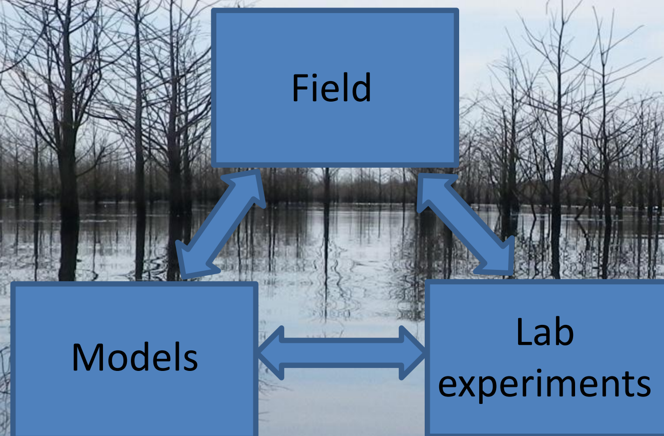
Simulating the Influence of Saltwater Intrusion on Coupled Element Cycles in Coastal Plain Wetlands



Ashley M. Helton[1], Geoffrey C. Poole[2], Emily S. Bernhardt[1], Robert A. Payn[2], Clemente Izurieta[3], and Amy J. Burgin[4]

[1]Biology Department, Duke University, Durham NC, USA
[2]Department of Land Resources and Environmental Sciences, Montana State University, Bozeman, MT, USA
[3]Computer Science Department, Montana State University, Bozeman, MT, USA
[4]School of Natural Resources, University of Nebraska-Lincoln, Lincoln, NE, USA

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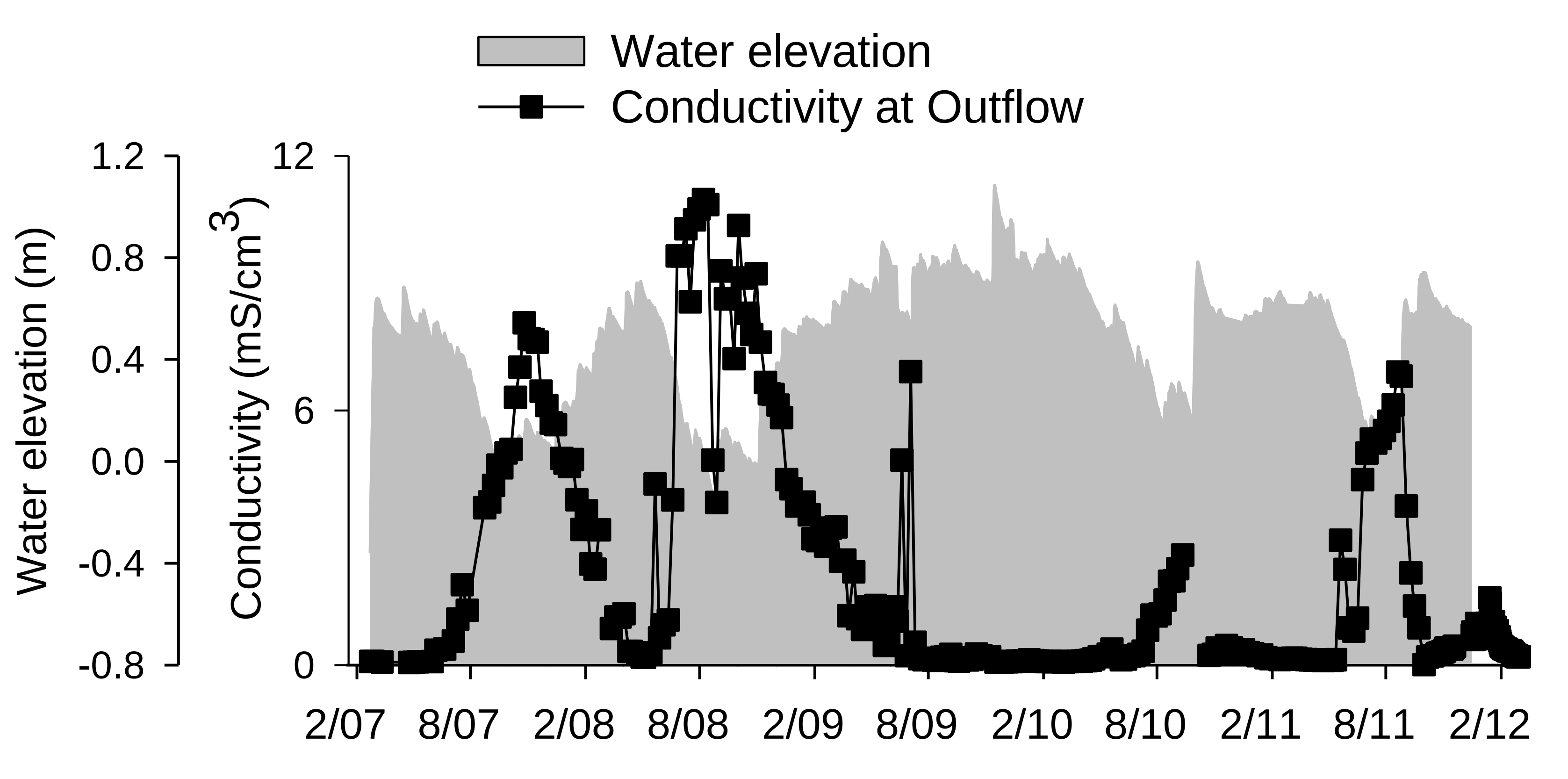
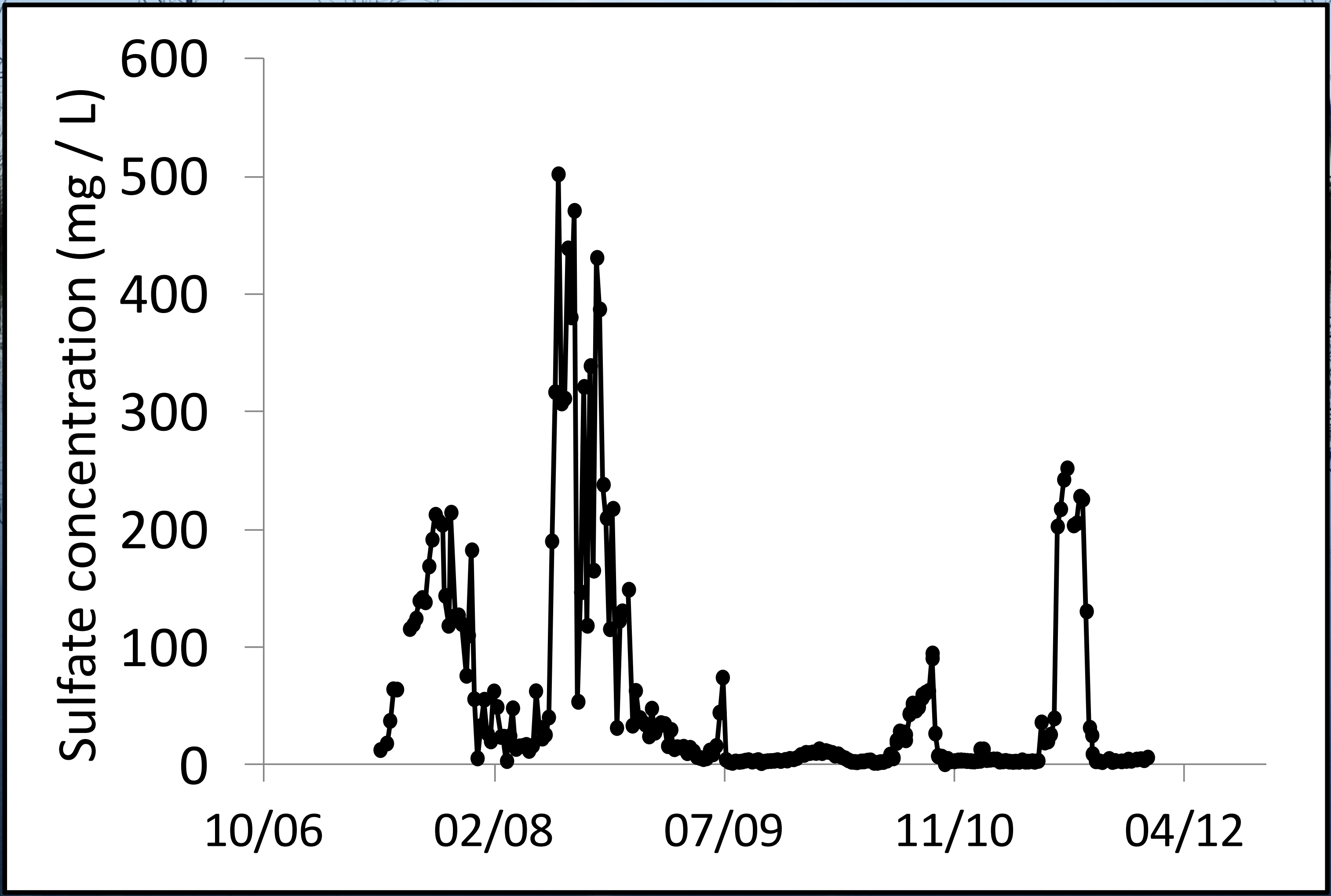
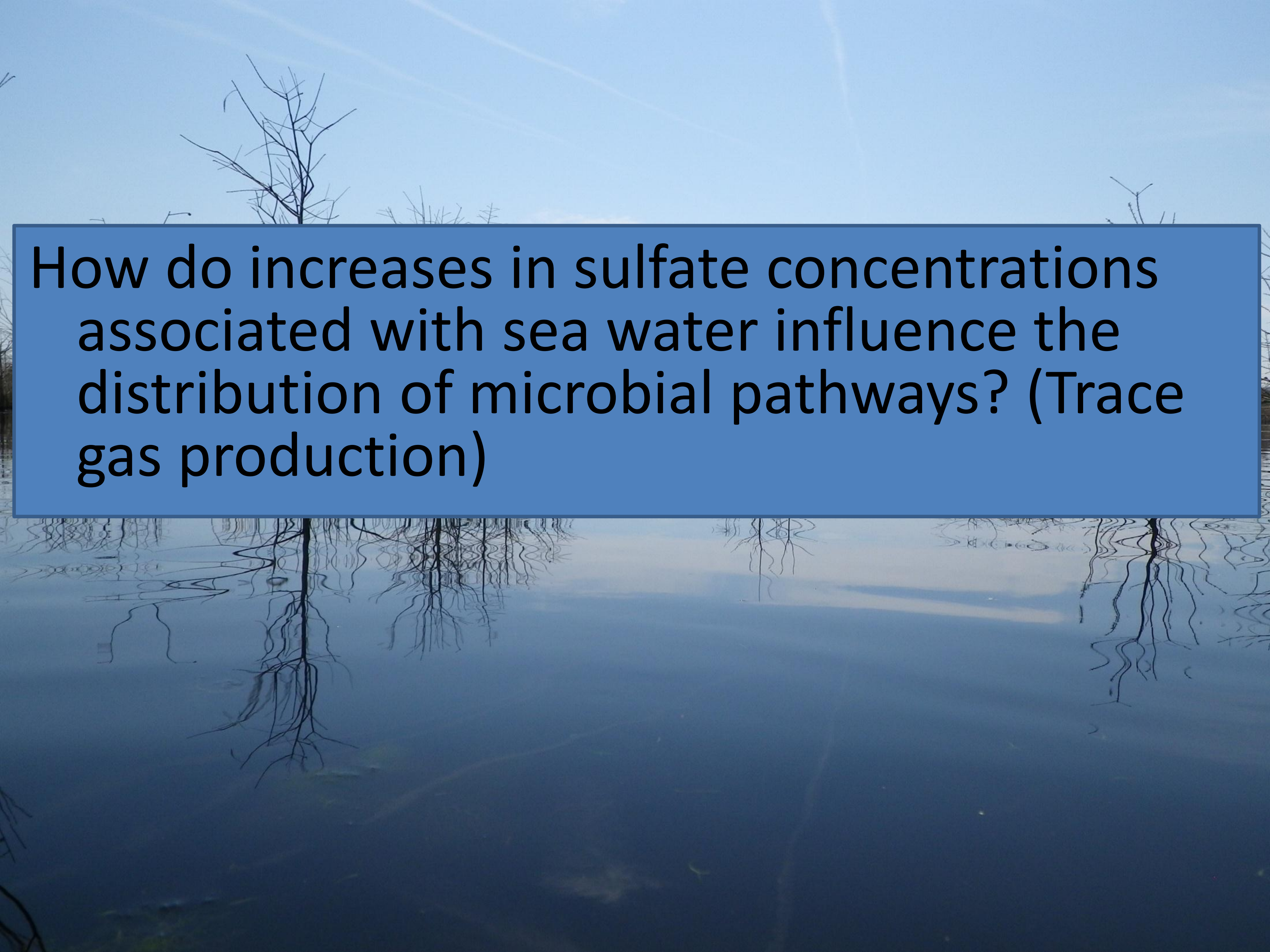
Biogeochemistry of salt water intrusion



