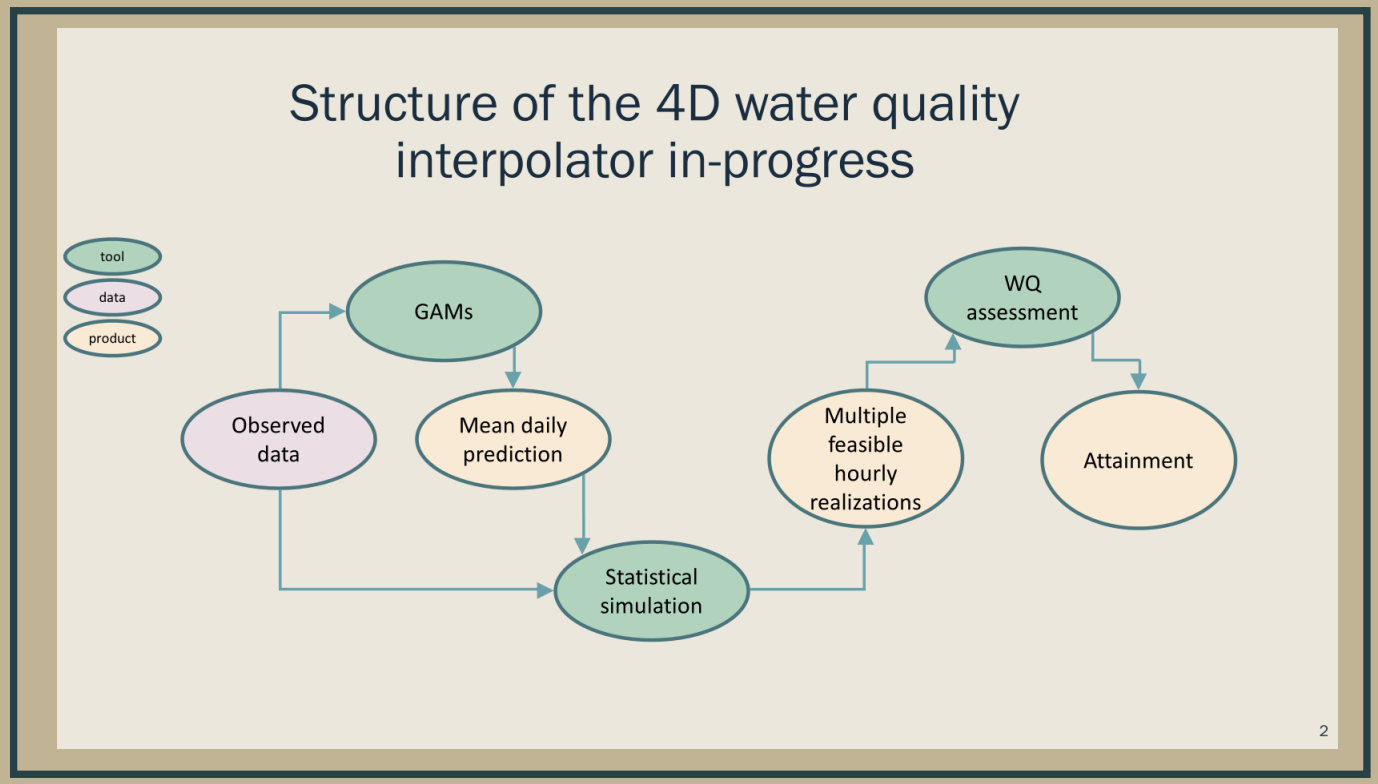
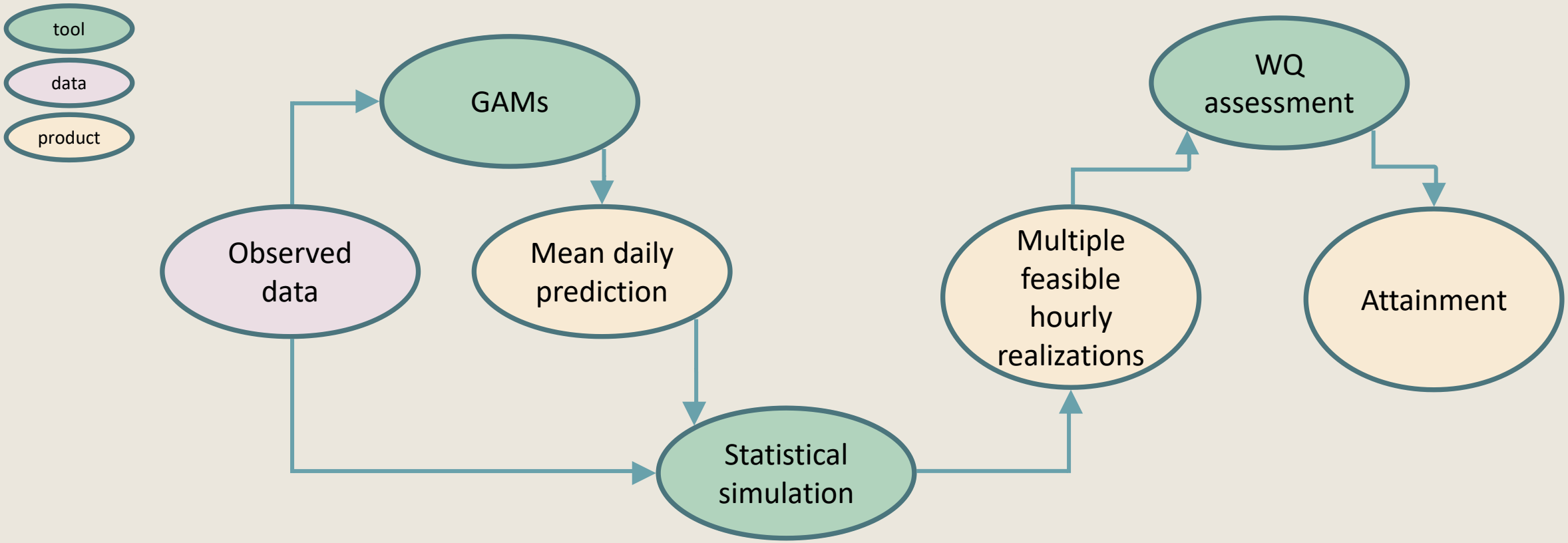
4D Interpolator – But wait! There's more!

Follow-up from the Phase 7 update to the WQGIT meeting.



Peter Tango and Rebecca Murphy
Co-chairs: Bay Oxygen Research Group
WQGIT 3/25/2024

Structure of the 4D water quality interpolator in-progress



Goal statement for new interpolator

To develop a spatial-and-temporal interpolation tool for water quality monitoring data collected in the tidal waters of the Chesapeake Bay, thus enabling the evaluation of both long- and short-duration water quality criteria.

