Parameterization of Temporally-Resolved Benthic Nutrient Fluxes in Lake Okeechobee

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Lake O sediment nutrient inputs

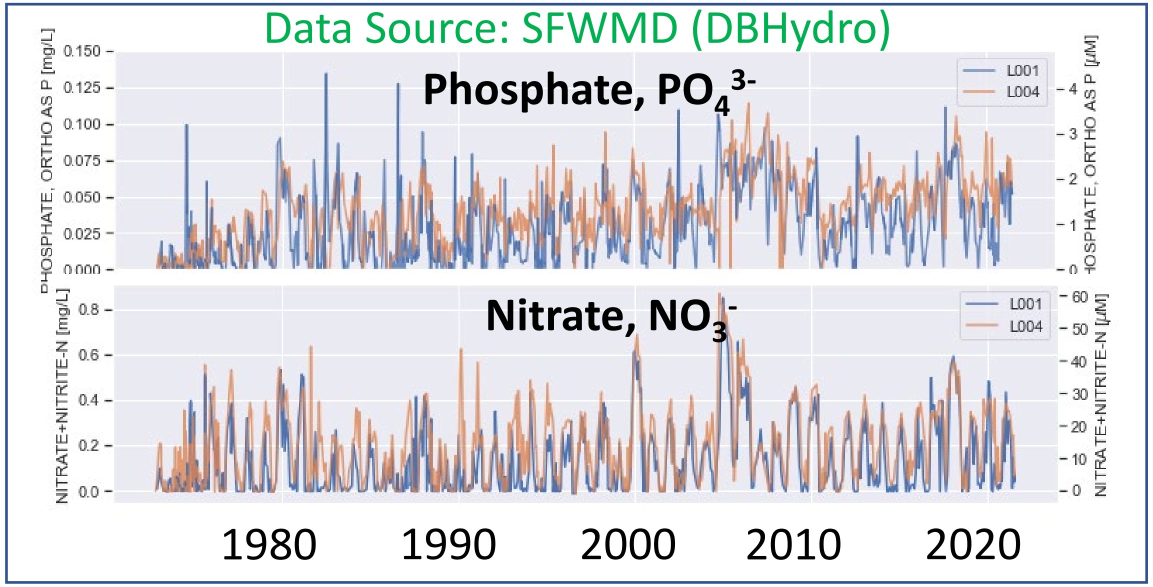
- 100+ years of nut. accumulations (> 60 cm) affect long term water quality
  (Brezonik & Engstrom, 1998)

- Diffusive fluxes: PO_4^{3-} : sed. internal ≈ external
  NH_4^+ : sed. internal ≈ 5x external (DIN)
  (Moore et al. 1998; Fisher et al. 2005)

- Sediment mapping : geographical, decadal patterns (Osborne et al. 2021)

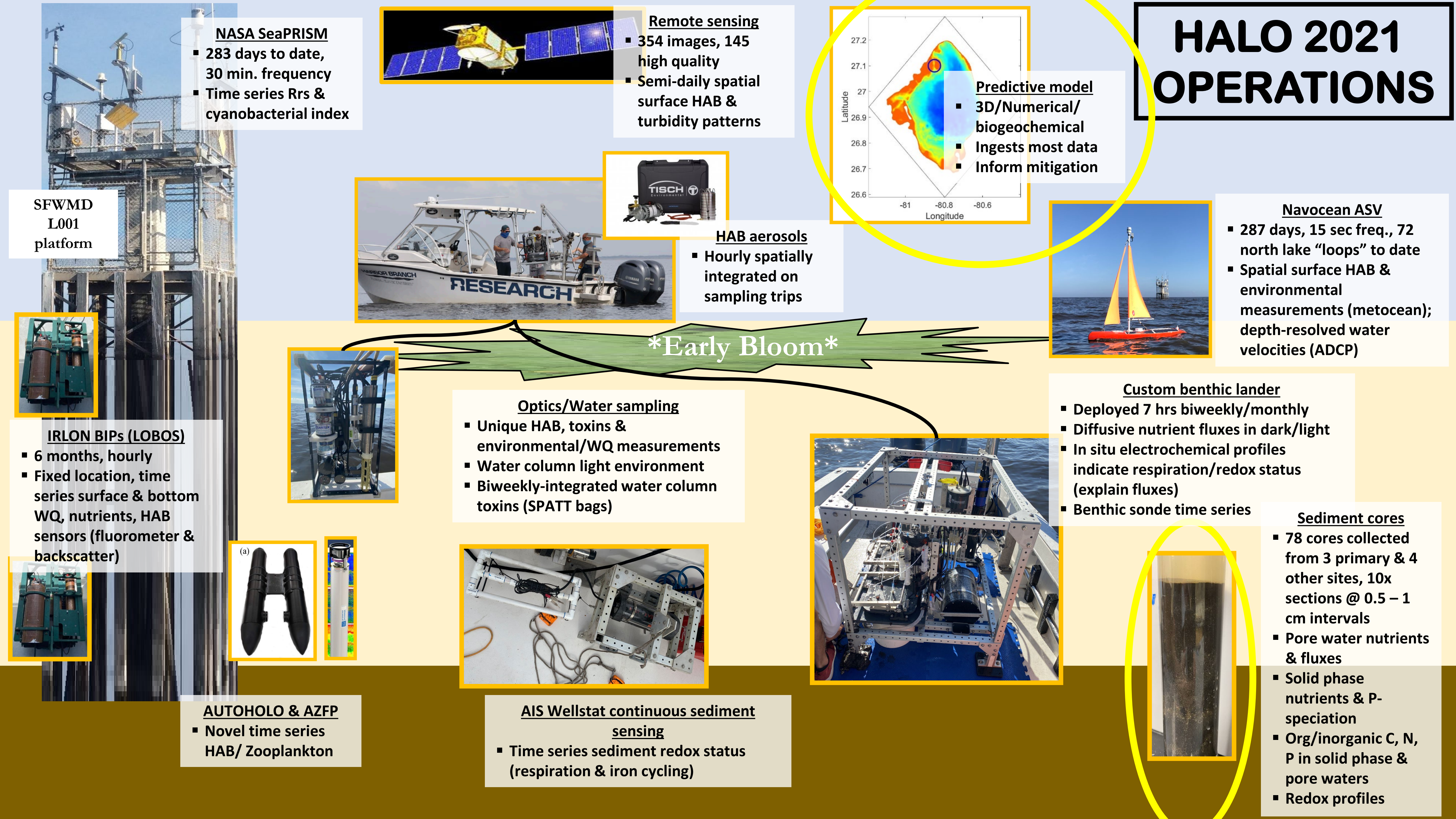
- This project: more focused on temporal dynamics & processes→ both nutrient diffusion and resuspension

- Previous Lake O resuspension nutrient work limited to modeling → substantial nutrient source
  (James et al. 1997, JAWRA)



Goals for this presentation:

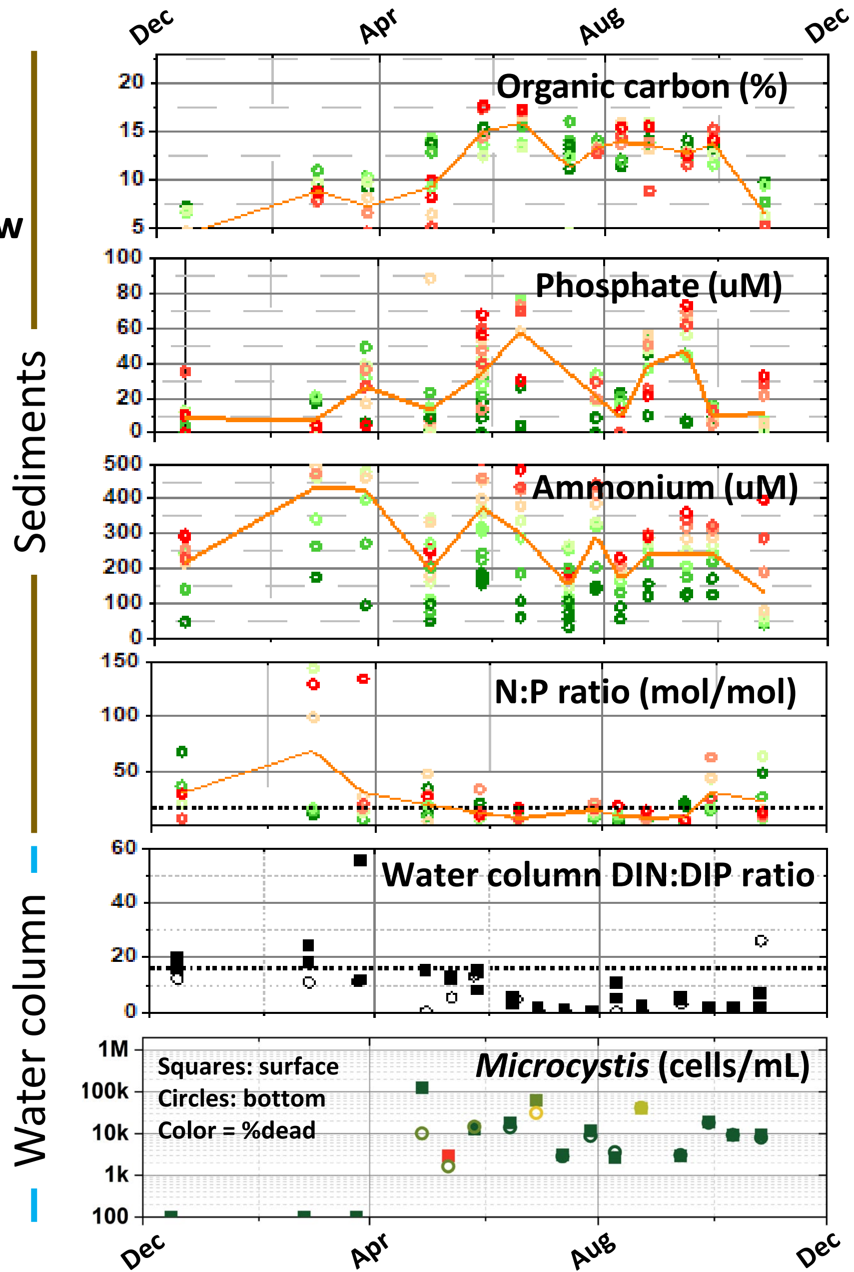
- Experimentally quantify resuspension fluxes / behavior
- Describe plans to parameterize sediment nutrient fluxes in high-resolution predictive HAB models

