Exploratory Analysis of historical data:
The influence of temperature on dissolved oxygen resources in the Open and Shallow waters of the Chesapeake Bay

CAP Workgroup

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Rebecca Murphy, UMCES at CBP and Breck Sullivan, CRC

Motivation:

It appears that the CBP climate change scenarios predict more negative impacts on summer dissolved oxygen (DO) concentrations in Open and Shallow Water areas than in Deep Water, but it is still under investigation how well the estuarine model is capturing Open and Shallow response to rising air temperatures.

Rationale:

We can gain some insight into the estuarine model climate change predictions by analyzing the tidal long-term monitoring data and comparing patterns in temperature and DO over the last 30 years.

Topic 1: Open Water (OW)

Approach:

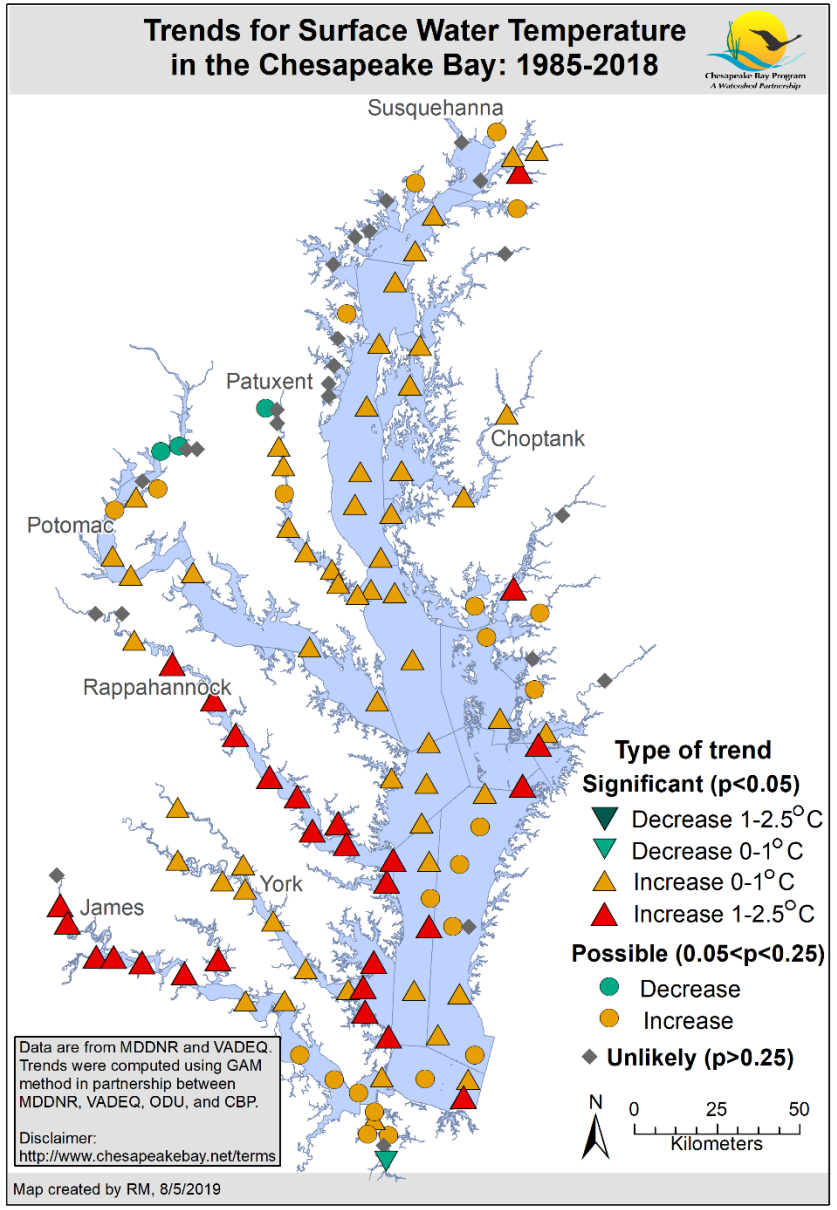
1. See how well monitored temperature change throughout the water column since the mid-1980s compares to estuarine model climate change predictions.

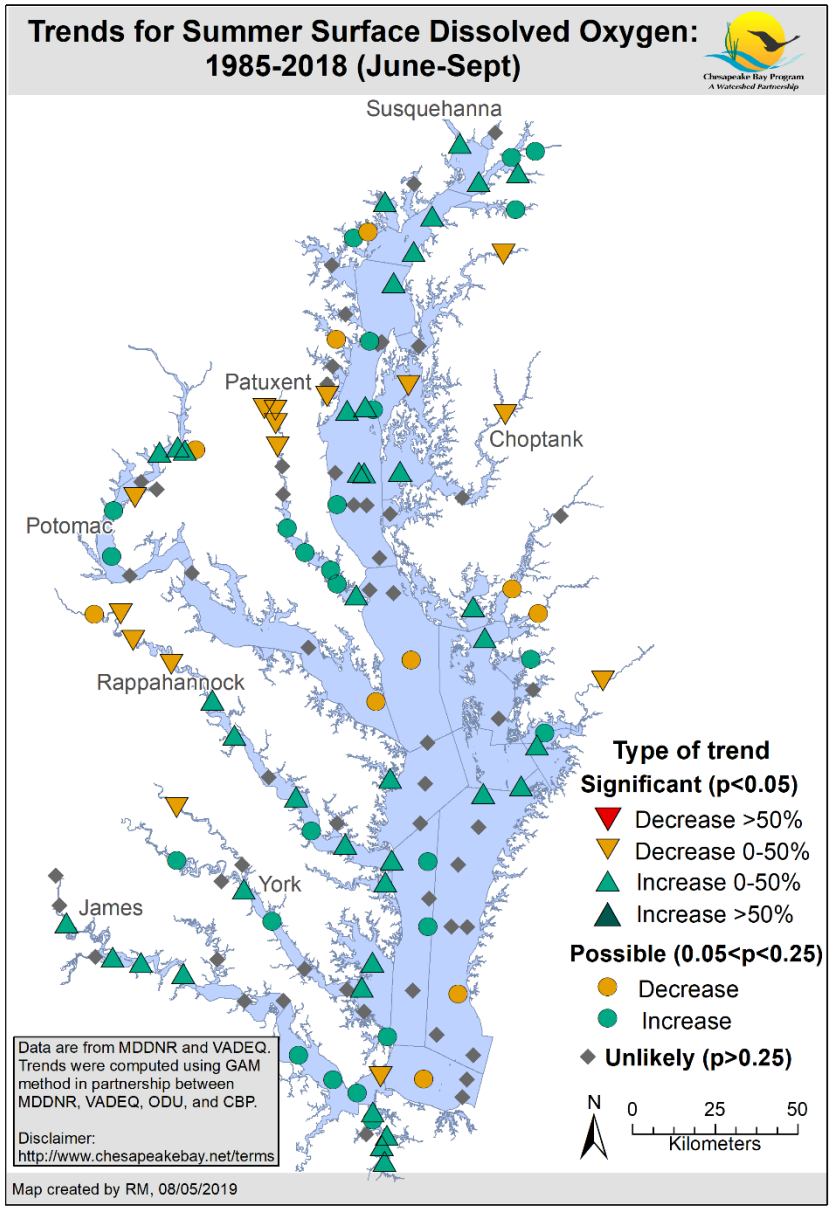
2. Investigate how well the past 30 years of DO saturation change throughout the water column compares to the estuarine model's climate change predictions.

Existing data analysis

- MD and VA state collaborators fit GAMs (generalized additive models) to DO and temperature annually, surface and bottom
- Surface temperature is increasing at almost all stations
- Surface DO trends are mixed

→ *We can take this a step further and fit GAMs to the data at each depth at each station to see if there are patterns with depth*



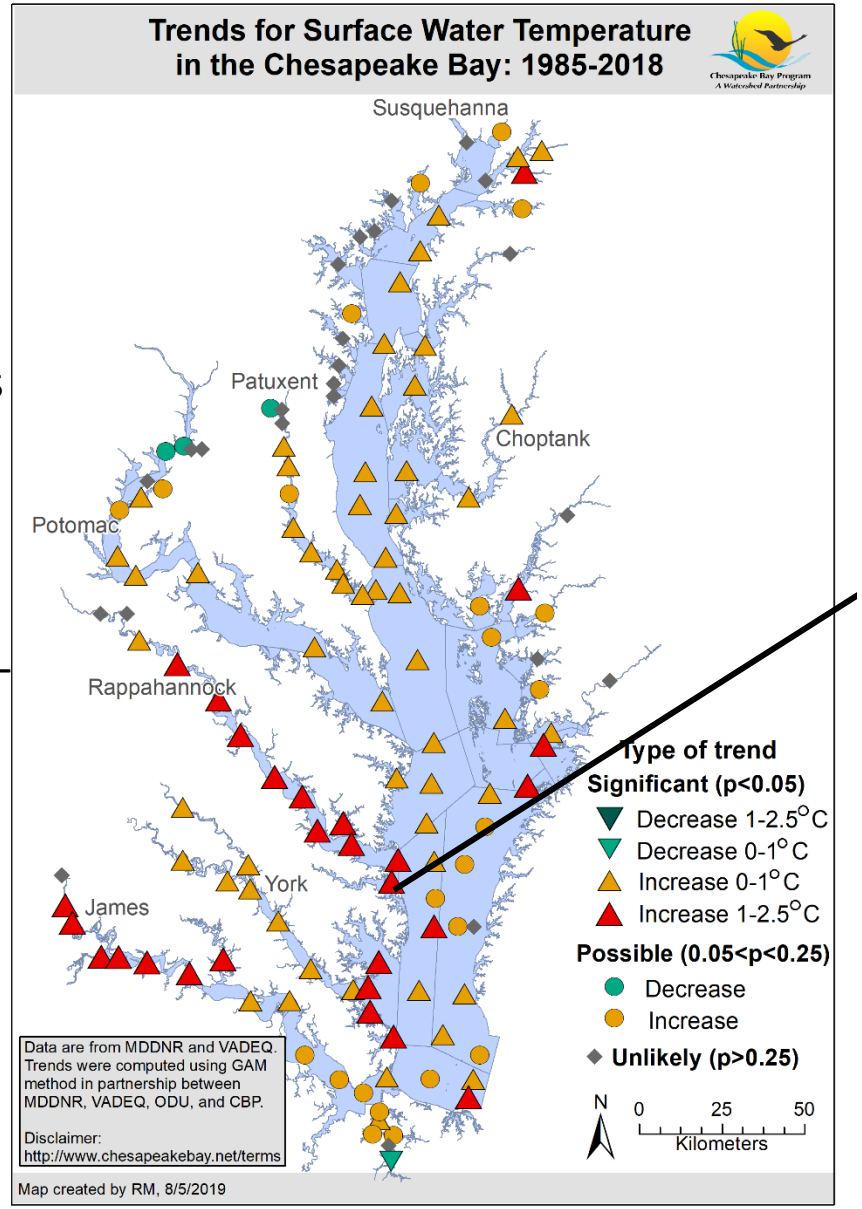


https://www.chesapeakebay.net/who/group/integrated_trends_analysis_team

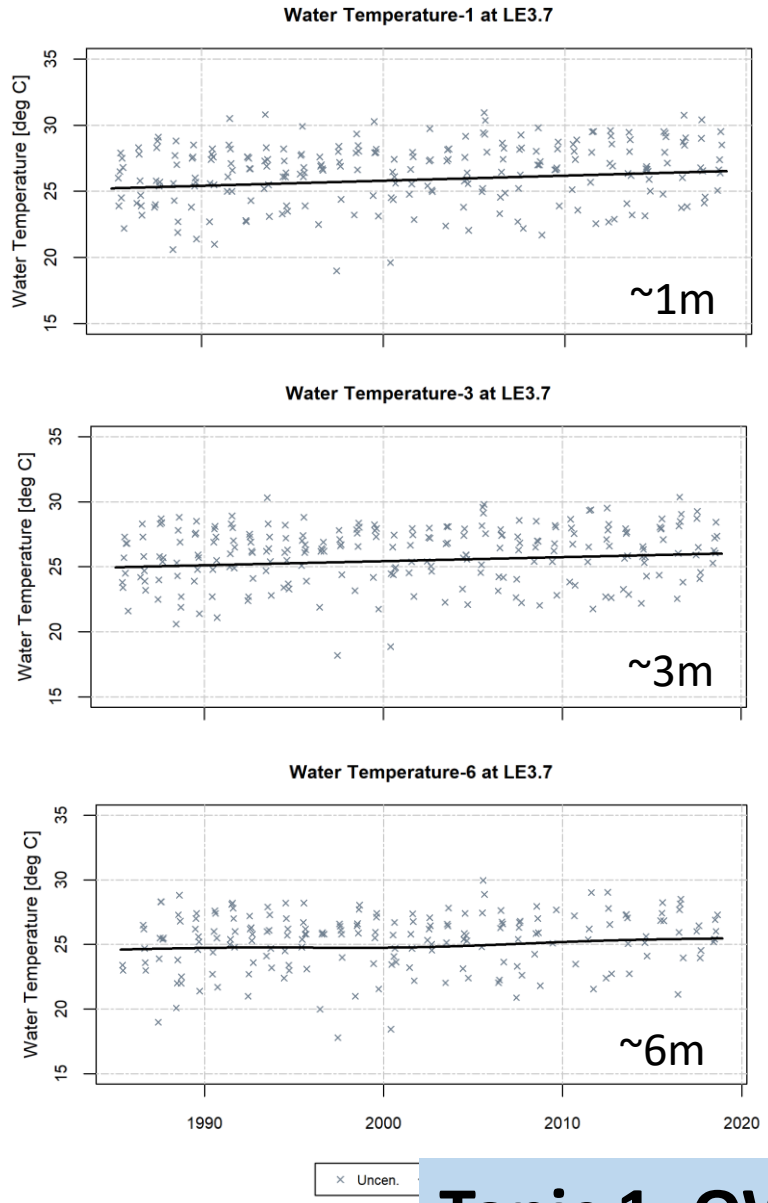
Topic 1: OW

Extended data analysis

1. Compile and identify any depth at any station with >300 samples from the 1980s to 2018 (DO, temp, salinity, computed DO-saturation)
2. Fit a GAM to evaluate change over time at each unique station-depth-parameter data set



Summer (June-Sept) only excerpts from full annual fit

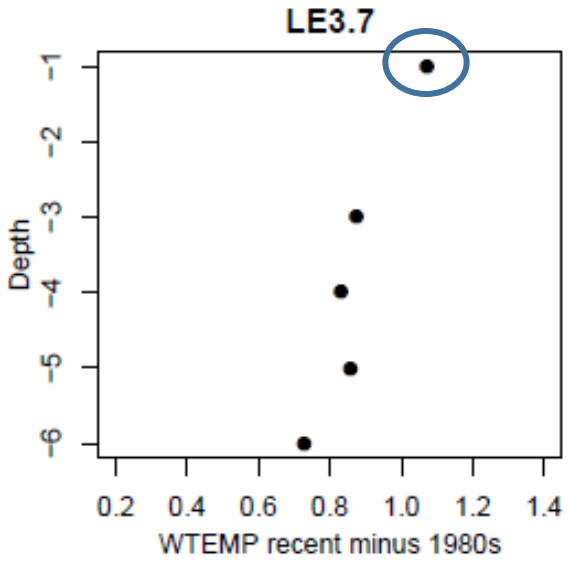


Topic 1: OW

Extended data analysis

1. Compile and identify any depth at any station with >300 samples from the 1980s to 2018 (DO, temp, salinity, computed DO-saturation)
2. Fit a GAM to evaluate change over time at each unique station-depth-parameter data set
3. Identify years from the beginning to end to compute change. Tested options, and settled on two 5-year periods with similar average input river flow (1985-1989 to 2013-2017)
4. Compute change, make plots by depth

Summer (June-Sept) change: 2013 to 2017 temperature minus 1985 to 1989 temperature



