4-dimensional (4-D) interpolator development overview

Modeling Workgroup
Oct. 8, 2025

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and Elgin Perry (statistics consultant)

Leadership/coordination team:

Breck Sullivan (USGS), Peter Tango (USGS), Kaylyn Gootman (EPA), and Allison Welch (CRC)

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

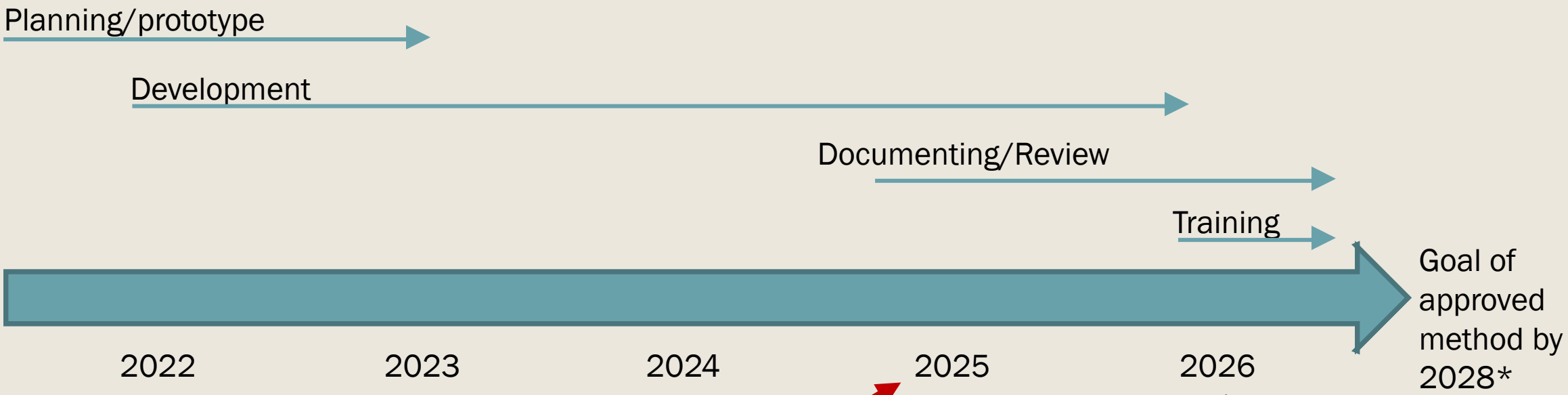
Why do we need a new method?

- The current interpolator (developed 20+ years ago) was not designed to interpolate through time and was not developed for use in assessment of shorter-term tidal WQ criteria.

- There is more high frequency data now to fill in temporal gaps.
  - *There would still be spatial and/or temporal bias if the data was used without interpolation because it is impossible to get equally distributed representation of DO everywhere.*

- A new interpolation will use all the data to fill in the gaps between data based on observed patterns to help accurately assess high frequency DO criteria.

4-D interpolator development timeline



By the end of 2025:

- Working 4-D tool,
- Examples applied to several segments,
- Collaboration ongoing with CAP on criteria assessment methods.

In 2026-2027:

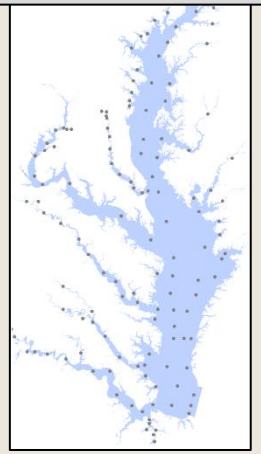
- Documenting,
- Additional functionality as needed for linking to criteria assessment,
- Preparing for review & review.

*with 2030 goal of reporting on all criteria

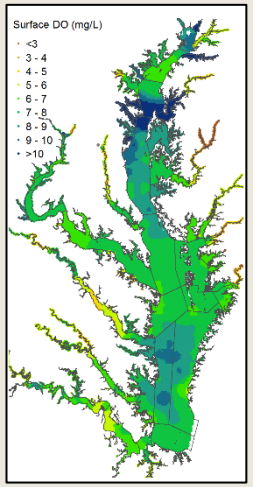
WQS Criterion Assessment

Current approach

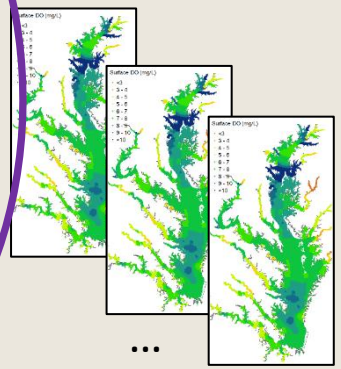
1. Collect bi-weekly to monthly data at each monitoring station



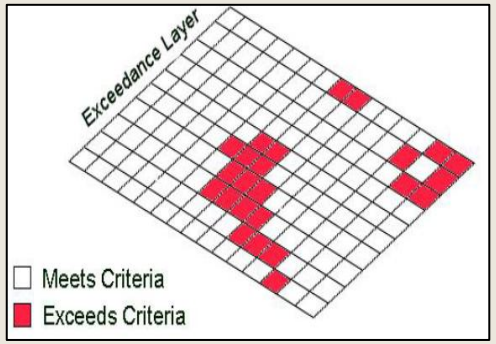
2. Interpolate bay-wide for a single cruise



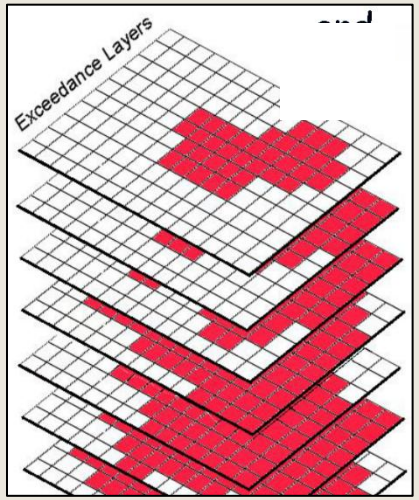
3. Conduct interpolations for a season over the 3-year period



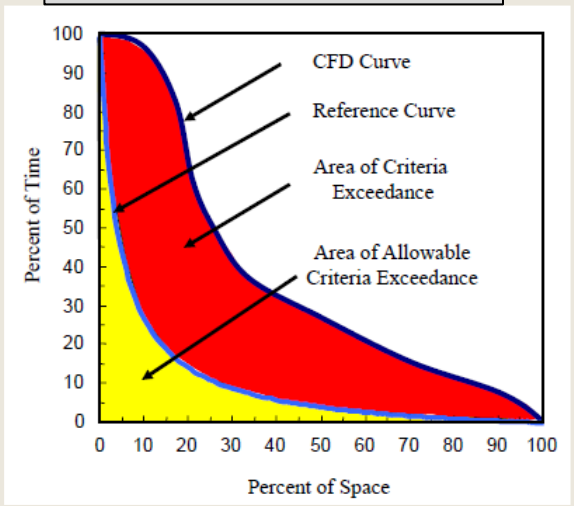
4. Average monthly if 30-day criterion, and compare the interpolated values with appropriate criterion values



5. Repeat Step 4 throughout the 3-year period



6. Calculate the cumulative frequency distribution (CFD) for extent of exceedance in space and time

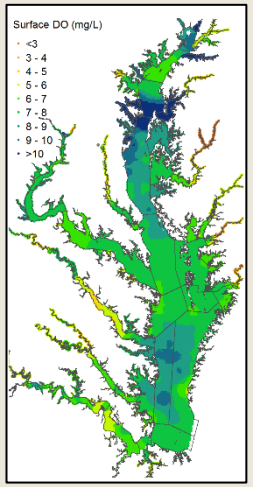


7. Quantify attainment status (attaining or not) for the 3-year period

From Peter Tango

Current interpolation

2. Interpolate bay-wide for a single cruise



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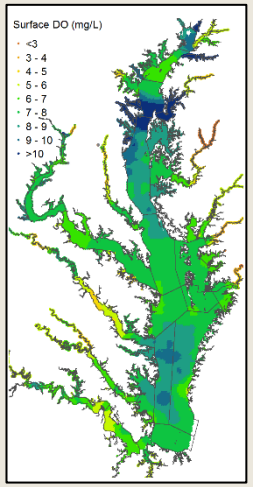