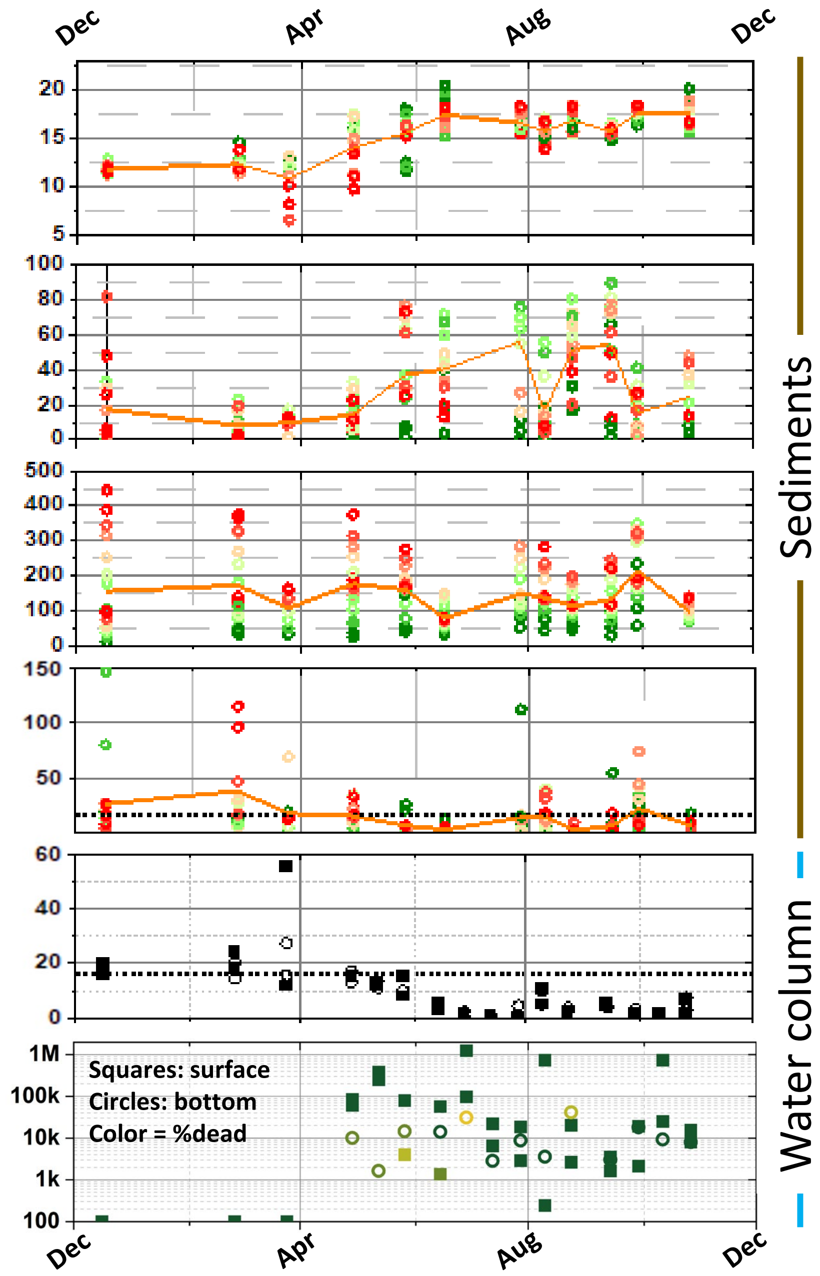

HALO 2021 OPERATIONS
NASA SeaPRISM
▪ 283 days to date, 30 min. frequency
▪ Time series Rrs & cyanobacterial index
Remote sensing
▪ 354 images, 145 high quality
▪ Semi-daily spatial surface HAB & turbidity patterns
27.2
27.1
27
26.9
26.8
26.7
26.6
Latitude
-81
-80.8
-80.6
Longitude
Predictive model
▪ 3D/Numerical/ biogeochemical
▪ Ingests most data
▪ Inform mitigation
SFWMD L001 platform
TISCH
HAB aerosols
▪ Hourly spatially integrated on sampling trips
RESEARCH
Navocean ASV
▪ 287 days, 15 sec freq., 72 north lake “loops” to date
▪ Spatial surface HAB & environmental measurements (metocean); depth-resolved water velocities (ADCP)
Early Bloom
Optics/Water sampling
▪ Unique HAB, toxins & environmental/WQ measurements
▪ Water column light environment
▪ Biweekly-integrated water column toxins (SPATT bags)
Custom benthic lander
▪ Deployed 7 hrs biweekly/monthly
▪ Diffusive nutrient fluxes in dark/light
▪ In situ electrochemical profiles indicate respiration/redox status (explain fluxes)
▪ Benthic sonde time series
IRLON BIPs (LOBOS)
▪ 6 months, hourly
▪ Fixed location, time series surface & bottom WQ, nutrients, HAB sensors (fluorometer & backscatter)
(a)
Sediment cores
▪ 78 cores collected from 3 primary & 4 other sites, 10x sections @ 0.5 – 1 cm intervals
▪ Pore water nutrients & fluxes
▪ Solid phase nutrients & P-speciation
▪ Org/inorganic C, N, P in solid phase & pore waters
▪ Redox profiles
AUTOHOLO & AZFP
▪ Novel time series HAB/ Zooplankton
AIS Wellstat continuous sediment sensing
▪ Time series sediment redox status (respiration & iron cycling)

Seasonal inventories are dynamic and impactful (2021)

L001

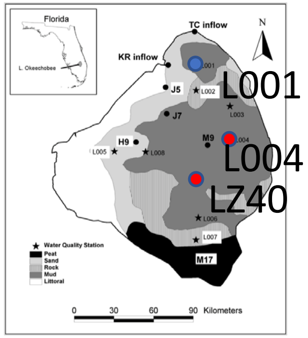
Intensification, Kissimmee inflow





L004/LZ40 merged

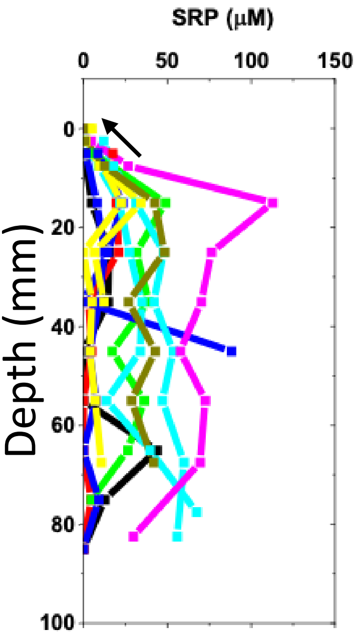
Pelagic, Turbid, Mud accumulation



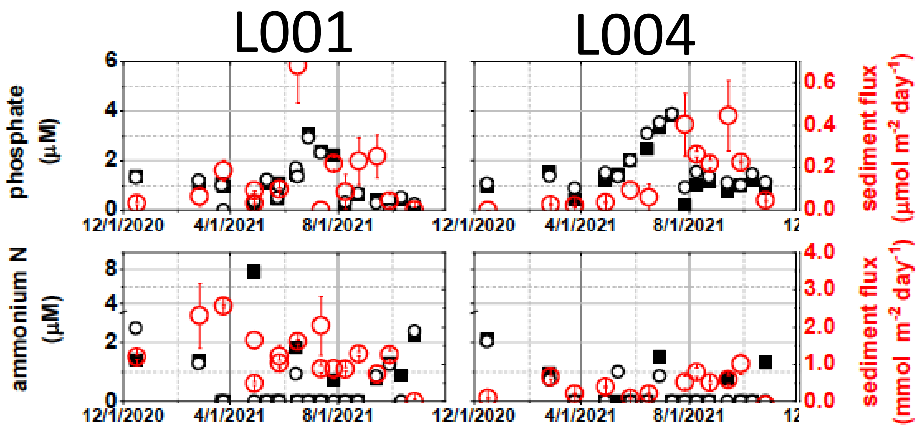
Fisher et al. 2009

Why NH_4^+ decrease?
→Iron oxide shielding of Org-N!

Empirical approach to diffusive flux parameterization



$F = D' * \Phi * dC/dz$



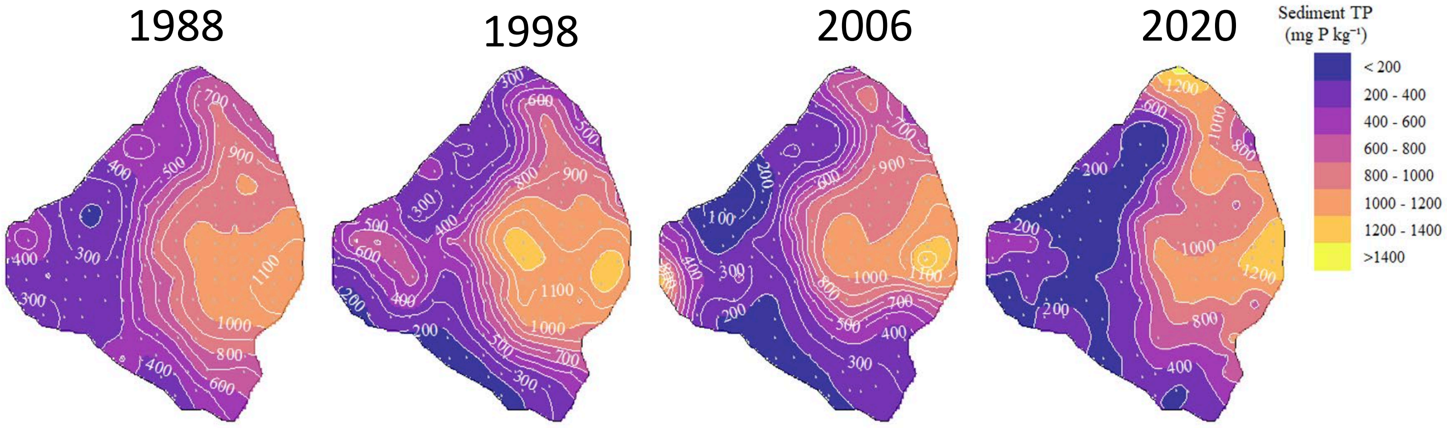
Theoretical diffusive fluxes based on near-surface pore water gradients; may not accurately represent flux across the sed/H2O interface, especially for SRP*

