Quantifying the Increased Resiliency of the Chesapeake Bay to Hypoxia: A Benefit of Nutrient Reductions

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VIMS WILLIAM & MARY VIRGINIA INSTITUTE OF MARINE SCIENCE

CHAMP Meeting
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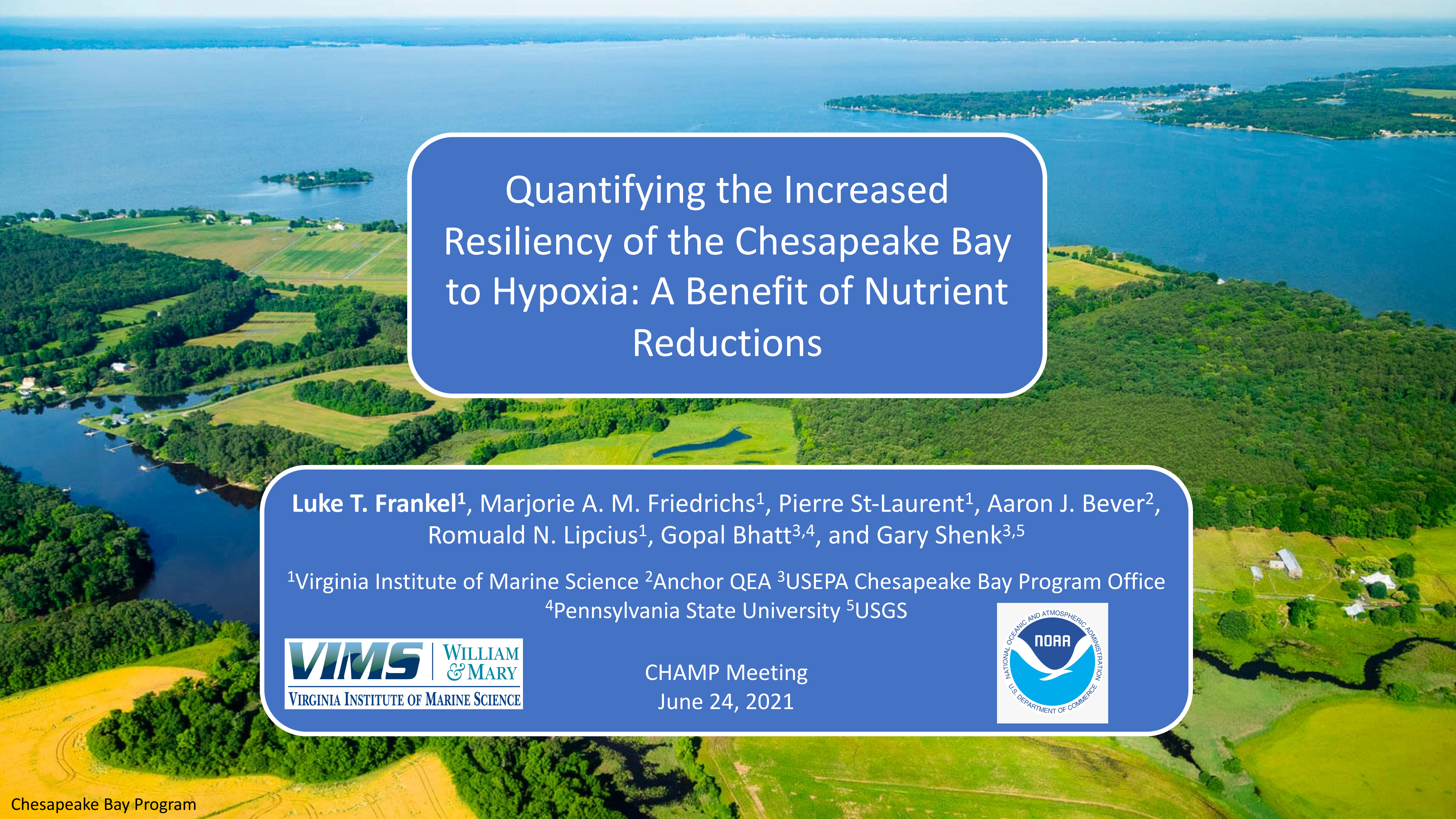
NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION U.S. DEPARTMENT OF COMMERCE

