Tidal Wetland Biogeochemistry in High Definition: Using High-Frequency Measurements to Estimate Biogeochemical Rates

Brian Bergamaschi, Bryan Downing, Tamara Kraus
and many, many, many others; several in the room

A special thanks to and remembrance of George Aiken, without whom my career would have taken a very different and less salubrious path

USGS

Outline

- Introduction
- Rate determination using continuous in situ measurements and proxies
- Rate determination using mapping together with residence time techniques
- Rate determination using multiple continuous sensor deployments and hydrodynamic models
- New and revisited efforts
- Final thoughts

Biogeochemical Rates

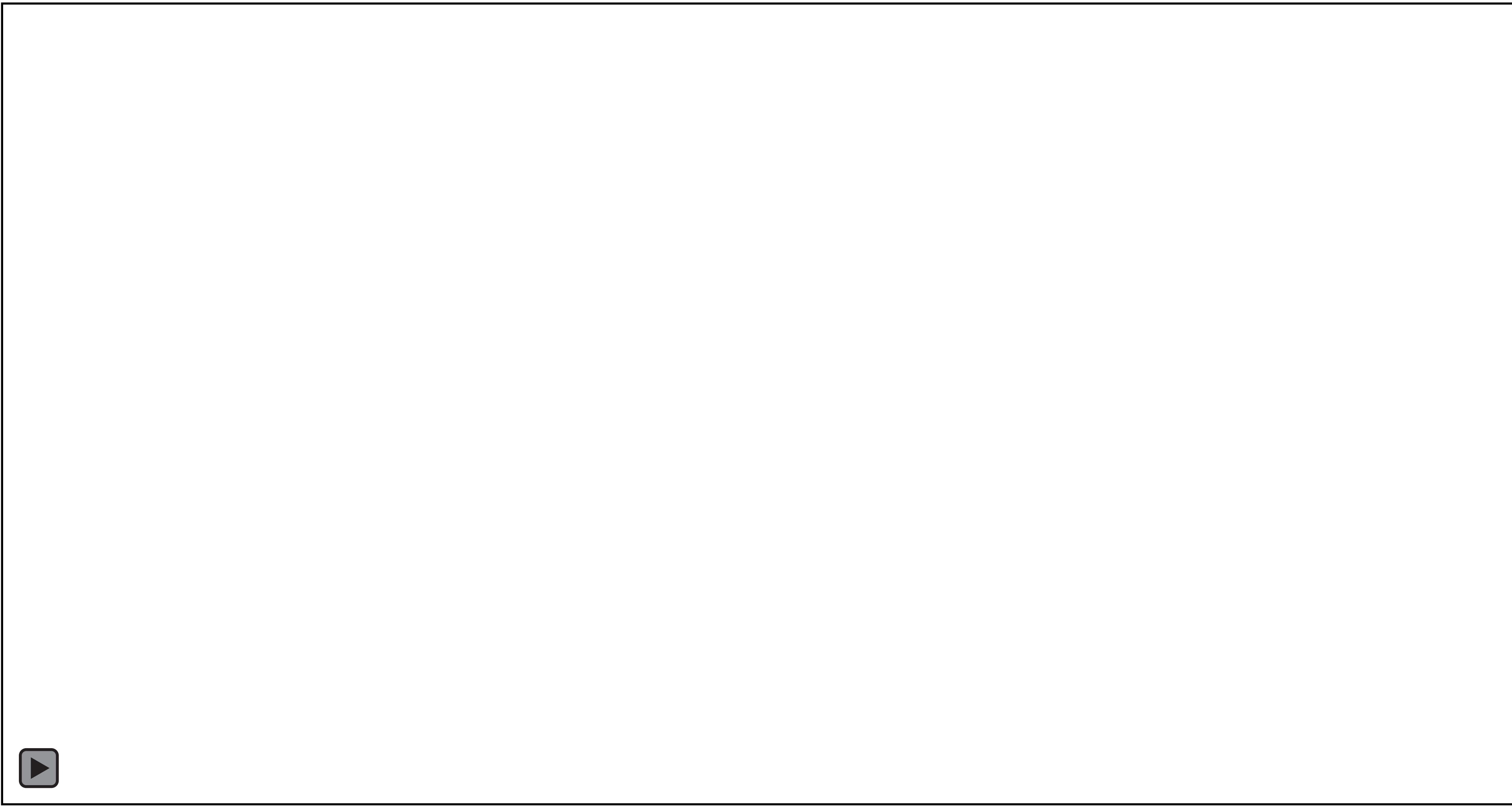
Assess how marsh interactions affect aquatic ecosystems as related to landscape elements, hydrodynamics and geomorphology

Rate

- Export production
- Nutrient cycling
- Sediment trapping
- Contaminant yield
  - Mercury
- Carbon and GHG balance