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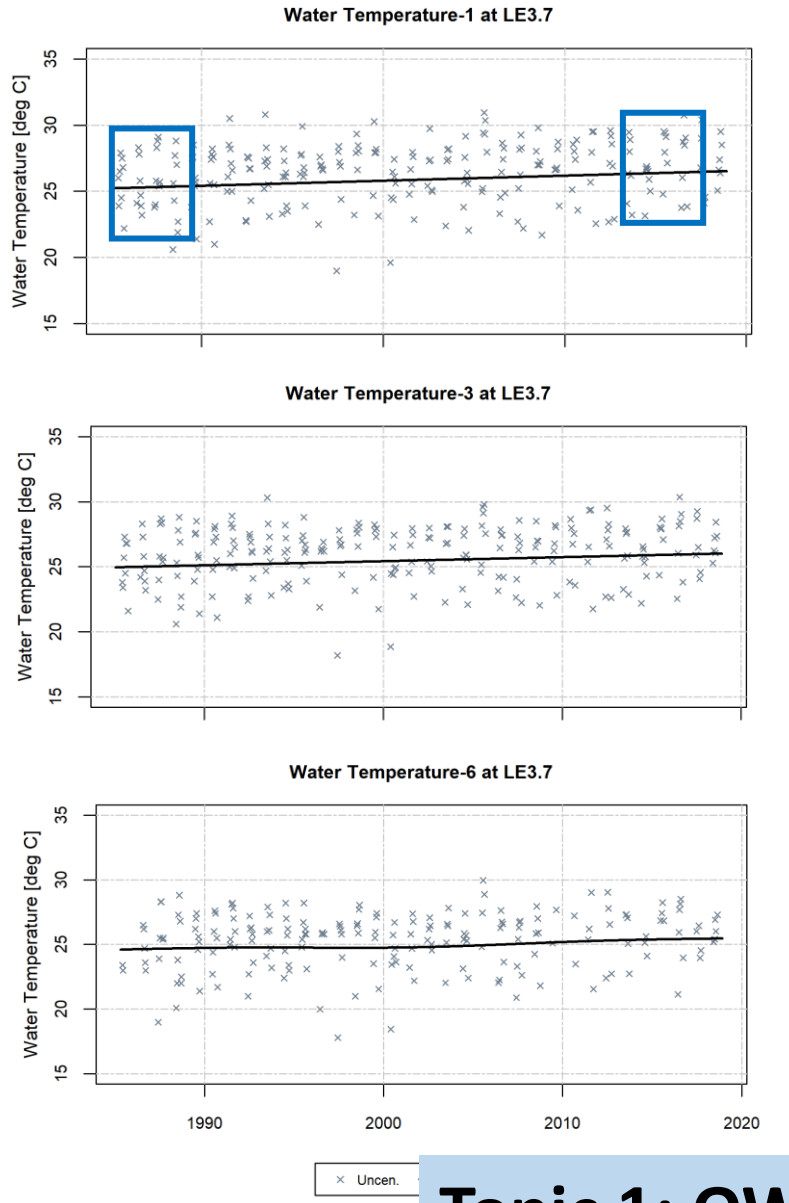
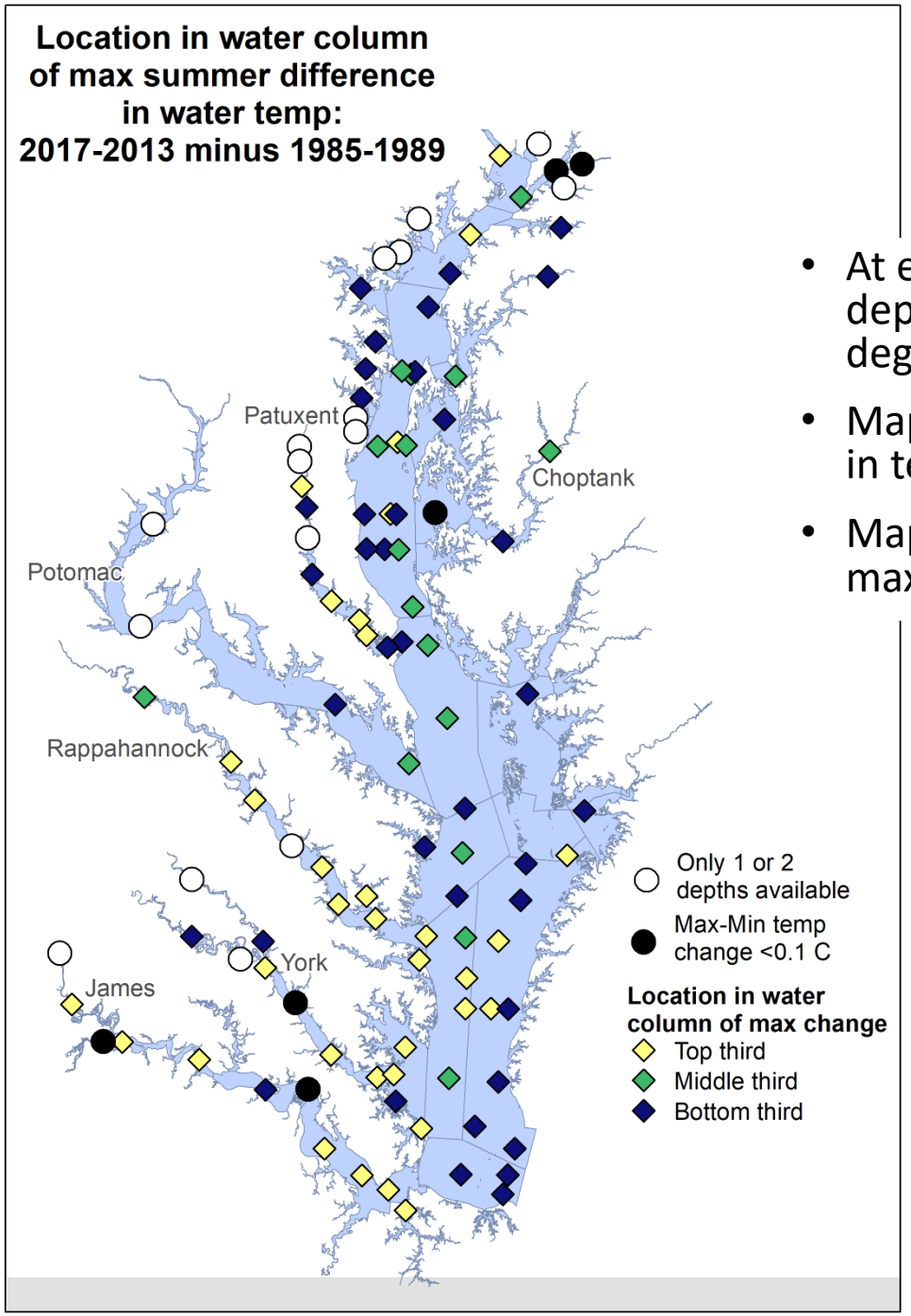
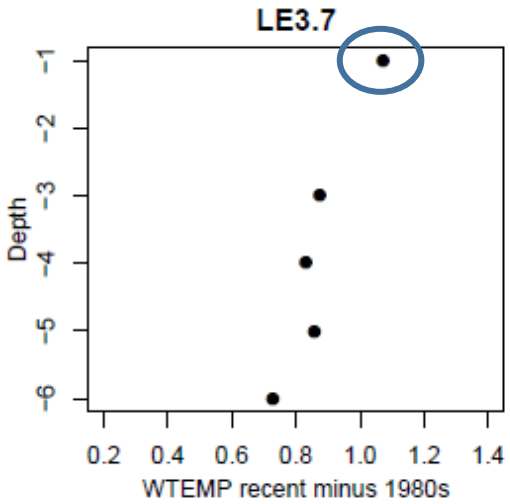
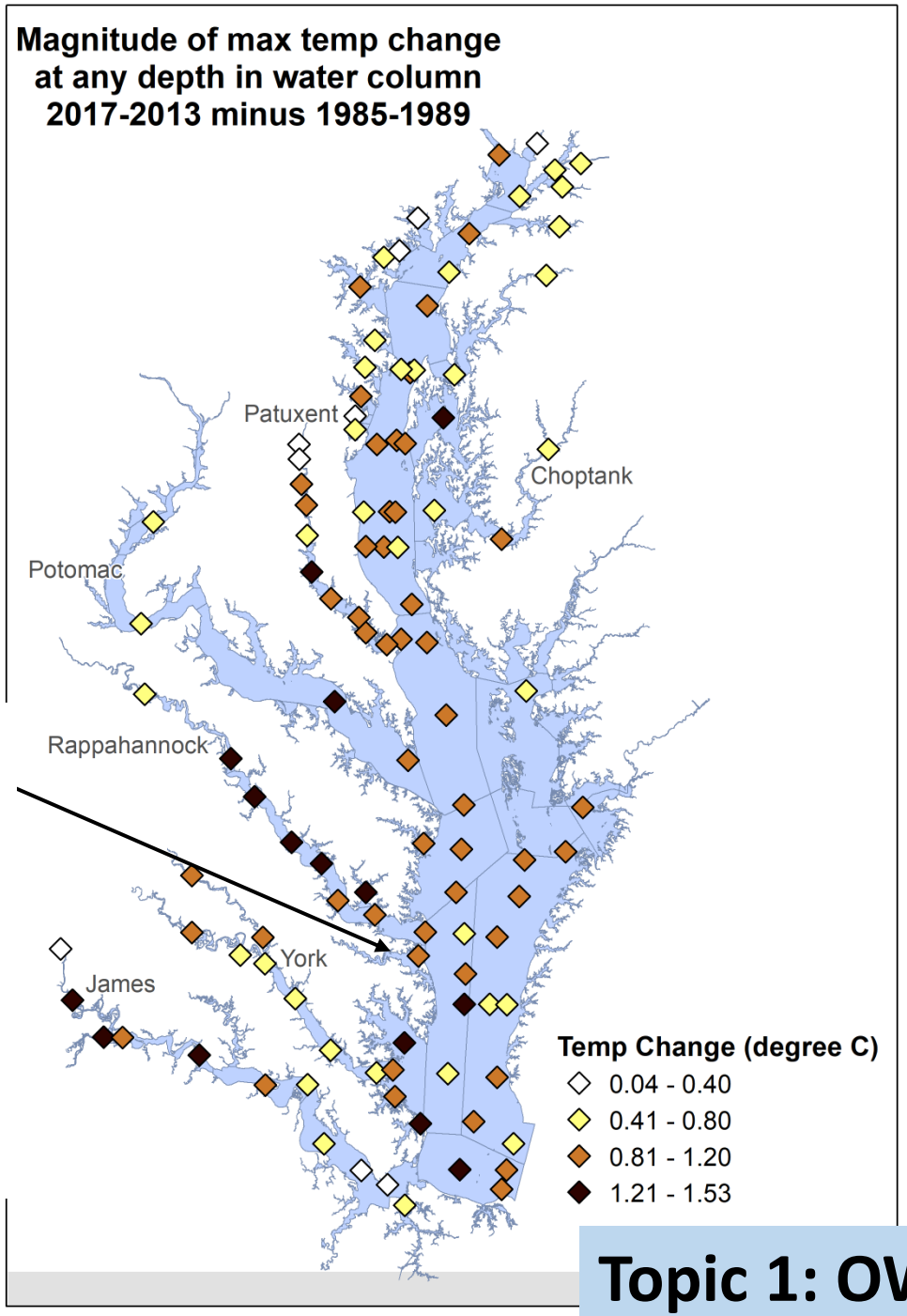


Topic 1: OW



- At each station, identify the depth with the largest degree change over time
- Map the maximum changes in temperature
- Map the depth of the maximum change





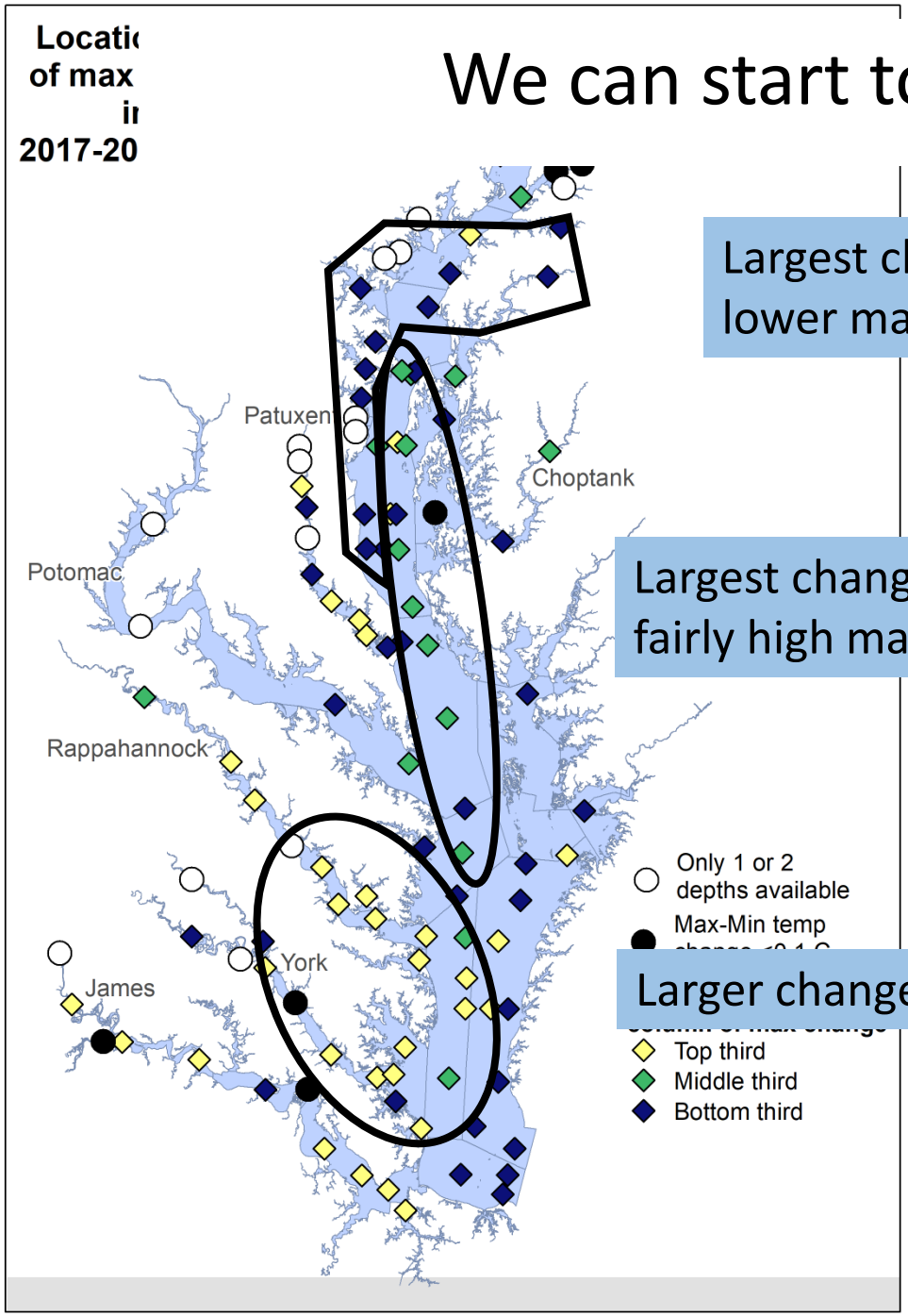
Topic 1: OW

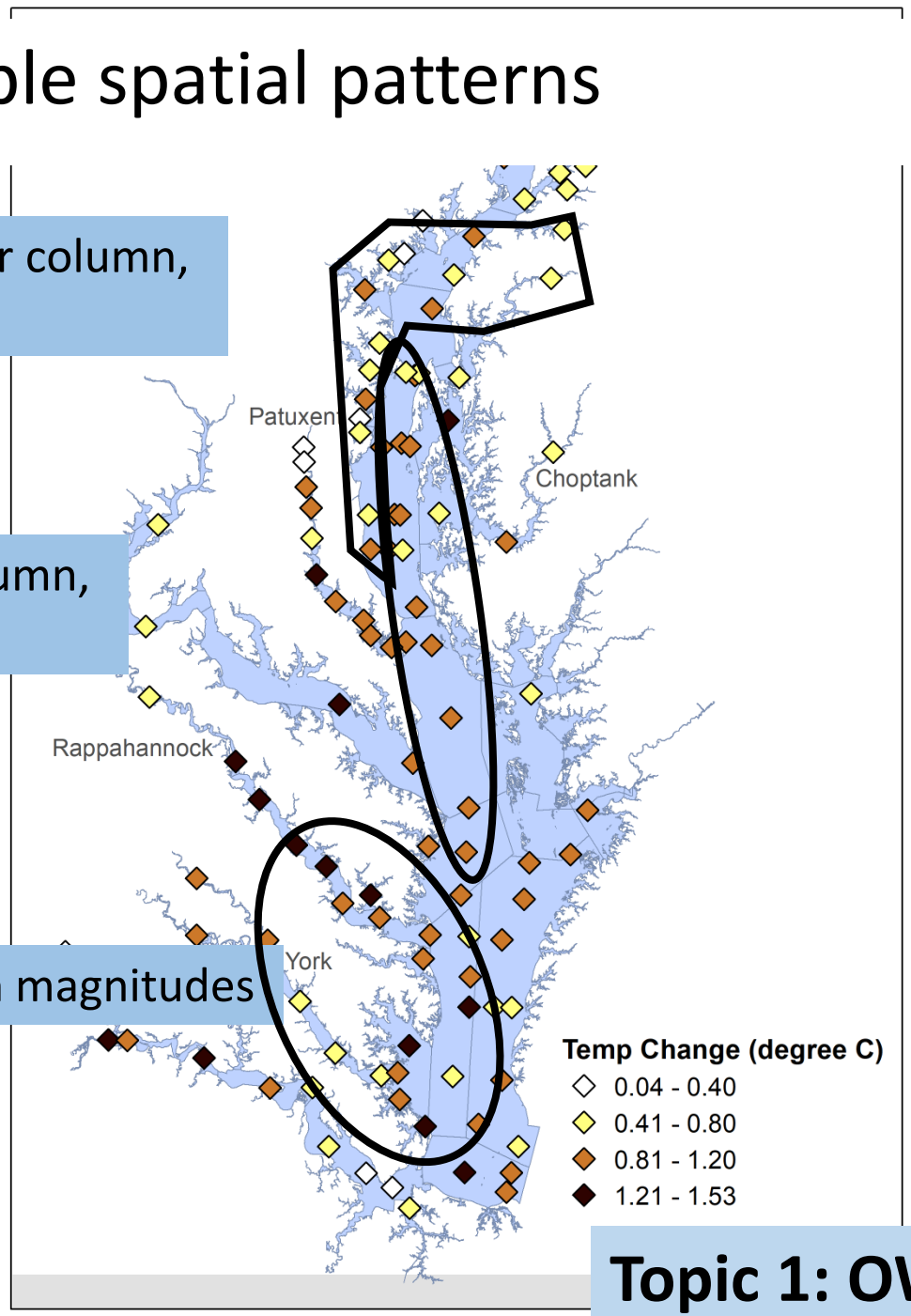
We can start to dig into possible spatial patterns

Largest change in bottom of water column, lower magnitudes

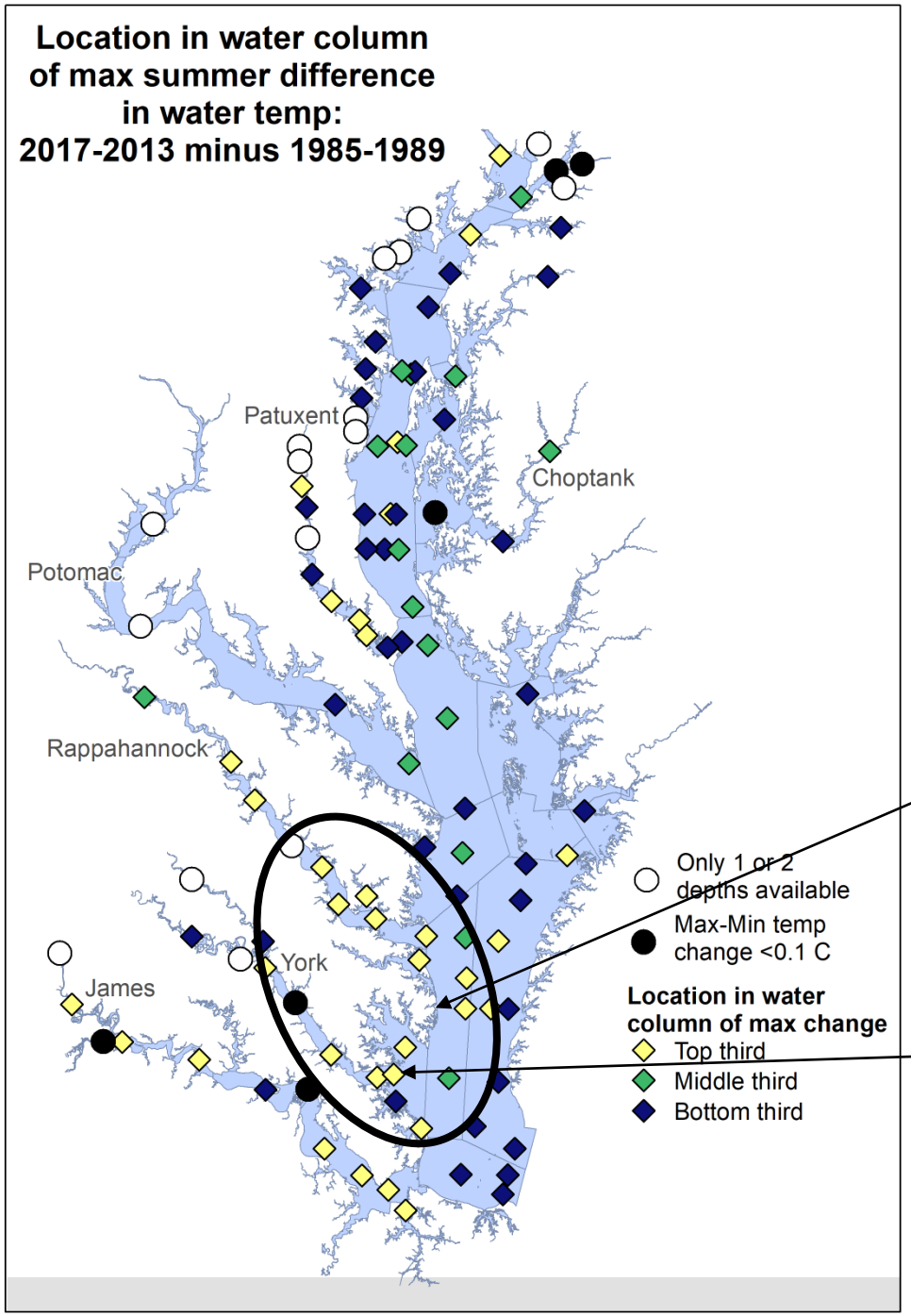
Largest change in middle of water column, fairly high magnitudes

