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

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Motivation

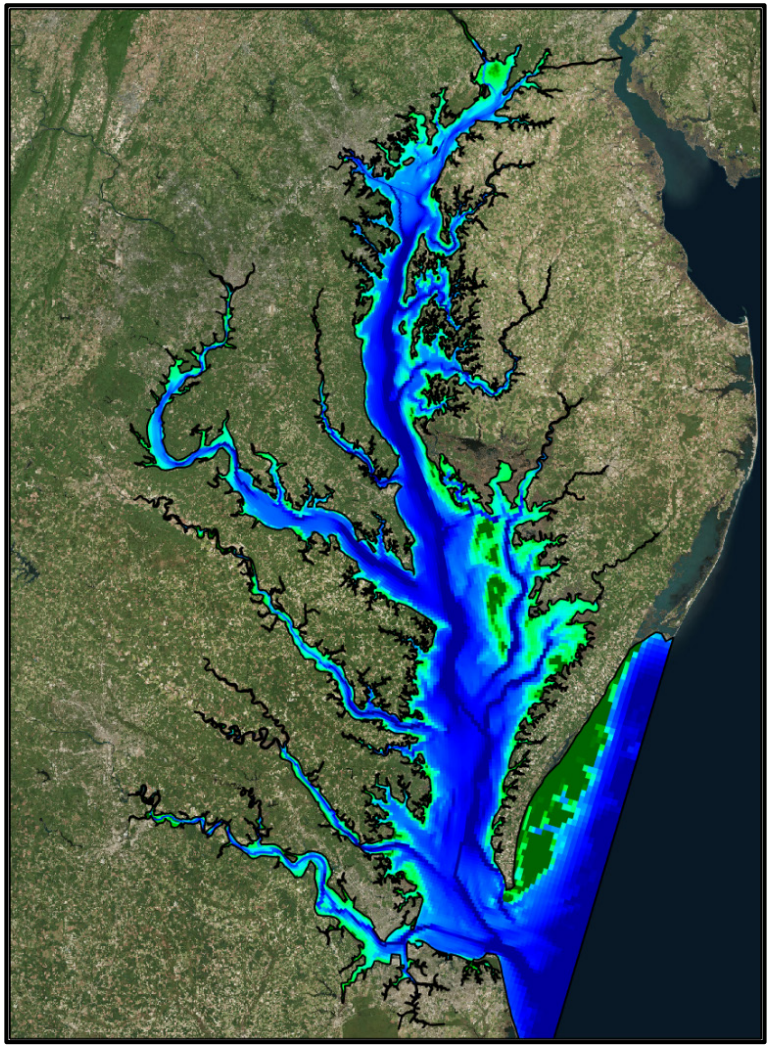
- Hypoxia has numerous detrimental effects on biota
- Measuring dissolved oxygen concentration is straightforward with modern instruments
  - Quantifying the amount of hypoxia is more difficult (hypoxic volume, HV)
- Management actions focus on reducing hypoxia

Objective

- Demonstrate that hypoxia is strongly constrained by the Bay geometry and daily hypoxic volume can be estimated using only two to three vertical profilers

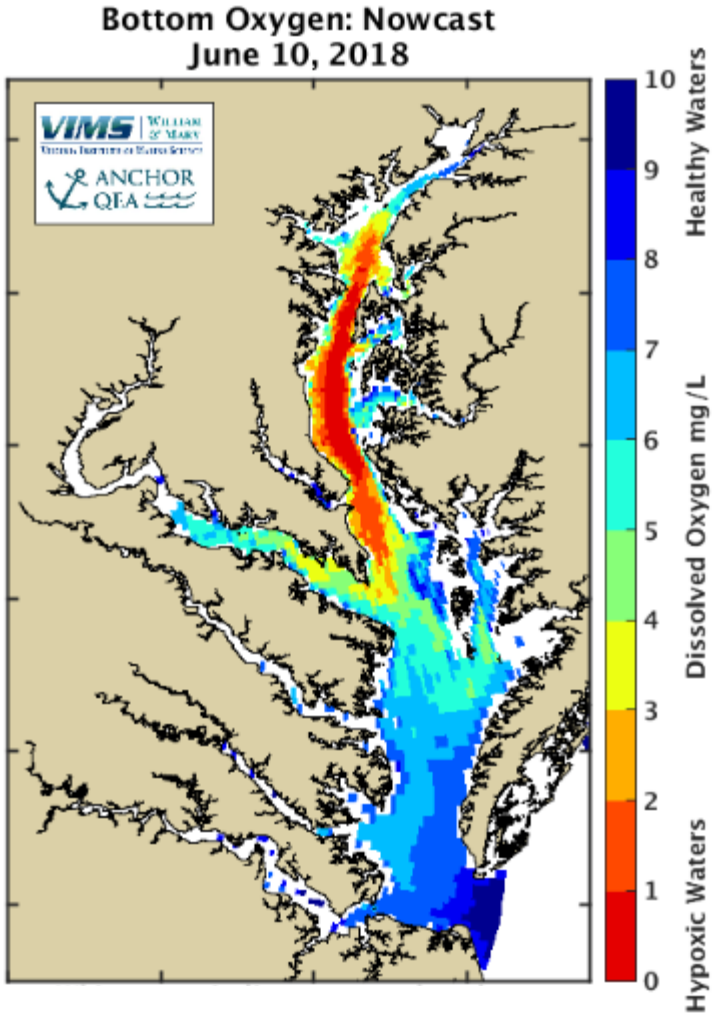
Outline

- Mainstem hypoxia
- Methods for a simple "geometric" hypoxic volume calculation
- Hypoxic volume estimates
- Interannual severity of hypoxia
- Conclusions