Landscape

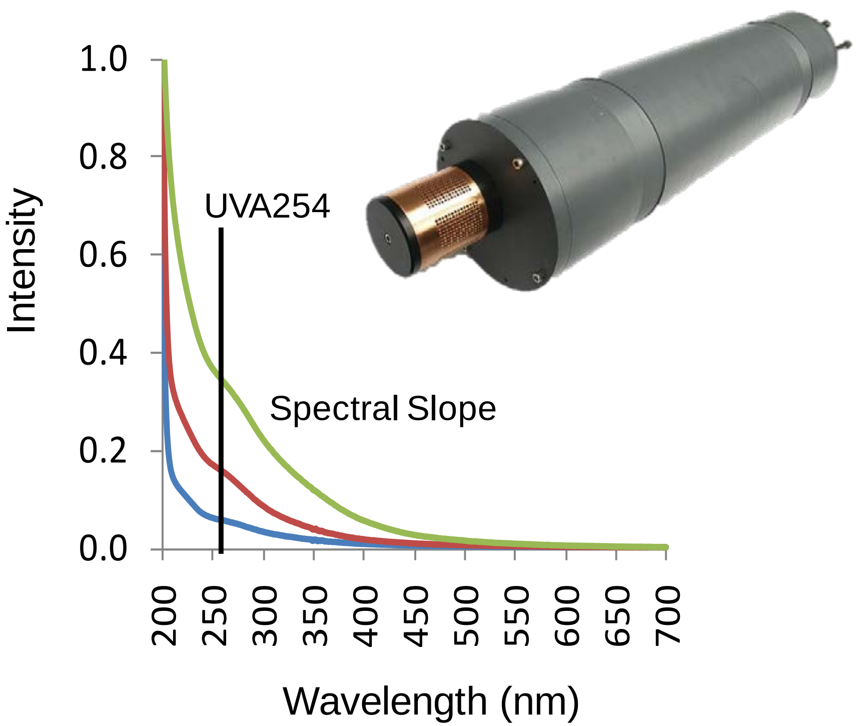
- Emergent marsh
- Marsh plain
- Submerged aquatic vegetation
- Small dendritic sub channels
- Inter-tidal mudflats

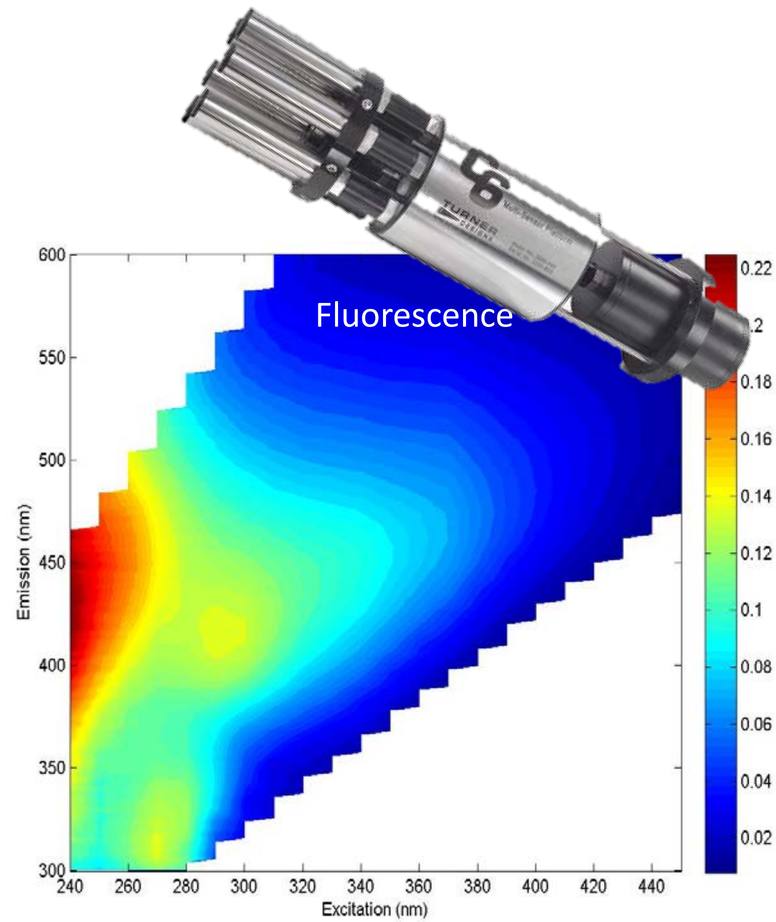


In situ measurements

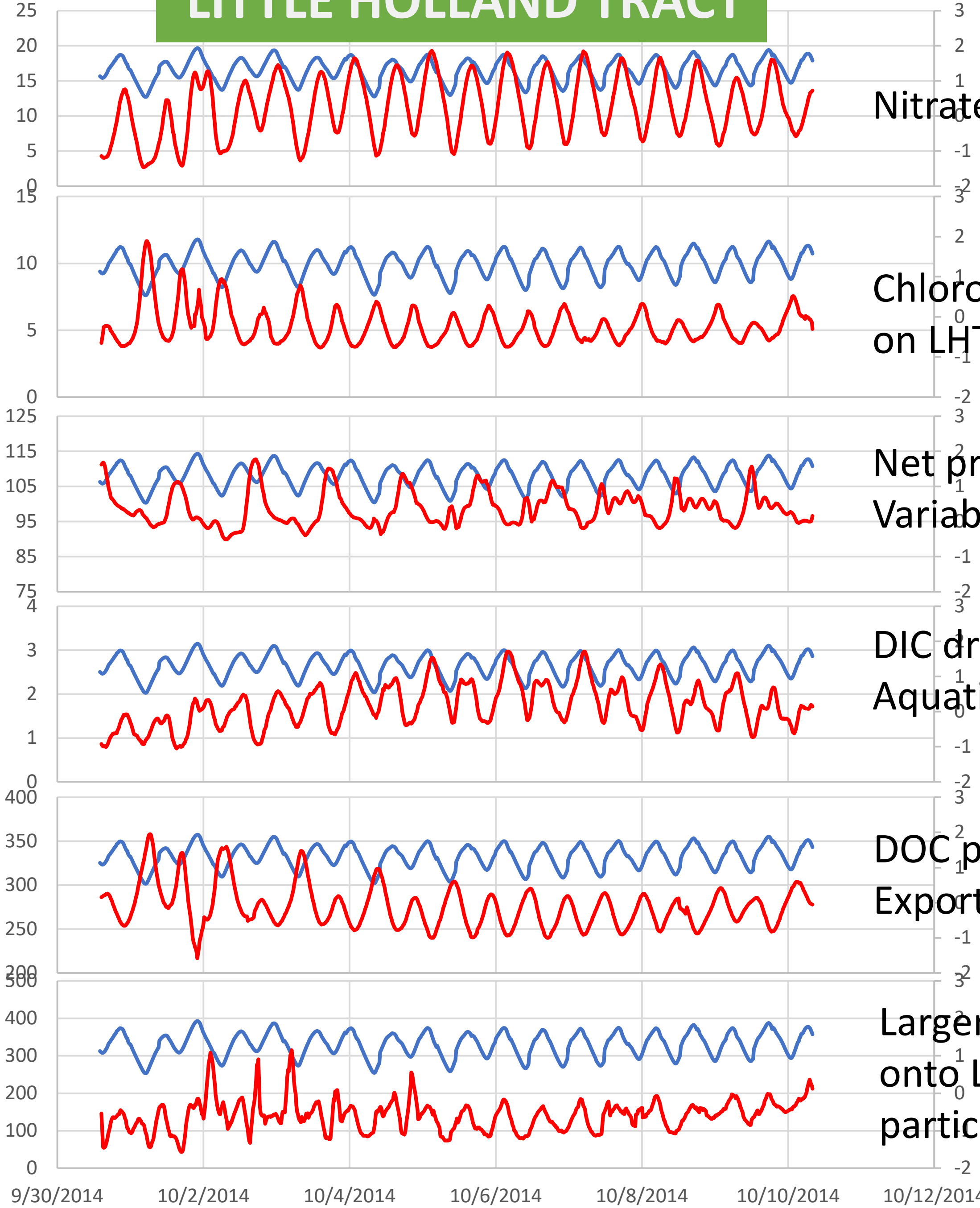
Commercially-available submersible instruments:

- Fluorometers – single and multiple wavelength; custom
- Spectrophotometers – UV and UV-vis
- Wet chemistry
- Optodes





LITTLE HOLLAND TRACT



NITRATE — Nitrate uptake on LHT

CHLOROPHYLL — Chlorophyll production on LHT and export

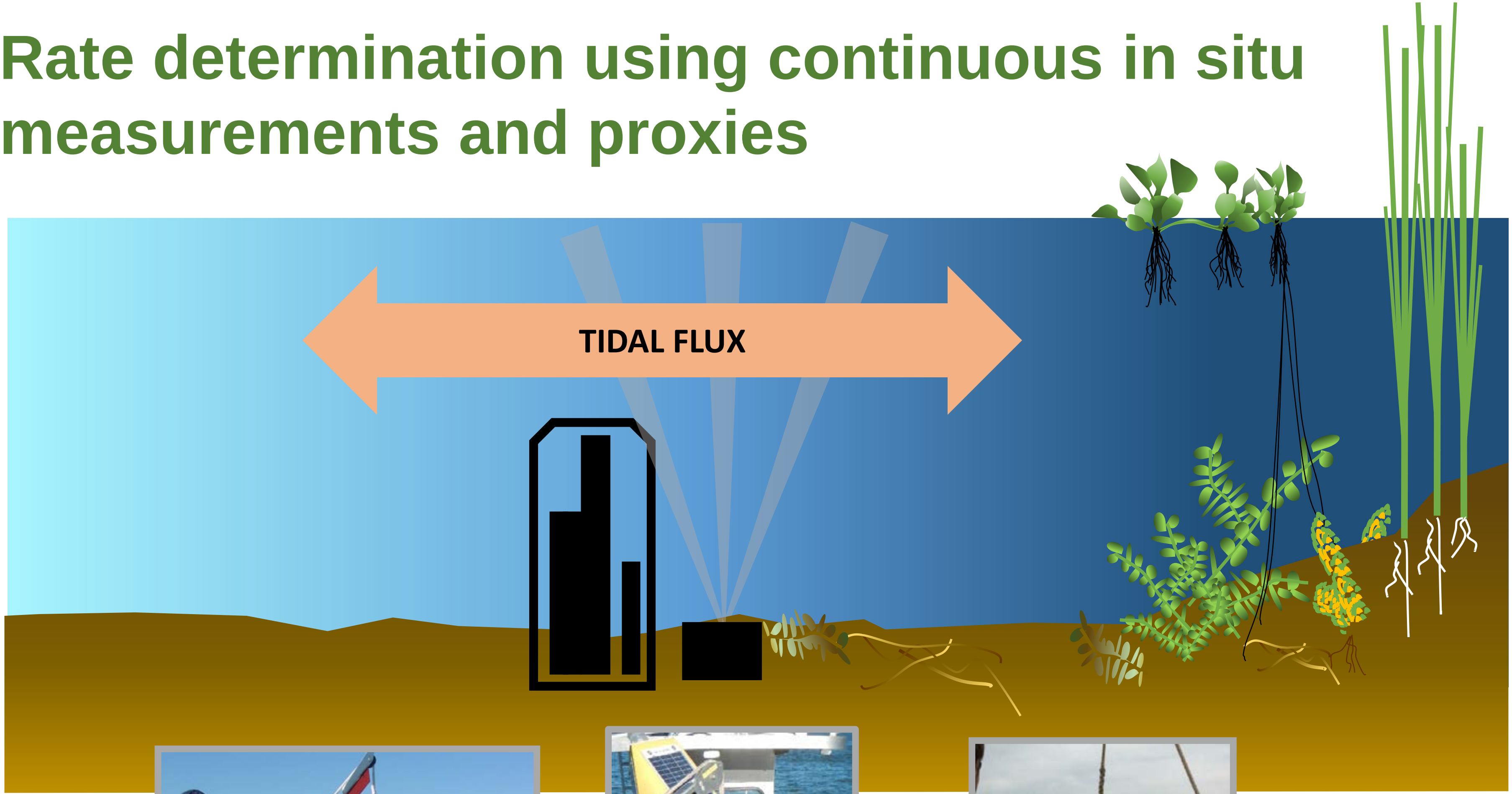
OXYGEN — Net production on LHT Variable over time