Larger change near surface, fairly high magnitudes

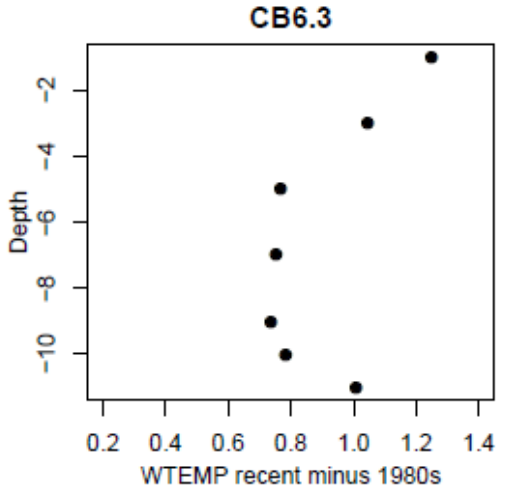


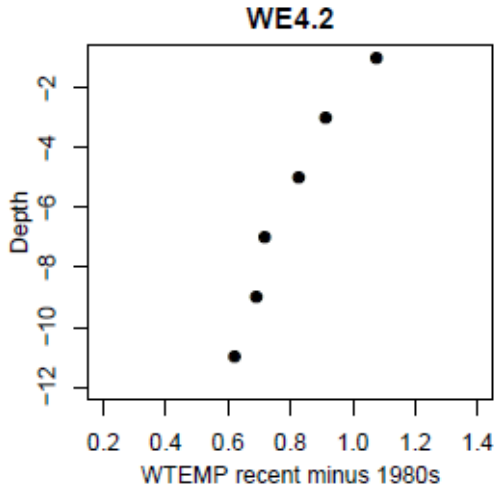


Topic 1: OW

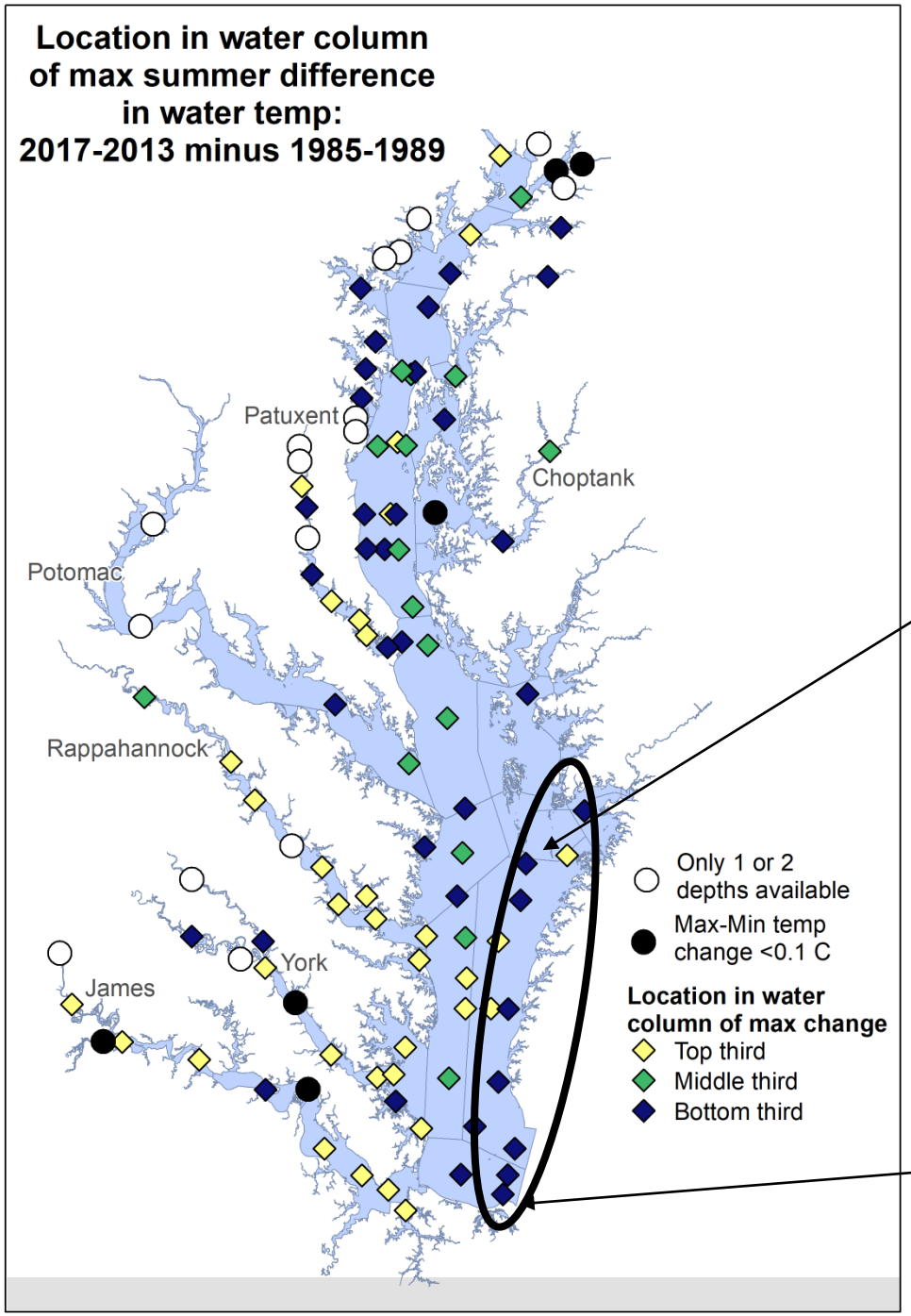


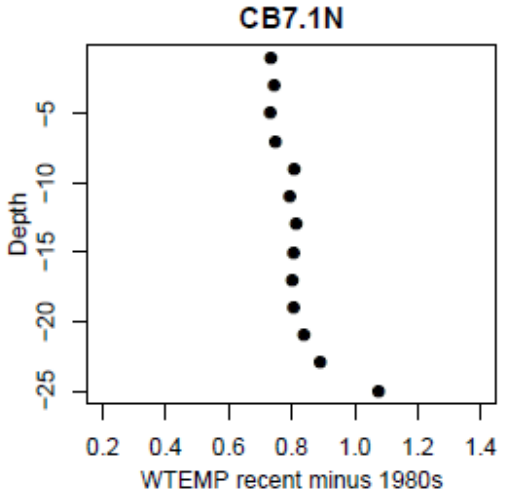
Lower Bay, western shore:
Larger change near surface, fairly high magnitude of change

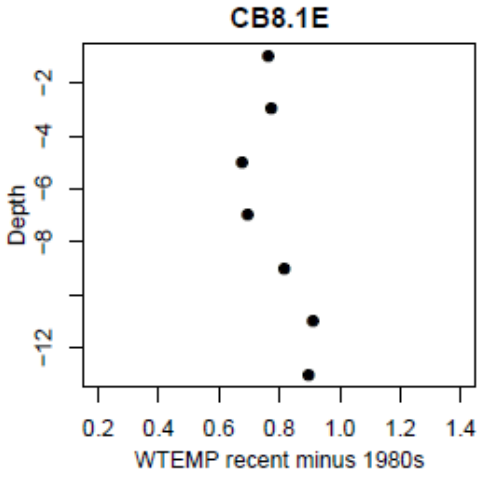




Topic 1: OW

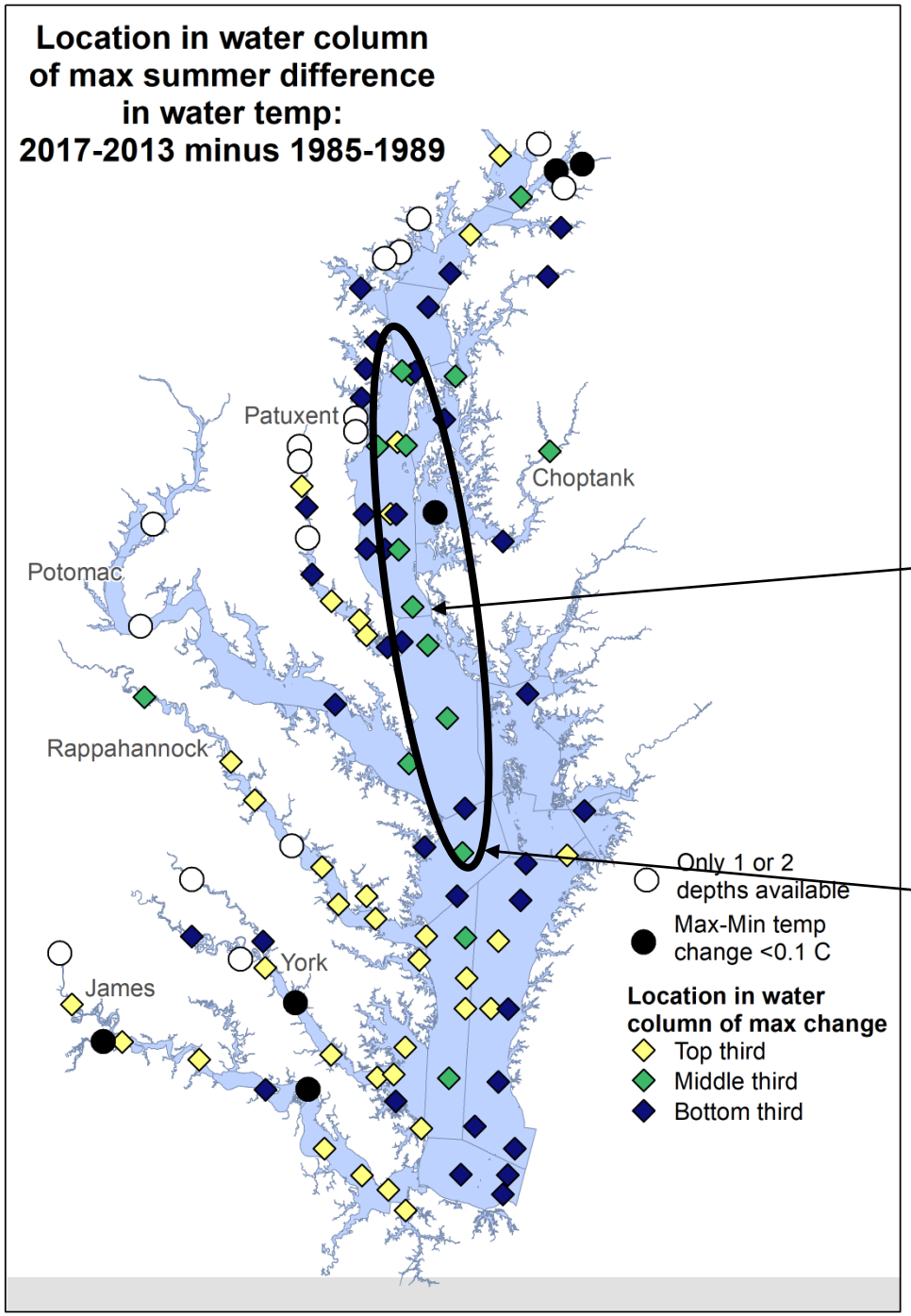




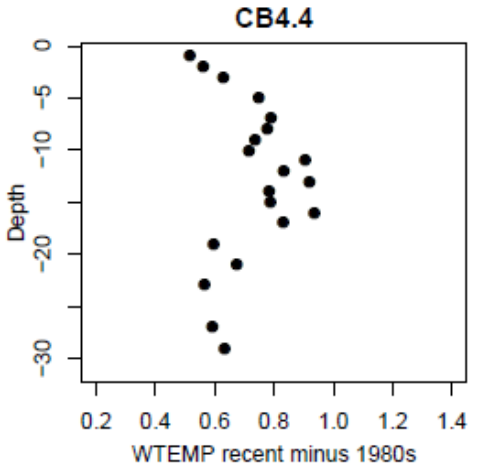


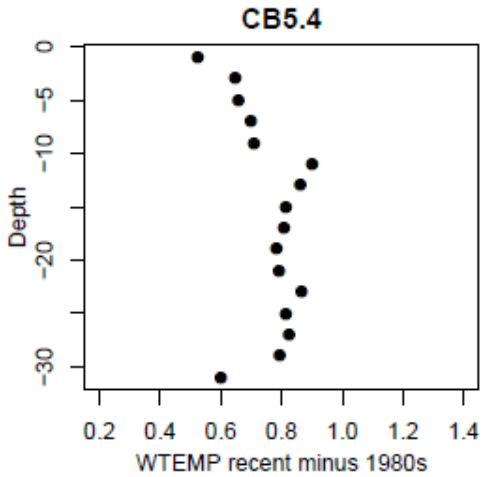
But surface increase the highest is not universally the pattern in lower bay. I think CB7PH is mixed, and CB8PH is definitely not.

Topic 1: OW



Mid-bay stations: Largest change in middle of water column, or relatively constant with depth





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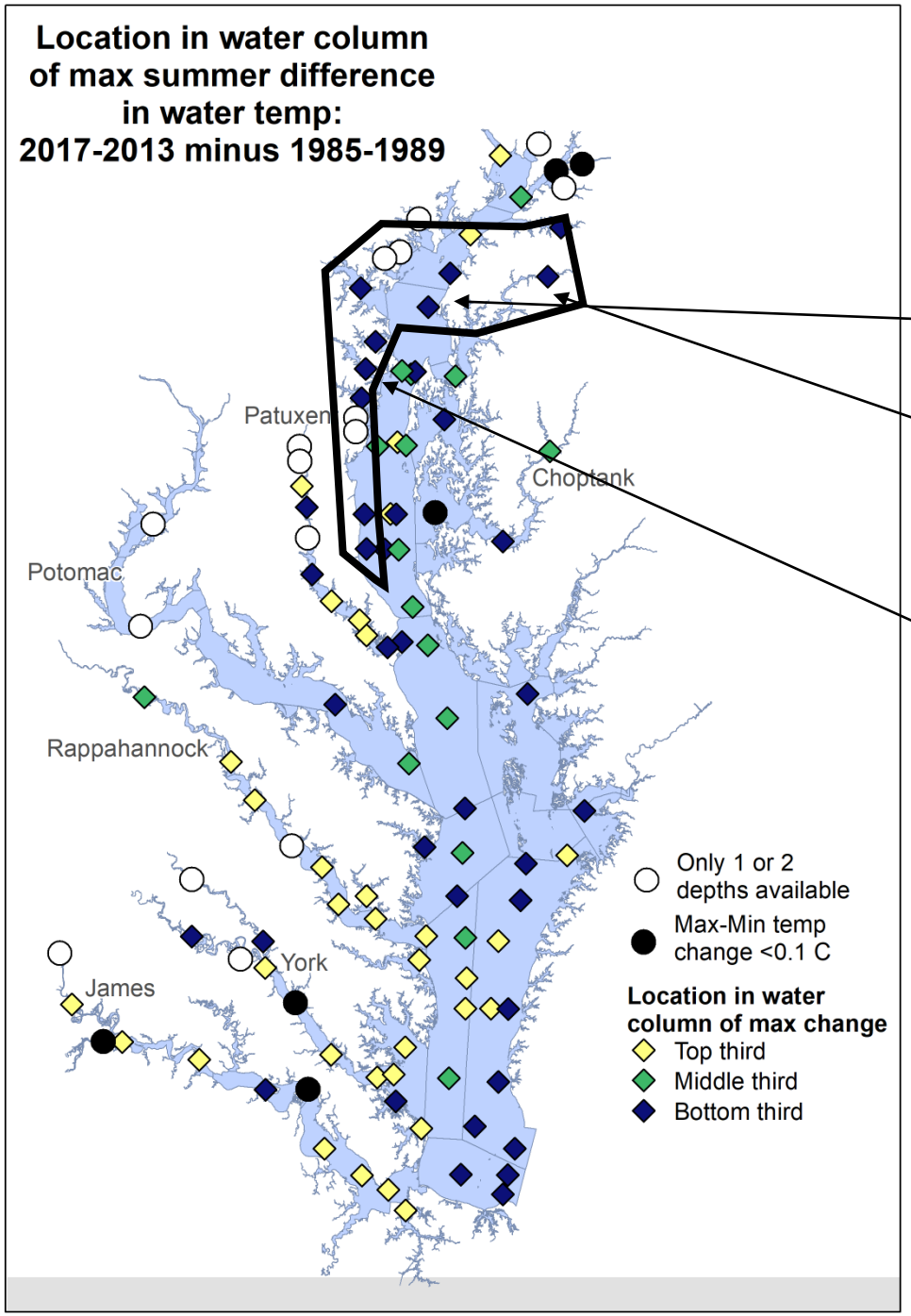
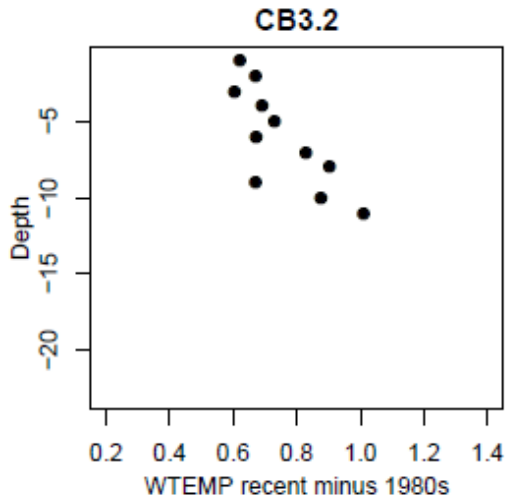
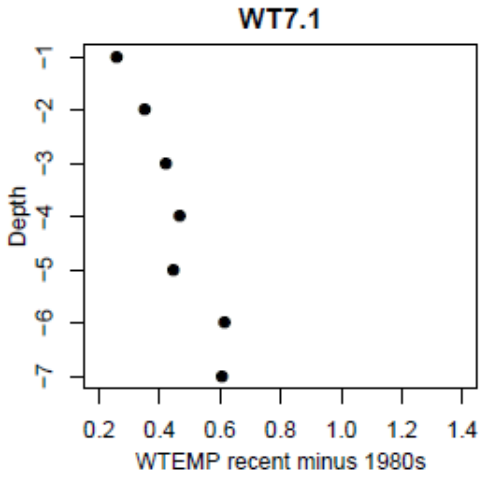
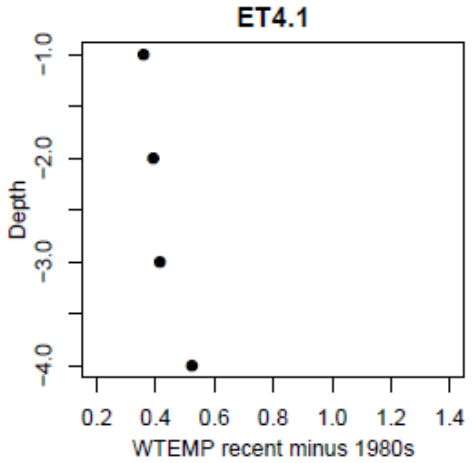