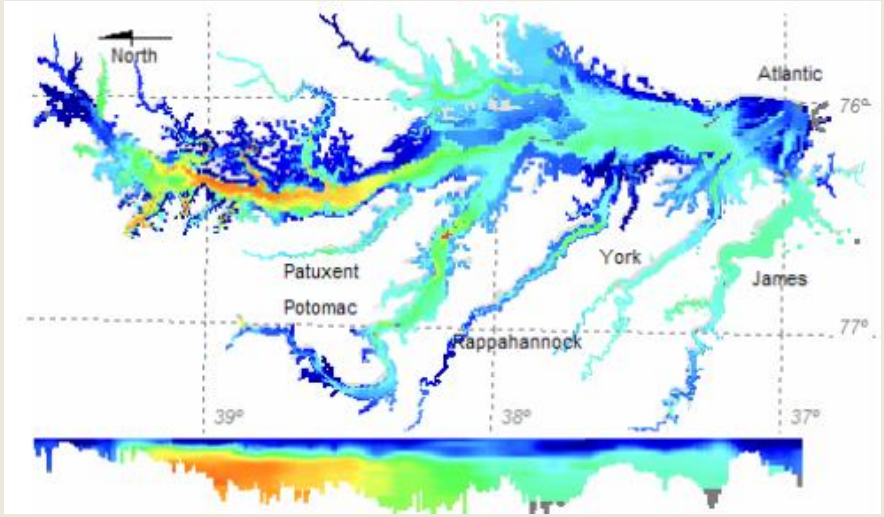
Specifically, the tool should be able to:

- *Interpolate observed dissolved oxygen in space and time ("4D"),**
- *Provide statistical estimates of uncertainty,*
- *Reproduce daily and hourly variability of the data, and*
- *Allow for post-processing of the interpolation output into designated uses (DU).*

*Note: Focus on development so far has been on dissolved oxygen, but ultimately chlorophyll *a* and clarity may be evaluated as well.

Current 3D interpolation

- Uses **inverse-distance weighting** of observations from long-term fixed stations, plus additional data as possible.
- **Temporal: snapshots,** generally using data collected within a week or two
- **Spatial:**
  - *Horizontal: Grid 1km x 1km in mainstem, finer (50m) in tribs*
  - *Vertically: Interpolation are done horizontally for every 1m in depth, and stacked to get 3d results*
- **Pycnocline:**
  - *An upper and lower pycnocline depth are interpolated horizontally as well*
  - *3D DO is split in DUs based on pycnocline*



VOL3d program output, Bahner 2006

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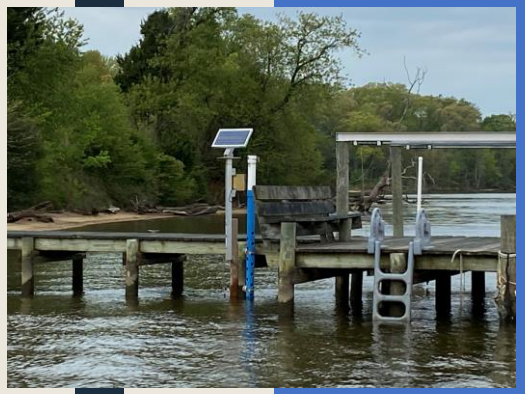
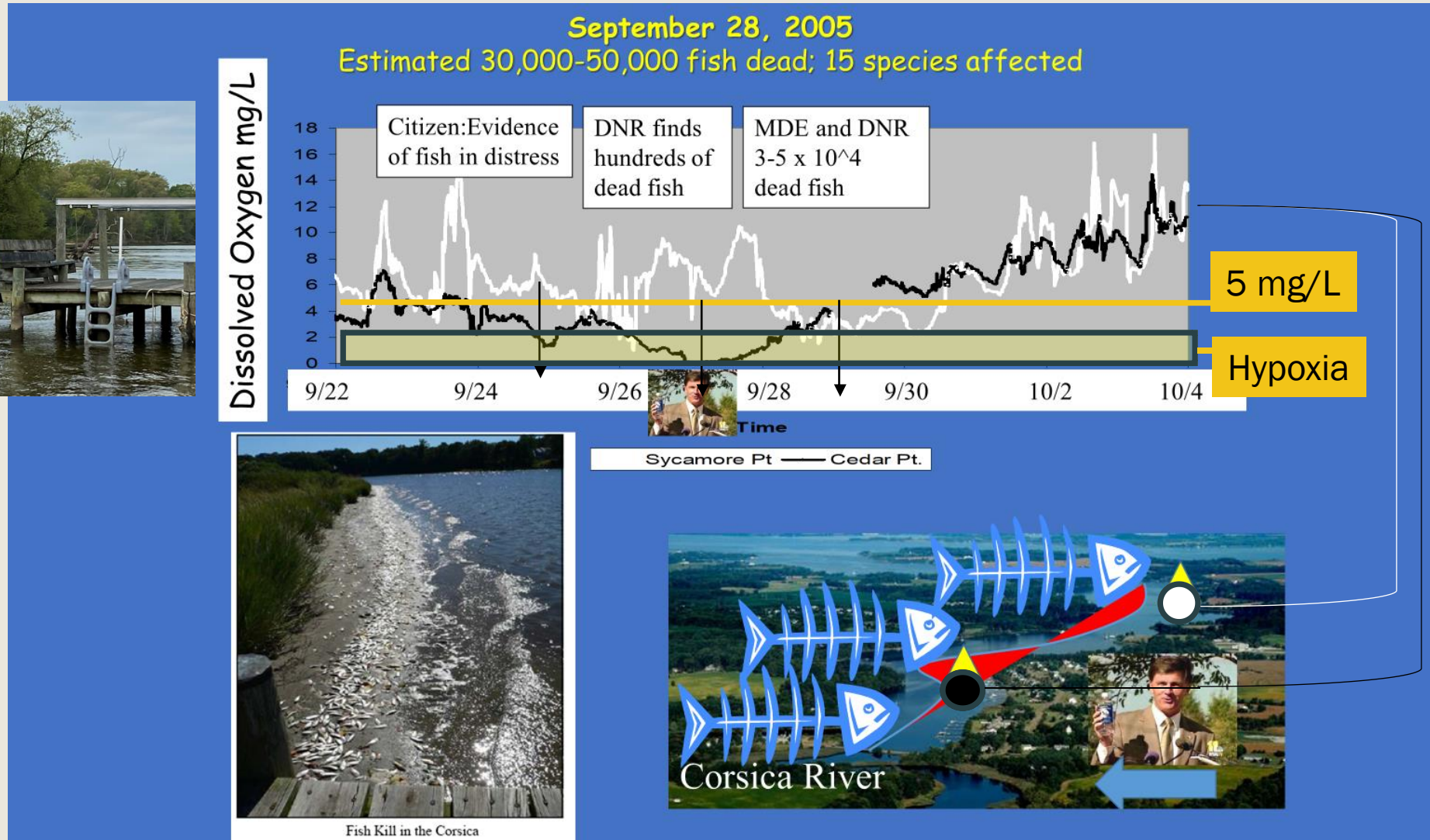
*This is a key limitation. We need to interpolate in **time** (1-D) as well as space (3-D) to evaluate all WQ criteria = "4-D"*