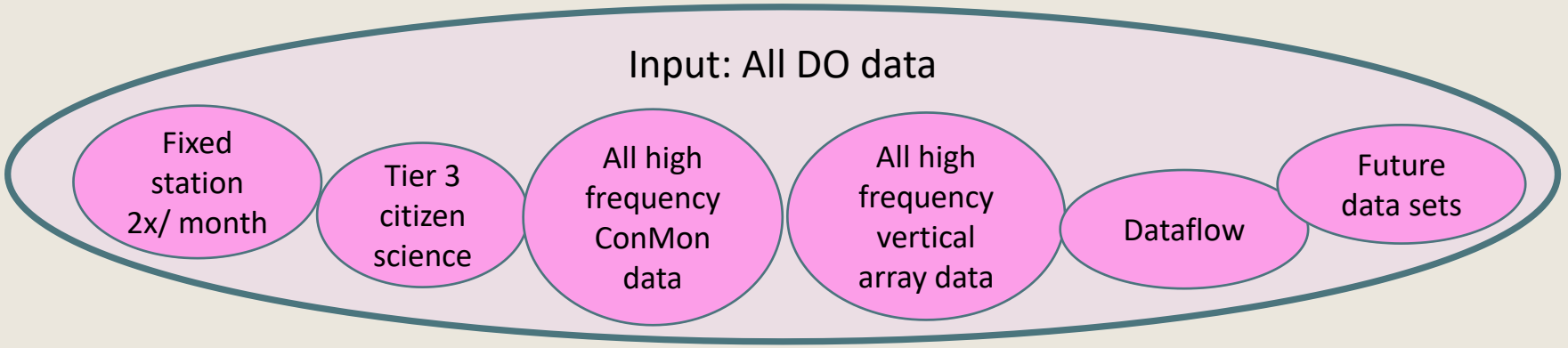
Problems with current interpolation

- Does not use the high frequency data at high frequency
- Vertical layers interpolated horizontally and stacked;
- One cruise at a time, meaning a 2-week period assumed static; and
- Not statistical.

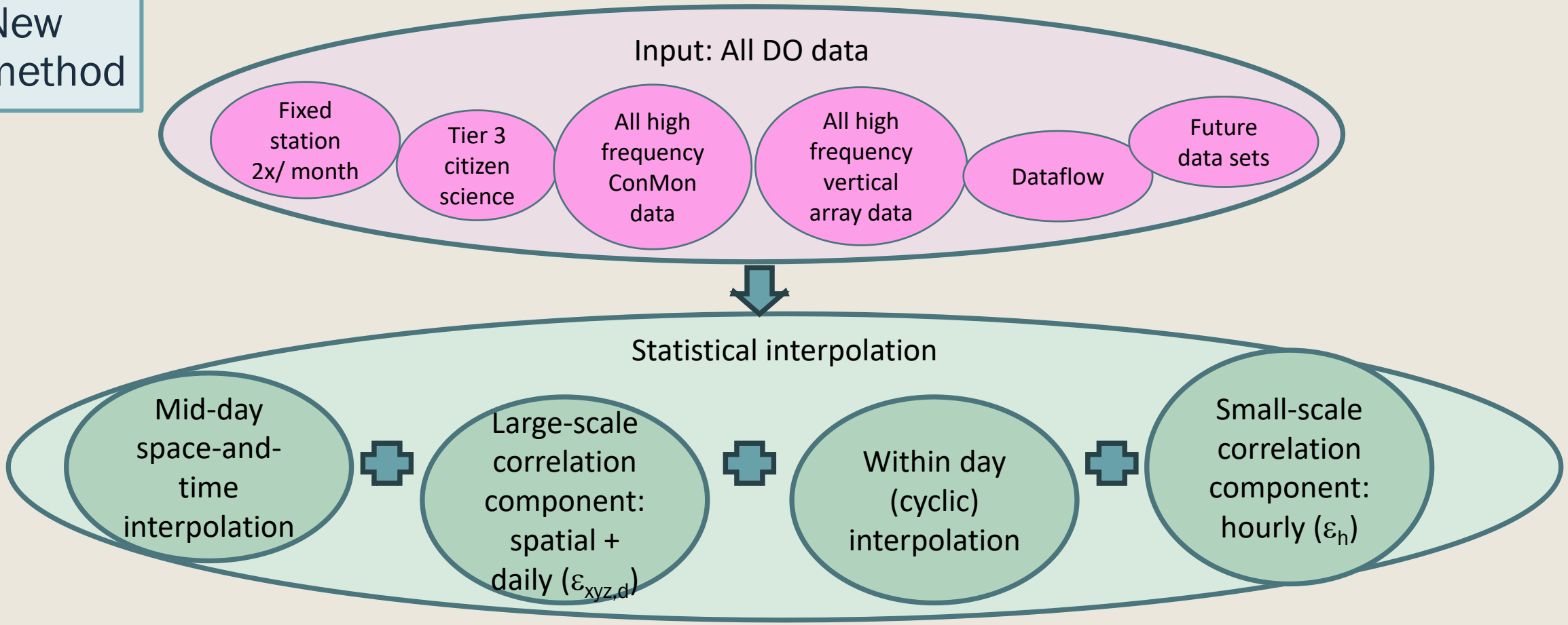
This NEW interpolation will:

- Use **ALL high frequency data** (ConMon, Dataflow, and vertical array)
- Interpolate all data together, not in layers.
- Interpolate in time, so that we do not have to artificially split time periods.
- Statistical – allowing for multiple realizations of interpolation results.

New method


Input: All DO data
Fixed station 2x/ month
Tier 3 citizen science
All high frequency ConMon data
All high frequency vertical array data
Dataflow
Future data sets

New method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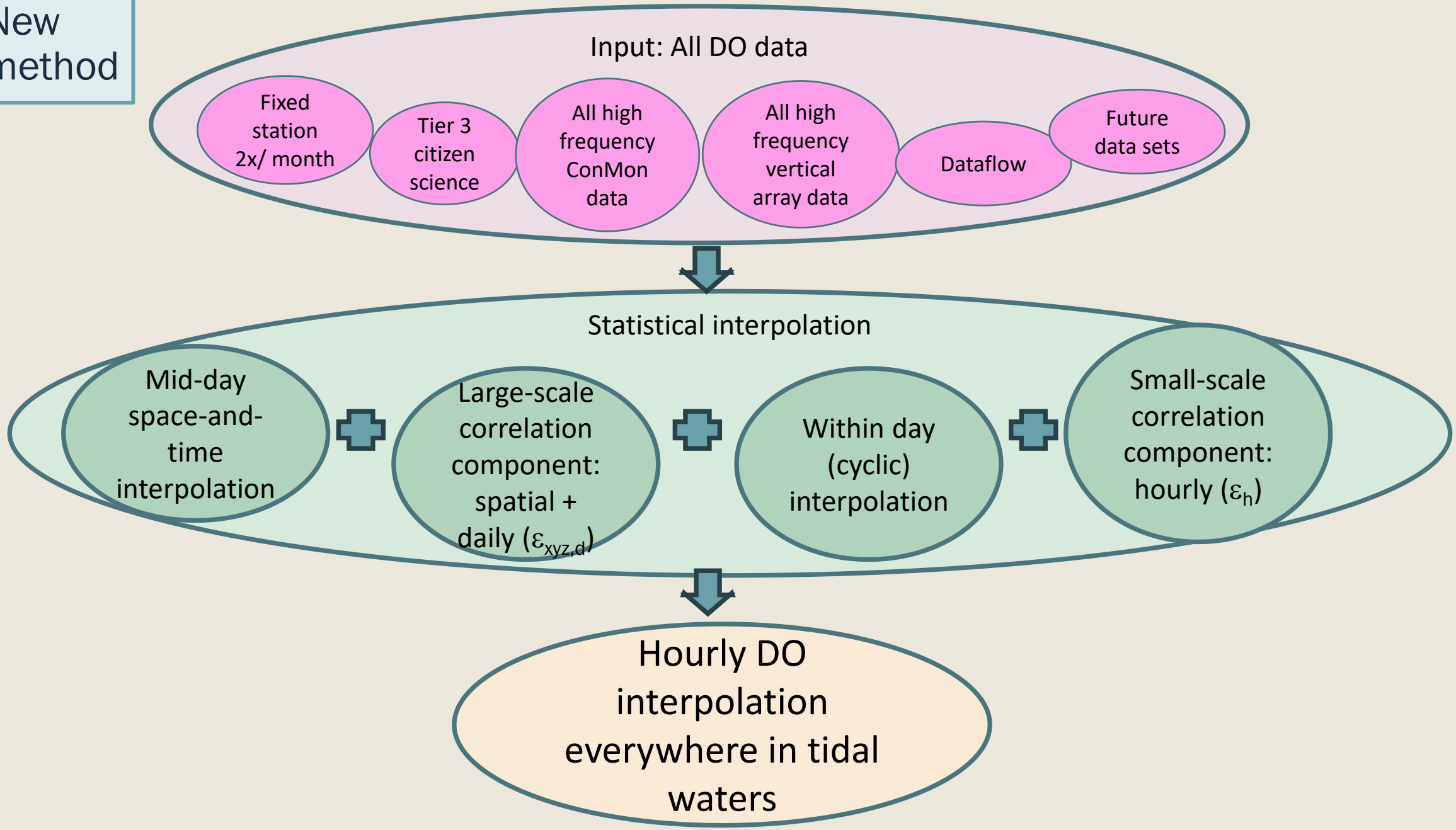
Statistical interpolation
Mid-day space-and-time interpolation
Large-scale correlation component: spatial + daily ($\varepsilon_{xyz,d}$)
Within day (cyclic) interpolation
Small-scale correlation component: hourly (ε_h)