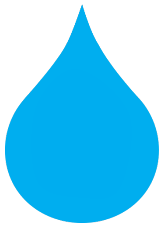


Chesapeake Bay Program

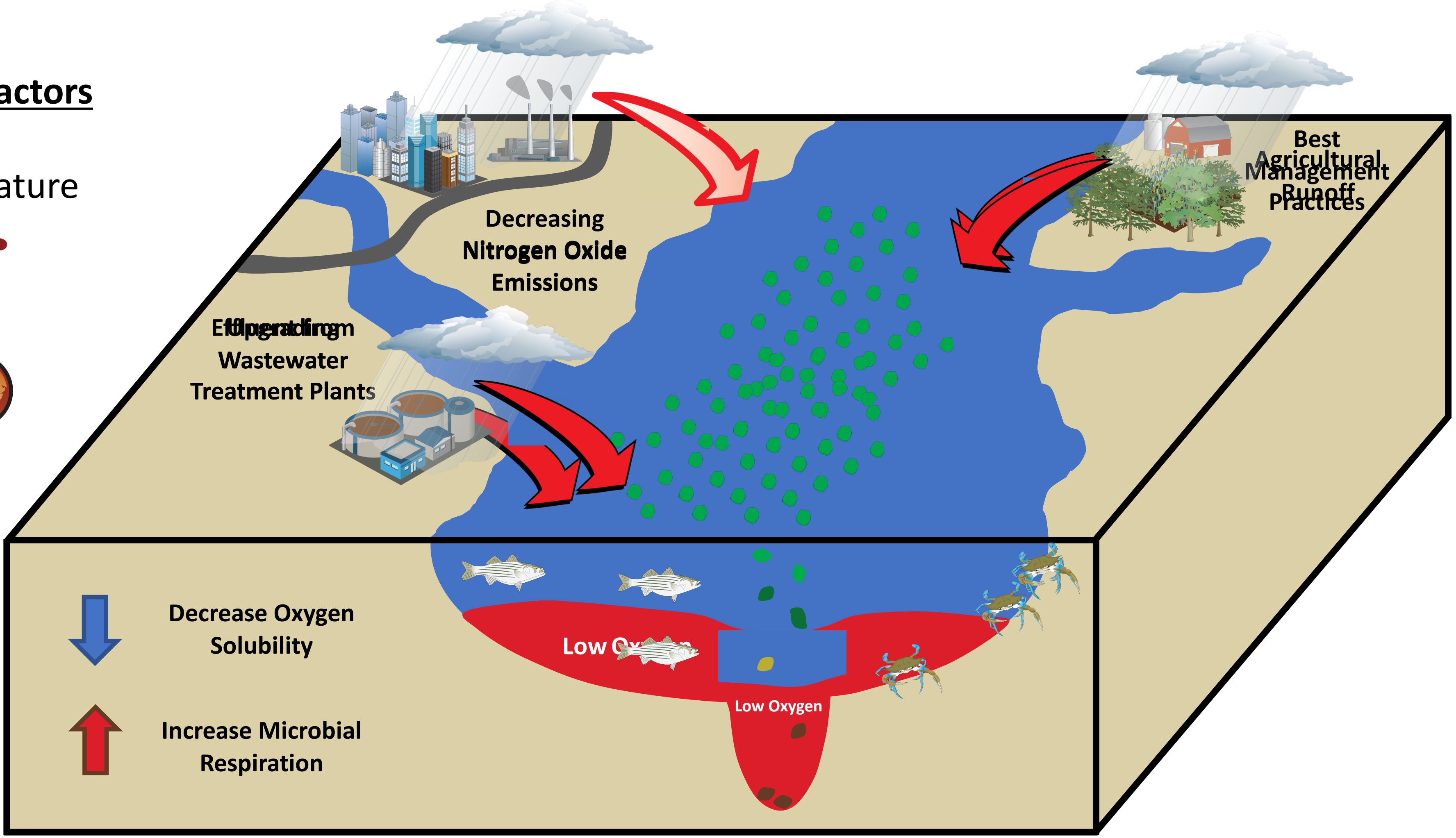
How Hypoxia Develops

<u>Other Environmental Factors</u>

Precipitation

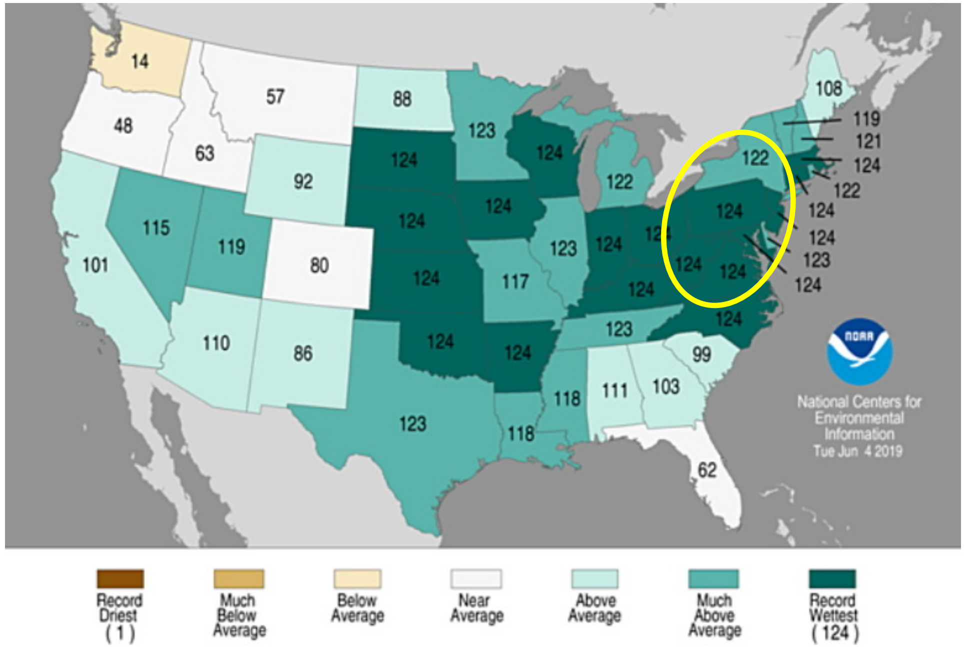


Temperature



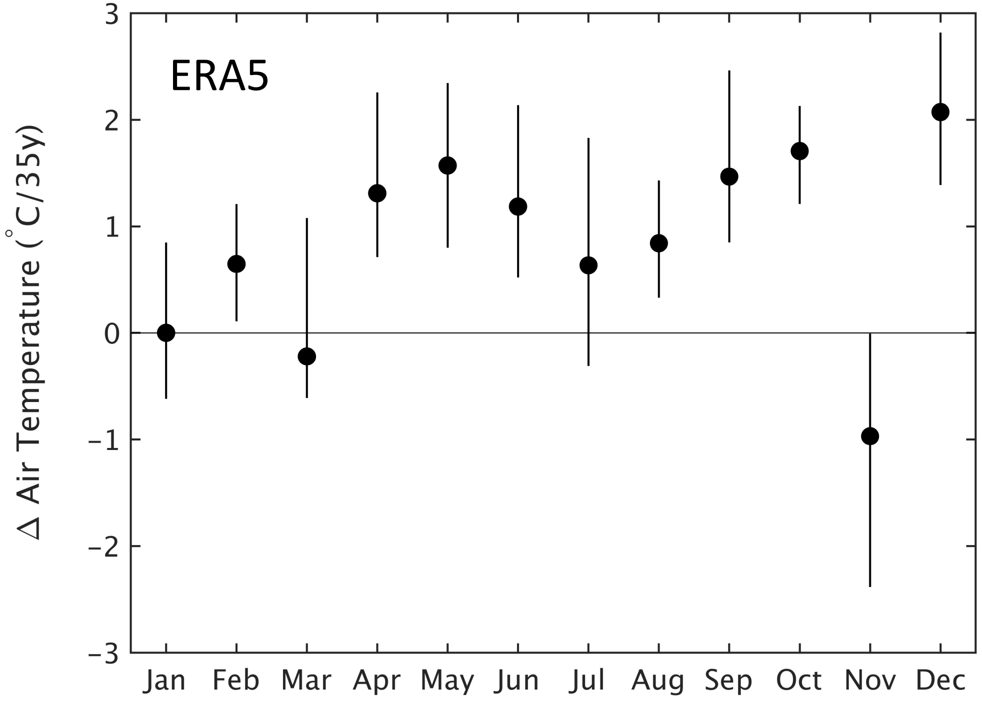
Environmental Conditions in Recent Years

Statewide Precipitation Ranks
June 2018 – May 2019
Period: 1895 – 2019



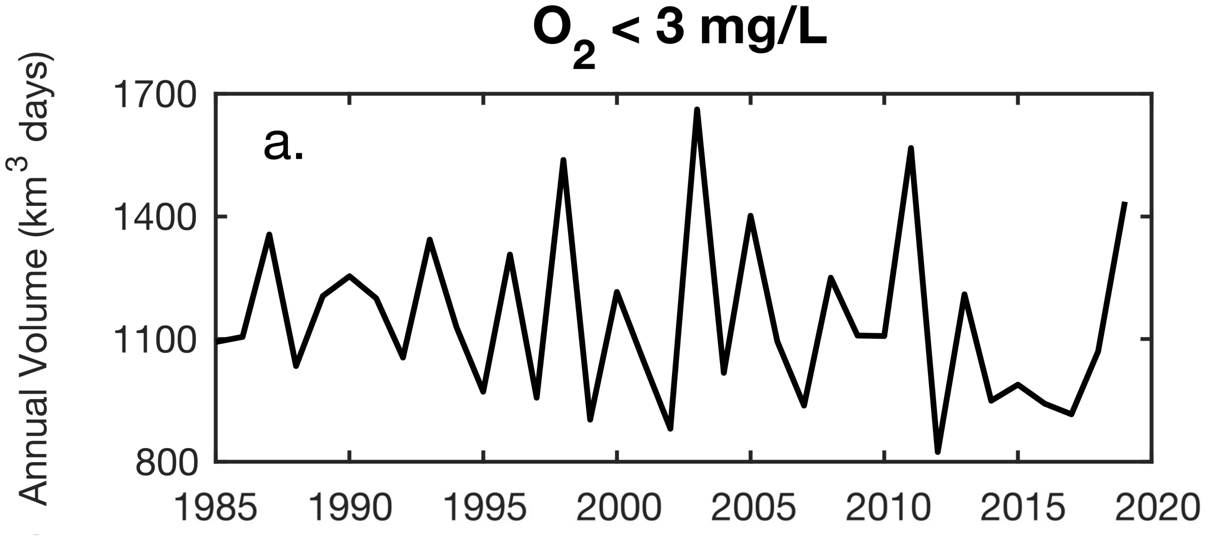
- 4/6 states in the watershed had the wettest 12-months since 1895
- Other two had 2nd and 3rd wettest

1985-2019 Δ Air Temperature

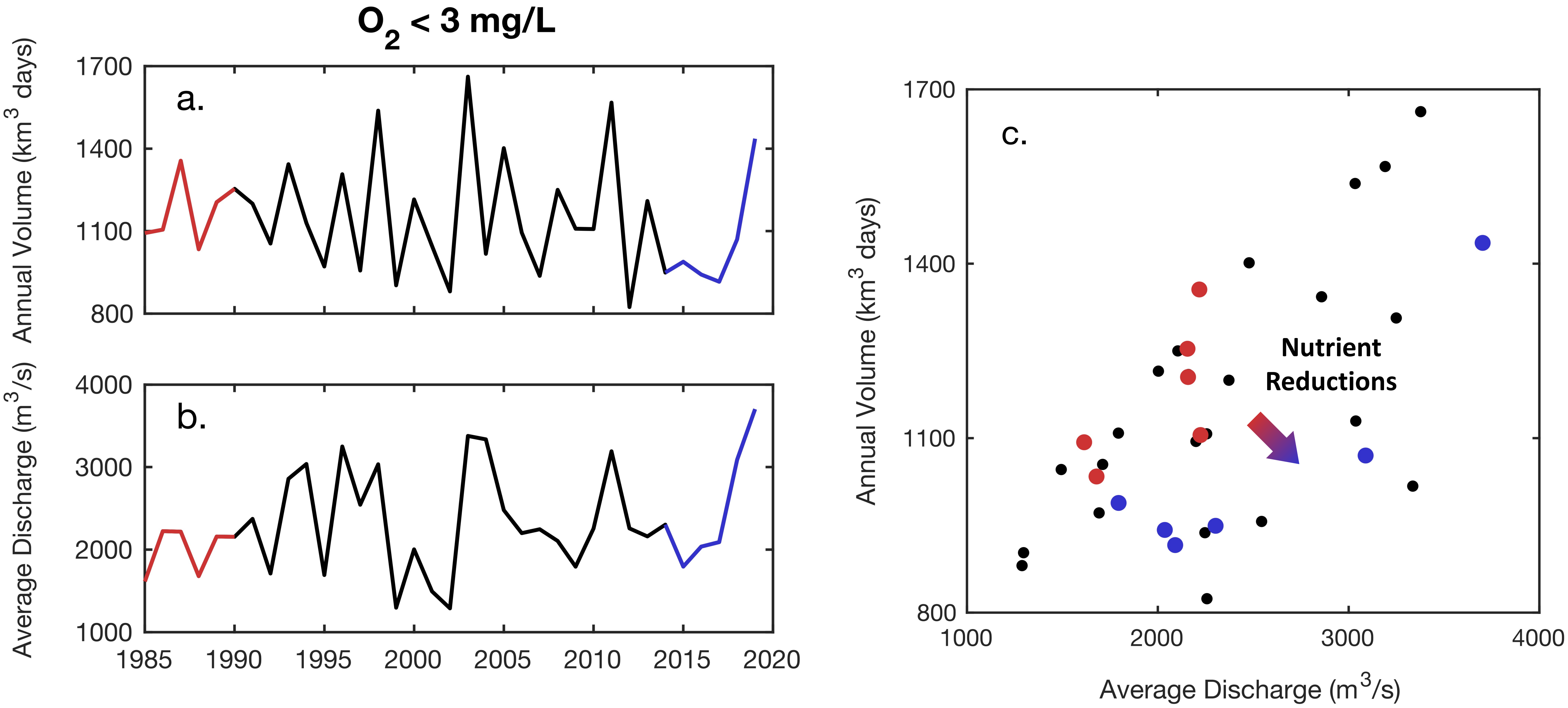


- April-October air temperatures have warmed by ~1°C
- Warming is generally greater over Bay waters

Time Series of Annual Hypoxic Volume



Time Series of Annual Hypoxic Volume



Methods to Quantify the Effect

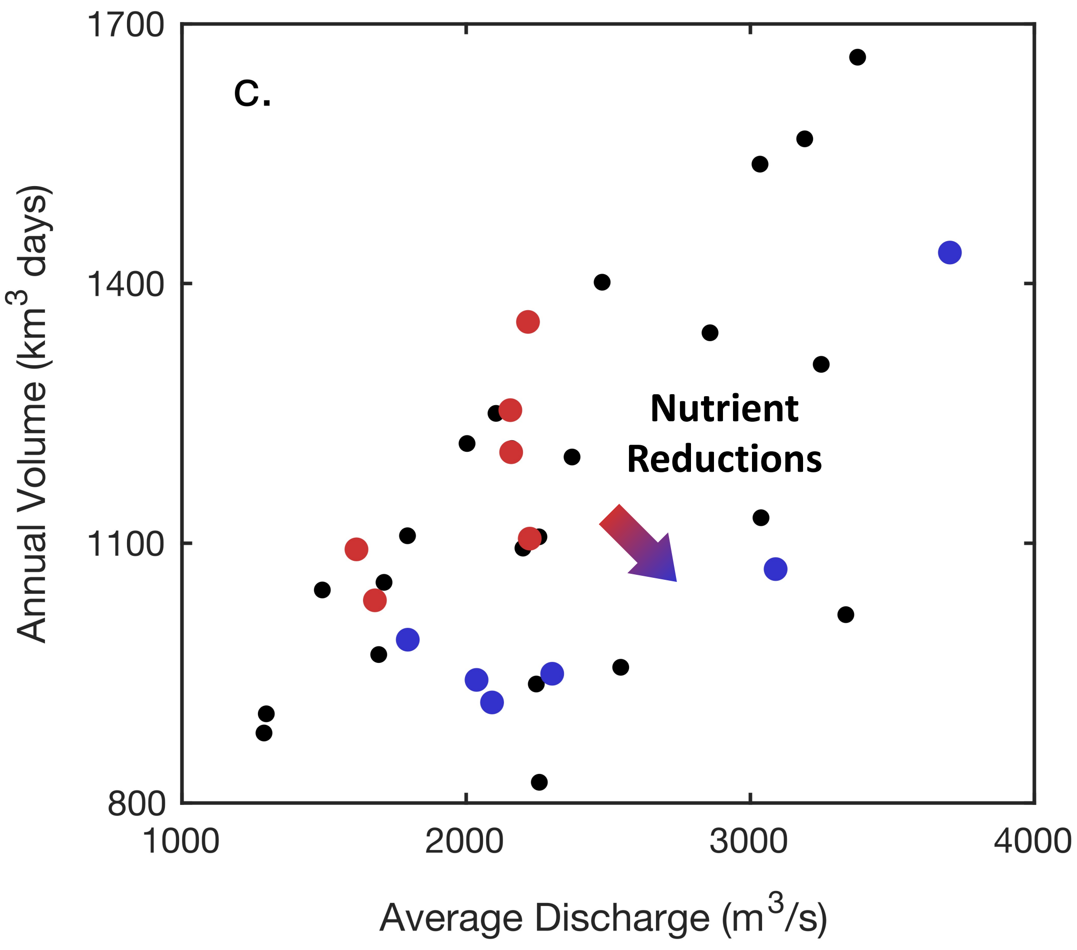
1. Generalized Linear Model (GLM) analysis