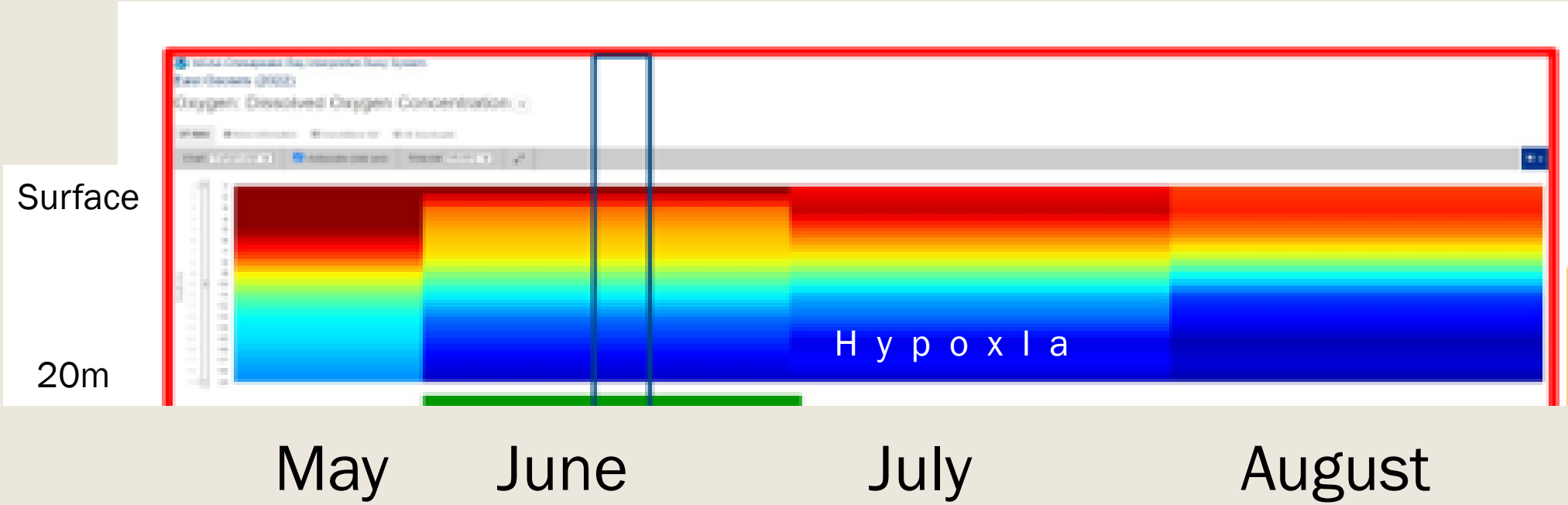
1-dimensional assessment of water quality.

One depth, through time. High temporal resolution, 13 days.
Catching the moment of a Corsica River, MD fish kill (2005).



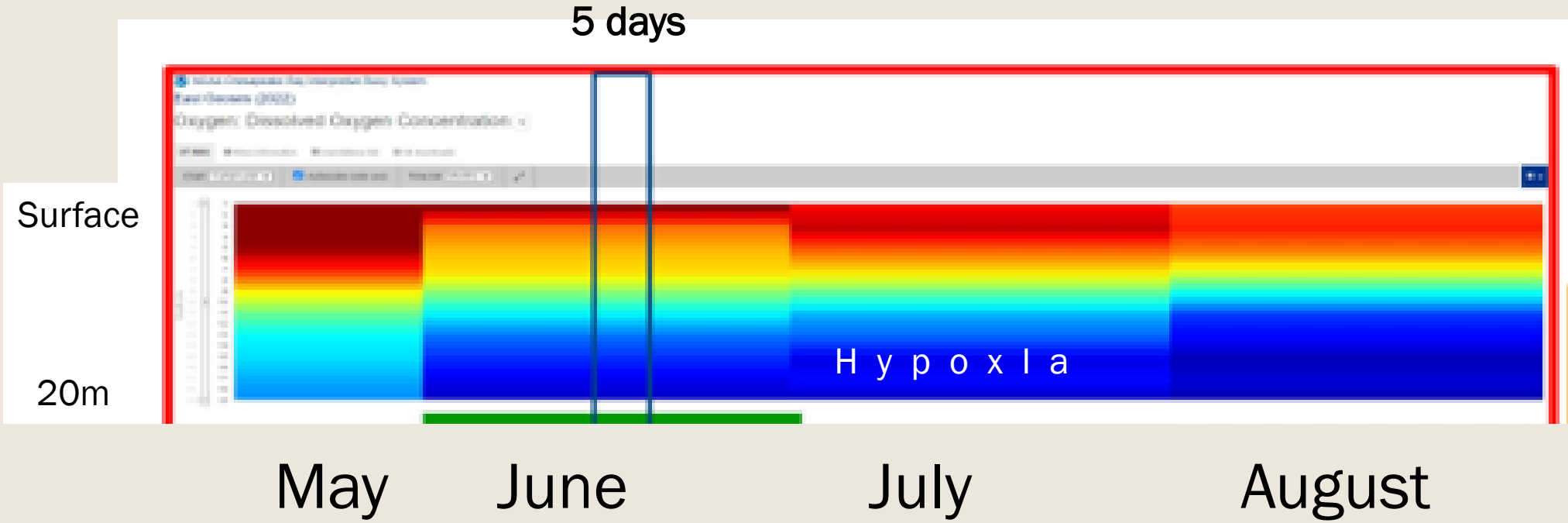


1 sample a month to estimate conditions makes a monitoring site look like this:



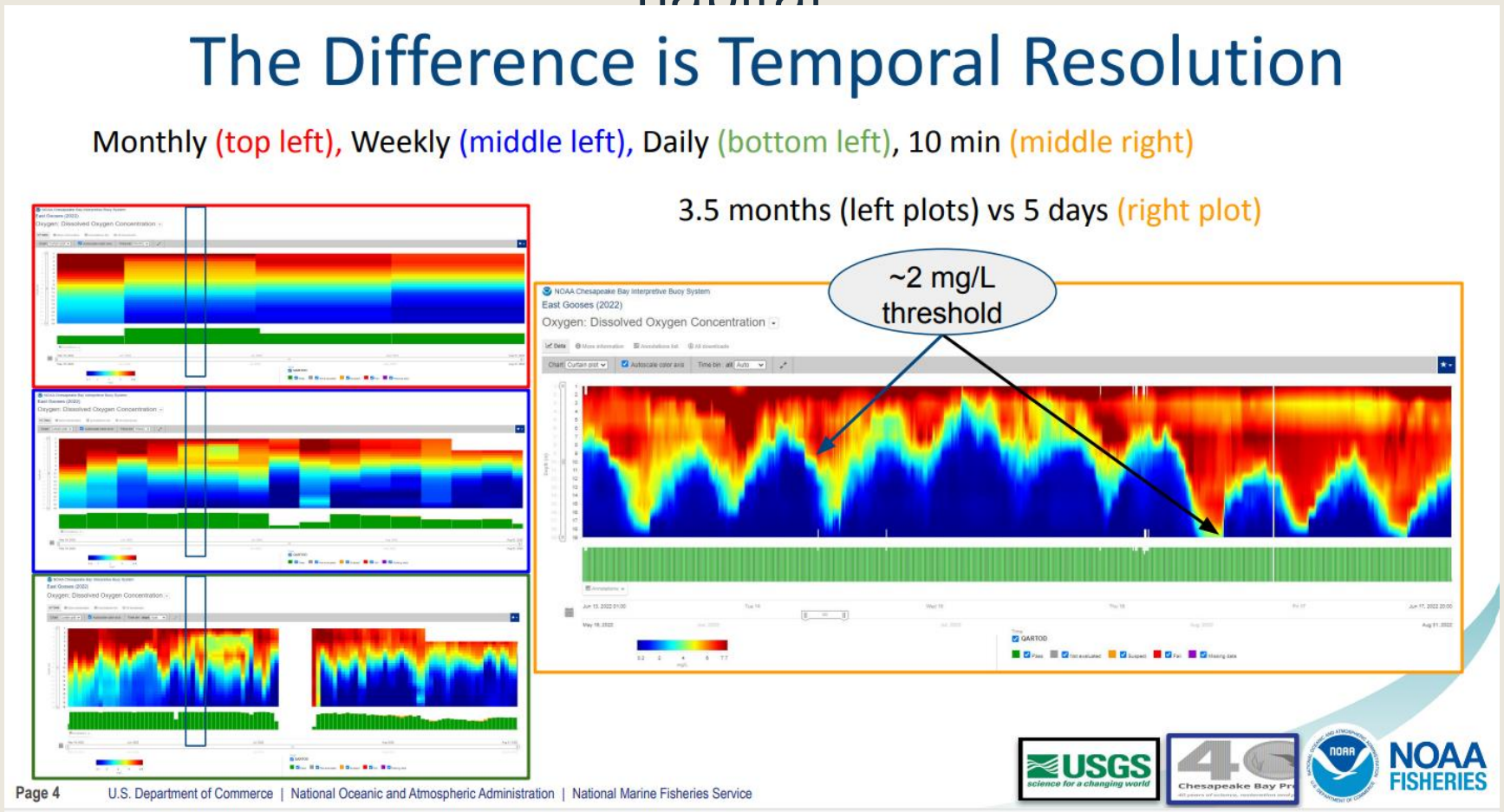
Dissolved oxygen: a single monitoring site in the Bay