New method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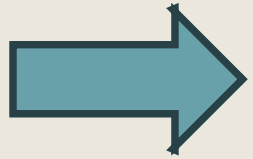
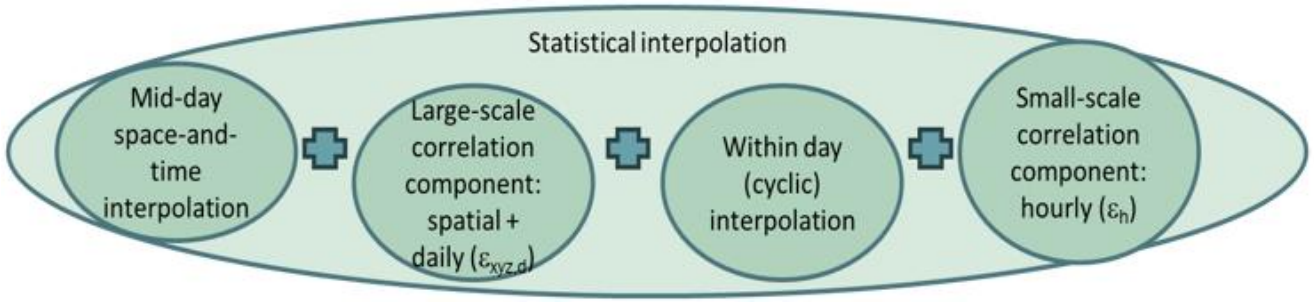
Mid-day space-and-time interpolation
Large-scale correlation component: spatial + daily ($\varepsilon_{xyz,d}$)
Within day (cyclic) interpolation
Small-scale correlation component: hourly (ε_h)
Hourly DO interpolation everywhere in tidal waters

What does this look like?

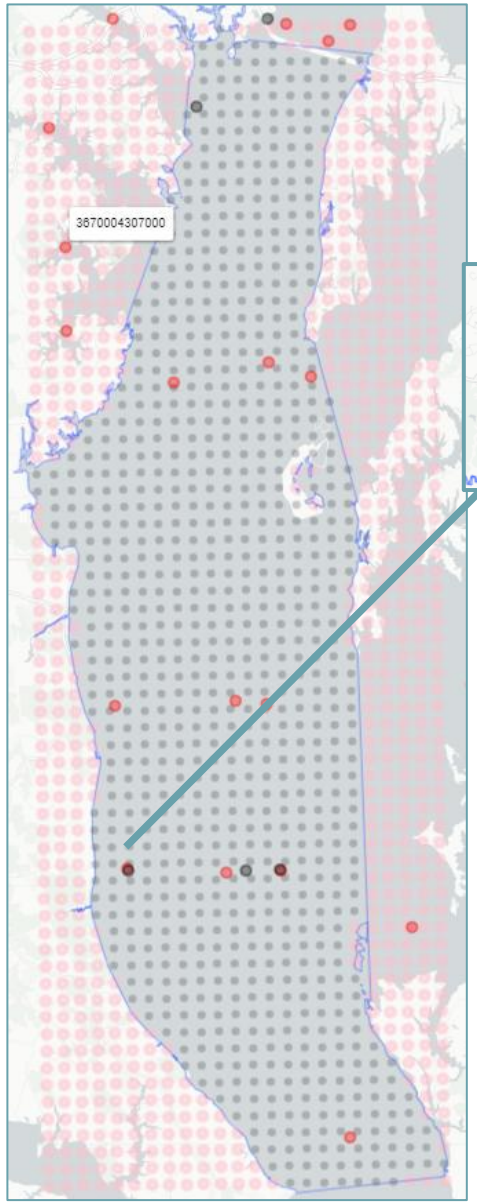
We can go into more detail on any part of this, but broad overview:



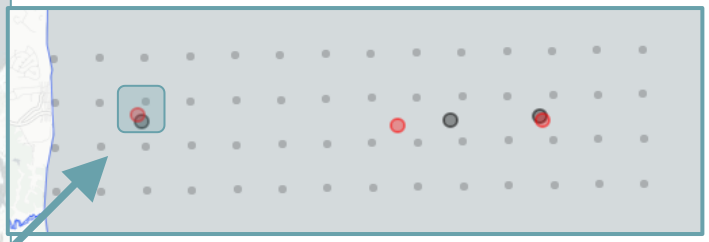
Statistical Interpolation – the “pieces”



CB4MH

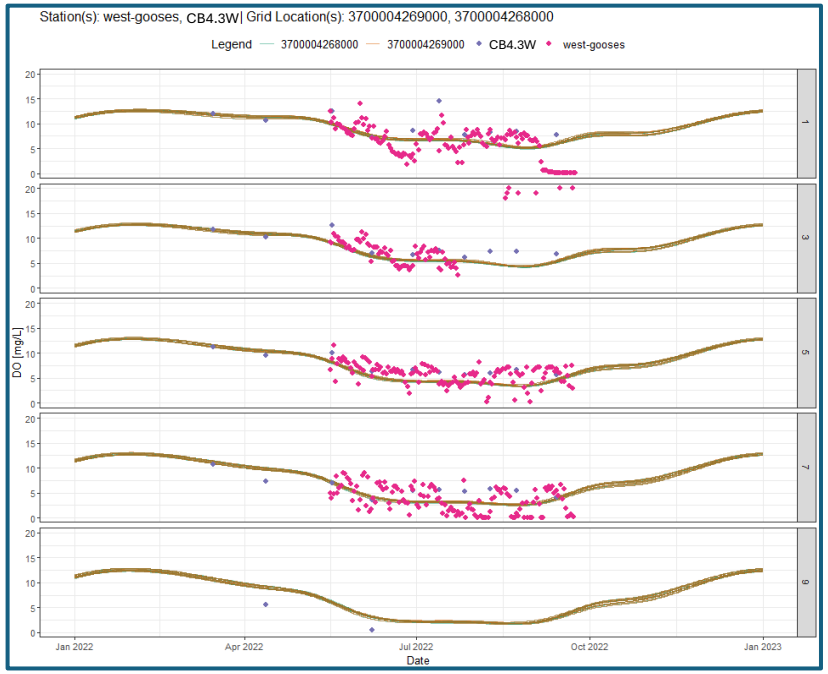


Stations: CB4.3W, west-gooses



A) Mid-day space-and-time interpolation

Generalized Additive Model: location, date, and time smooths fit to ALL data collected in one year within a group of segments.