Many upper bay tributary and the OH stations: Largest change in bottom of water column, lower magnitude of change



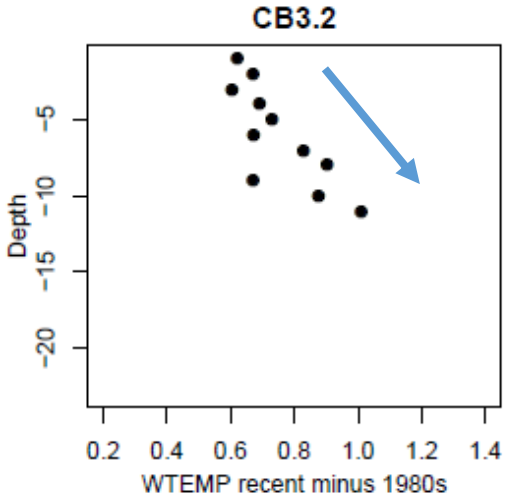


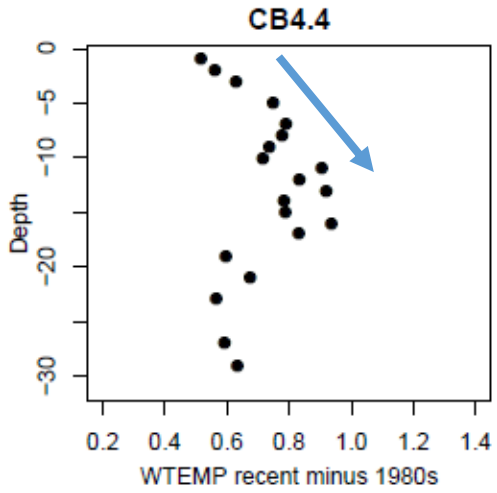


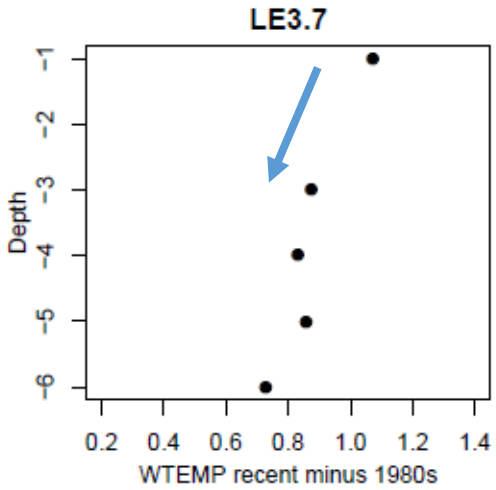
Topic 1: OW

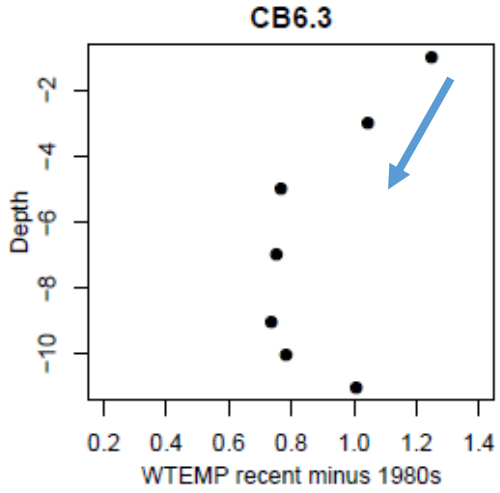
Open Water Temperature: How do these compare to model results?

Monitoring: Summer difference between 2013 to 2017 minus 1985 to 1989

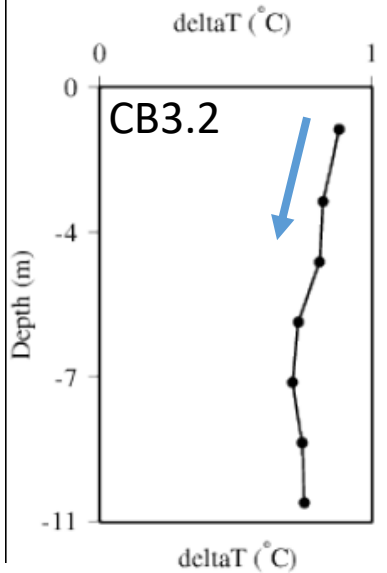


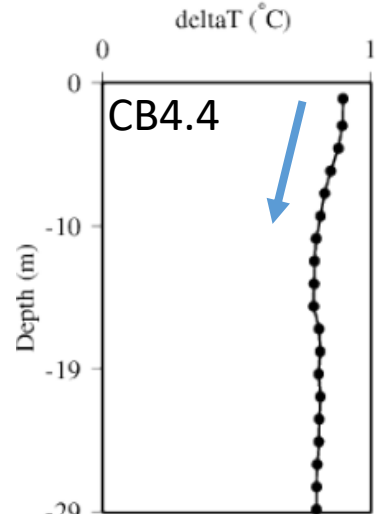




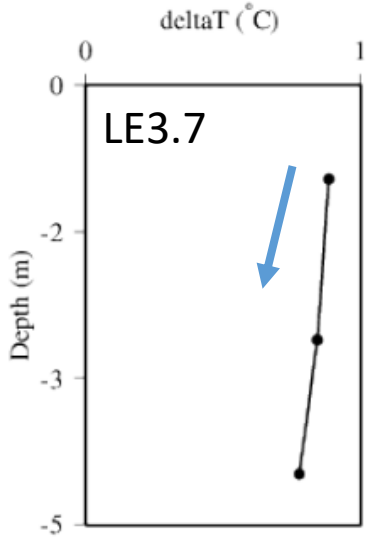


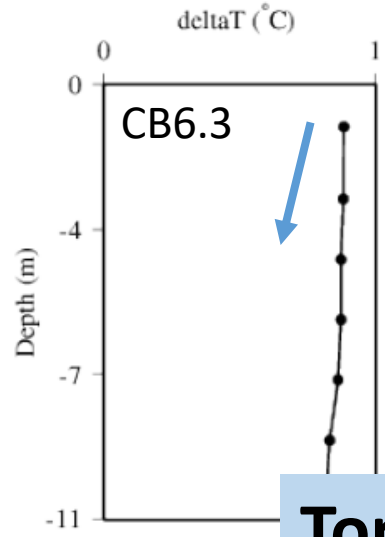
Model: Summer difference between climate change scenario centered on 2025 and 1991-2000 simulation





Modeling and monitoring are different for stations where largest change in the data is NOT at the surface.





More similar with depth when largest temp change in the data is at the surface.

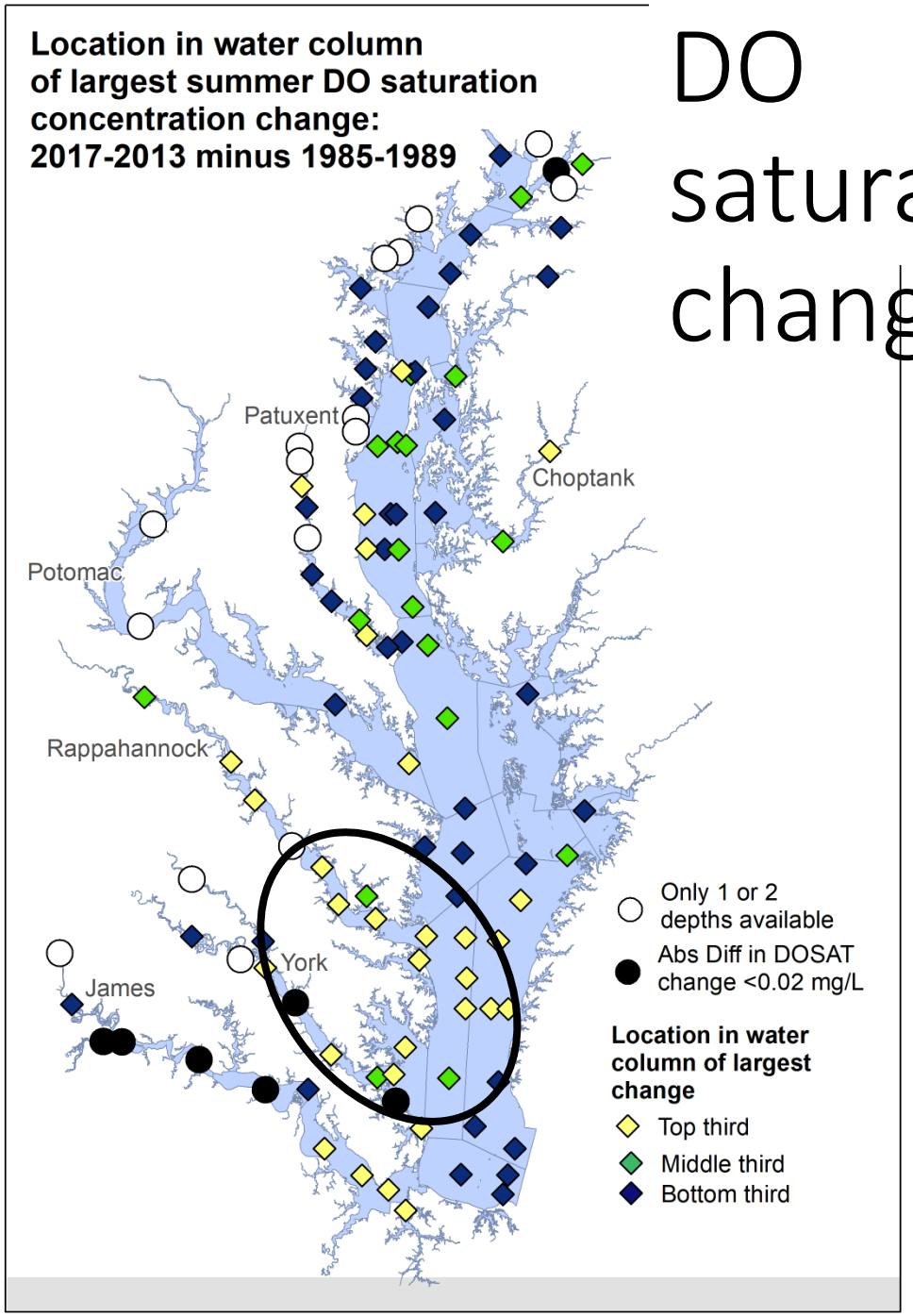
From Richard Tian

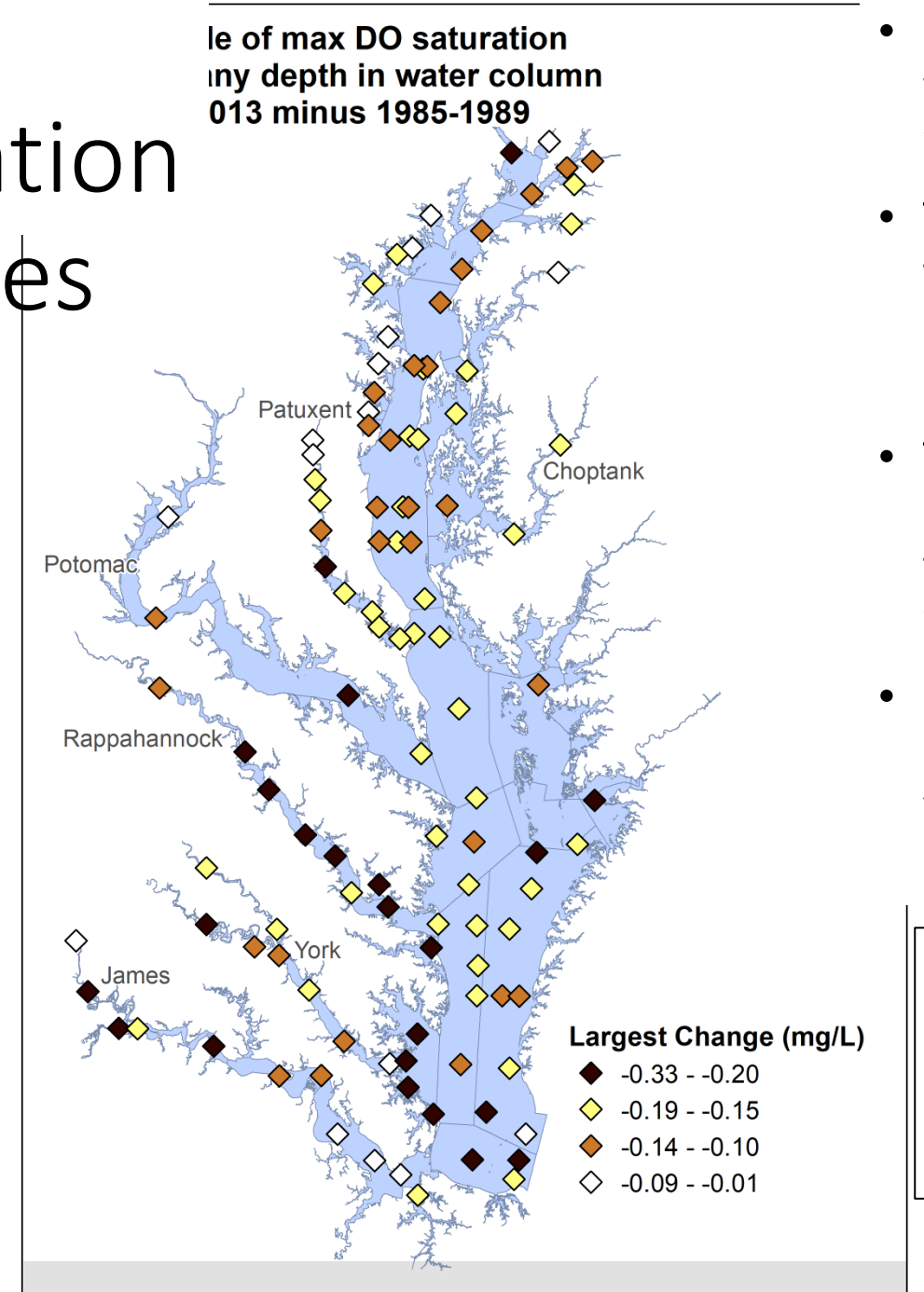
Topic 1: OW

Open water: DO saturation changes

- Computed and analyzed DO-saturation with the same approach as temperature to start to address questions:
  - Could decreases in DO saturation due to temperature increases be impacting the ability to meet Open Water Criteria?

DO saturation changes



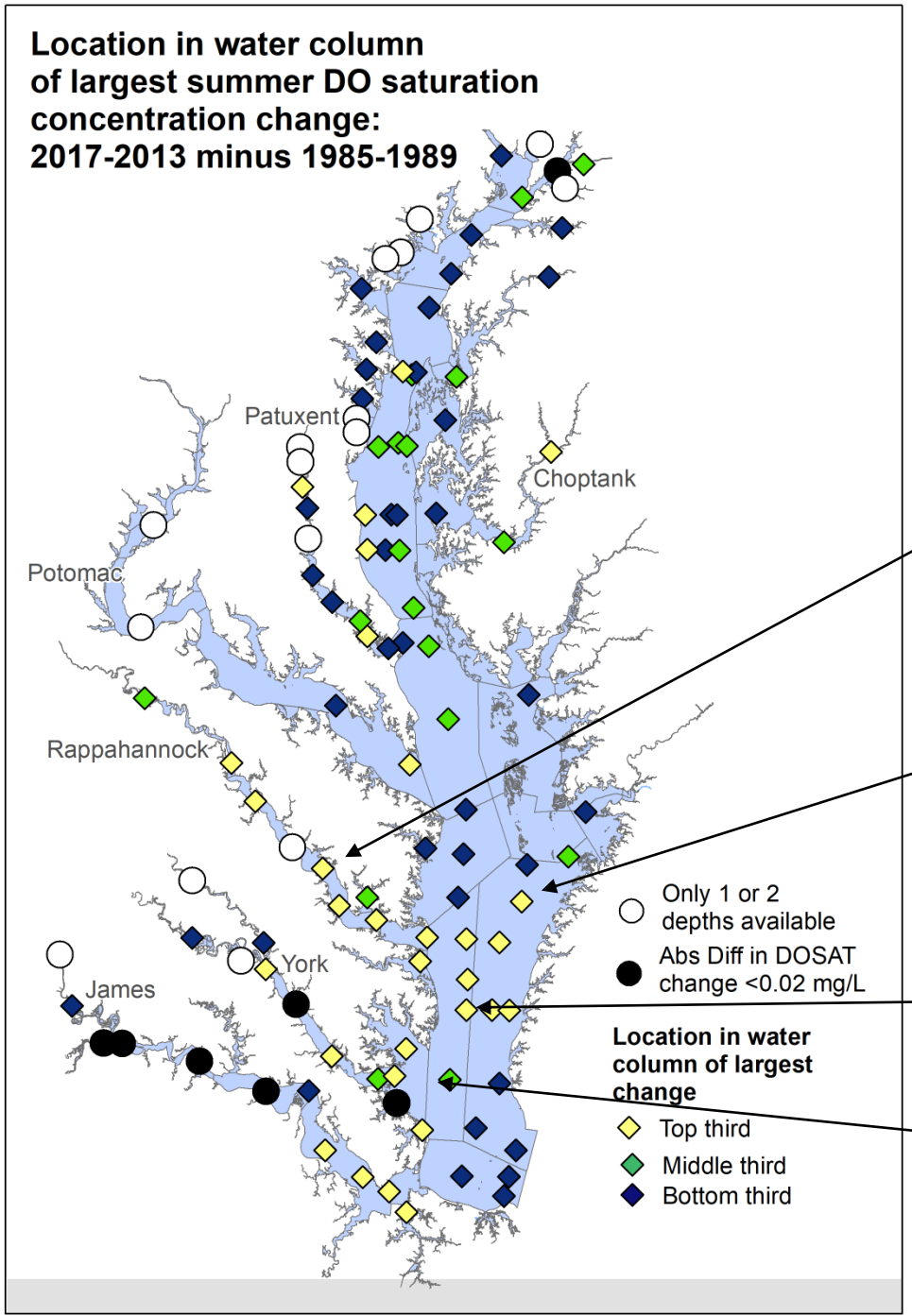


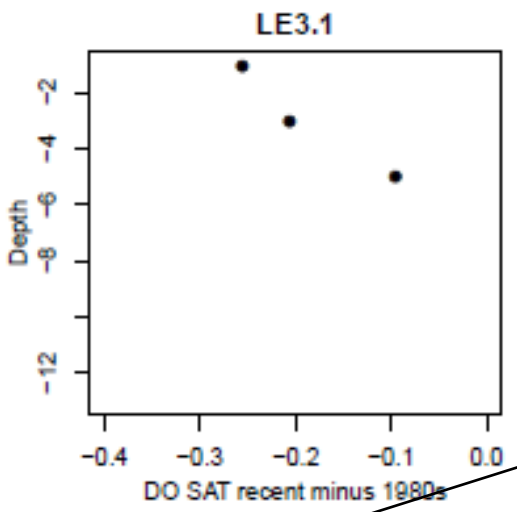
- Spatial patterns are very consistent with water temp.
- The magnitude of the DO saturation changes varies from 0 to -0.33 mg/L.
- The largest changes mostly appear in the lower tidal waters.
- Bay-wide, the depth of max change varies.

