Modeling Hypoxia & Ecological Responses to Climate & Nutrients

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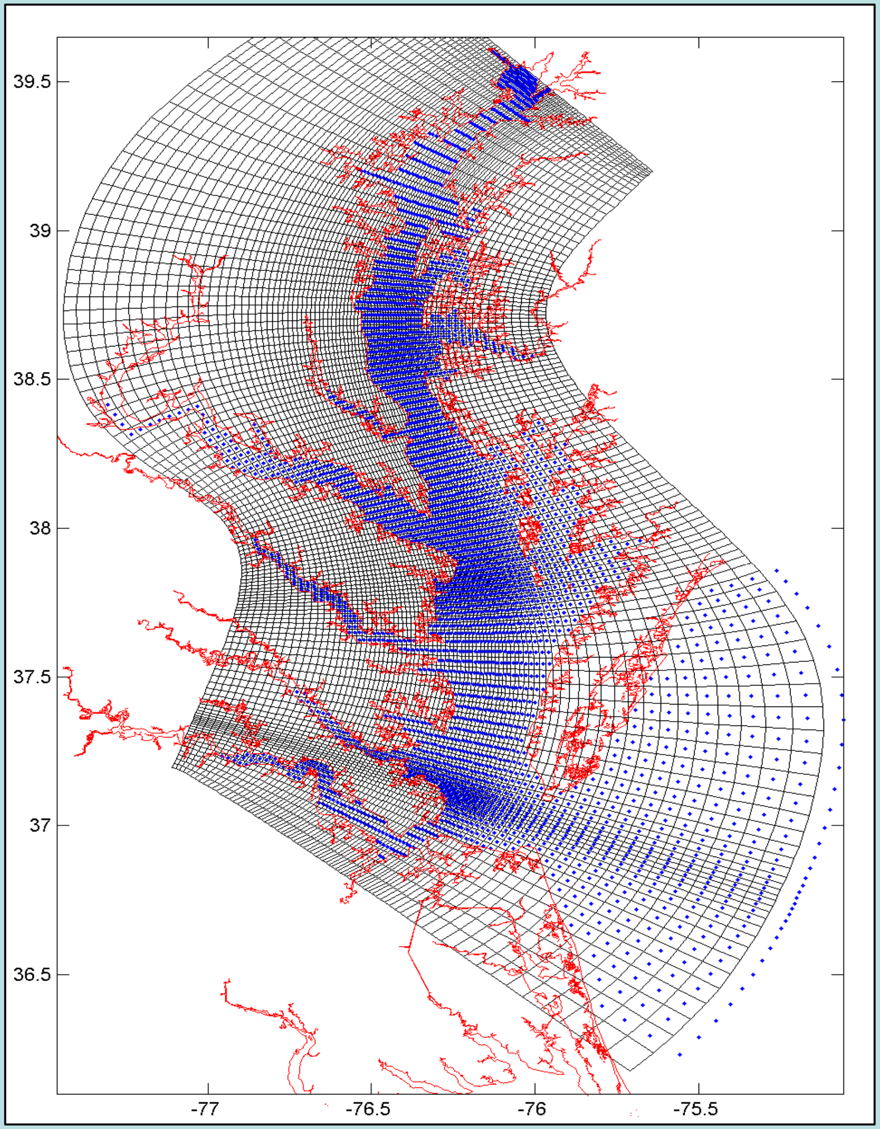
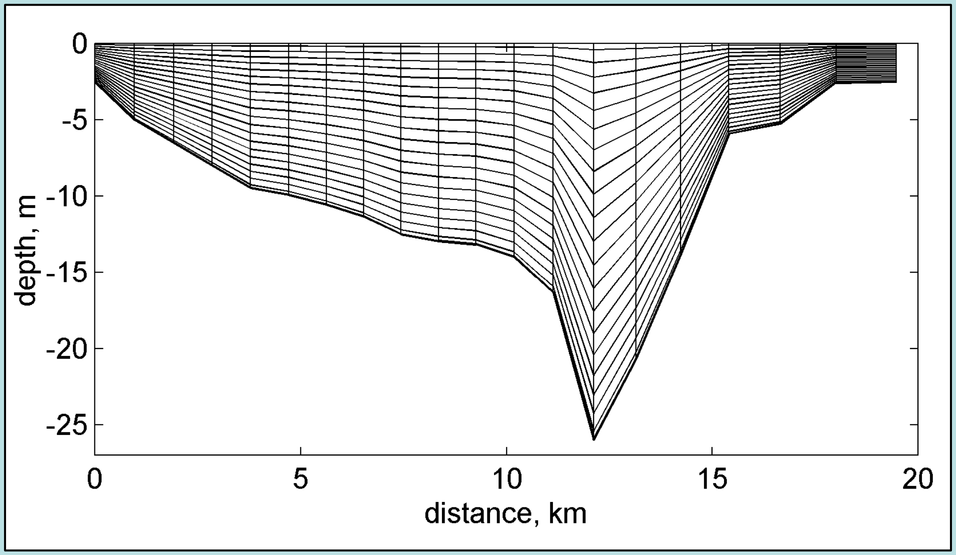
Structure of CHRP:CB Research Program

- ***Simulation Studies (Prognostic)***
  - (1) Predicting hypoxia scenarios at seasonal & interannual scales
  - (2) Formal parameter optimization to improve model skill
  - (3) Incorporating uncertainty w/ ensemble simulations
- ***Diagnostic Assessment***
  - (3a) Understanding climate & nutrient input controls on hypoxia
  - (3b) Simulating ecosystem processes & feedback regulation
- ***Retrospective Analysis***
  - (4) Focus on mechanisms controlling hypoxia in CB & DIB
  - (5) Understand “Regime Shift” in hypoxia per unit nutrient load
- ***Habitat Evaluation***
  - (6) Fish/Invert habitat & “production” responses to climate & mgmt?
- ***Science Education Outreach***

Configuration of ROMS model for Chesapeake Bay

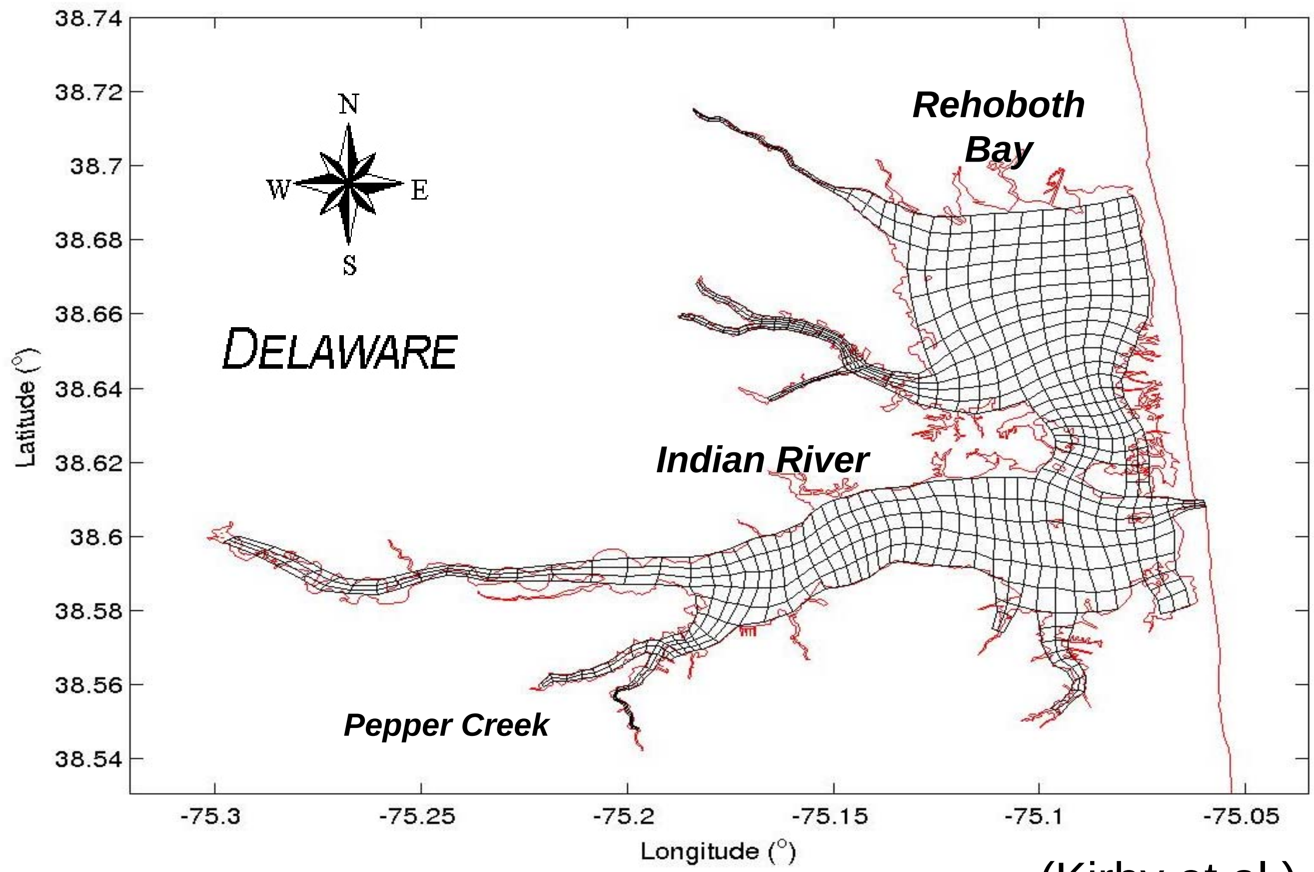


• Develop existing implementation of ROMS for Chesapeake Bay
• Curvilinear horizontal coordinates with grid spacing about 1 km.
• Generalized terrain-following vertical coordinate with 20 layers.