Mainstem Hypoxia

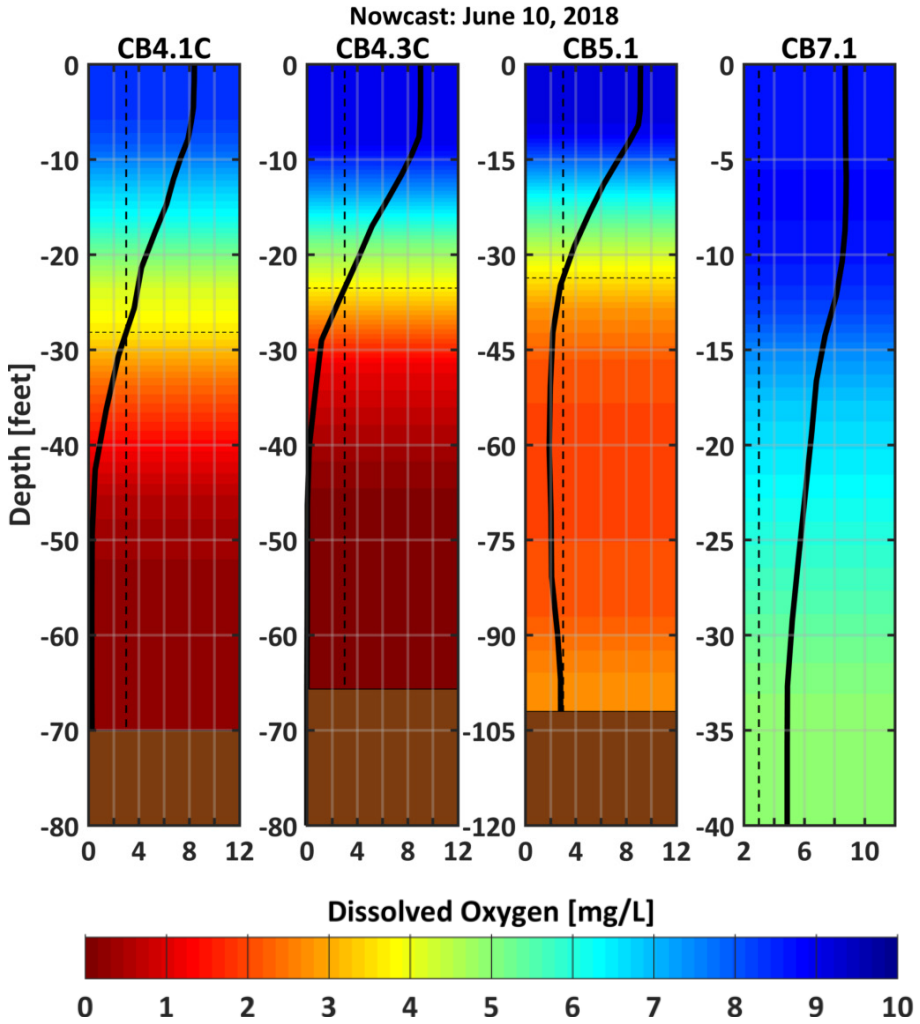
- Chesapeake Bay has a deeper region behind a sill
- Hypoxia occurs annually in the deeper portion of the mainstem
- Begins near the bed and fills the mainstem from the bottom up



Source: www.vims.edu/hypoxia
See Hagy et al. 2004; Officer et al. 1984

Mainstem Hypoxia

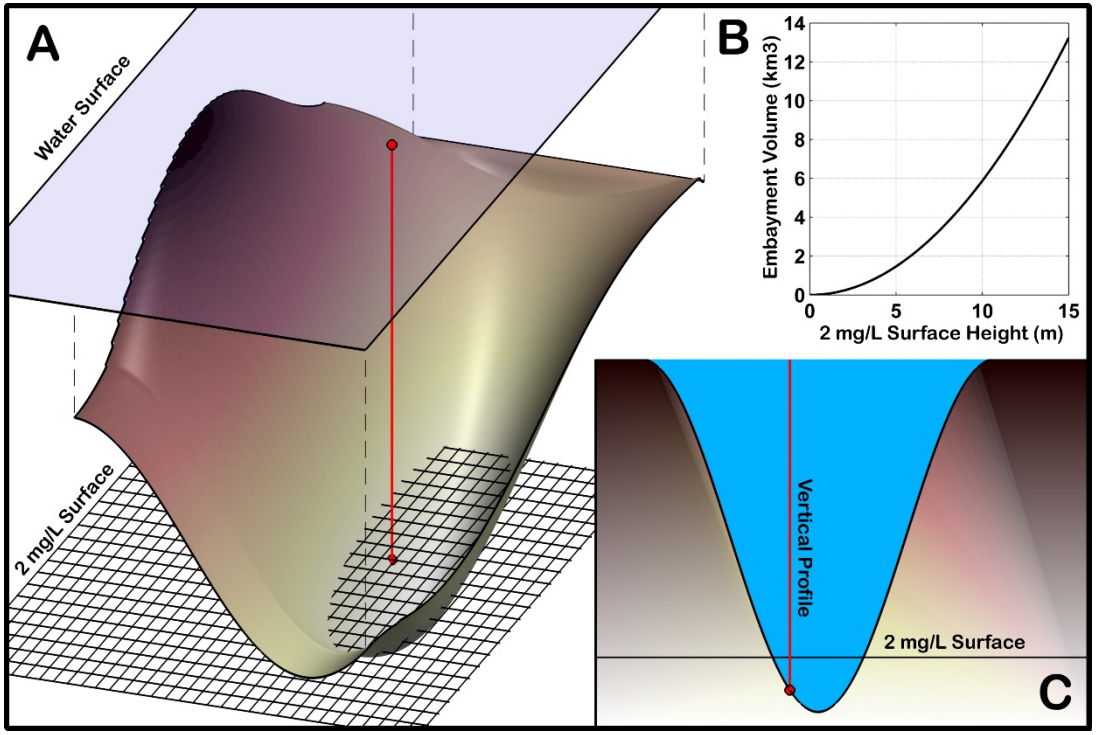
- Extent is estimated by interpolating vertical profiles
  - Cruise-based profiles span multiple days
  - Collected twice monthly
- Uncertainty from twice-monthly cruises can be as large as from interpolation
- Annual metrics possibly biased by cruise dates