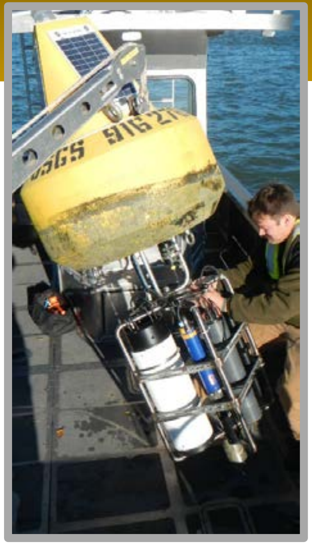
CO_2 — DIC drawdown on LHT Aquatic production

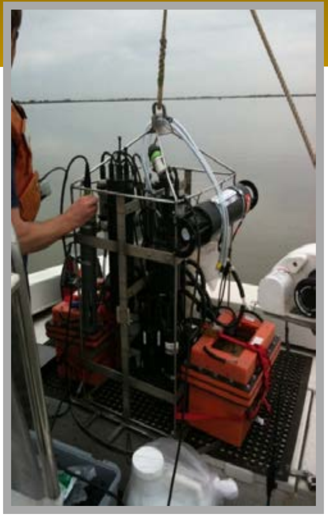
DISSOLVED ORGANIC CARBON — DOC production on LHT Export of DOC