Time series fluxes OR *inventories (HALO project)

Flux(t) = f(day of year, average sediment TP & TN, other factors…)

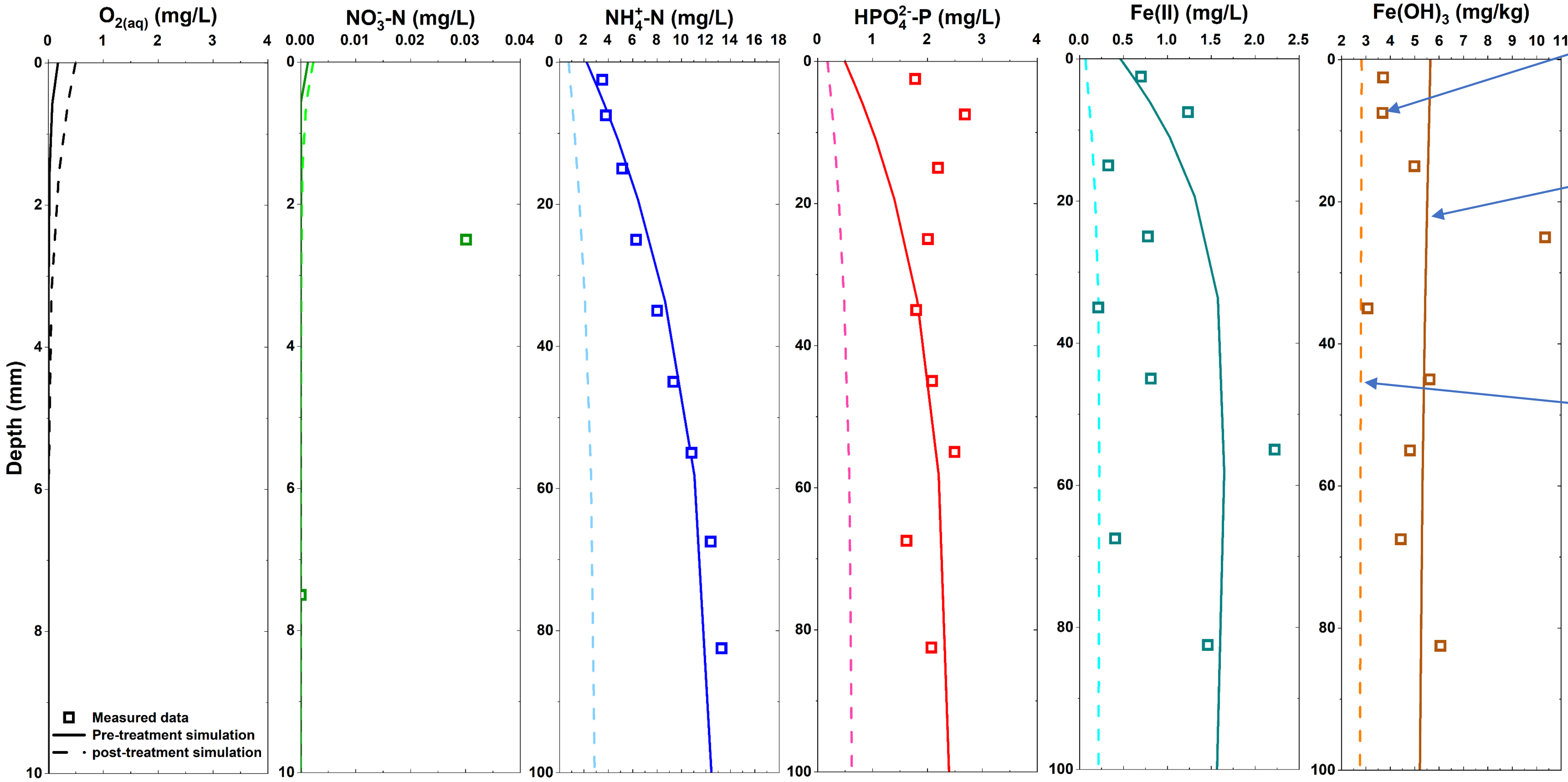
Extrapolate lake-wide

$Flux_{Diff}$(day of year,lat,lon)



Sediment solid phase nutrient maps (Osborne et al. 2021 , SFWMD report)

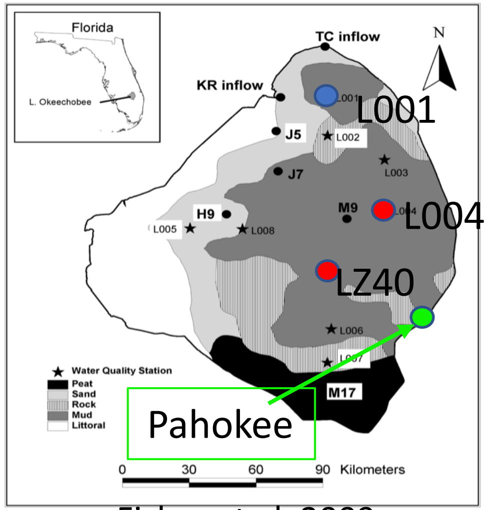
Alternative approach – coupled diagenetic modeling



Pahokee Marina measured data

Simulated steady state: Pahokee Aug. 2021

Simulated steady state after 80% organic C/N/P reduction



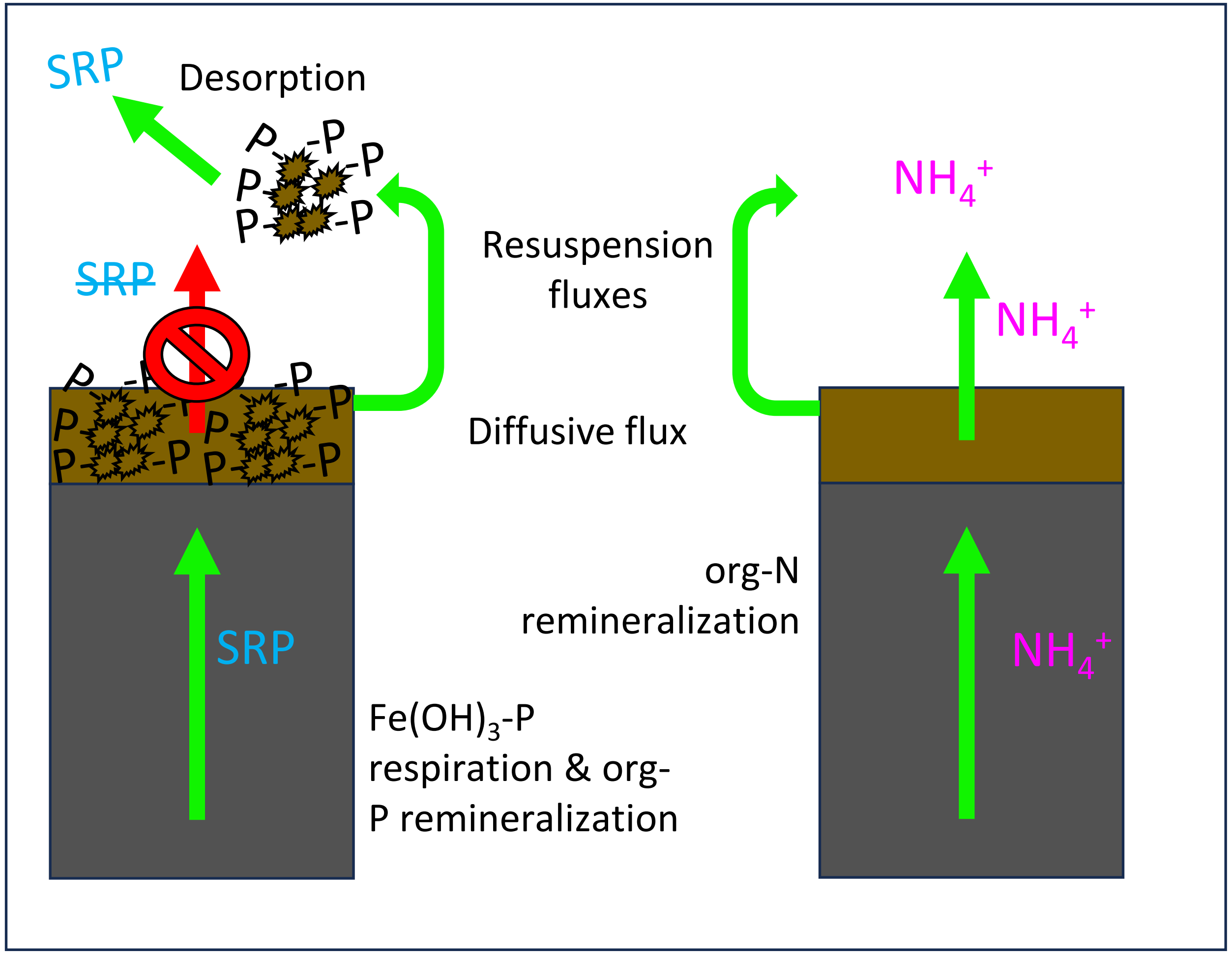
Fisher et al. 2009

Couple to 3D numerical model to enable responsive sediment dynamics.