Source: www.vims.edu/hypoxia
See Bever et al. 2013

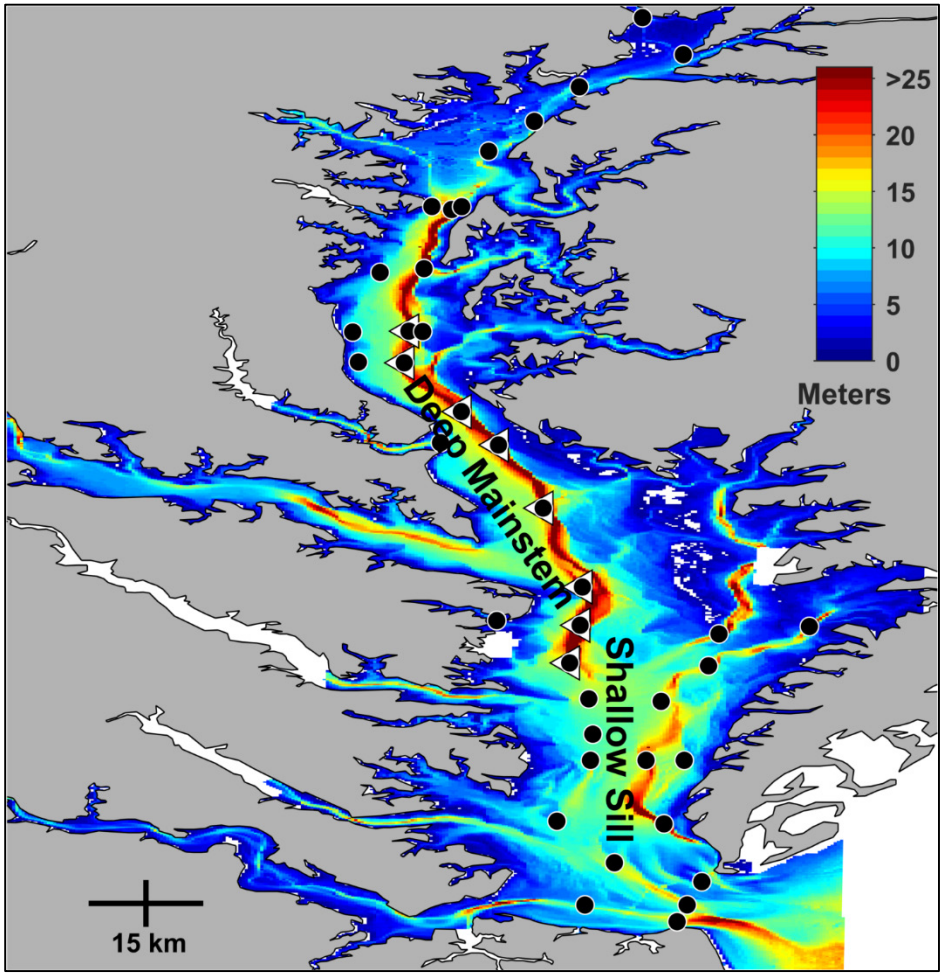
Geometric Hypoxic Volume

- Hypoxic water is constrained by the geometry
- Determine embayment volume above the deepest depth
- Height of 2 mg/L surface correlates to hypoxic volume



Geometric Hypoxic Volume

- Vertical profiles based on long-term regional monitoring stations
- Geometric HV calculated from individual profiles
- Individual HVs are averaged to estimate Bay-wide HV
- Trailing mean smooths short-duration variability