PARTICLE SIZE — Larger particles coming onto LHT; export of smaller particles

Rate determination using continuous in situ measurements and proxies

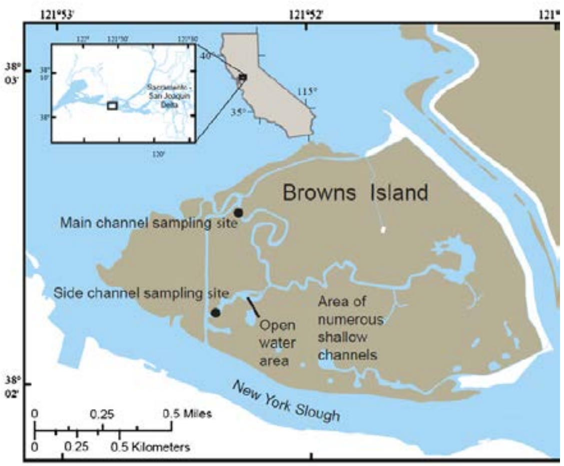


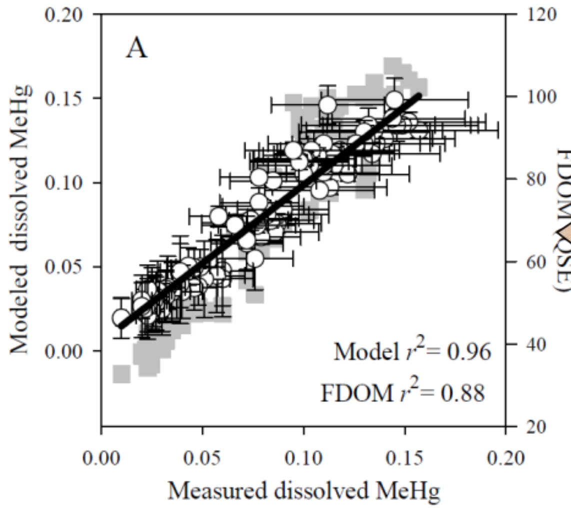


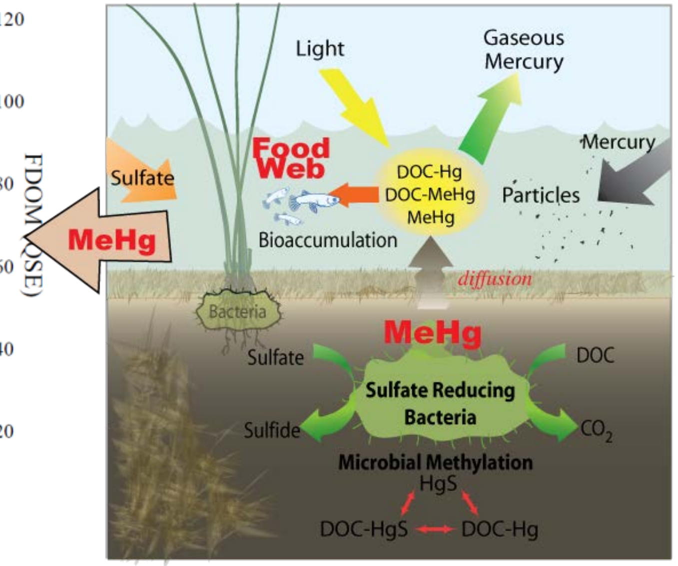


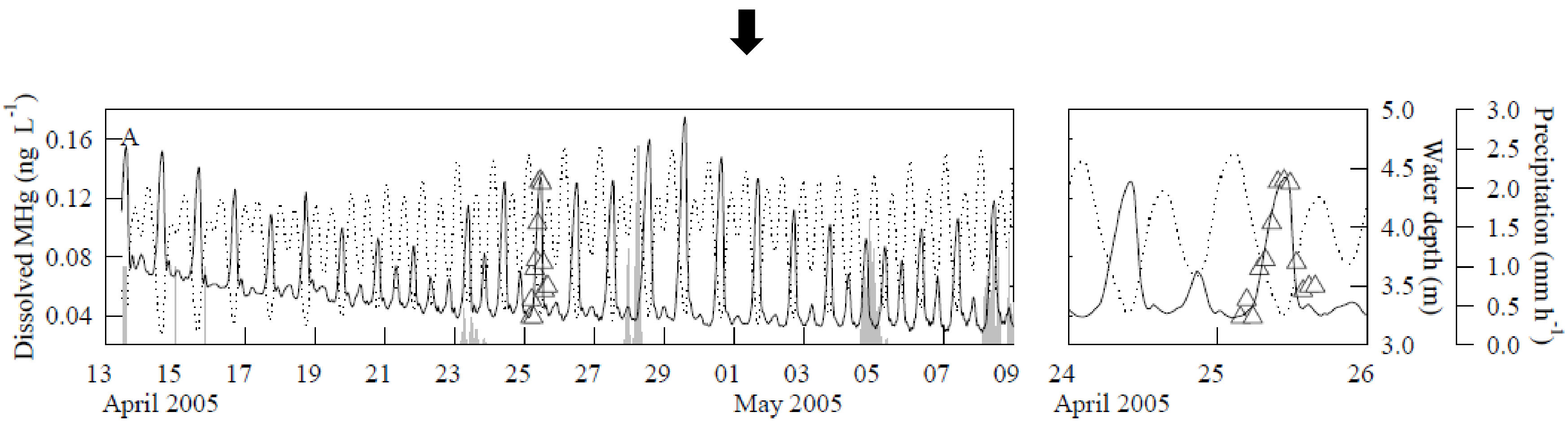
PROXY MEASUREMENT: Methylmercury export

Proxy measurements for high resolved MeHg flux from a tidal wetland, Browns Island, CA



