Understanding Summer Hypoxia Using Monitoring Data and Numerical Simulations

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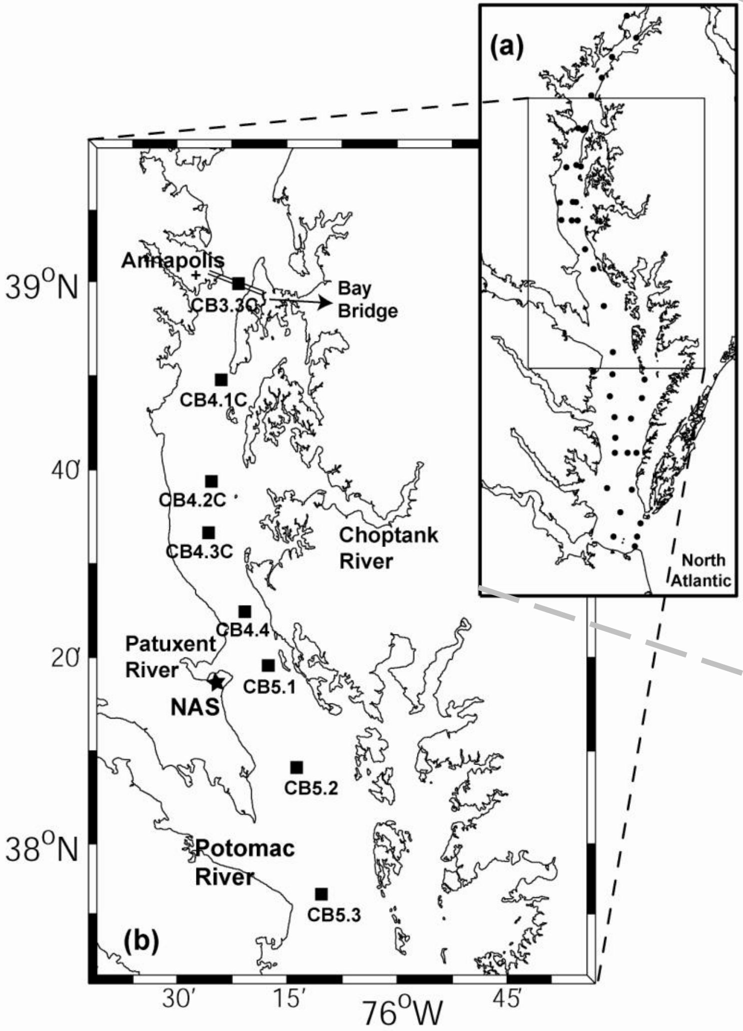
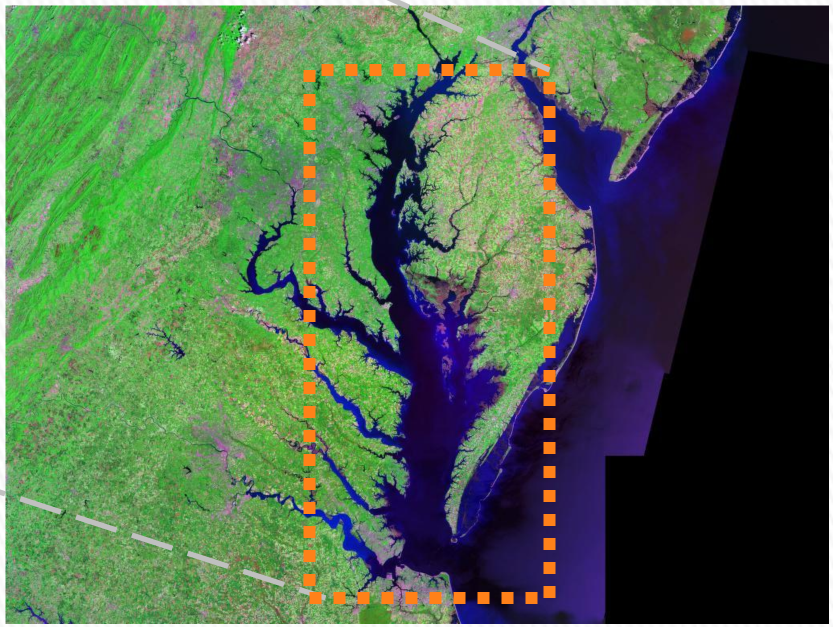
Outline

- Data and Method
- Summer Hypoxia
  - Dissolve Oxygen Patterns
  - Controlling Factors
- Data Analysis
  - Multiple Linear Regression
  - Summer Hypoxia Prediction
- Climate Effects
- Numerical Simulations
- Summary

Chesapeake Bay



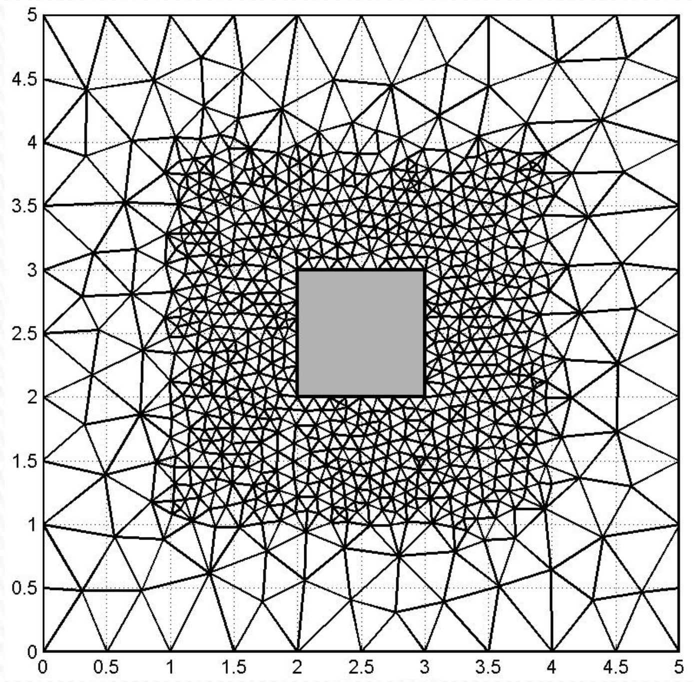


Data

- CBP Data from 1985 to 2007
  - Dissolved Oxygen
  - Water Temperature
  - Chlorophyll-*a*: algal biomass
- River Discharge and Total Nitrogen
  - Susquehanna River at Conowingo (ID: 01578310)
- Wind Speed and Direction
  - Naval Air Station at the mouth of Patuxent River
- Sea-Level Pressure
  - NCEP/NCAR Reanalysis data

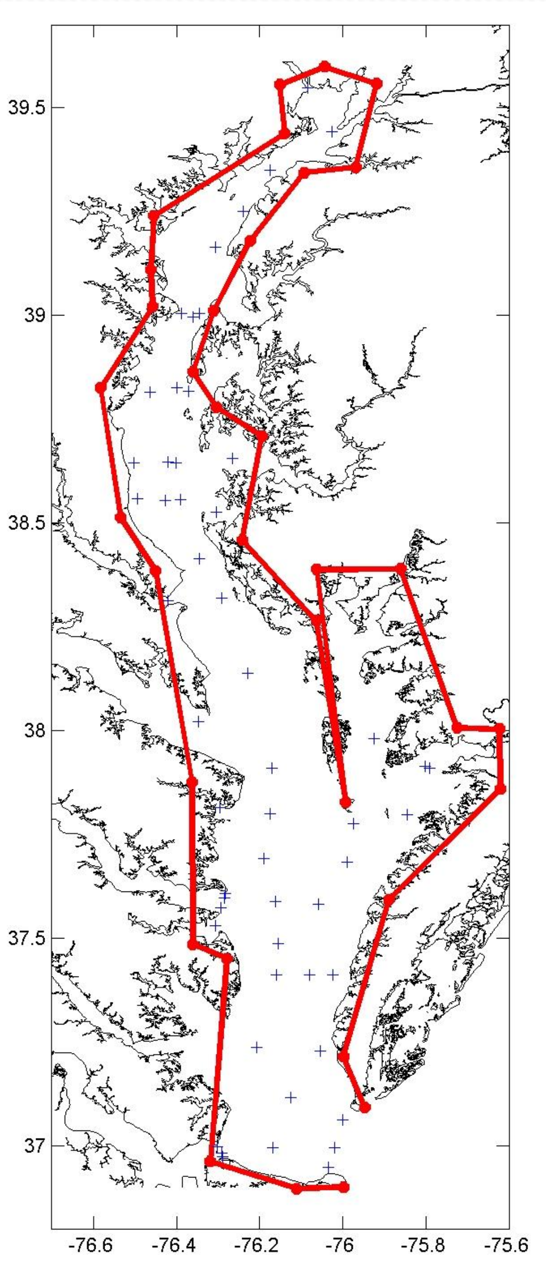
Method

- DIVA (Data Interpolating Variational Analysis) software
  - Spatial interpolation on a a finite element resolution
  - Large data set: highly optimized
  - Coastline taken into account