(Ming Li et al.)

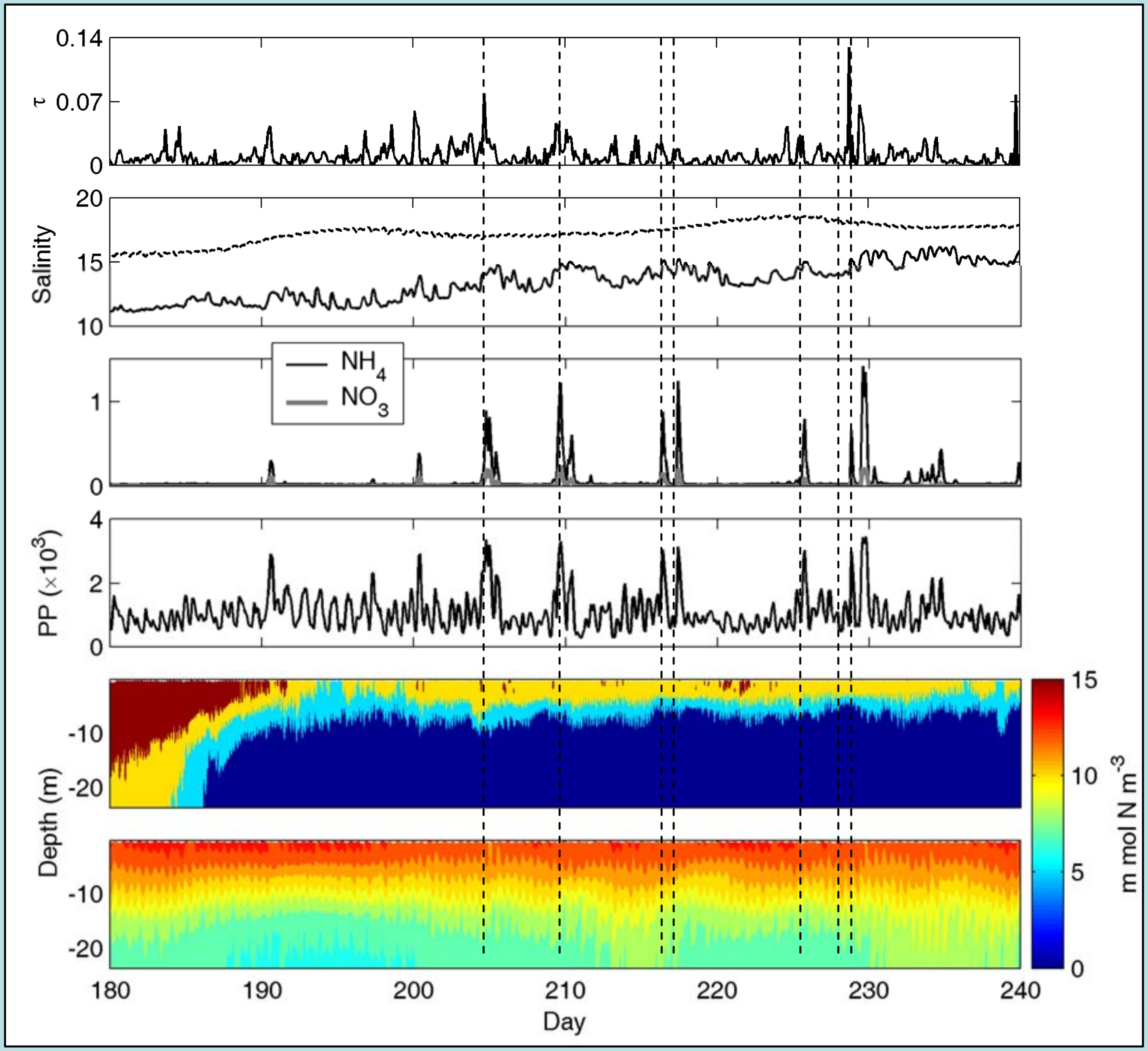
Delaware Inland Bays ROMS Grid



(Kirby et al.)

- Existing implementation of ROMS for Delaware Inland Bays
- Eutrophic lagoonal system with mean depth ~ 2 m
- Problems documented with diel cycling hypoxia

Diagnostic Analysis: Event-Enhanced Production

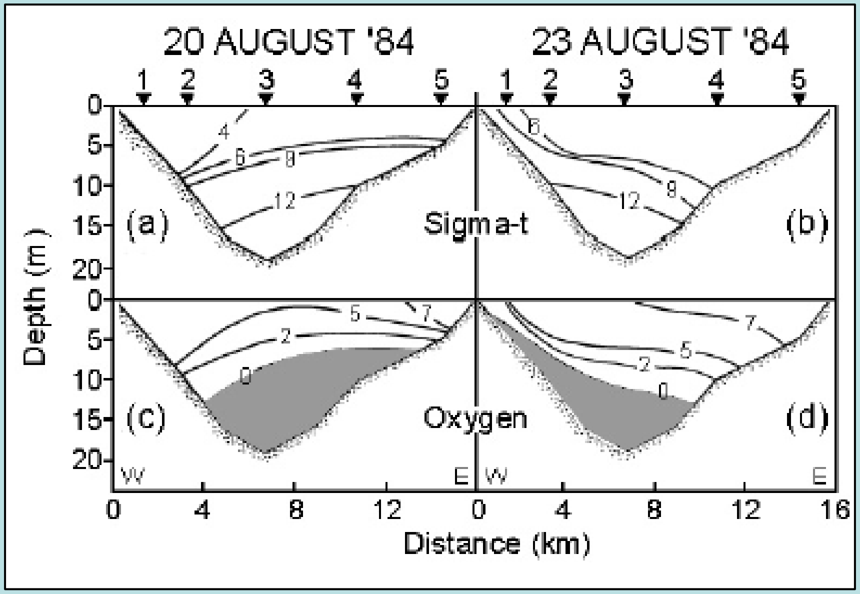


(Li, Harding)

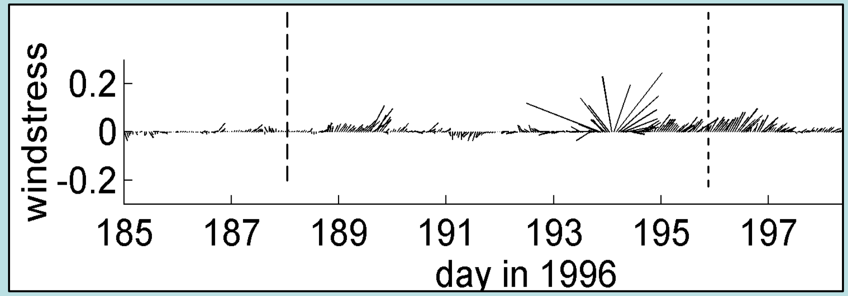
- Simulation experiments to understand wind-forced productivity.
- Vertical wind mixing stimulates lateral nutrient upwelling
- Model experiments deepen understanding of ecological processes

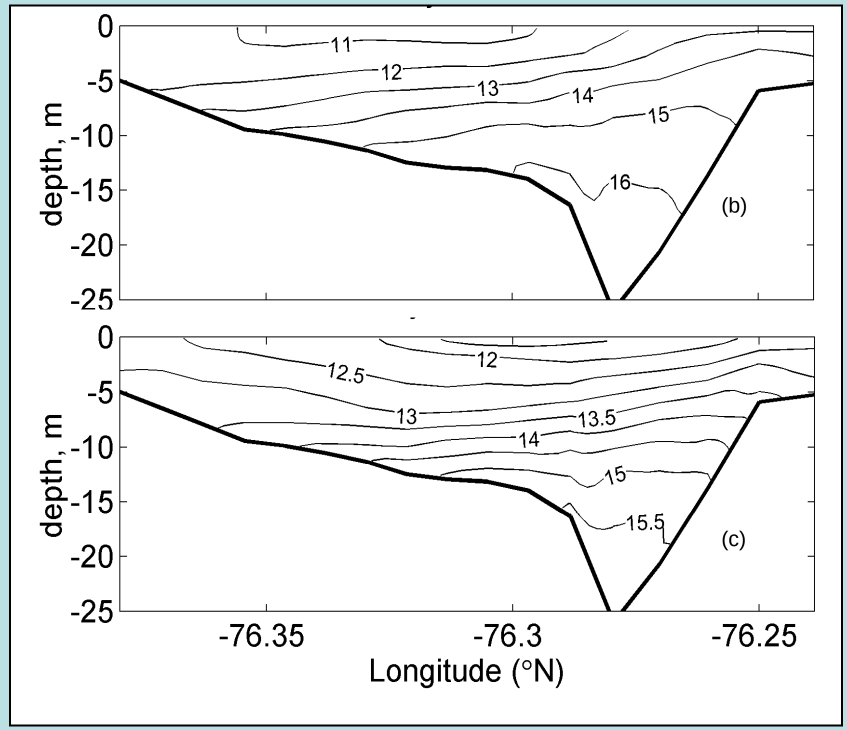
Forecasting: Event Induced Pycnocline Tilting

Observations (Malone et al. 1986)