Disadvantages: Many unknown reactions, and computationally expensive

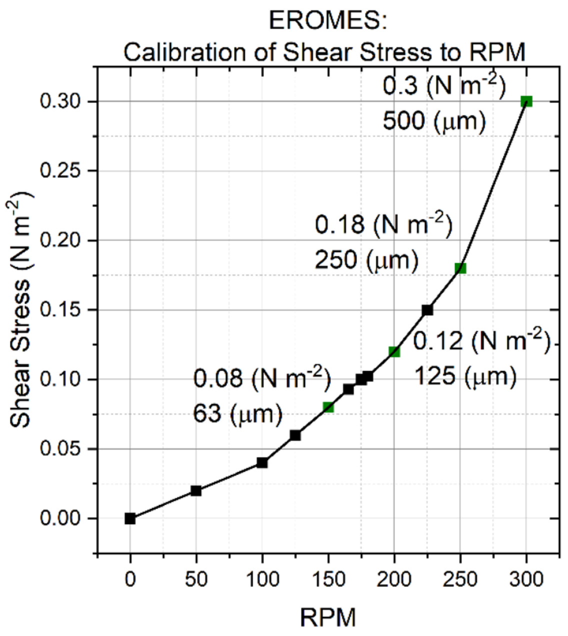
Are diffusive fluxes overrated in Fe-rich turbid lakes?

- SRP fluxes low across sed/H_2O interface unless hypoxic (rare…)
  (Moore et al. 1998; Fisher et al. 2005)
- Surface floc layer constantly remobilized & reoxidized (SRP trap)
- Resuspension also directly introduces pore water dissolved nutrients
- Lake O sediment/water mixing experiments observed both SRP addition and removal observed)
  (Hansen et al. 2009)

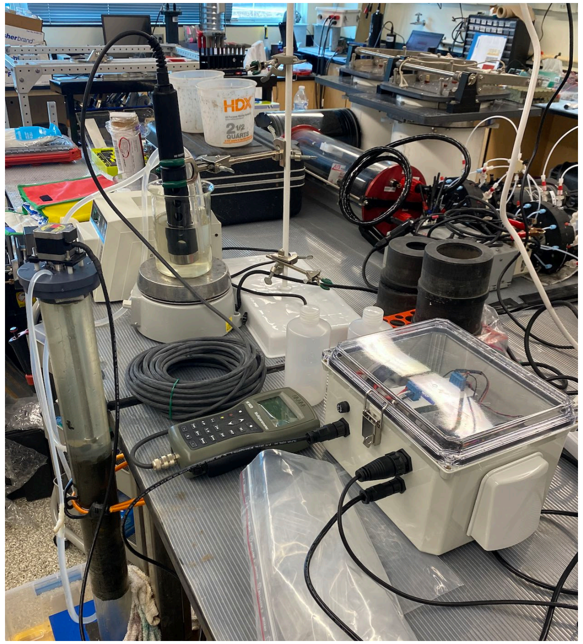


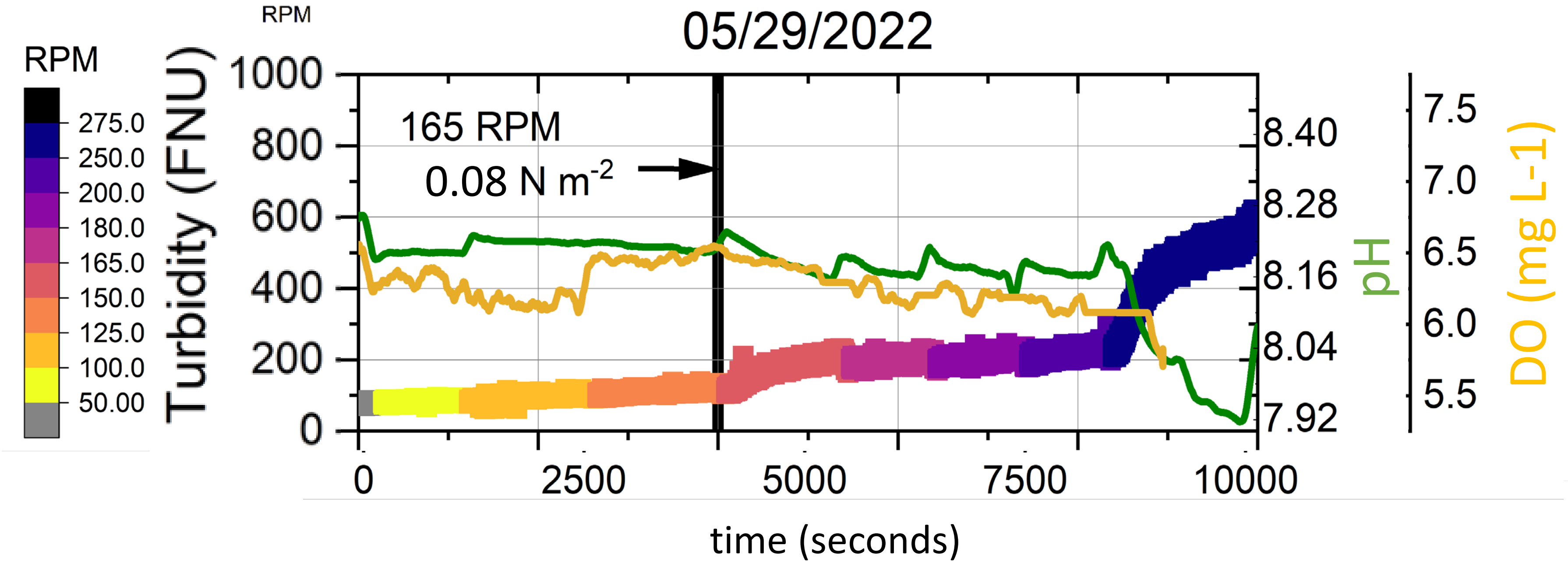
Goal: Experimentally parameterize resuspension-derived nutrient fluxes and include in a 3-D model.

Resuspension experiments

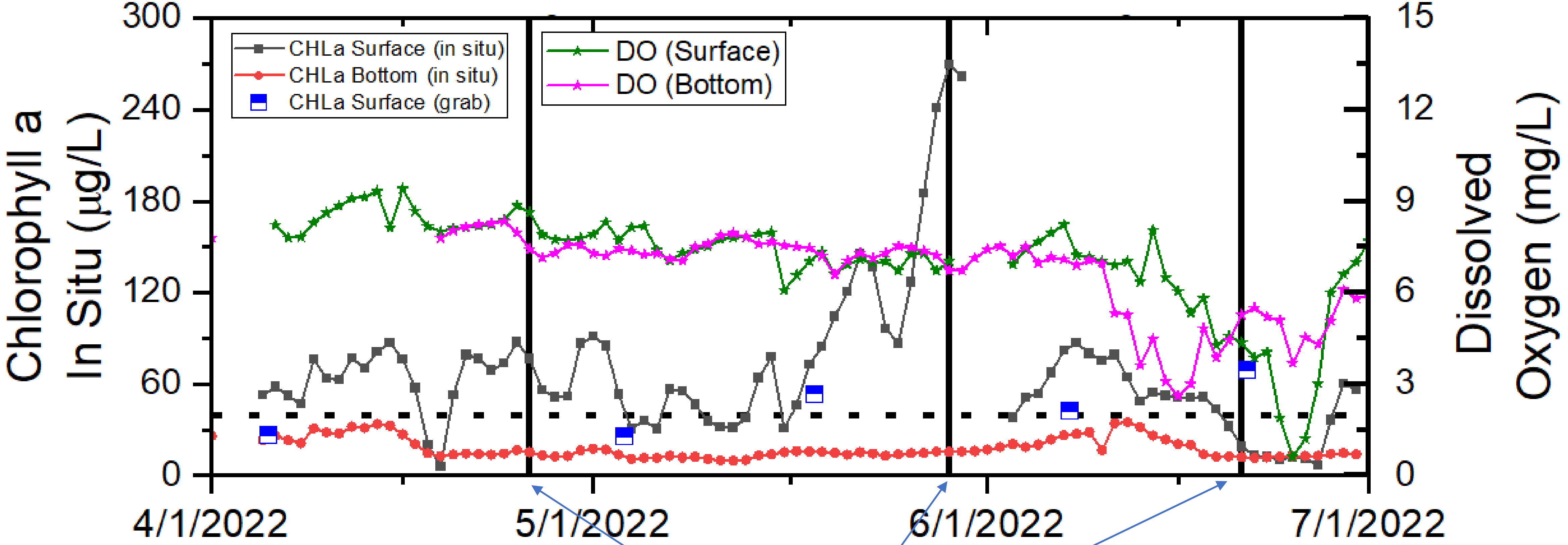


EROMES system
(based on
Kaljenais et al. 2007)

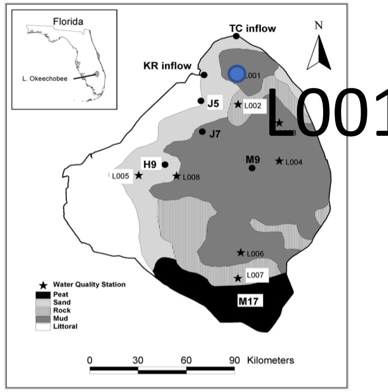




In situ time series during erosion experiments (2022)