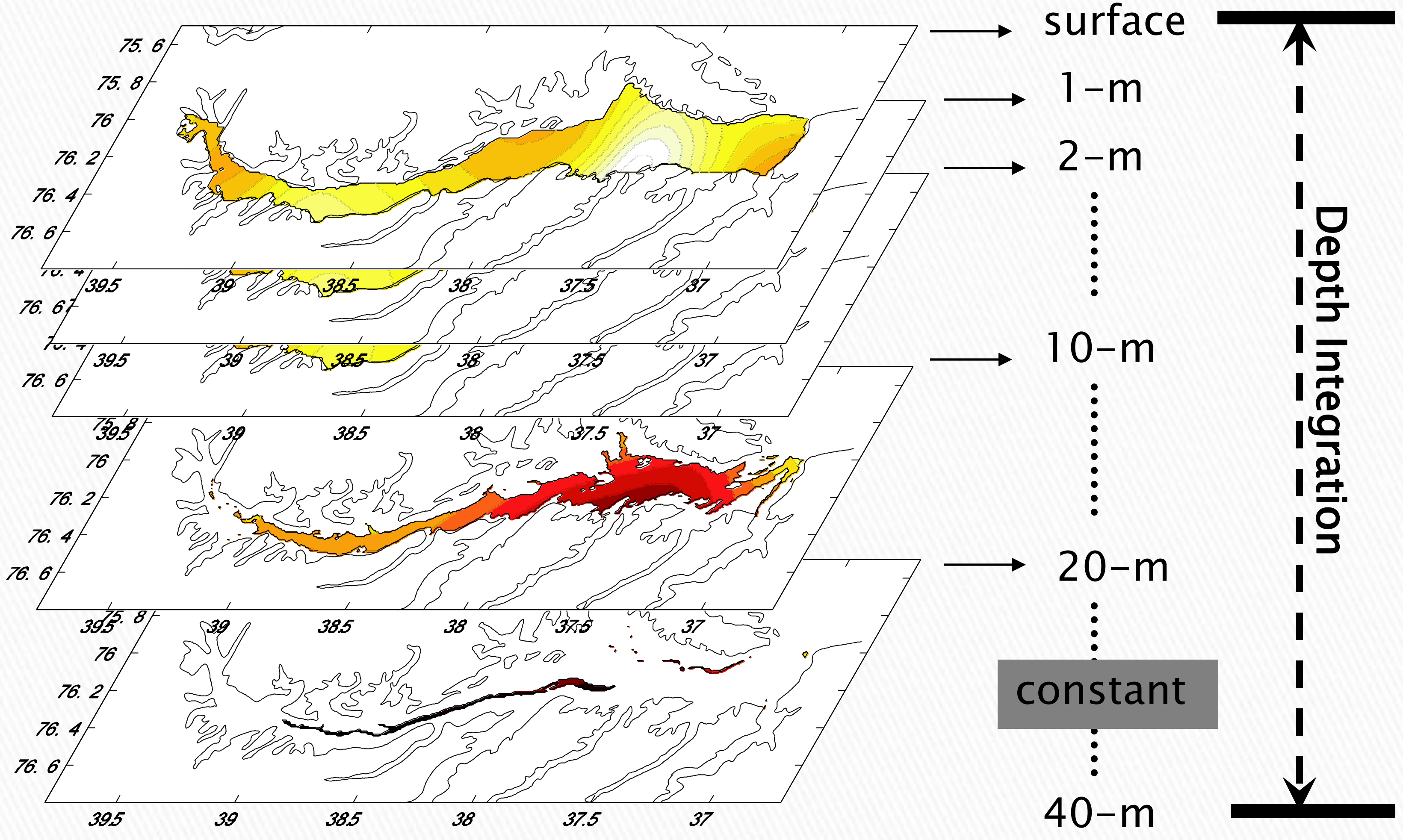


DO Interpolation

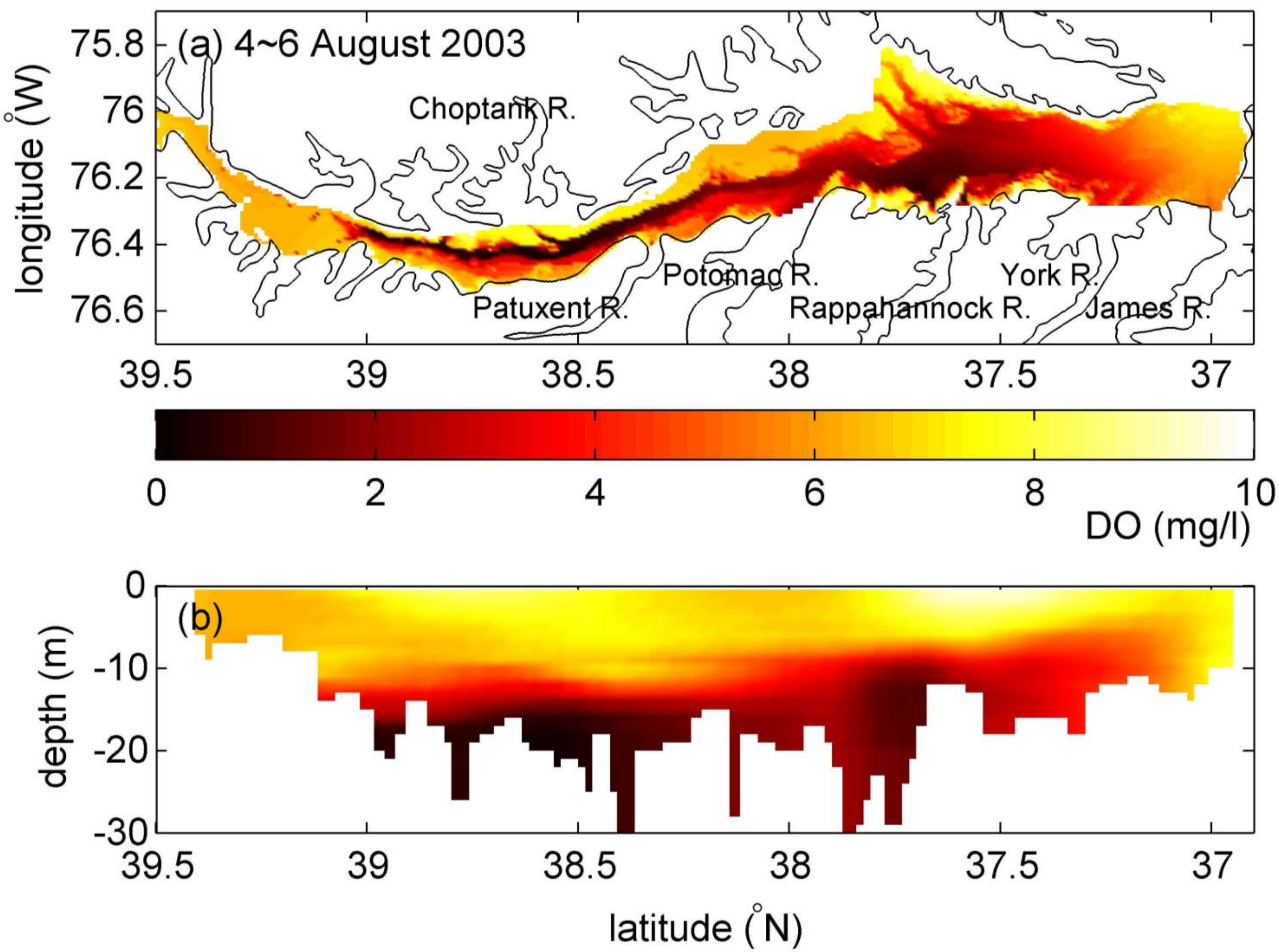
- Based on cruises completed within 5-day periods with a minimum of 28 sampling stations during May-September
- DO vertical profiles were rearranged at 1-m depth interval from the surface to the bottom
- Resolution: 373×157×45
  - Horizontal grid spacing: 30 sec (~ 900 m)
  - Vertical resolution: 1 m