Model Hindcast



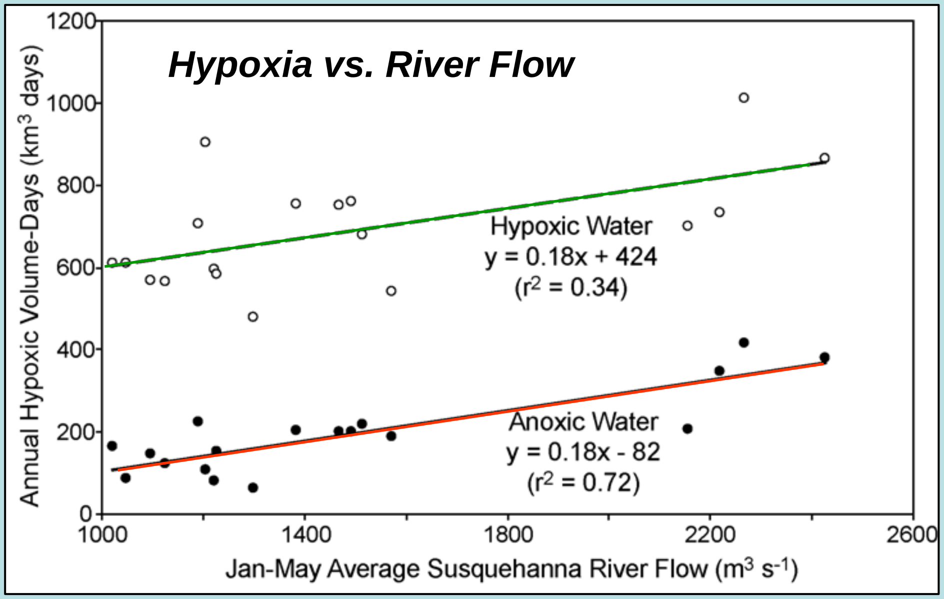


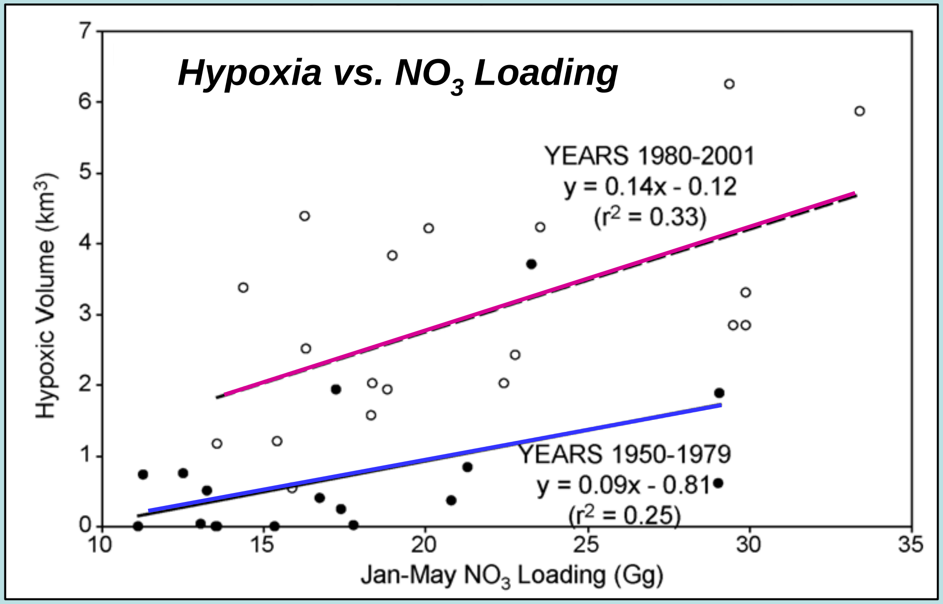
- Model captures observed lateral ‘seiching’ driven by wind events
- Seiching causes upwelling of hypoxic water onto shallow flanks
- Large ecological & economic impacts result from events

(Li, Kemp, Boynton)

Retrospective Analysis: CB Hypoxia Regime Shift

- **Volumes of summer hypoxic (O_2 < 1 mg/L) and anoxic (O_2 < 0.5 mg/L) clearly related to winter-spring river flow.**
- **Abrupt increase in slope of time trend from 1950-1980 (blue line) to 1980-2003 (magenta line). Currently, there is more hypoxia per unit NO_3 Loading.**

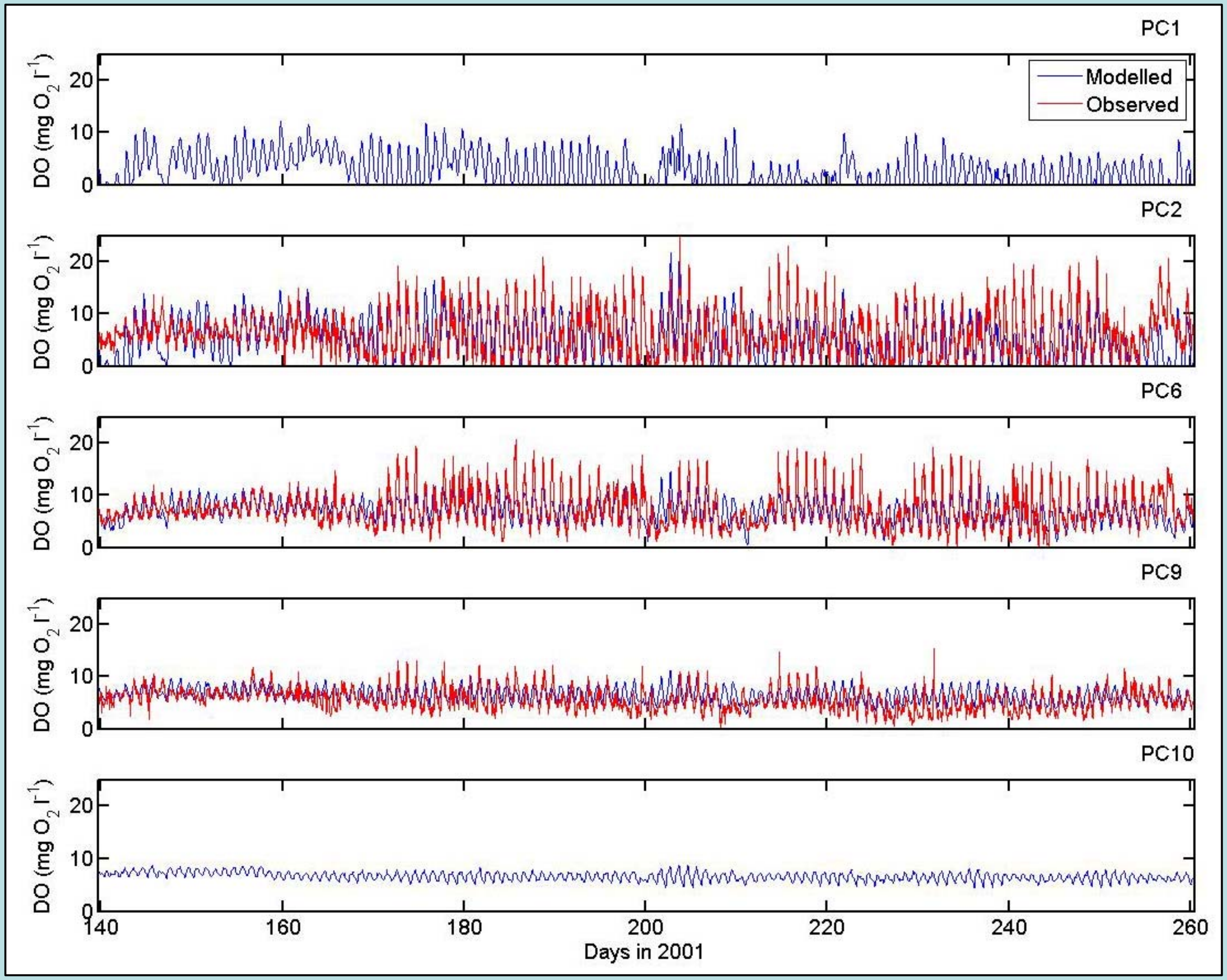




- **What factors have contributed to this abrupt "regime shift" leading to more hypoxia per loading?**
- **Novel approaches are needed to simulate these dynamics**

(Kemp, Boynton, et al.)