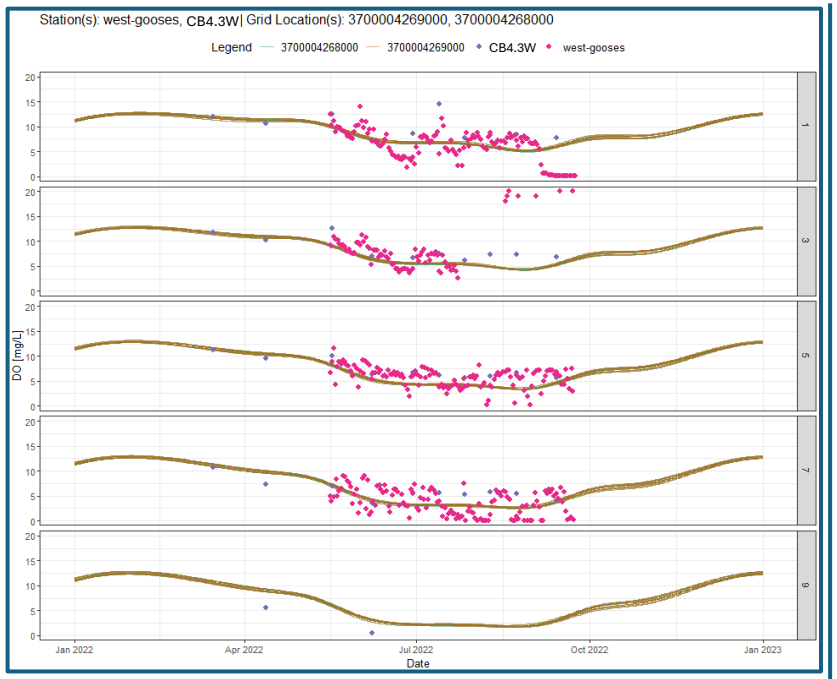
C) Within day (cyclic) interpolation

B) Mid-day + Large-scale correlation: spatial + daily ($\varepsilon_{xyz,\,d}$)

D) Small-scale correlation component (ε_h)

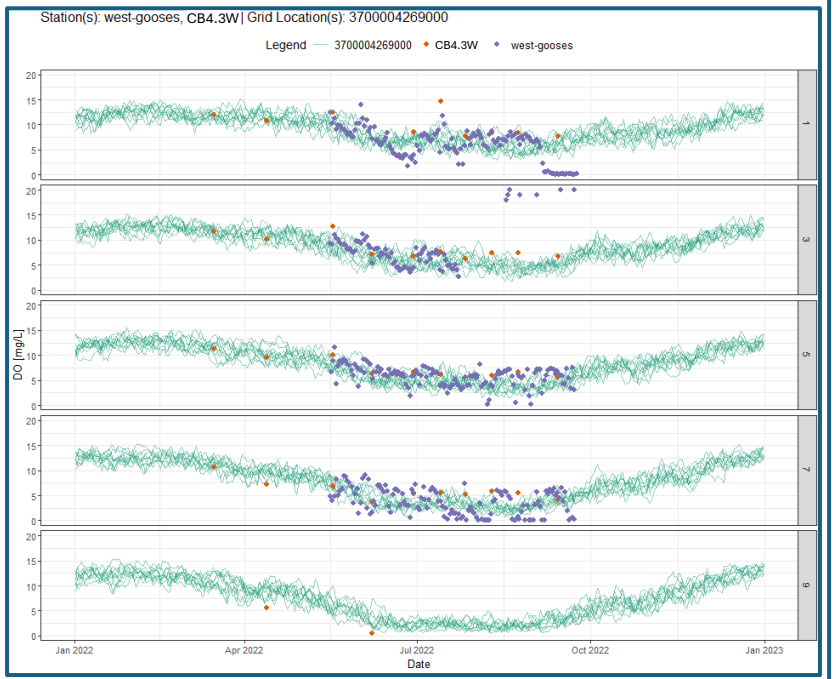
Graphics generated by Jon Harcum, Tetra Tech

A) Mid-day space-and-time interpolation



B) Mid-day + Large-scale correlation: spatial + daily ($\varepsilon_{xyz,\,d}$)

Simulation using correlation coefficients computed from many years of data sets (common, dataflow and vertical profiles)



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Graphics generated by Jon Harcum, Tetra Tech

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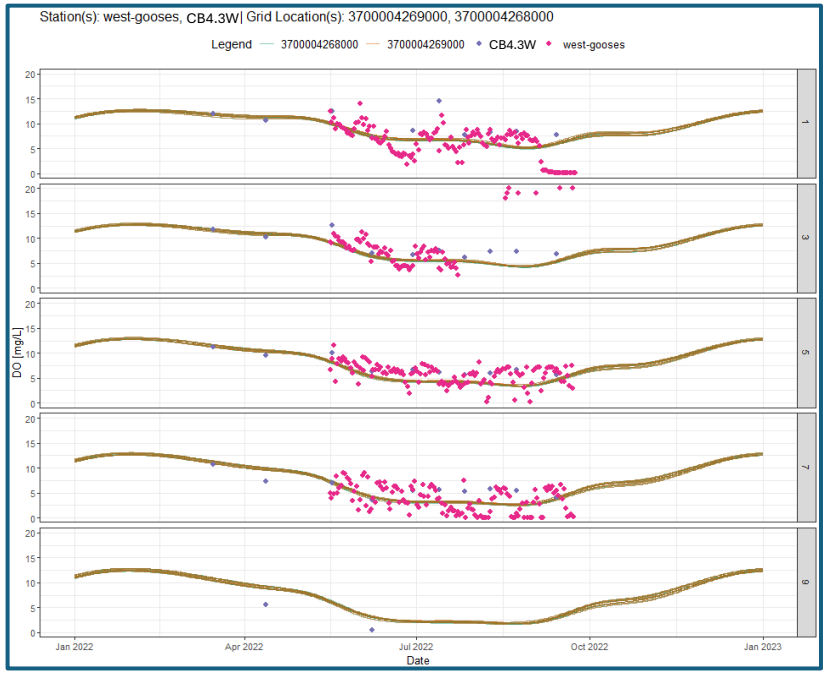