DO Interpolation



Example: DO in August 2003



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- Summer Hypoxia
  - Dissolve Oxygen Patterns: SOM analysis
  - Controlling Factors: Nutrients, River Flow, Algal Biomass, Stratification, and Wind
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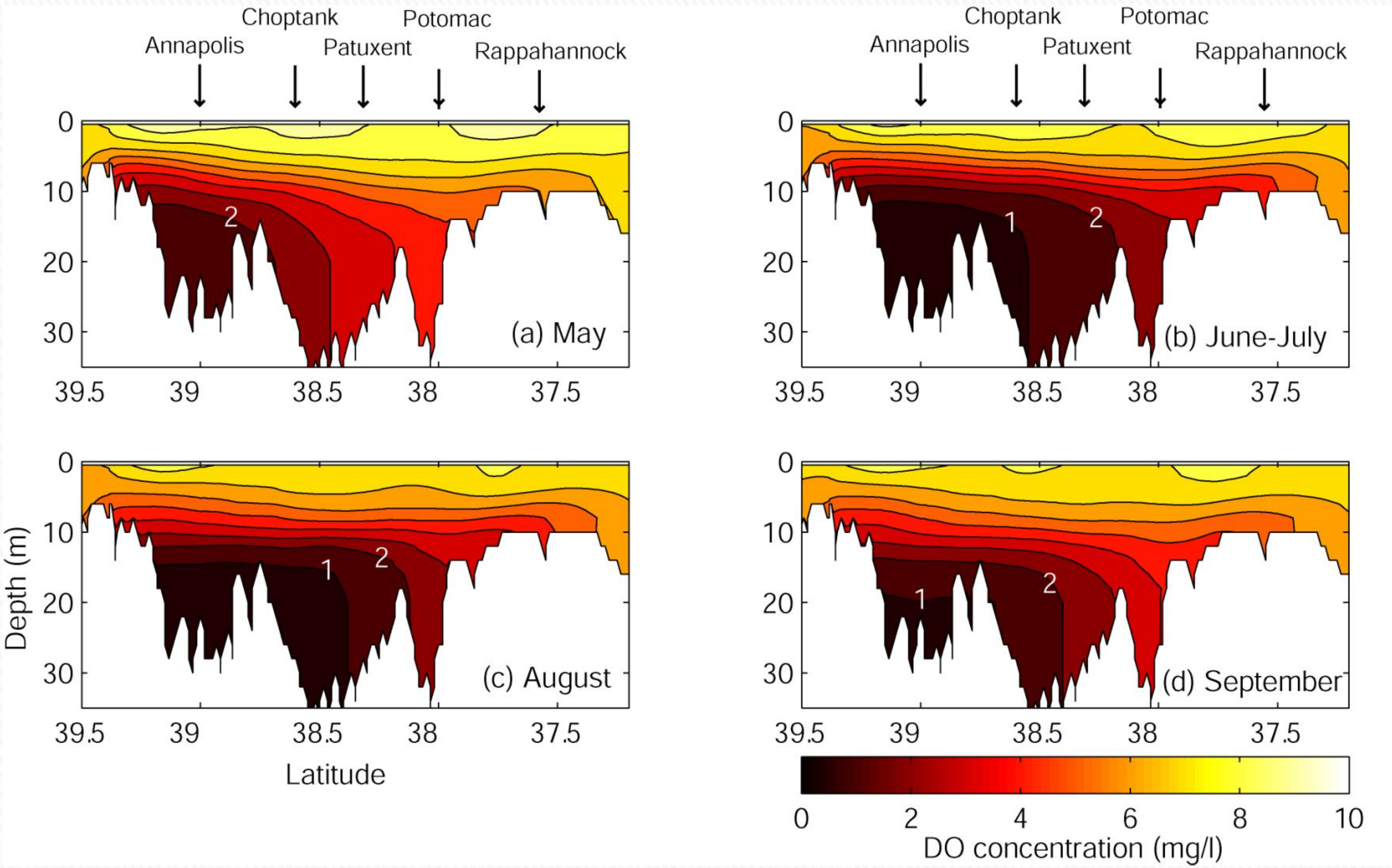
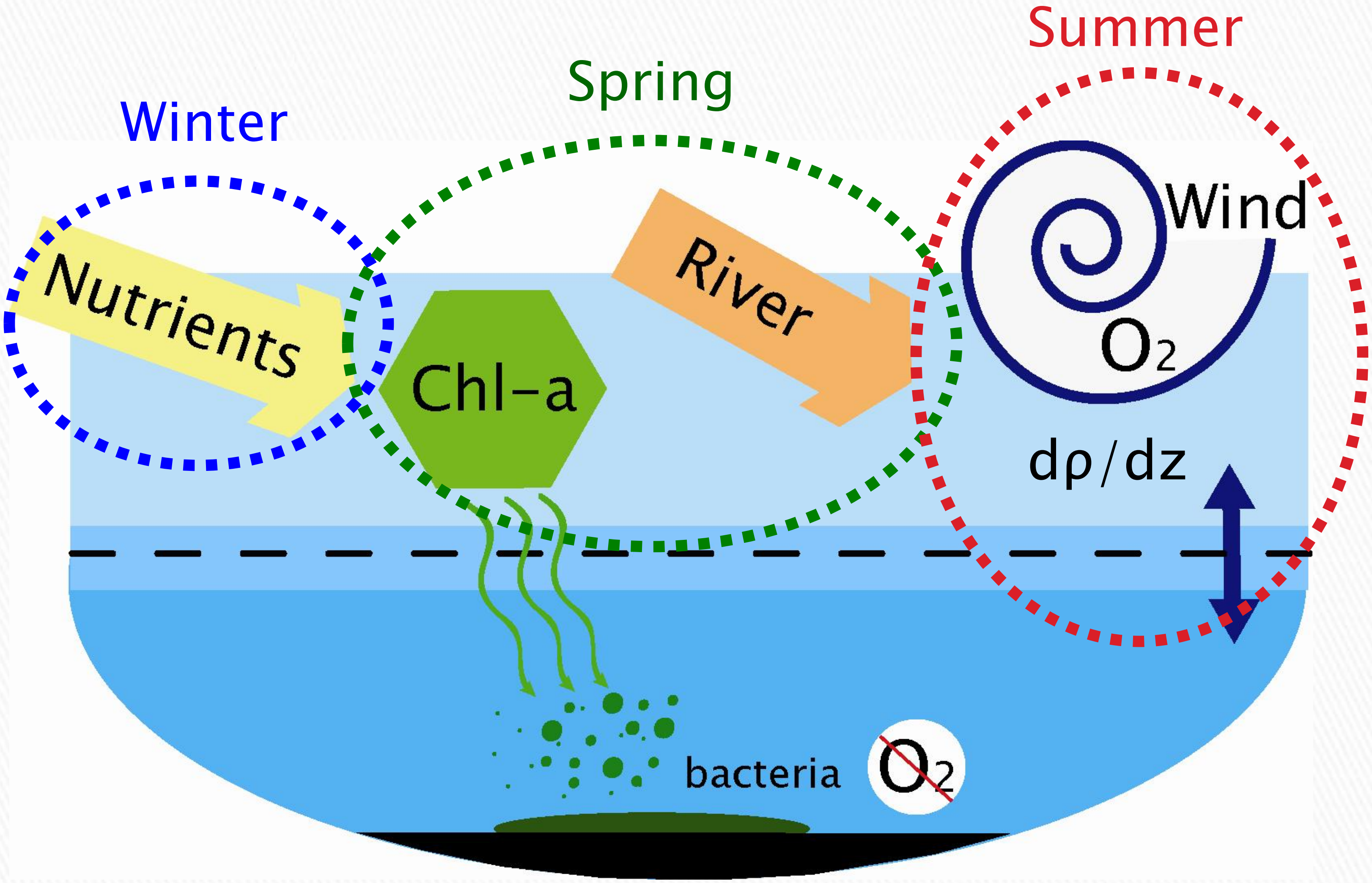
Summer DO Patterns



Factors Controlling Hypoxia

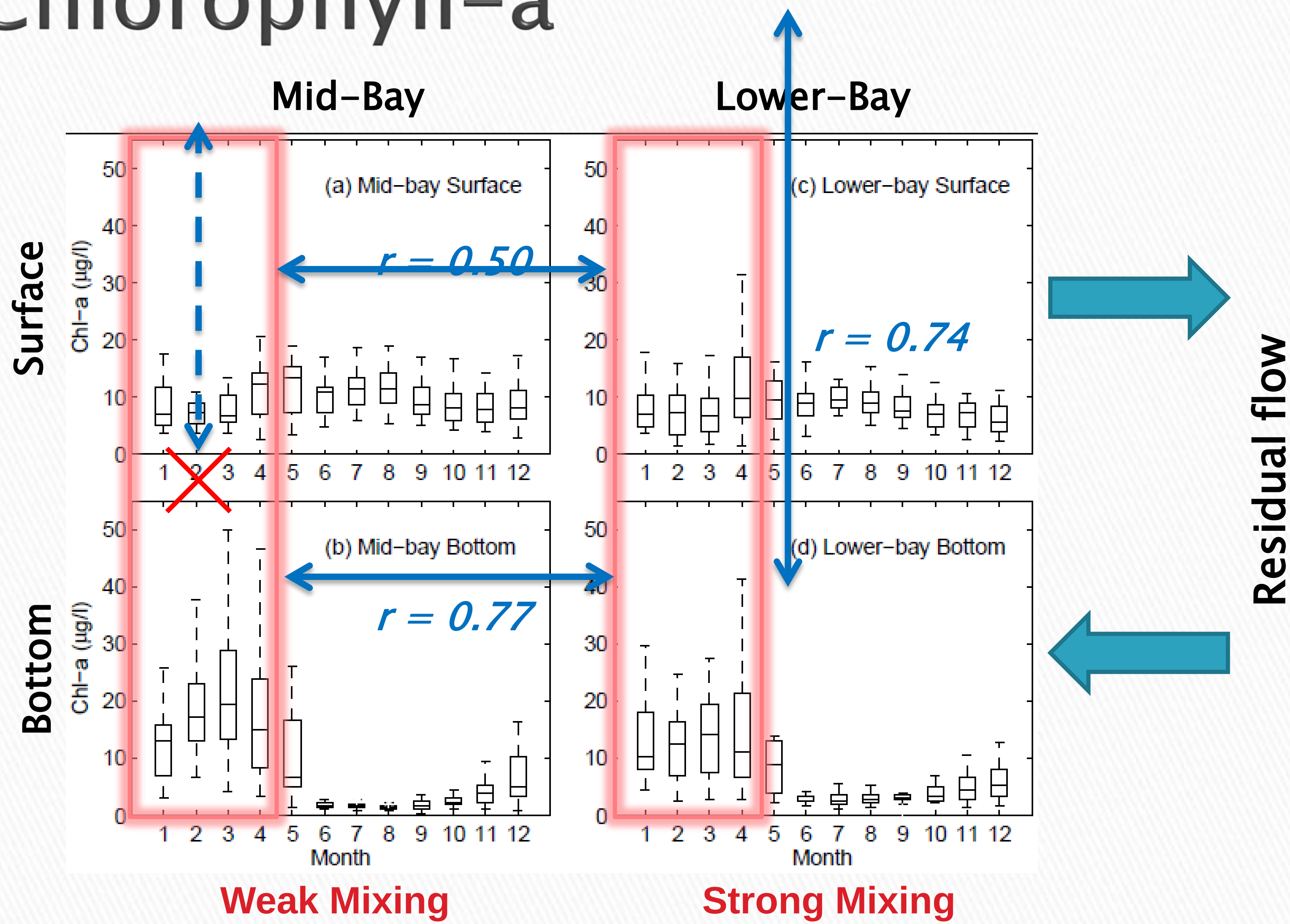


Relationship with Hypoxia

	Hypoxic Volume	River	TN load	Chl-*a*	N^2_{max}	Zonal wind	Meridional wind
		Winter-Spring			Summer		
Hypoxic Volume		**0.60**	**0.59**	**0.42**	**0.70**	0.06	-0.13
River			**0.95**	**0.44**	**0.80**	0.14	0.20
TN load				**0.48**	**0.70**	0.17	0.30
Chlorophyll-*a*					0.35	0.19	0.07
N^2_{max}						0.20	-0.16
Zonal Wind							**0.44**
Meridional Wind							

