Quantifying the impacts of past and future climate and eutrophication on the dynamics of dissolved oxygen in the shallow waters of Chesapeake Bay

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Motivation

- Dissolved oxygen is a key factor in living resources habitat, elemental cycling
- Extensive past research on seasonal, mainstem hypoxia, less so in shallows
- Shallow waters can cycle through low oxygen on a daily basis
- Shallow-waters are where many people live and fish
- Available data present a unique opportunity to examine the rich spatial and temporal variability in shallow-water oxygen
- Future climate change will impact shallow water oxygen dynamics and vulnerability to oxygen depletion, but we lack the understanding to be predictive

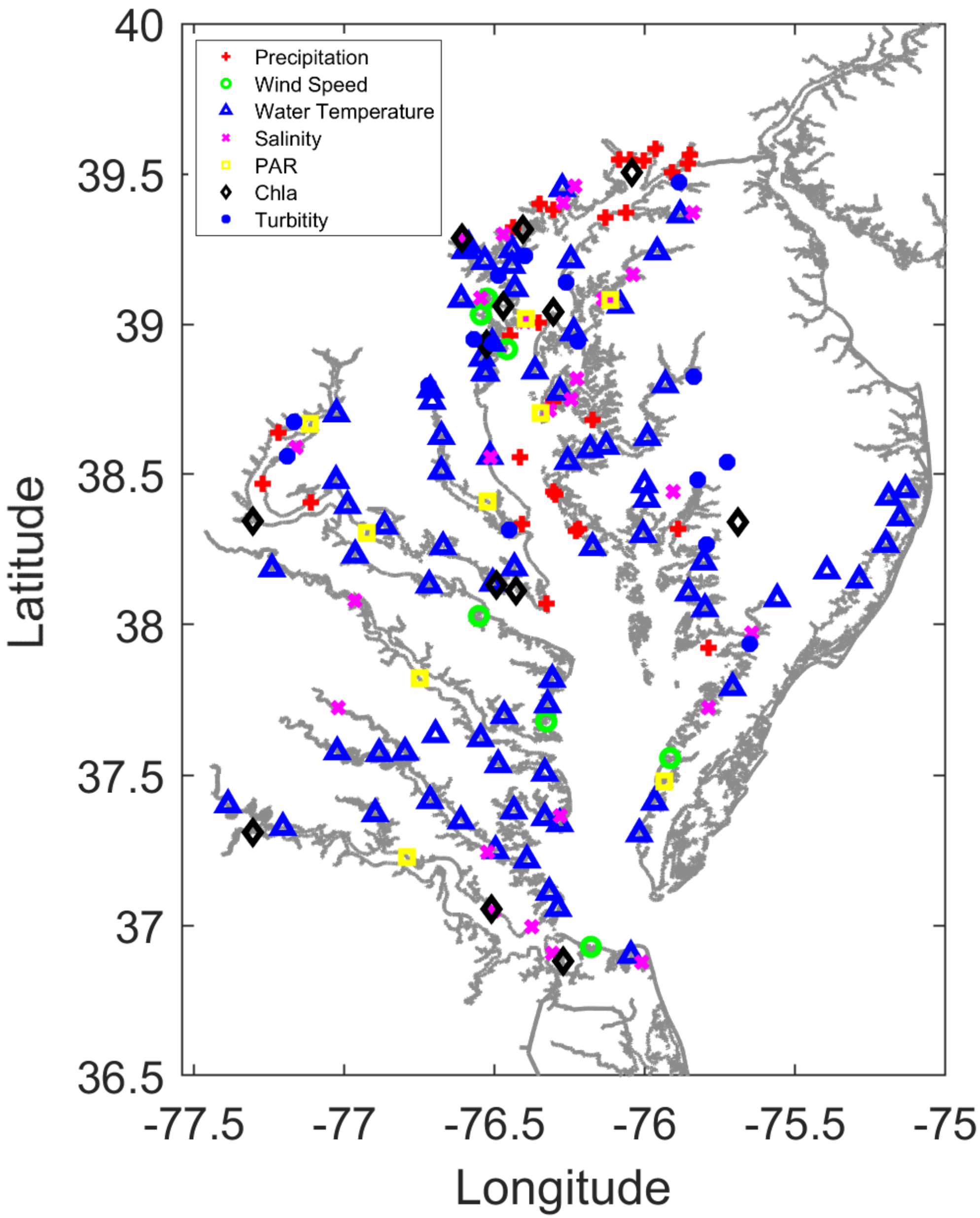
Project Objectives

- Utilize the extensive high-frequency datasets in MD and VA for dissolved oxygen (DO) to understand which variables control oxygen variability and low-oxygen conditions, the timescale of the control (hourly, daily), and how controls vary over space

- Discern the magnitude and spatial variation in physical influence (salinity, temperature, PAR) versus biological influence (e.g., Chl-a)

- Develop or enhance statistical and numerical models to be predictive of shallow-water DO change and vulnerability to future conditions

Data



Continuous time-series of oxygen, chl-a, turbidity, temperature, salinity across 181 stations (MD + VA)

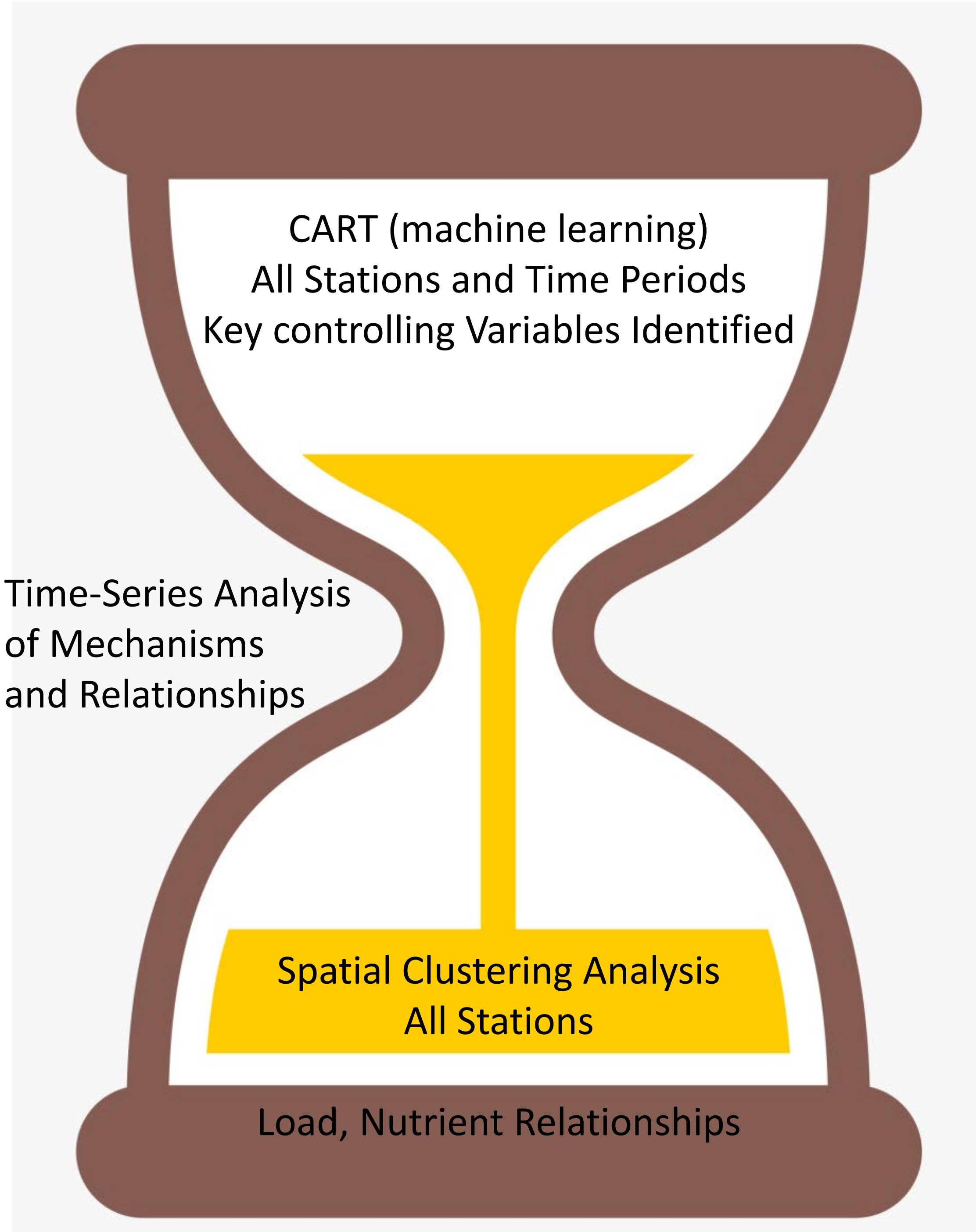
PAR, wind speed, and precipitation from regional climate products (NLDAS, ERA5)

Discrete 'water quality' measurements Made every 2-4 weeks

Focus on April –October period

Rotated deployment of sensors across stations (not deployed at the same time)