1 sample a month to estimate a 30-day mean condition looks like this



Dissolved oxygen: a single monitoring site in the Bay

2-Dimensional improvement with new depth specific, water column data. More accurate information to inform criteria assessment, characterize habitat



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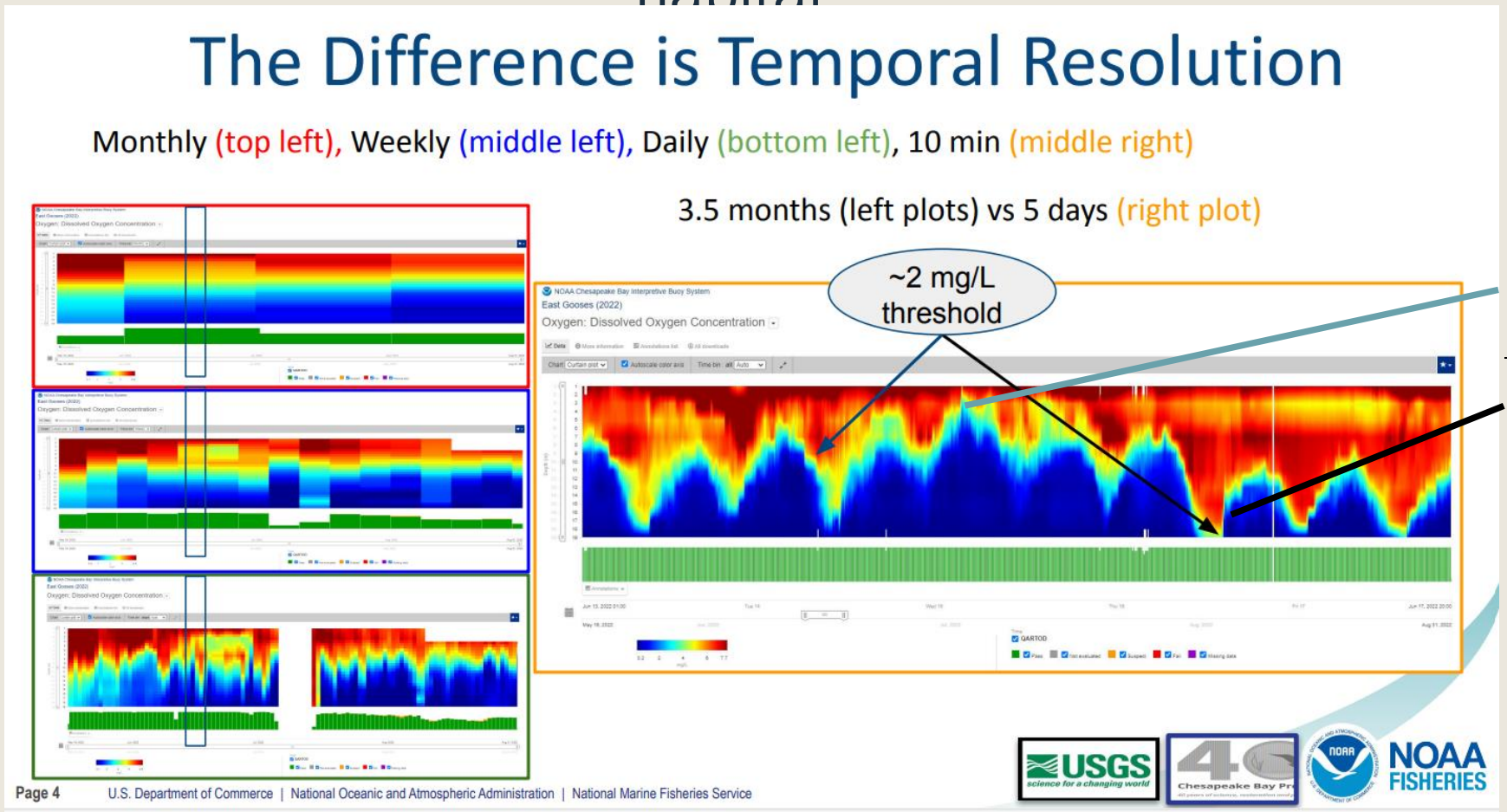
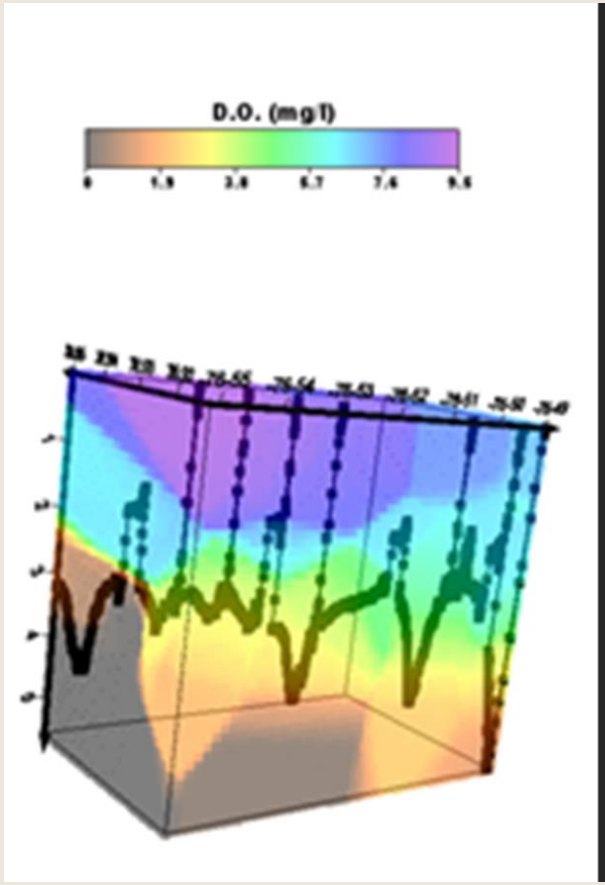


1 sampling cruise in the bay allows us to compute a 3-D picture estimating habitat conditions as a snapshot volume in time



DO 3D

Severn River

From Andrew and Diana Mueller

The data were from an UAV that would dive and surface, dive and surface. That allows for 3-D interpolation as if we had multiple profiles of WQ and some at depth horizontal measurements. Single day monitoring event.