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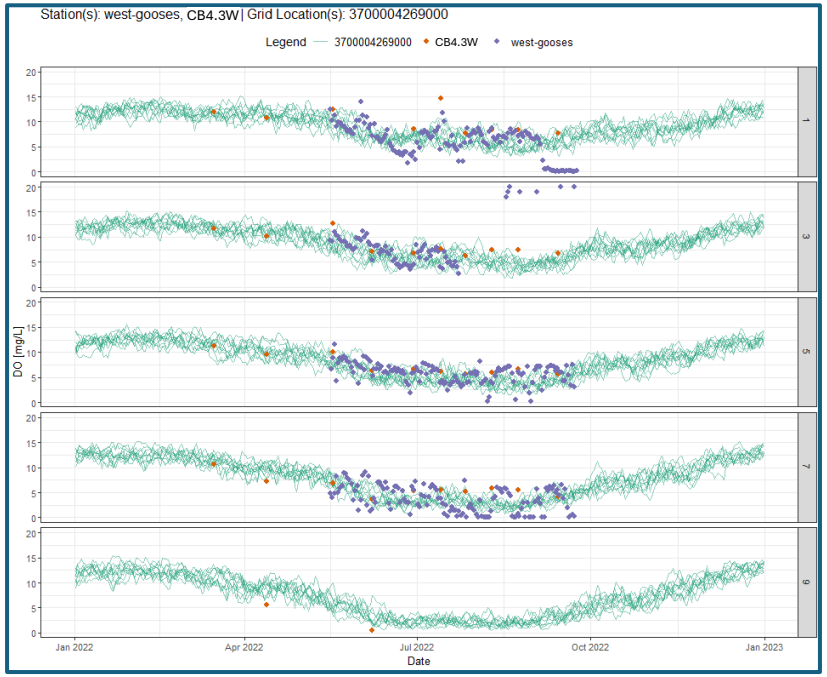
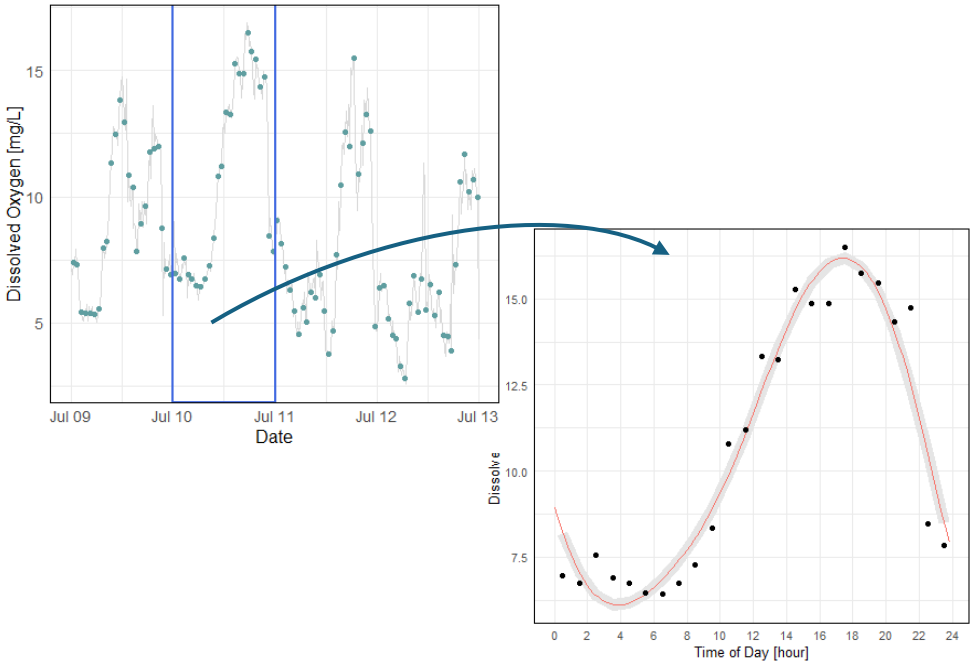


C) Within day (cyclic) interpolation

Tidal and daily cycles identified from all conmon data. (Work likely to still include varying coefficients by location and time.)



D) Small-scale correlation component (ε_h)

Graphics generated by Jon Harcum, Tetra Tech

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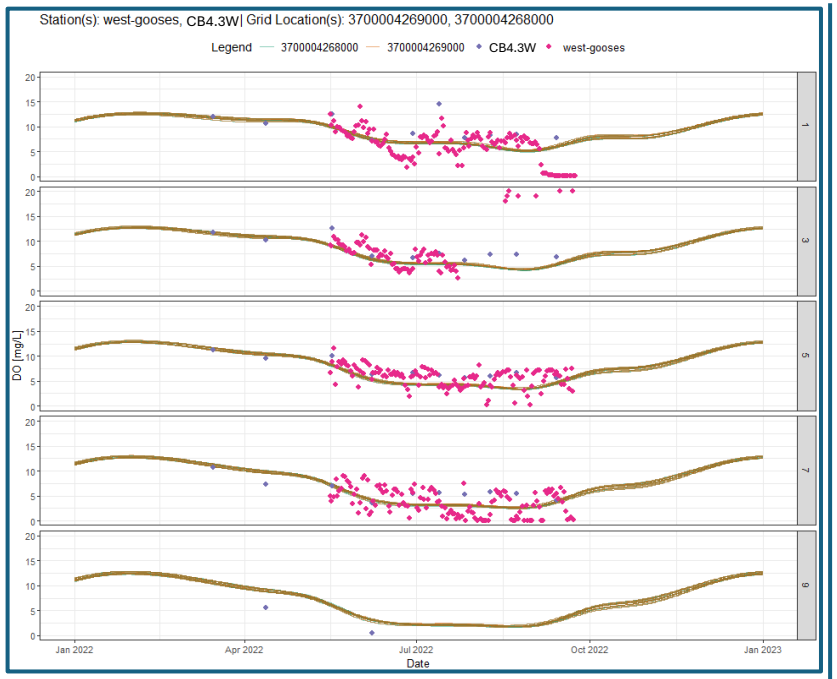
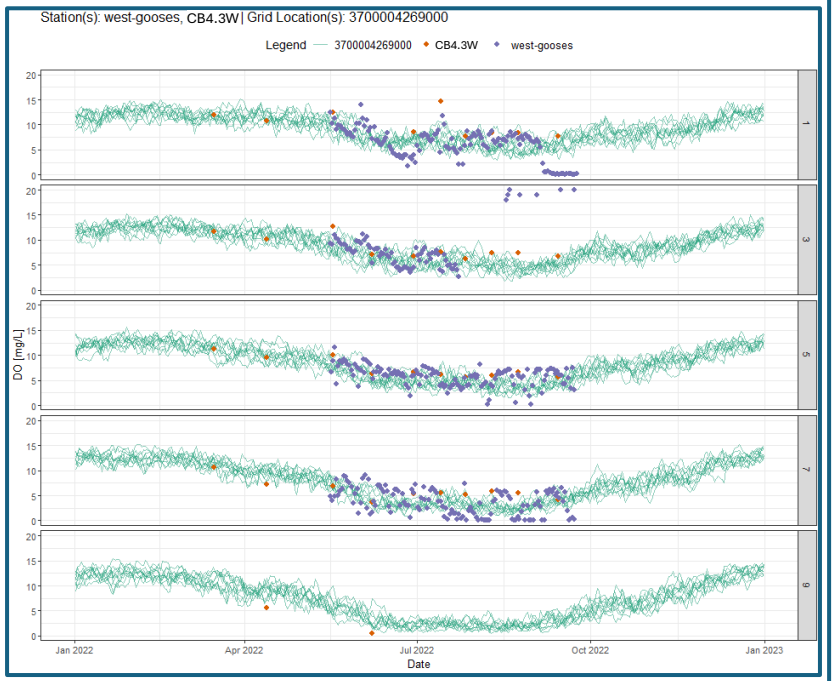


B) Mid-day + Large-scale correlation: spatial + daily ($\varepsilon_{xyz,\,d}$)