N^2_{max}: water column maximum Brunt-Väisälä frequency

Chlorophyll-a



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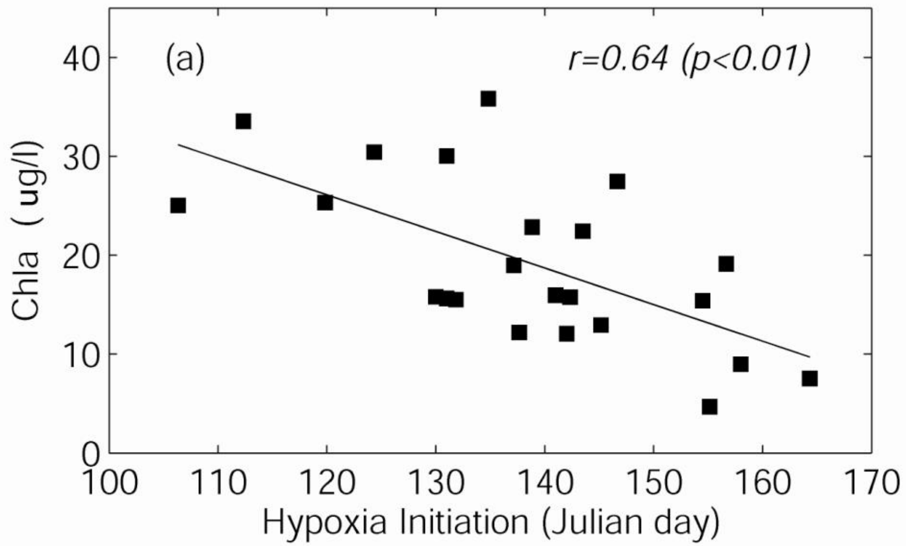
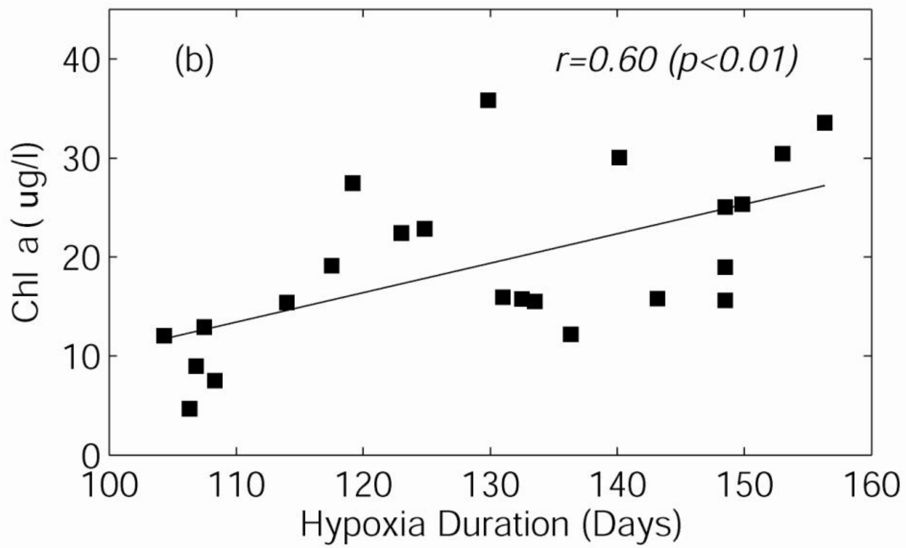
Spring Bottom Algal Biomass

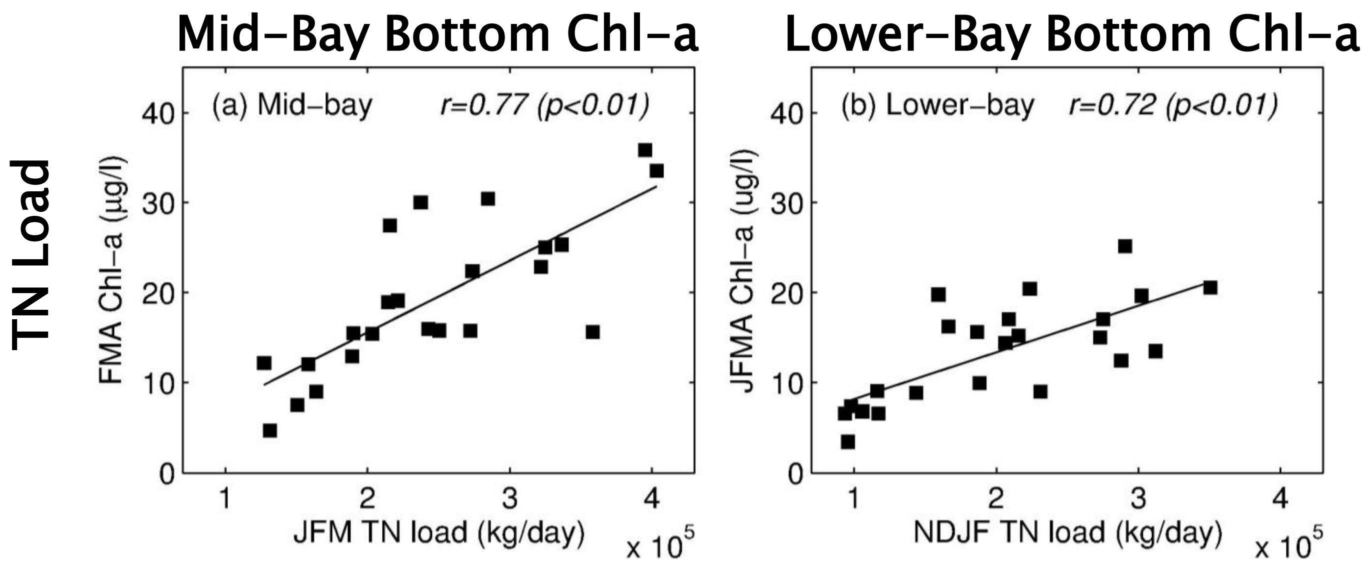
Mid-Bay Bottom

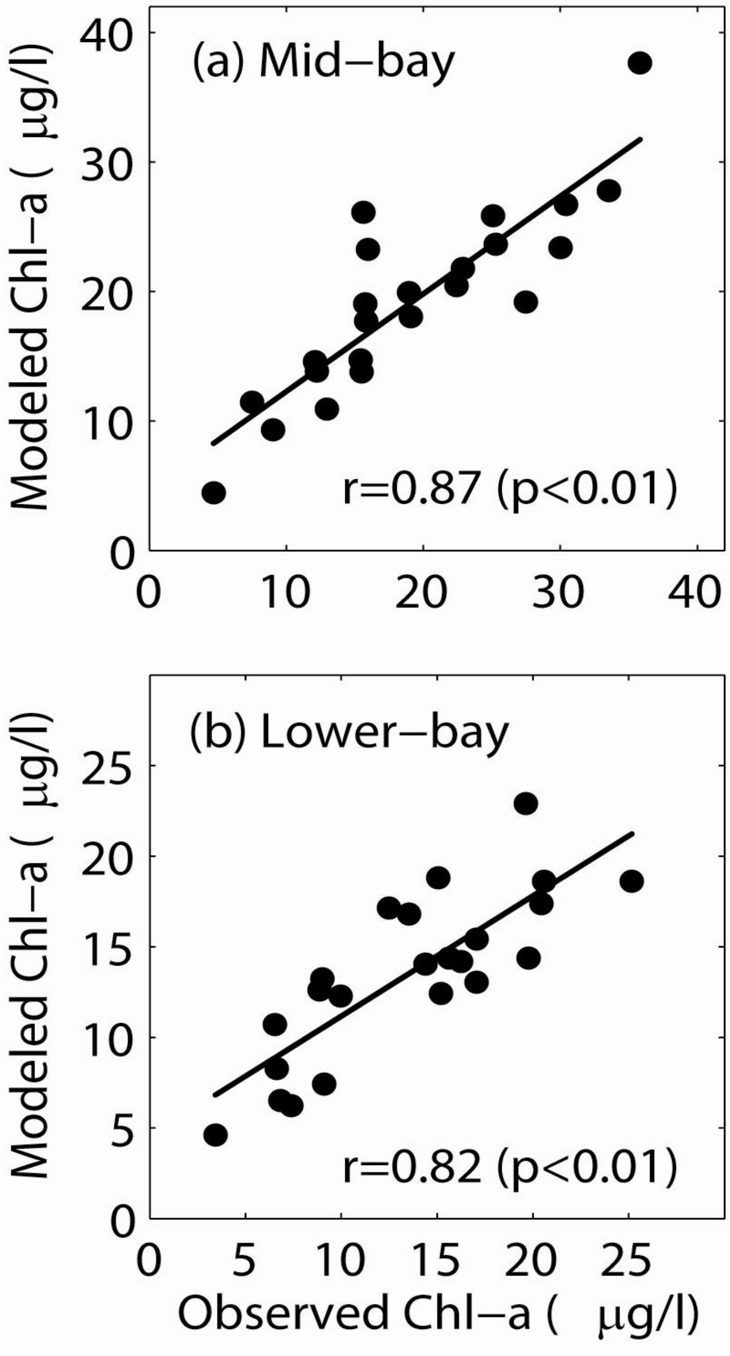


Mid-Bay Bottom



Chlorophyll-a with TN load & T





(a) Mid−bay
r=0.87 (p<0.01)
Modeled Chl−a (μg/l)
0
10
20
30
40
(b) Lower−bay
r=0.82 (p<0.01)
Modeled Chl−a (μg/l)
0
5
10
15
20
25
Observed Chl−a (μg/l)