Hourglass Approach

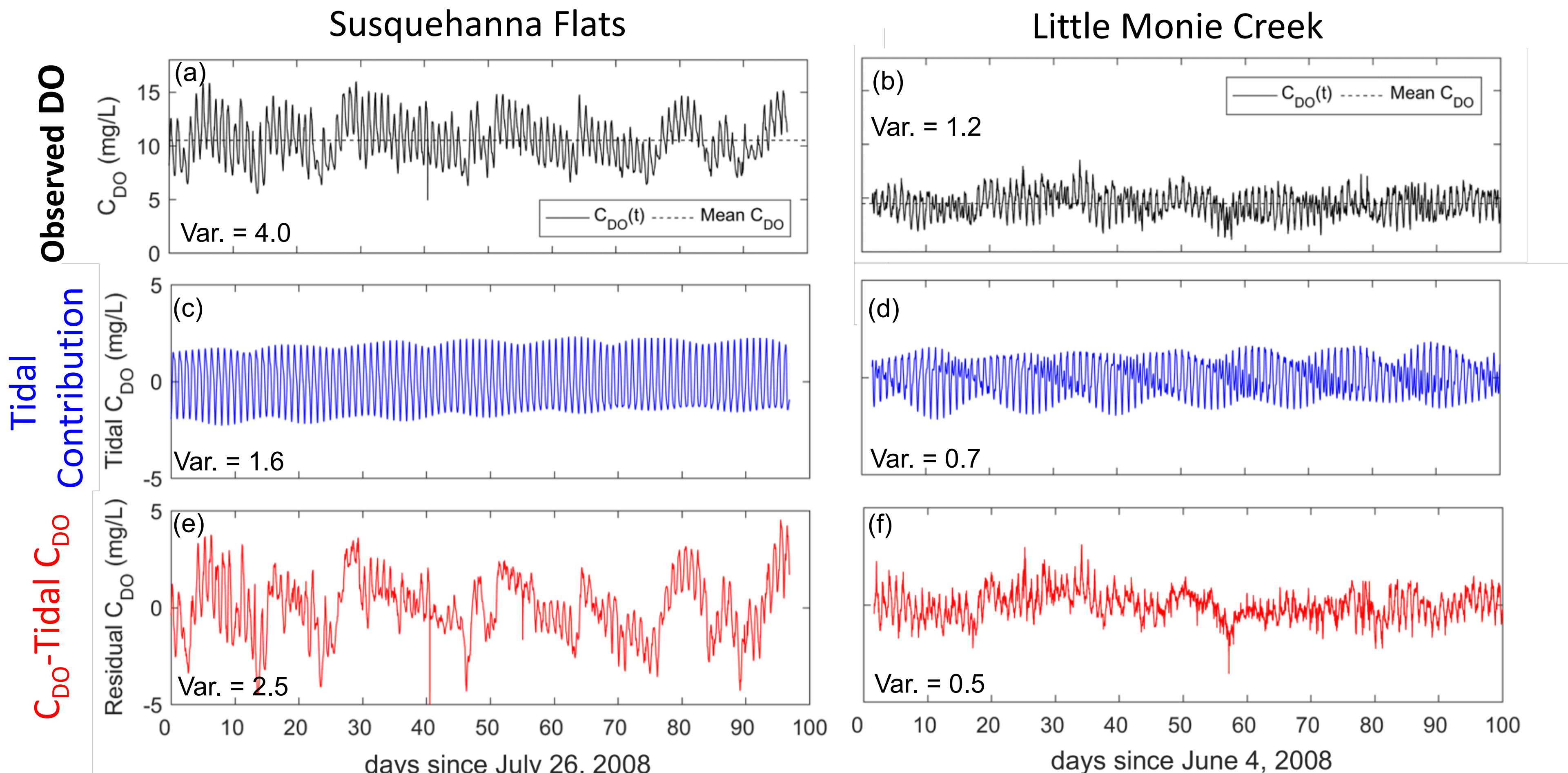


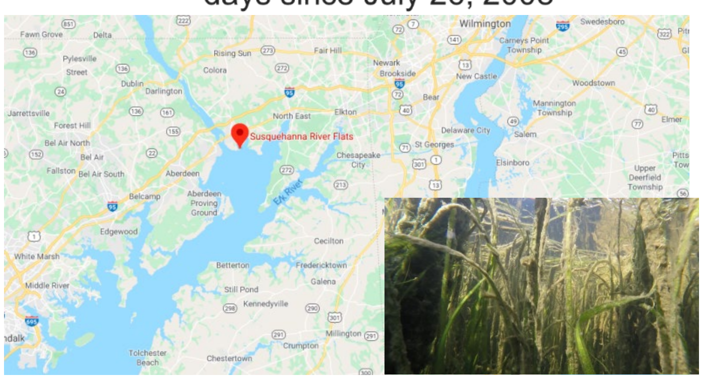
Baywide Analysis of All Data

Verify Nature of Relationships, Identify Mechanisms

Explain Why Mechanism Important Across Space

Comparing Contributors to Oxygen Saturation in 2 Different Habitats



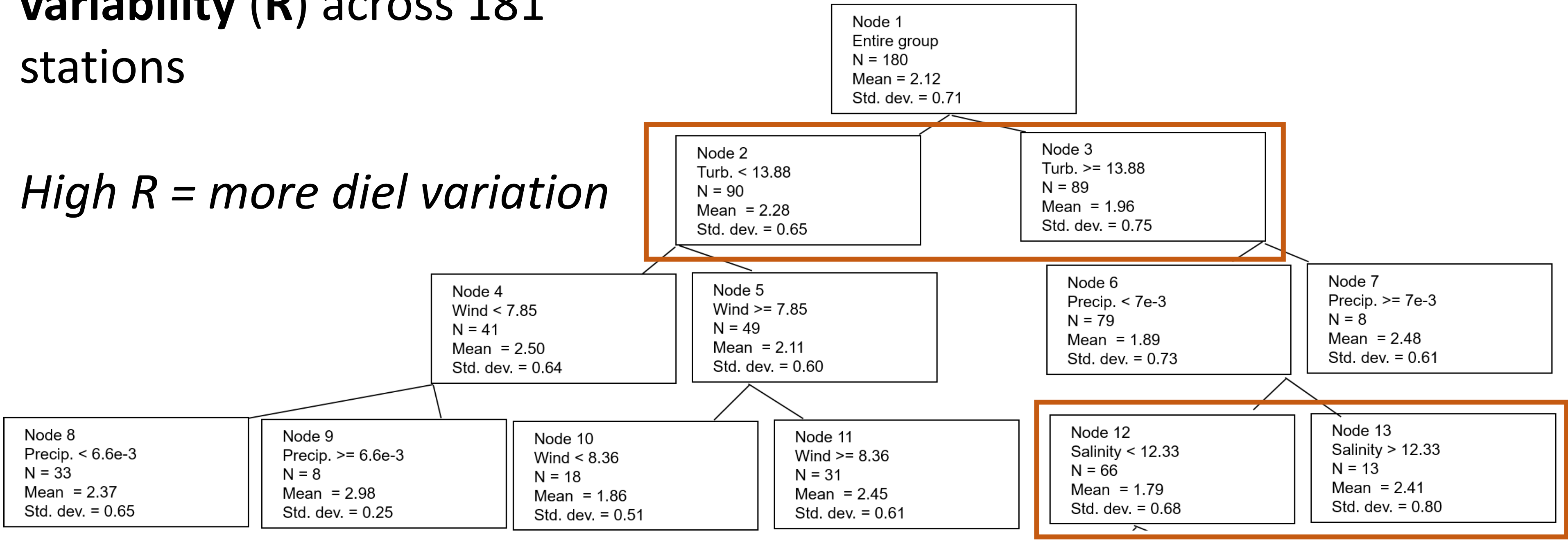


CART analysis to Explain Spatial Patterns of Control on Oxygen Variability

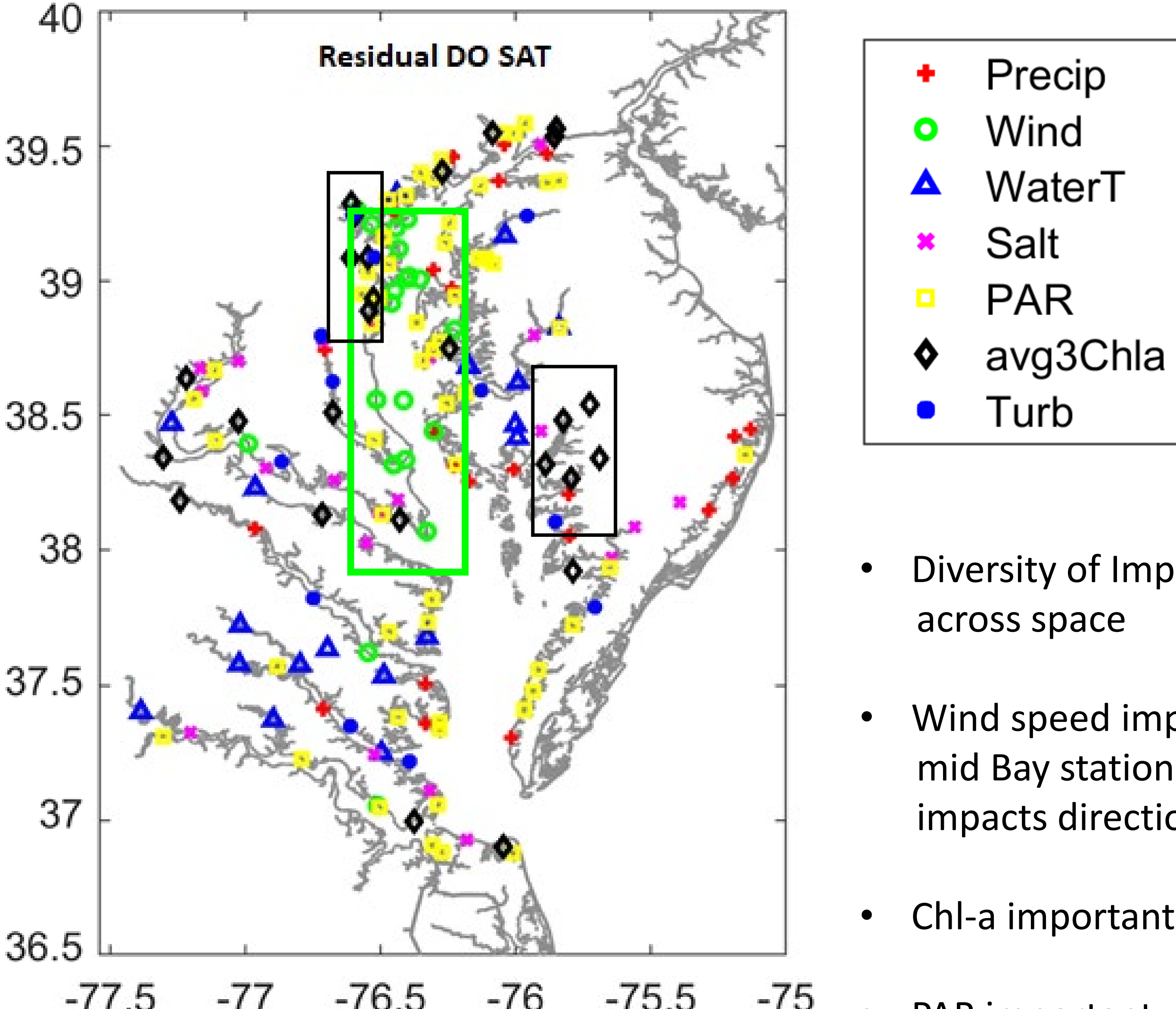
<u>Example:</u>

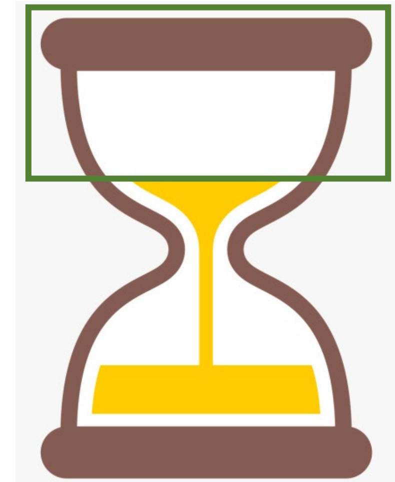
Ratio of **diel to tidal variability** (**R**) across 181 stations

High R = more diel variation



CART: Most important predictor, by station

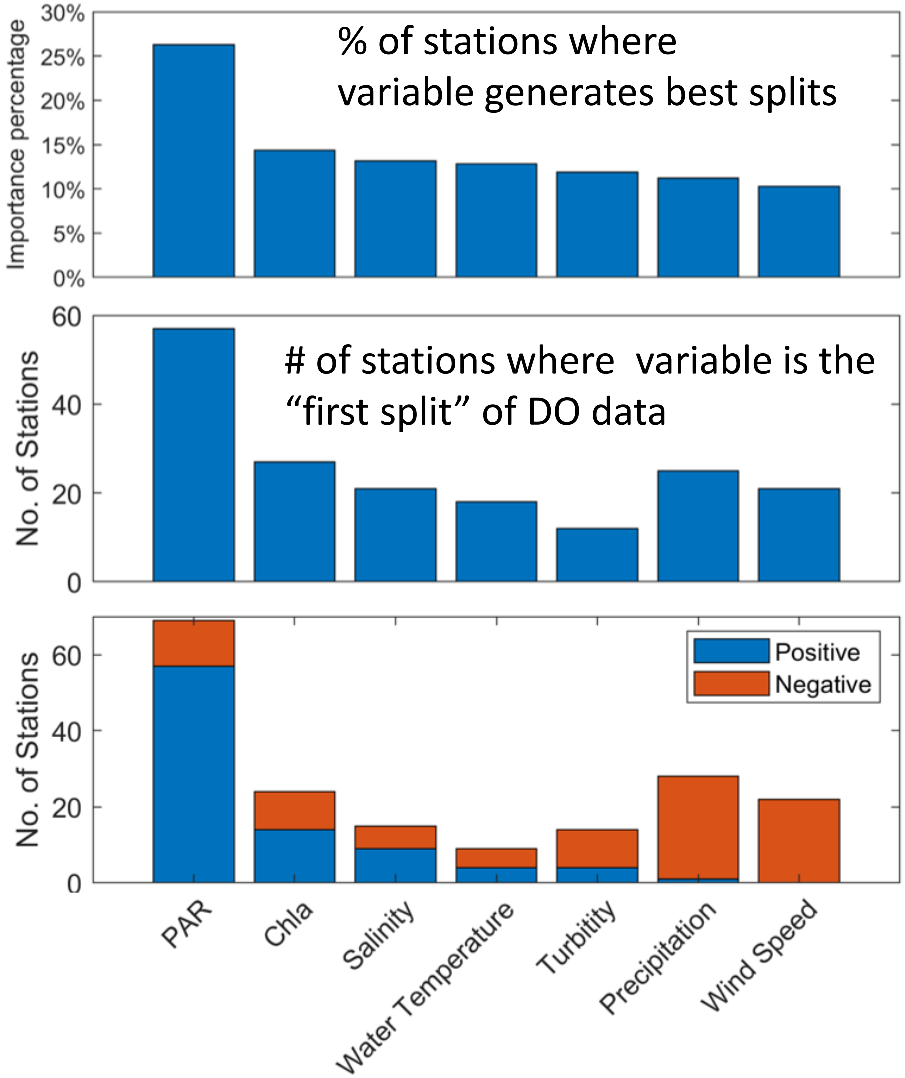




- Diversity of Important variables across space
- Wind speed important in open, mid Bay stations (wind direction impacts direction(±) of DO effect
- Chl-a important in some inland regions
- PAR important, often along mainstem fringe