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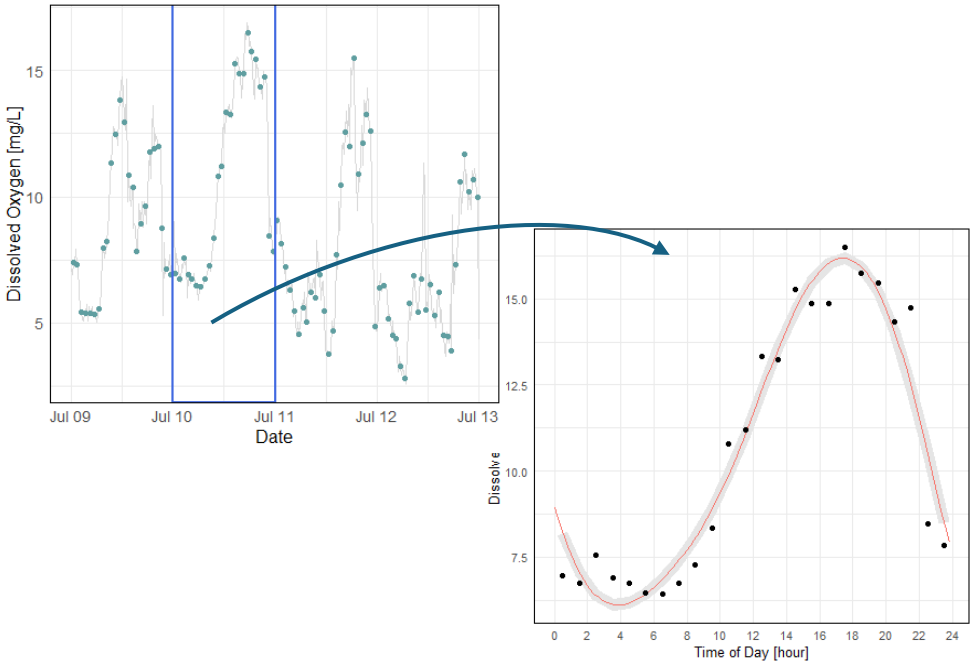
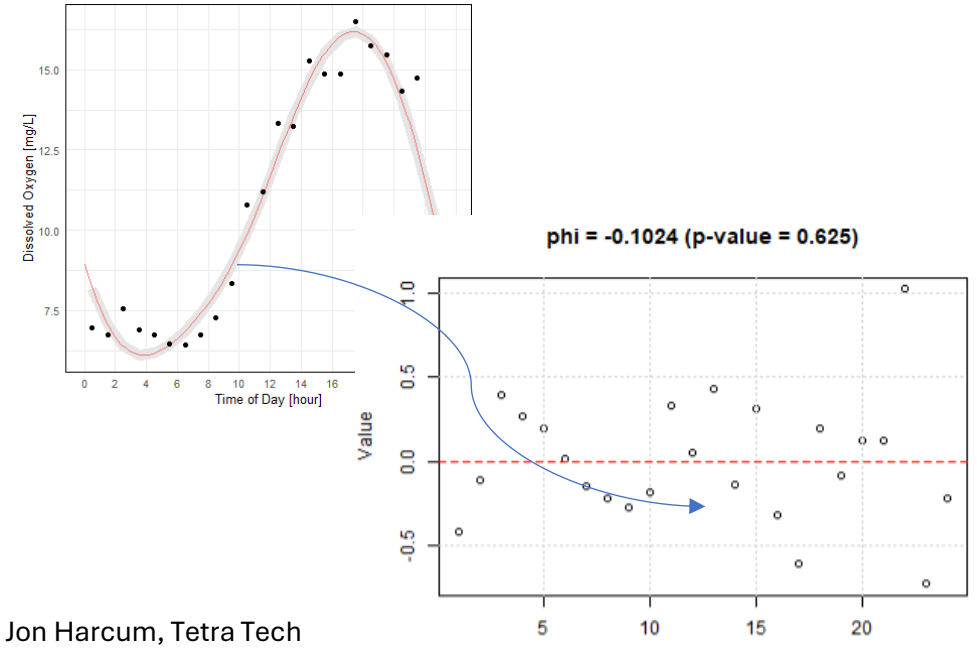


D) Small-scale correlation component (ε_h)

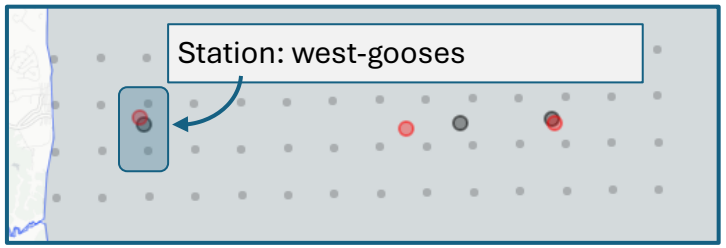
Residuals from all daily and tidal cycles used to identify small scale correlation

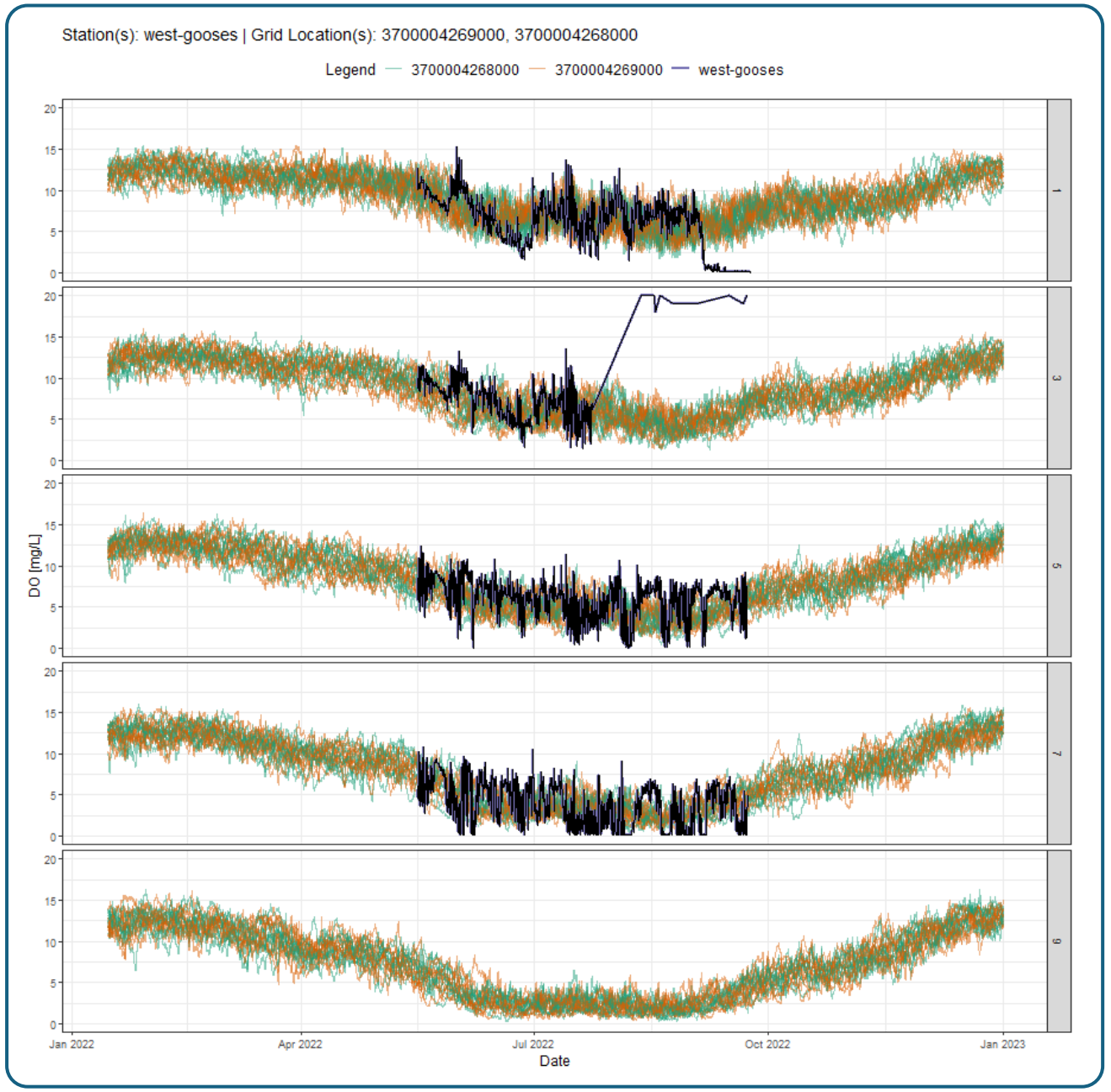


Graphics generated by Jon Harcum, Tetra Tech

Statistical Interpolation – comparison with high frequency data

- Add the 4 interpolation pieces together to get one realization
- Generate multiple realizations to account for the range of possible conditions
- Example 10 realizations from grid cells near “west-gooses” vertical array
  - 2022