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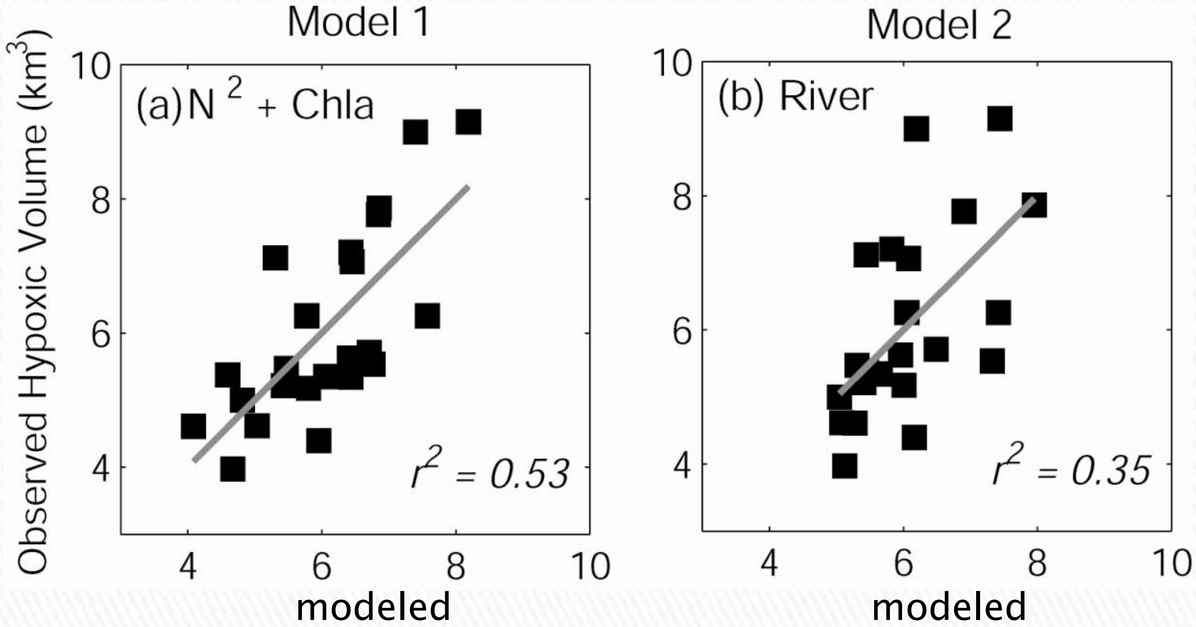
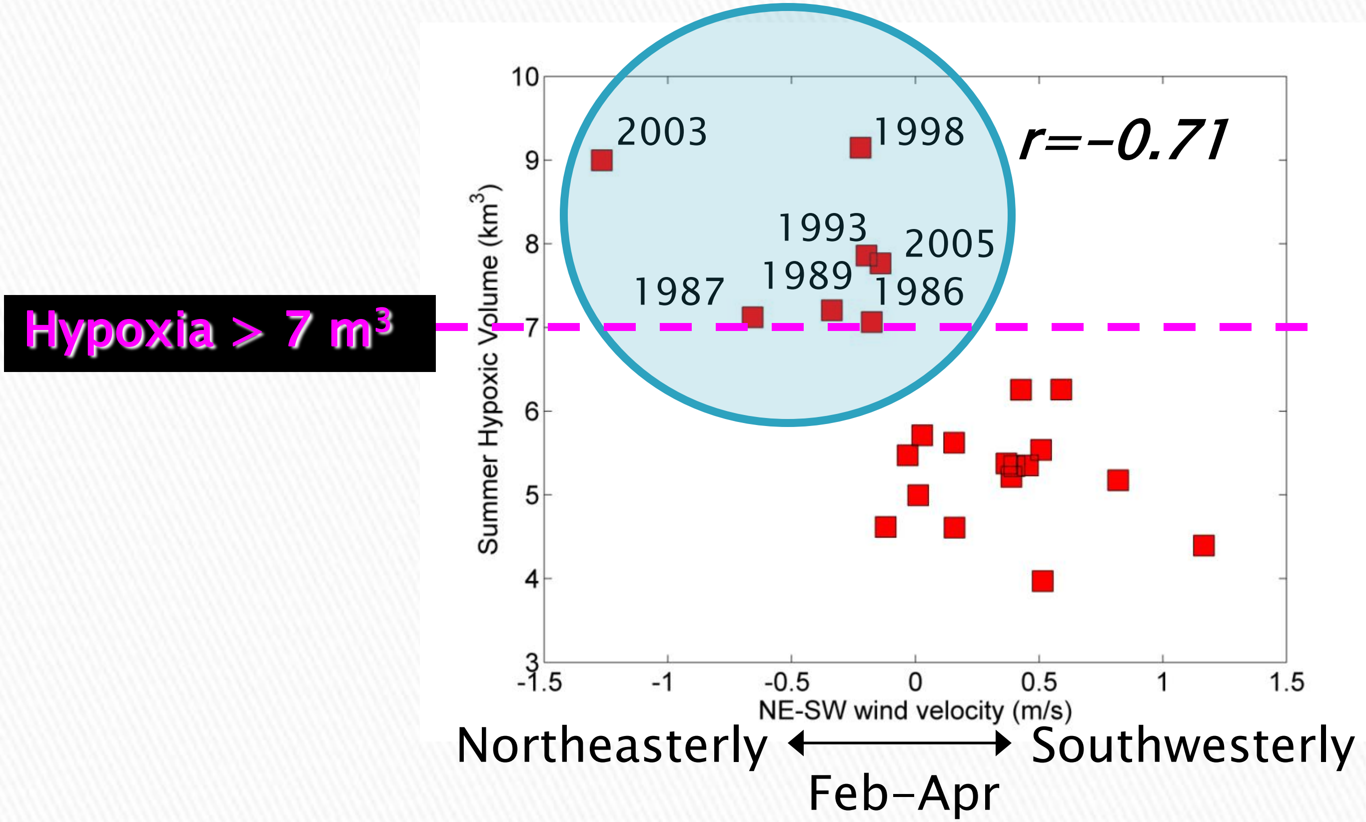
Regression Analysis I

- Multicollinearity (River–TN–Stratification)
- Model 1
  - Summer Stratification
  - Spring Phytoplankton Biomass
- Model 2
  - Winter–Spring River Discharge



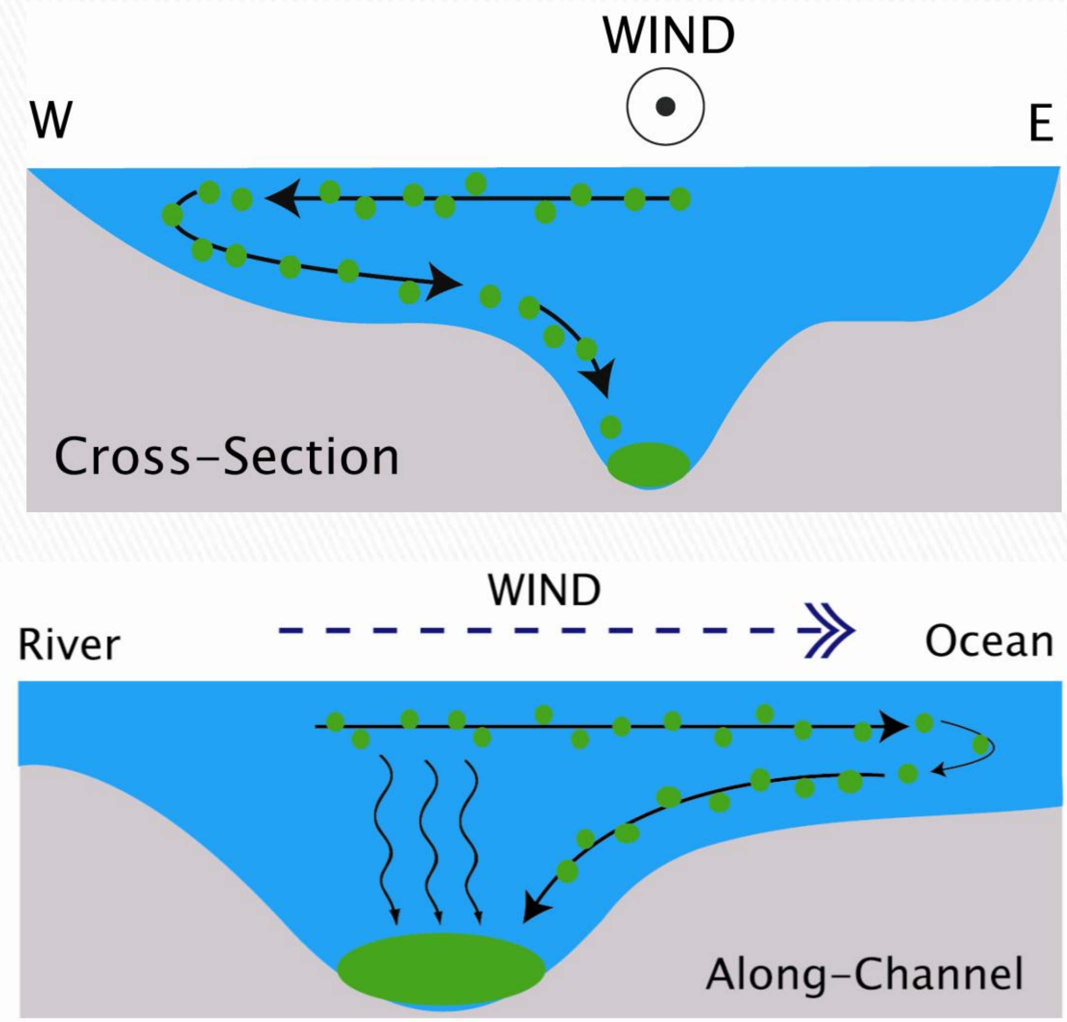
Improving the Fit



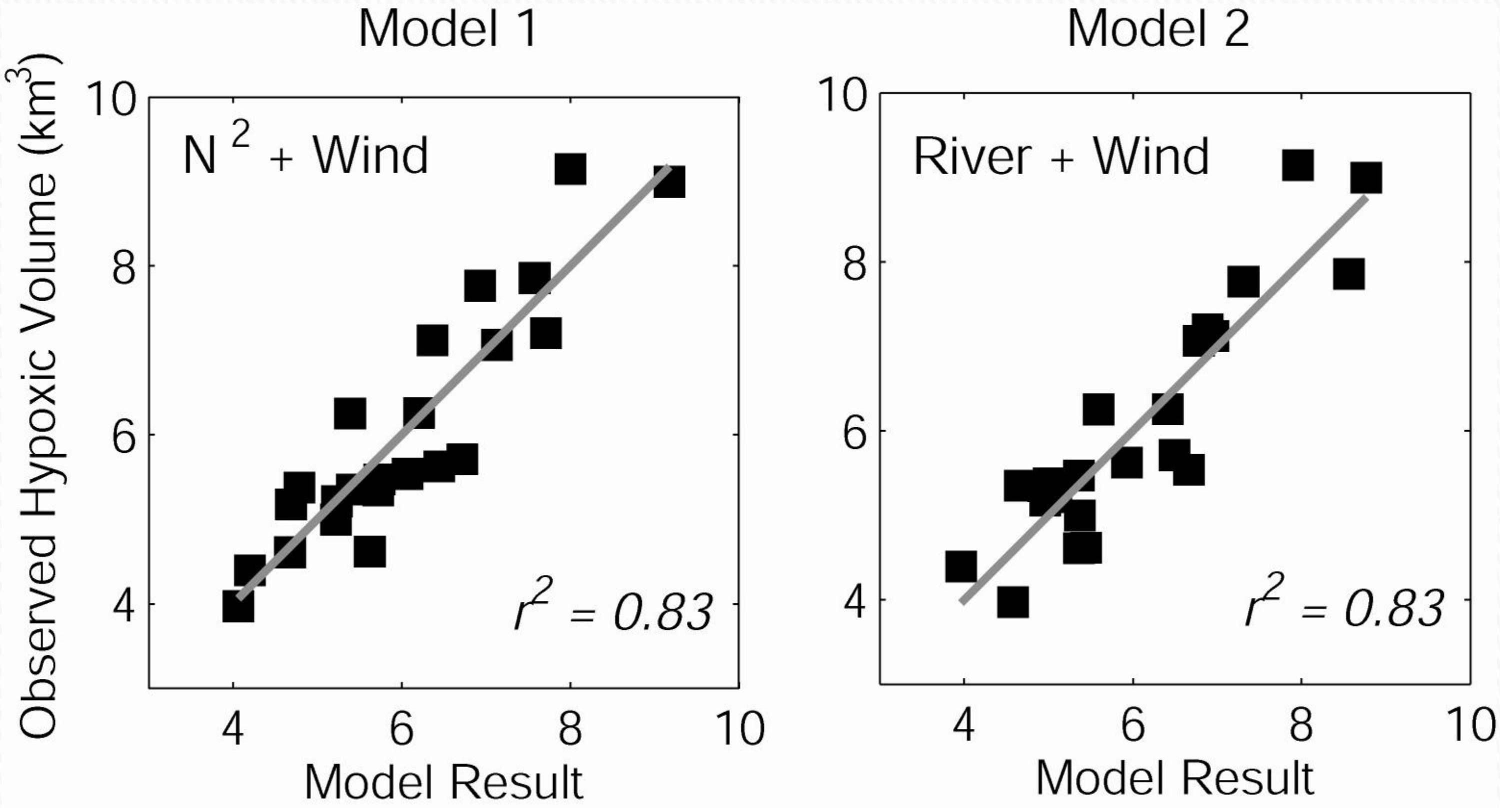
- Years with more spring northeasterly wind tend to be associated with larger volume of summer hypoxia