   Hypoxic Volume ~ (Discharge)+(Time period)

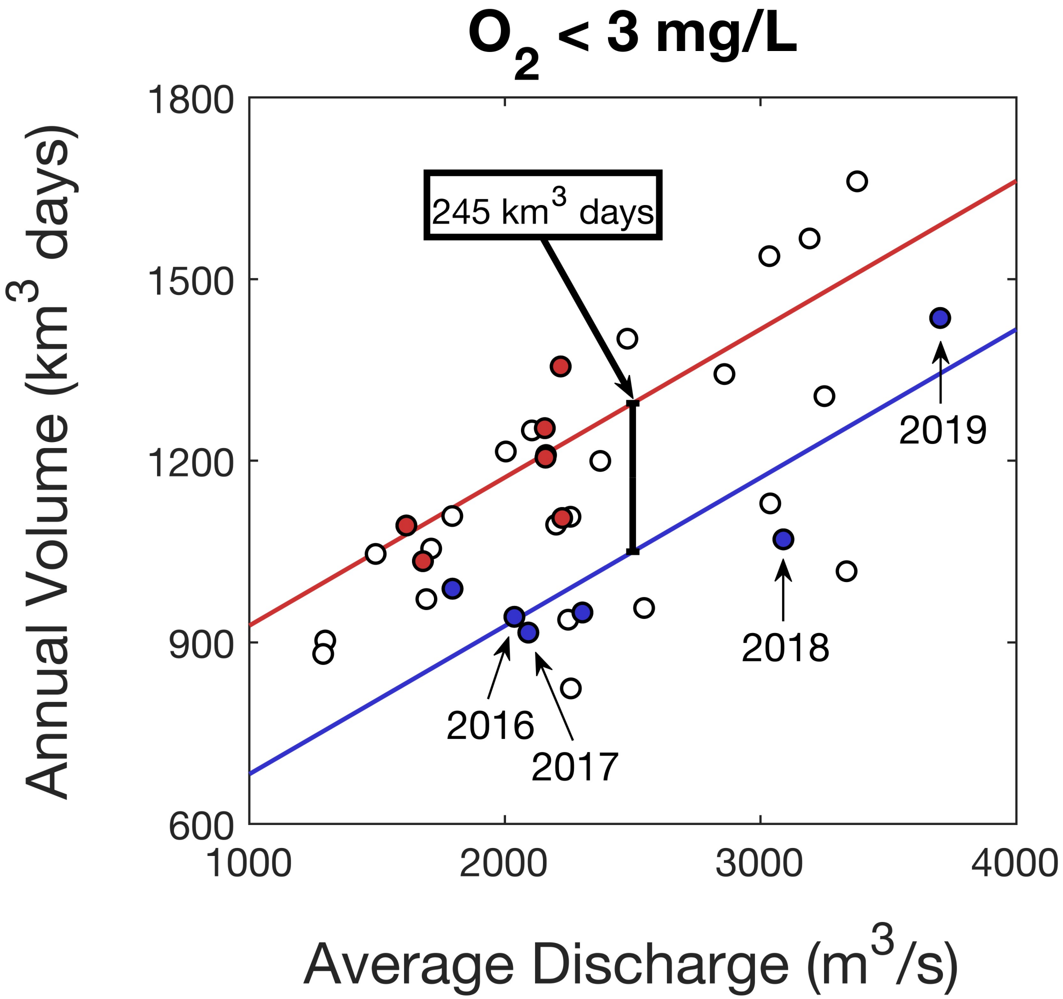
   Time period A: 1985-1990
   Time Period B: 2014-2019

2. Numerical model simulations of Chesapeake Bay from 2016-2019

Simulation	Watershed DIN Input	Watershed ON Input	Air Temperature
Realistic	2016-2019	2016-2019	2016-2019
1985 TN	**1985**	**1985**	2016-2019
1985 DIN	**1985**	2016-2019	2016-2019
1985 ON	2016-2019	**1985**	2016-2019
1985 Temp	2016-2019	2016-2019	**1985**



Generalized Linear Model (GLM) Results



- Hypoxic volume is 245 km^3 days larger in 1985-1990 compared to 2014-2019

Year	Additional Hypoxia in 1985-1990 (%)
2016	26
2017	26
2018	21
2019	18

Numerical Model Set-up

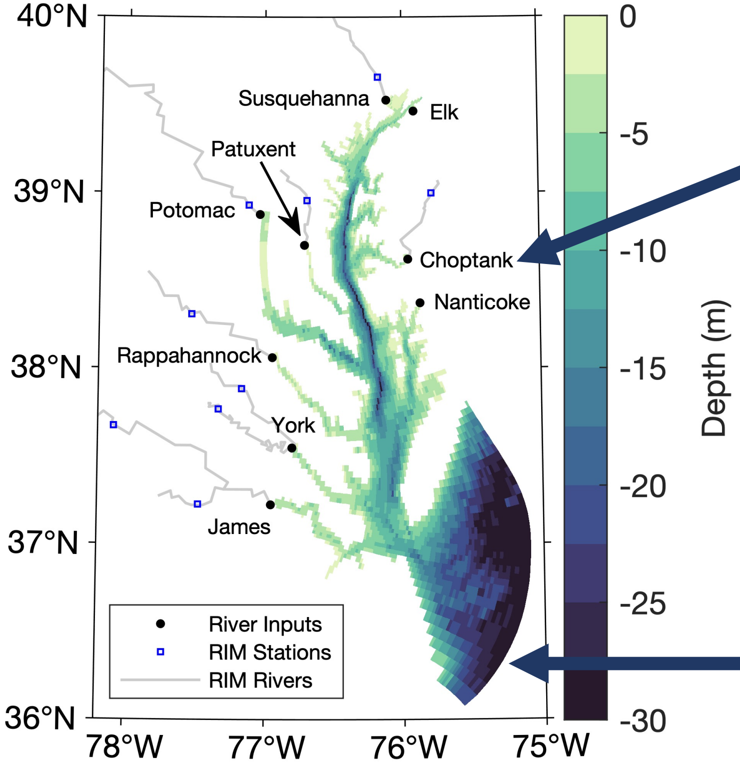
Hydrodynamic Model

- Regional Ocean Modeling System
- 150 X 100 Cell Grid
- ~1 km Resolution
- 20 Vertical Levels

Biogeochemical Model

- Full C and N Cycles
- 14 State Variables

ChesROMS-ECB



Riverine Forcing

- Freshwater: USGS Gauges
- Nutrients: Phase 6 / DLEM Relationships

Atmospheric Forcing

- ERA5 Reanalysis
- Winds from the North American Mesoscale Forecast System (NAM)

