^3. This is larger than that due to sampling at discrete stations and interpolating/extrapolating to the entire Chesapeake Bay (2.4 km^3). As a result, sampling fewer, selected stations over a shorter time period is likely to reduce uncertainties associated with interpolating HV from observed profiles. A function was derived that when applied to a subset of 13 stations, significantly improved estimates of HV. Finally, multiple metrics for quantifying bay-wide hypoxia were examined, and cumulative hypoxic volume was determined to be particularly useful, as a result of its insensitivity to temporal errors and climate change. A final product of this analysis is a nearly three-decade time series of improved estimates of HV for Chesapeake Bay.

Citation: Bever, A. J., M. A. M. Friedrichs, C. T. Friedrichs, M. E. Scully, and L. W. J. Lanerolle (2013), Combining observations and numerical model results to improve estimates of hypoxic volume within the Chesapeake Bay, USA, *J. Geophys. Res. Oceans*, *118*, doi:10.1002/jgrc.20331.



Extent of Anoxic Conditions

Summer dissolved oxygen profiles in Chesapeake Bay:

Four years with near average January–May Susquehanna River flow

Source: Hagy et al. 2004