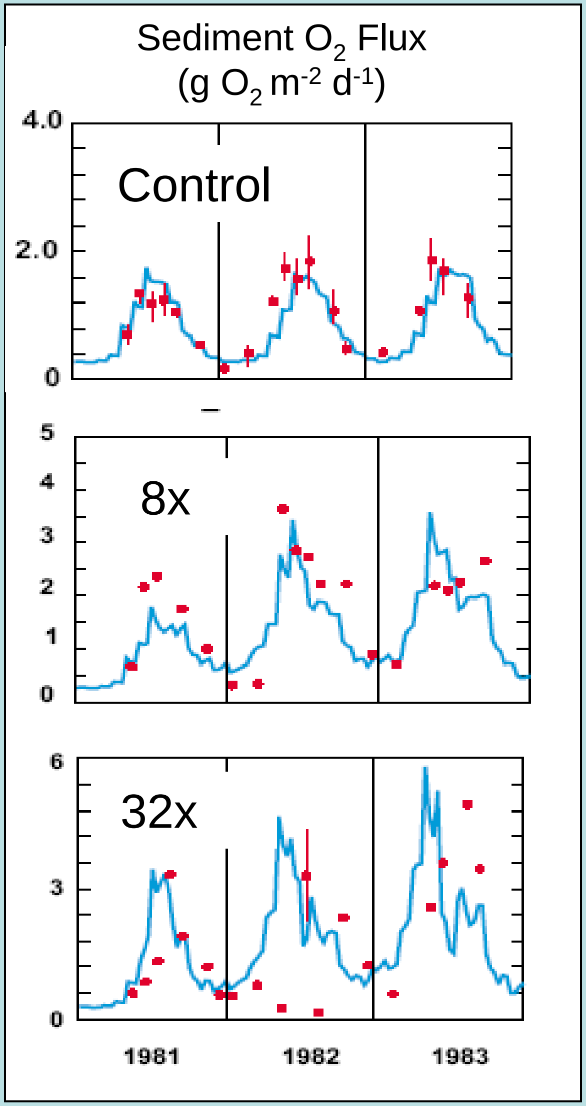
Forecasting & Diagnostics: Diel O_2 in DIB

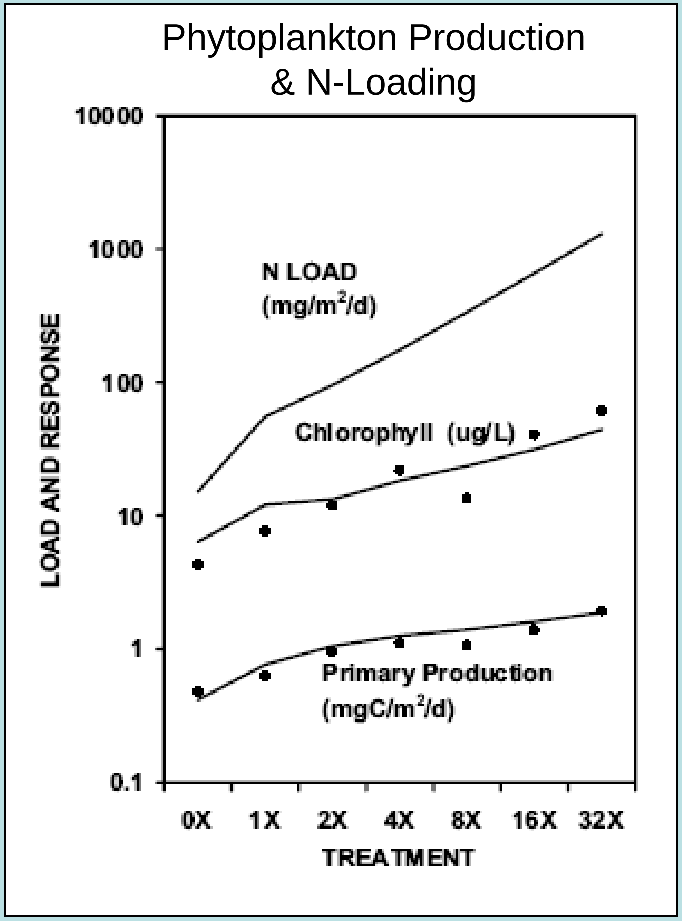


- Diel variations in O_2 reveal night time hypoxia common in summer
- Existing water quality models (blue) do not capture dynamics
- New ROMS biophysical model simulates these patterns well

(Kirby, DiToro, Kemp)

Forecasting: Using Assimilation of MERL Data to Calibrate Biogeochemical Model

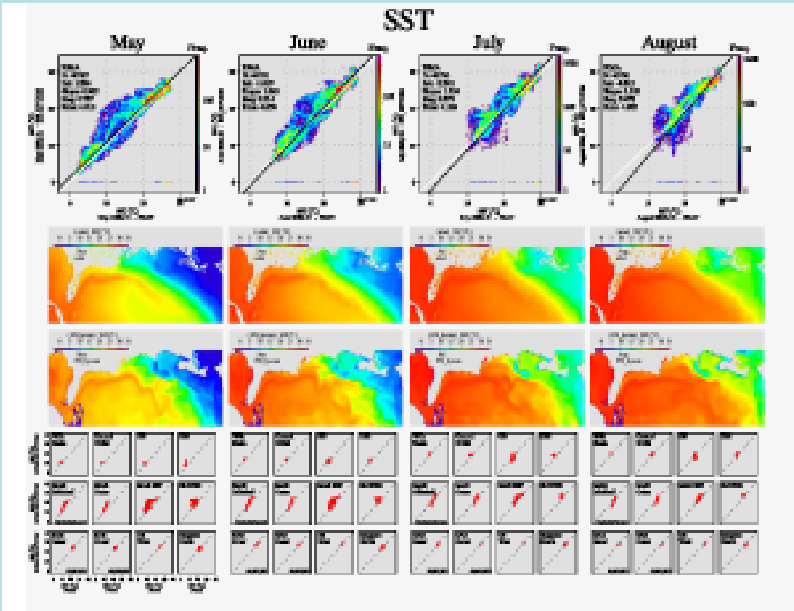


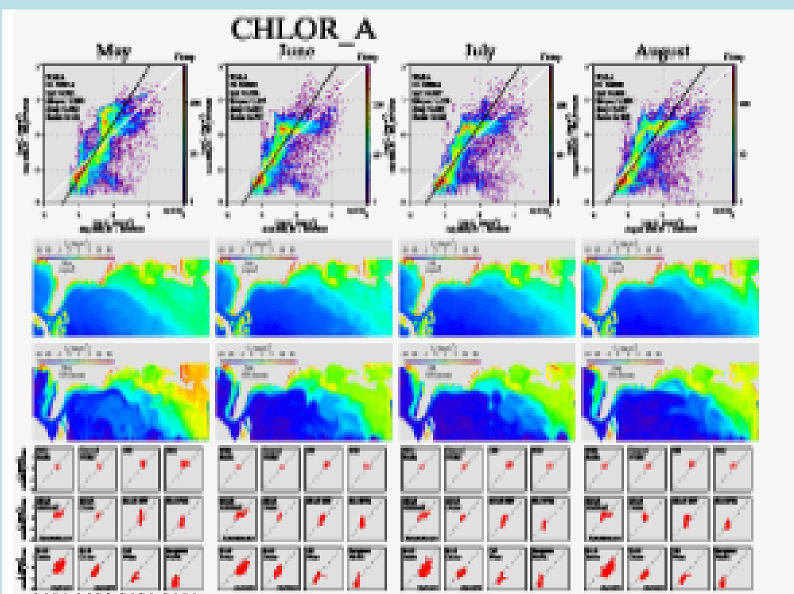


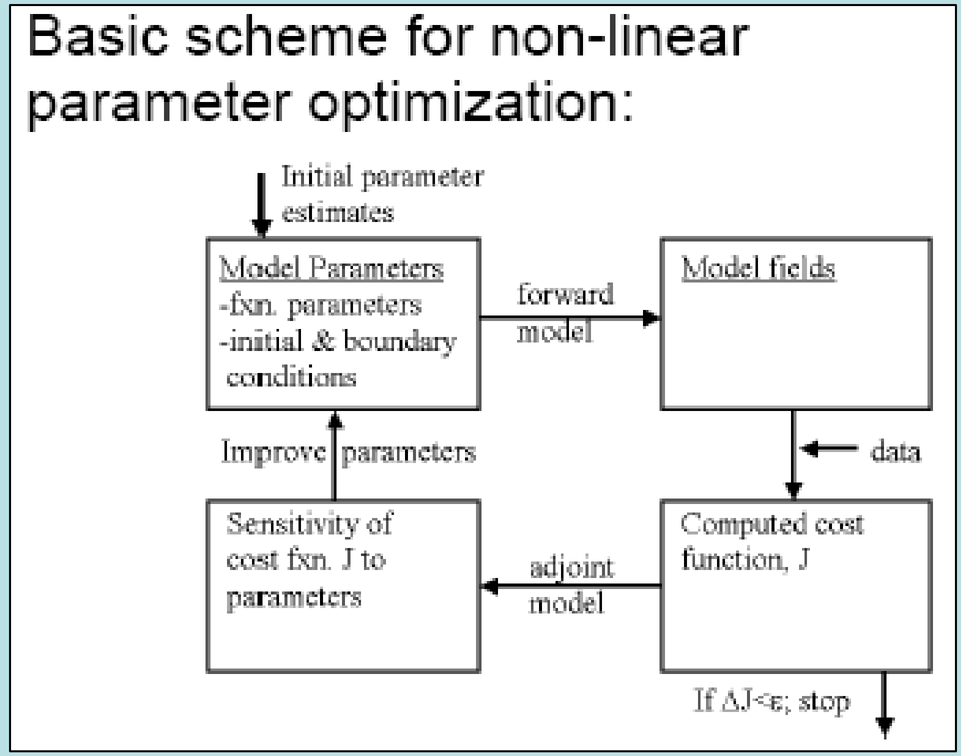
Use zero-dimensional models of experimental ecosystems to optimize parameter set and test model uncertainty

(DiToro, Fennel, Kemp)

Forecasting: Data Assimilation







(Katja Fennel)