Ocean Boundary

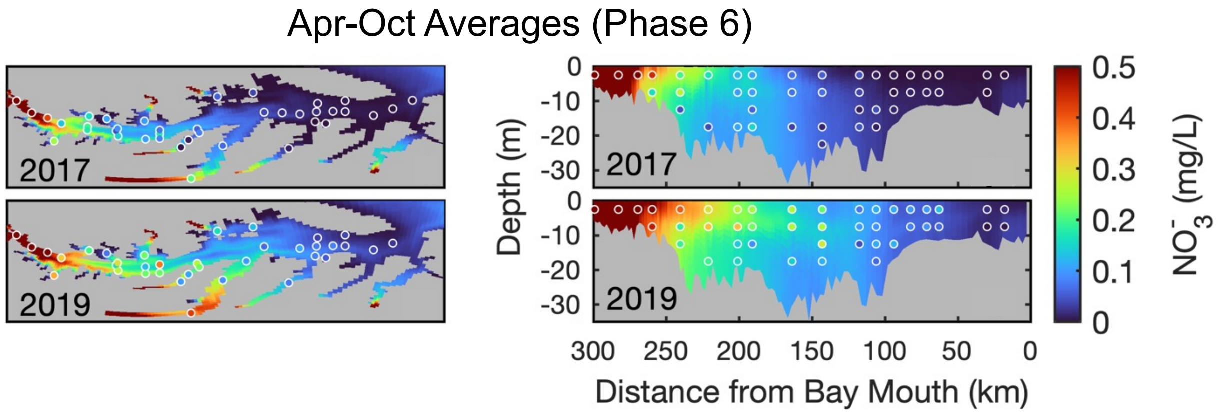
- NOAA Cruise Data

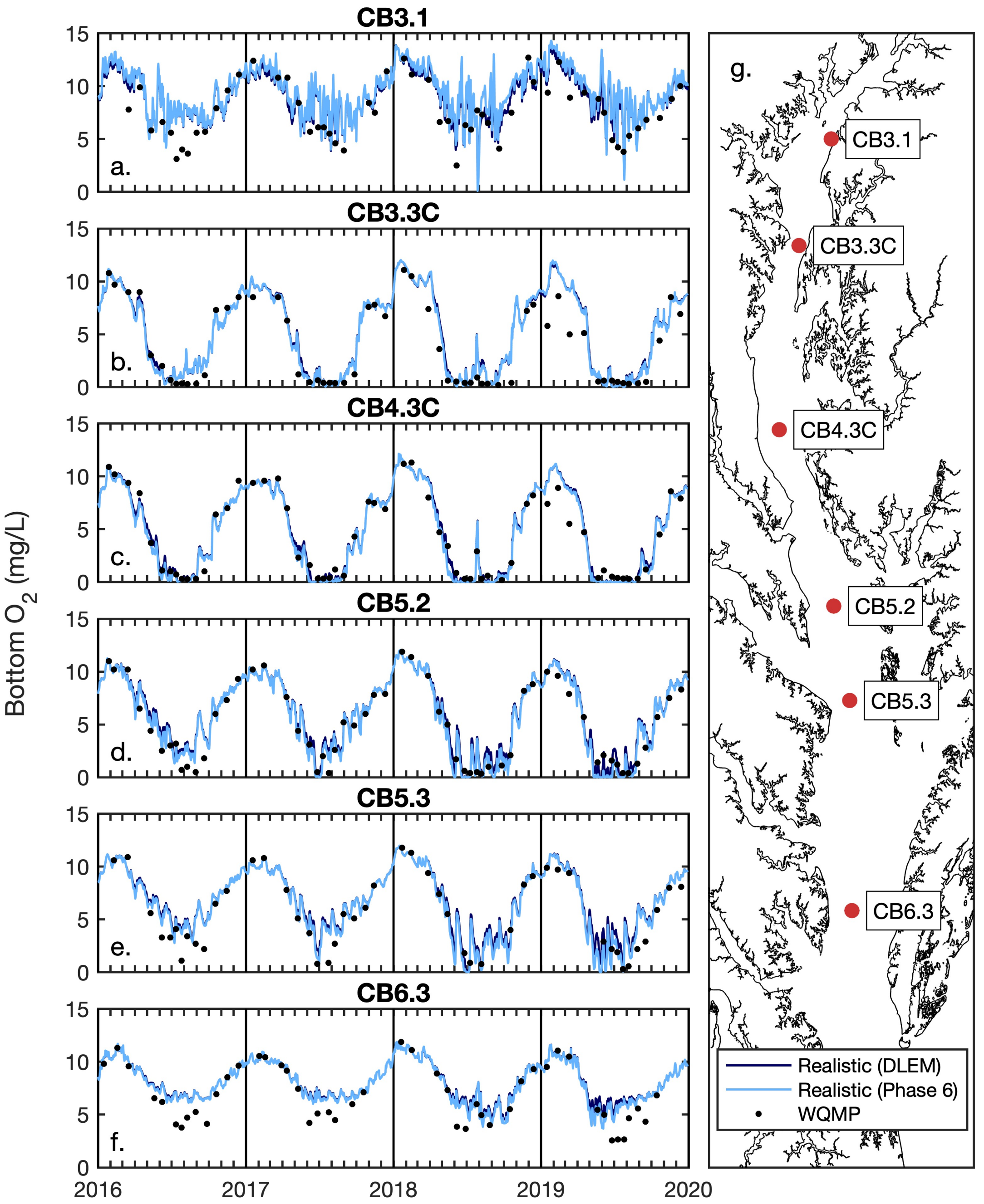
Loading Trends

- Above RIM: Data from stations
- Below RIM: CAST model output

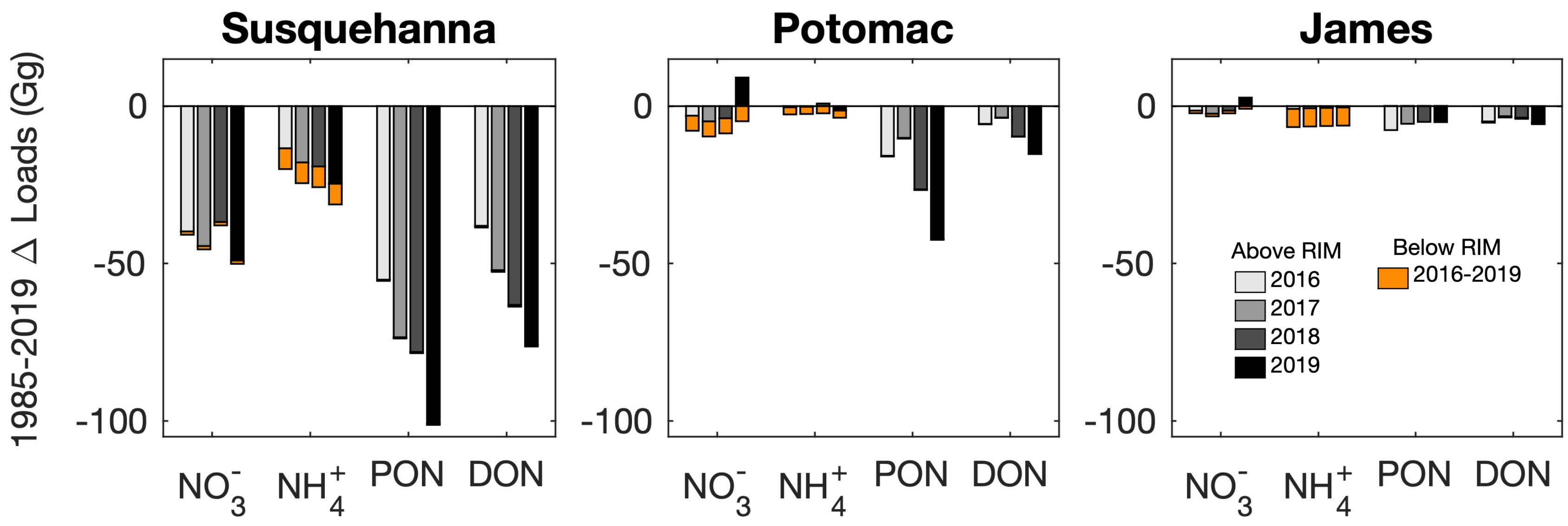
Model Skill

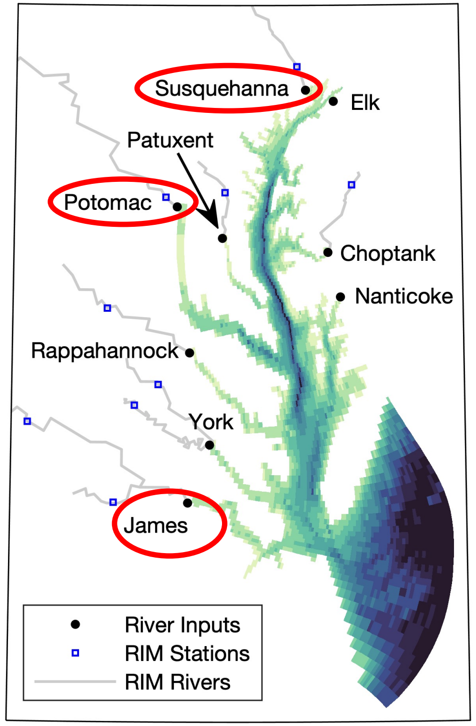
- The model captures the spatial distribution and interannual variability of NO_3^- well
- Interannual differences in O_2 are also captured, with a slight overprediction of concentrations in the southern mesohaline Bay





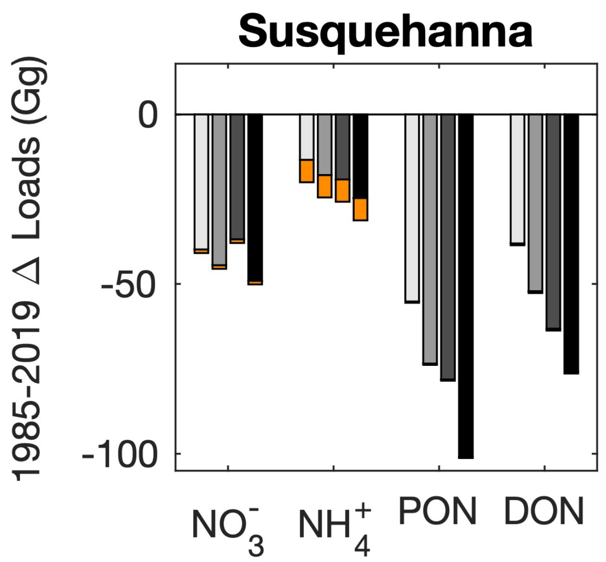
1985-2019 Nitrogen Reductions



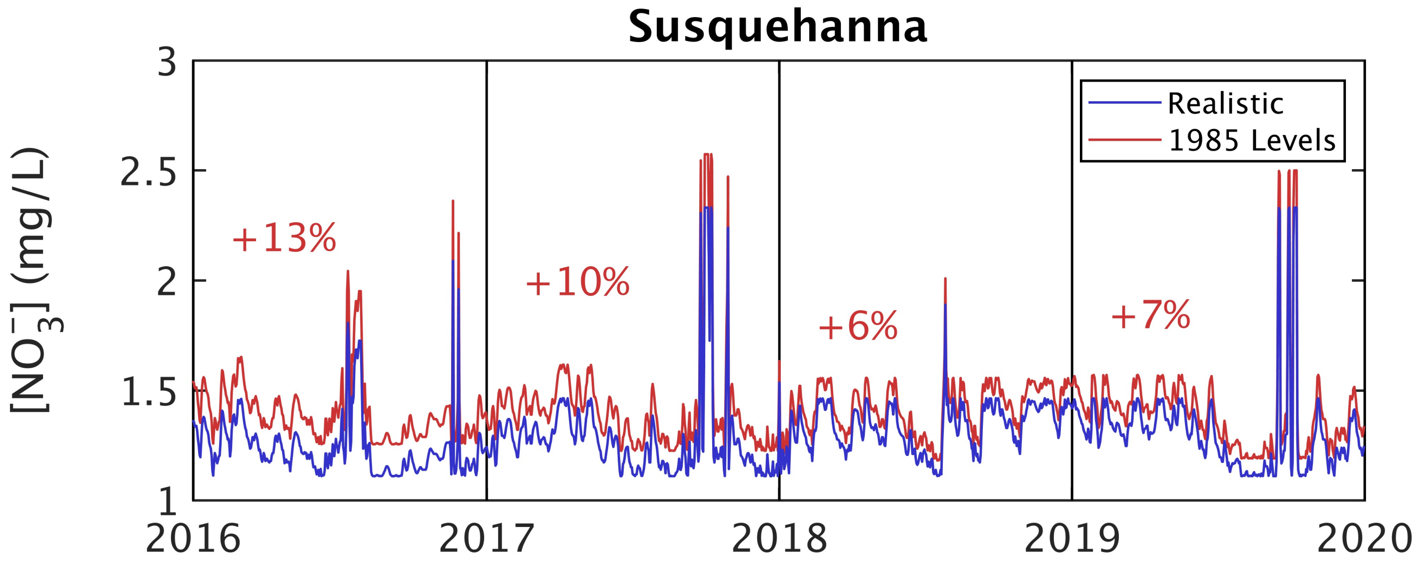


- Most of the reductions are from the above RIM portion of the watershed
- Largest reductions are in the Susquehanna River
- Reductions in organic nitrogen (PON, DON) are generally greater than inorganic nitrogen (NO_3^-, NH_4^+)
- Other rivers show reductions, but the magnitude is smaller