Interpolating 3D volume through time = 4D.

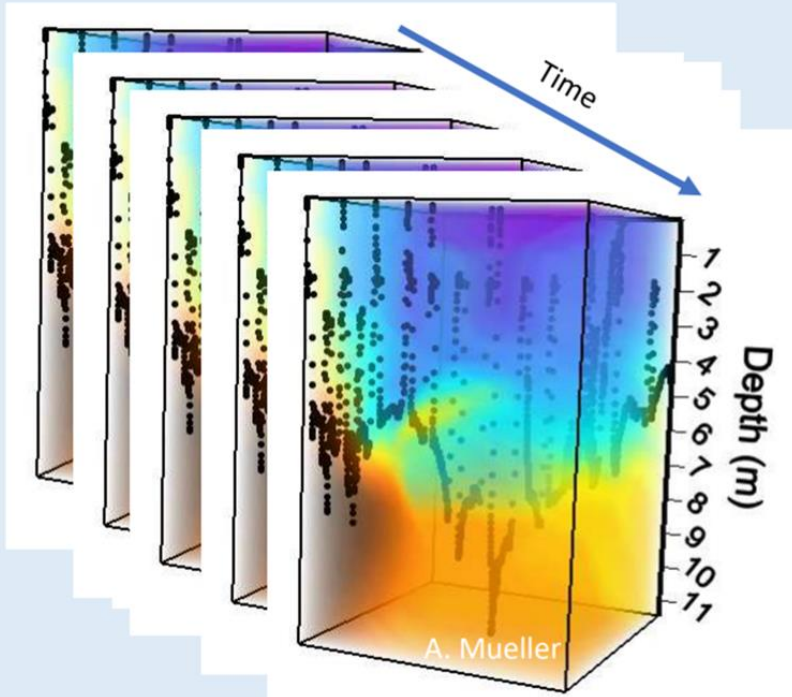
We fill in the time voids to get at short duration d.o. criteria assessment, high temporal and spatial habitat assessment.

4D Interpolator Tool Development

Decision-support needs: Improve water quality habitat characterization and assessment

Varied data resources are desired to feed a monitoring-based 4-D assessment.

- **The Bay Oxygen Research Group formed in 2021 and started development of a 4-dimensional interpolator for Chesapeake Bay.**



USGS science for a changing world

Purpose: Build a tool for more complete criteria assessment

DO criteria that currently can be evaluated with existing approaches and data

Table 1. Chesapeake Bay dissolved oxygen criteria.

Designated Use	Criteria Concentration/Duration	Protection Provided	Temporal Application
Migratory fish spawning and nursery use *	7-day mean ≥ 6 mg liter^{-1} (tidal habitats with 0-0.5 ppt salinity)	Survival/growth of larval/juvenile tidal-fresh resident fish; protective of threatened/endangered species.	February 1 - May 31
	Instantaneous minimum ≥ 5 mg liter^{-1}	Survival and growth of larval/juvenile migratory fish; protective of threatened/endangered species.	
	Open-water fish and shellfish designated use criteria apply		June 1 - January 31
Shallow-water bay grass use	Open-water fish and shellfish designated use criteria apply		Year-round
Open-water fish and shellfish use	30-day mean ≥ 5.5 mg liter^{-1} (tidal habitats with 0-0.5 ppt salinity)	Growth of tidal-fresh juvenile and adult fish; protective of threatened/endangered species.	Year-round
	30-day mean ≥ 5 mg liter^{-1} (tidal habitats with >0.5 ppt salinity)	Growth of larval, juvenile and adult fish and shellfish; protective of threatened/endangered species.	
	7-day mean ≥ 4 mg liter^{-1}	Survival of open-water fish larvae.	
	Instantaneous minimum ≥ 3.2 mg liter^{-1}	Survival of threatened/endangered sturgeon species.[1]	
Deep-water seasonal fish and shellfish use	30-day mean ≥ 3 mg liter^{-1}	Survival and recruitment of bay anchovy eggs and larvae.	June 1 - September 30
	1-day mean ≥ 2.3 mg liter^{-1}	Survival of open-water juvenile and adult fish.	
	Instantaneous minimum ≥ 1.7 mg liter^{-1}	Survival of bay anchovy eggs and larvae.	
	Open-water fish and shellfish designated-use criteria apply		October 1 - May 31
Deep-channel seasonal refuge use	Instantaneous minimum ≥ 1 mg liter^{-1}	Survival of bottom-dwelling worms and clams.	June 1 - September 30
	Open-water fish and shellfish designated use criteria apply		October 1 - May 31