Why NE Wind Matters?

- Northeasterly (NE) wind may contribute to
  - The transport of phytoplankton biomass from the western flank area to the deep channel
  - The retention of organic carbon in the mid-bay region.



Regression Analysis II



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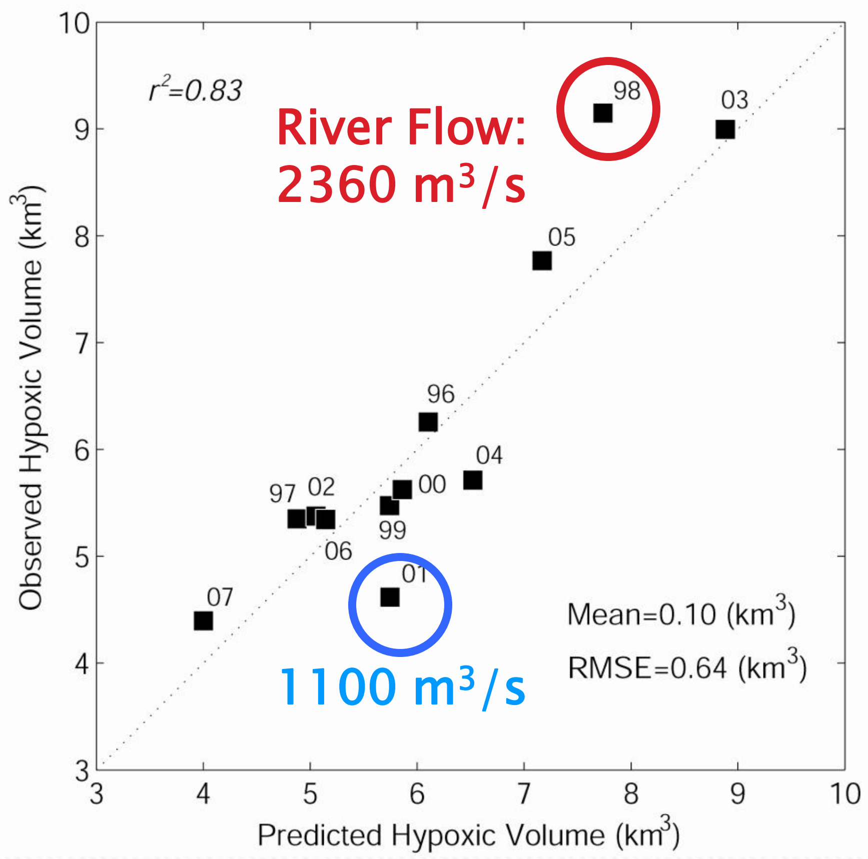
Hypoxia Prediction using Model 2

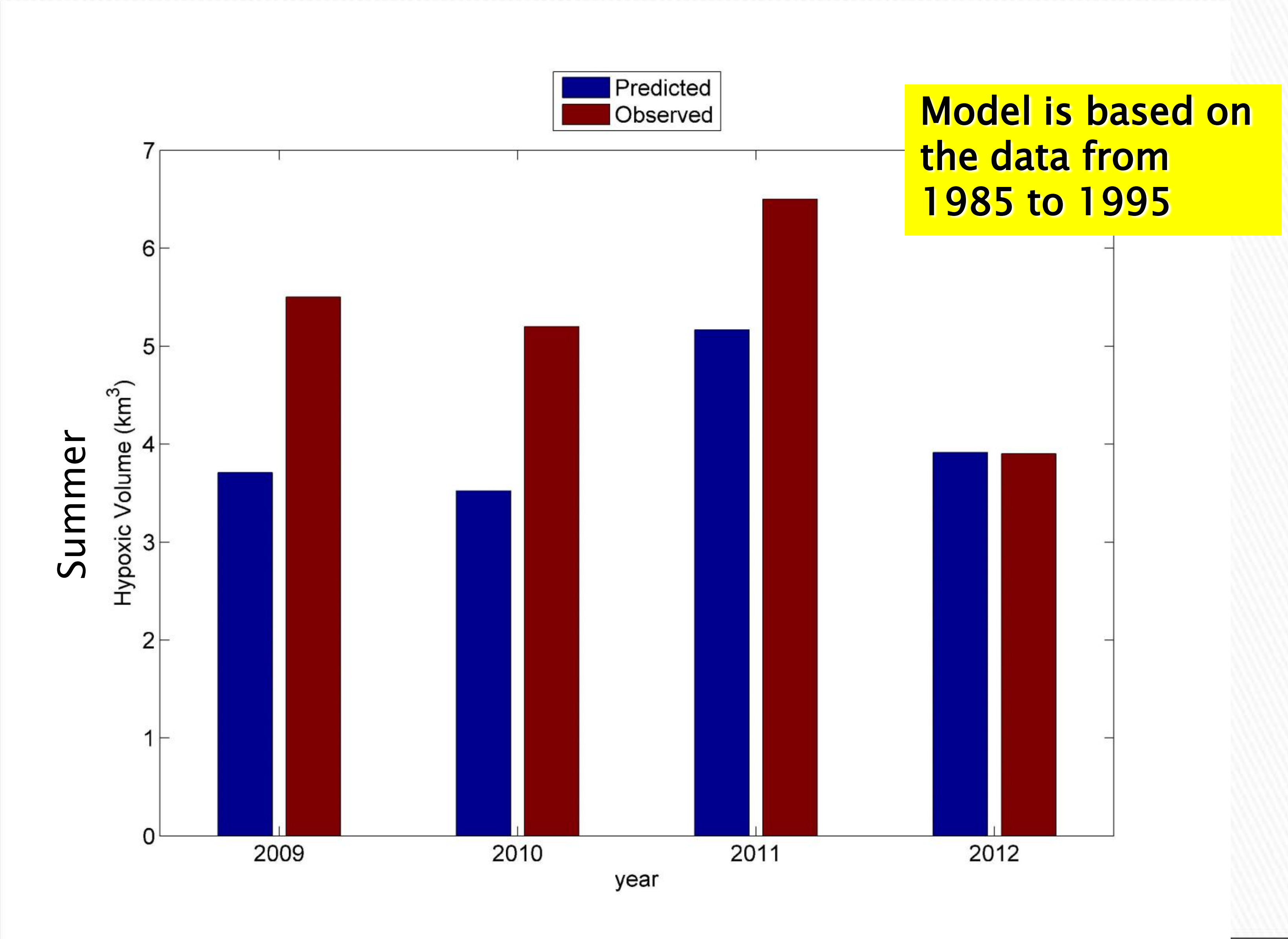
- Two Independent Variables
  - River Flow (Jan–May)
  - NE–SW Wind Speed (Feb–Apr)
- Using the data from 1985 to 1995, hypoxic volume is predicted for 1996–2007
- Extreme years of 1998 and 2001

Jun–Aug 1996–2007



$$\text{Hypoxia Vol.}_{predicted} = 0.00142 \cdot \text{River} - 1.99 \cdot \text{Wind} + 3.94$$