Recreating Past Nitrogen Concentrations

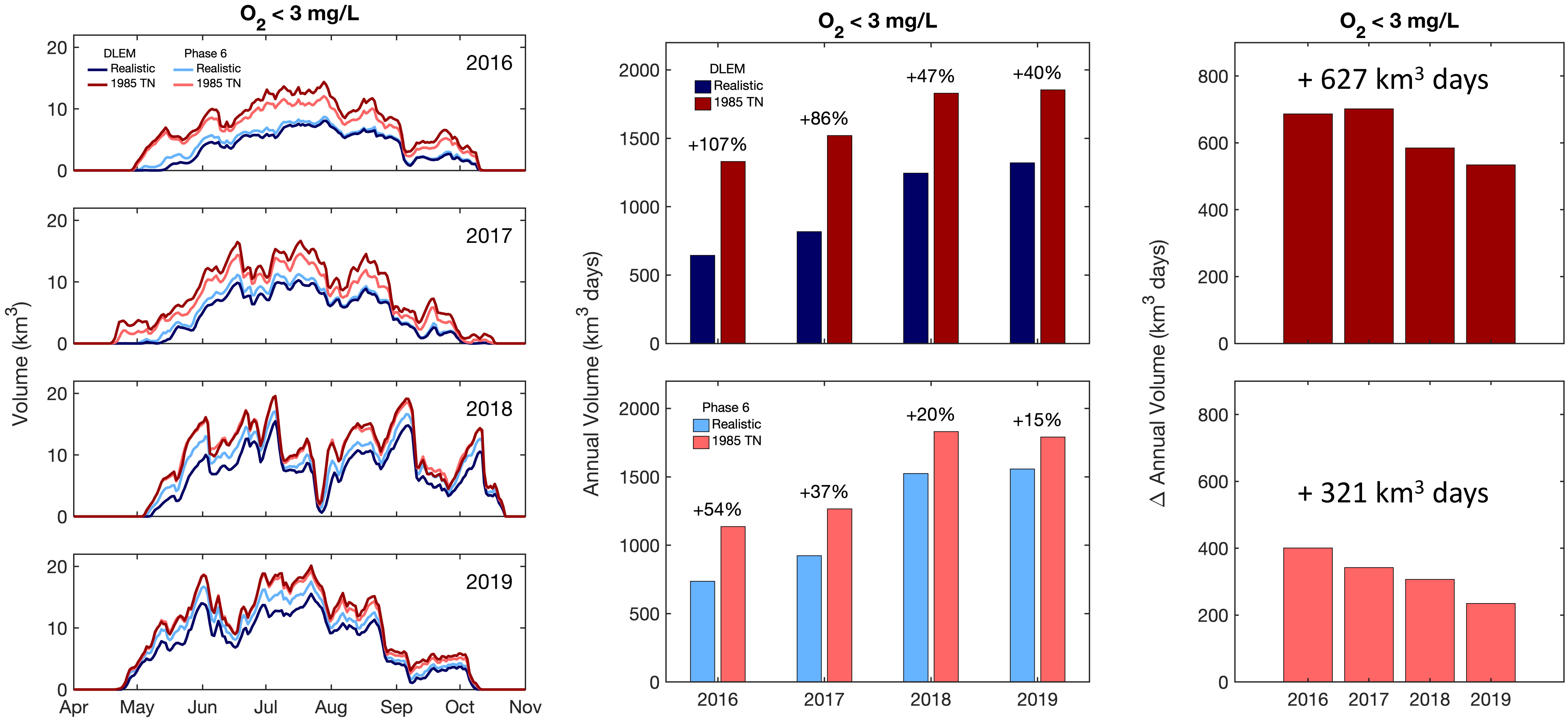


Year	%Δ
2016	-13
2017	-10
2018	-6
2019	-7



Δ NO_3^- loading → Calculate percent change → Increase by percentage to get 1985 levels

Impact of Nitrogen Reductions on Hypoxia



Reconciling Differences in Modeled Hypoxia

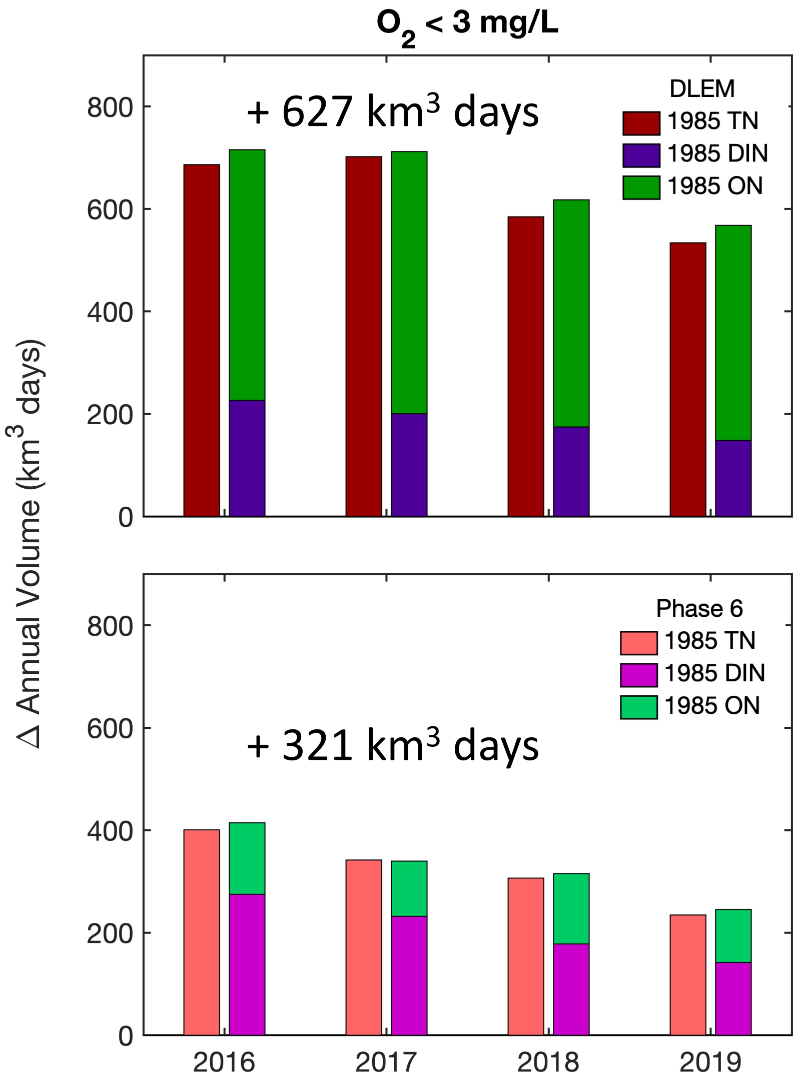
- Most of the difference between DLEM and Phase 6 is due to ON reductions

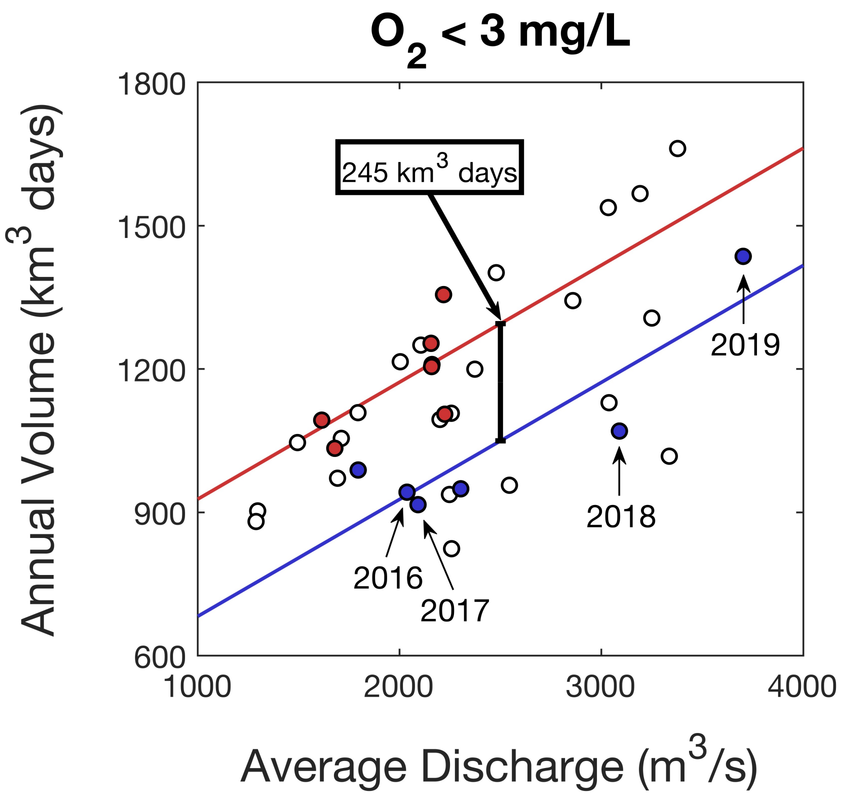
  DLEM: + 466 km^3 days
  Phase 6: + 122 km^3 days