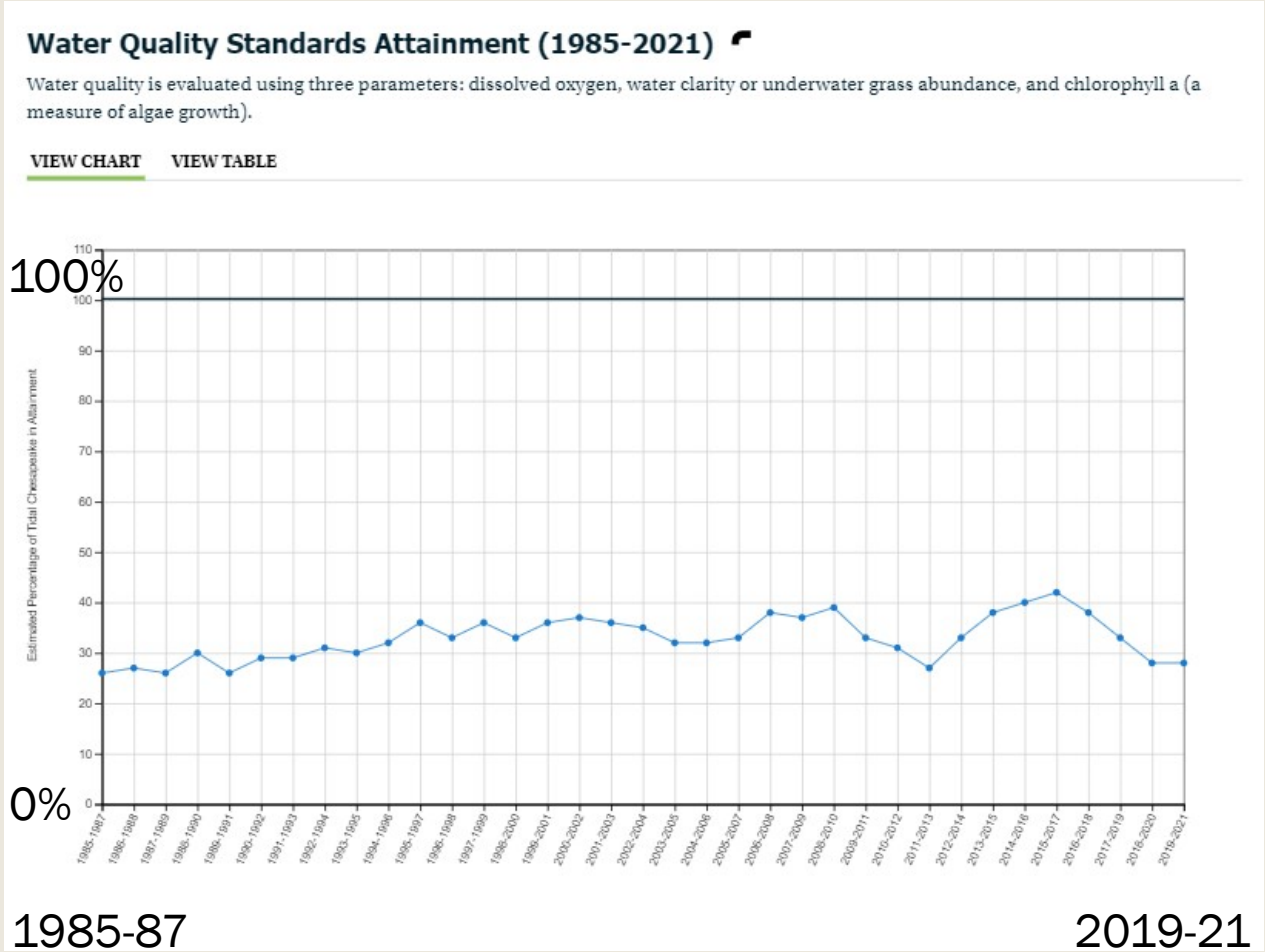
[1] At temperatures considered stressful to shortnose sturgeon (>29°C), dissolved oxygen concentrations above an instantaneous minimum of 4.3 mg liter^{-1} will protect survival of this listed sturgeon species.

*Note a 30-day mean 6 mg/L MSN value is evaluated for purpose of the WQ indicator.

From EPA 2003 Ambient Water Quality Criteria

Water Quality Standards Indicator

- The indicator provides an ***estimate*** of what a full accounting (i.e., *hundreds of individual decisions we do not have data for*) for water quality criteria will show us.



New data + New interpolator:

Building a tool for more complete criteria assessment

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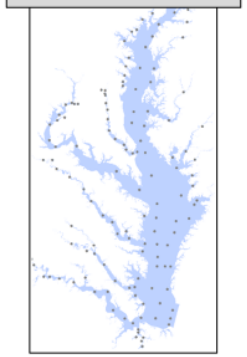
Table from USEPA 2003

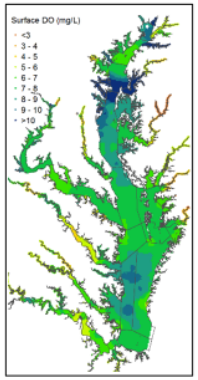
Reminder of our assessment procedure

WQS Criterion Assessment

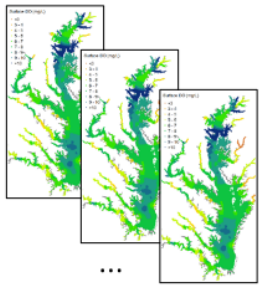
1. Collect bi-weekly to monthly data at each monitoring station



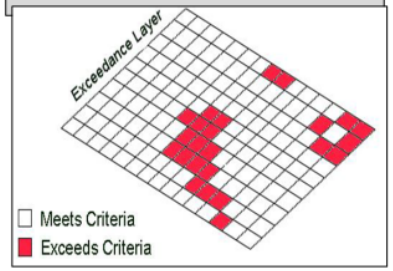
2. Convert the station DO data to Baywide values using the CBP interpolator



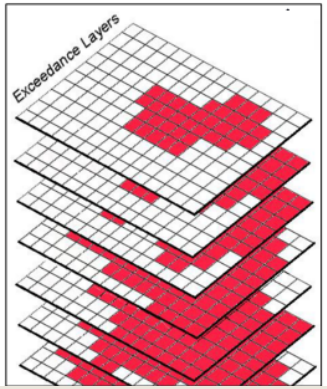
3. Combine interpolations for a season over the 3-year period



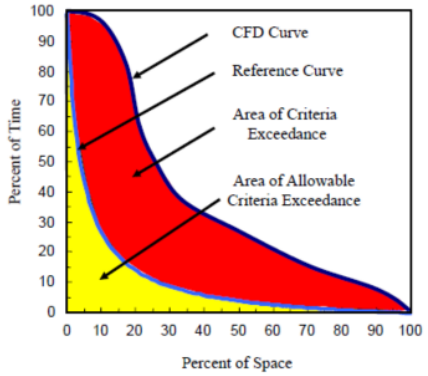
4. Compare the interpolated values with appropriate criterion values to compute the spatial extent of exceedance



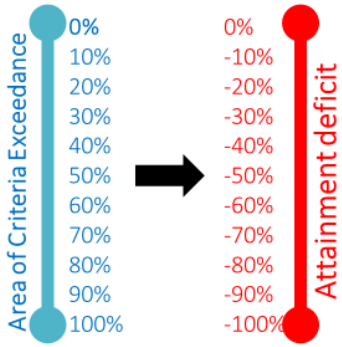
5. Repeat Step 4 for each sampling event in the 3-year period to determine the cells' extent of exceedance



6. Calculate the cumulative probability distribution (CFD) for extent of exceedance for all cells within each segment



7. Quantify attainment status (attaining or not) for the 3-year period



11

WQS Criterion Assessment

3. Determine the compliance status of each cell in the segment volume.

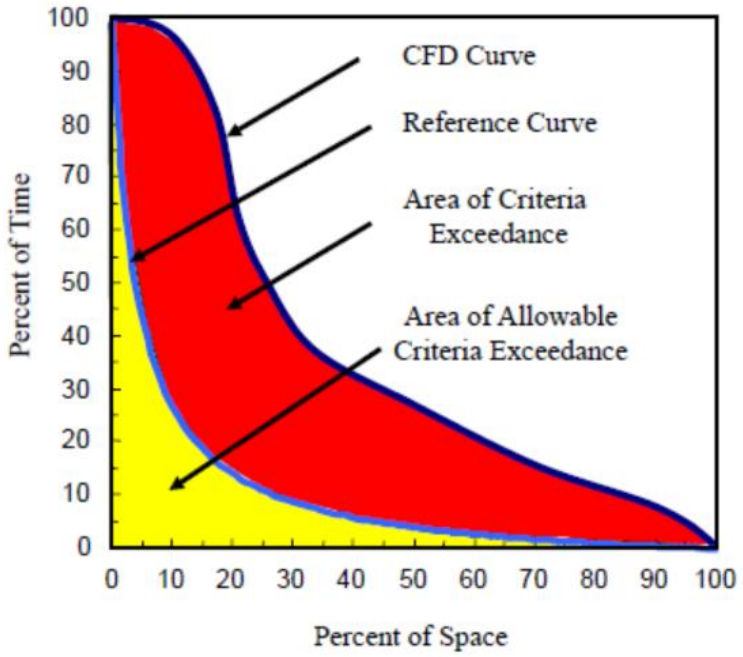
4. Produce a percent compliance matrix with sample period and percent space in compliance.