Habitat Assessment: Suitability Models

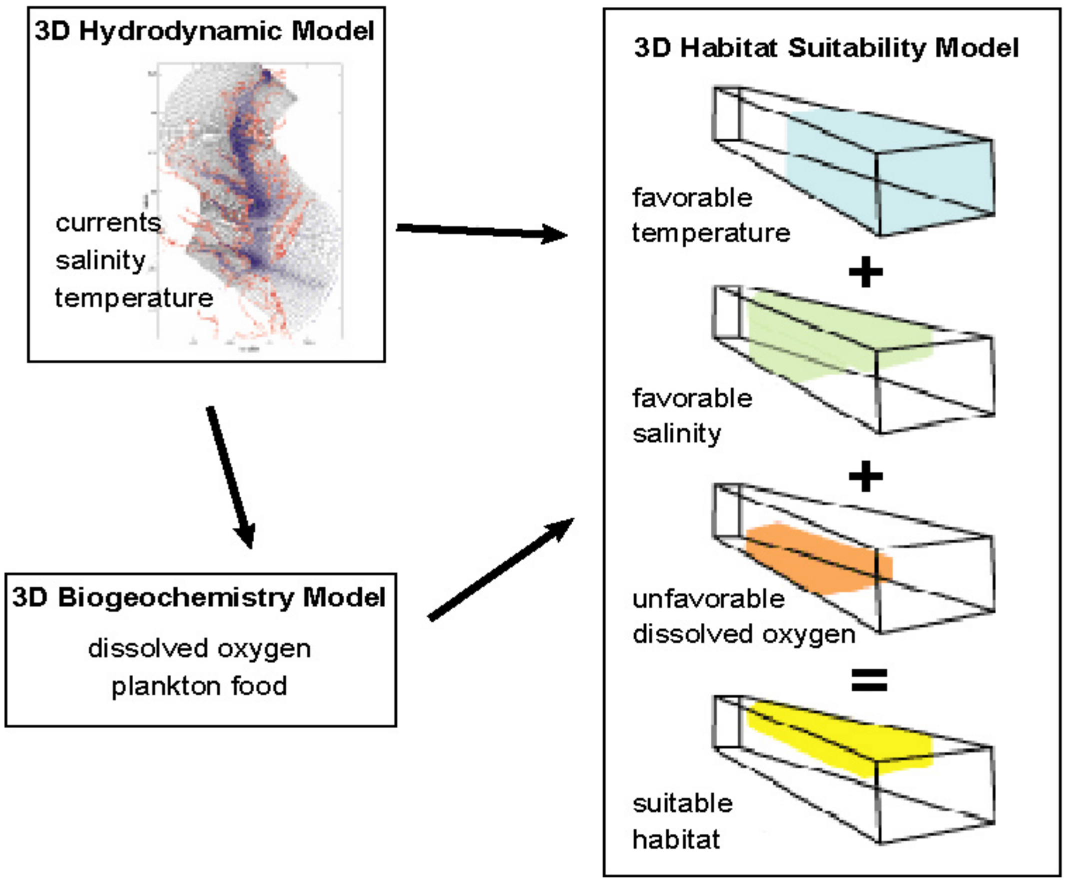


Fig. 12. Conceptualization of Habitat Suitability Model.

(North, Secor)

Sequencing CHRP Research Effort

Milestone Chart: NOAA CHRP 07, Kemp et al.

Task	Responsible PIs	Year 1				Year 2				Year 3				Year 4				Year 5			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Retrospective analysis																					
Data (WQ, climate, loads)	Boynton, Kemp	■	■	■	■																
Develop GAM & CART	Boynton, Kemp		■	■	■	■	■	■					■	■	■	■	■				
Develop ARMA models	Kemp, DiToro		■	■	■	■	■	■					■	■	■	■	■				
Test statistical models	Kemp, Boynton							■	■	■	■	■	■			■	■	■	■		
Diagnostic assessment																					
Climate response	Li, Kemp,	■	■	■	■	■	■	■	■	■											
Nutrient response	Kemp, Li,					■	■	■	■	■	■	■	■								
Non-linear hypoxia	Kemp, DiToro	■	■	■	■	■	■	■	■	■	■	■	■								
Hypoxia, upwelling & diel	DiToro, Li, Kemp					■	■	■	■	■	■	■	■	■	■						
Forecasting studies																					
Stat model forecasts	Boynton, Kemp	■	■			■	■			■	■			■	■			■	■		
ROMS devel (CB, DIB)	Li, DiToro	■	■	■	■	■	■	■	■												
RCA calibrate (CB, DIB)	Fennel,		■		■	■	■	■	■	■	■	■	■	■	■	■	■		■		
ROMS-RCA coupling	Li, Fennel, DiToro					■	■	■	■	■	■	■	■	■	■	■	■				
Ensemble simulations	DiToro, Li, Fennel		■	■			■	■			■	■			■	■			■	■	
Model skill evaluation	Fennel, Li, DiToro									■	■	■	■	■	■	■	■	■	■	■	■
Nutrient-climate scenarios	Li, DiToro, Kemp									■	■	■	■	■	■	■	■	■	■	■	■
Habitat Evaluation																					
Habitat suitability model	North, Secor		■		■		■		■	■	■	■	■	■	■	■	■				
Bioenergetic model	Secor, North		■		■		■		■	■	■	■	■	■	■	■	■				
Habitat/productn scenarios	North, Secor													■	■	■	■	■	■	■	
Integration & Communication																					
Education Outreach	LM, All		■	■	■		■	■	■		■	■			■	■	■		■	■	■
Meetings of PIs, managers	All		■		■		■		■		■		■		■		■		■		■
Website forecasts, analyses	All	■		■		■		■		■		■		■		■		■		■	
Synthetic analysis & writing	All							■	■					■	■	■	■	■	■	■	■

Concluding Comments

- **We have successfully completed the first year of this study (despite severe budget cuts).**

- ***Simulation Studies* linking ROMS-RCA model are complete & data assimilation for parameter optimization & model error are underway.**

- ***Diagnostic Modeling* studies have revealed mechanisms by which wind regulates vertical mixing and channel-flank coupling.**

- ***Retrospective Analysis* has led to improved understanding of the controls on “Regime Shift” in hypoxia per nutrient loading—key biogeochemical processes have been identified.**

- ***Habitat Evaluation* has effectively generated oyster habitat models using particle tracking model as basis.**

- ***Science Education Outreach* has engaged HS teachers into research program and provided online lesson plans and activities.**

Epilogue: Biogeochemical Mechanism for Hypoxia-Nitrogen Regime Shift

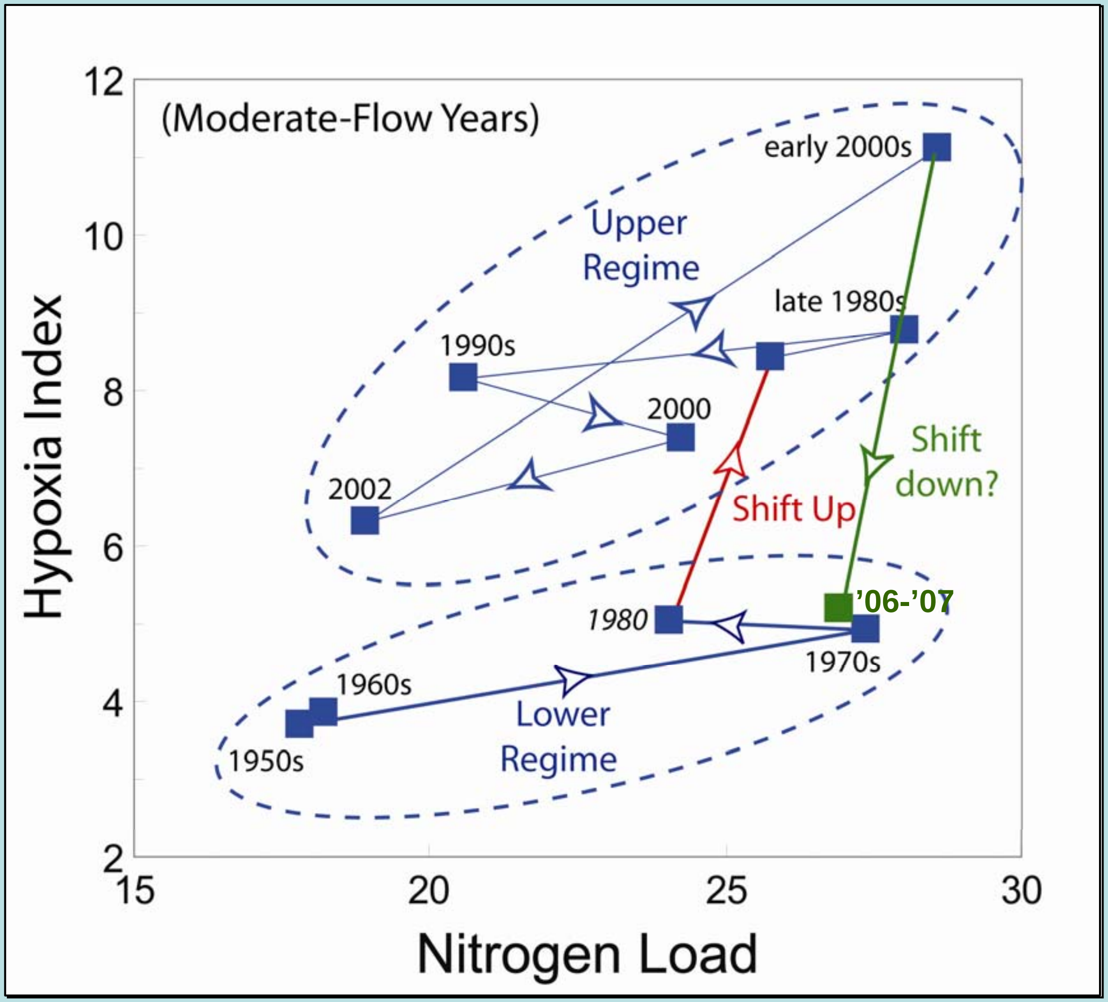
- **Hypothesized that extended low-O_2 conditions has led to higher fraction of N-loading being recycled to reinforce phytoplankton growth and eutrophication process.**