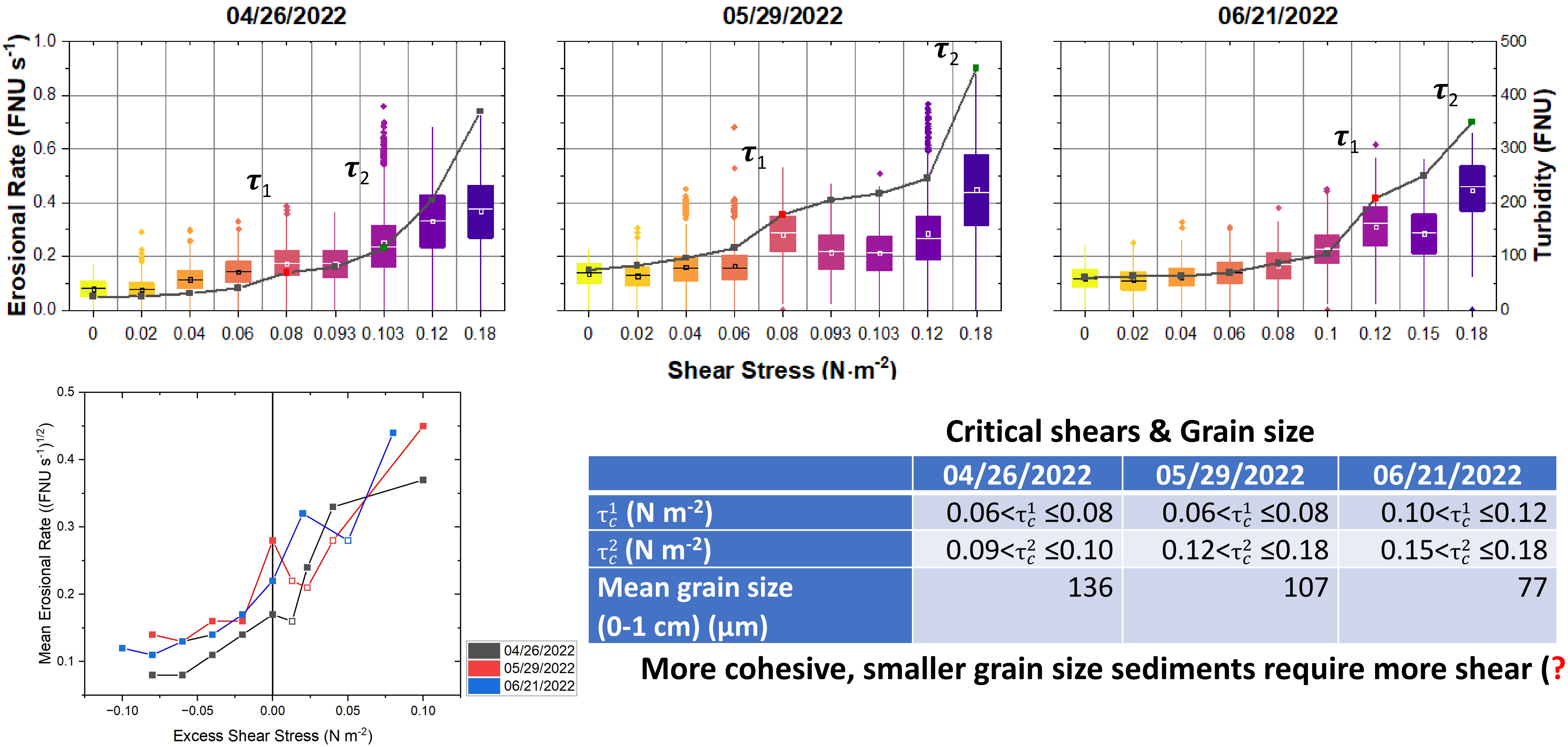


3 sampling dates



Fisher et al. 2009

Biphasic "floc" (τ_1) & bed (τ_2) erosion response

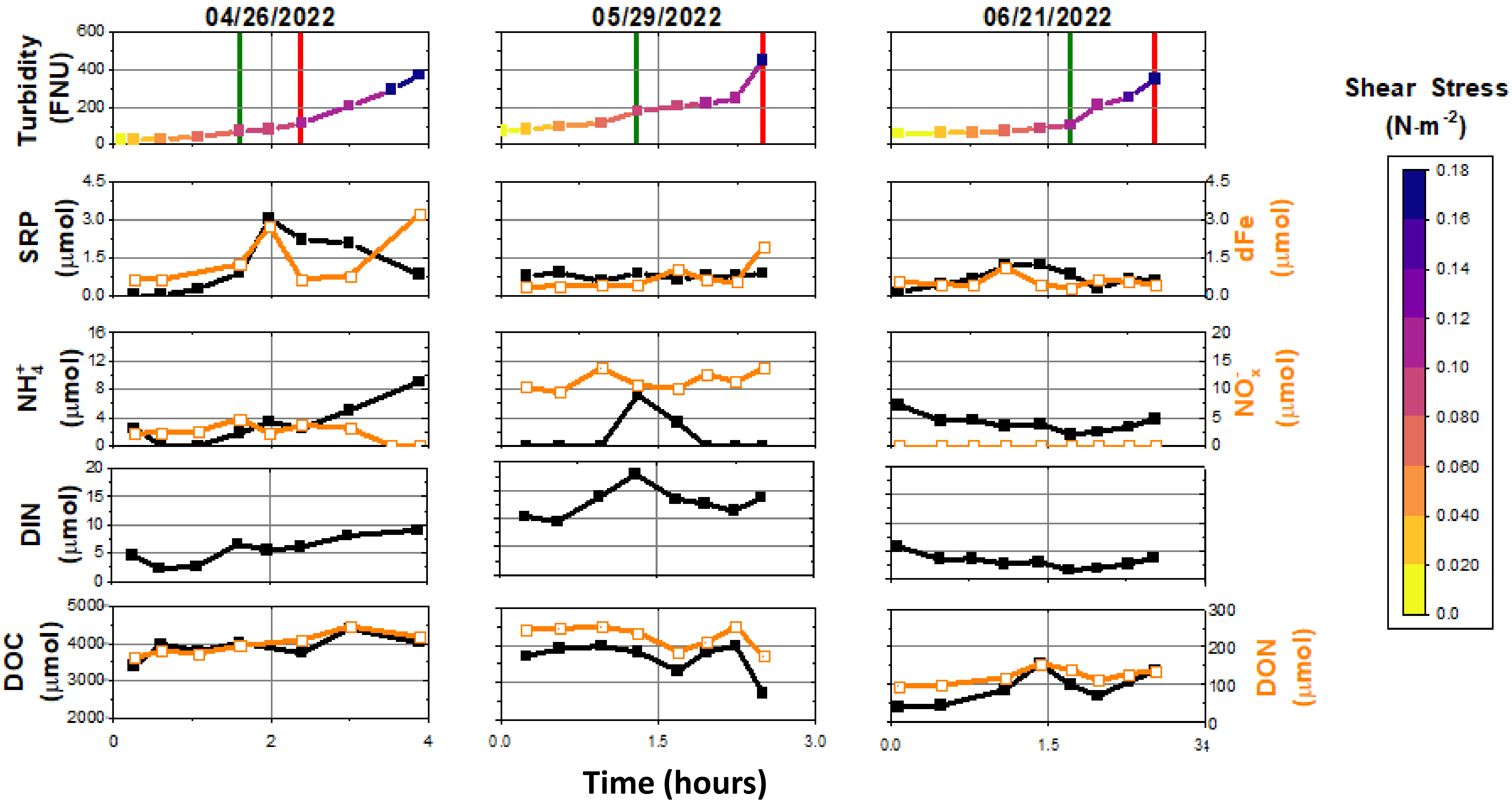


Critical shears & Grain size

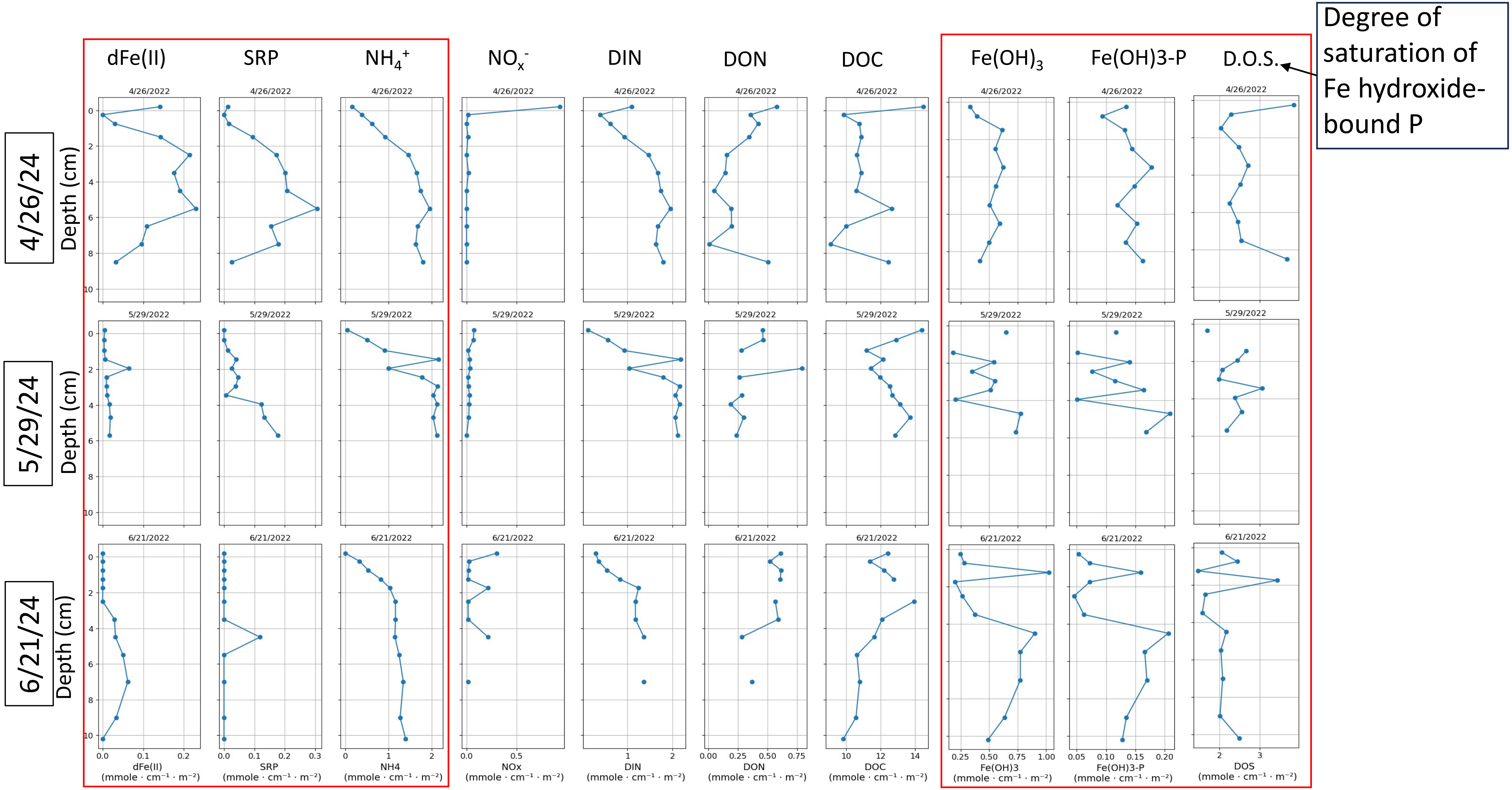
	04/26/2022	05/29/2022	06/21/2022
τ_c^1 (N m^{-2})	$0.06<\tau_c^1 \leq 0.08$	$0.06<\tau_c^1 \leq 0.08$	$0.10<\tau_c^1 \leq 0.12$
τ_c^2 (N m^{-2})	$0.09<\tau_c^2 \leq 0.10$	$0.12<\tau_c^2 \leq 0.18$	$0.15<\tau_c^2 \leq 0.18$
Mean grain size (0-1 cm) (μm)	136	107	77

More cohesive, smaller grain size sediments require more shear (?)