Note: these are the total change over ~28 years. Divide by 28 to get change per year. Or 3 to get change/decade.

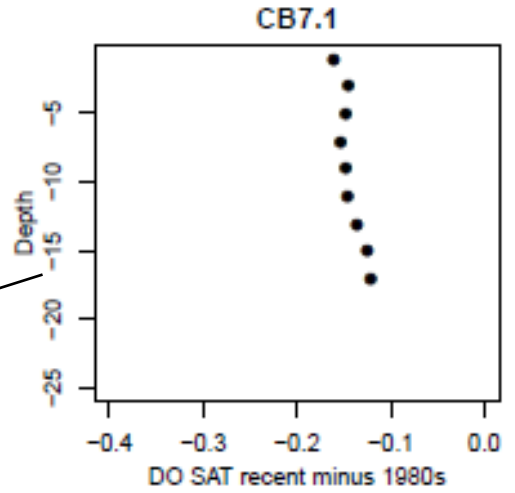
Topic 1: OW

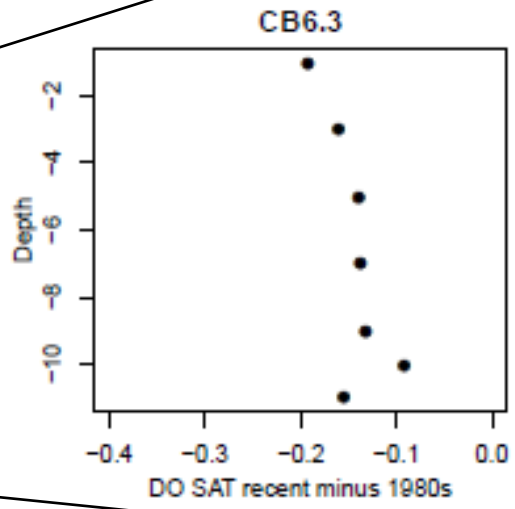
Locations where DO Saturation is decreasing the most near the surface

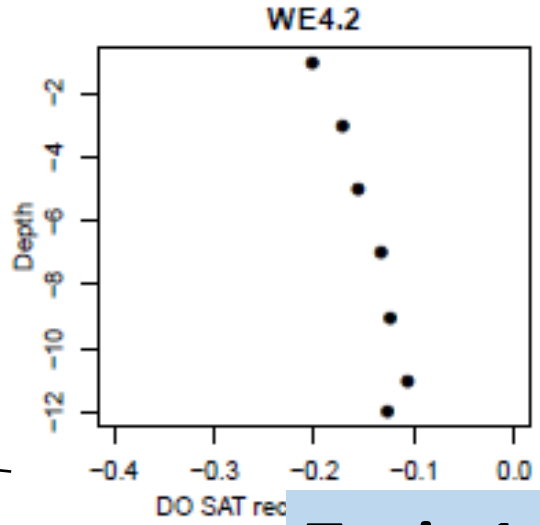




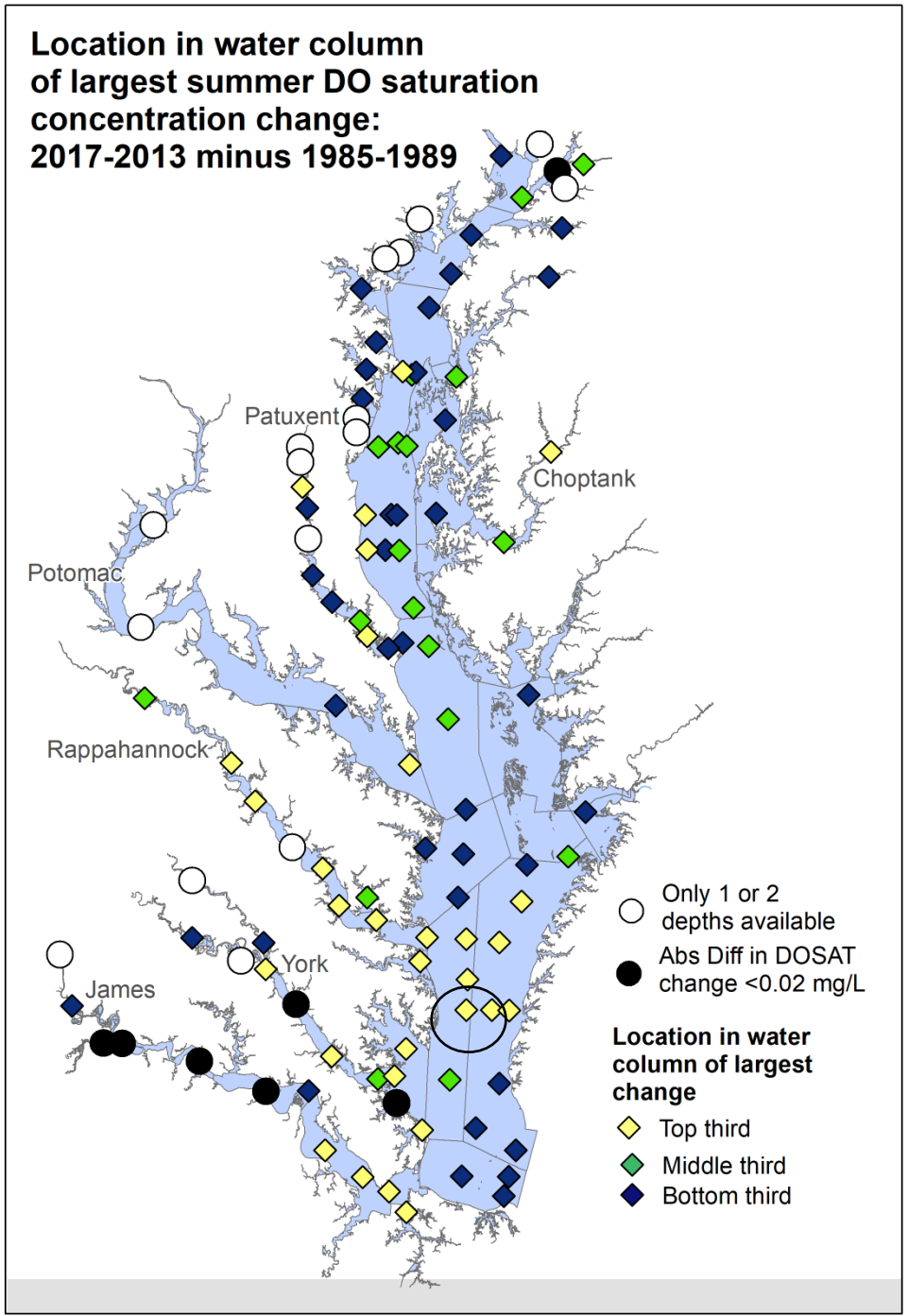
Same locations where temperature is increasing the most at the surface



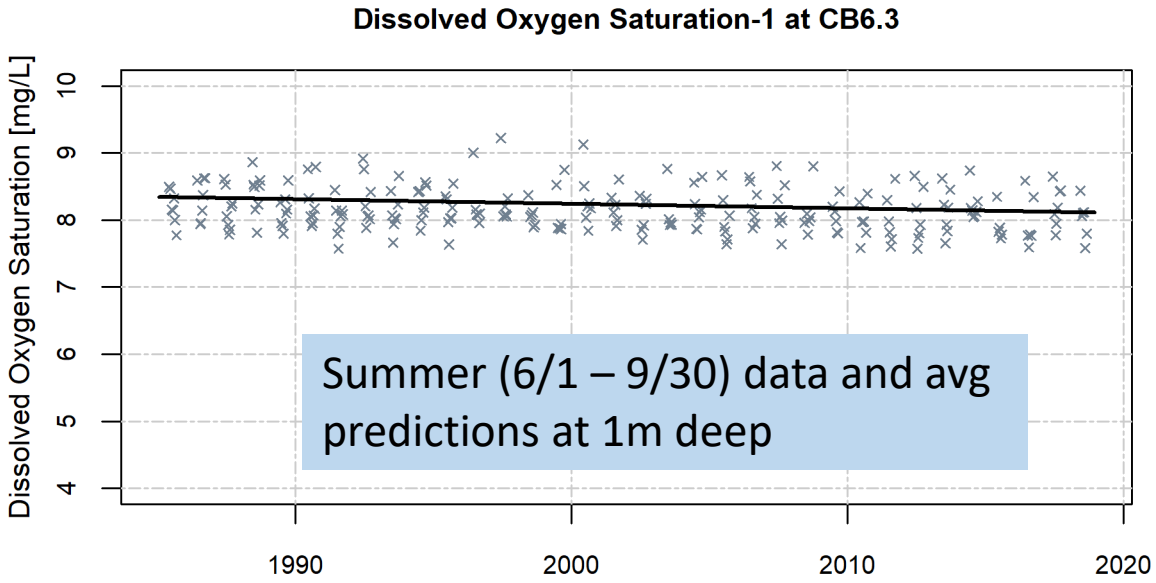




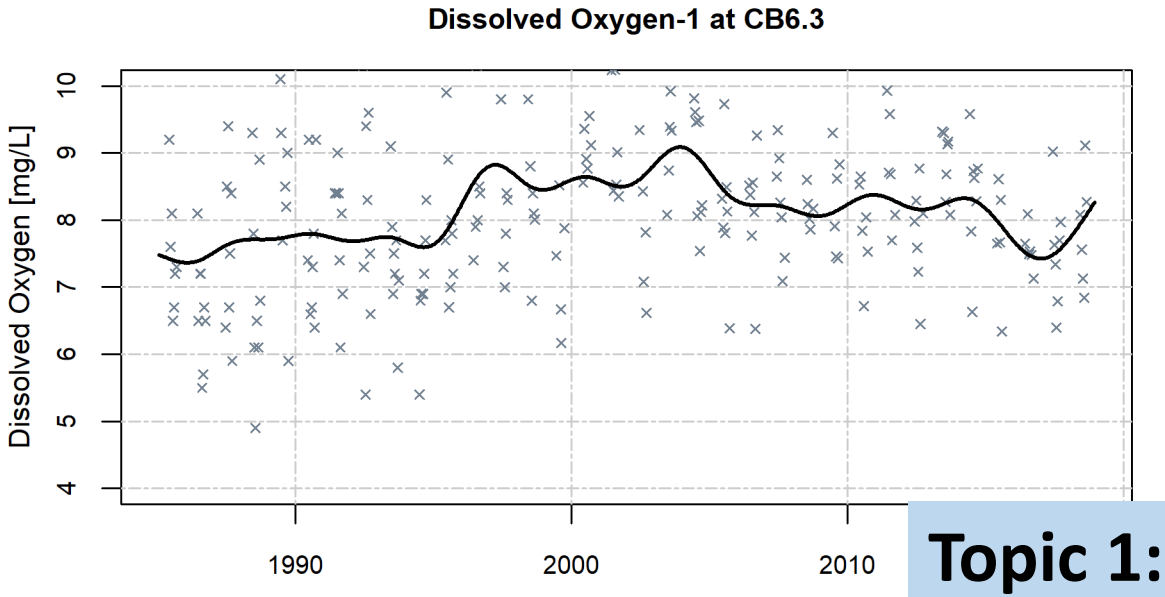
Topic 1: OW



DO Saturation: Example graphs showing change over time



Summer (6/1 – 9/30) data and avg predictions at 1m deep



Topic 1: OW

Open water summary

- Water temperature is increasing and DO-saturation concentrations are decreasing at almost all depths and stations baywide (looking at summer results).

- Evaluation of the long-term data does not support the idea that surface waters are universally getting warmer faster than the deeper waters.
  →Although this is the case in some locations, perhaps more in the southern bay

- The magnitude of model-generated changes over 30 years are similar to the data, but the location of maximum modeled change in the water column does not always match the data.

- Future work could include examining changes in spring and fall and more detailed comparison with model results.

Topic 1: OW

Topic 2: Shallow Water (SW)
CBP Modeling Team Question

CBP climate change scenarios predict that DO in “shallow” waters (~1-3m total depth to bottom) will be more impacted than Open Water. ***Are the monitoring data showing evidence of this effect?***

Approach:

1. Evaluate whether the frequency of DO criteria violation has increased at a select set of shallow water monitoring stations over the period of record.

2. Investigate how water temperature change relates to DO criteria violation in shallow waters.

3. Compare temperature and DO trends in shallow water monitoring data to nearby long-term monitoring stations.

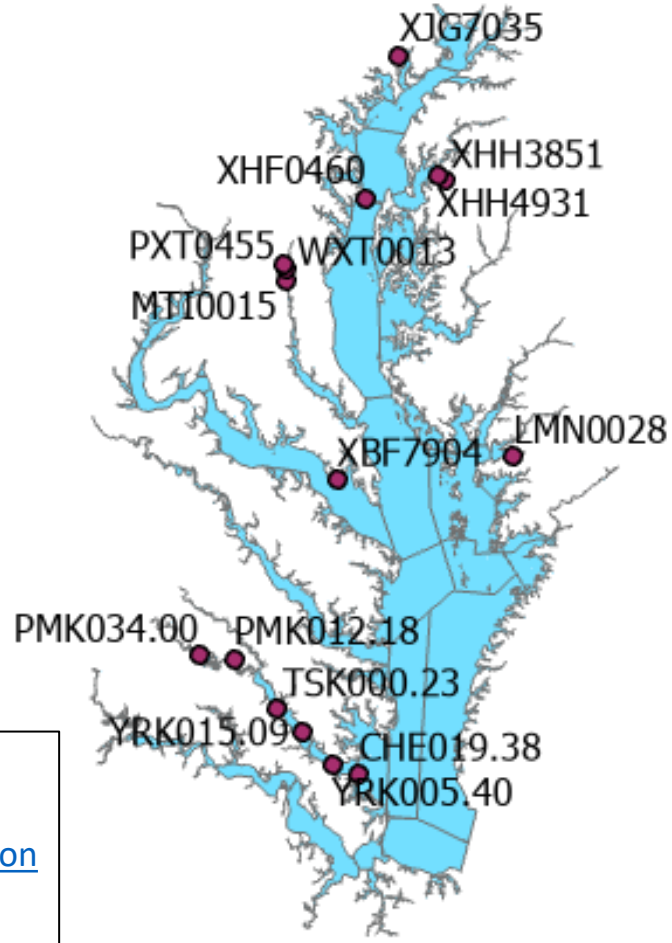
Shallow Water Stations

MD Stations

- **Chester River**
  - XHH3851: 2005 – 2017
  - XHH4931: 2006 – 2016
- **Jug Bay**
  - WXT0013: 2003 – 2019
  - PXT0455: 2003 – 2019
  - MTI0015: 2003 – 2019
- **Wicomico River**
  - LMN0028: 2006 - 2019
- **Potomac River**
  - XBF7904: 2006 - 2019
- **Sandy Point**
  - XHF0460: 2004 - 2019
- **Bush River**
  - XJG7035: 2003 - 2019

VA Stations

- **York River**
  - CHEO19.38: 2006 - 2019
  - TSK000.23: 2005 -2019
  - YRK005.40: 2005 -2019
  - YRK015.09: 2005 -2019
- **Pamunkey River**
  - PMK012.18: 2005 -2019
  - PMK034.00: 2005 -2019



MD data collected by MDDNR continuous monitoring program: http://eyesonthebay.dnr.maryland.gov/contmon/ContinuousMonitoring.cfm
VA data collected by VIMS / CBNERR-VA continuous monitoring program: http://vecos.vims.edu/; Verification data is a research product not posted on VECOS.

Topic 2: SW

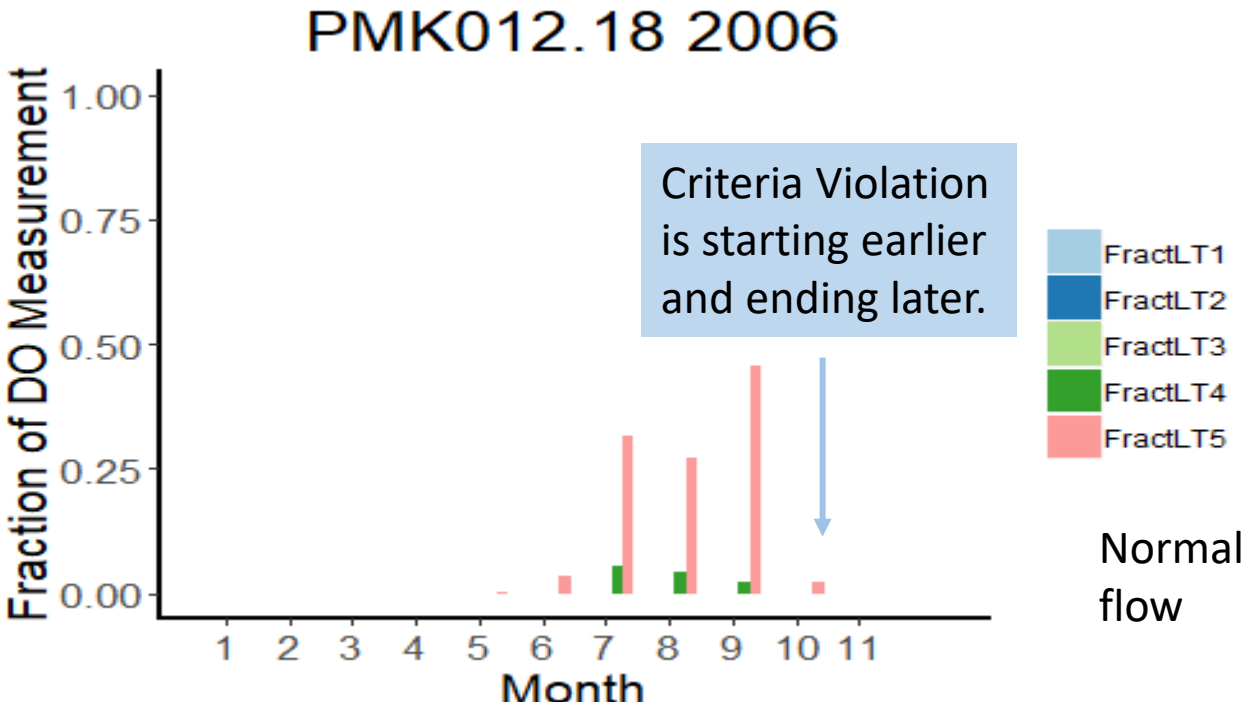
Shallow Water Data

Calibration Data

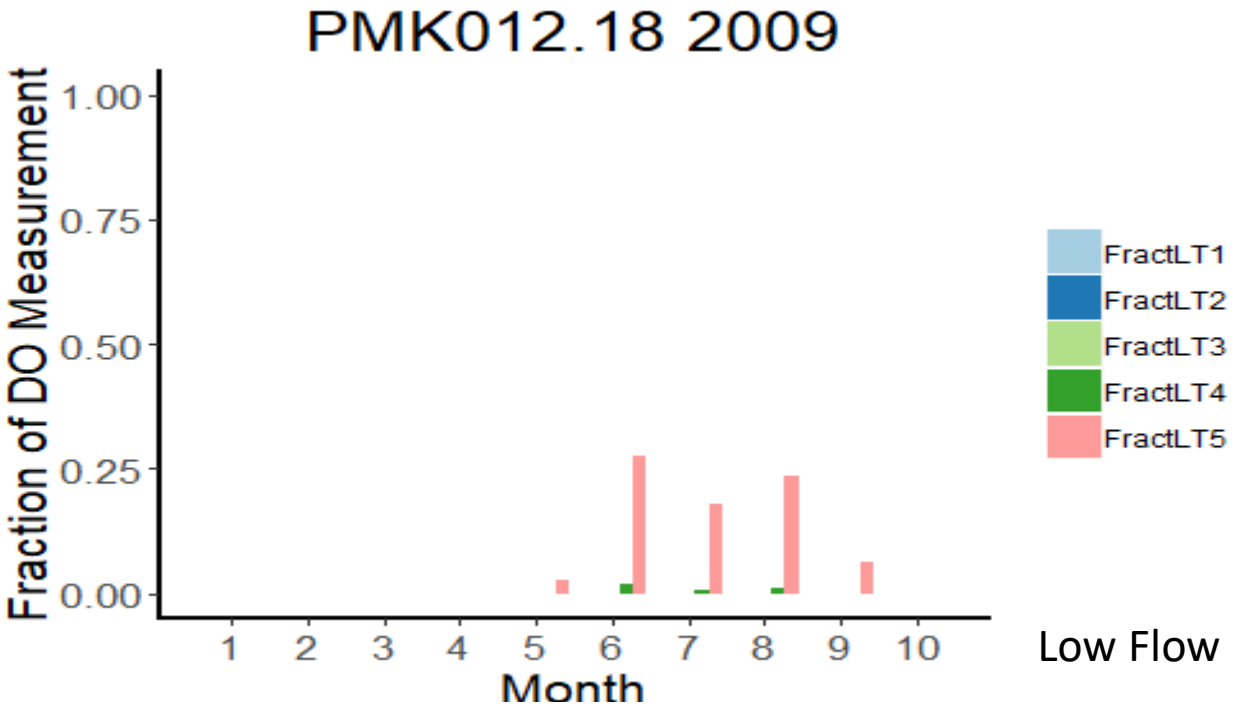
- Collected once or twice a month
- Parameters
  - DO (mg/L)
  - WTMEP (° C)
- Used in Approach #2 & #3