- **This because coupled nitrification-denitrification is lost, and more of NH_4 produced in bottom respiration is recycled to overlying water rather than being transformed to bio-unavailable N_2 in denitrification.**

- **In addition, hypoxia-caused loss of benthic macrofauna eliminates their bio-irrigation processes that enhance nitrification-denitrification.**

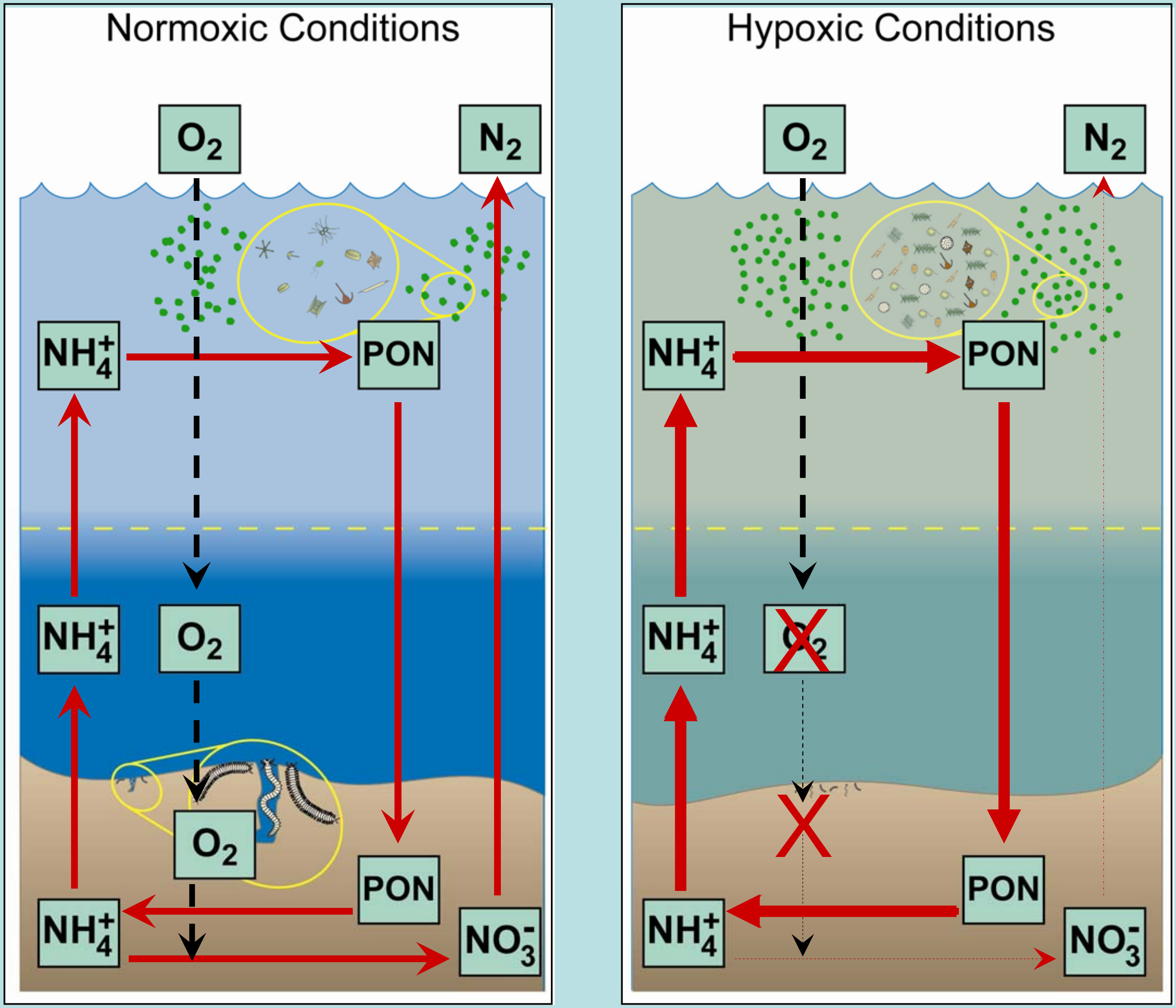
- **Analysis of historical data bears this out, and these mechanisms are being added to forecasting models to improve model skill and application for management-relevant scenario simulations.**

"Regime Shift" for Hypoxia per N-Load



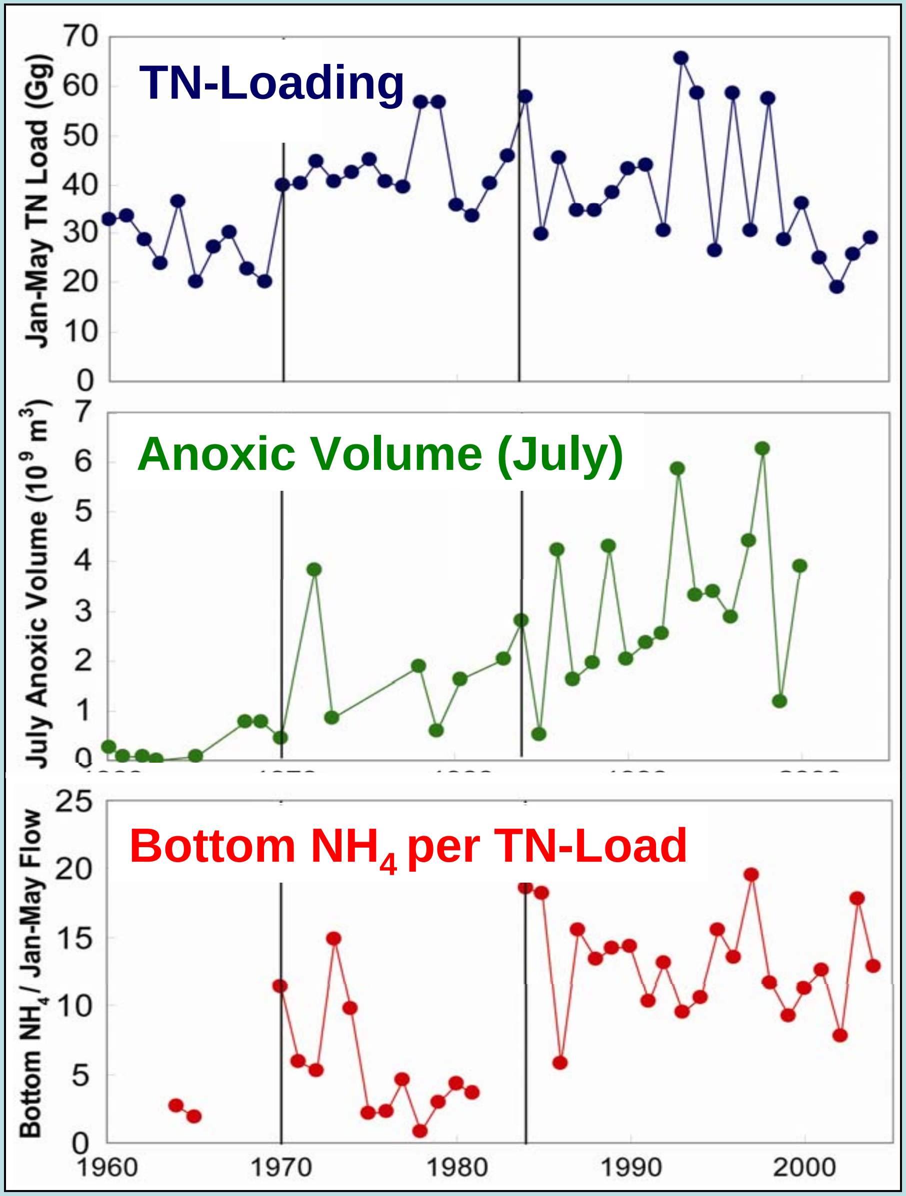
- **Hypoxia volume generally related to Nitrogen loading**
- **In early 1980s, relation between hypoxia & N-load jumped to upper regime, with 2-3x more hypoxia per N-load**
- **Many contemporaneous changes in ecosystem; are there parallel biogeochem-ical feedbacks that would help simulate pattern?**

Hypothesis for Hypoxia-Enhanced N-Recycling



(J. Testa & M. Kemp 2009)