Nutrient behavior during erosion experiments



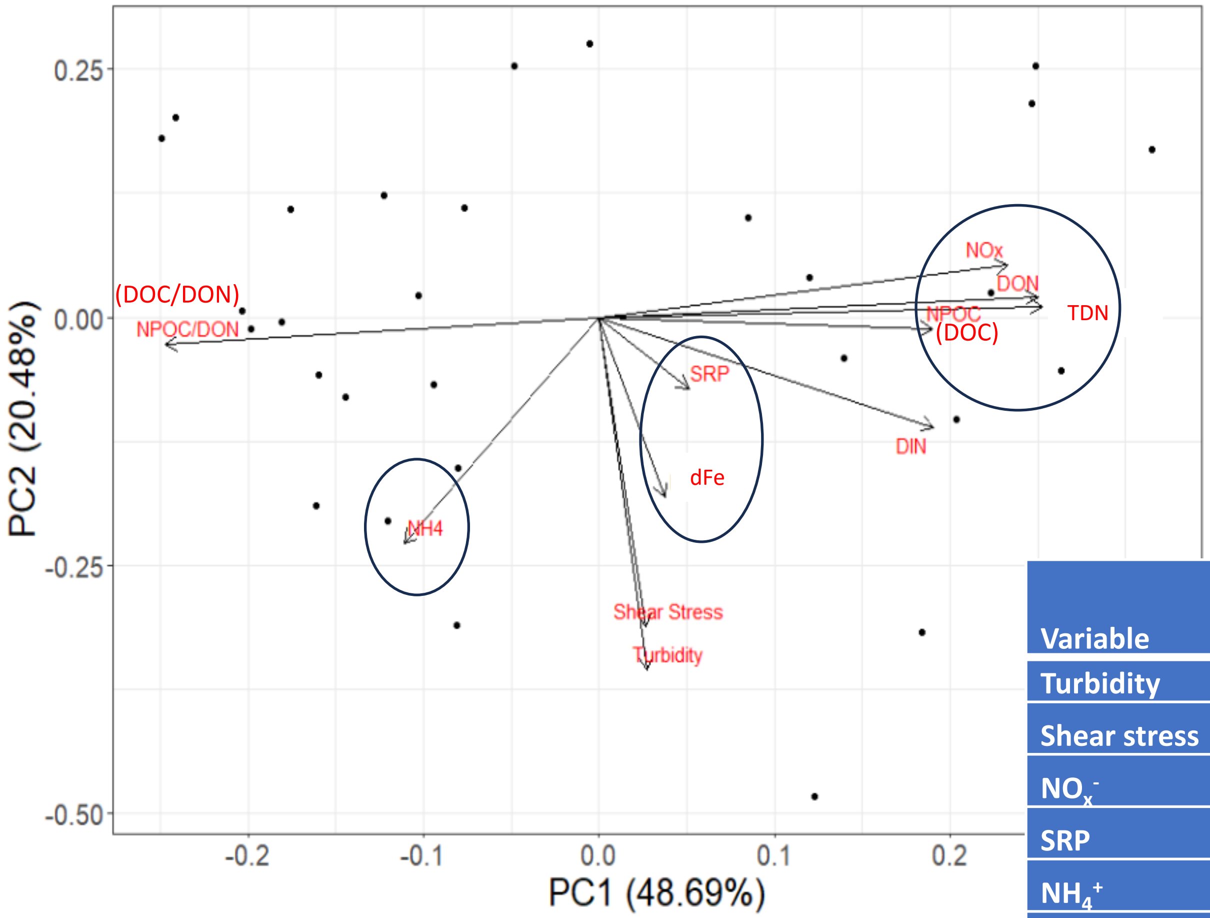
Underlying sediment core profiles



Fluxes & erosional depth required for mass balance

Nutrient	Date	Maximum nutrient release (mmol m^{-2})	$\frac{\sum C(\text{mole m}^{-2})}{D(\text{cm})}$ (mmol · cm^{-1} m^{-2})	Sediment erosion depth required for release (cm)
SRP	04/26/2022	0.670	0.16	5.2 (deeper than visually resuspended)
	05/29/2022	0	0.06	-
	06/21/2022	0.15 ± 0.1	0.01	>10.5 (deeper than core)
DIN	04/26/2022	1.8	1.47	2
	05/29/2022	2.0	1.70	1.65
	06/21/2022	0.57 ± 0.11	1.14	0.85
DON	04/26/2022	12.6	0.21	>8.5 (deeper than core)
	05/29/2022	-16	0.35	WC sink
	06/21/2022	6.11 ± 2.67	0.47	>10.5 (deeper than core)
DOC	04/26/2022	139.7	10.78	>8.5 (deeper than core)
	05/29/2022	-278	12.59	WC sink
	06/21/2022	139 ± 37	11.51	>10.5 (deeper than core)

Principle Component Analyses: nutrients & shear

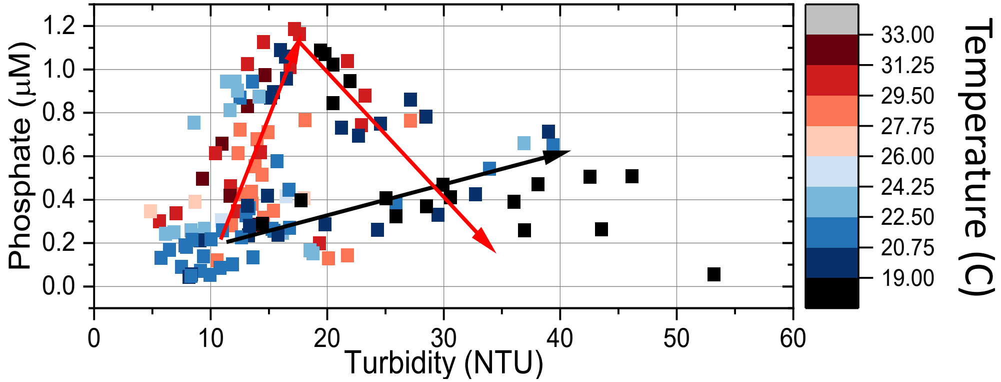


PCA is of individual water samples from core overlying water during resuspension experiment

Variable	Turb	Shear Stress	NO_x^-	SRP	NH_4^+	DIN	TDN	DOC	DON	DOC : DON	dFe
Turbidity	1.00	**0.77**	0.11	0.16	**0.37**	**0.44**	0.05	-0.05	0.02	-0.05	0.16
Shear stress		1.00	-0.02	0.17	0.19	0.16	0.07	0.11	0.06	-0.07	0.27
NO_x^-			1.00	-0.01	**-0.55**	**0.77**	**0.77**	**0.38**	**0.74**	**-0.87**	0.01
SRP				1.00	0.12	0.08	0.29	0.29	0.29	-0.22	**0.42**
NH_4^+					1.00	0.11	-0.34	-0.13	**-0.37**	**0.51**	0.13
DIN						1.00	**0.65**	0.35	**0.60**	**-0.65**	0.11
TDN							1.00	**0.83**	**1.00**	**-0.92**	0.15
DOC								1.00	**0.84**	**-0.57**	0.12
DON									1.00	**-0.91**	0.14
DOC:DON										1.00	-0.20
dFe											1.00

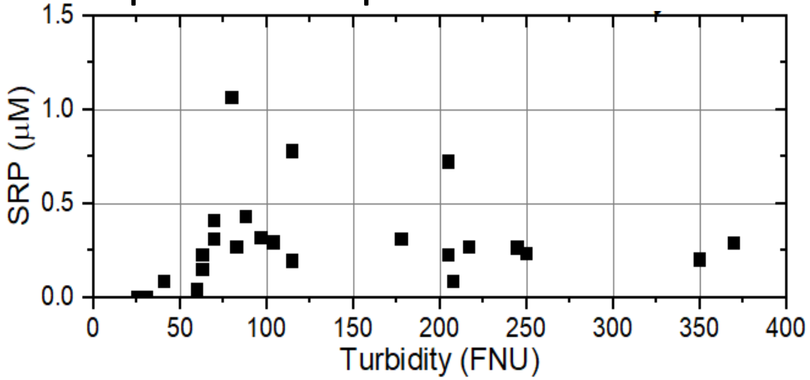
SRP behavior during sediment resuspension

In situ data: L001-B: 07/01/21-01/29/22

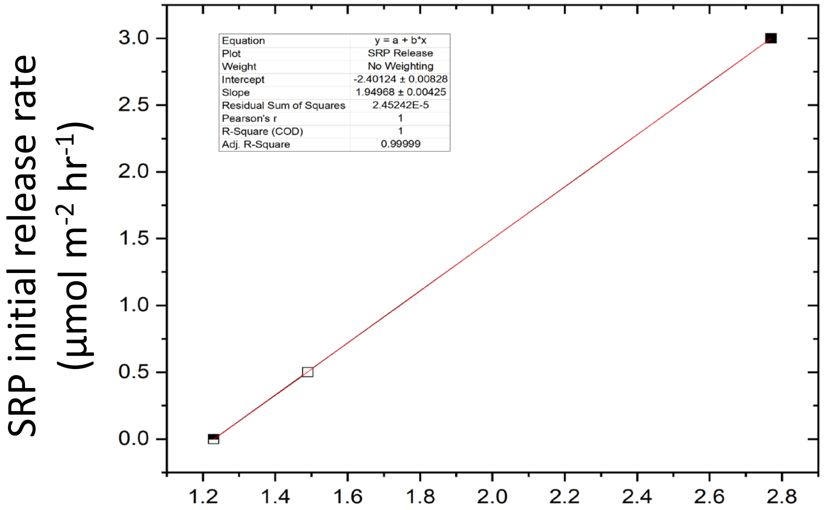


SRP released via desorption from P-saturated surface floc (τ_1), but scavenged by less saturated bed sediments during stronger turbidity events (τ_2)