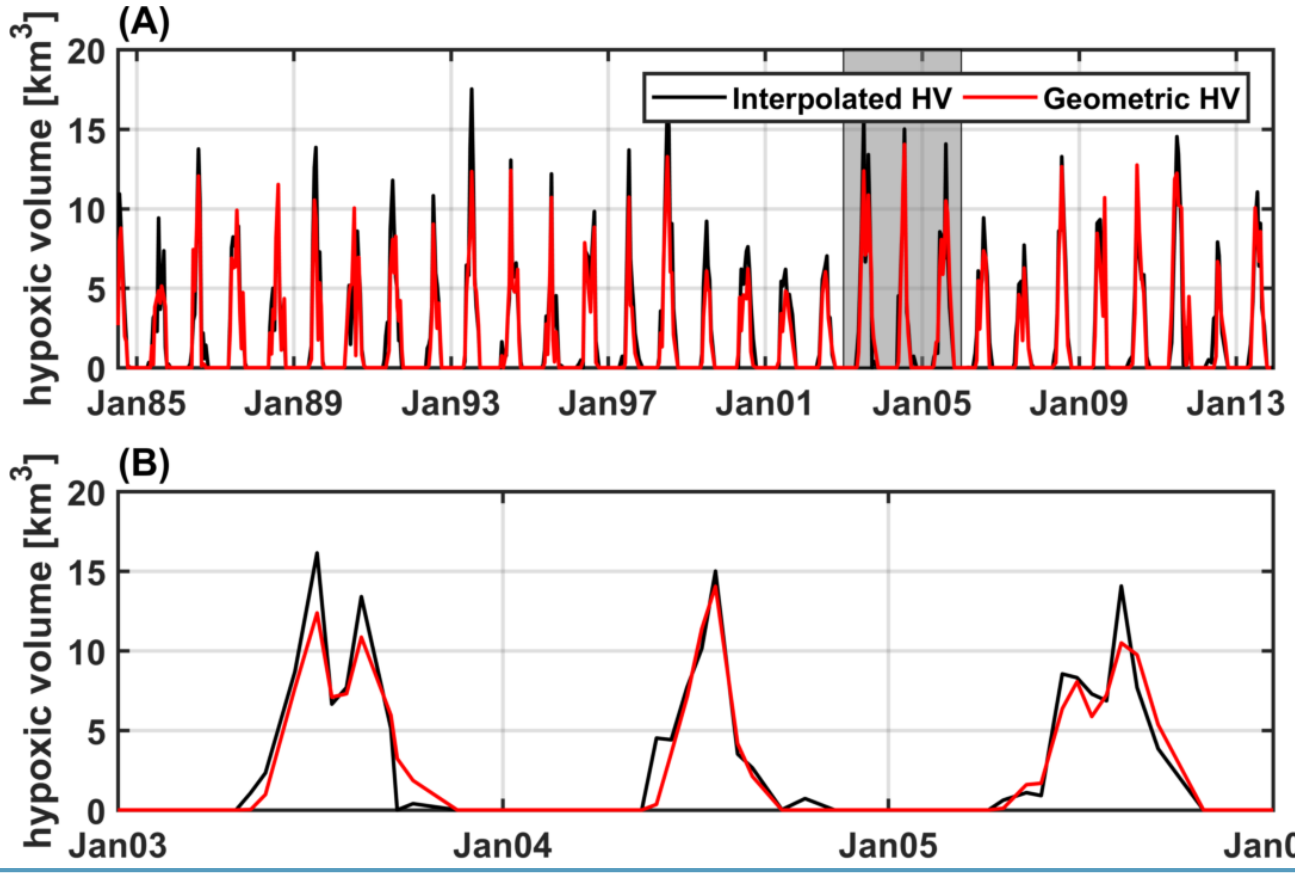
● Regional Monitoring Station

Hypoxic Volume Calculations

- Interpolated and Geometric HVs
  - Interpolated HV (IHV) calculated using 13 and two stations
  - Geometric HV (GHV) calculated using combinations of one to eight stations
- Long-term regional-monitoring cruise-based data
  - 1985–2013
  - Twice monthly, cruises span multiple days
- 3-D numerical model results
  - 1985–2005
  - Provides a "true" reference daily 3-D HV from 3-D grid cells
  - Vertical profiles are averaged over 24 hours and used to estimate a continuous daily HV

Geometric vs. Interpolated (Cruise-based Data)

- Geometric HV reproduces Interpolated HV to within uncertainty in Interpolated HV



Interpolated
13 Stations
(current method)

Geometric
2 Stations

Geometric vs. Interpolated (Cruise-based Data)

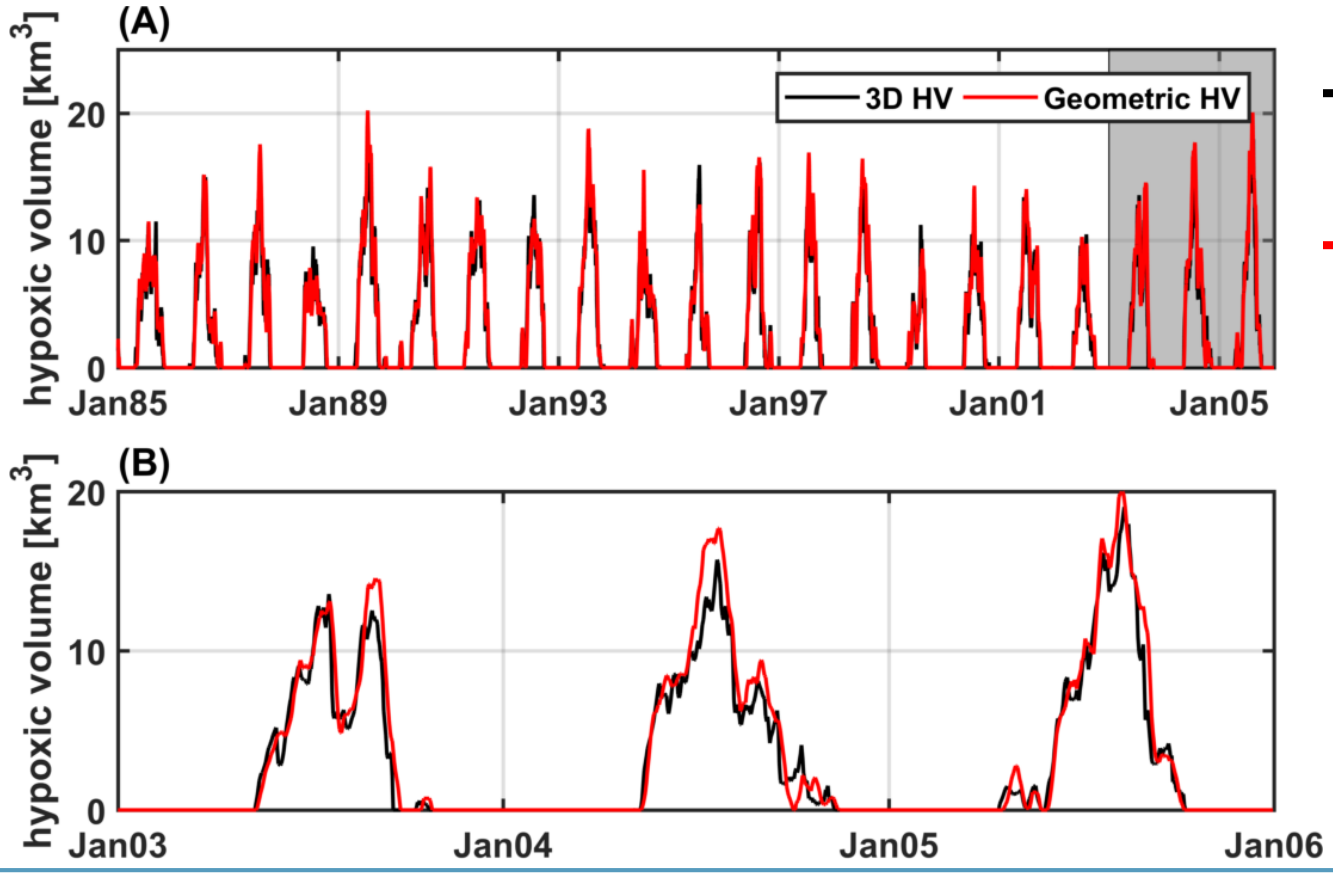
- Geometric HV reproduces Interpolated HV to within uncertainty in Interpolated HV

How Well Geometric HV Reproduces Interpolated (13 stations)