Frequency of "Importance" of Internal and External Controlling Variables

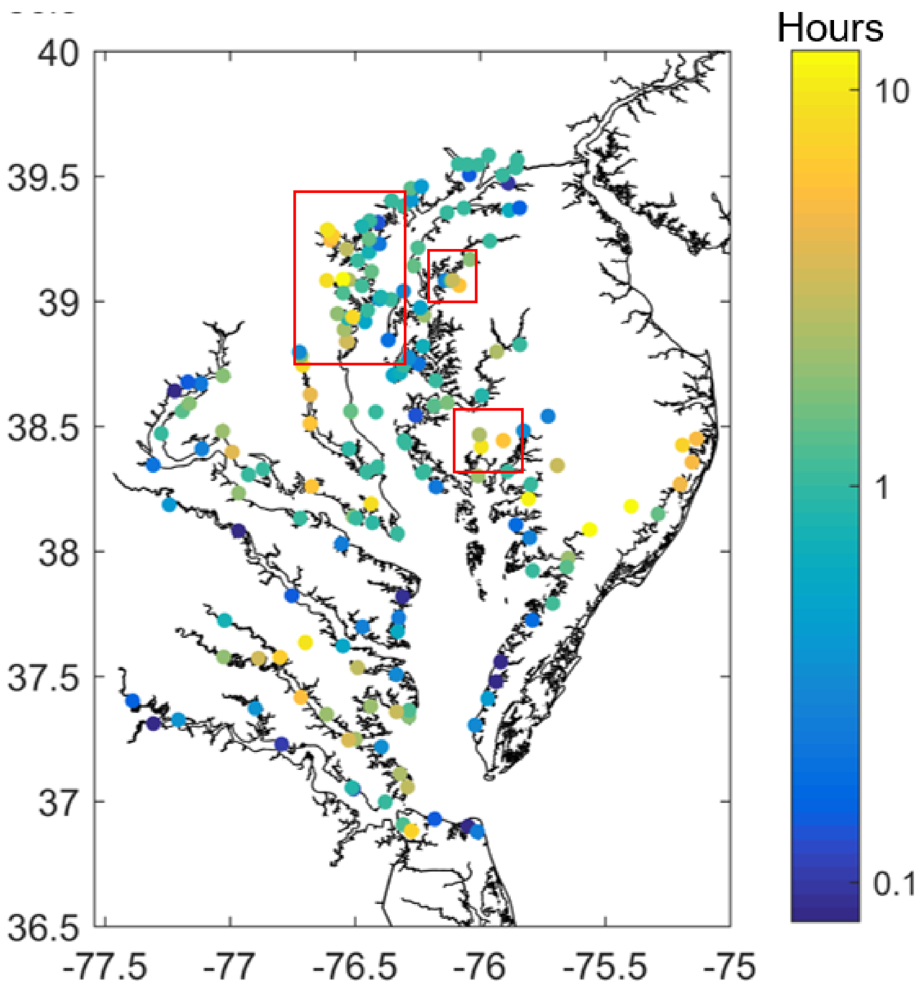
Residual %DO Saturation



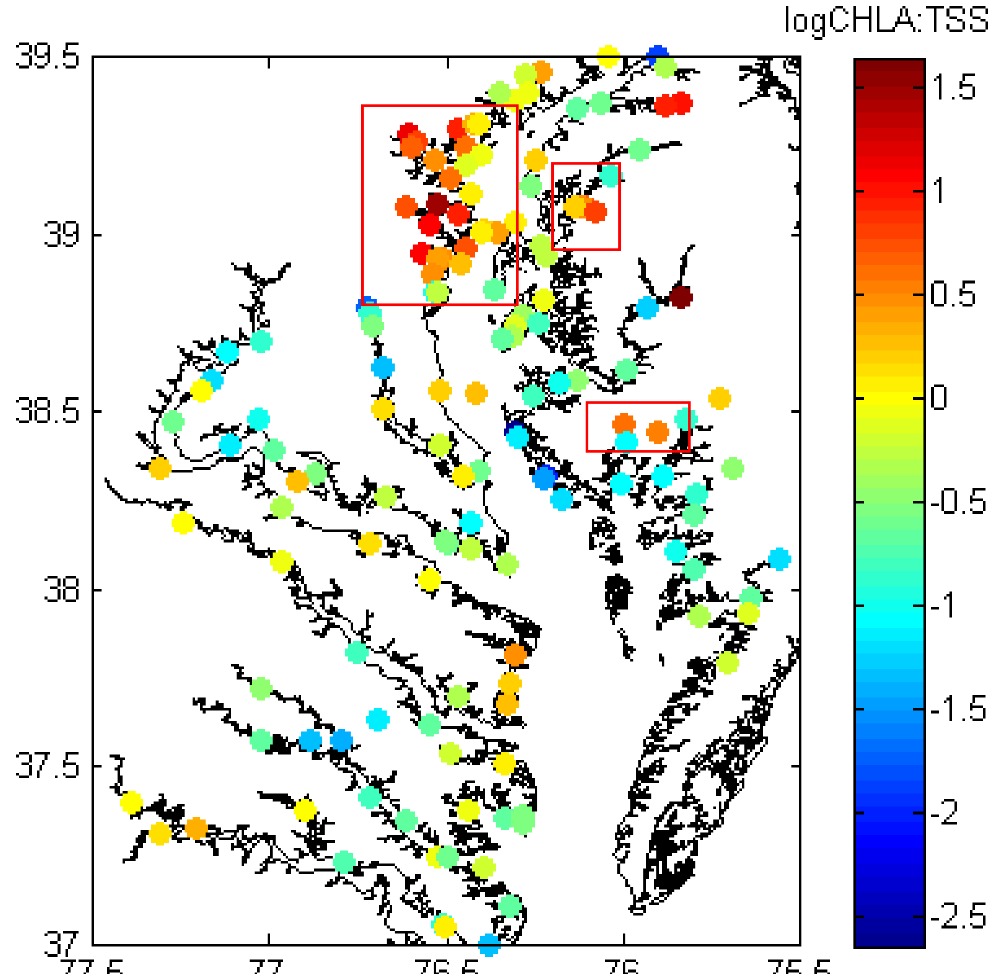
- CART results on residual %DO, where tidal and seasonal temperature effects removed
- PAR most frequent key control, generally positive effect
- Other variables somewhat split
- Chl-a and salinity can be positive or negative
- Precipitation, wind speed , and turbidity are negative (Precipitation related to PAR)
- Each of these bars merits more detailed investigation

Local Chl-a Effect on Hypoxia

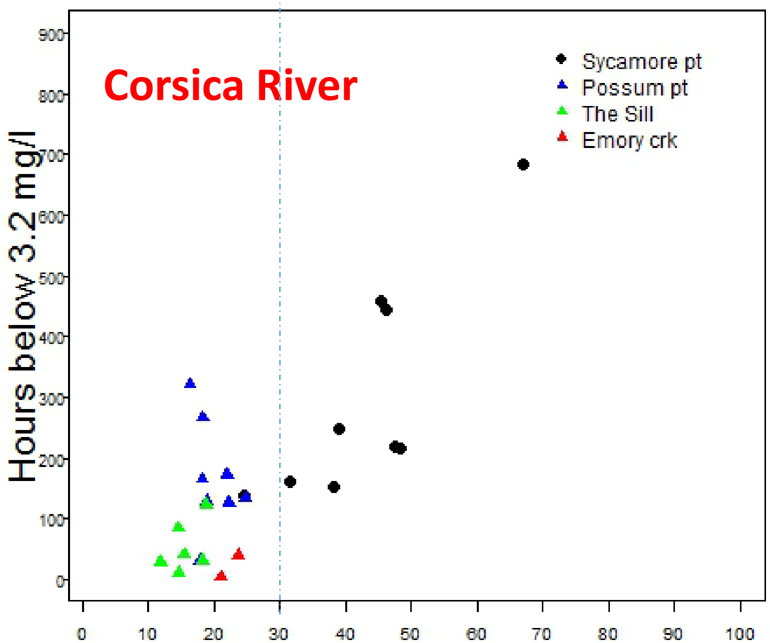
Hours of Hypoxia

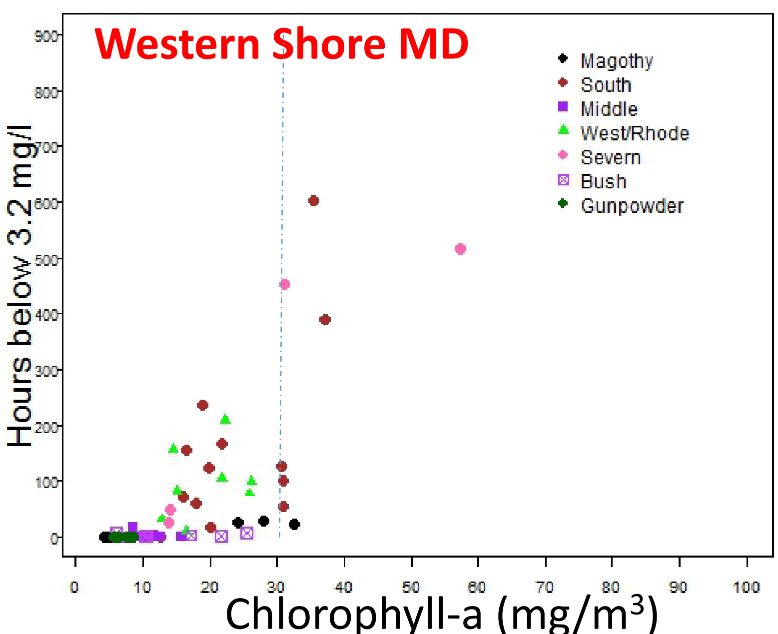


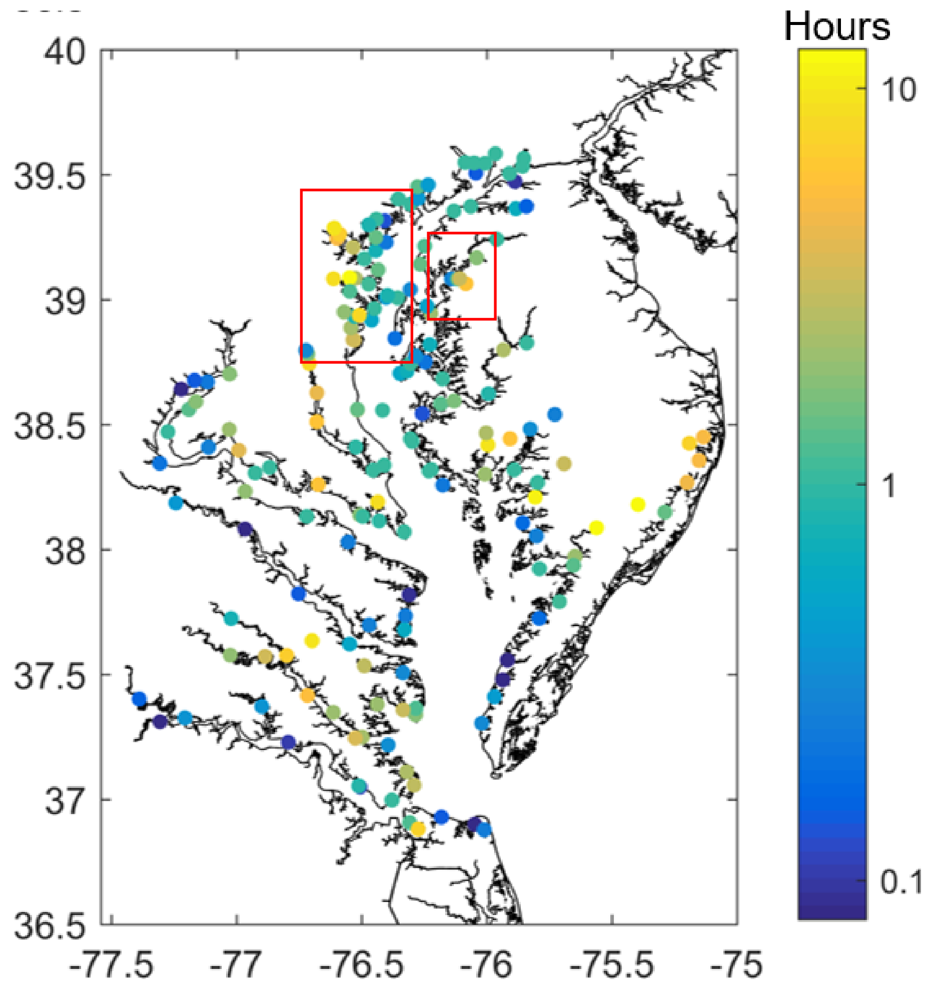
Chl-a: Total Suspended Solids



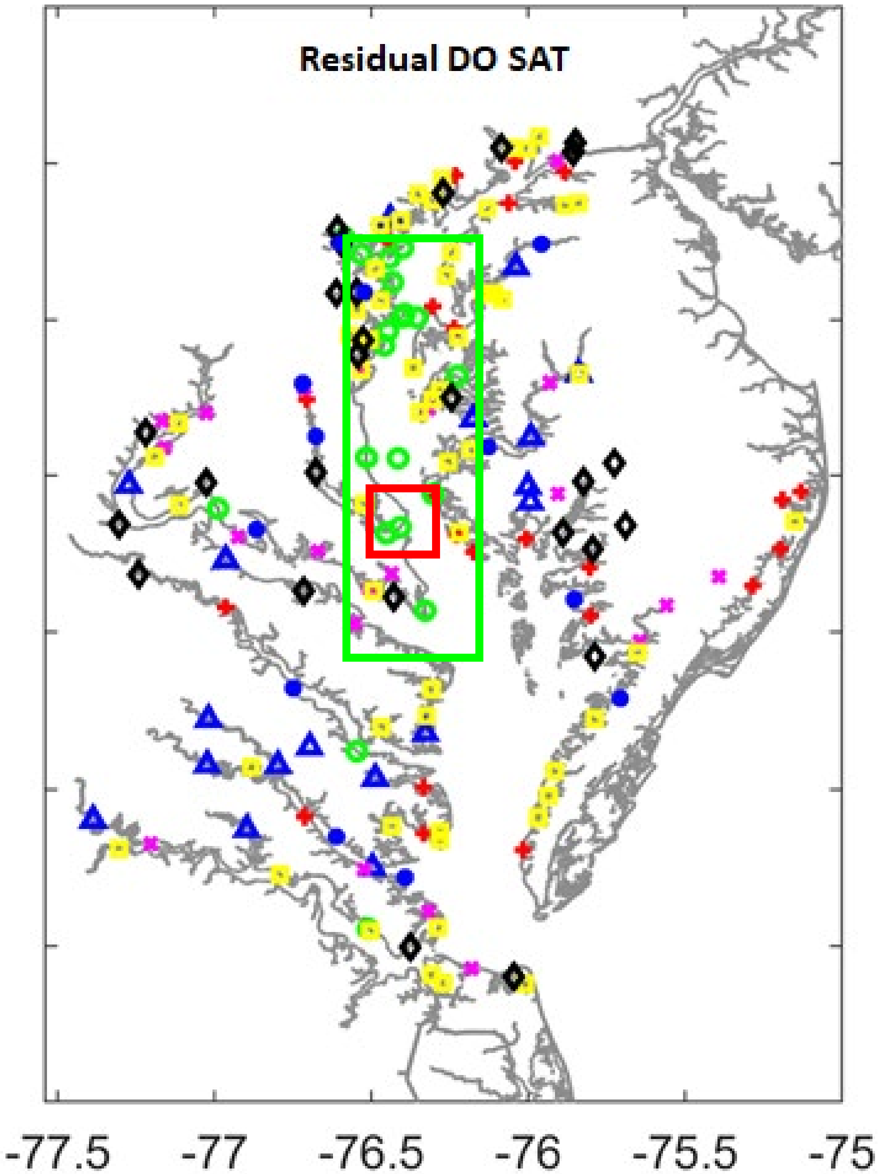
Linear or Non-Linear Chl-a Effect on Hypoxia?