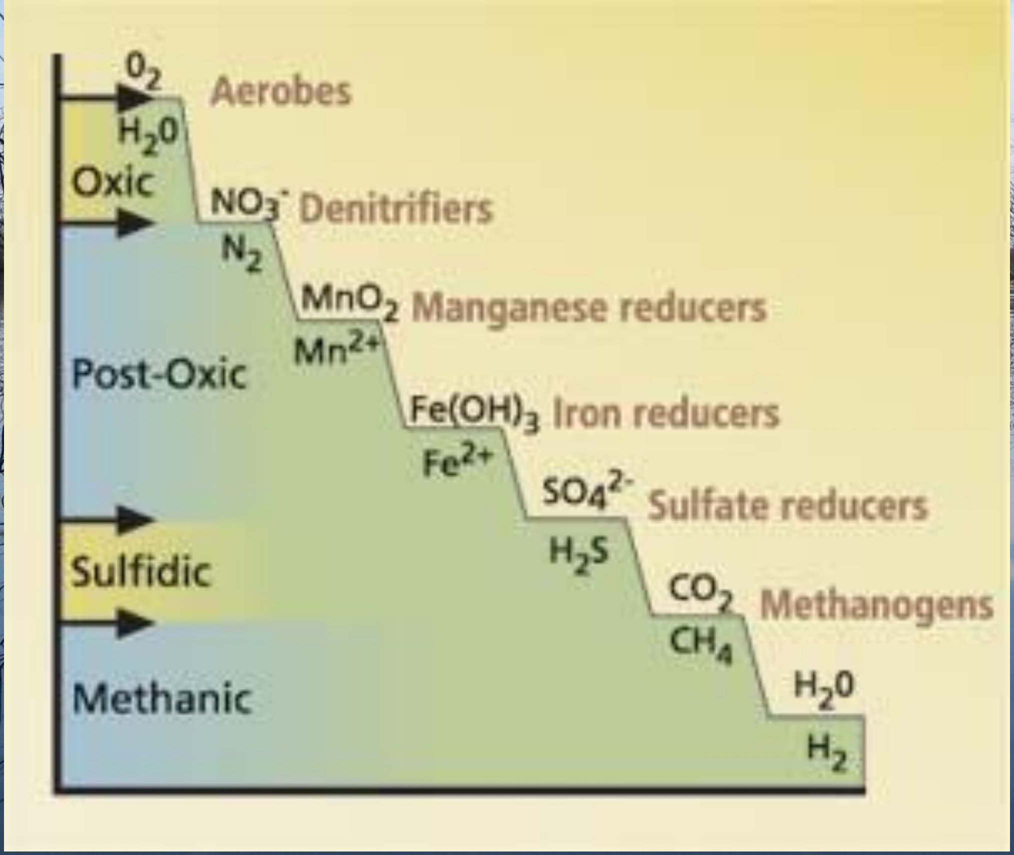
Biogeochemistry of salt water intrusion



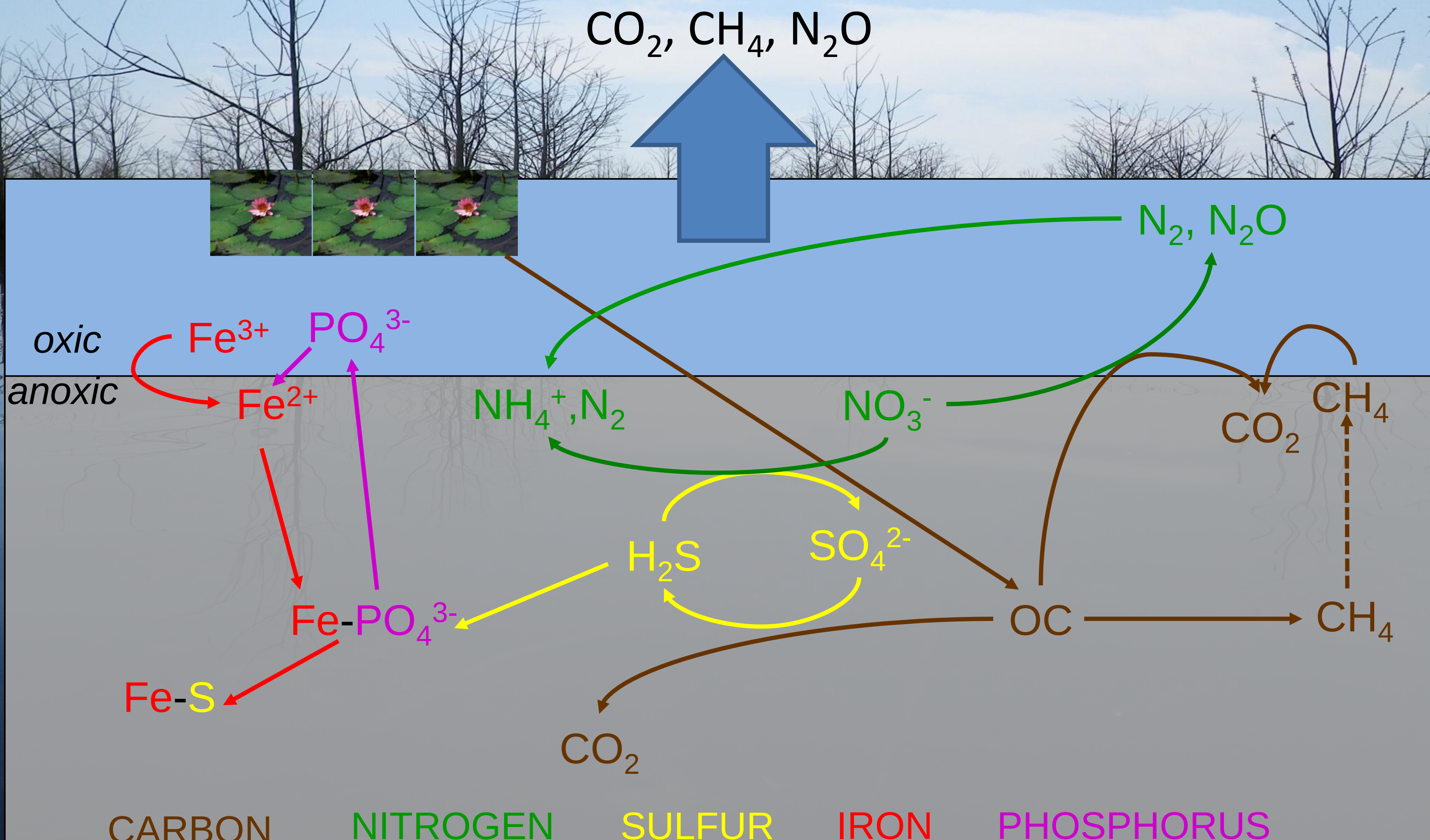


How do increases in sulfate concentrations associated with sea water influence the distribution of microbial pathways? (Trace gas production)

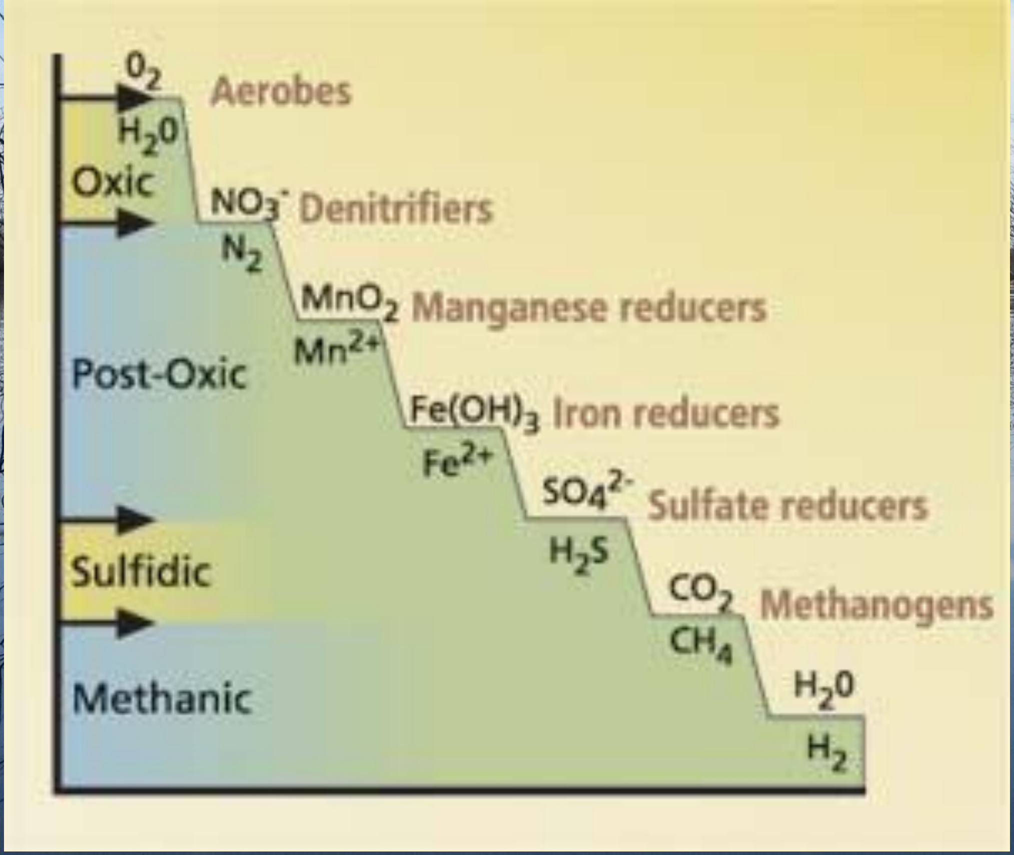
Redox Ladder as Organizing Concept