Hypoxia Prediction for 2009–2012



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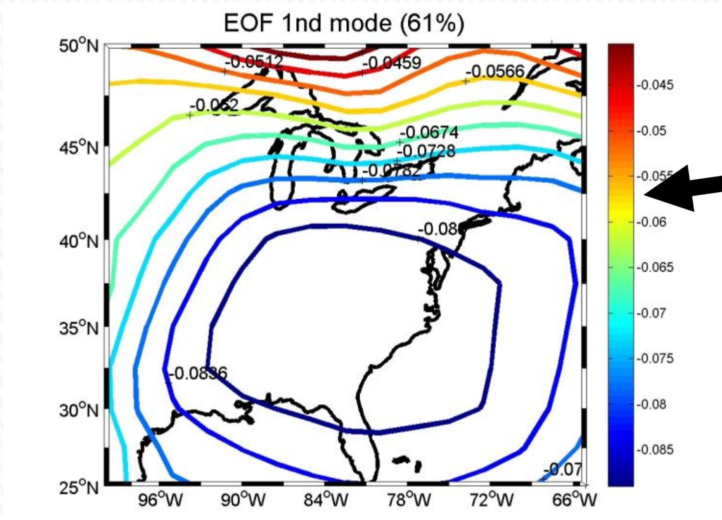
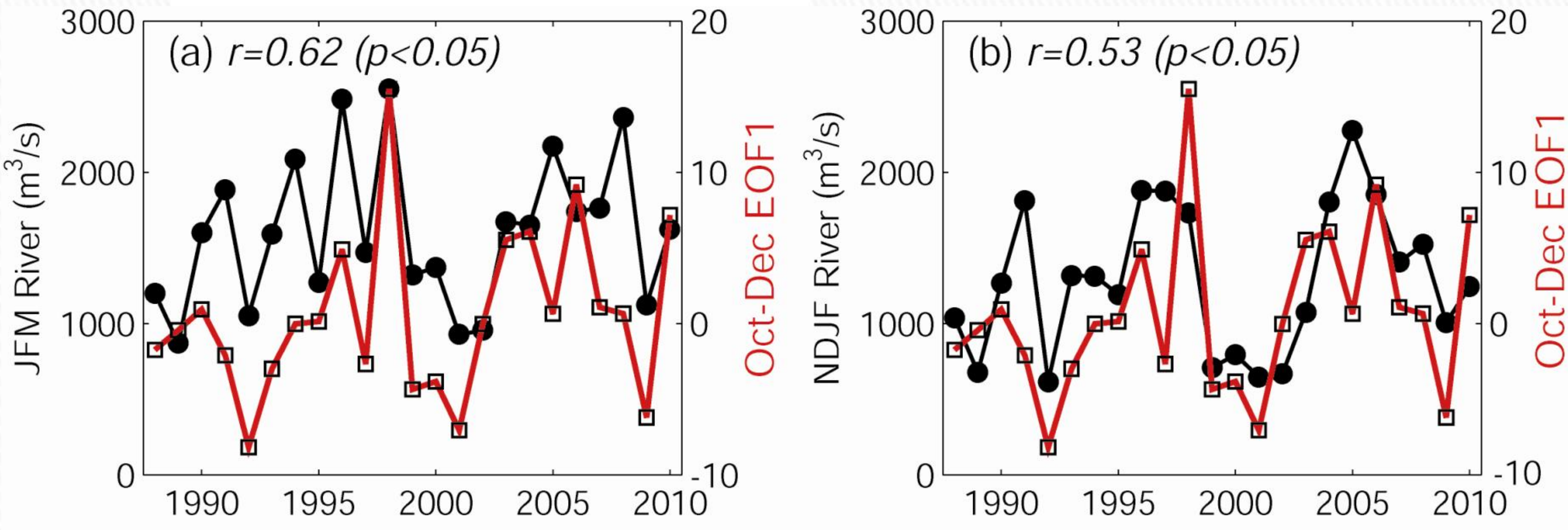
EOF Analysis

- Empirical Orthogonal Function (EOF) Analysis
  - A statistical technique used to extract information from large data sets by identifying spatial and temporal structures
  - The first few modes explain most of the variance and may then be linked to possible dynamical mechanisms
- NCEP/NCARR Monthly Sea-Level Pressure Anomaly
- The first three modes are linked to river discharge, wind condition, and temperature, respectively.