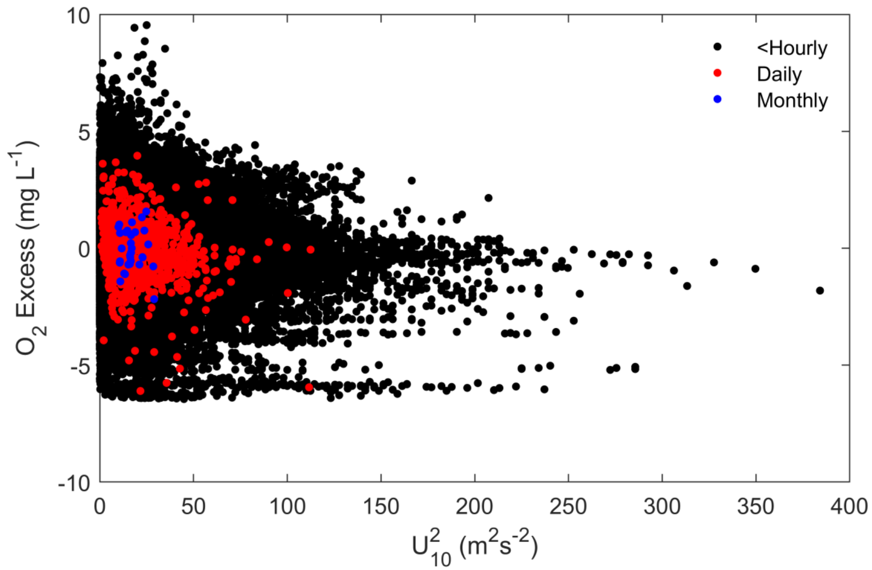


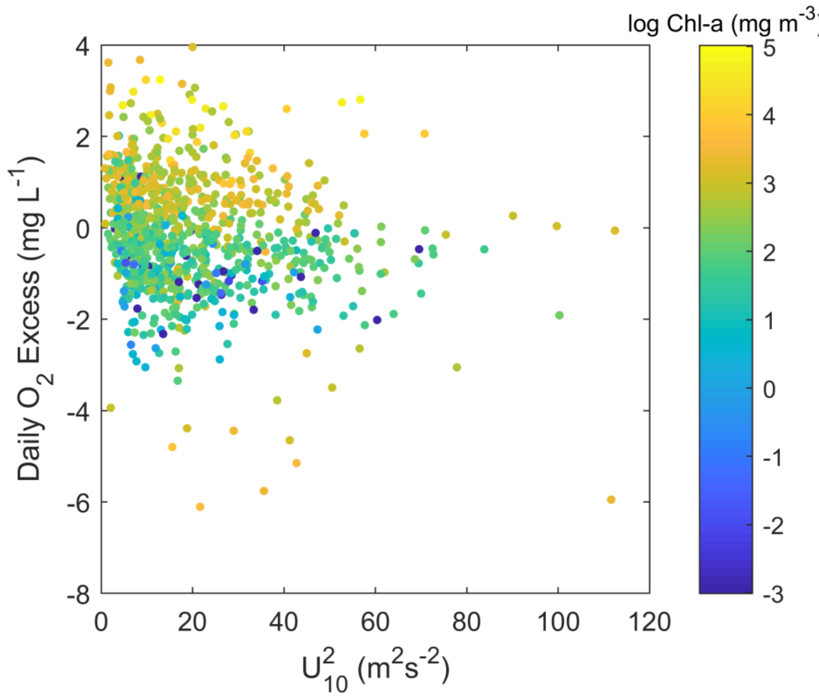




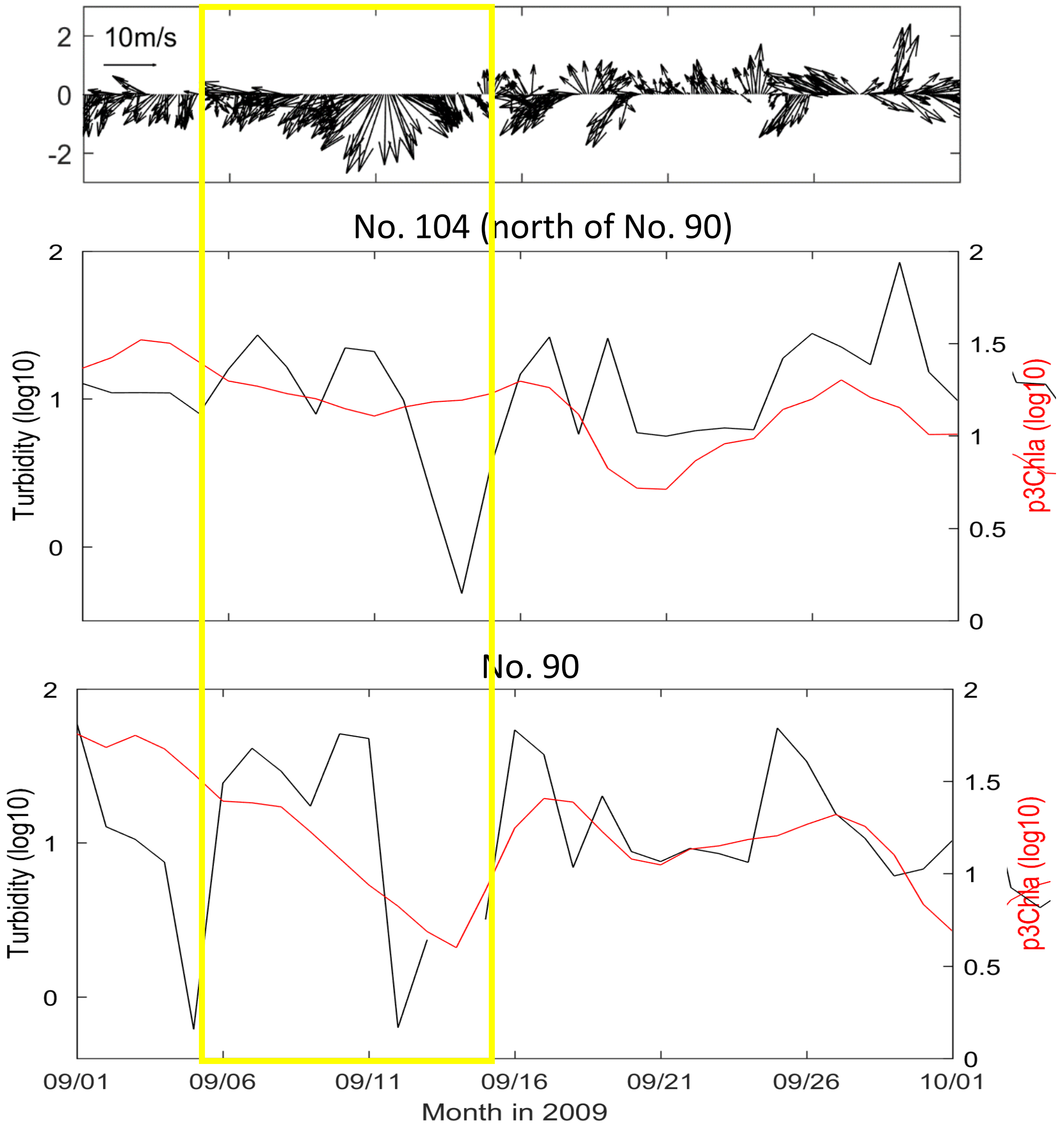
Effect of Wind



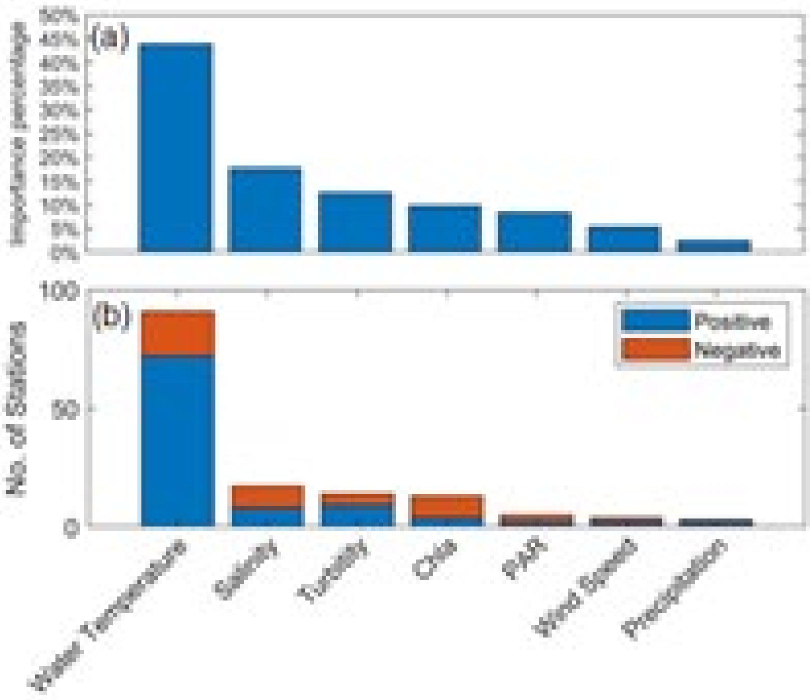


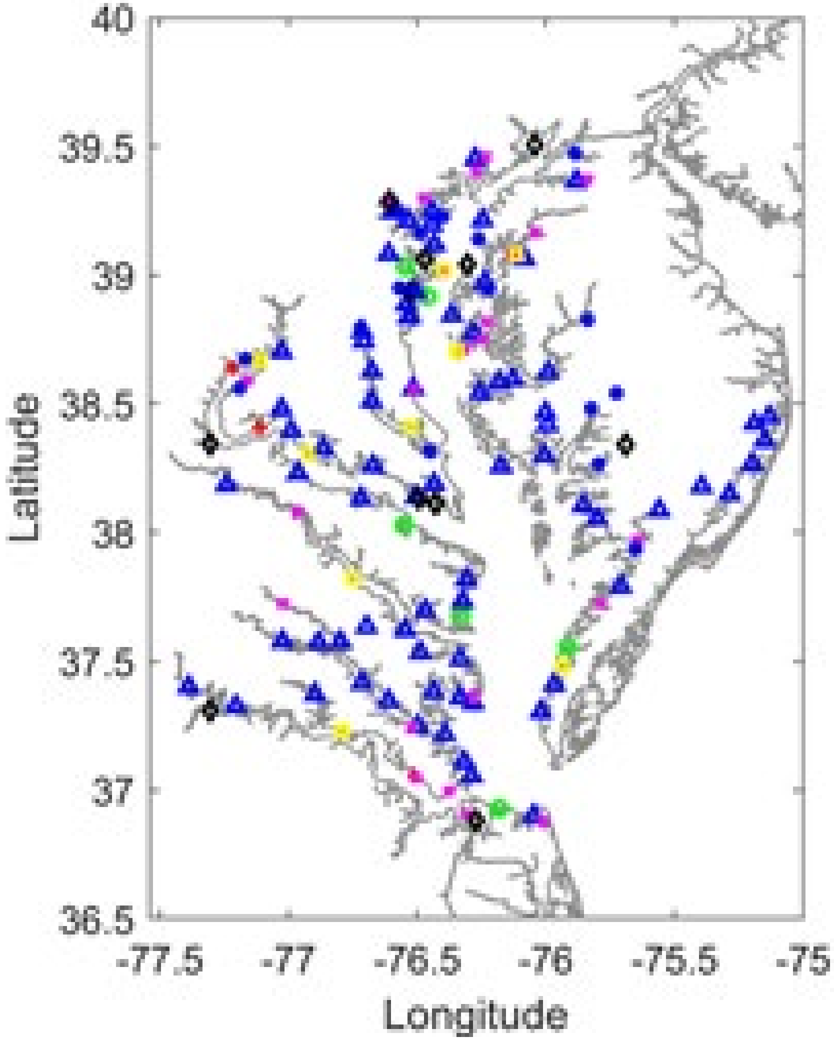


Under strong North Wind, Chlorophyll-a declines and turbidity increases = lower DO



Controls on Hypoxia Duration





Water temperature is the dominant MIP, primarily leads to more hypoxia (< 5 mg/L)

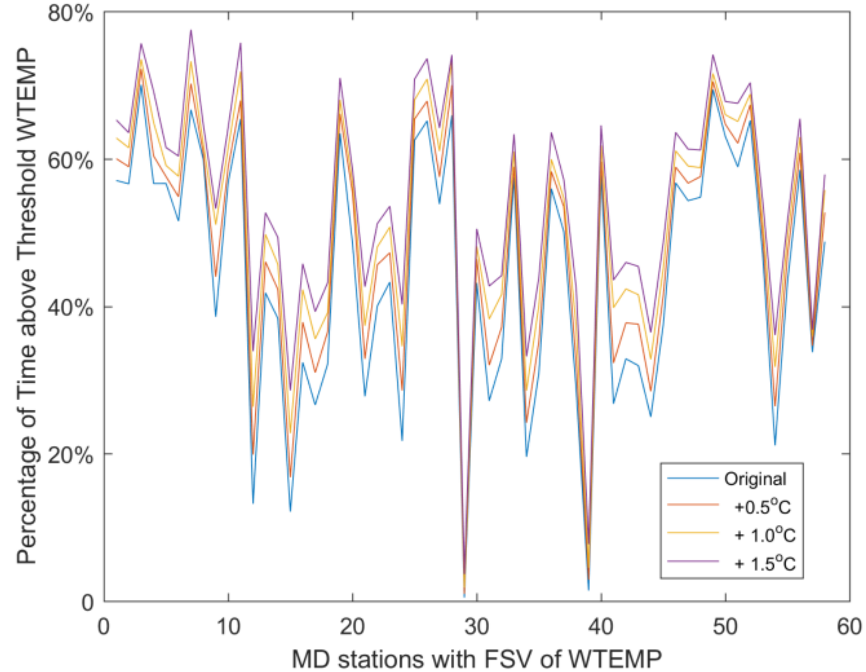
Potential Warming Impacts on Hypoxia

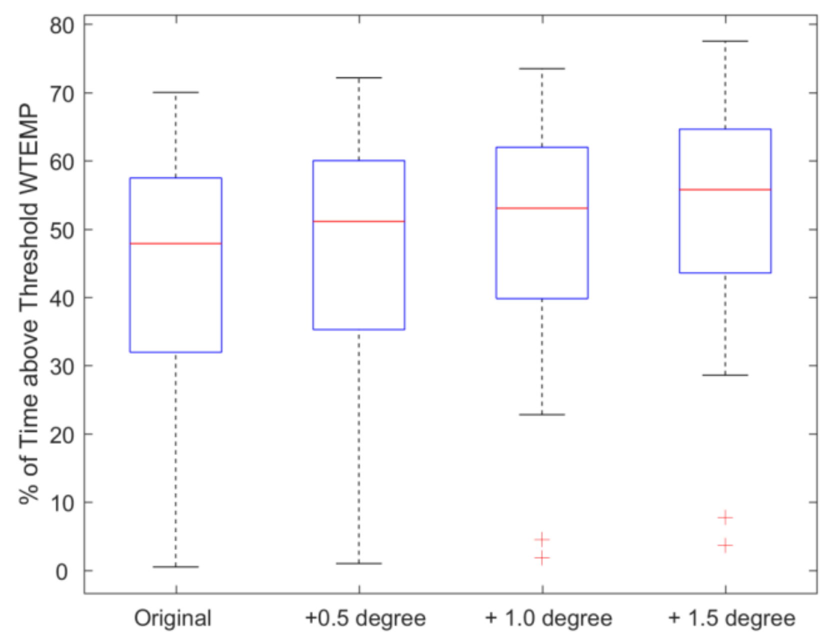
(1) Compute temperature threshold that splits (first split) record into hypoxic or non-hypoxic