Number of Stations	Total RMSD [km^3]	r^2	Stations Used							
1	2.19	0.73	CB5.2							
2	1.68	0.85	CB5.1	CB5.4						
3	1.40	0.91	CB4.2C	CB5.2	CB5.4					
4	1.24	0.90	CB4.2C	CB5.1	CB5.2	CB5.4				
5	1.29	0.91	CB4.2C	CB5.1	CB5.2	CB5.3	CB5.4			
6	1.25	0.91	CB4.2C	CB4.3C	CB5.1	CB5.2	CB5.3	CB5.4		
7	1.30	0.92	CB4.2C	CB4.3C	CB5.1	CB5.2	CB5.3	CB5.4	CB5.5	
8	1.30	0.91	CB4.2C	CB4.3C	CB4.4	CB5.1	CB5.2	CB5.3	CB5.4	CB5.5

Geometric vs. True 3-D HV (Model-based)

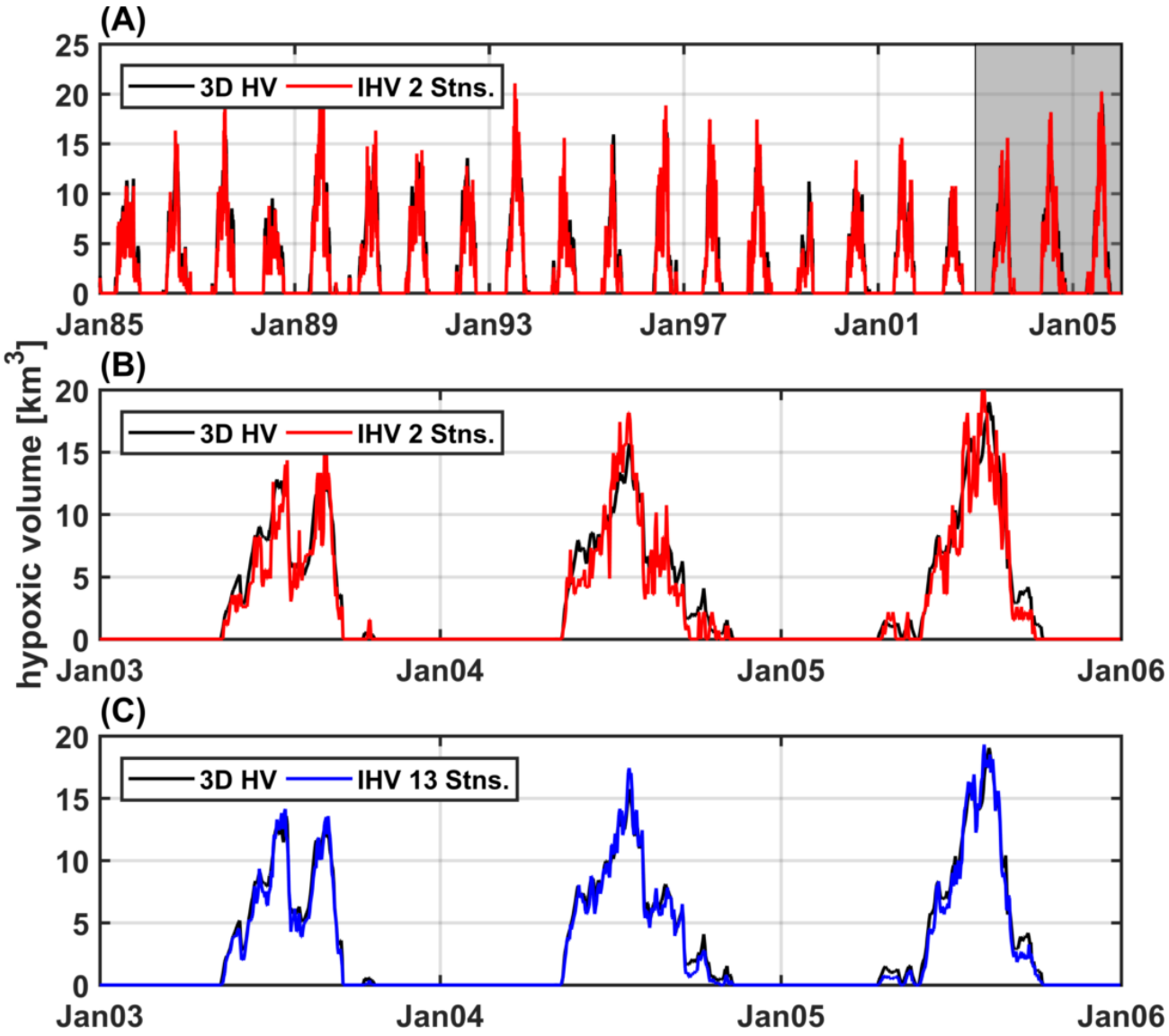
- Geometric HV reproduces daily true 3-D HV using only two stations



True 3-D HV

Geometric
2 Stations

Interpolated versus True 3-D HV (Model-based)