High Frequency

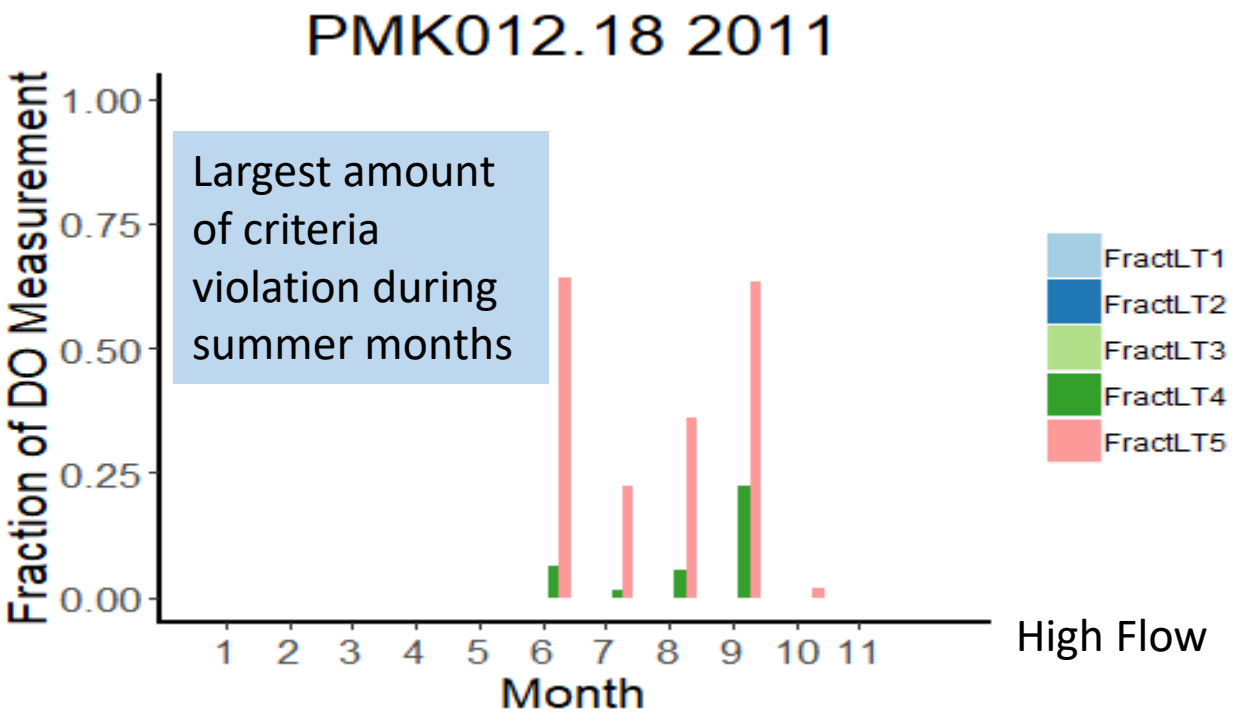
- Continuous data collected every 15 minutes
- Parameters
  - DO (mg/L)
  - Do Saturation (%)
- Used in Approach #1



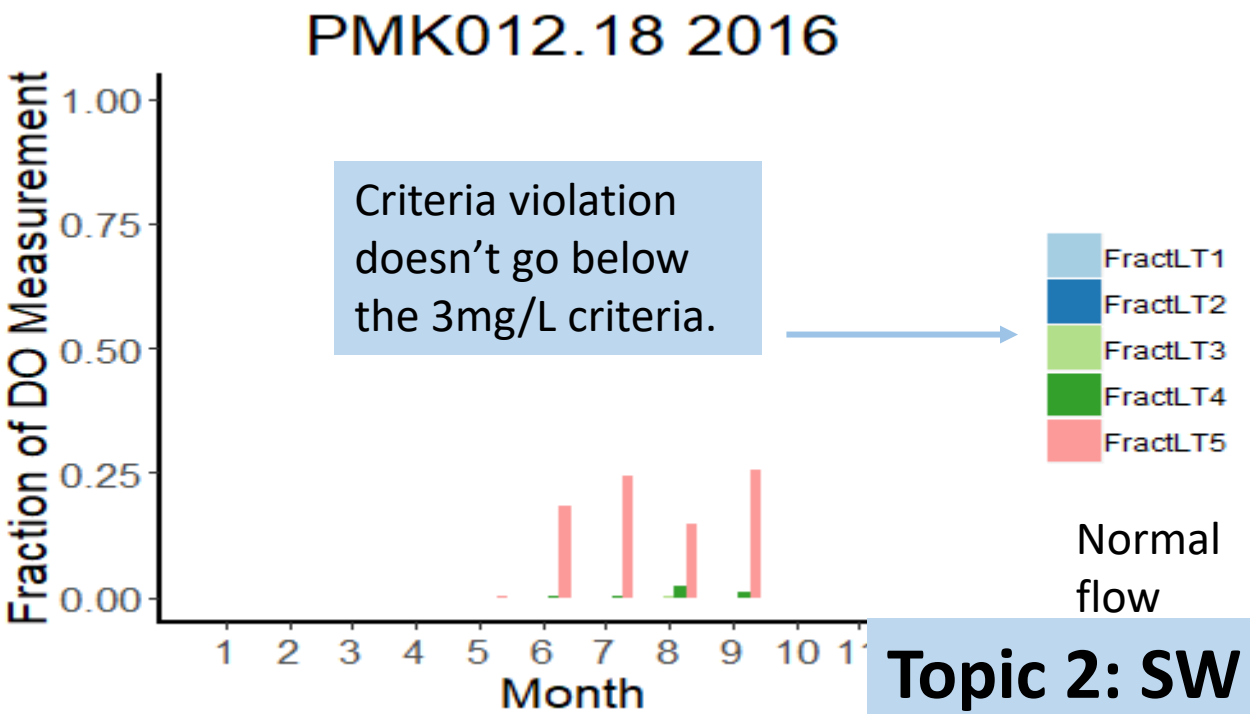
Normal flow



Low Flow



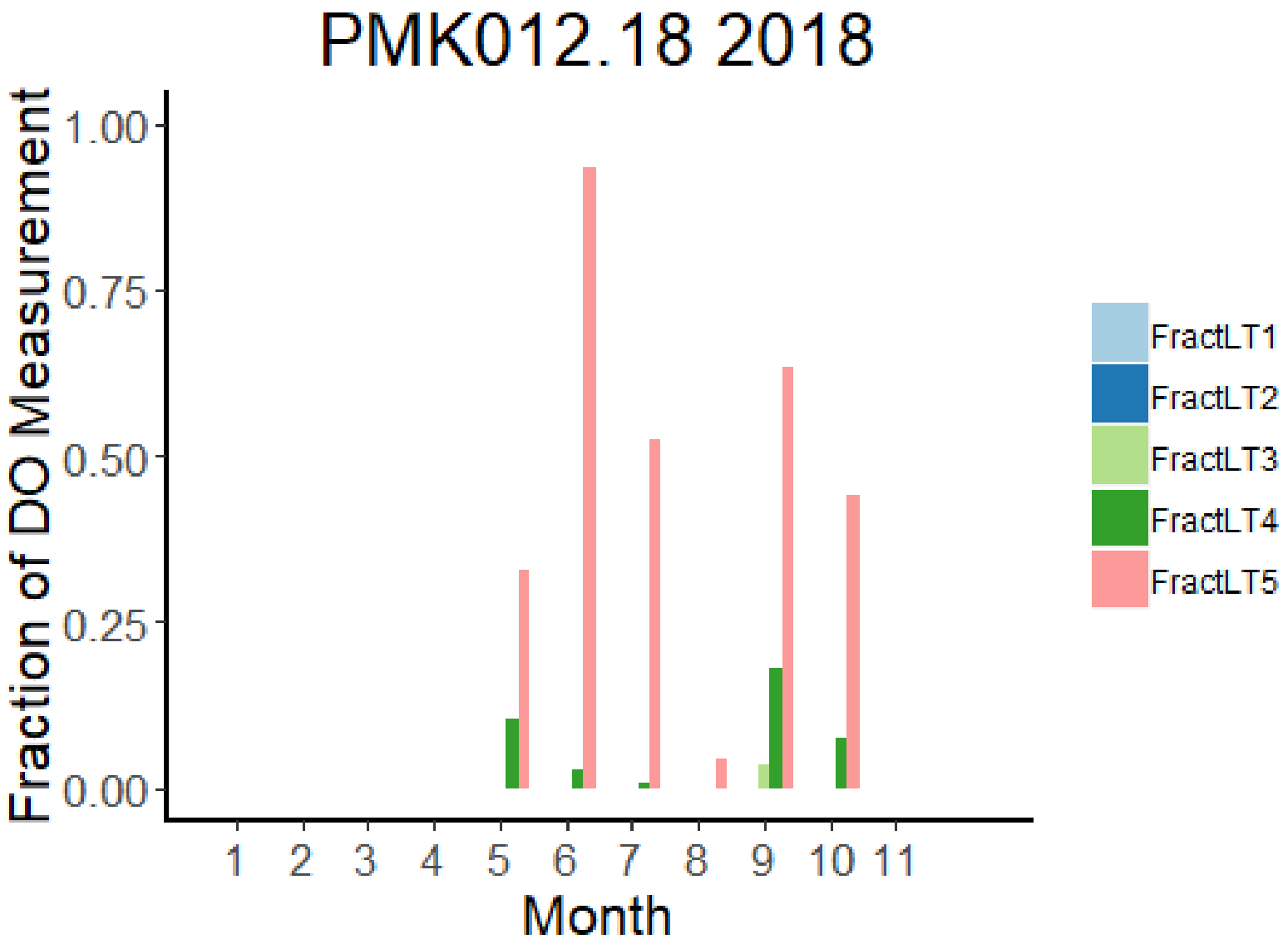
High Flow



Normal flow

Topic 2: SW

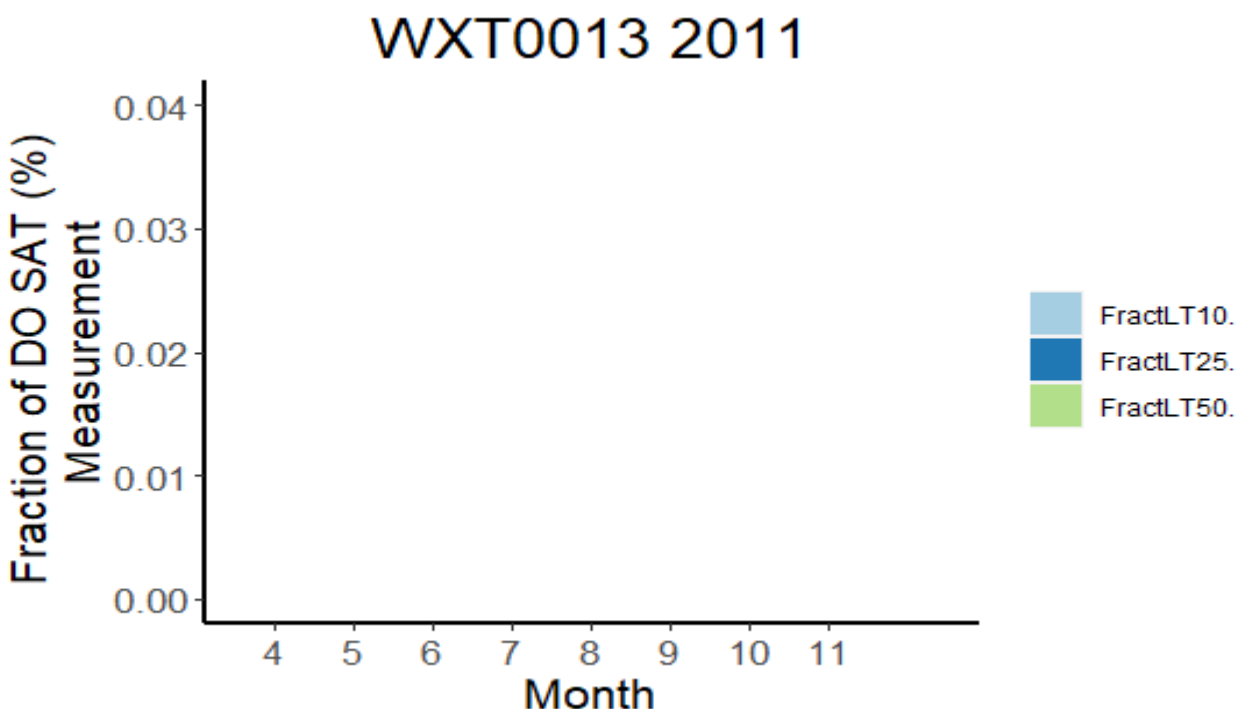
Large spike in criteria violation in 2018.

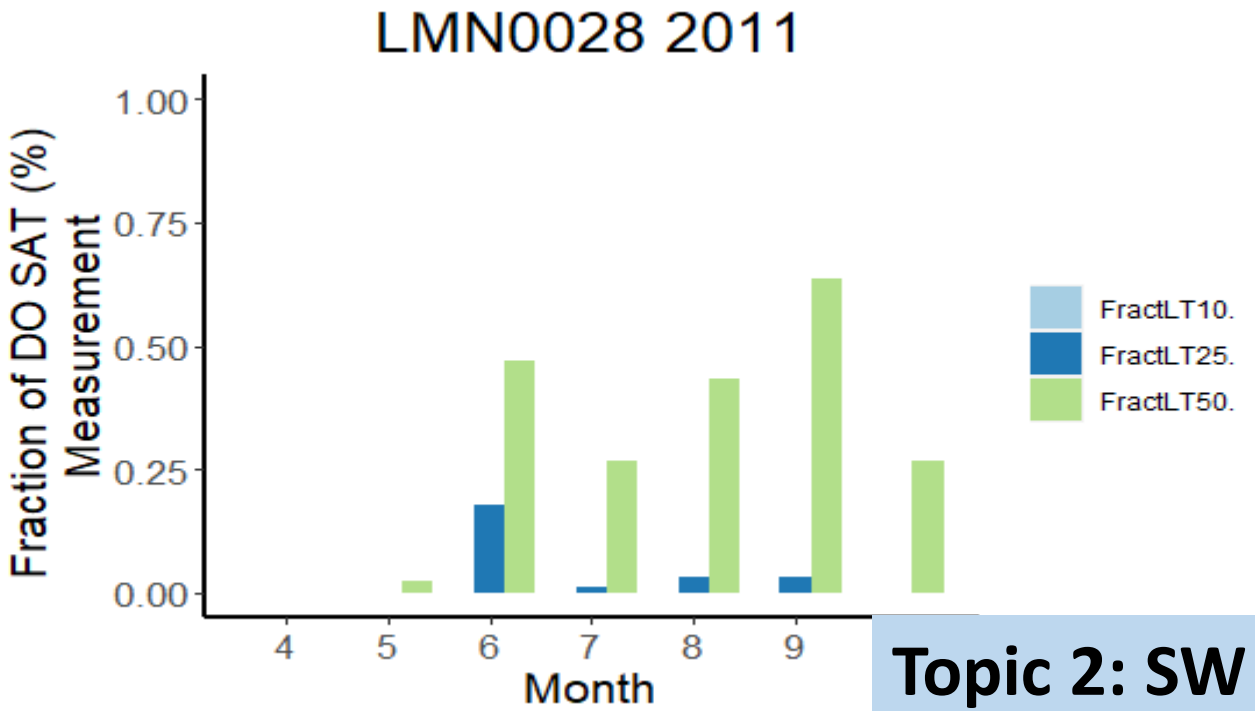


Topic 2: SW

Approach #1: Evaluate whether the frequency of DO and percent DO saturation criteria violation has increased at a select set of shallow water monitoring stations over the period of record.