(2) Estimate % of year above that threshold

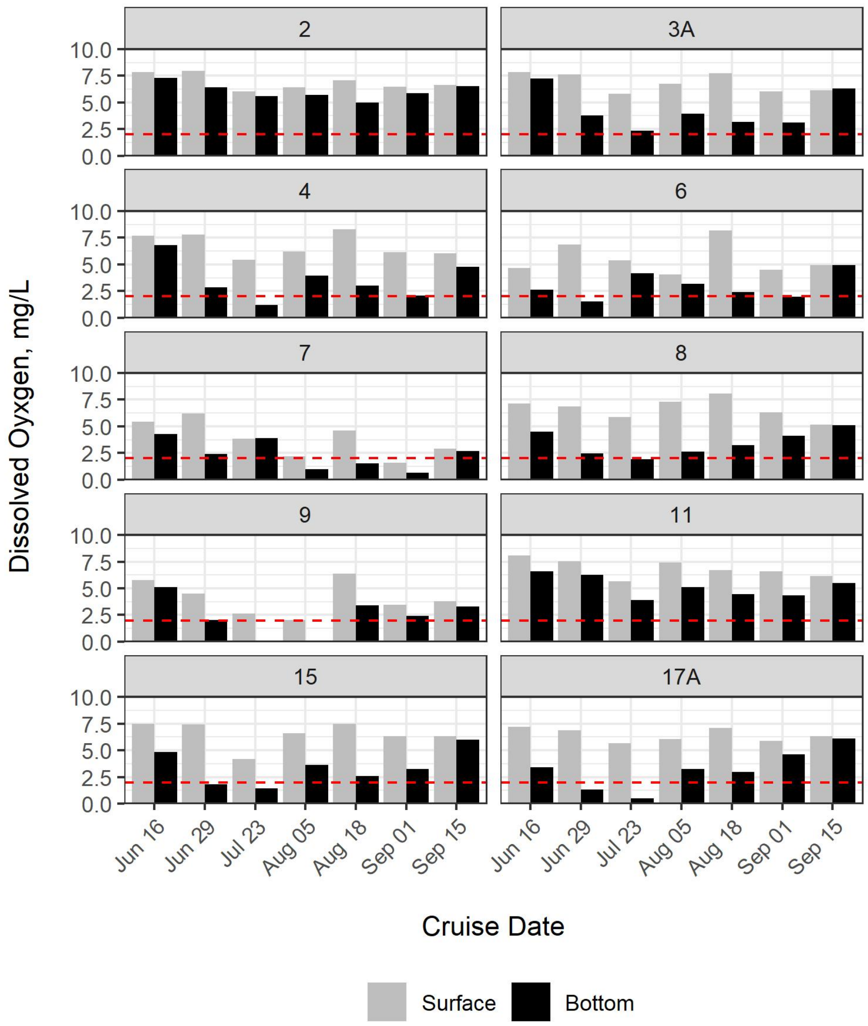
(3) Apply warming rate to contemporary measurements

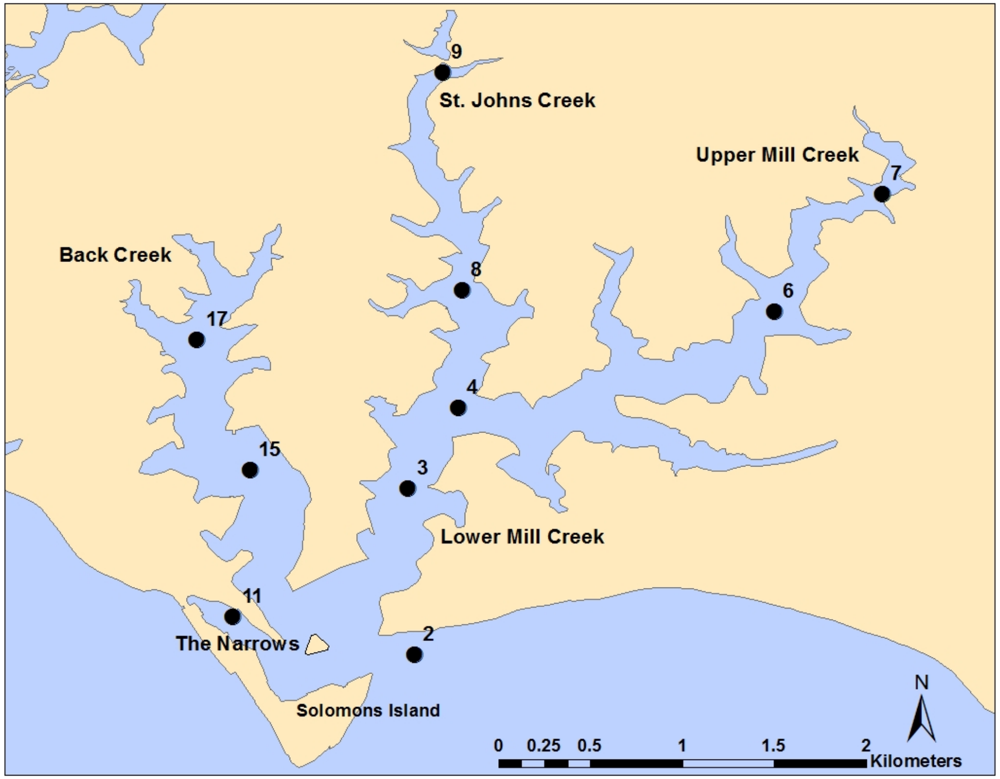
(4) How much more time might this threshold be crossed?





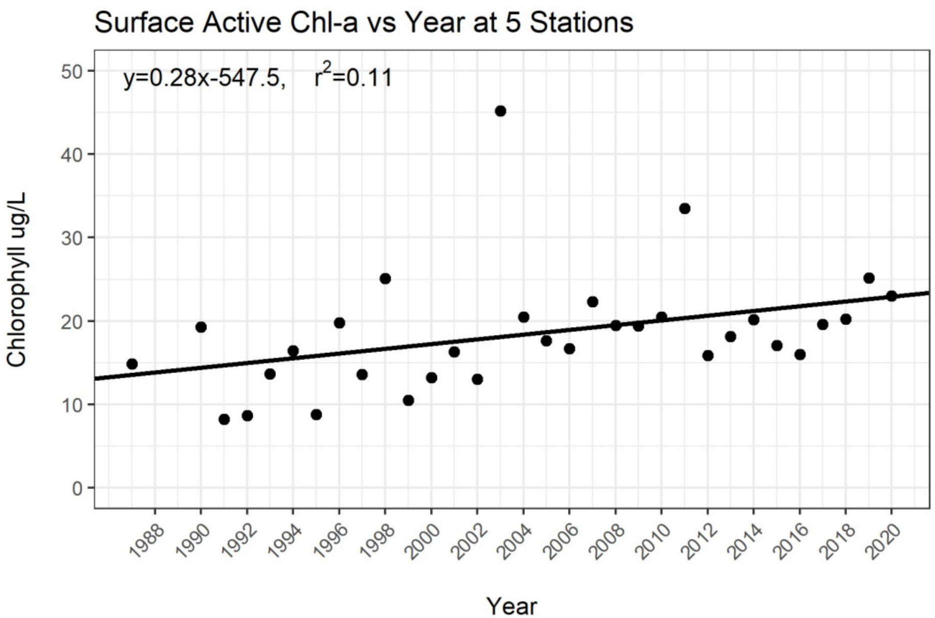
Looking Ahead: How do we Approach 'Shallow' Waters?

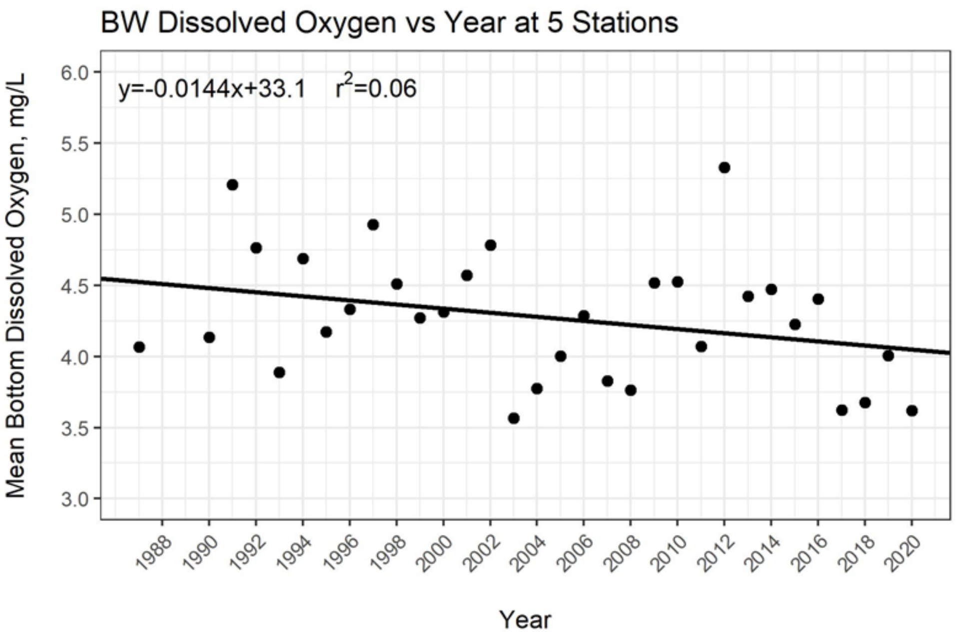




Calvert County Long-Term Monitoring Program

Looking Ahead: How do we Approach 'Shallow' Waters?





These are long-term patterns, with apparent trends, measured in the deepest part of a 'shallow' system

Would a ConMon program have measured this?

Conclusions and Implications

- Diversity of controls on oxygen variability, regional similarities in controls

- Temperature, PAR, and chlorophyll are key drivers of oxygen (hypoxia) variability, *but they interact with other forces (e.g., wind, nutrient loading) – previous presentations*

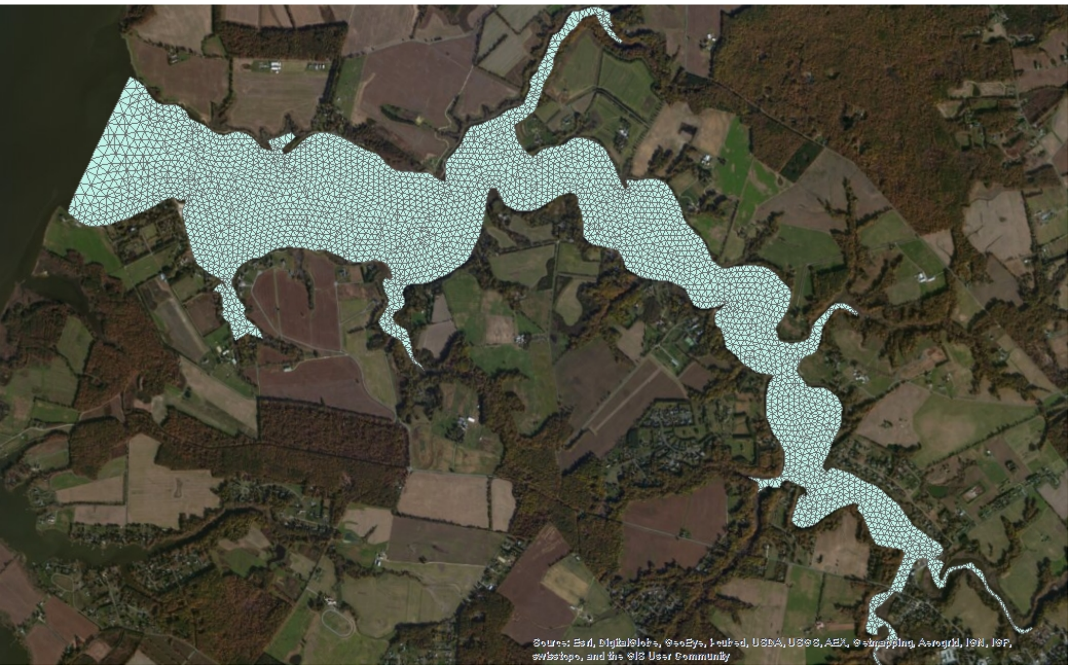
- Chlorophyll-a has both positive and negative effects on hypoxia: (a) excessive chlorophyll-a appears to associate with diel-cycling hypoxia, *but moderate chlorophyll-a leads to higher DO– previous presentations*