True 3-D HV

Interpolated 2 Stations

Interpolated 13 Stations

Model-based Hypoxic Volumes

How Well Geometric and Interpolated HVs Reproduce True 3-D HV

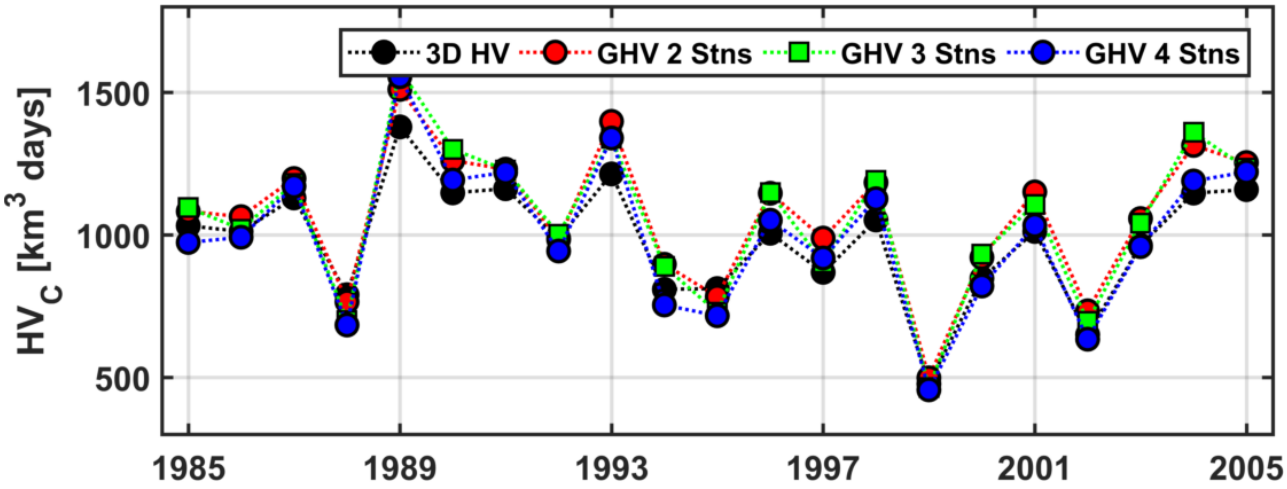
HV method	Number of Stations	Total RMSD [km^3]	r^2	Stations Used						
GHV	1	2.65	0.79	CB5.1						
GHV	2	1.57	0.89	CB5.2	CB4.2C					
GHV	3	1.65	0.88	CB5.1	CB5.2	CB4.1C				
GHV	4	1.65	0.88	CB5.1	CB5.2	CB5.1W	CB4.3C			
GHV	5	1.69	0.89	CB5.1	CB5.2	CB5.1W	CB4.3C	CB4.1C		
GHV	6	1.85	0.88	CB5.1	CB5.2	CB5.1W	CB4.4	CB4.3C	CB4.1C	
GHV	7	2.01	0.88	CB5.1	CB5.2	CB5.1W	CB4.4	CB4.3C	CB4.2C	CB4.1C
IHV	2	1.29	0.91	CB5.2	CB4.2C					
IHV	13	0.60	0.98	CB3.2	CB3.3C	CB4.1C	CB4.2C	CB4.3C	CB4.4	CB5.1
				CB5.2	CB5.4	CB6.2	CB6.4	CB7.1	LE2.3	

GHV: Geometric HV

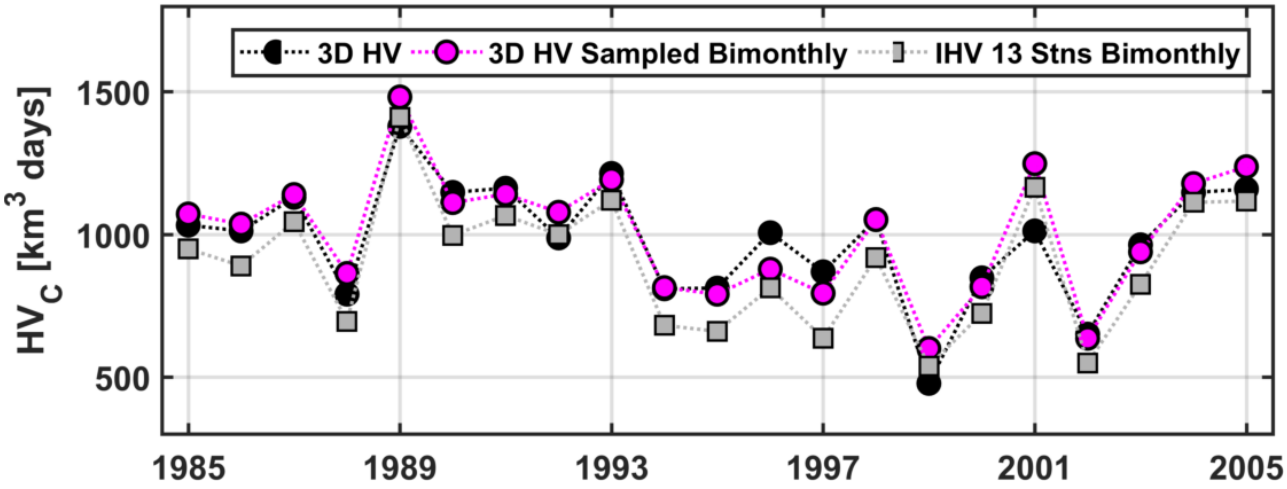
IHV: Interpolated HV

Annual Severity of Hypoxia

Cumulative Hypoxic Volume (HV_C)



Uncertainty from sparse sampling



Uncertainty from twice-monthly sampling

Annual Severity of Hypoxia: Uncertainty from Twice-monthly Sampling

- Continuous data at two locations is as accurate as knowing the dissolved oxygen everywhere twice monthly