Connections in elemental cycles often lead to multi-dimensional, non-linear feedbacks both on the cycle of interest and other cycles

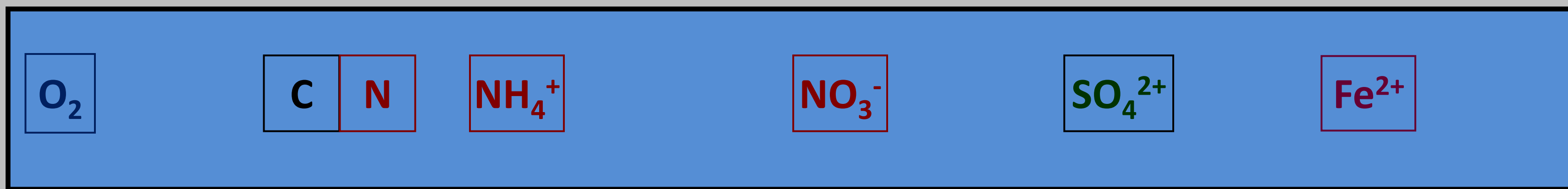


Redox Ladder as Organizing Concept



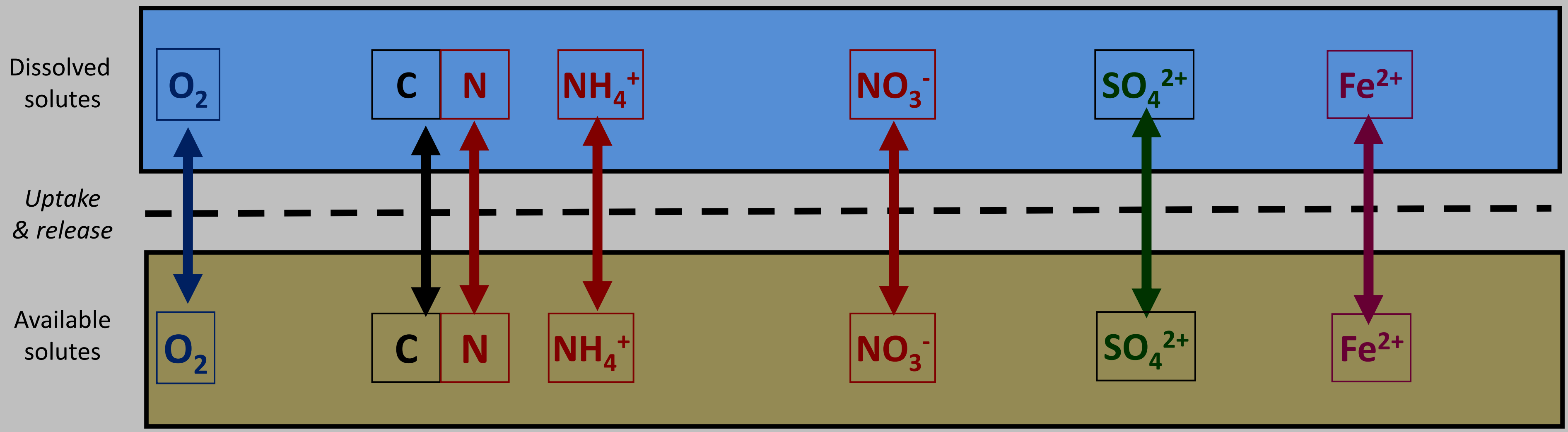
Model Structure

Dissolved solutes



Measured distribution from 5 years of surface and piezometer samples from coastal North Carolina wetland.