- Impact of DIN reductions is more similar

  DLEM: + 187 km^3 days
  Phase 6: + 207 km^3 days

- The effect is greater in the numerical modeling results compared to the GLM





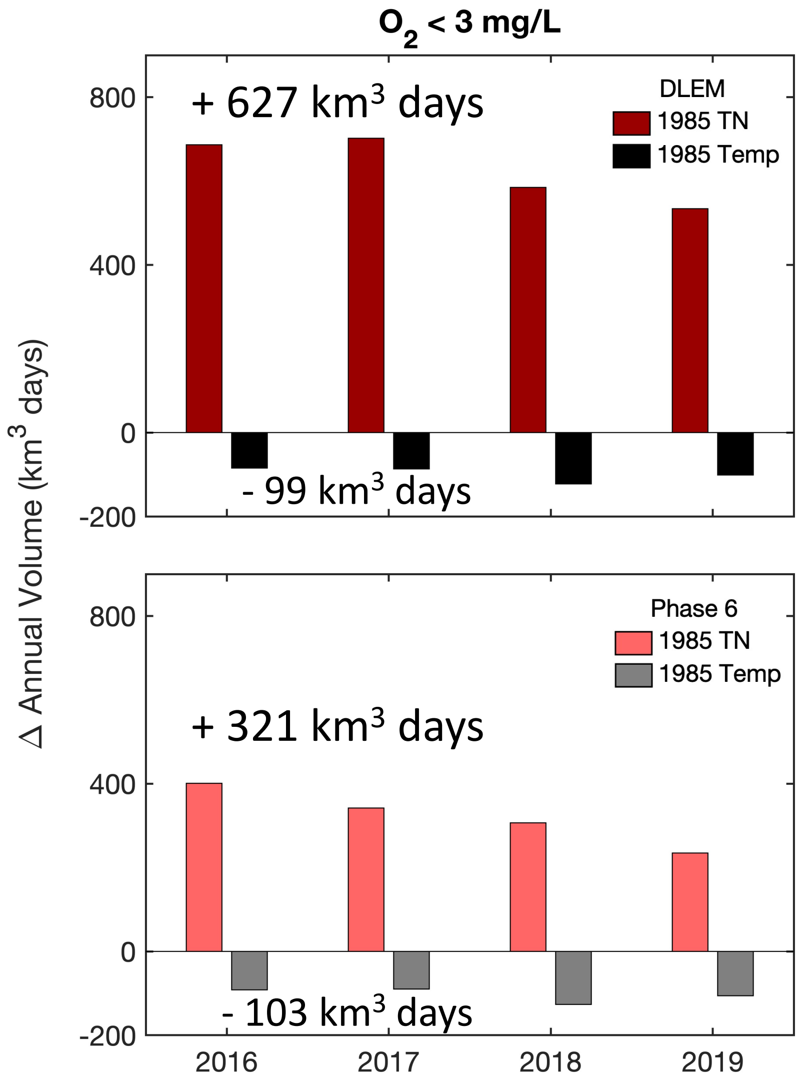
Counteracting Effect of Temperature

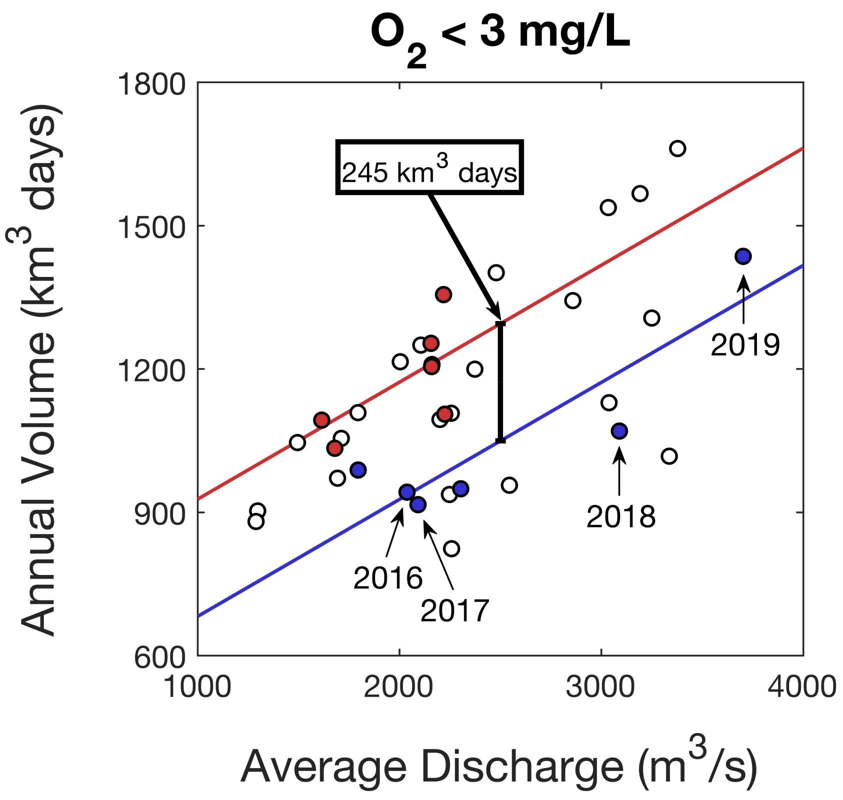
- Increasing temperatures account for a large portion of this difference between the numerical modeling results and the GLM

  DLEM: 528 km^3 days
  Phase 6: 218 km^3 days

- Depending on the year, the temperature effect has offset 12-45% of the improvement in hypoxia from nitrogen reductions

  DLEM: 12-21%
  Phase 6: 23-45%





Conclusions

1. Without nutrient reductions, hypoxic volumes (O_2 < 3 mg/L) would have been larger in recent years
    - ~40-100% larger for average discharge conditions (2016-2017)
    - ~20-50% larger for wet conditions (2018-2019)
2. Differences between DLEM and Phase 6 are primarily due to differences in organic nitrogen loading
3. Increasing temperatures have offset 12-45% of the improvement due to nutrient reductions depending on the year
4. Once temperature is considered, the magnitude of the numerical modeling results better agrees with the observational data
5. Although these results are encouraging for policymakers and managers, they demonstrate that greater reductions are needed to counteract the ever-increasing impact of climate change

Questions?

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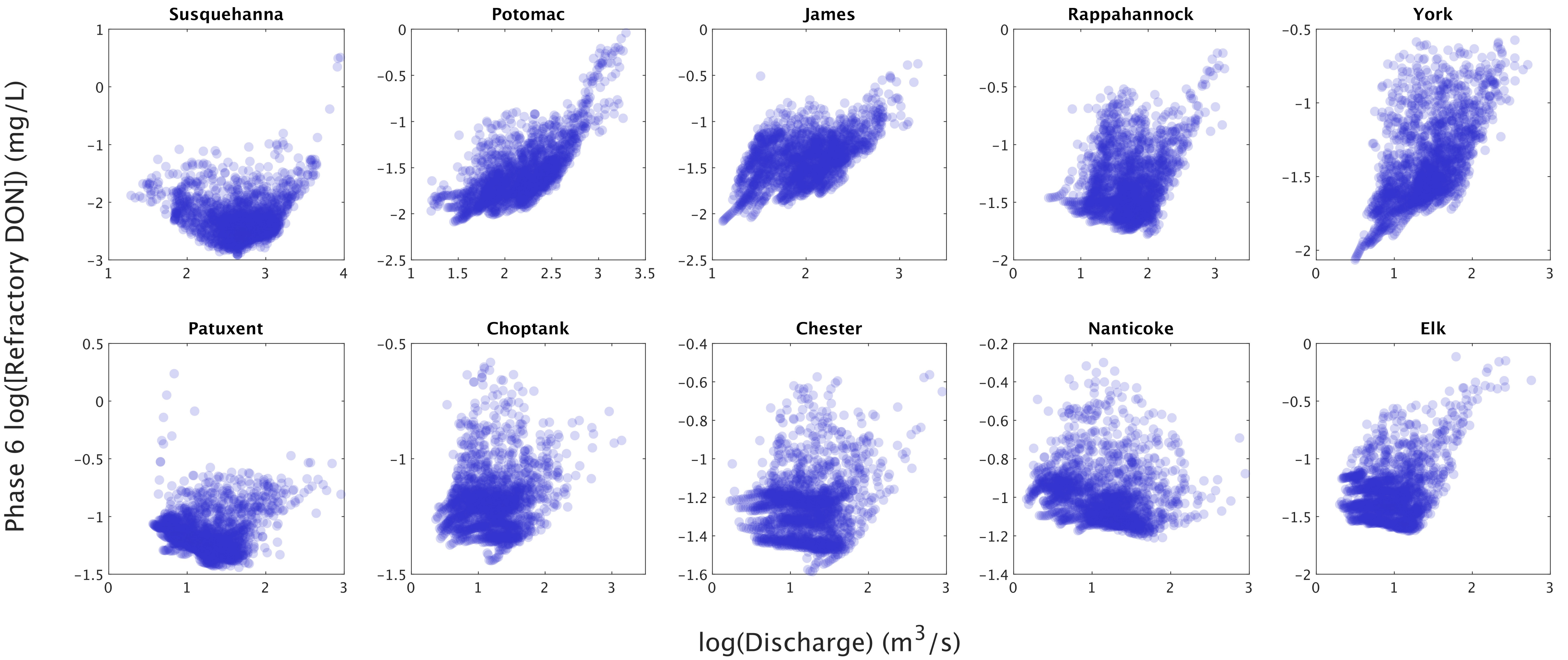
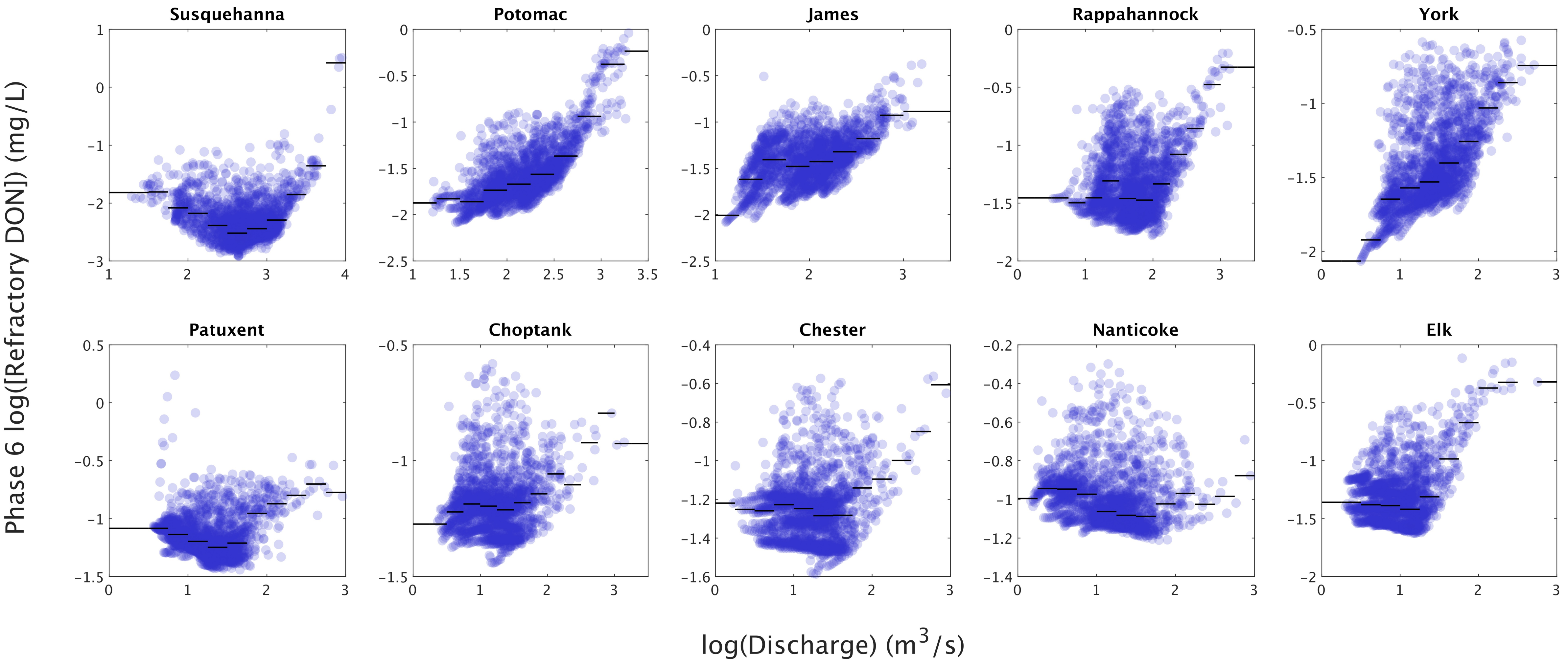
Chesapeake Bay Program