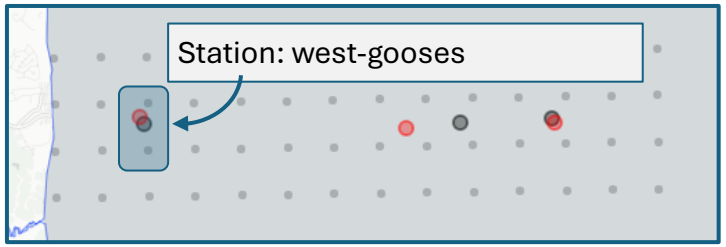


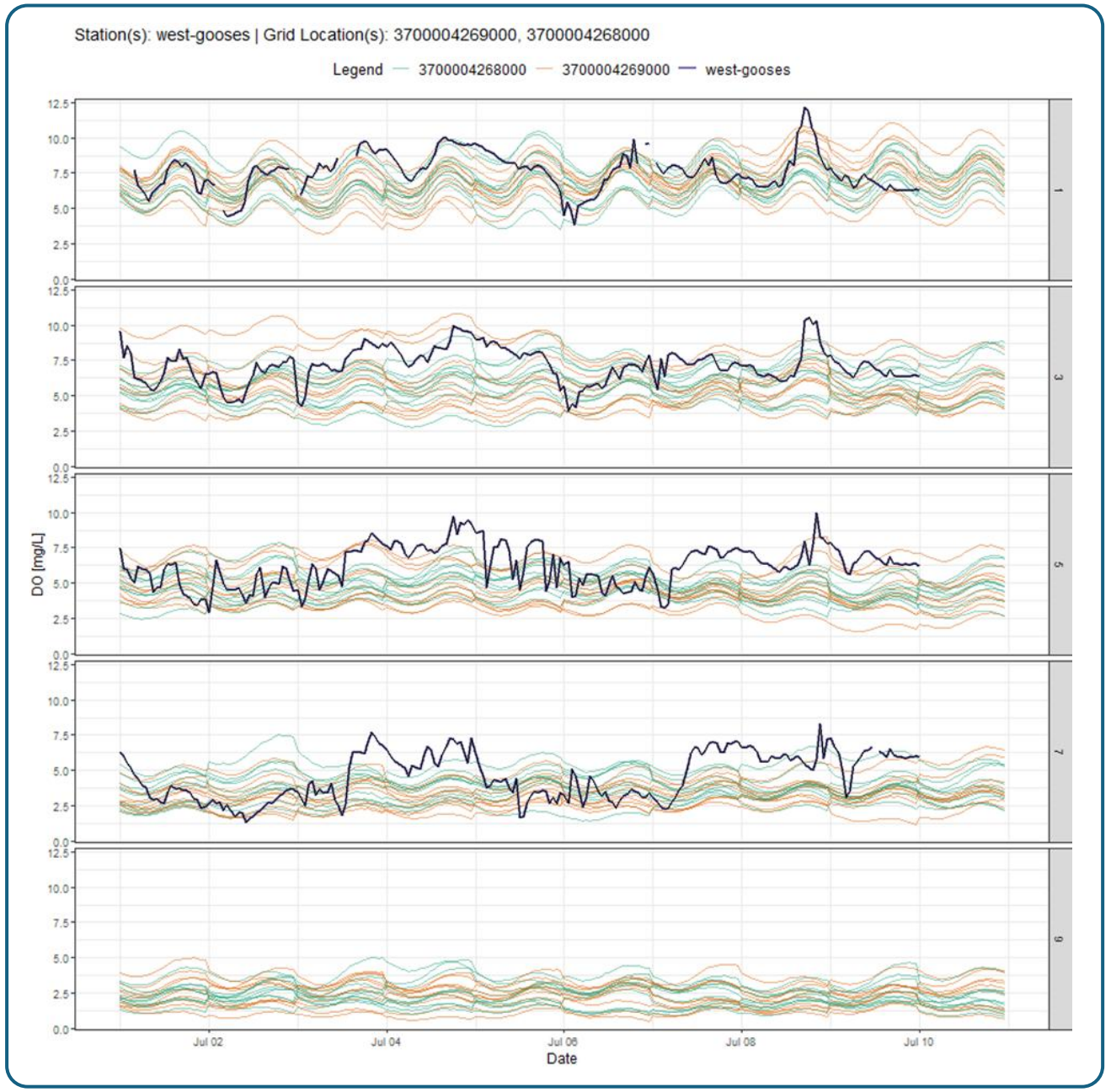


Graphics generated by Jon Harcum, Tetra Tech

Statistical Interpolation – comparison with high frequency data

- Zoom in: 10 realizations from grid cells near “west-gooses” vertical array
  - July 1-10, 2022