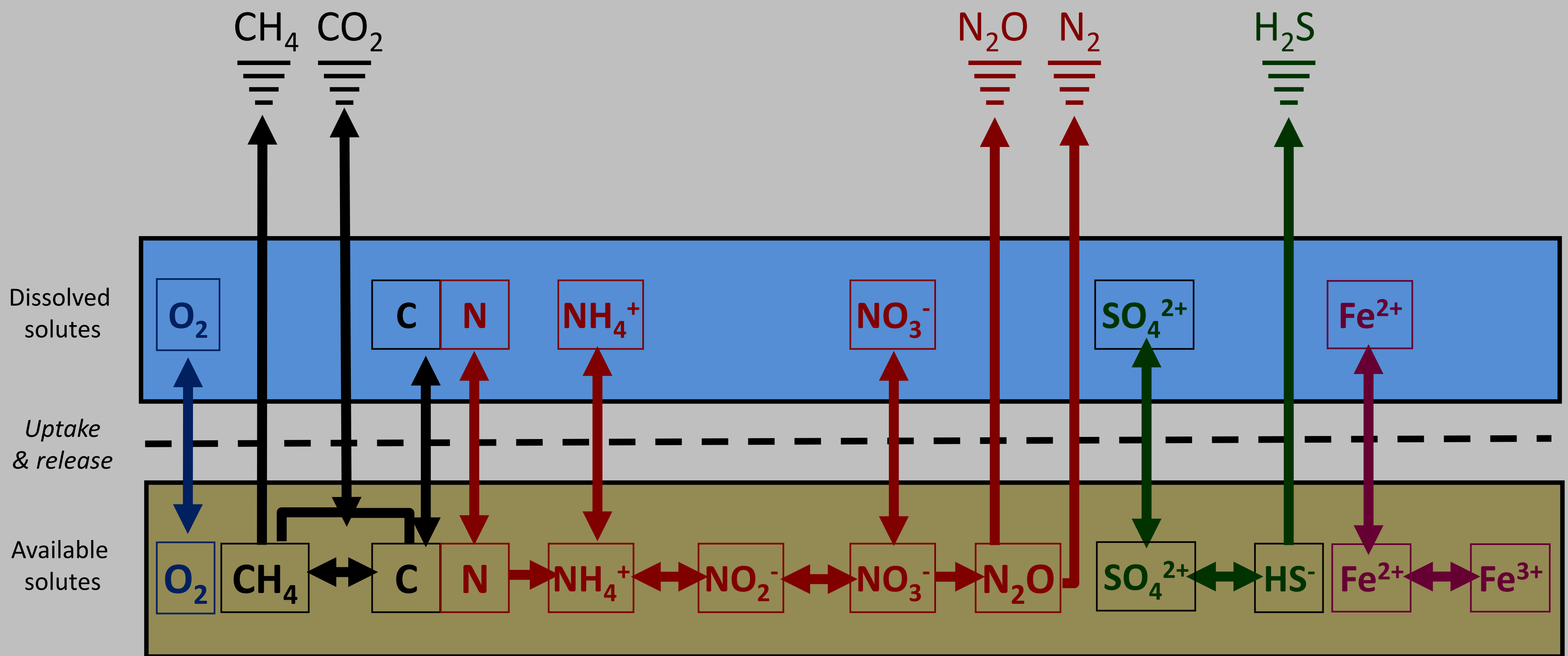
Model Structure



Michaelis-Menten Uptake: $U_c = [C] \times \mu_{max} / ([C]+K_s)$

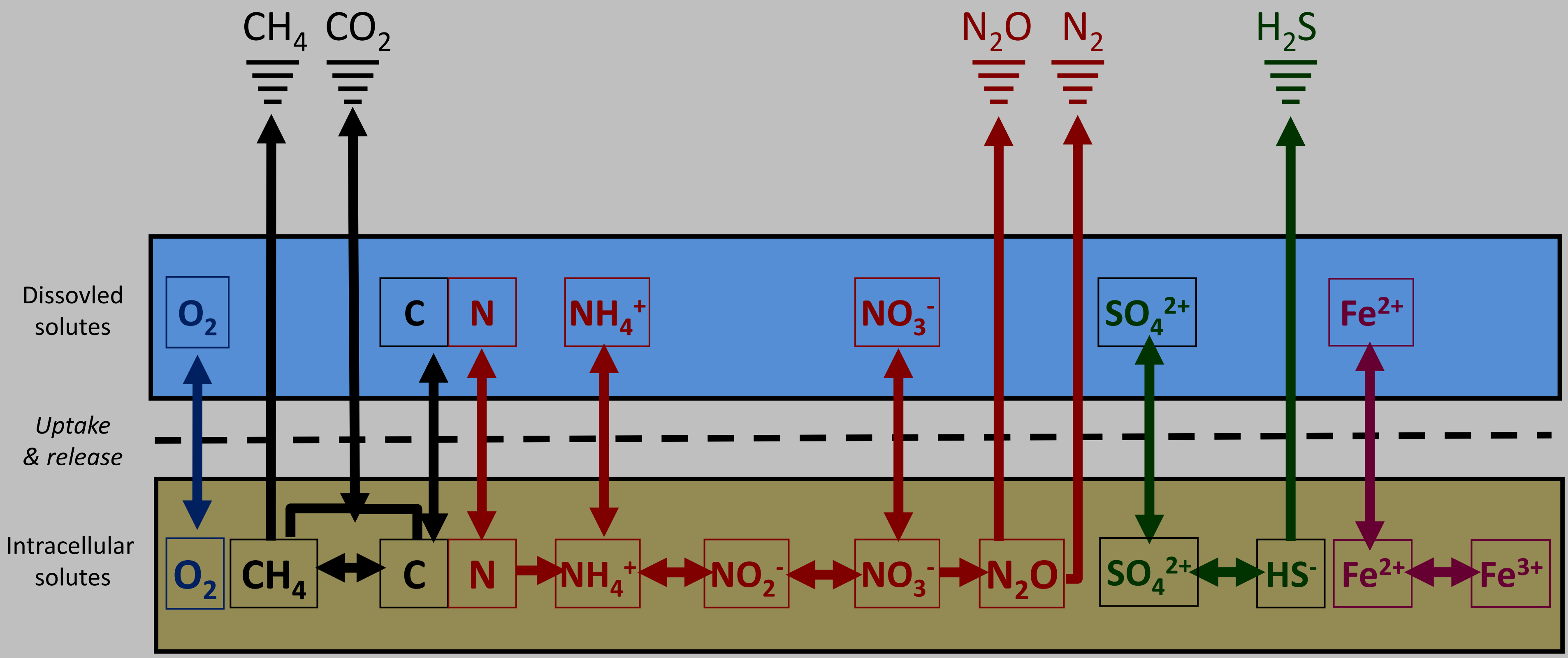
Average μ_{max} and K_s from Piel and Gaudy, 1971, Appl. Microbiol., 21 pp. 253–256