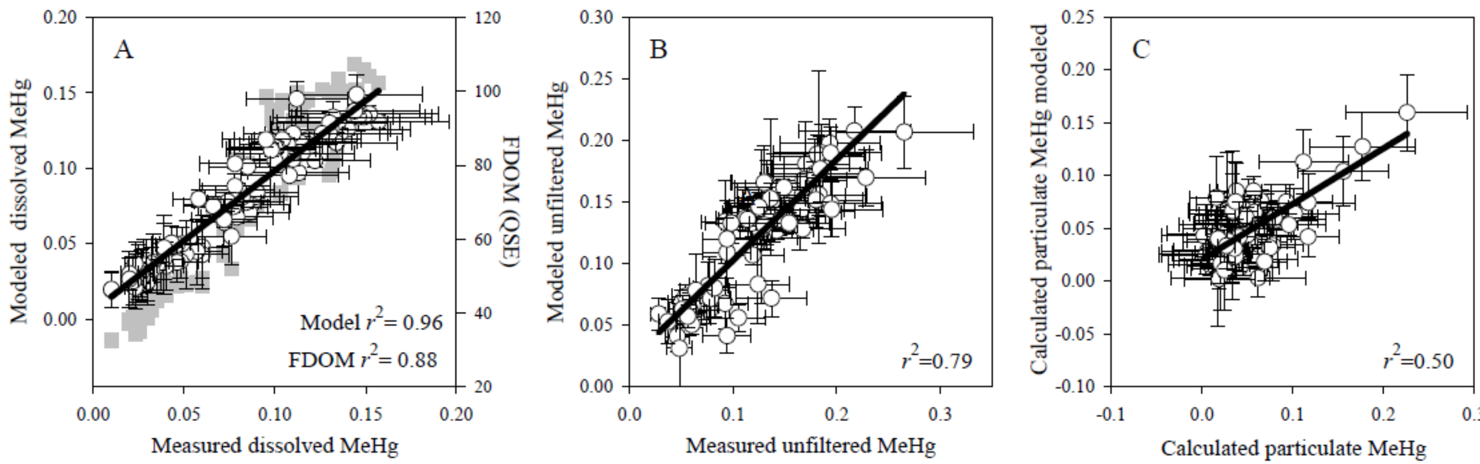






Bergamaschi et al., *2011,*

PROXY MEASUREMENT:
All mercury species and phases



DISSOLVED UNFILTERED PARTICULATE

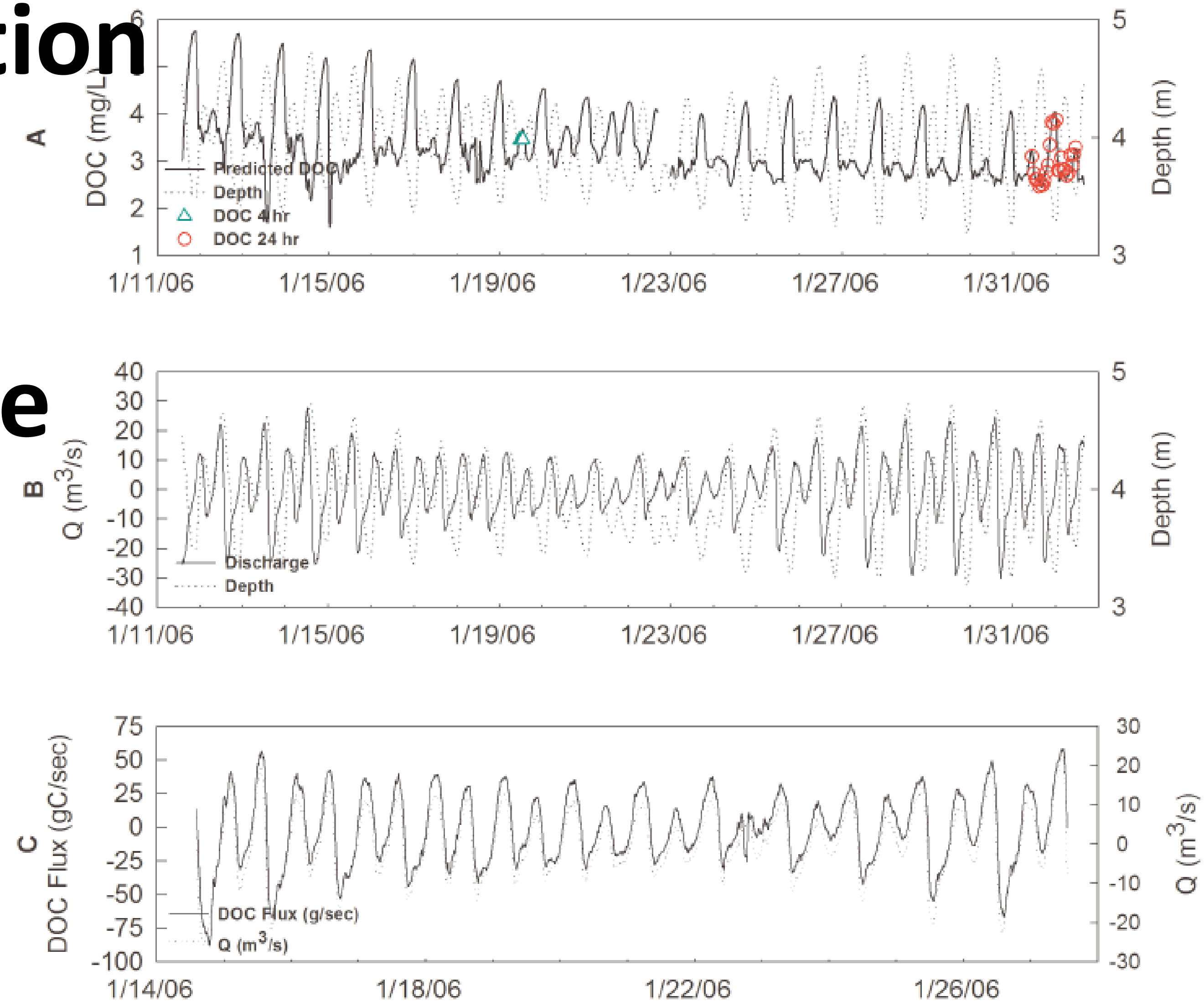
Bergamaschi et al., *2011,*