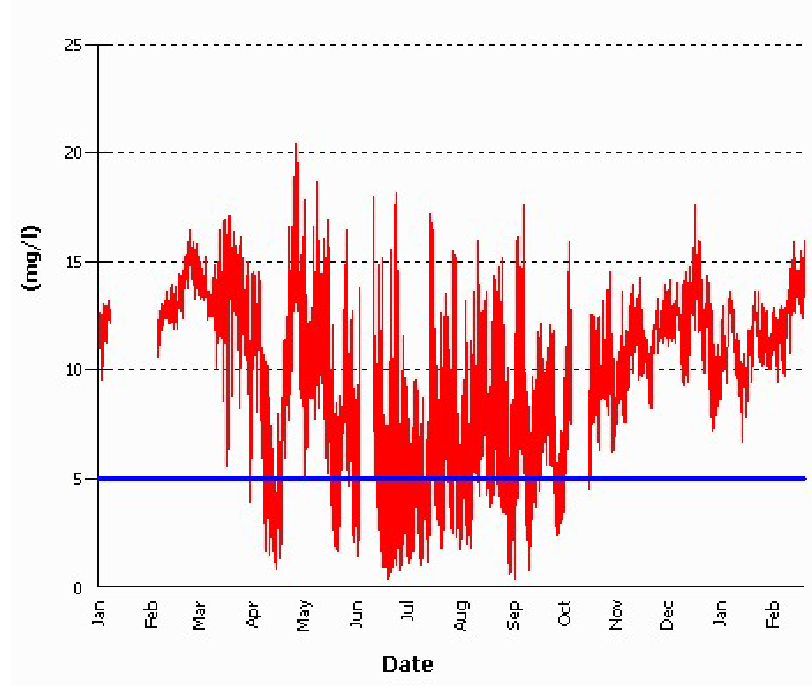
- Ecosystem metabolism, as a proxy for oxygen variability, declined with nutrient load reductions

- A universal statistical explanation for oxygen variability is elusive so far, but detailed case studies reveal system-specific controls

- *Can fine-scale modeling of these processes better inform our understanding?*

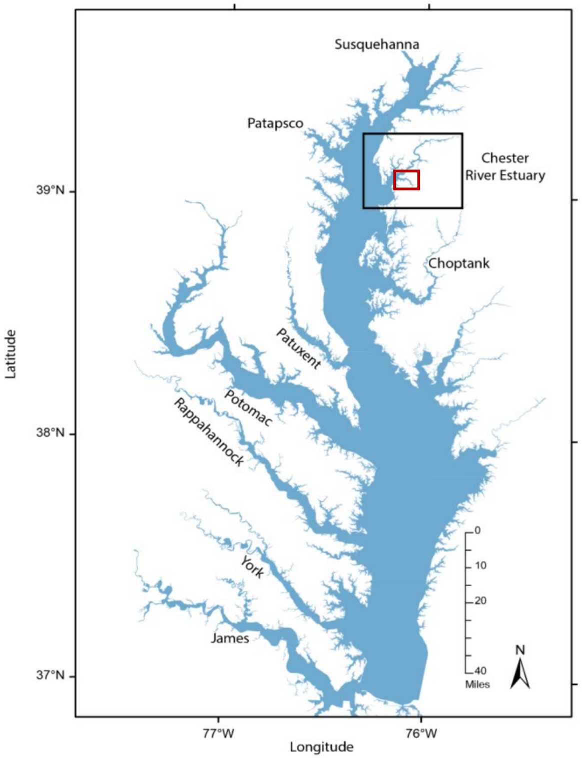
High-Resolution Numerical Model of a Shallow Water System: the Corsica River Case Study





Case Study: Numerical Model of a Shallow Water Estuary

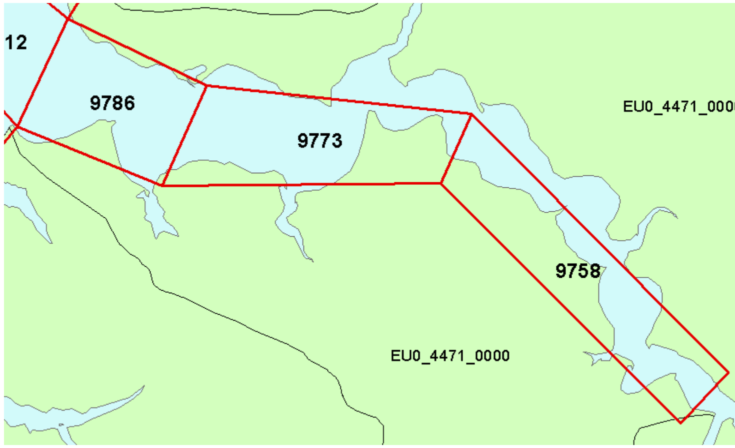
Richard Tian, Lewis Linker, Damian Brady, Jeremy Testa



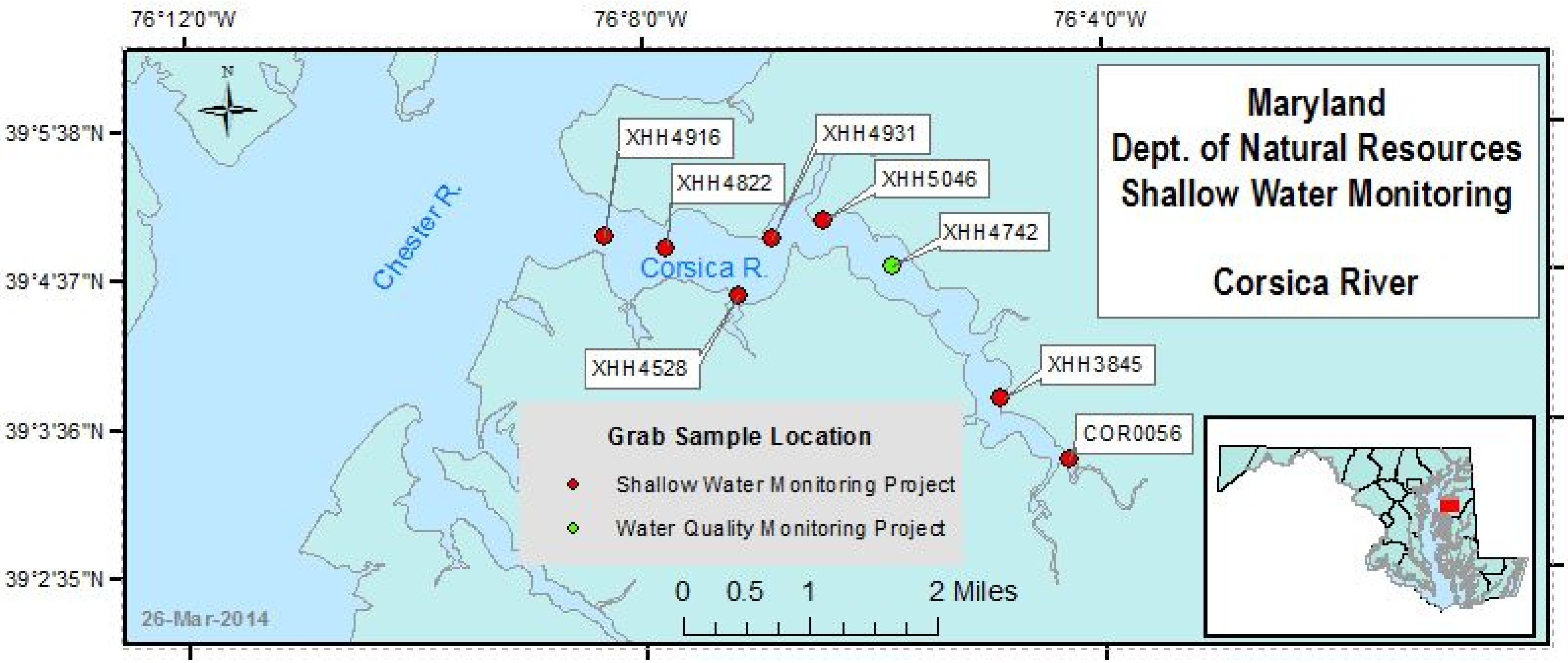
Corsica Model Grid

SCHISM-ICM

- 20m resolution on coast, 100m at the mouth;
- 5029 cells, 5 layers
- Simulation year = 2006
- Phase 5.3 Watershed Model Loads

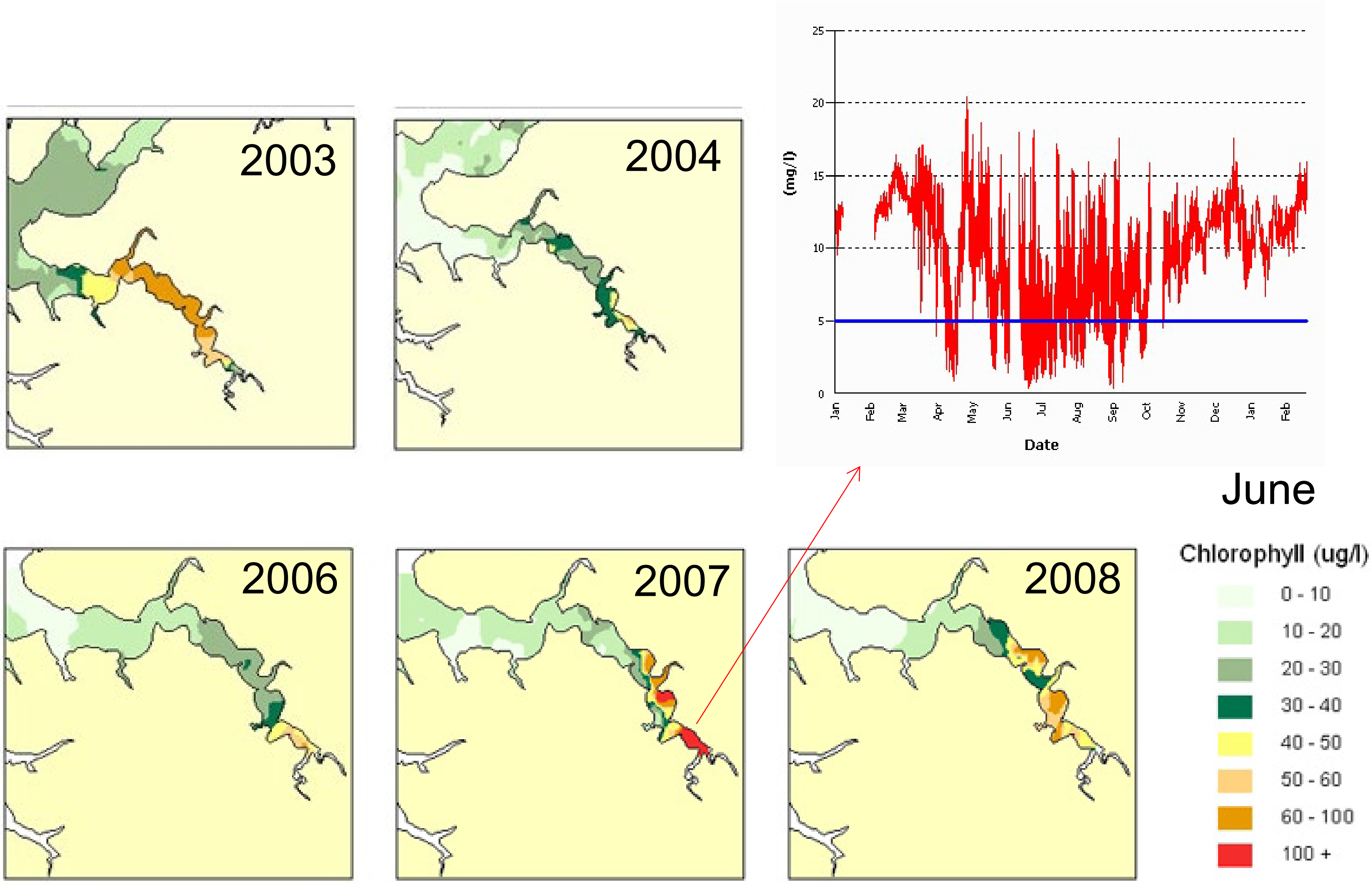


DNR monitoring stations in Corsica R.