Model Structure



Microbial Process	Reaction	$\Delta G_0'$ (kJ)
Aerobic organic carbon oxidation	$CH_2O + O_2 \rightarrow CO_2 + H_2O$	-502
Denitrification:		
Nitrate reduction	$CH_2O + 2NO_3^- \rightarrow CO_2 + 2NO_2^- + H_2O$	-354
Nitrite reduction	$CH_2O + 2NO_2^- + 2H^+ \rightarrow CO_2 + N_2O + 2H_2O$	-481
Nitrous oxide reduction	$CH_2O + 2N_2O \rightarrow CO_2 + 2N_2 + H_2O$	-710
Nitrification:		
Ammonium oxidation	$O_2 + 2/3NH_4^+ \rightarrow 2/3NO_2^- + 4/3H^+ + 2/3H_2O$	-183
Nitrite oxidation	$O_2 + 2NO_2^- \rightarrow 2NO_3^-$	-148
Methanogenesis	$CH_2O \rightarrow 1/2CO_2 + 1/2CH_4$	-93
Methane oxidation	$O_2 + 1/2CH_4 \rightarrow 1/2CO_2 + H_2O$	-409
Dissimilatory nitrite reduction to ammonium	$CH_2O + 2/3NO_2^- + 4/3H^+ \rightarrow CO_2 + 2/3NH4^+ + 1/3H_2O$	-319
Anaerobic ammonium oxidation	$NH_4^+ + NO_2^- \rightarrow 2H_2O + N_2$	-358
Sulfate reduction	$CH_2O + 1/2SO_4^{-2} + 1/2H^+ \rightarrow 1/2HS^- + CO_2 + H_2O$	-104
Sulfide oxidation	$O_2 + 1/2HS^- \rightarrow 1/2SO_4^{-2} + 1/2H^+$	-398
Iron reduction	$CH_2O + 4Fe(OH)_3 + 8H^+ \rightarrow 4Fe^{+2} + CO_2 + 11H_2O$	-232
Iron oxidation	$O_2 + 4Fe^{+2} + 6H_2O \rightarrow 4FeOOH + 8H^+$	-429

Model Structure



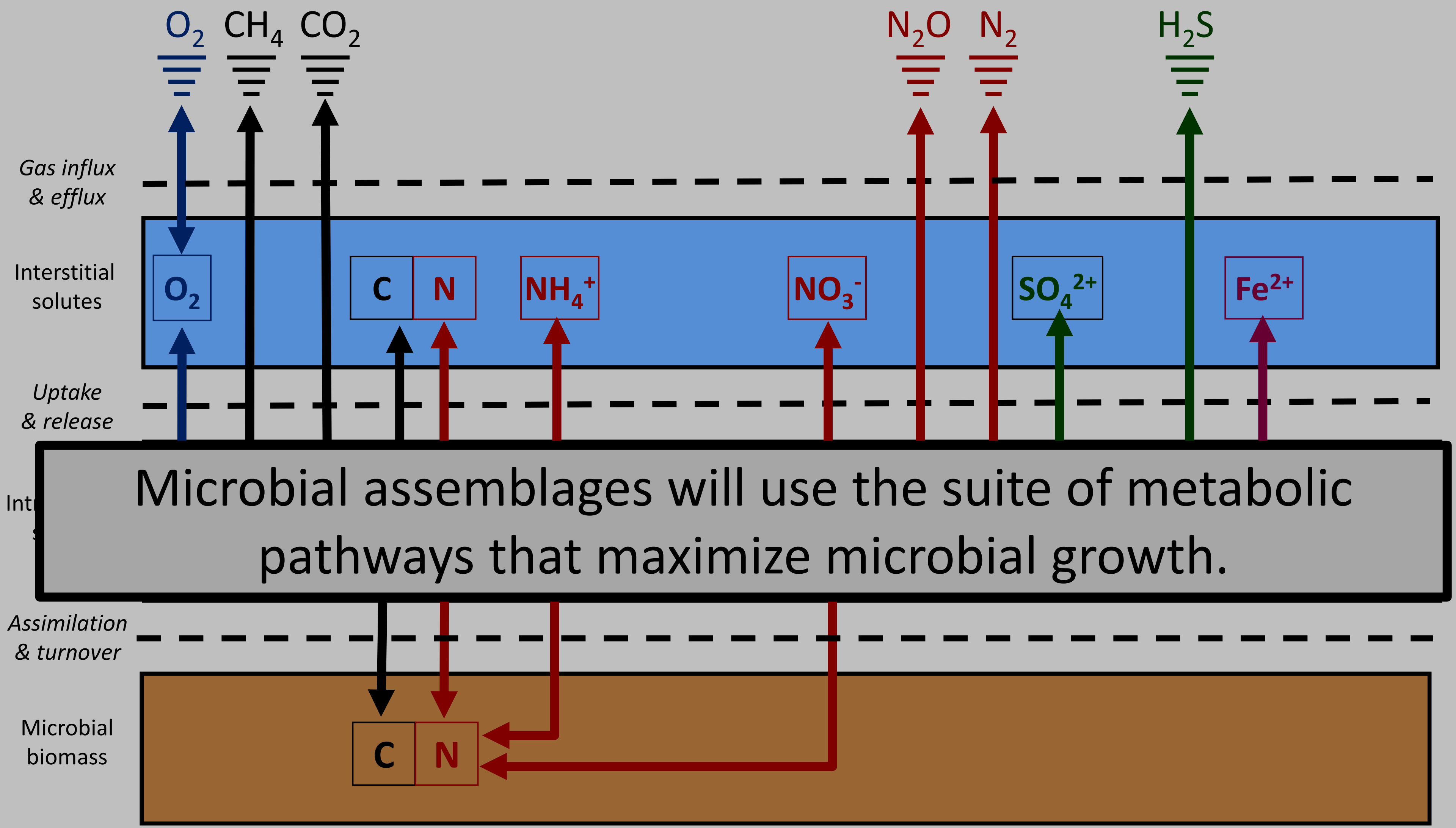
Important Assumptions:

-Energy yields static. Standard free energy at pH = 7.

-Energy requirement (biomass maintenance; heterotrophic growth; chemoautotrophic CO_2 fixation; methanotrophic growth). Tijhuis et al. 1993. Biotechnology and bioengineering 42:509-19.

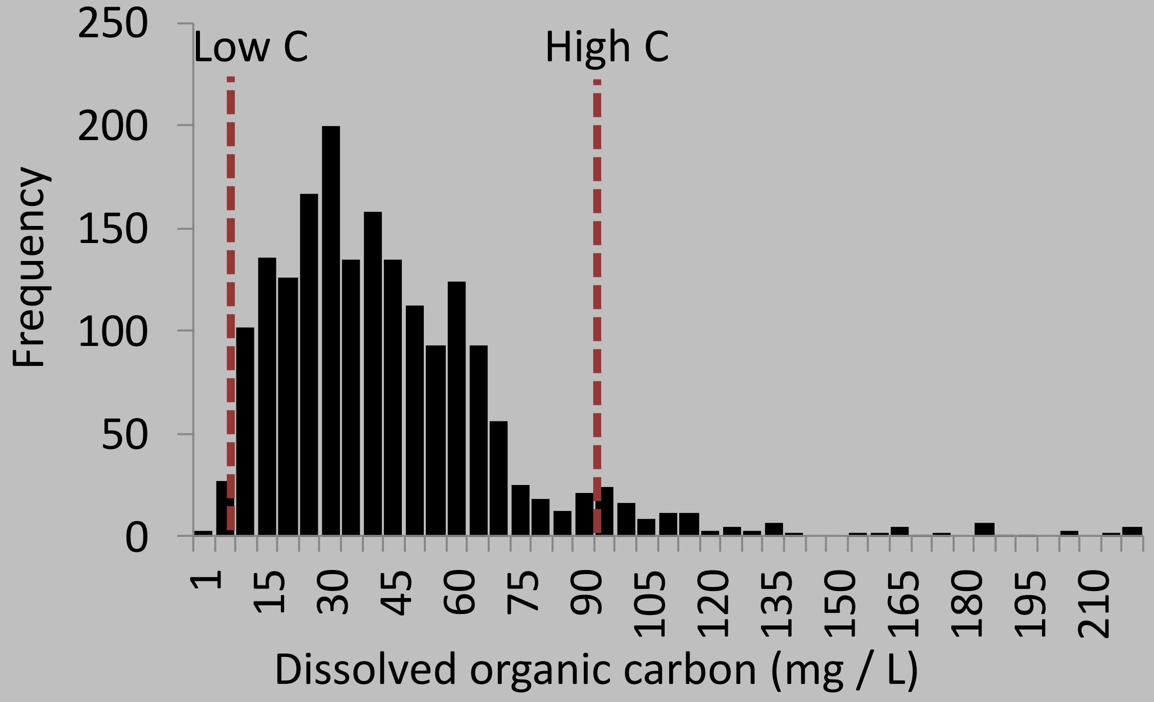
-Chemoautotrophic growth rates (CO_2 fixed per mol ED; CH_4 growth per mol ED for methanotrophs). Heijnen and Van Dijken. 1992. Biotechnology and bioengineering 39:833-58.