Resuspension experiments: L001



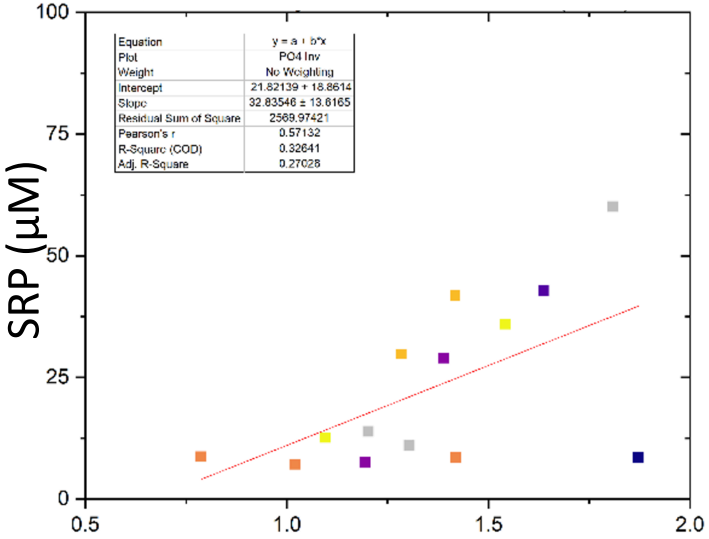
Resuspension experiments



Equation	y = a + b*x
Plot	SRP Release
Weight	No Weighting
Intercept	-2.40124 ± 0.00828
Slope	1.94968 ± 0.00425
Residual Sum of Squares	2.45242E-5
Pearson's r	1
R-Square (COD)	1
Adj. R-Square	0.99999

Degree of Saturation of P on Fe hydroxides in floc layer

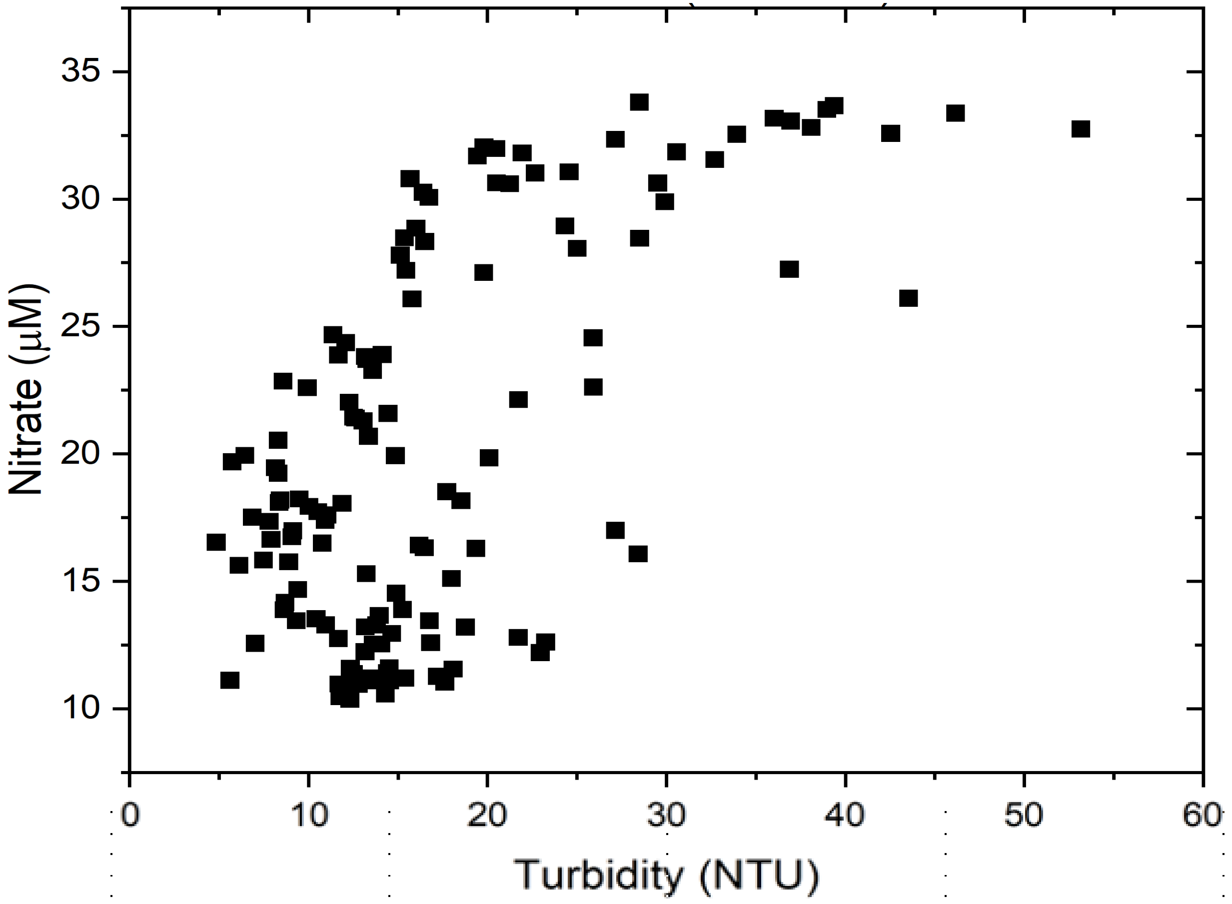
2021 sediment cores



Equation	y = a + b*x
Plot	PO4 Inv
Weight	No Weighting
Intercept	21.82139 + 18.8614
Slope	32.83546 ± 13.6165
Residual Sum of Square	2569.97421
Pearson's r	0.57132
R-Square (COD)	0.32641
Adj. R-Square	0.27028

Degree of Saturation of P on Fe hydroxides in floc layer

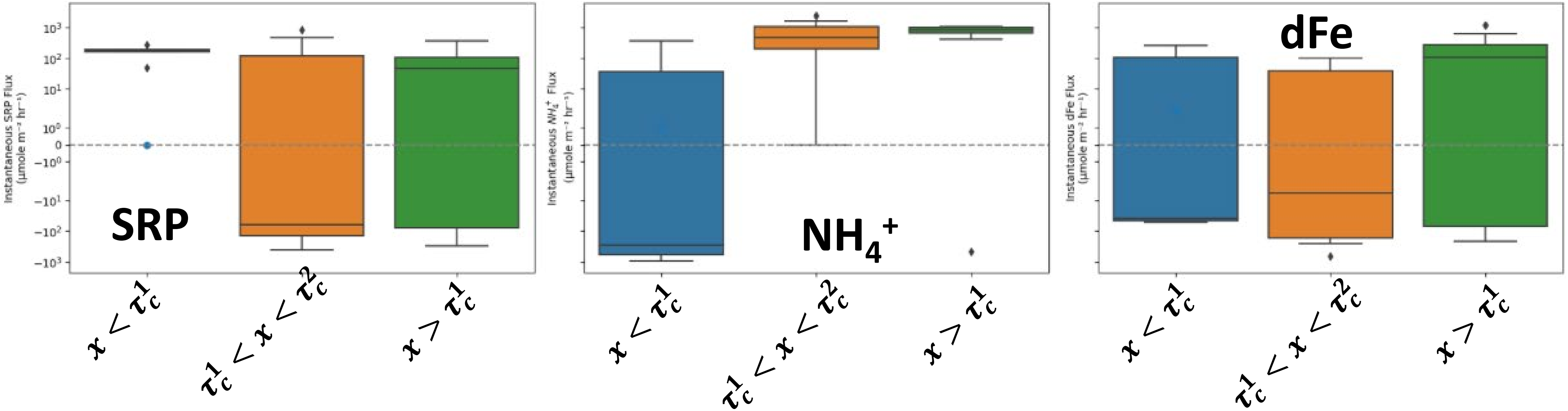
DIN release is more conservative

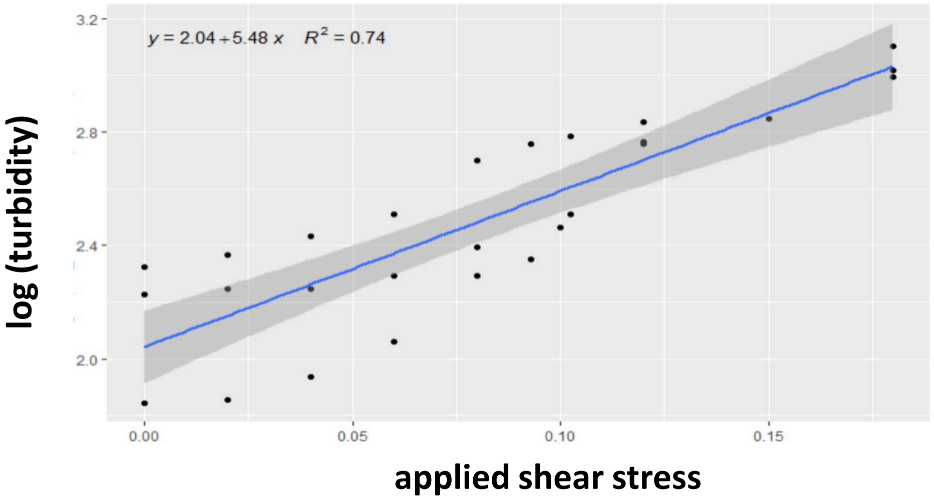


In situ nitrate data from L001 site

Generating a lake nutrient resuspension time series

Instantaneous fluxes binned by critical shear intervals





1. Relate experimentally observed turbidities to applied shear (3D model currently does not simulate waves – important!)
2. Using in situ lake turbidities, derive an applied in situ shear time series normalized for a ~30x larger water column height
3. Create flux time series based on erosional shear/flux relationships.