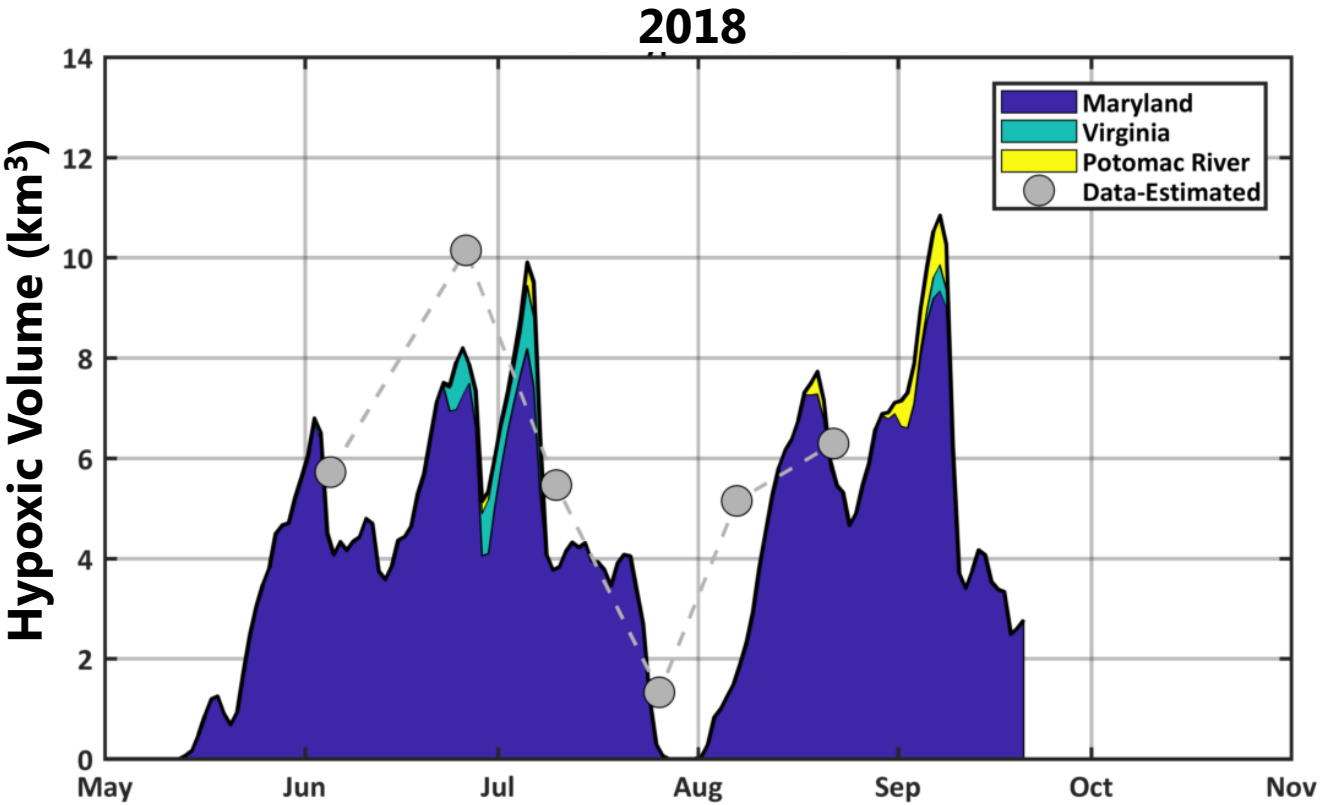
Difference from True 3-D Cumulative HV

HV Method	Number of stations	Temporal Frequency	RMS Difference [km^3 days]	RMS % Difference
GHV	2	Continuous	102	9.9%
GHV	3	Continuous	104	9.8%
GHV	4	Continuous	69	6.7%
3-D	Data everywhere	Bimonthly CBP dates	79	9.2%
IHV	13	Bimonthly CBP dates	120	13.2%

Sparse sampling uncertainty, Temporal uncertainty, Both

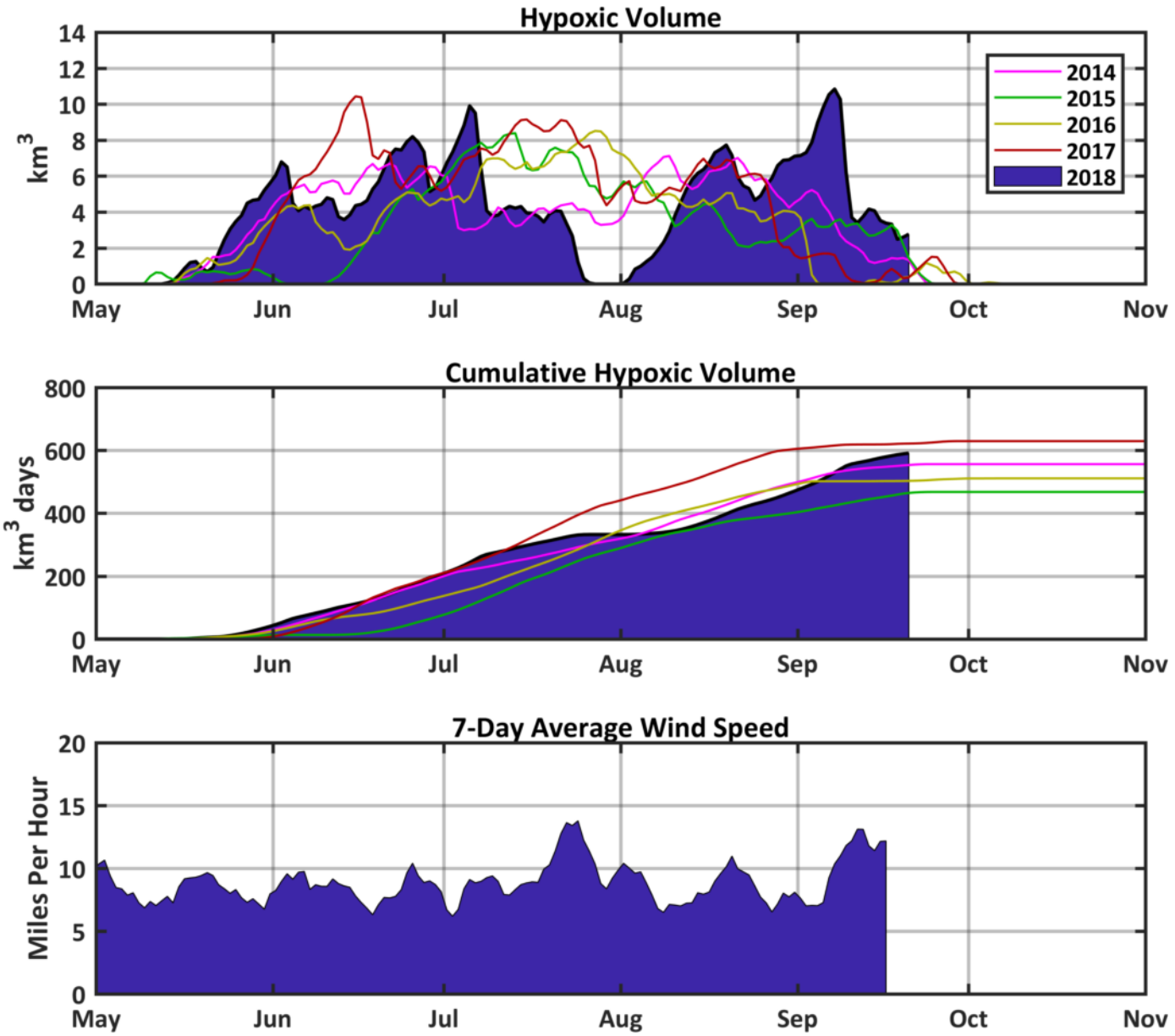
Real-time Hypoxic Volume Estimates

- Hypoxic volume is being estimated in real time using the VIMS Chesapeake Bay Hypoxia Model