2010-2014 Watershed Model Relationships



2010-2014 Watershed Model Relationships



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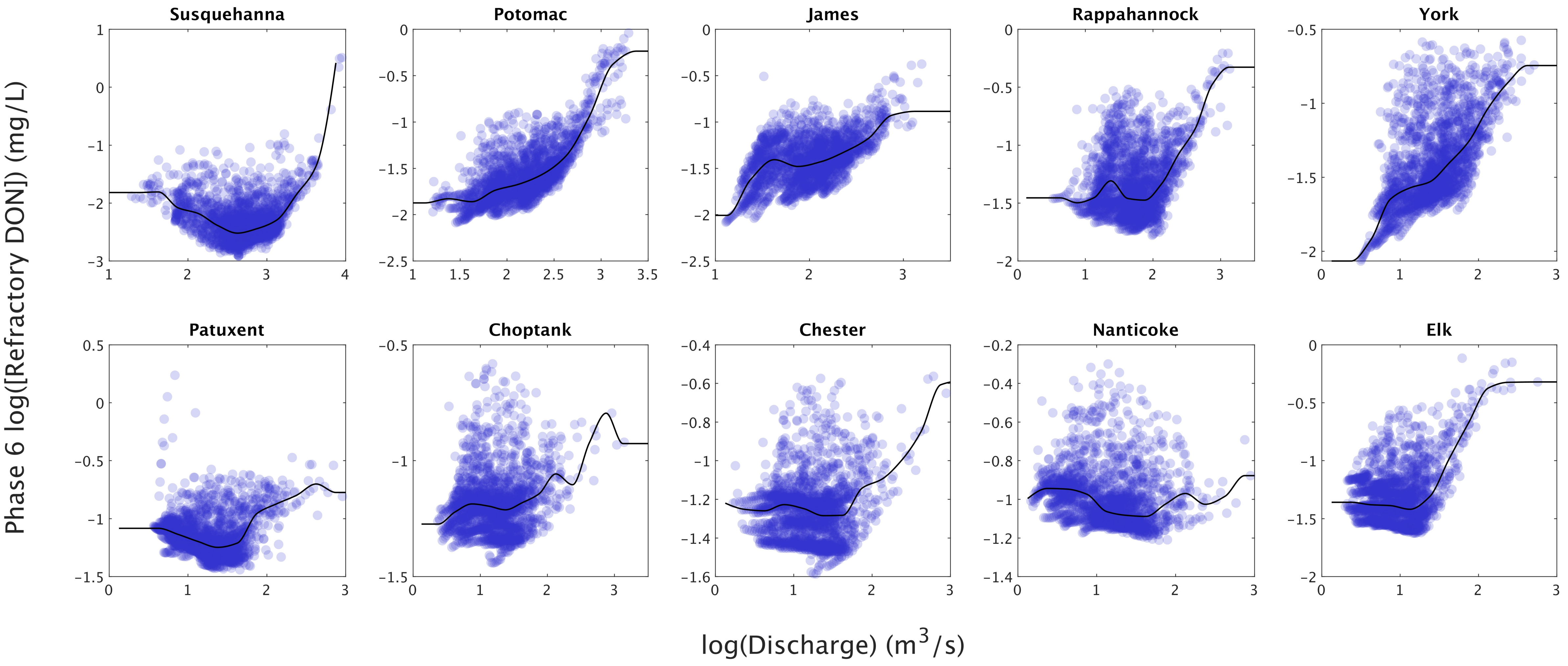
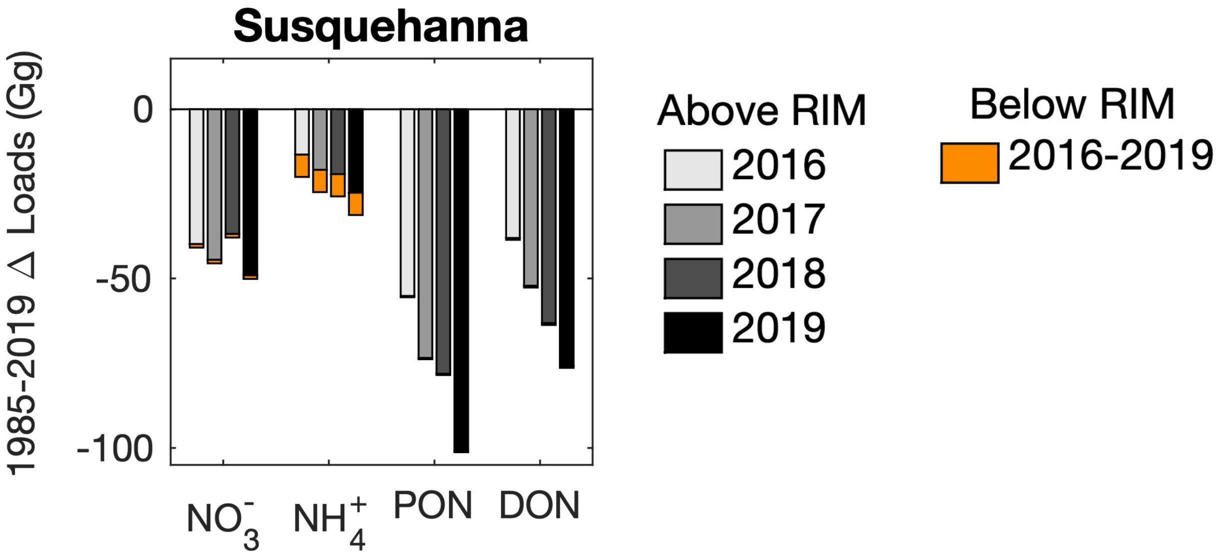
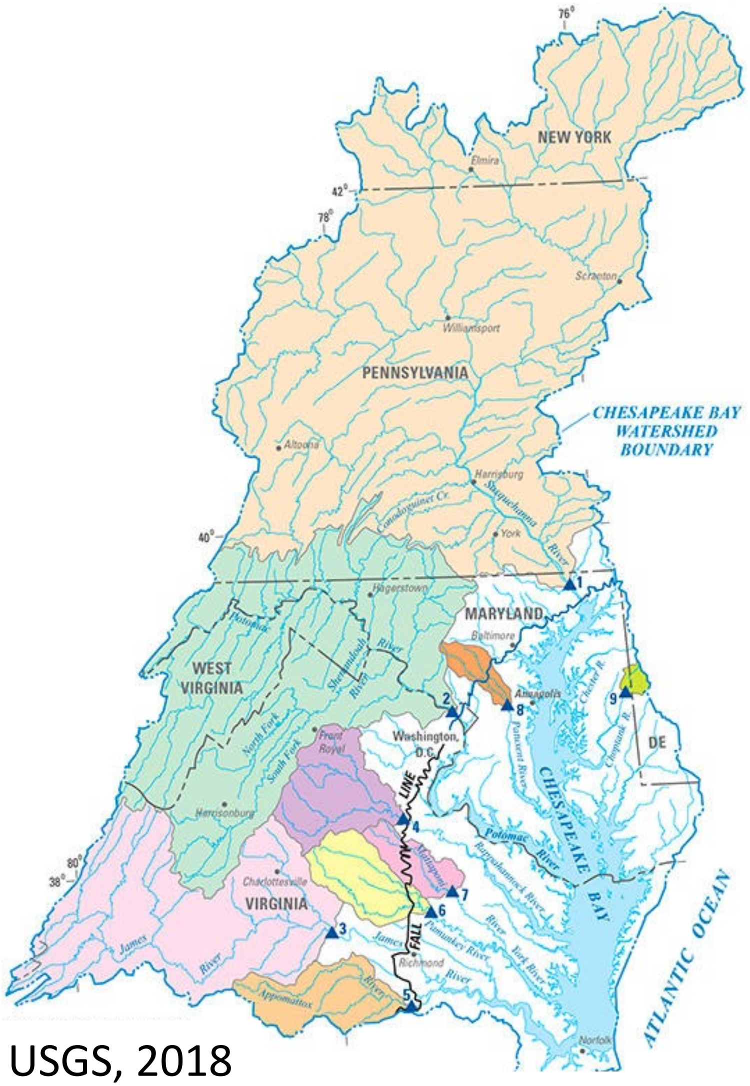


Calculating 1985-2019 Nitrogen Reductions

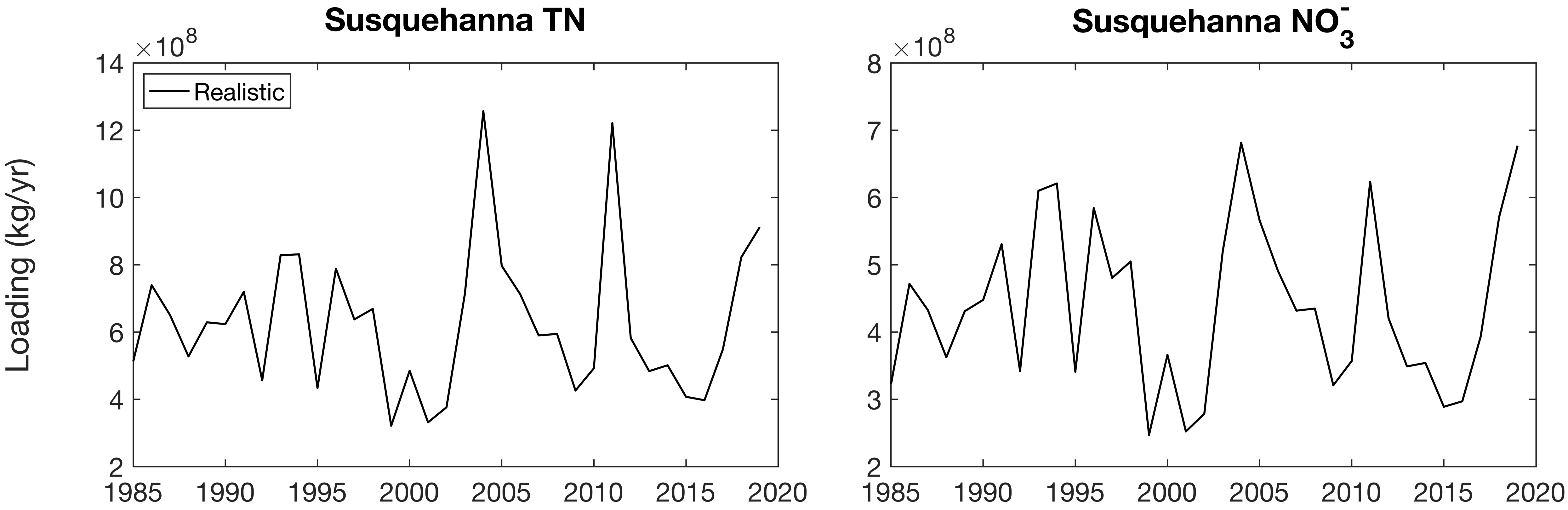




USGS, 2018

- Above RIM portion of the watershed using stationary WRTDS models of available data
- Below RIM portion of the watershed using output from CAST

Stationary WRTDS Models



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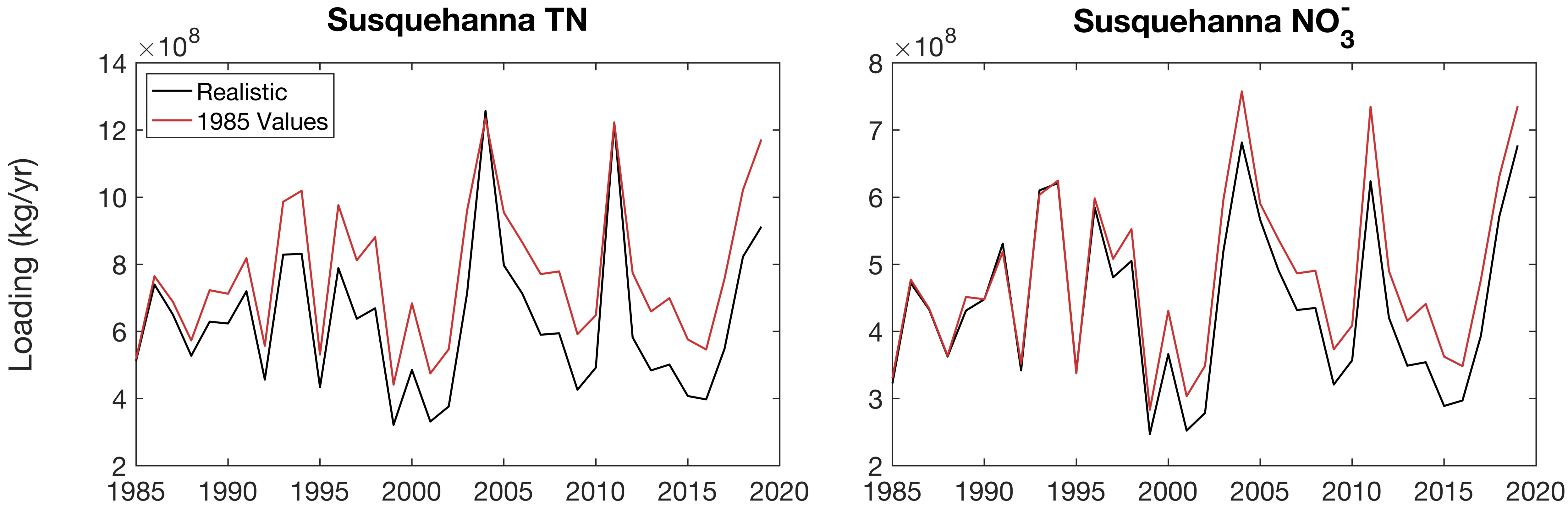