5. Rank the percent compliance in space from greatest to lowest values and assign percent of time associated with the compliance values.

6. Plot ranked percent space (x-axis) against percent time (y-axis).

7. Evaluate compliance against the reference curve.

For 1 specific segment



Source: Tango and Batiuk (2013)

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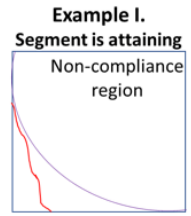
Breakdown of Attainment Status by Threshold 2019-2021

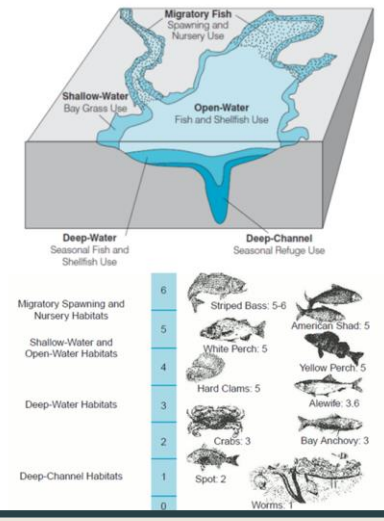


	Deficit	Count
Segments attaining	0%	?
Segments approaching Attainment expressed as % away from attainment	0%-0.0001%	?
	0.0001-0.001%	?
	0.001-0.01%	?
	0.01-0.1%	?
	0.1-1%	?
	1-2%	?
	2-3%	?
	3-5%	?
	5-10%	?
	>10%	?
	ND	?

Nearly 200 segment-designated use-dissolved oxygen criterion assessments evaluated: Some are fractionally close to attainment

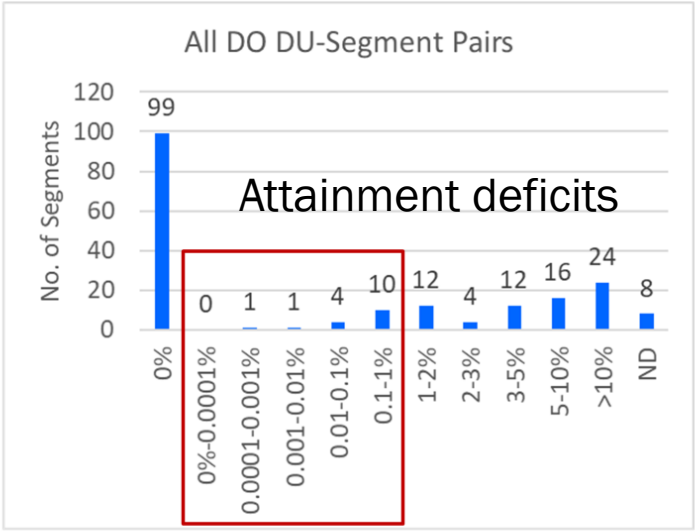
Examples: Breakdown of Attainment Status by Threshold 2019-2021

Designated Uses (DUs)



- Each segment contains **up to five DUs**:
  - DC: deep channel,
  - DW: deep water,
  - OW: open water,
  - SW: shallow water,
  - MSN: migratory fish, spawning & nursery.
- Each DU has its own set of criteria for **one or more of the following**:
  - Dissolved oxygen,
  - Water clarity/SAV, and
  - Chlorophyll-a.

4



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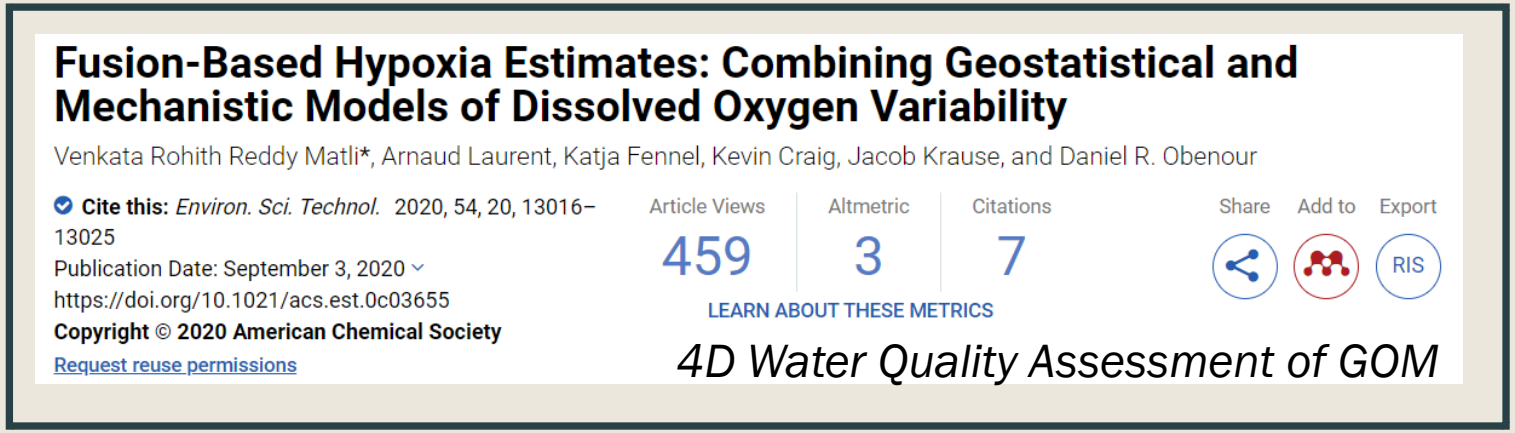
Lessons on benefits of 4D dissolved oxygen assessment

The Gulf of Mexico dead zone

- More accurate representation of conditions, improved confidence in assessment
- Reduced hypoxic area uncertainties by 11% on average
- Reduced hypoxic area uncertainties up to 40% in months with sparse sampling.