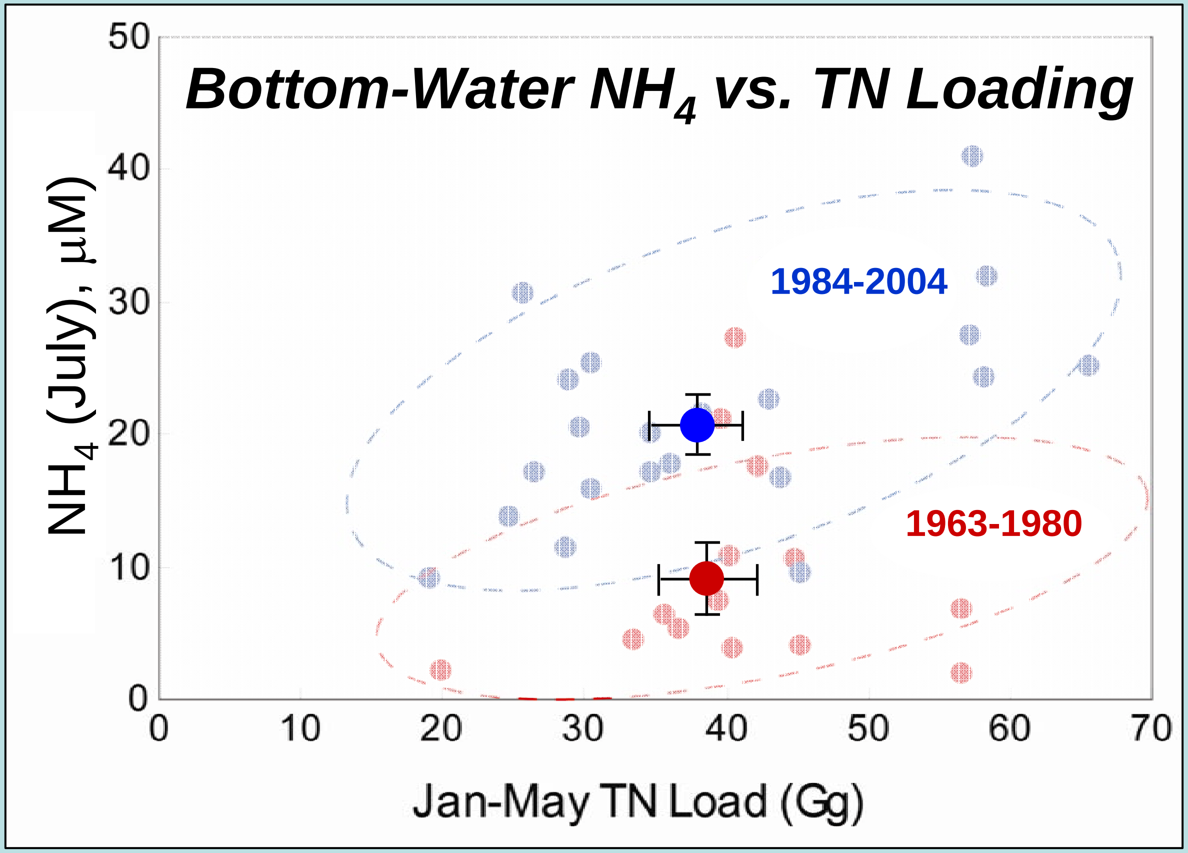
Shift in Bottom Water NH_4 Pool Tracks Hypoxia per Nutrient Loading



- **TN-loading increases until mid-1980s, then fluctuates & declines**
- **Anoxia volume fluctuates, but increases steadily into 2000s.**

- **Bottom-water NH_4 pool per N-load fluctuations & jumps up in 1980s**

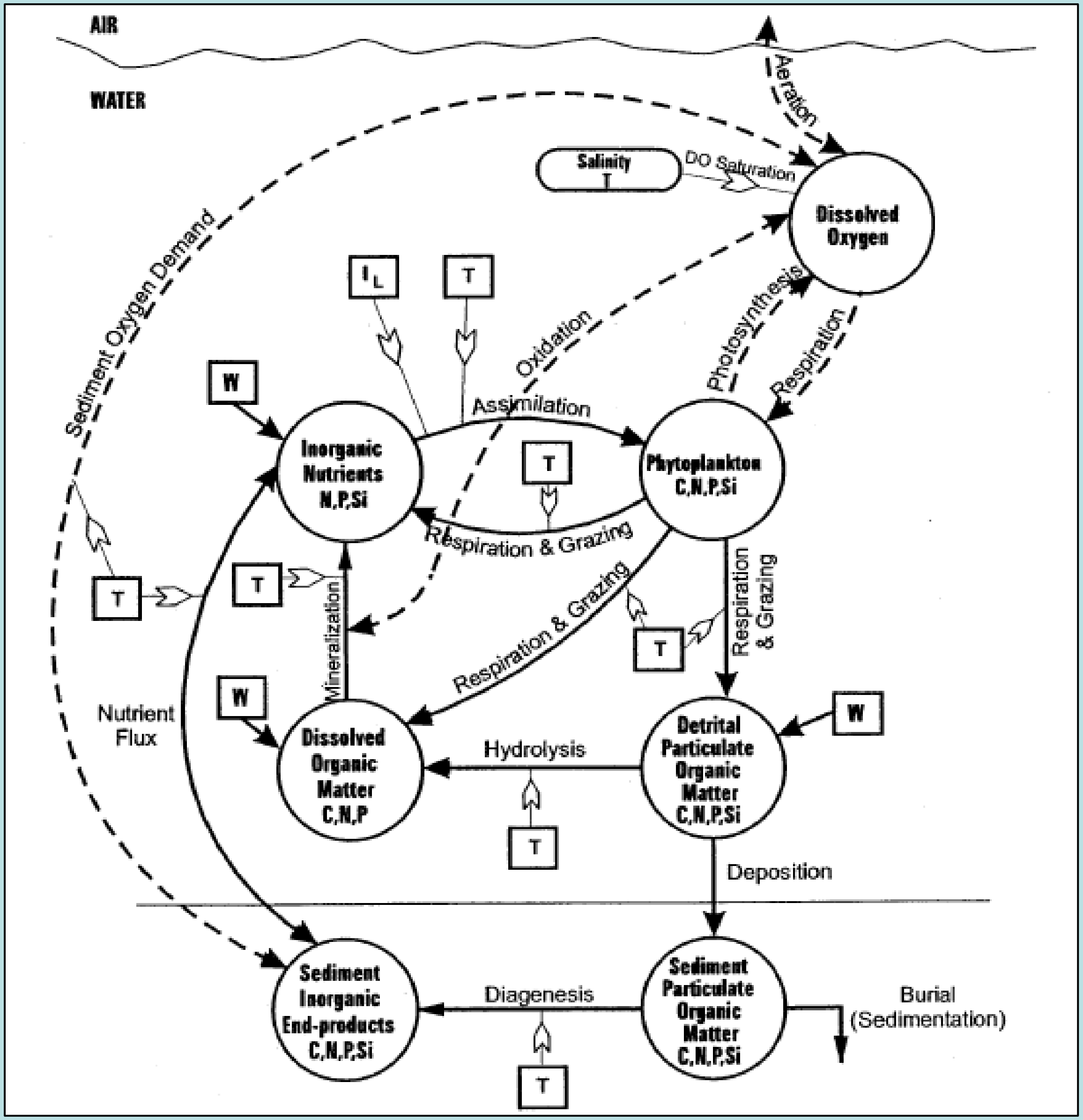
Significant Shift in Bottom Water NH_4 Pools Since Early 1980s



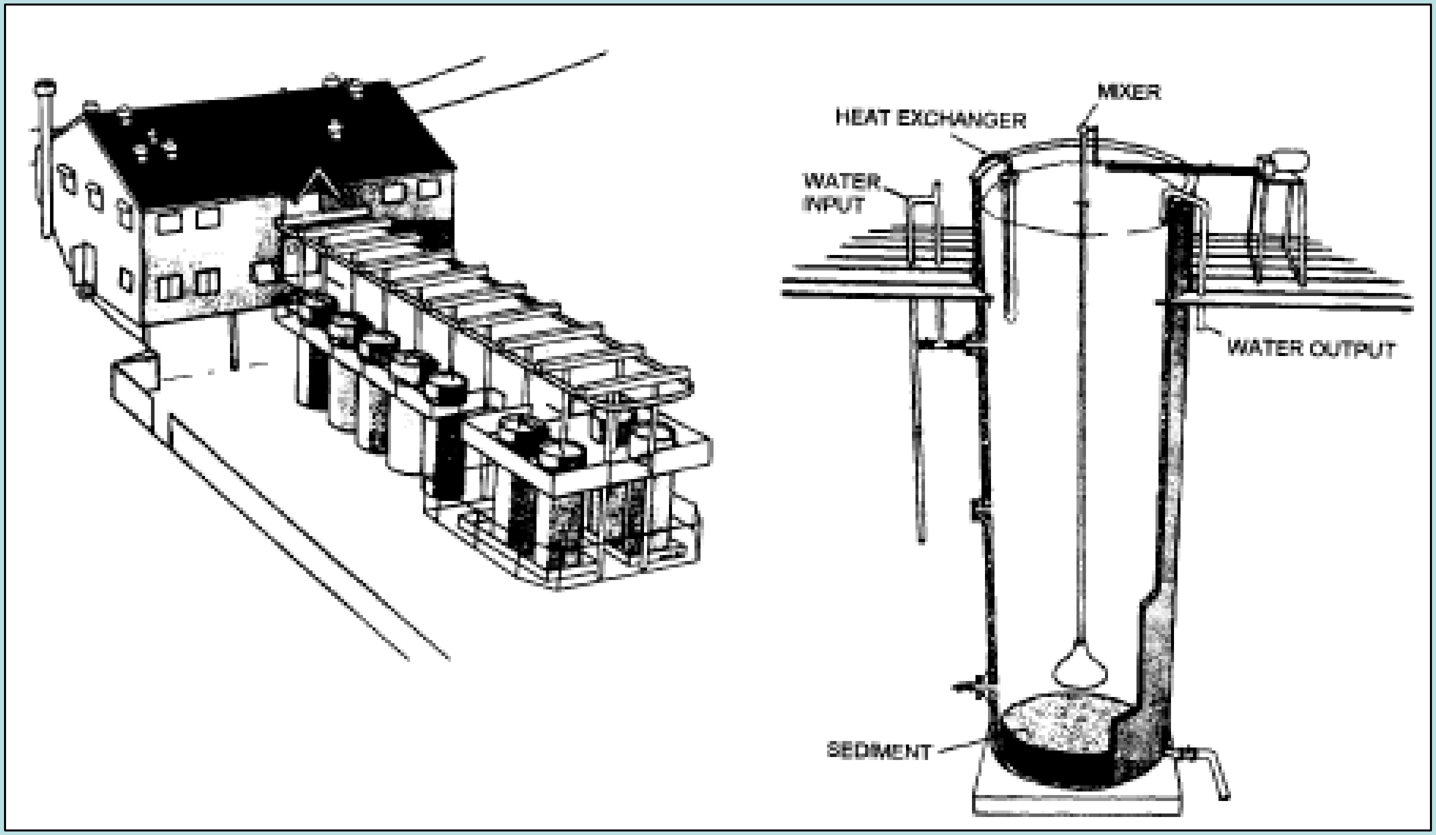
- **Bottom-water NH_4 pools generally increase with TN loading.**
- **In early 1980s the size of the bottom NH_4 pools increased (>2x) abruptly**
- **Biogeochemical change (hypoxia, macrofauna?)**