Model Structure

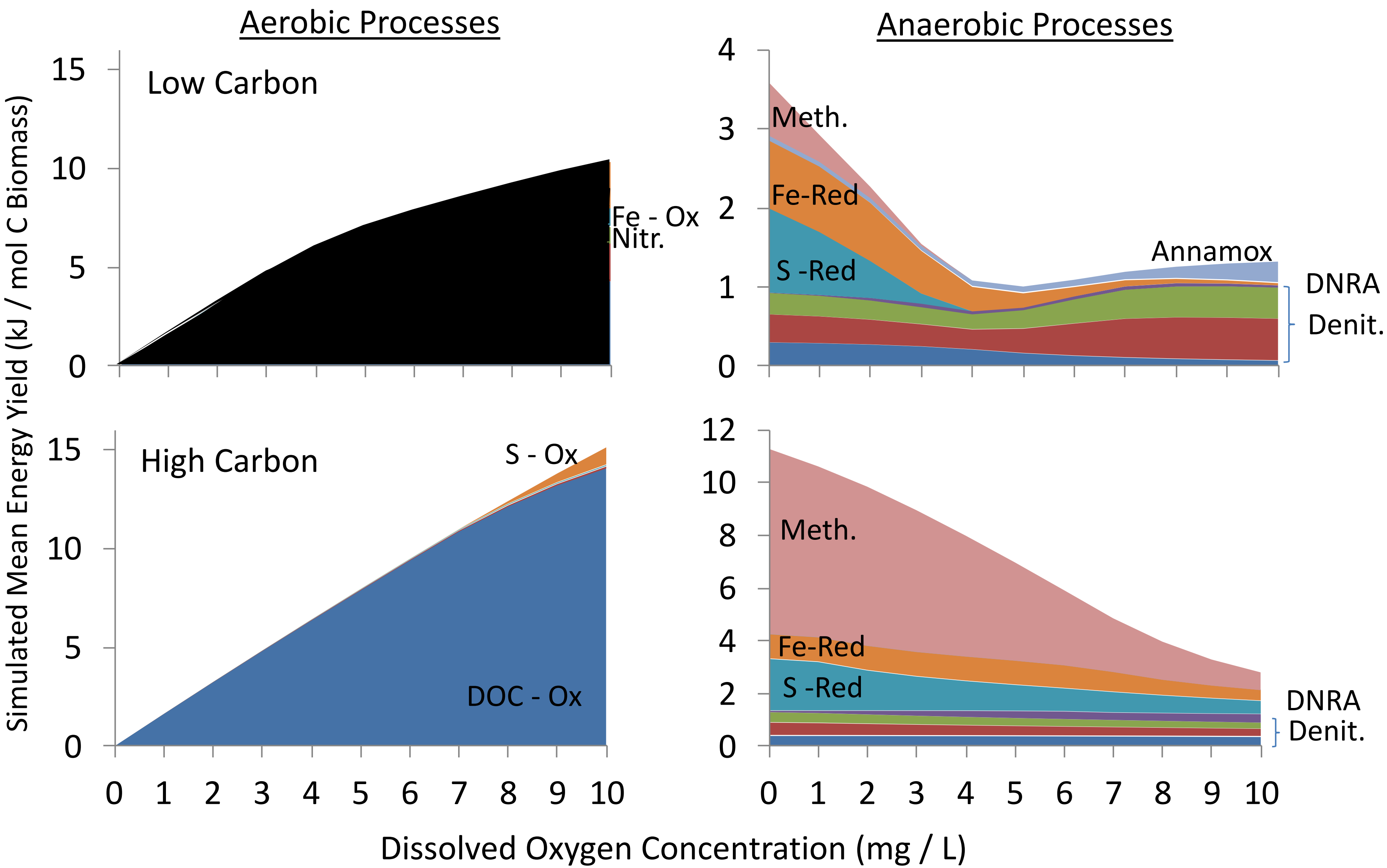


Model Simulations

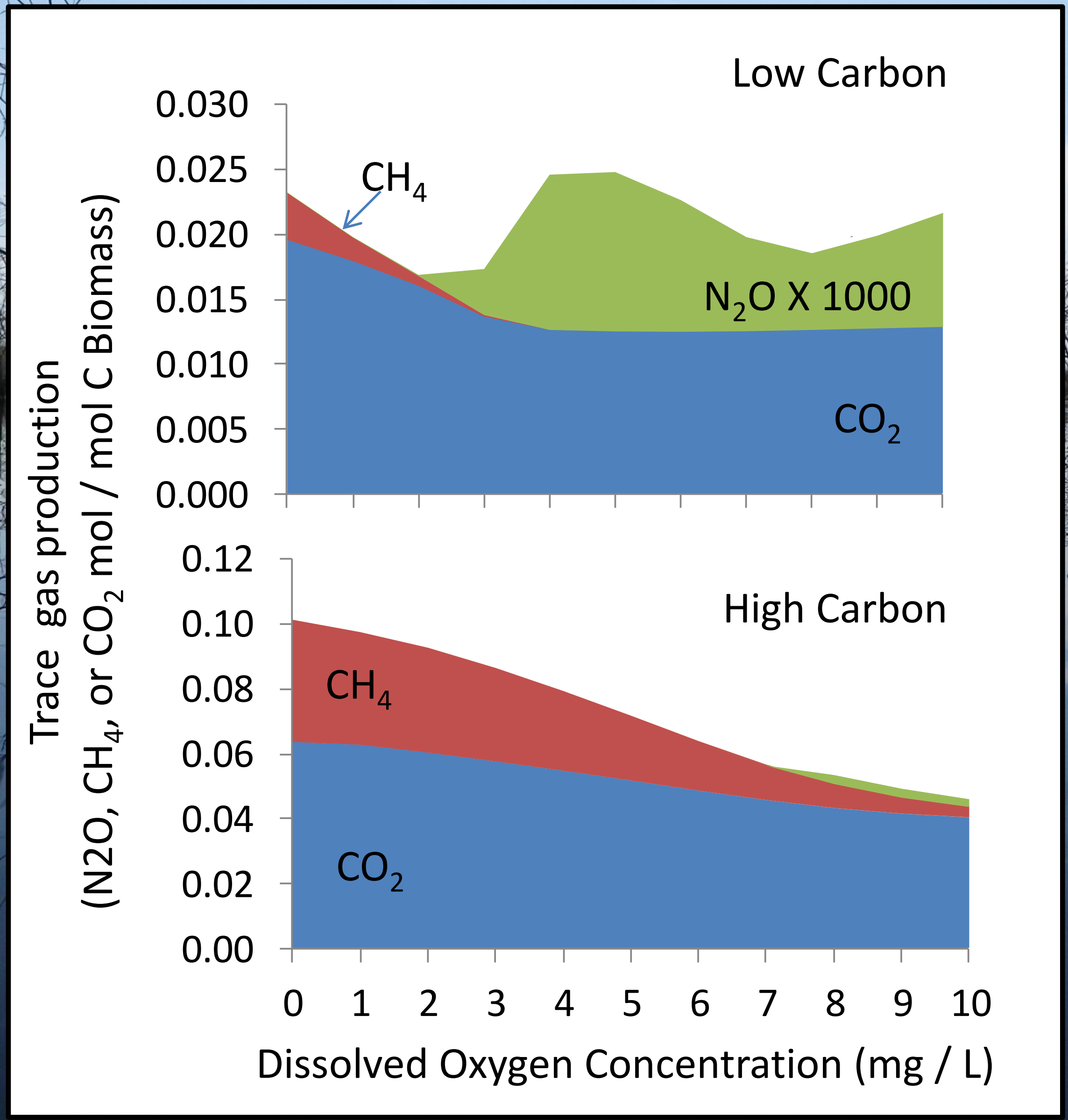
- Model implemented in linear programming (LPSolve) with Monte Carlo wrapper (Java)
- 10,000 values for each solute based on distributions from coastal NC wetland across range of DO concentration (0 – 10 mg / L)
- >300,000 single time step model runs