Resuspension 2021 flux time series (mmol m^{-2} day^{-1})

Annualized fluxes: Diffusive vs. Erosive

Consistent with
Moore et al. 1998;
Fisher et al. 2005

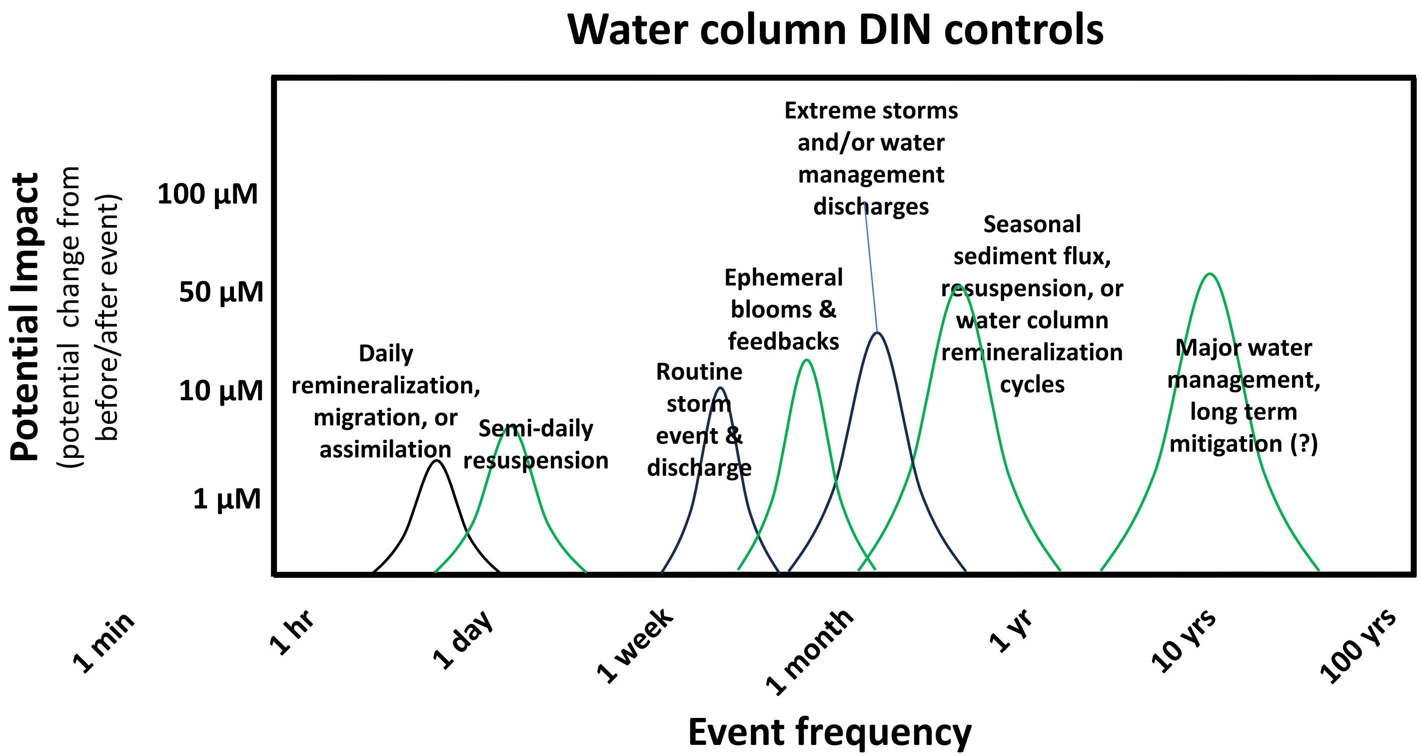
Fluxes in units of metric tonnes year^{-1}, extrapolated over mud area of lake

	NH_4^+	SRP	dFe(II)
Diffusive	**1,276** (1,101 to 1,447)	**609** (331 to 885)	**434** (327 to 535)
Erosive	**14,303** (5,645 to 24,084)	**1,970** (-7,752 to 10,142)	**7,448** (-10,707 to 21,152)
Erosive / Diffusive	**~11x**	**~3.2x**	**~17x**

Upper/Lower bounds represent the uncertainty associated with non-consistent accumulation/depreciation nutrient behavior under specific shear conditions

Conclusions

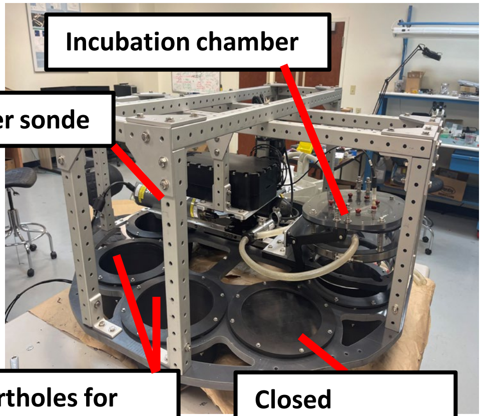
- Resuspension dynamics in geochemical context generally poorly understood, yet can dominate nutrient fluxes
- At a minimum, sediment surface layer geochemistry (Fe/P) should be routinely characterized
- NH_4^+ release a function of pore water inventory
- Excess DOC/DON released during resuspension (opposite of Fe shielding?)→ Fresh substrate?



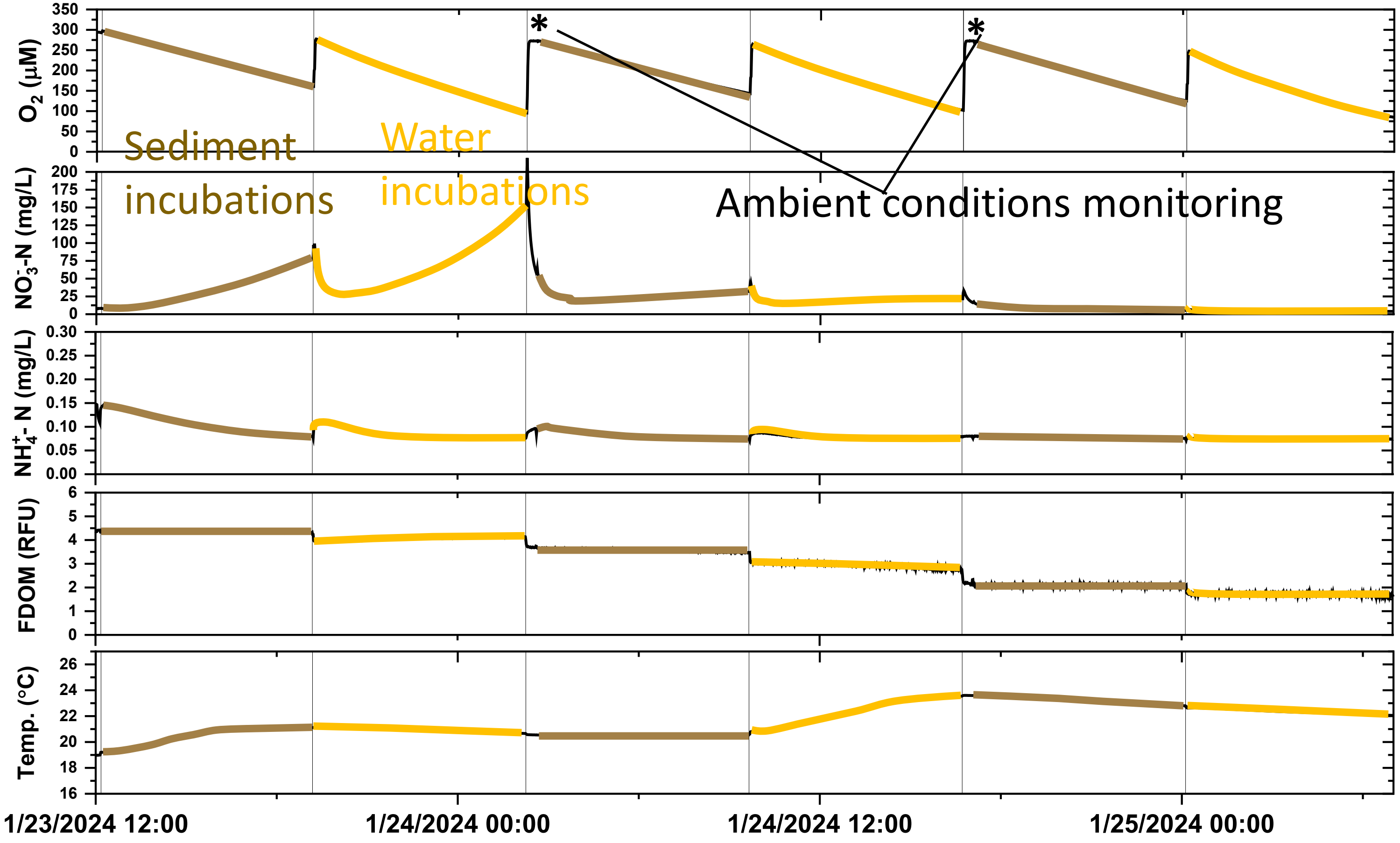
- <u>Empirical fluxes</u> may serve as worthwhile starting point, but high resolution (sediment) analytical models likely required for spatial predictions b/c of rapid HAB/sediment feedbacks

Technology to monitor flux dynamics

See Mason Thackston's poster!



1. **Sediment incubations** can include deliberate resuspension to simulate lake
2. **Ambient water incubations** provide critical measurements <u>and</u> allow correction of sediment fluxes for in-water processes (transparent/opaque chamber or day/night incubations→ photosynthesis/respiration nutrient behavior discrimination)
3. **Periodic open-chamber measurements** provide ambient water conditions time series



Phosphate coming soon!

SEDIMENT TECHNOLOGIES

HARBOR BRANCH
FLORIDA ATLANTIC UNIVERSITY
Ocean Science for a Better World