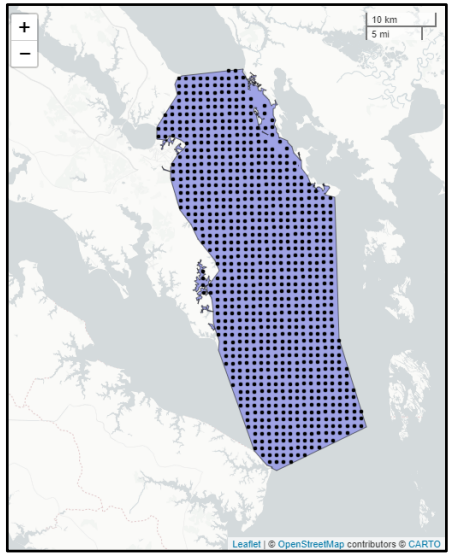


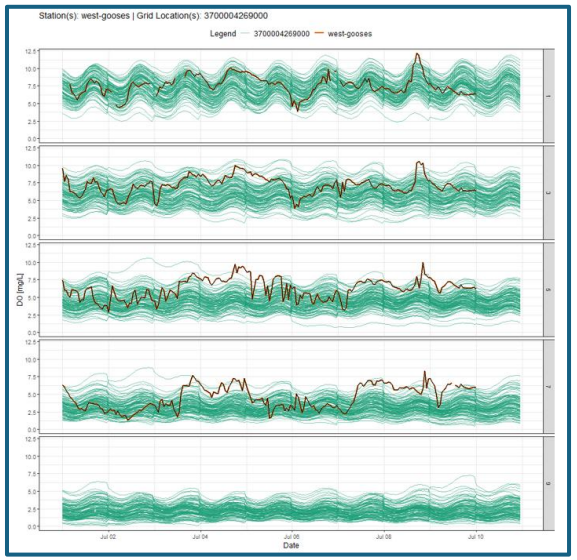


Graphics generated by Jon Harcum, Tetra Tech

Scaling up

Use interpolation grid and bathymetry data in every segment

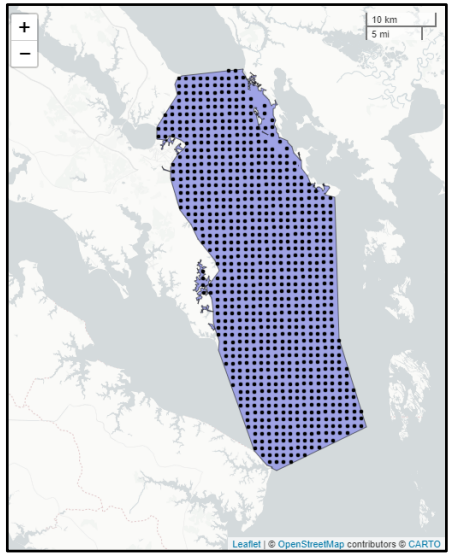


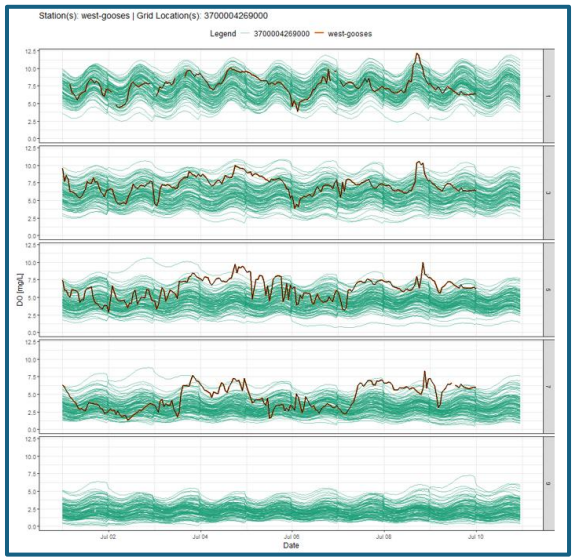


Interpolate DO every hour in a year, with ~100 realizations

Scaling up

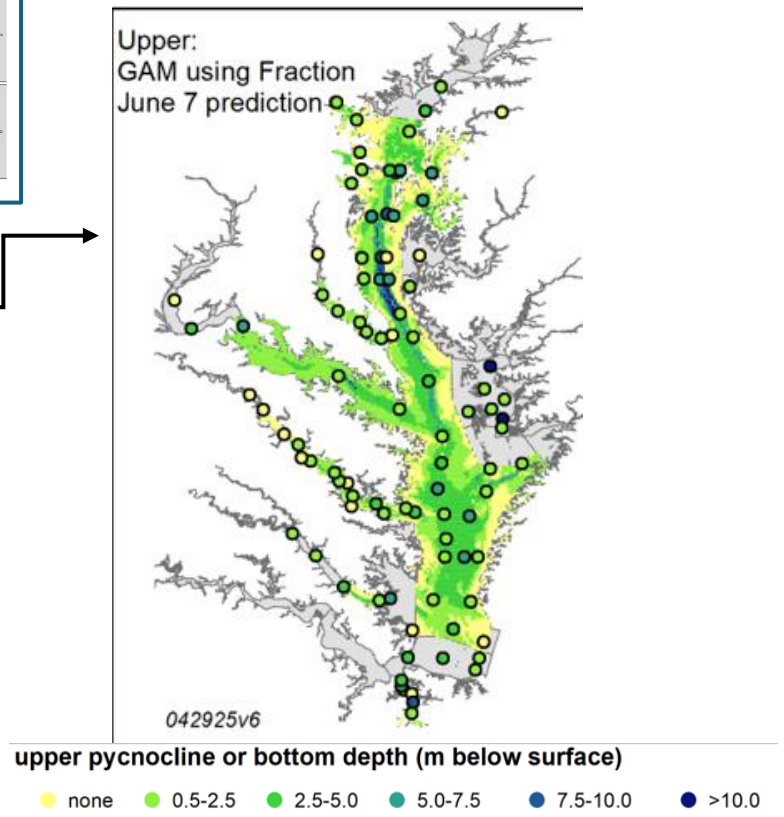
Use interpolation grid and bathymetry data in every segment





Interpolate DO every hour in a year, with ~100 realizations

Compute and interpolate daily pycnocline in summer months, applicable DUs



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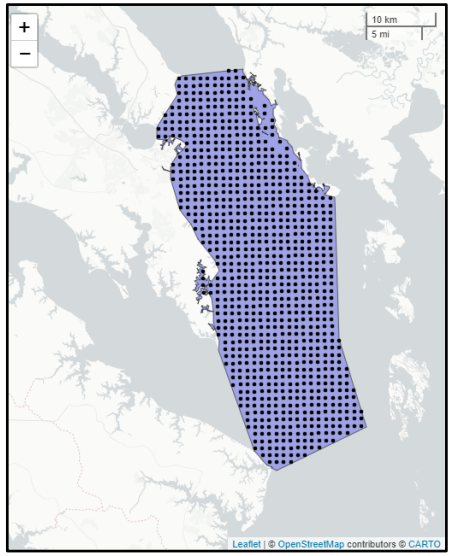

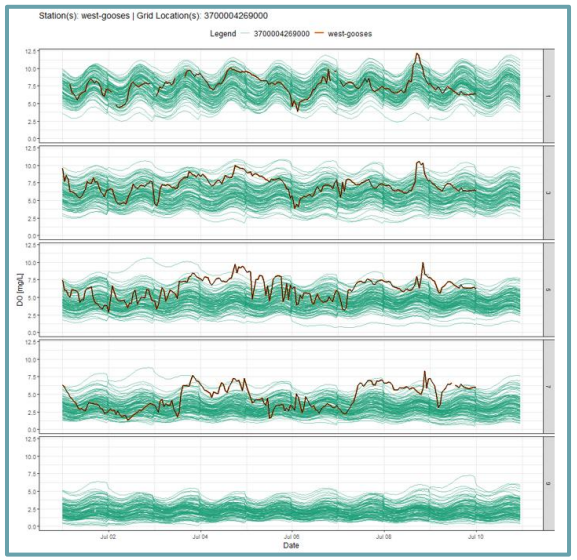

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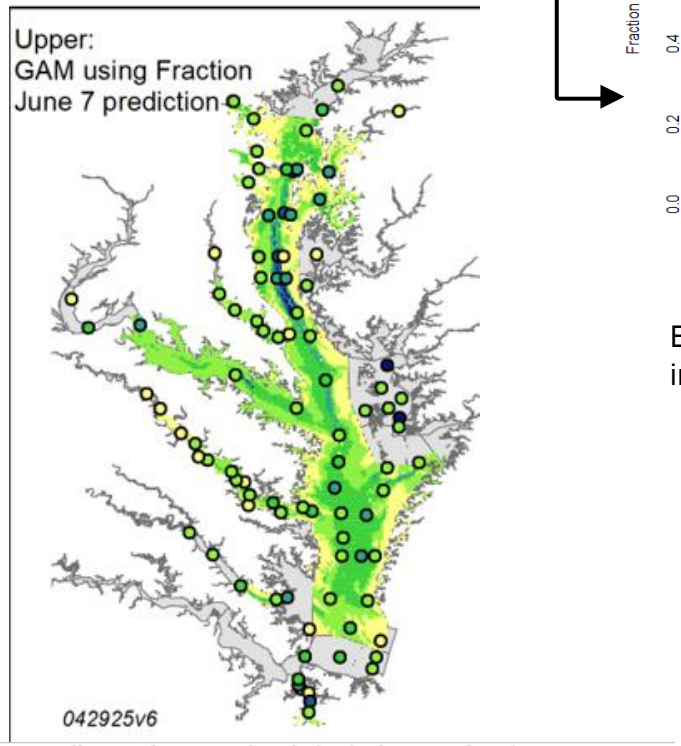
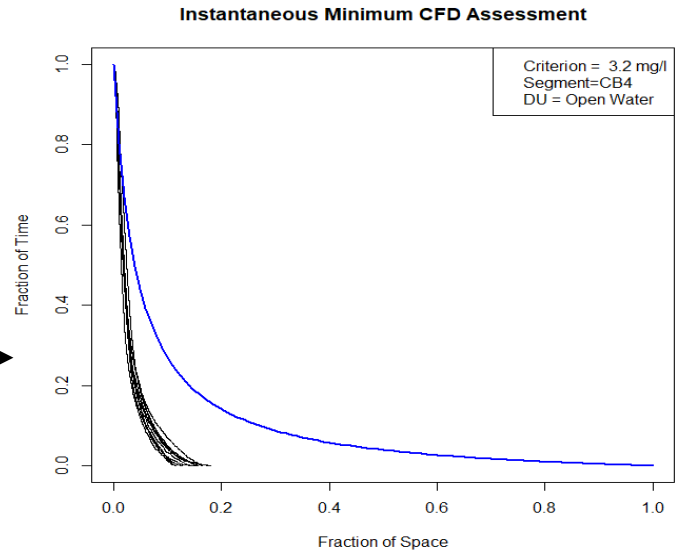


Output can be used in current CFD approach (working with CAP on some of the details)



Elgin Perry's work example: 10 simulations, OW instantaneous CB4MH 2022

Next steps relevant to modeling team

- Remaining development:
  - *Finish 4-D simulation approach and initial parameterization (2025).*
  - *Evaluate and compare to data and 3-D interpolator via case study (2025 into early 2026)*
  - *Implement/test methods for using interpolation results to evaluate high frequency criteria based on CAP's direction (2026).*

- Considerations for using 4-D interpolator in scenario assessment of model output:
  - *We should be able to input "model-as-data" estuarine model results into 4-D interpolation, just like 3-D is done.*
  - *We will be informing the high frequency variability with data collected after the 1990s.*