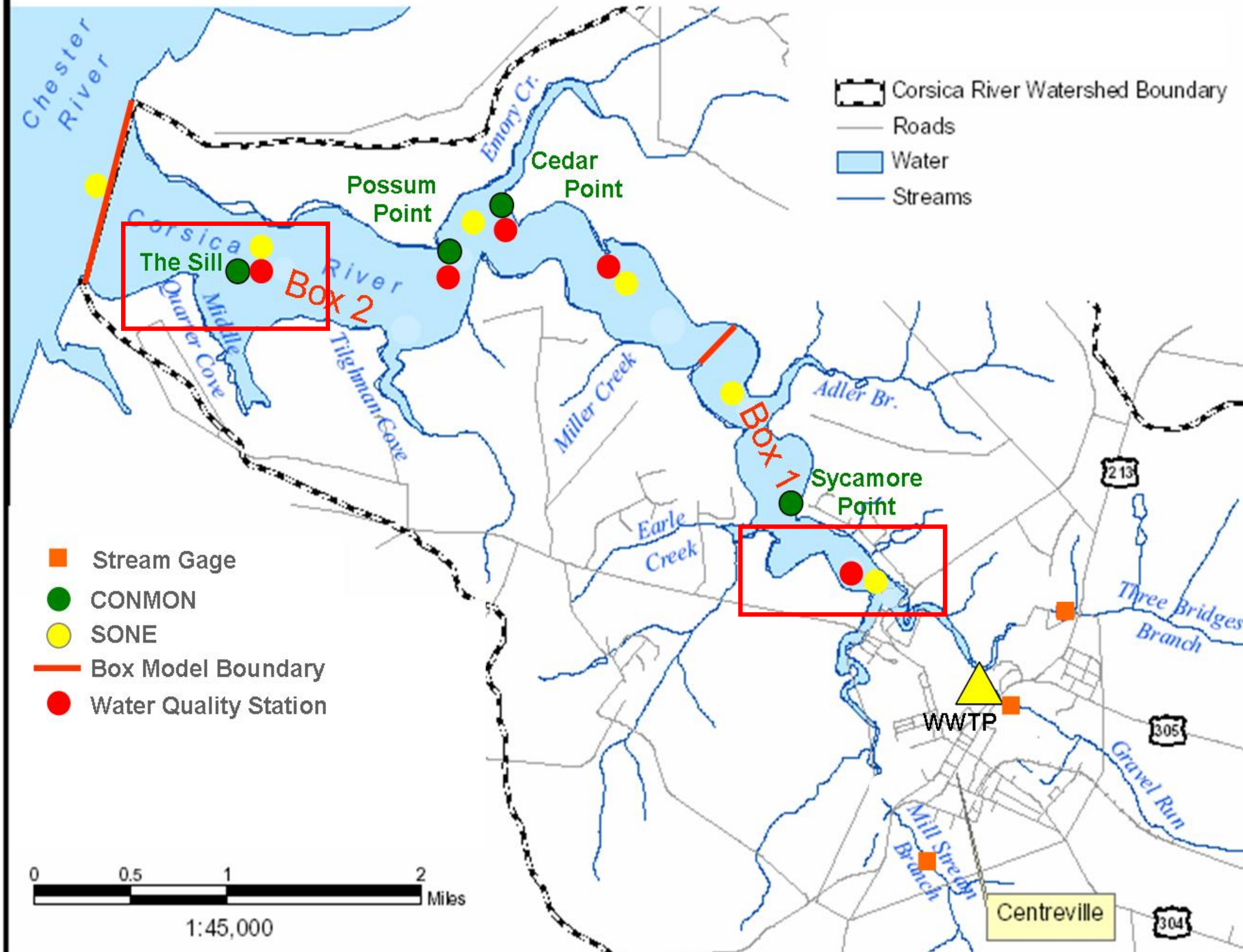


Station	Cmon	Dflow	Tributaries	CMON yrs	Dflo yrs
XHH3851	x	x		2005 - 2013	2005 - 2013
XHH4528		x			2006 - 2013
XHH4742			x		
XHH4822		x			2003 - 2005
XHH4916	x	x		2006 - 2011	2006 - 2013
XHH4931	x	x		2006 - 2013	
XHH5046	x			2005 2006	2006 - 2013
COR0056		x			2006 - 2013

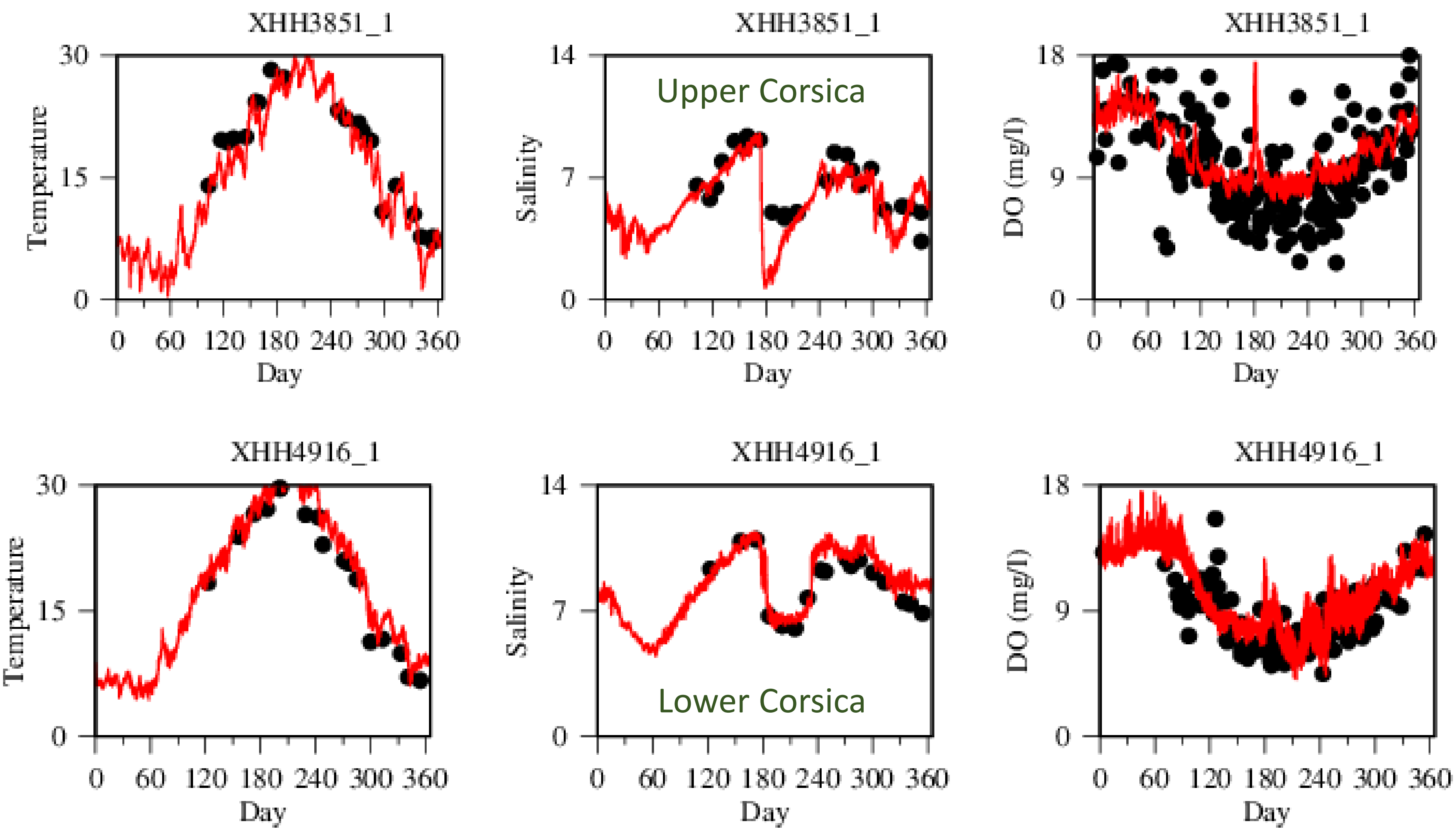
Inter-Annual and Spatial Changes in CHL-a



Corsica River and Key Features (map courtesy DNR)