2018 data provided by Maryland DNR Source: www.vims.edu/hypoxia

Real-time Hypoxic Volume Estimates



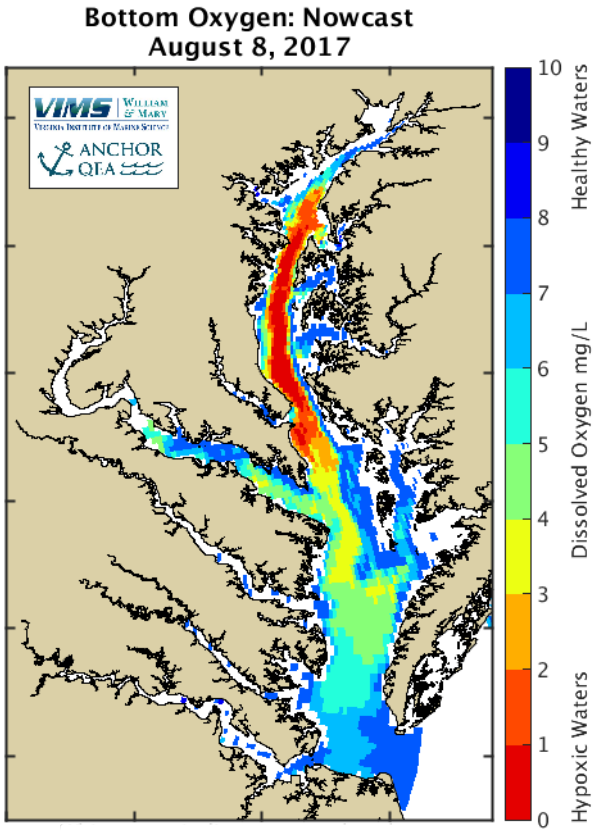
Conclusions

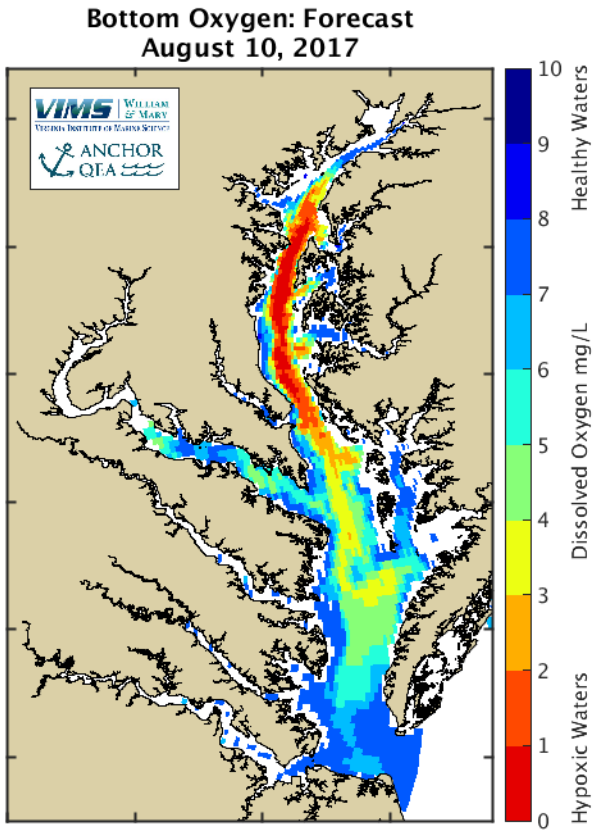
- Hypoxia in Chesapeake Bay is strongly constrained by the bathymetry and embayment geometry
- Continuous data at two locations is as accurate as knowing the dissolved oxygen everywhere twice monthly
- Automated sampling at a few locations will not be potentially biased by dates of sampling
- Automated sampling at a few locations can provide continuous HV estimates and accurate estimates of the annual severity of hypoxia

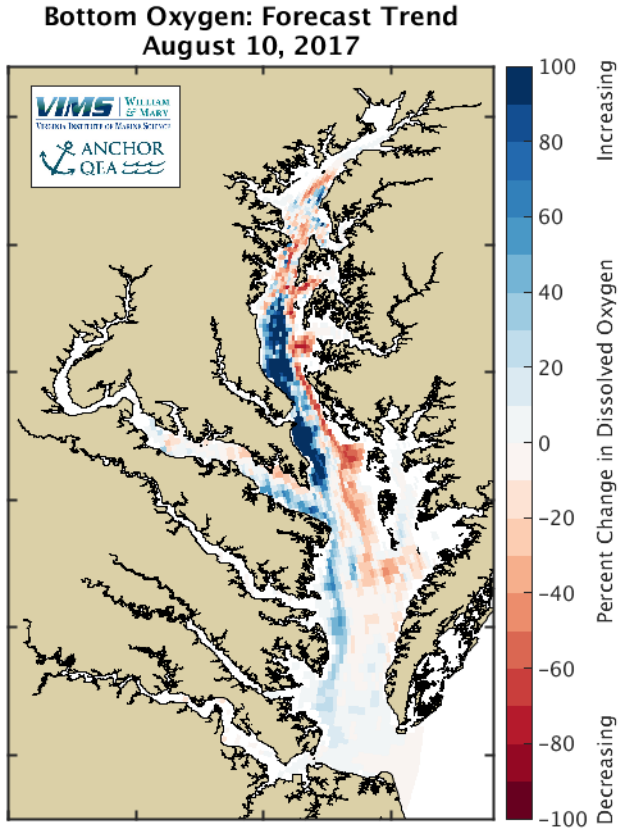
Conclusions

- Estimates from the real-time model are complimentary to the cruise-based estimates of HV
  - Model estimates help understand variability between the data collection cruises
  - Continuous HV estimates would provide validation data for the high-frequency variability predicted by models

Questions







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