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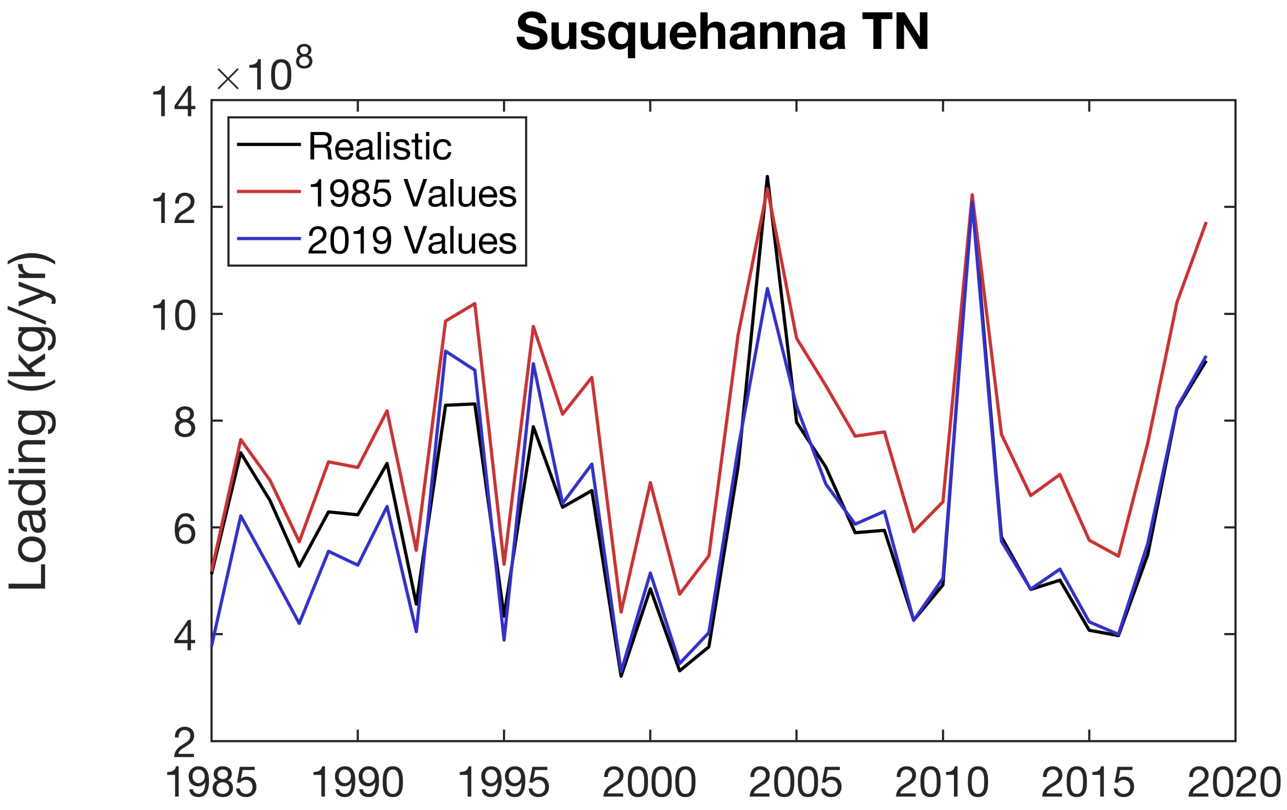
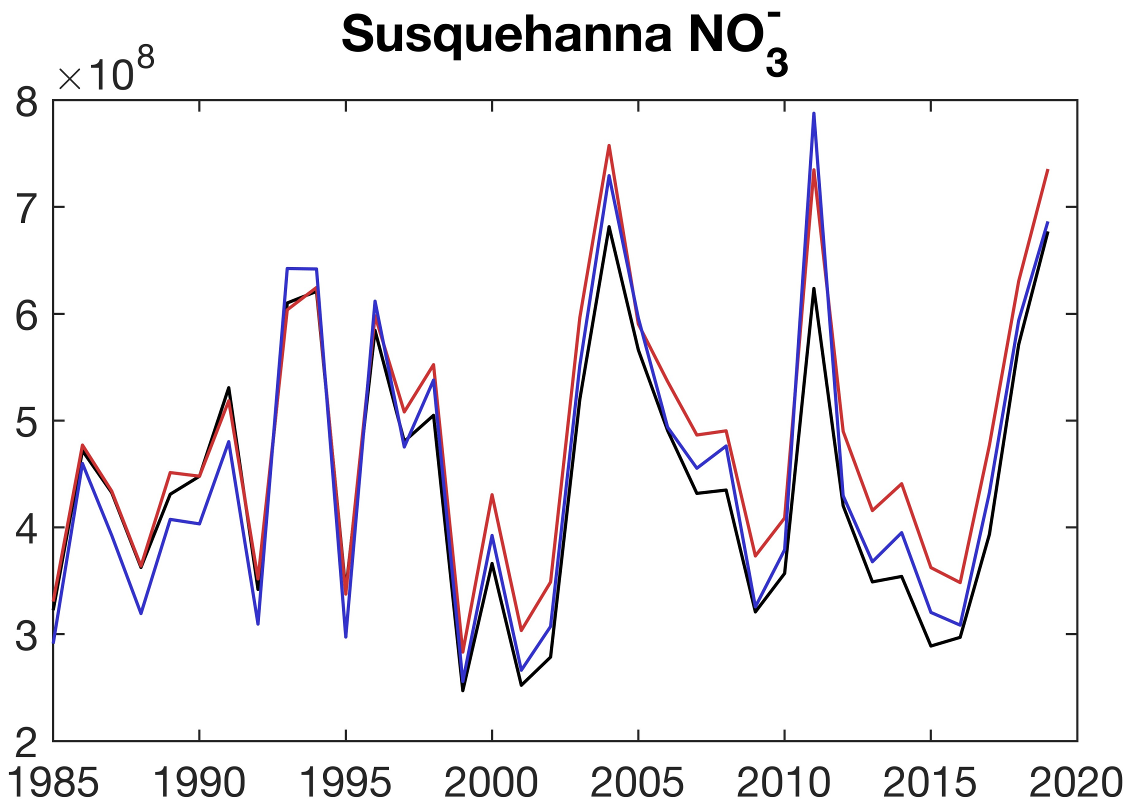
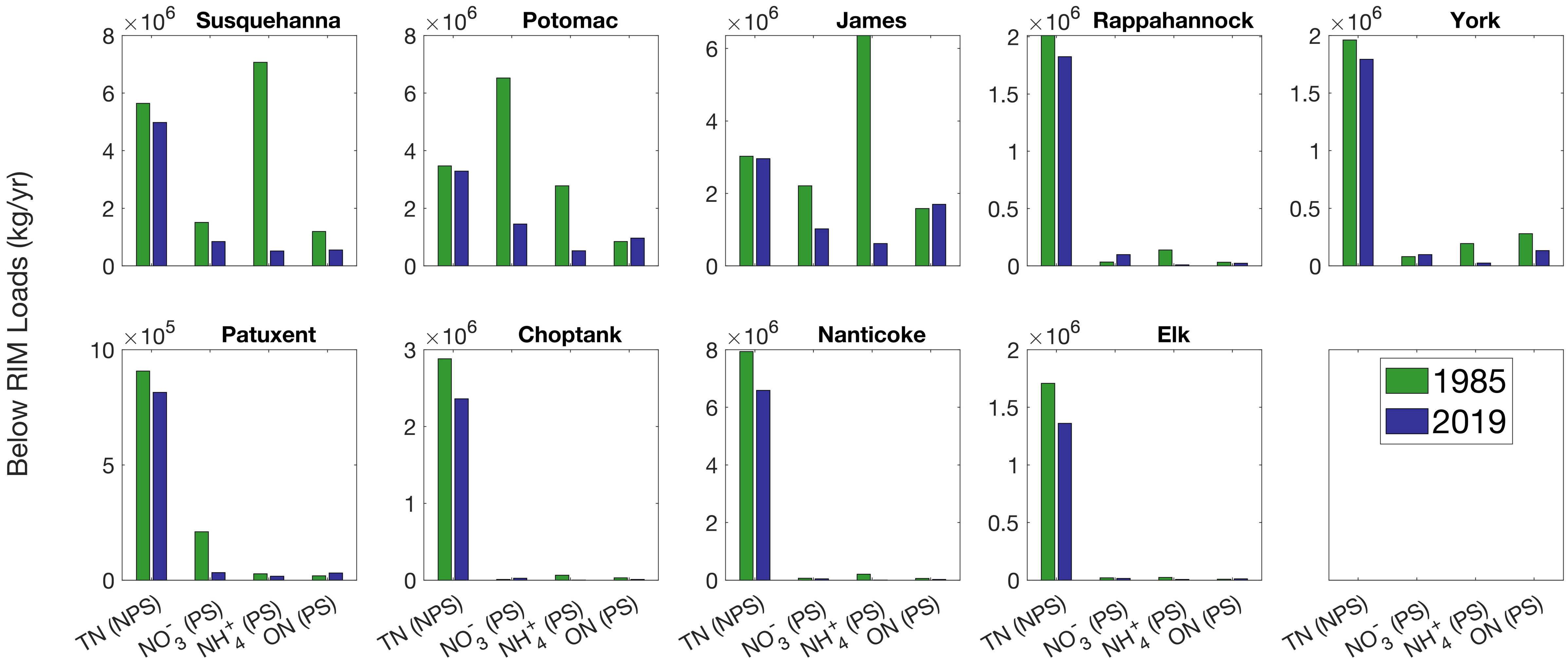




Below RIM Loads From CAST



Spatial Impact of Nitrogen Reductions

O_2 < 3 mg/L