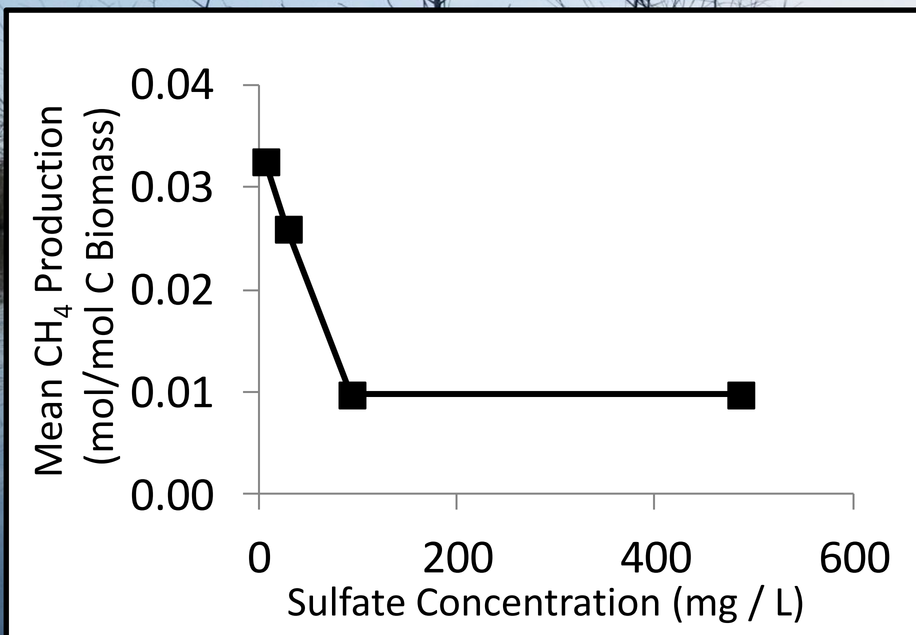
Example of model simulation results

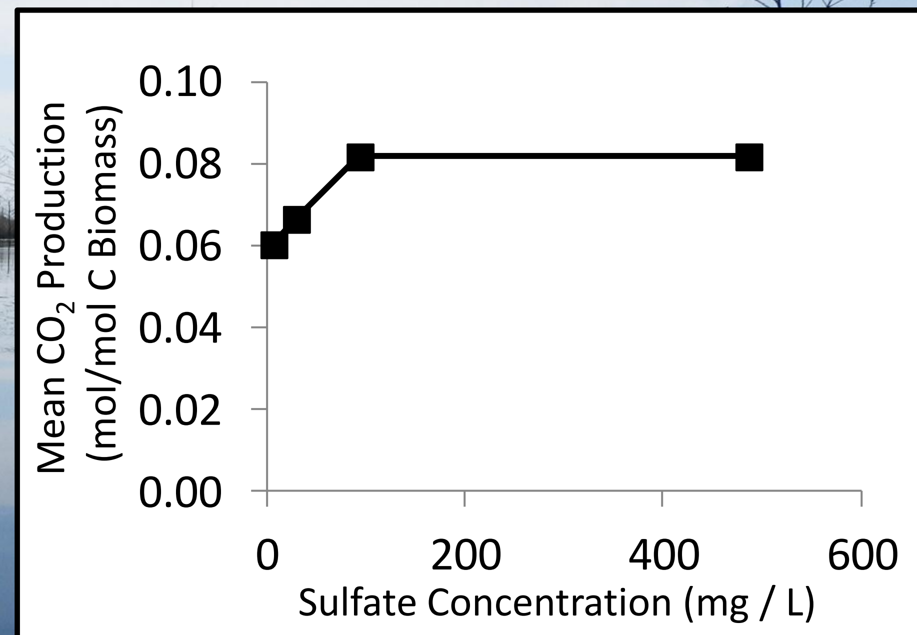


Model-derived trace gas production



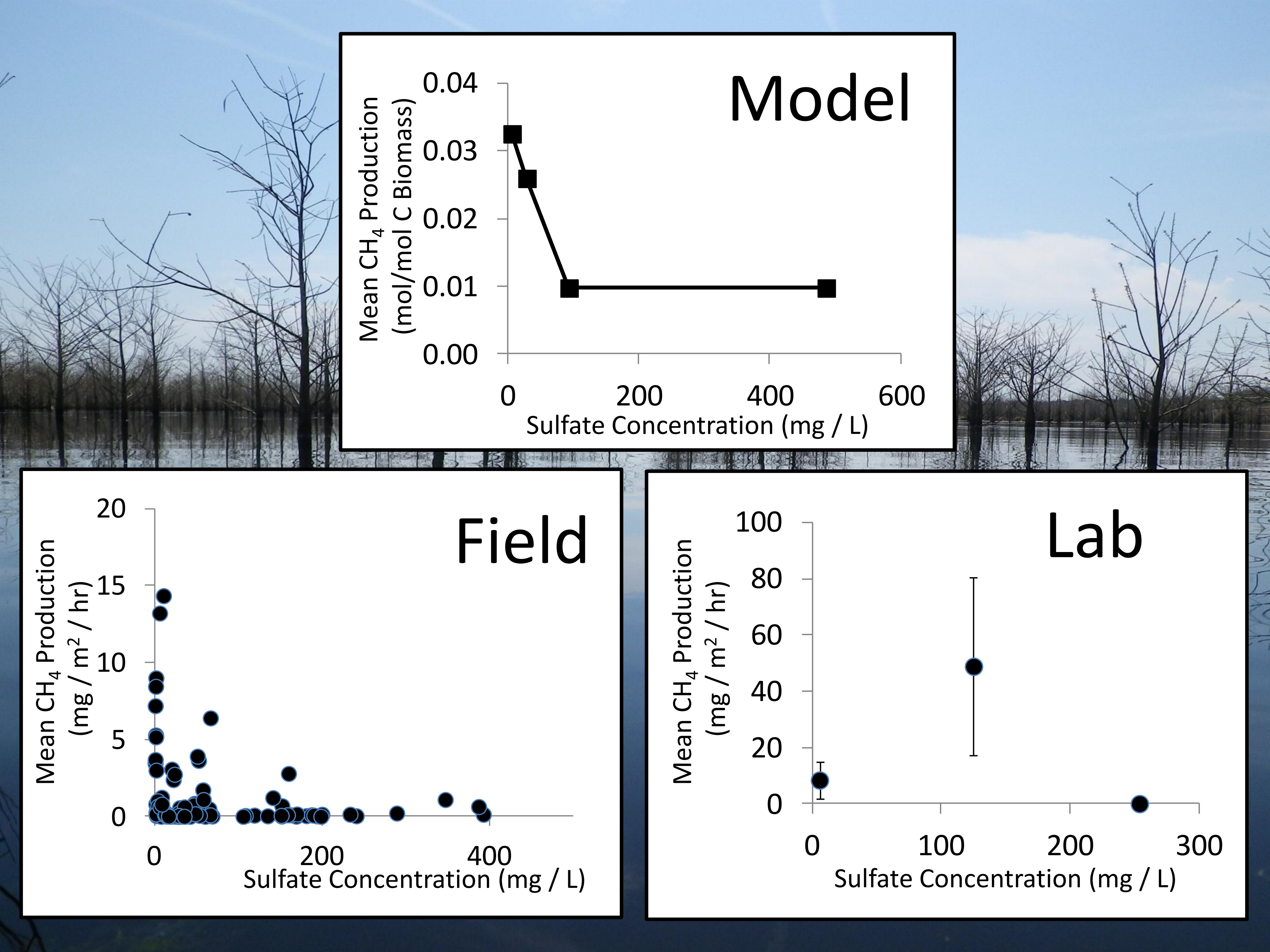
Trace gas production and sulfate loading: Model generated hypotheses