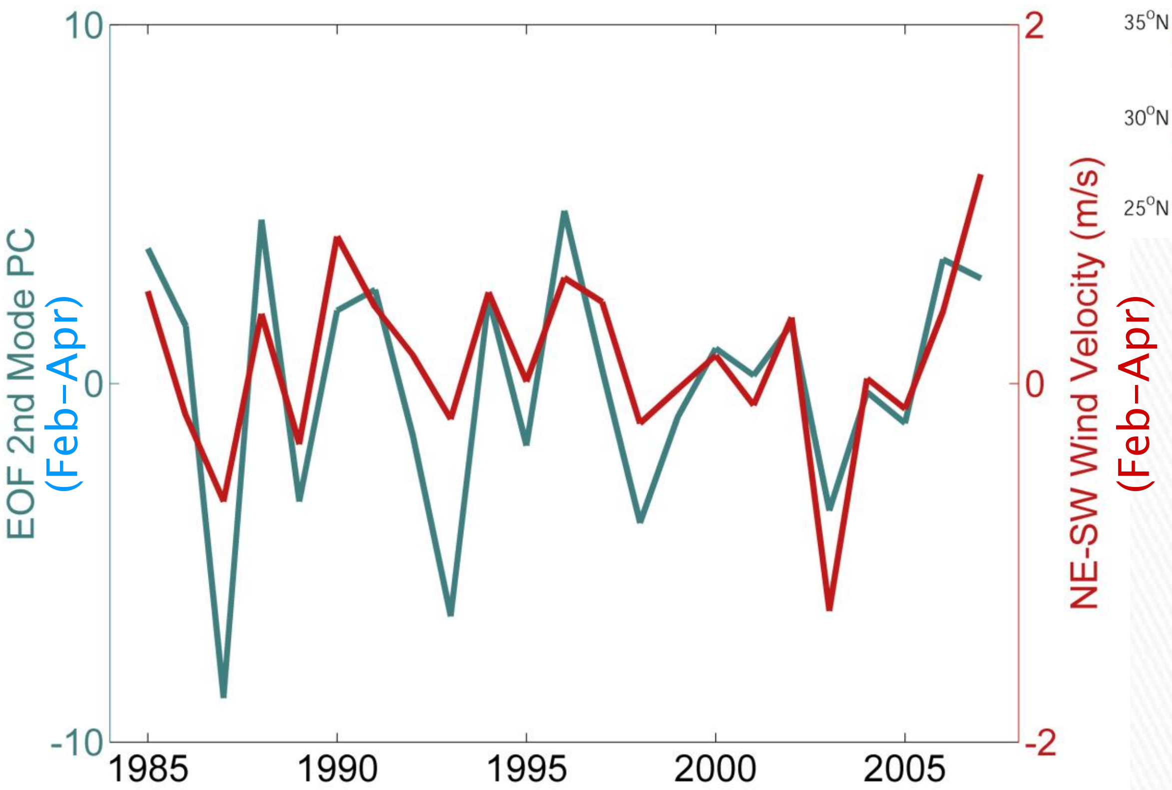
EOF of SLP Anomaly: 1st Mode

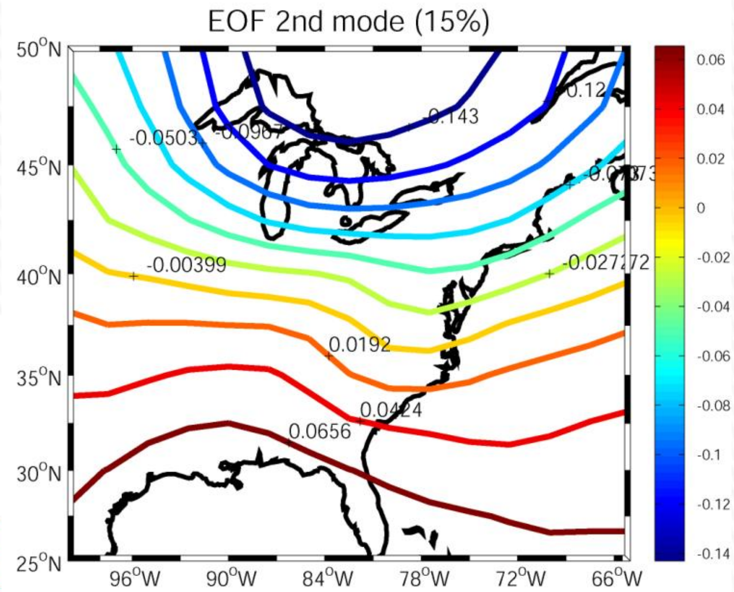


North Atlantic Oscillation/
Artic Oscillation



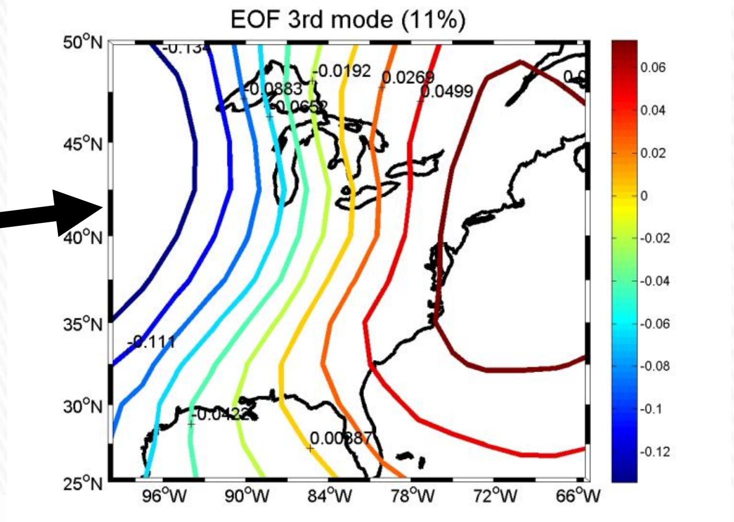
EOF of SLP Anomaly:2nd Mode

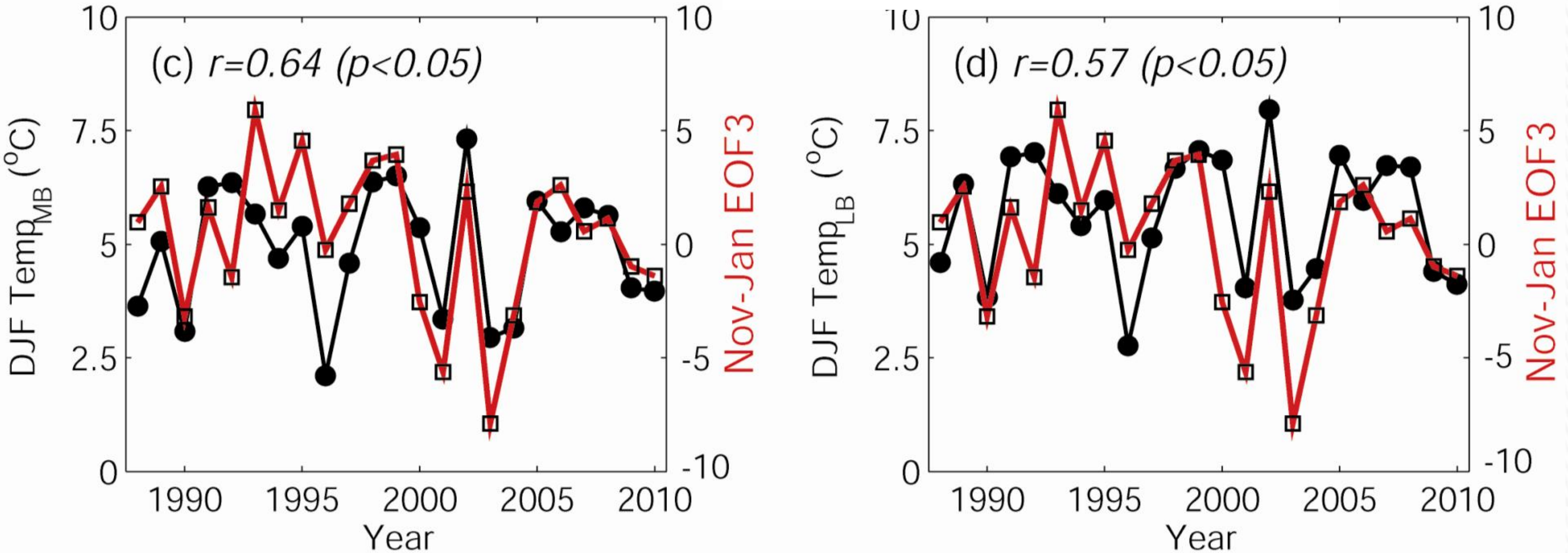




EOF of SLP Anomaly:3rd Mode

Bermuda High Index





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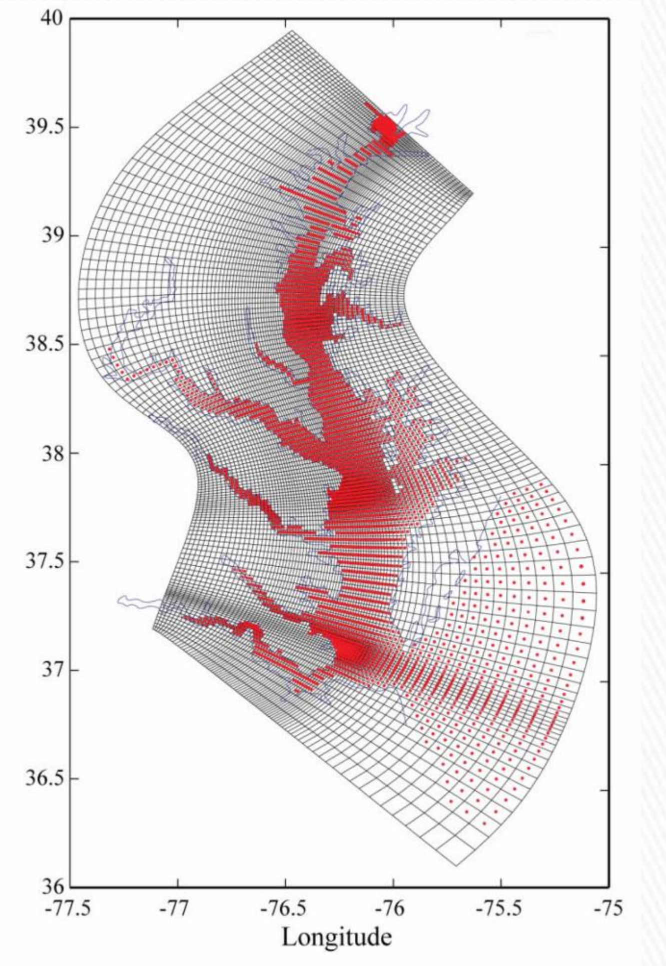
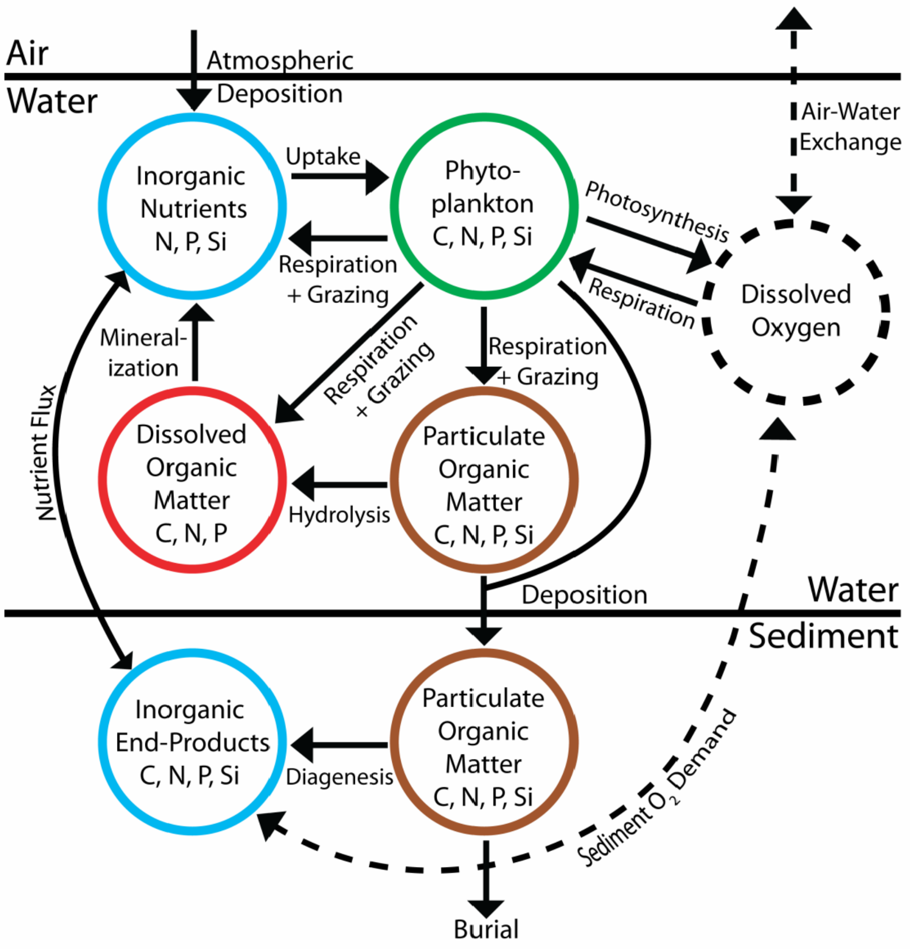
Hydrodynamic Ocean Model

- Regional Ocean Modeling System (ROMS)
- It was developed for Chesapeake Bay by Dr. Ming Li at HPL.
- 80 x 120 grid cell domain with 20 vertical layers
- The background diffusivity and viscosity set at $1x10^{-6}$ m^2 s^{-1}
- The model is simulated by freshwater discharge from 8 major rivers, sea-level fluctuations (tidal and sub-tidal) at open boundary, and atmospheric forcing from North American Regional Reanalysis (NARR) from NOAA/NCEP.



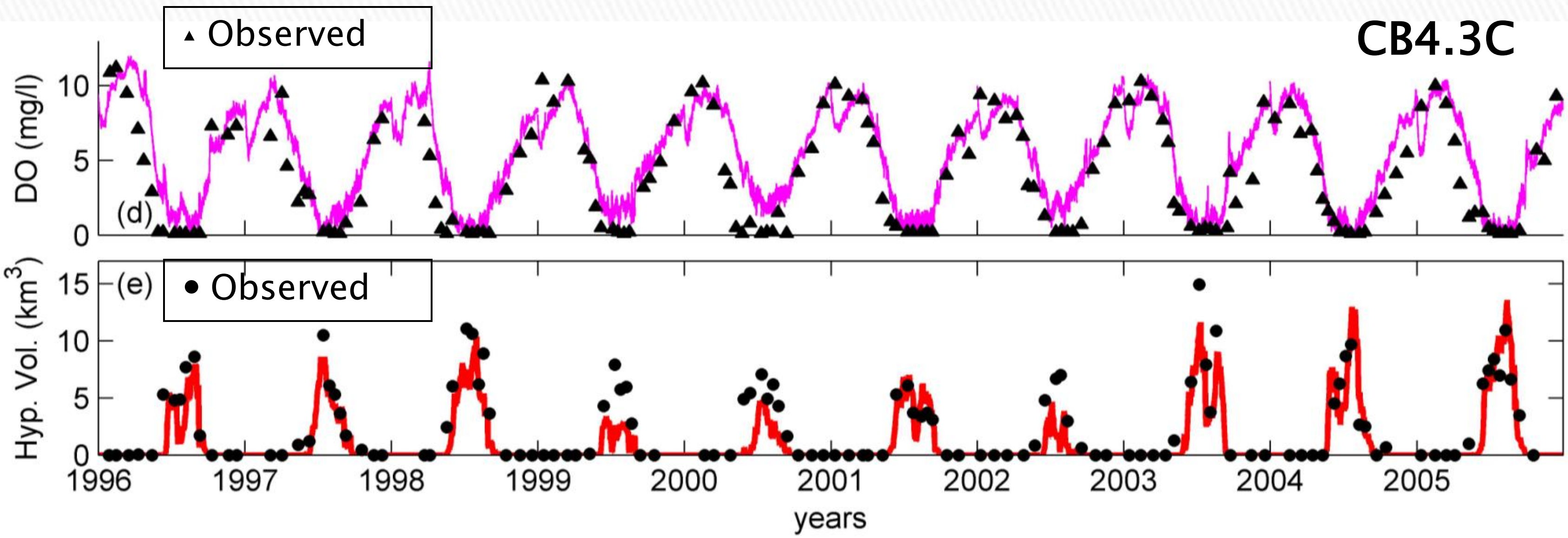
Water–Quality Model

- RCA is a 3-D generalized water quality model developed by HydroQual.
- It is coupled with ROMS simulations via NetCDF interface.
- The model formulates mass balance equations for water quality variables (C, N, P, Si, and O_2)



Testa et al. (2013)

Model Prediction (1996-2005)



Summary

- Hypoxia in Chesapeake Bay are more influenced by winter-spring conditions than summer ones.
- Summer hypoxia can be predicted using winter-spring processes, i.e., river flow and NE-SW wind.
- Phytoplankton biomass more affects the initiation of hypoxia than its magnitude.
- Regional climate variability influences river discharge, wind, and water temperature which are related to spring phytoplankton biomass as well as summer hypoxia.

Thank you

- This work is the part of the project <u>*"CHRP07: Modeling Hypoxia and Ecological Responses to Climate and Nutrients"*</u> which is funded by NOAA under grant NA07NOS4780191.
- Chesapeake Bay Program
- Drs. Kamazima Lwiza, Jeremy Testa, Ming Li, Yun Li, and Mike Kemp
- Dong-Yoon Lee