Thank you's! Development Process & Community updates

1. **Development team**
   - *CBP staff, contractors, EPA researchers, state partners and academic future users*
   - *Provides guidance and feedback on development details*
   - *Meets monthly*
2. **Bay Oxygen Research Group (larger):**
   - *Development team plus broader community of interested parties from partnership*
   - *Provides feedback on big-picture impacts*
   - *Approximately every 3 months*
3. **Collaboration among workgroups: Modeling workgroup, CAP workgroup, STAR Hypoxia Collaborative**
   - *Overlapping team members and update presentations at these meetings will continue for coordination and feedback*
4. **STAC Review:** *Coordination for 2026 with Phase 7 development timeline*

4-D interpolator development timeline

Draft January 2024

Priority categories for 2024 are in red

Calendar Year	2022				2023				2024				2025				2026				2027			
Calendar Quarter	Q1 Jan-Mar	Q2 Apr-Jun	Q3 Jul-Sep	Q4 Oct-Dec	Q1 Jan-Mar	Q2 Apr-Jun	Q3 Jul-Sep	Q4 Oct-Dec	Q1 Jan-Mar	Q2 Apr-Jun	Q3 Jul-Sep	Q4 Oct-Dec	Q1 Jan-Mar	Q2 Apr-Jun	Q3 Jul-Sep	Q4 Oct-Dec	Q1 Jan-Mar	Q2 Apr-Jun	Q3 Jul-Sep	Q4 Oct-Dec	Q1 Jan-Mar	Q2 Apr-Jun	Q3 Jul-Sep	Q4 Oct-Dec
Project Year	Year 1				Year 2				Year 3				Year 4				Year 5				Year 6			
1. Development-daily estimates	■	■	■	■	■	■	■	■	■	■	■													
2. Develoment-hourly estimates					■	■	■	■	■	■	■	■												
3. Development - shallow water							■	■	■	■	■	■	■	■	■									
4. Development - GIS tasks	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■							
5. Development -combined daily & hourly								■	■	■	■	■	■											
6. Development-criteria evaluation								■	■	■	■	■	■	■	■	■								
7. Software							■	■	■	■	■	■	■	■	■	■								
8. Documenting	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■				
9. Training													■	■	■	■								
10. Year of Review																	■	■	■	■				
11. Operational																					■	■	■	■

Requirements for an Updated Chesapeake Bay Interpolator

- **New features (compared to current interpolation approach):**
  - *Temporal and spatial interpolation of water quality parameters in Chesapeake Bay*
  - *Statistical estimates of uncertainty in the estimates*
  - *Reproduce the short-term variability in the data*
  - *Integrated vertical interpolation technique*

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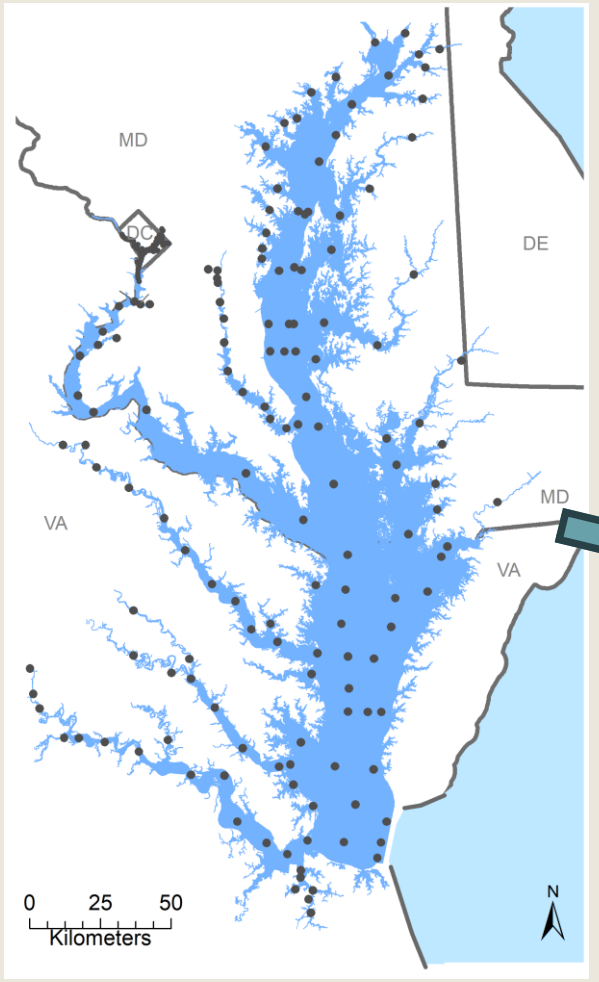
  - *Integrated vertical interpolation technique*
- **Features to retain and update:**
  - *Usability by partner analysts with automation for routine analyses*
  - *Visualization of the results*
  - *Analysis of dissolved oxygen, clarity, and chlorophyll a*
  - *Post-processing to identify regions for each designated use (DU)*
  - *Reasonable spatial extents for interpolation (e.g., not interpolating across land)*
  - *Incorporation of new data streams & types, as available*

Combine existing and emerging data sets

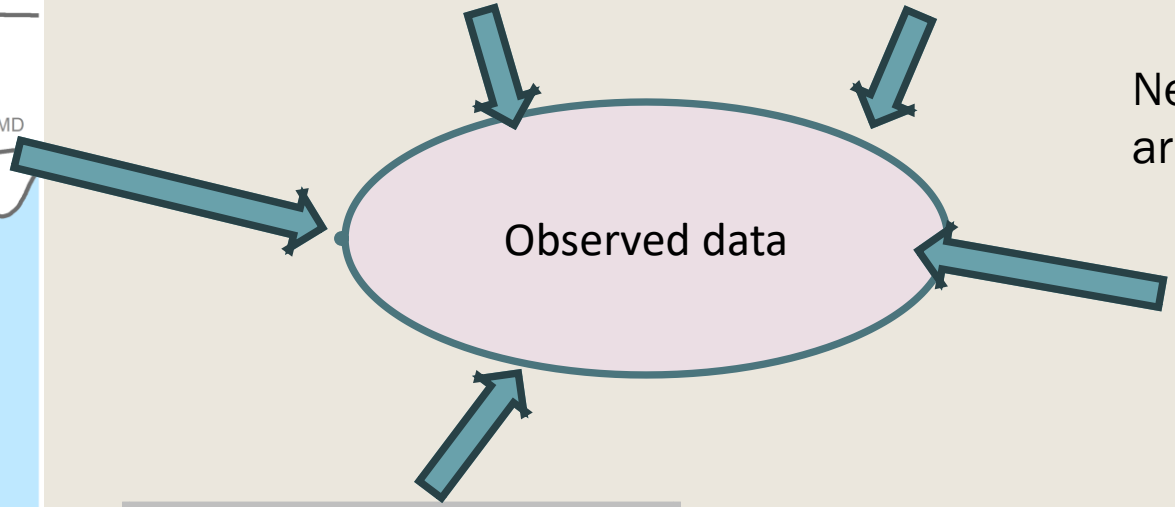
Bi-weekly long-term sampling (DOEE, MDDNR, VADEQ, CBP)



Shallow water continuous monitoring (MDDNR and VECOS)

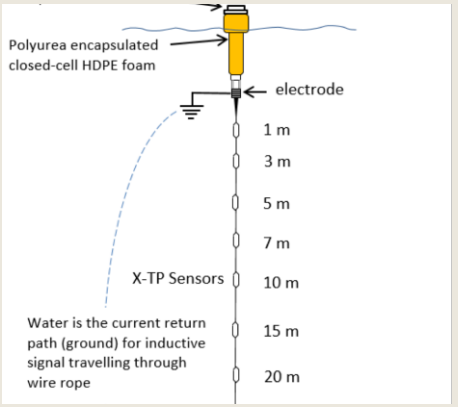
From https://eyesonthebay.dnr.maryland.gov/

From http://vecos.vims.edu/



And more: Citizen science, riverkeepers, and research data sets

New continuous vertical arrays (NOAA & CBP)



https://www.chesapeakebay.net/who/group/hypoxia-collaborative-team