- Frequency graphs for DO SAT (%) are similar to the DO graphs
- Next steps include fitting statistical models to frequencies over time to identify any change





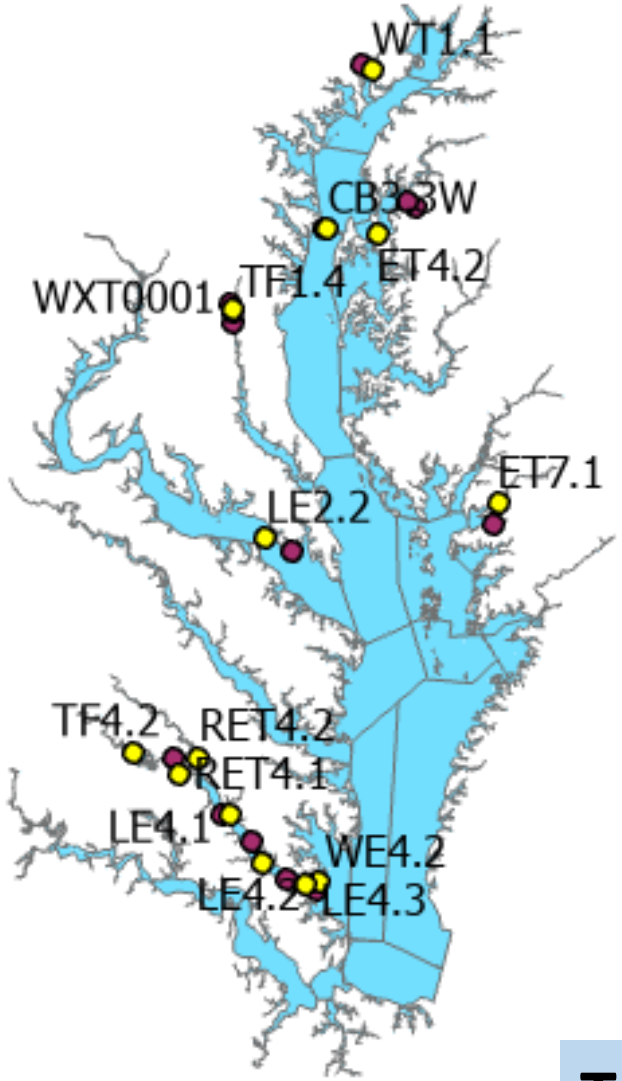
Approach #1: Summary

- With the high frequency data, the largest amount of criteria violation is during summer months
- Criteria violation can start as early as April and end as late as October for some stations
- Eastern Shore stations seem to have more criteria violation than western shore stations
- Future evaluation is under way of temporal patterns

Approach #3: Compare temperature and DO in shallow water monitoring data to nearby long-term monitoring stations.

Long-term Monitoring Stations

Shallow Water Station	State	Long-Term Station
XHH3851	MD	ET4.2
XHH4931	MD	ET4.2
WXT0013	MD	WXT0001
PXT0455	MD	WXT0001
MTI0015	MD	TF1.4
LMN0028	MD	ET7.1
XBF7904	MD	LE2.2
XHF0460	MD	CB3.3W
XJG7035	MD	WT1.1
CHE019.38	VA	WE4.2
TSK000.23	VA	LE4.1
YRK005.40	VA	LE4.3
YRK015.09	VA	LE4.2
PMK012.18	VA	RET4.1
PMK034.00	VA	TF4.2



Topic 2: SW

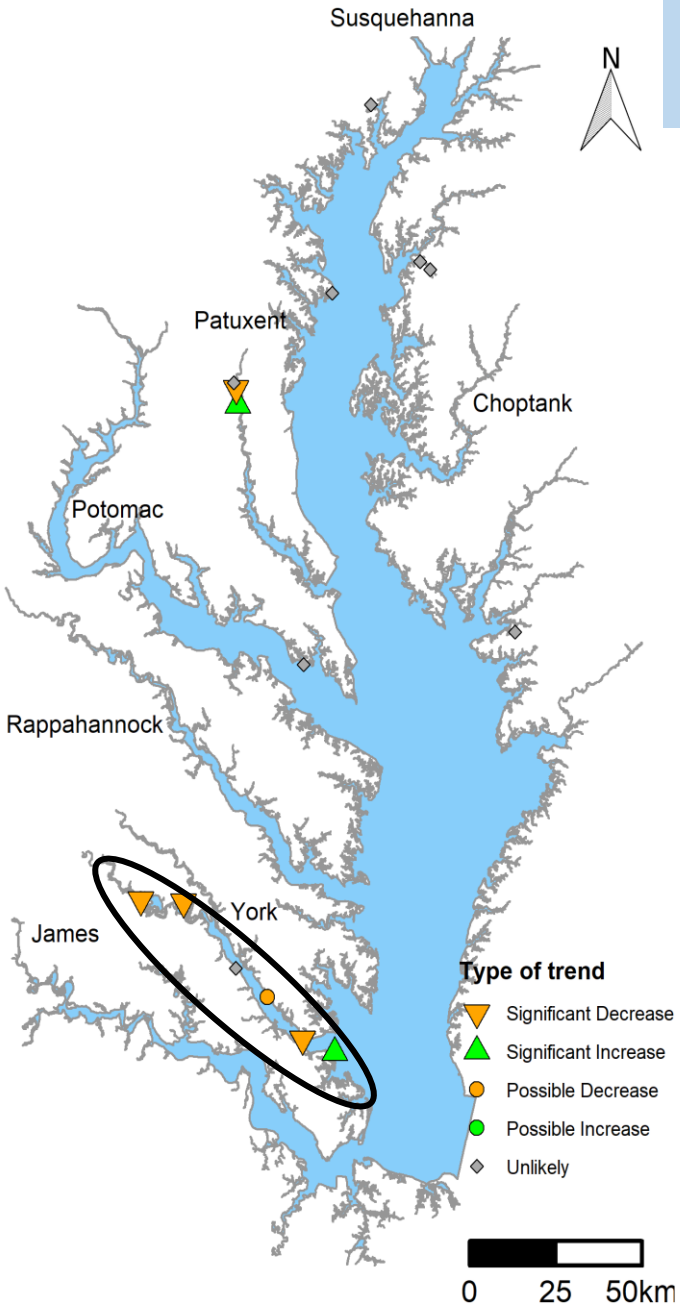
Shallow Water DO Trends

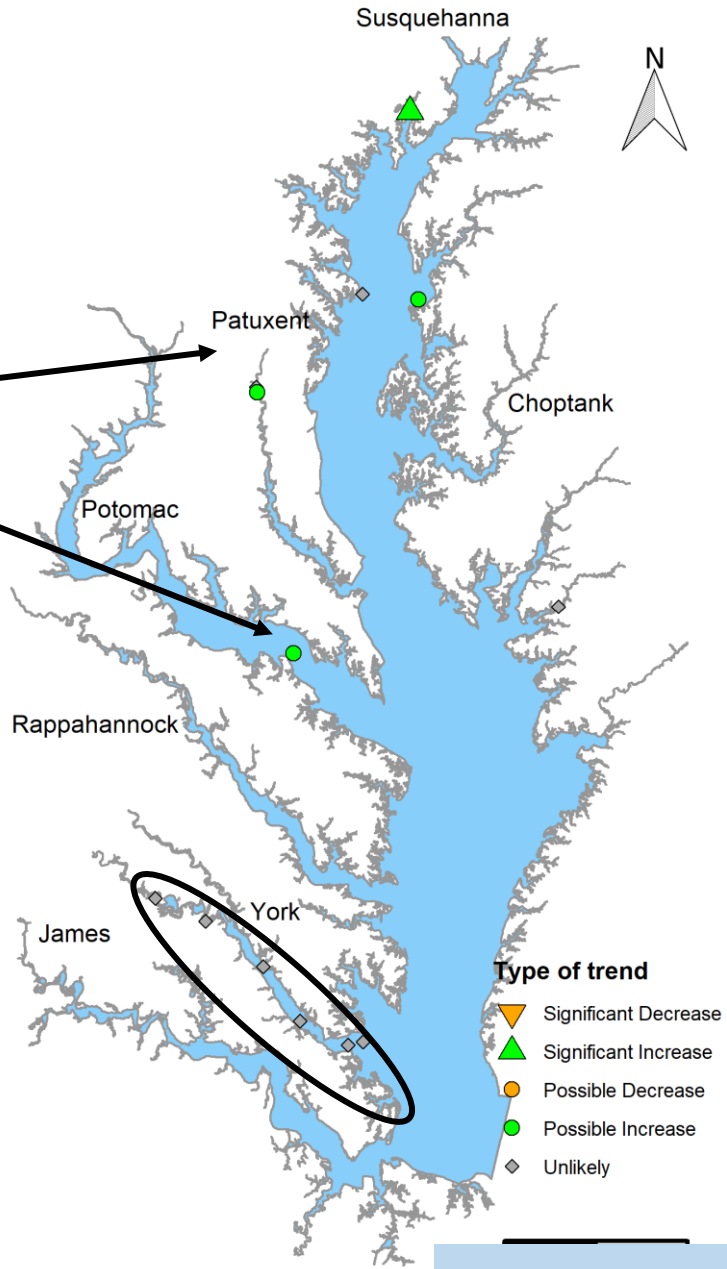
Long-term Monitoring DO Trends

Approach #3: Compare temperature & DO in shallow water monitoring data to nearby long-term monitoring stations.

More possible increases in DO for MD long-term stations than shown for the shallow water stations.

VA long-term stations are unlikely to have a trend while multiple VA shallow water stations have a significant decrease in DO and one has a significant increase.





Topic 2: SW

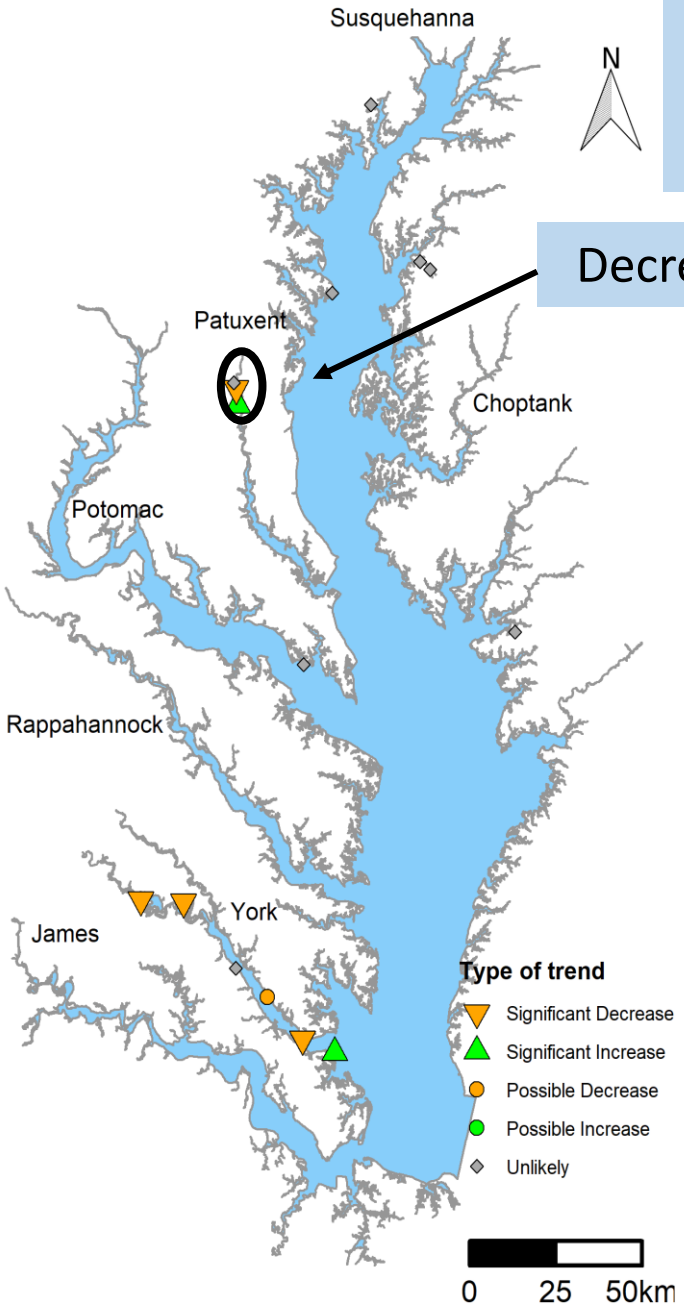
Shallow Water DO Trends

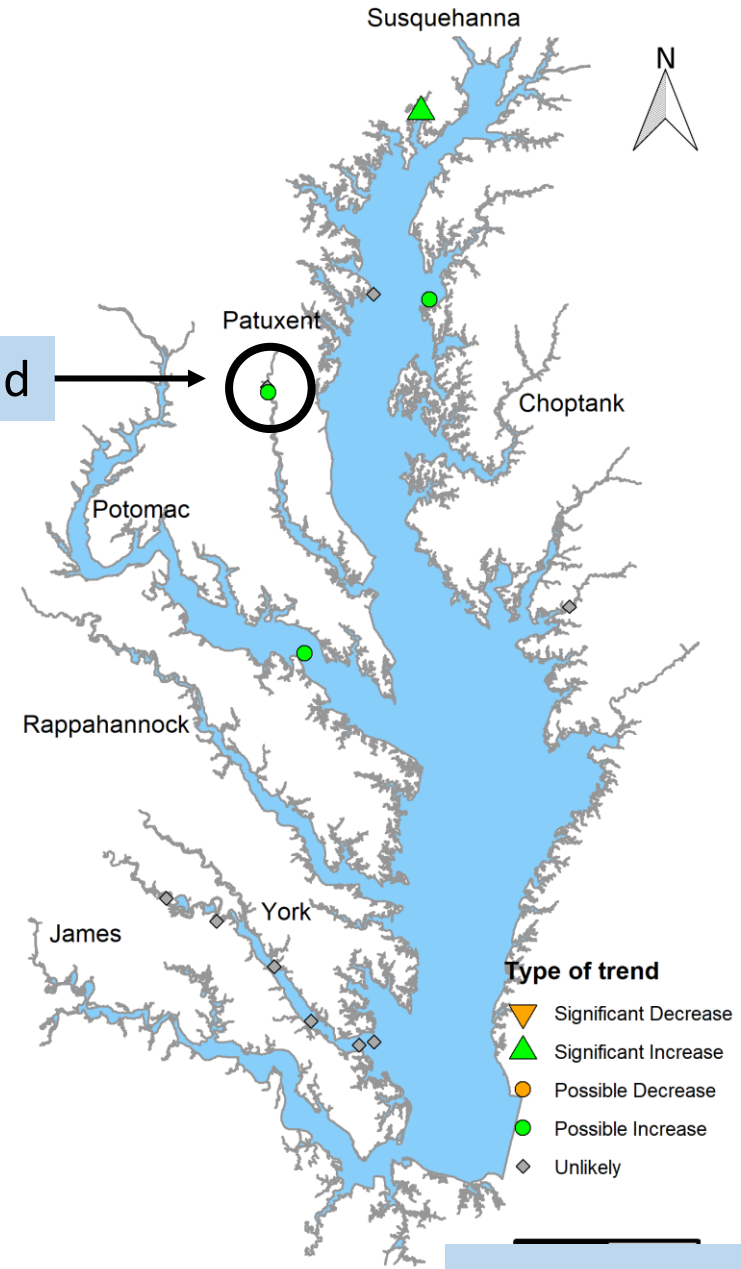
Long-term Monitoring DO Trends

Approach #3: Compare temperature & DO trends in shallow water monitoring data to nearby long-term monitoring stations.

Decreasing Shallow Water Trend

Unlikely Long-term Trend

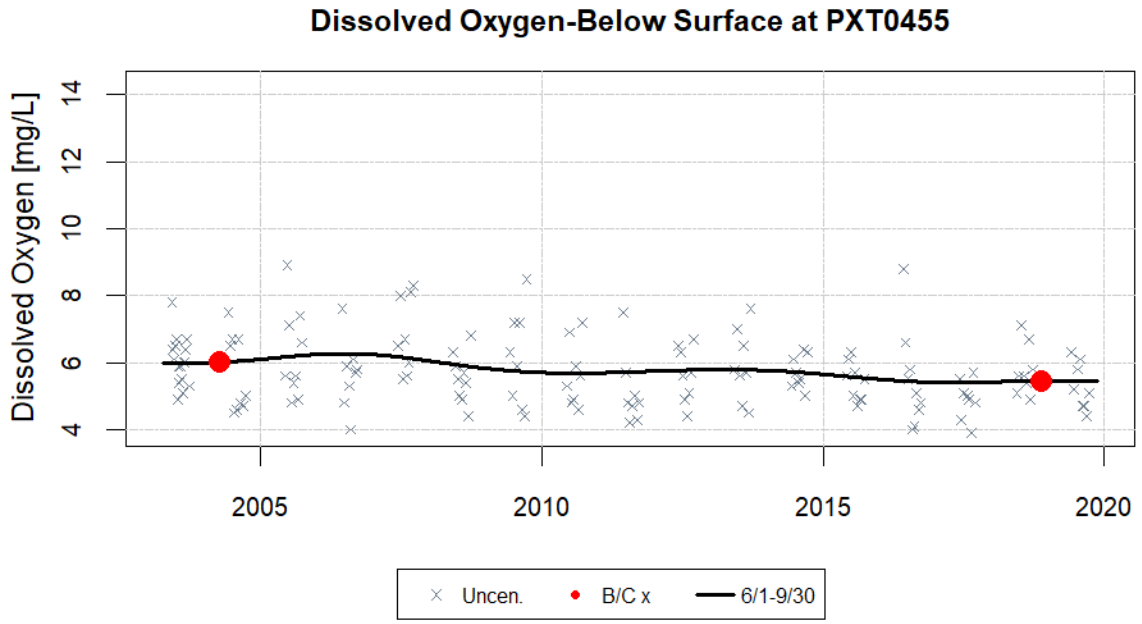




Topic 2: SW

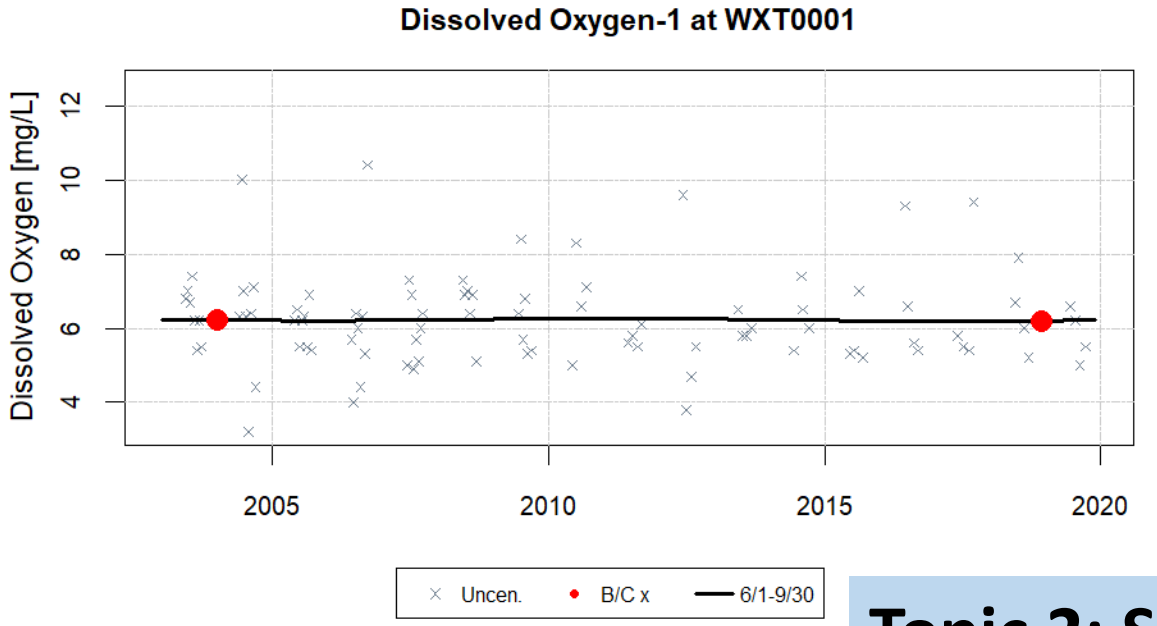
Shallow Water Station PXT0455:

- 17-year change is: 9.71% decrease (p = 0.016)
- Beginning DO Level ≈ 5.95 mg/L
- End DO Level ≈ 5.37 mg/L



Long-term Monitoring Station WXT0001:

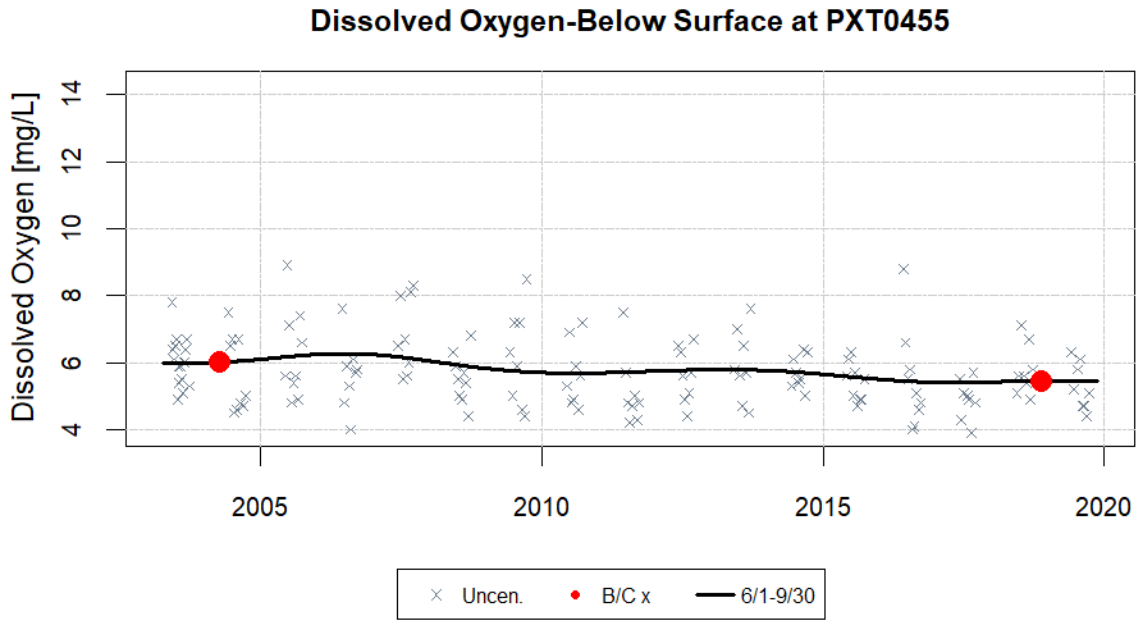
- 17-year change is: 0.21% decrease (p = 0.95)
- Beginning DO Level ≈ 6.18 mg/L
- End DO Level ≈ 6.17 mg/L

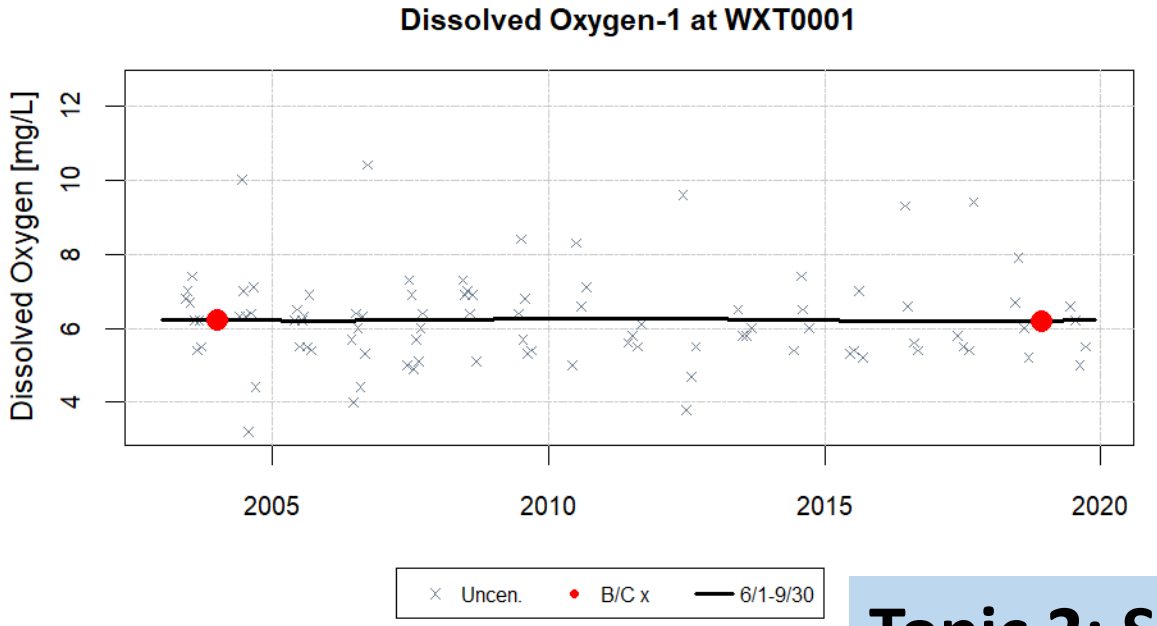


Topic 2: SW

Overview:

- Shallow water station has a decreasing trend vs the unlikely trend for the long-term station, but the decreasing change is not that large (B = 5.95 mg/L vs C = 5.37 mg/L).
- Throughout the period of record the DO measurements are not very different.
- The most change for the shallow water station happens at the end of the period of record



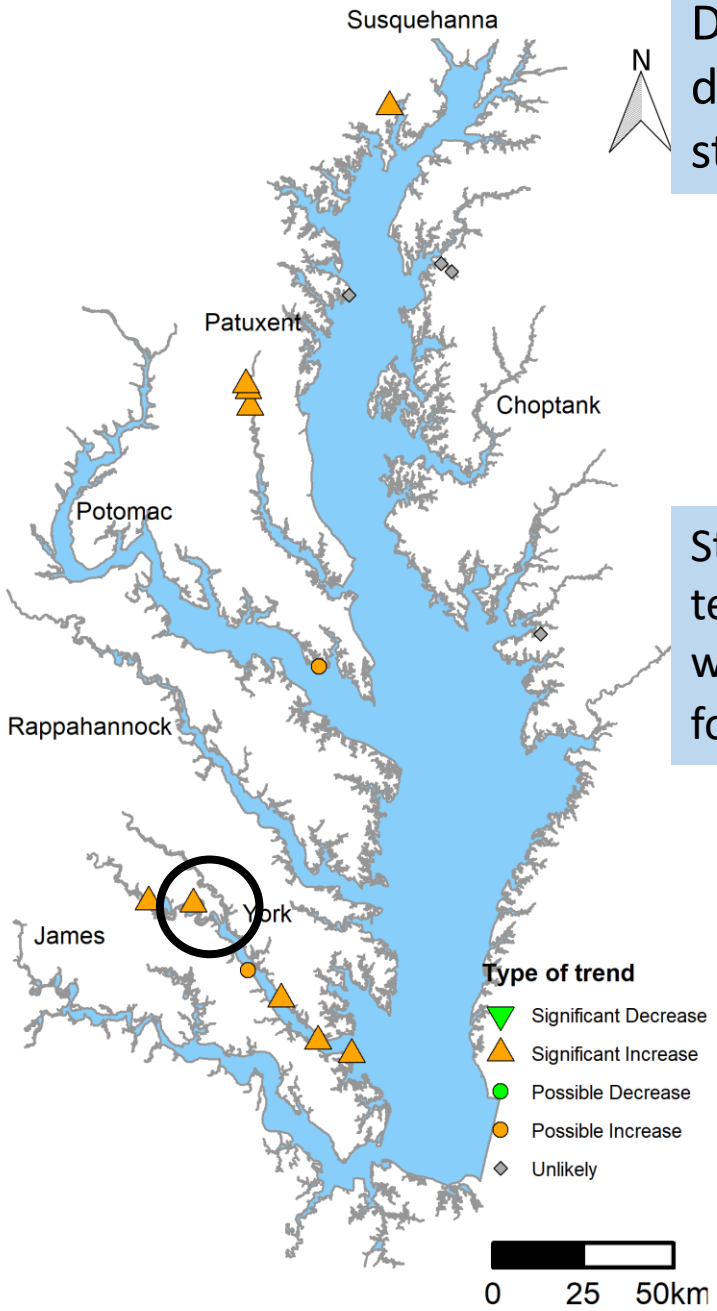


Topic 2: SW

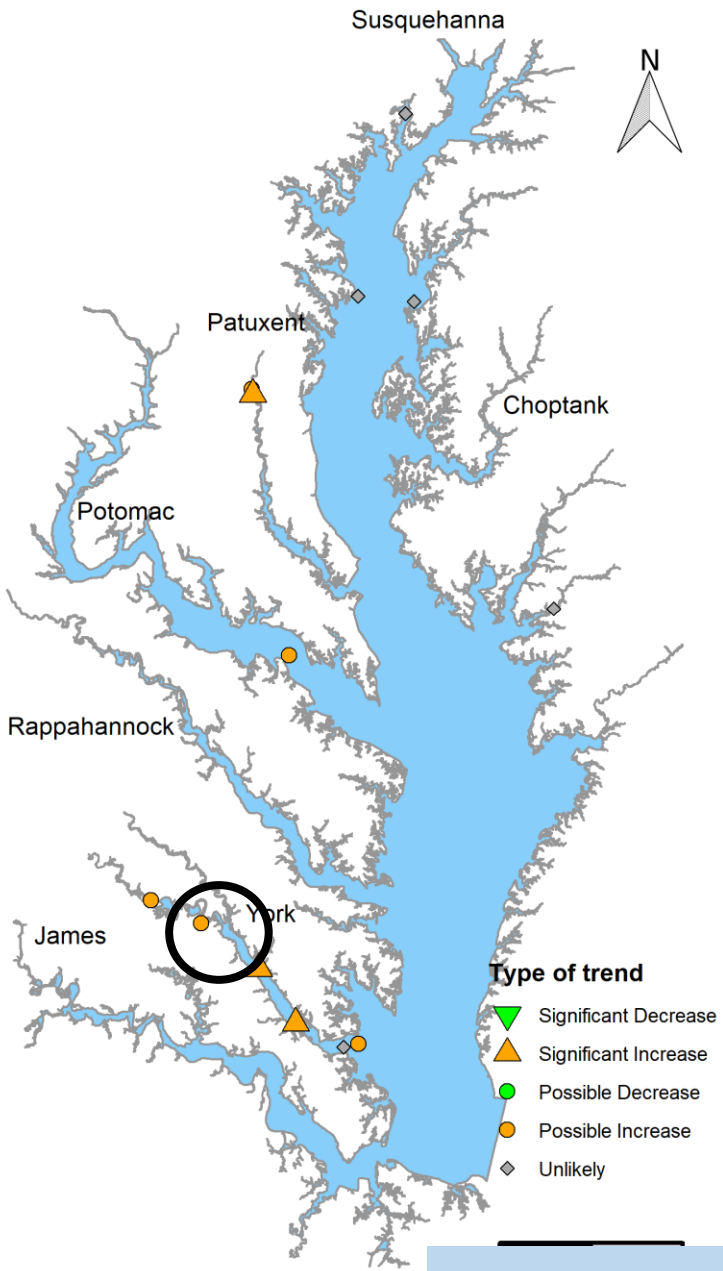
Approach #3: Compare temperature & DO trends in shallow water monitoring data to nearby long-term monitoring stations.

Stations for both shallow water and long-term are increasing, but a few more shallow water stations are significantly increasing for water temp.

Shallow water WTEMP Trends



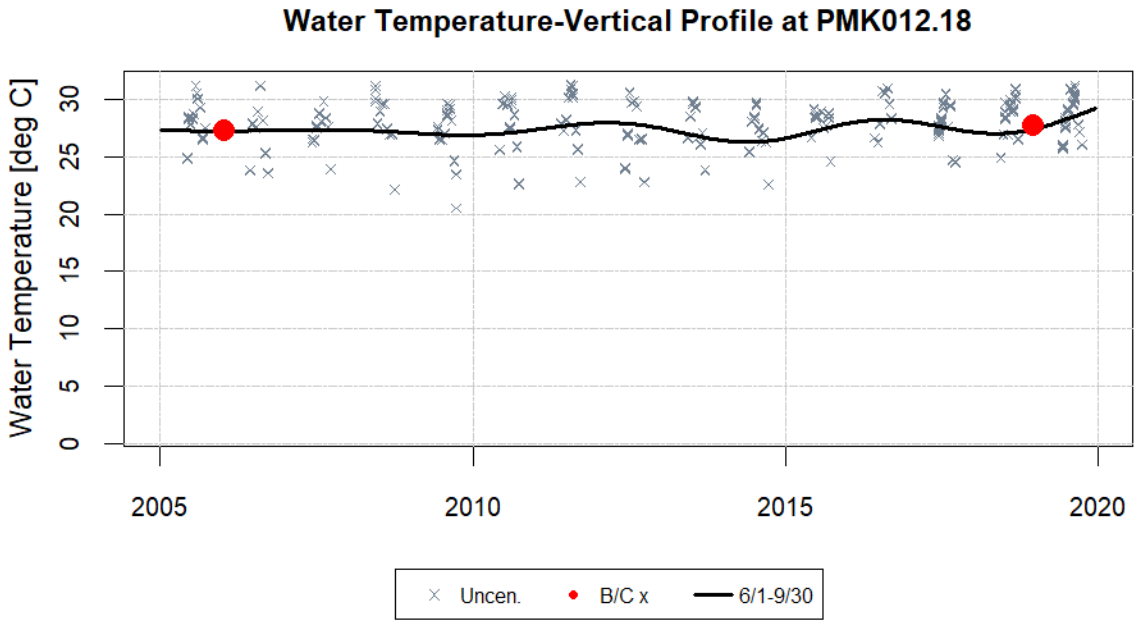
Long-term Monitoring WTEMP Trends

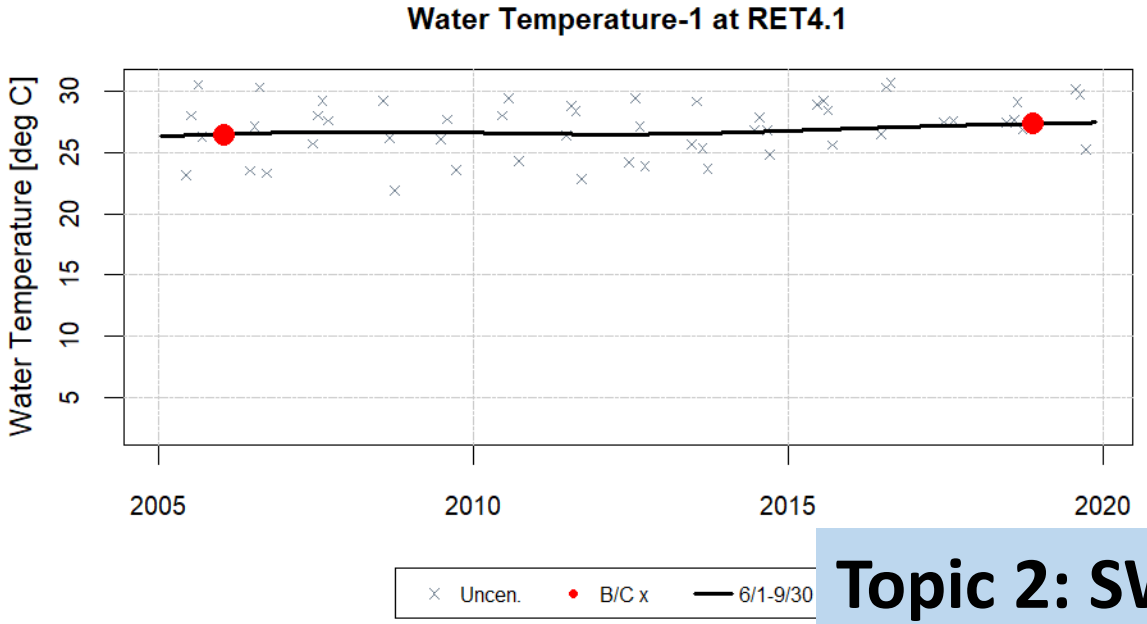


Topic 2: SW

Overview:

- Most shallow water stations have a significant increase while the long-term has possible increase. The difference in increase between the two stations are not drastic in both states, and they have similar current summer water temp levels.
- At some stations in MD, the shallow water temp is significantly increasing over the period of record by the current summer water temp is still lower than long-term current summer water temp.





Topic 2: SW

Approach #3: Summary

- When comparing the trends in shallow water stations to near by long-term monitoring stations,
  - There are mores shallow water stations with significant or possible decreasing DO trends than with the long-term stations.
    - There is not a drastic decrease in DO for most of the shallow water stations compared to the long-term monitoring stations

Will shallow water be more impacted than open water?

- The impact is not universal! It changes depending on state and within the state.
- The trends show more differences when comparing VA shallow water stations to VA long-term than for all MD stations.
- MD Eastern Shore stations have a lower DO then the Western Shore stations, but they show no trends over the period of record.
- If a shallow water station is more impacted compared to a long-term monitoring station, the difference is not drastic.

Are shallow water monitoring stations more impacted due to rising water temperatures?

- Rising water temperatures may be one factor.
- When looking at nearby shallow water stations within a state, both stations could have a significant increase in water temp but opposing DO trends.
  - Could nearshore watershed characteristics be driving these differences?

Topic 2: SW

LOCATION

LOCATION

LOCATION

Next Steps:

- Gain knowledge of general watershed characteristic for each station starting with nearby stations showing opposing trends
- Look into different drivers: Shoreline characteristics, development, precipitation

Next Steps based on CAP WG:

- Is there a way to change the analysis on the high frequency data that would help answer specific questions the CAP WG has on criteria (Approach #1)?
- Do have suggestions on how to gain general patterns on shallow waters in comparison to long-term monitoring (Approach #3)?
- Would it be more useful to look at DO saturation instead of DO concentration or both?

Questions?

Topic 1: Open Water (OW)

- CBP climate change scenarios predict that over approximately a 30-year period, summer DO concentrations in the Open Water (OW) designated use will be more negatively affected by climate change than summer DO in deeper layers. ***Do the magnitudes and depths of observed changes in the monitoring data support the modeling results that OW is more negatively affected than deeper water?***

Topic 2: Shallow Water (SW)

CBP climate change scenarios predict that DO in “shallow” waters (~1-3m total depth to bottom) will be more impacted than Open Water. ***Are the monitoring data showing evidence of this effect?***