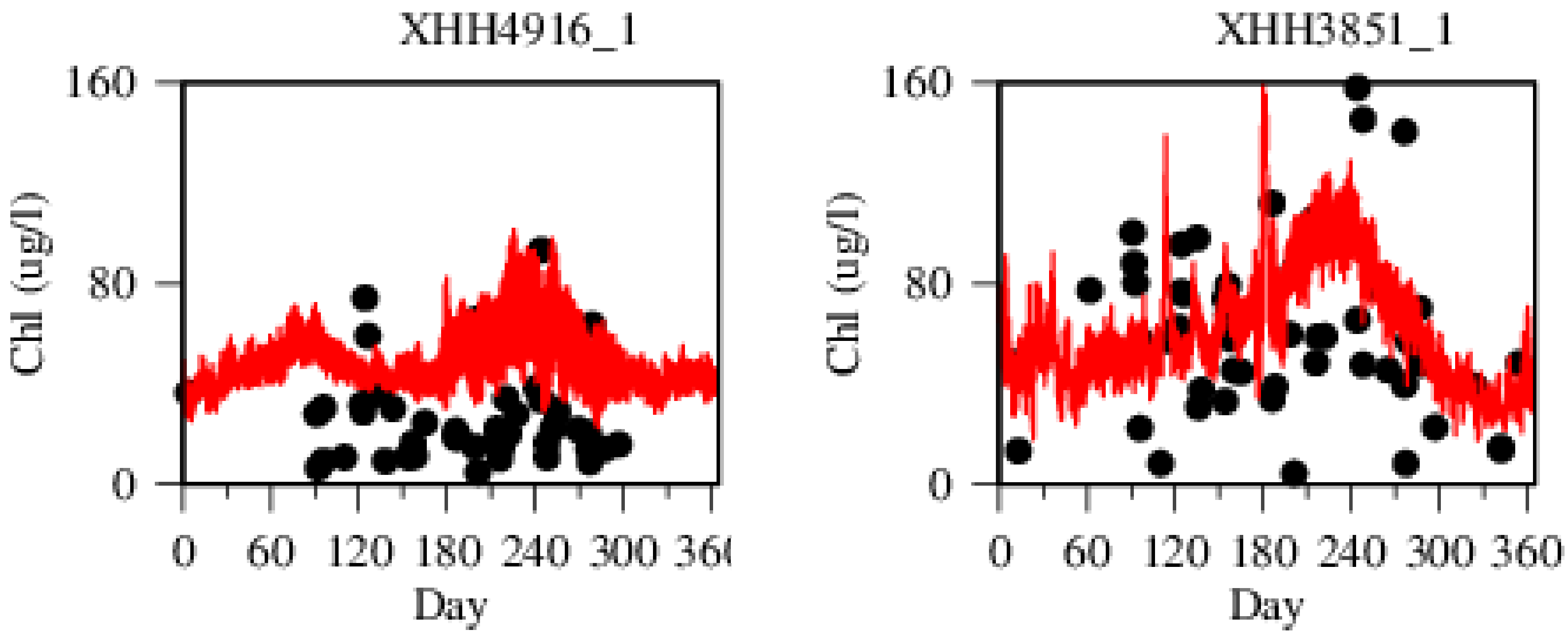


Case Study: Validation of Water Temperature, Salinity, DO

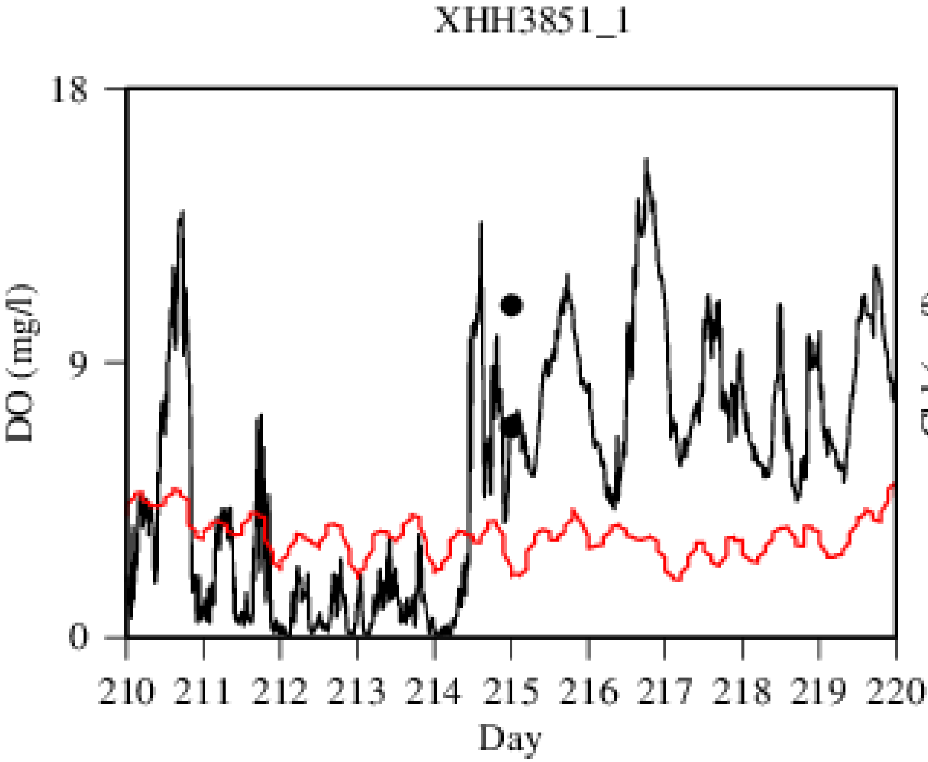


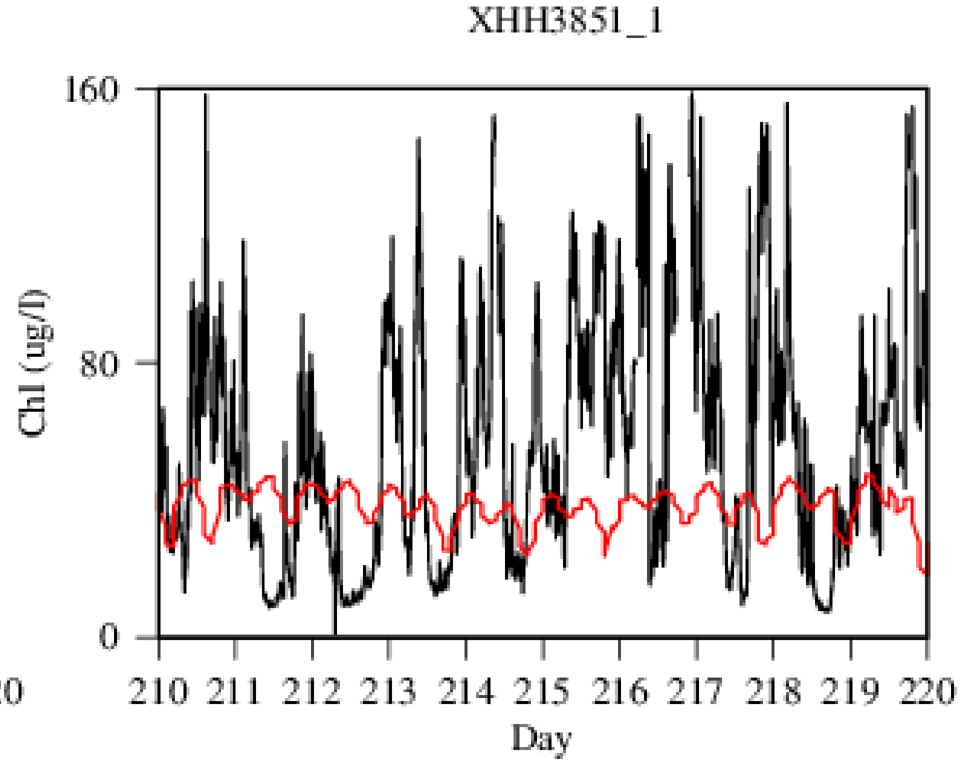
Case Study: Validation of Surface CHL-a

Very high chl-a concentrations predicted, but variability missed



Short-Term Variation in Model *Underestimates* Observations

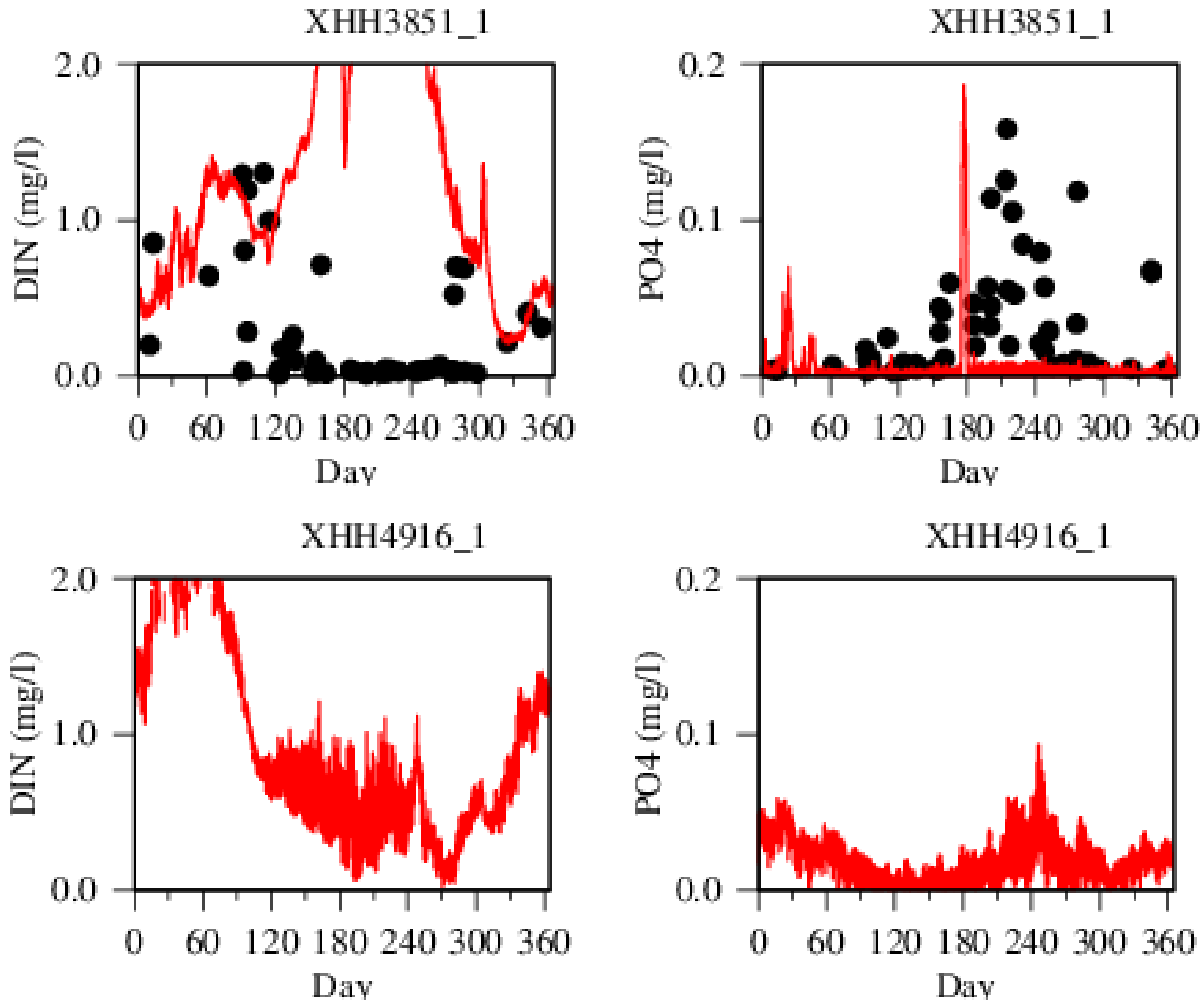




Model *Underestimates* DIP, Overestimates DIN
P-limitation emerges in the model

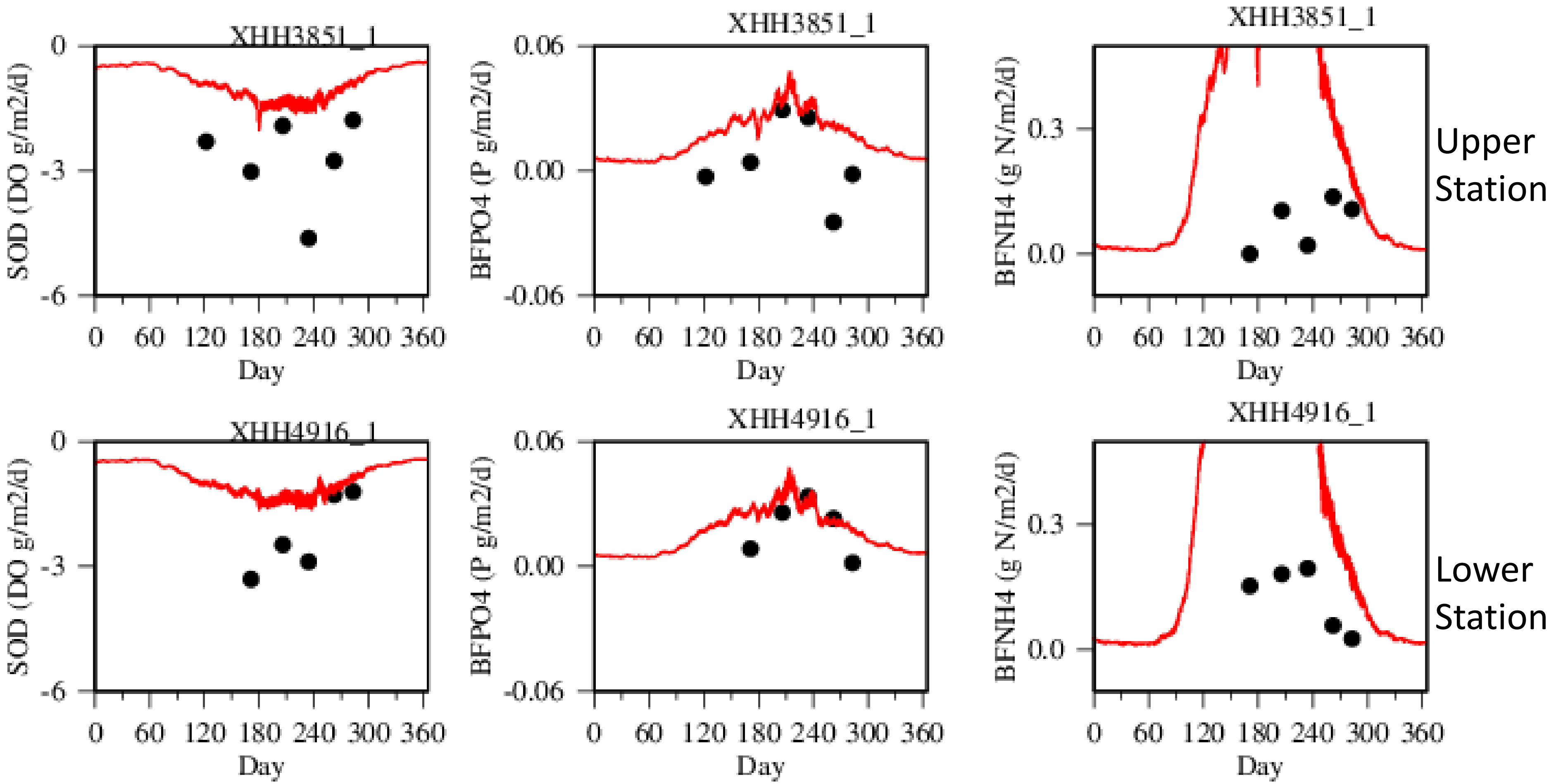
Upper Station

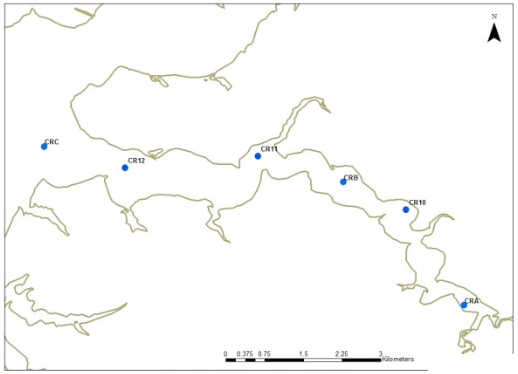
Lower Station



Model *Underestimates* Sediment Oxygen Consumption, Overestimates NH_4 Efflux

Consistent with missed O_2 minima, and high WC DIN

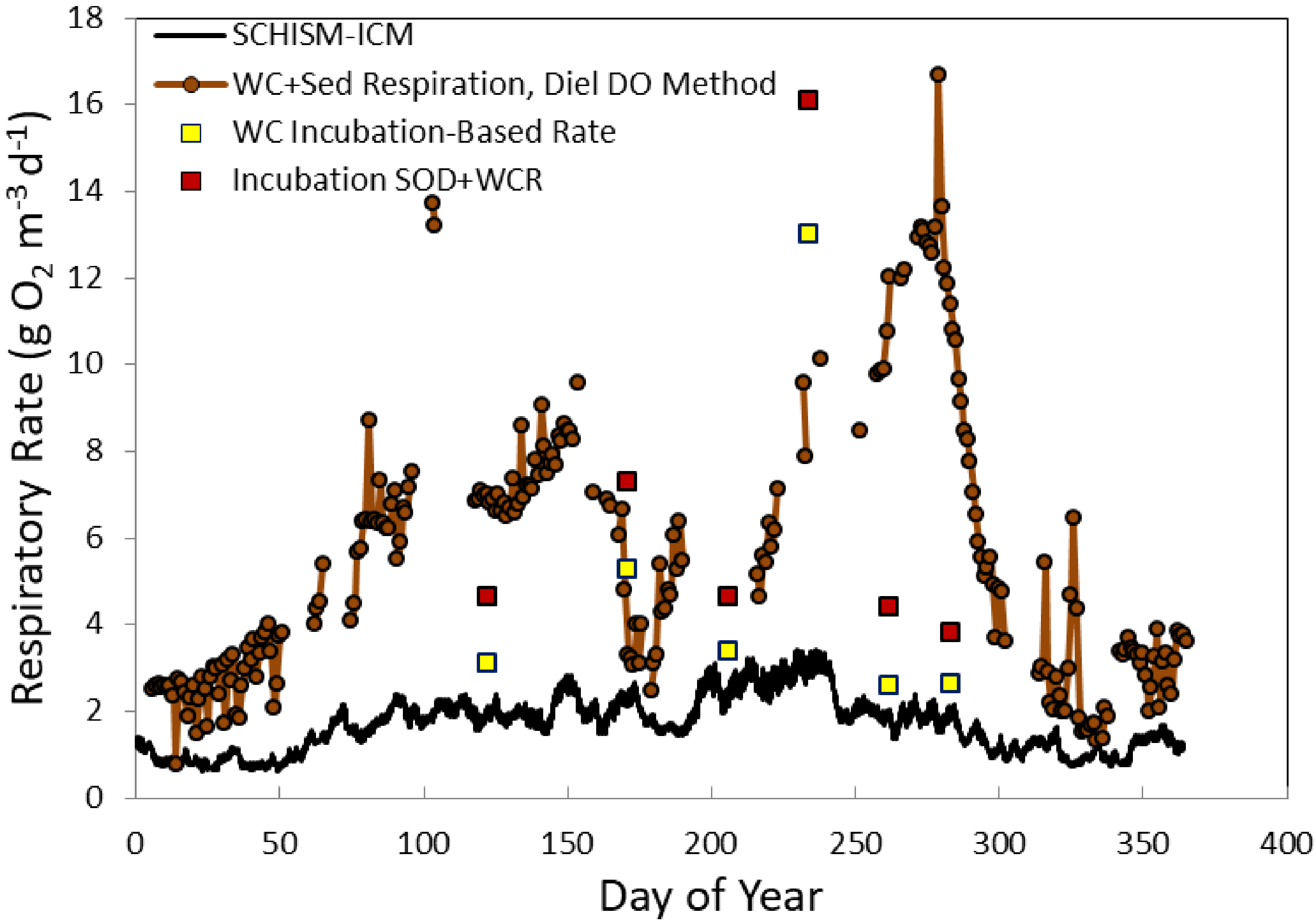




Corsica River Flux Stations

Model *Underestimates* Overall O_2 consumption

<u>Consistent with missed O_2 Variability</u>



Conclusions to Date

(1) Even when implemented at extremely high resolution, current model does not capture diurnal variations in dissolved oxygen in a highly dynamic site.

(2) Continued investigations will continue, particularly addressing the following questions:

(a) Is natural variability in PAR adequately forced on the model at short enough (~hour) time steps?

(b) Do the metabolic rates of primary production and respiration computed within the model agree with the substantial rates derived from observations?

(c) Is wind-stress properly applied in protected shallow tributaries, given most wind products are based on larger scales?

(b) Will fine-scale watershed model inputs be necessary to represent fine-scale effects of freshwater inputs to shallow waters and their associated circulation effects?