Other Slides that “Missed the Cut”

Simplified Schematic of Ecological Model (RCA)

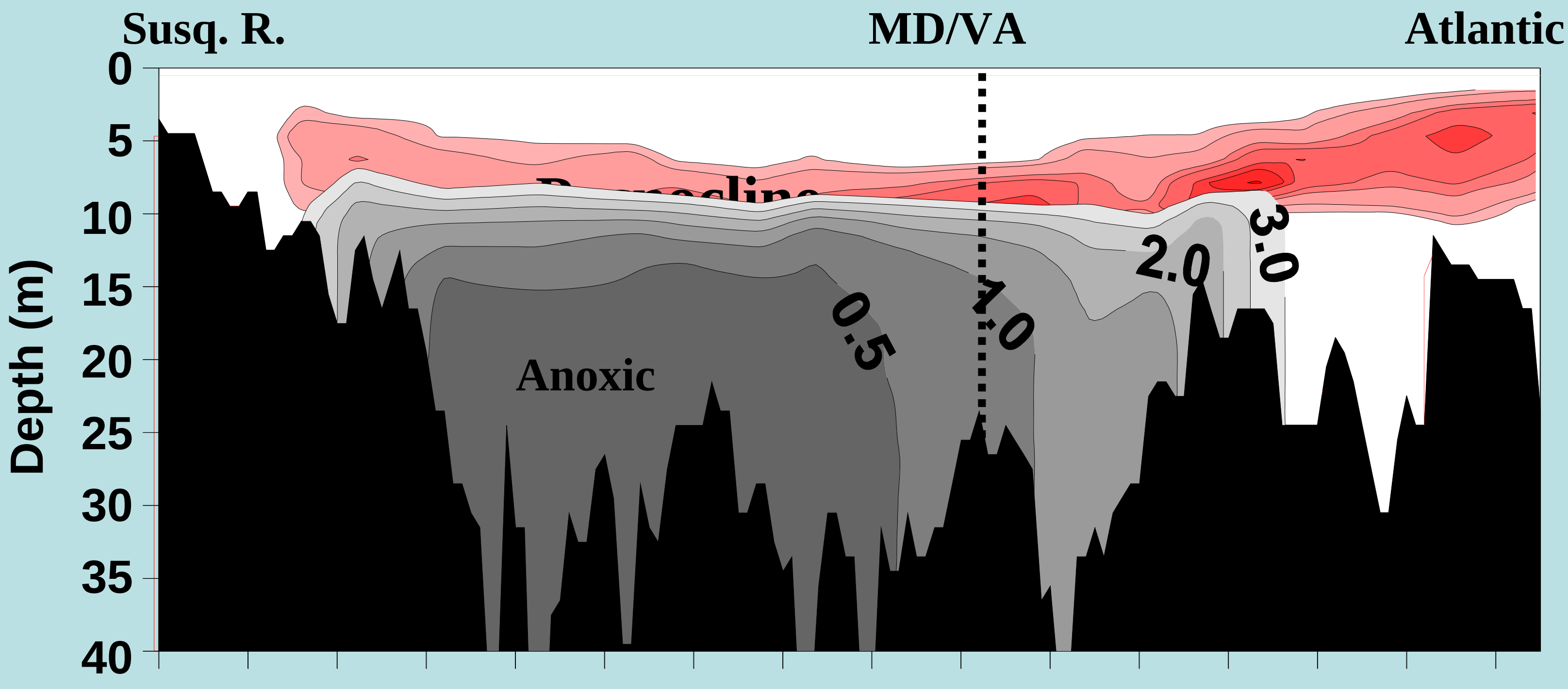


Calibrating RCA with MERL (drawing of facility)



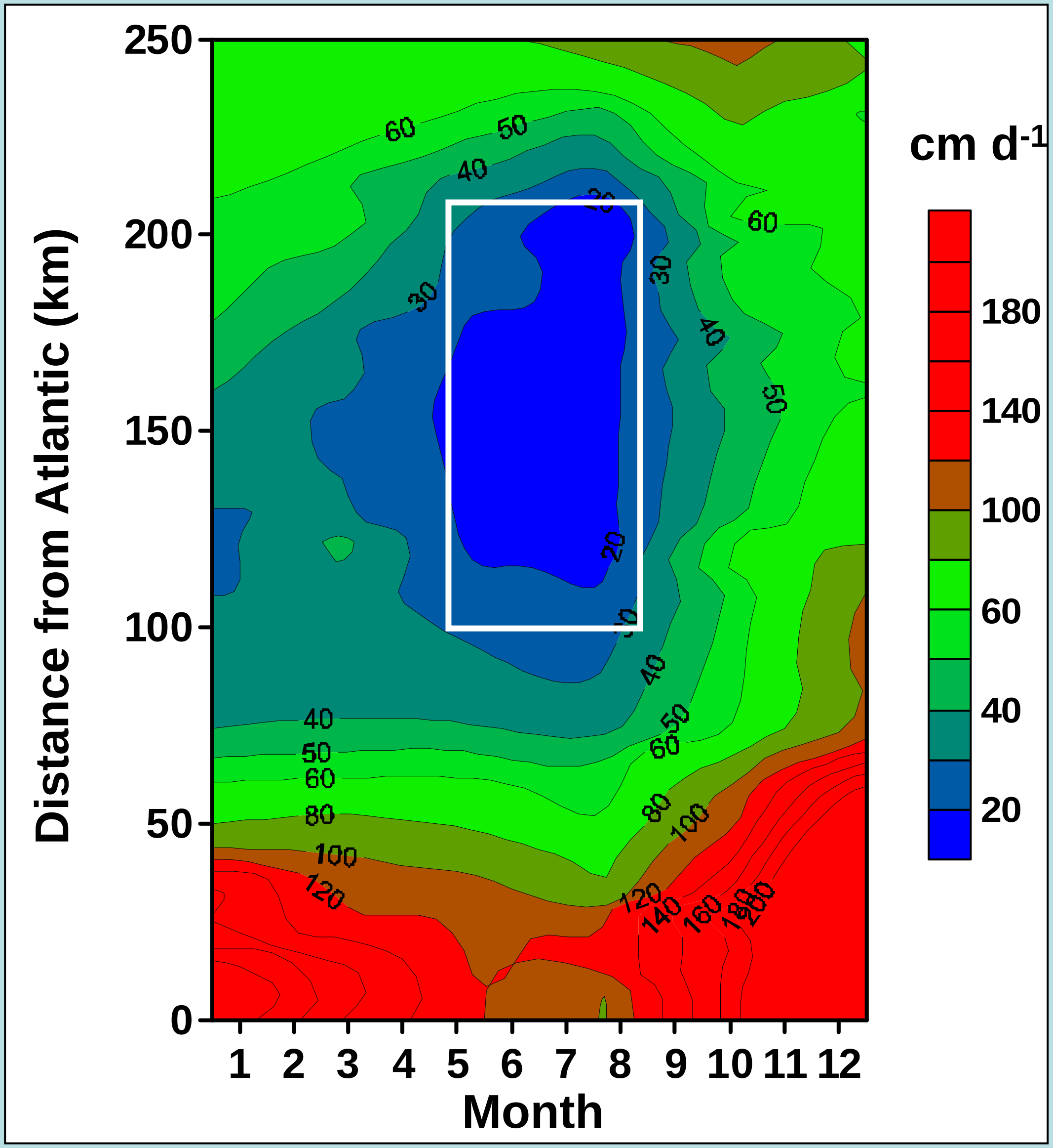
MERL Experimental Ecosystems, URI (Nixon, Oviatt et al.)

Stratification Control of Hypoxic Region in Chesapeake Bay



DO declines along landward advecting flow …

Vertical Exchange between Upper & Lower Layers of Chesapeake Bay



- **Vertical exchange is minimal in mid-Bay from May-August**
- **Corresponds to location and duration of hypoxia (white box).**
- **How does it vary inter-annually?**

(Hagy 2002)

Sources of Oxygen Replenishment in Hypoxic Bottom-Layer of Mid Chesapeake Bay