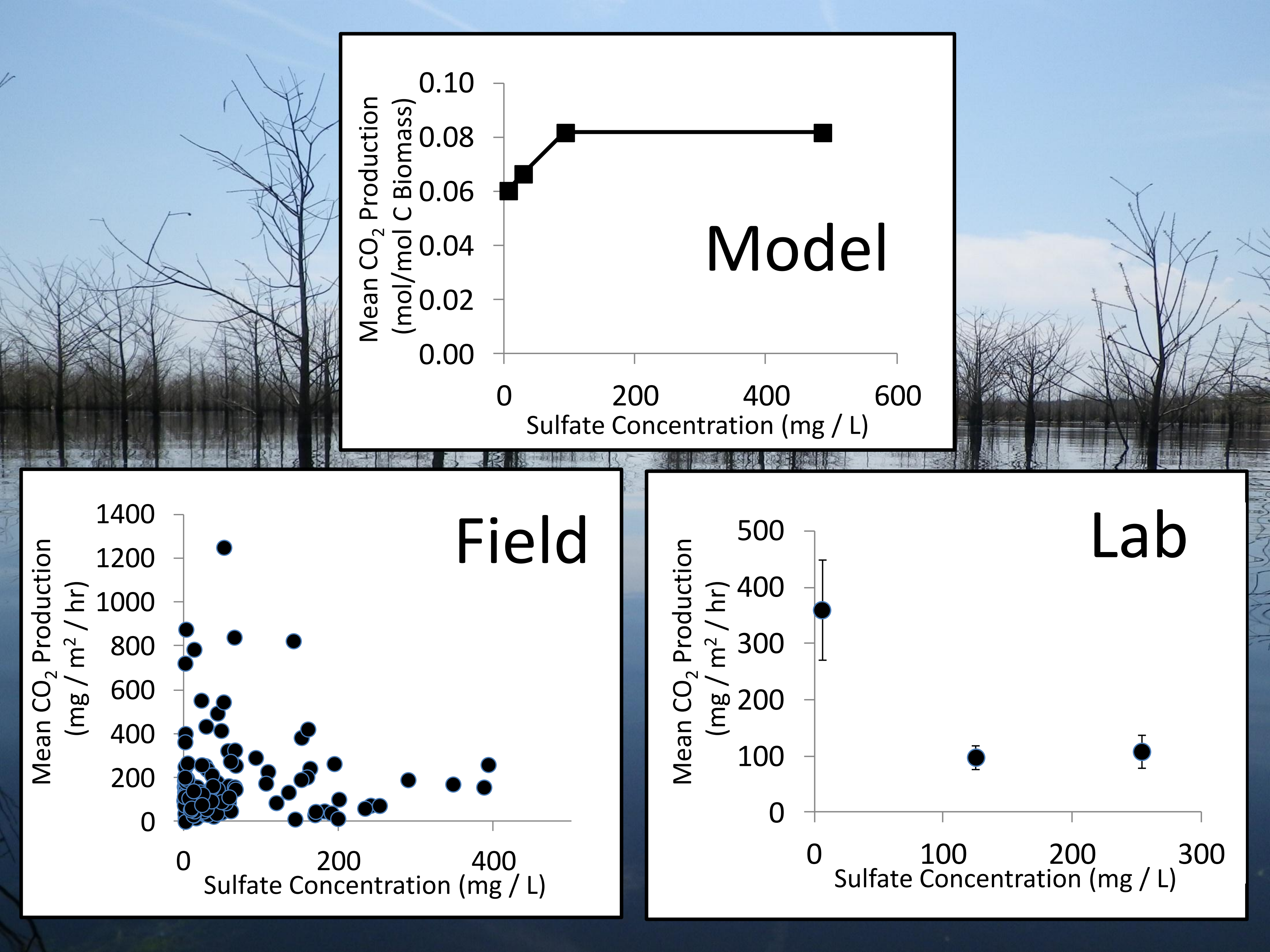


Redox Ladder Hypotheses:

1. CH_4 decreases because sulfate reducers outcompete methanogens.
2. CO_2 increases because sulfate provides new source of electron acceptors to sulfate reducers.



Model
Mean CH_4 Production (mol/mol C Biomass)
0.00
0.01
0.02
0.03
0.04
0
200
400
600
Sulfate Concentration (mg / L)
Field
Mean CH_4 Production (mg / m^2 / hr)
0
5
10
15
20
0
200
400
Sulfate Concentration (mg / L)
Lab
Mean CH_4 Production (mg / m^2 / hr)
0
20
40
60
80
100
0
100
200
300
Sulfate Concentration (mg / L)



Model
Mean CO_2 Production (mol/mol C Biomass)
0.10
0.08
0.06
0.04
0.02
0.00
0
200
400
600
Sulfate Concentration (mg / L)
Field
Mean CO_2 Production (mg / m^2 / hr)
1400
1200
1000
800
600
400
200
0
0
200
400
Sulfate Concentration (mg / L)
Lab
Mean CO_2 Production (mg / m^2 / hr)
500
400
300
200
100
0
0
100
200
300
Sulfate Concentration (mg / L)

Summary

With increasing SO_4 concentrations:

1. CH_4: In the model, field, and lab CH_4 emissions decrease EXCEPT high salt concentrations in the lab increase CH_4 emissions.

2. CO_2: In the model, CO_2 emissions increase. Field results are inconclusive. Laboratory CO_2 emissions decrease.

Additional drivers and next steps

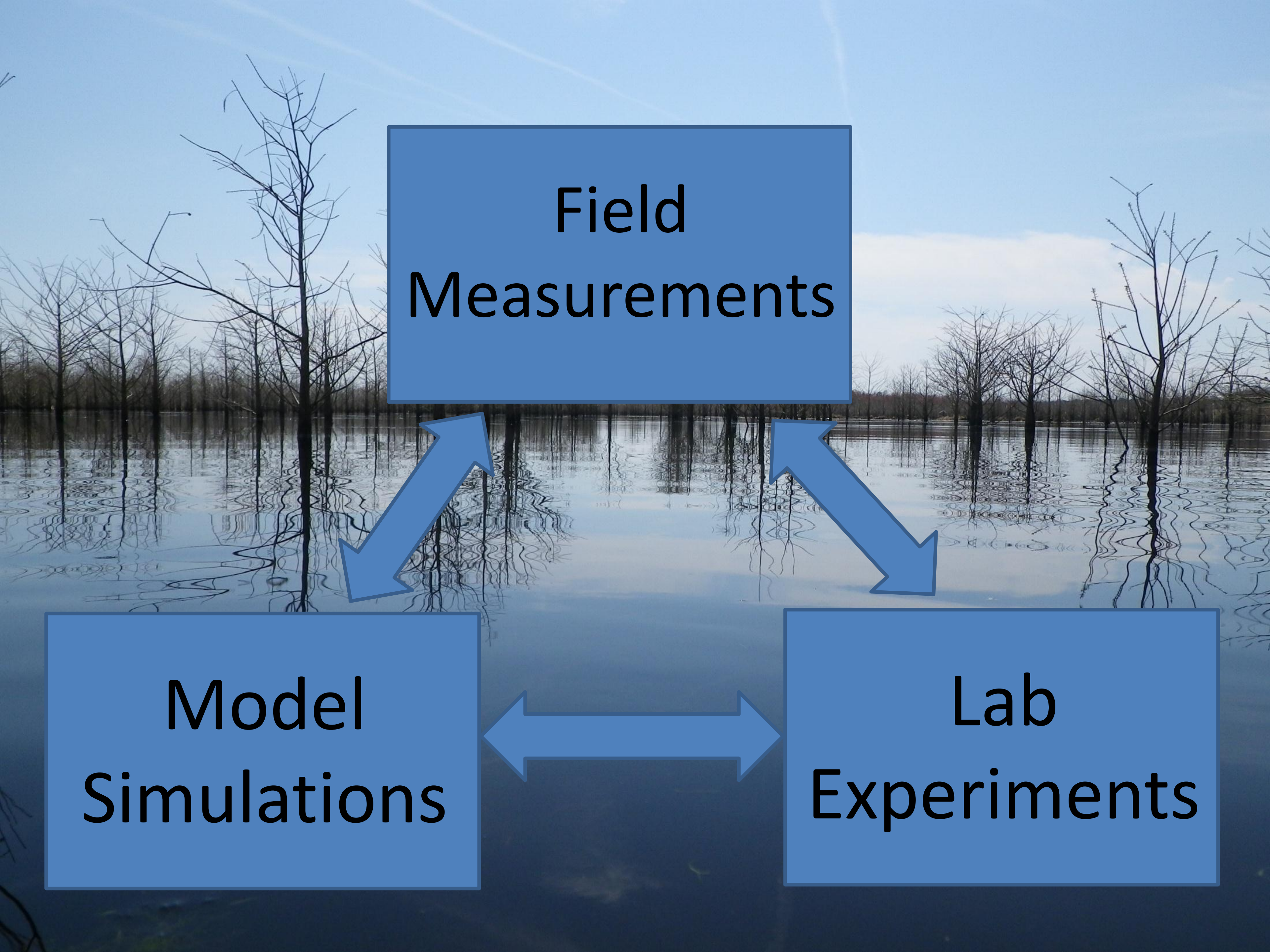
Geochemical

- NH_4^+ released from sediments
- DOC flocculation

Hydrologic: Wet v. Dry

Biological

- Actual free energy yield.
- Novel pathways (AOM, AOS).
- Carbon breakdown (fermentation).
- Competition for H_2 (hydrogenotrophic methanogenesis).
- Stress.


Field Measurements
Model Simulations
Lab Experiments

Model simulations