Concentration

X

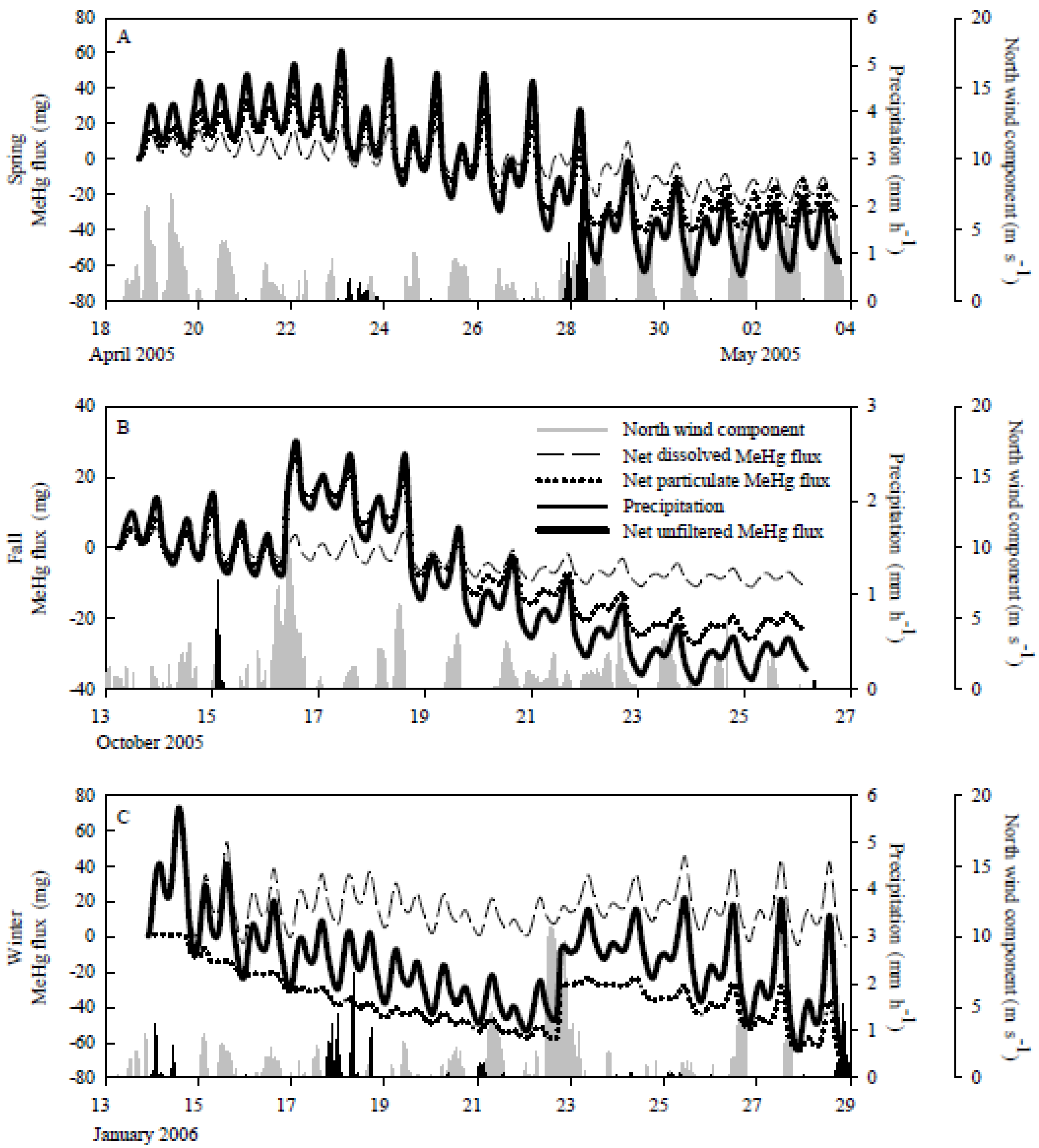
Discharge

Flux



(Downing et al., 2009)

Methylmercury fluxes and yields



YIELDS:

2.5 μg m^{-2} yr^{-1}

4-40 times previously published yields

Variation related to:

Tides

River flow

Storms

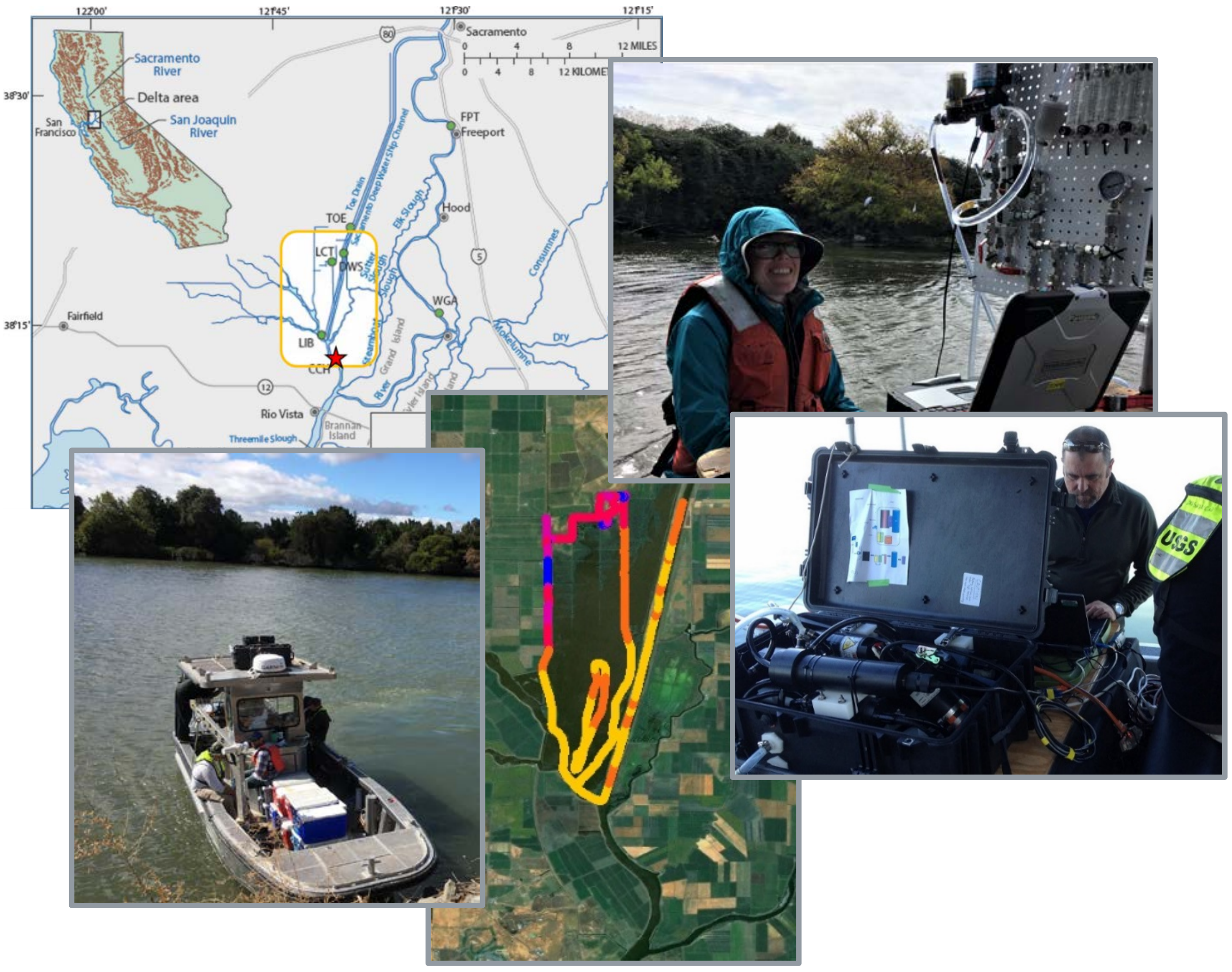
Wind direction

Barometric pressure

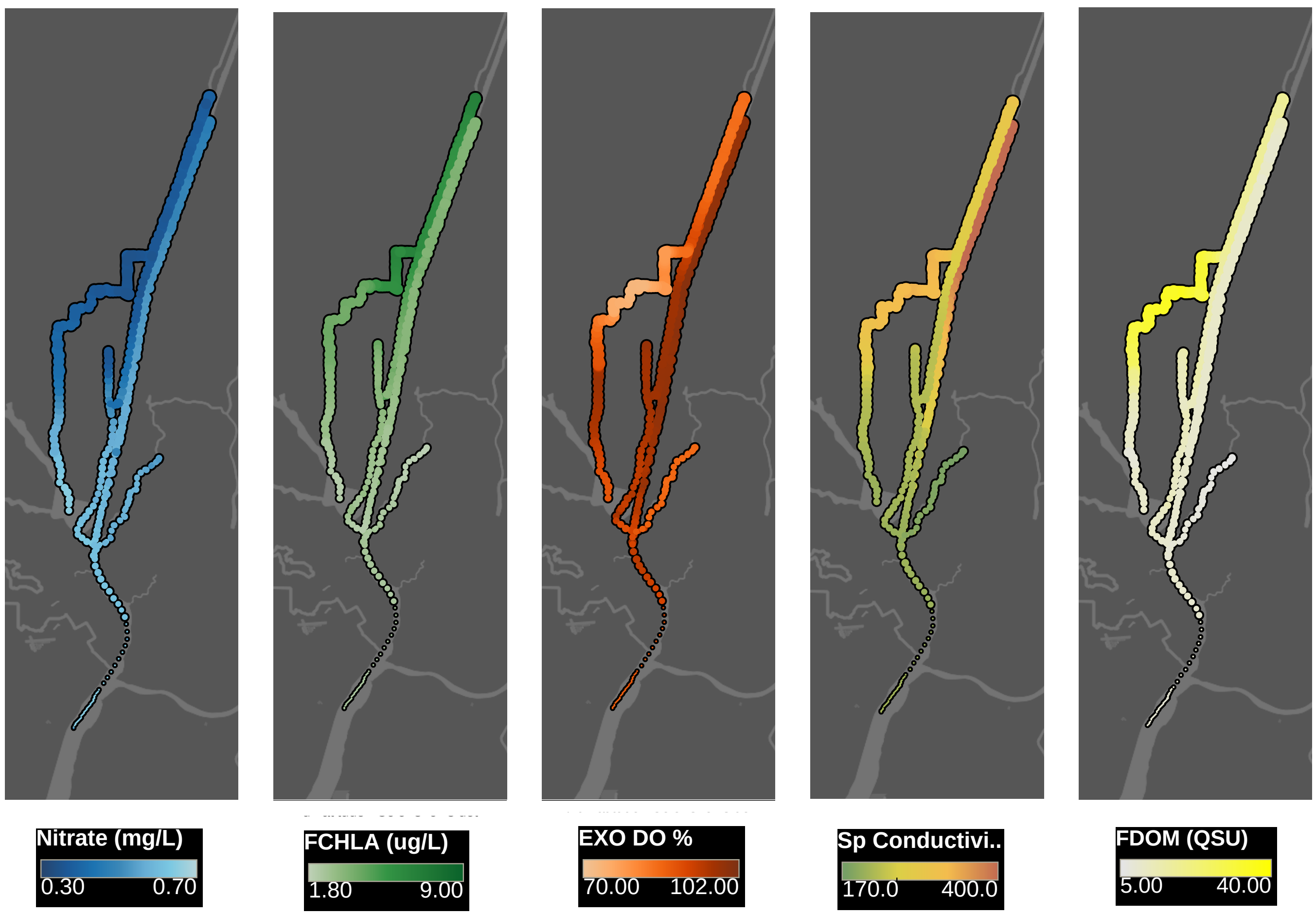
Bergamaschi et al., *2011*

Bergamaschi et al., *2012*

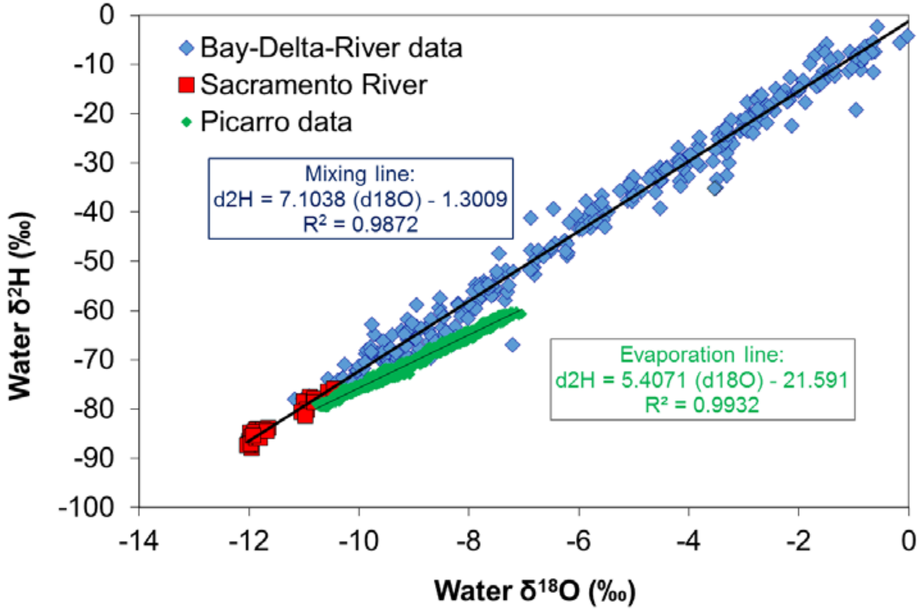
Rate determination using mapping together with residence time techniques



Water Quality in the Study Area



Mapping of water isotopes $\delta^{18}O$ and δ^2H



From water isotope ratios to residence time

$$\delta^2 H \ or \ \delta^{18} O = \frac{R_{sample}}{R_{standard}} - 1$$

Evaporation:Inflow (*E:I*) ratio
Steady-State.
(e.g. Brooks et al, 2014)

$$\frac{E}{I} = \frac{\delta I - \delta_L}{m(\delta^* - \delta_L)}$$

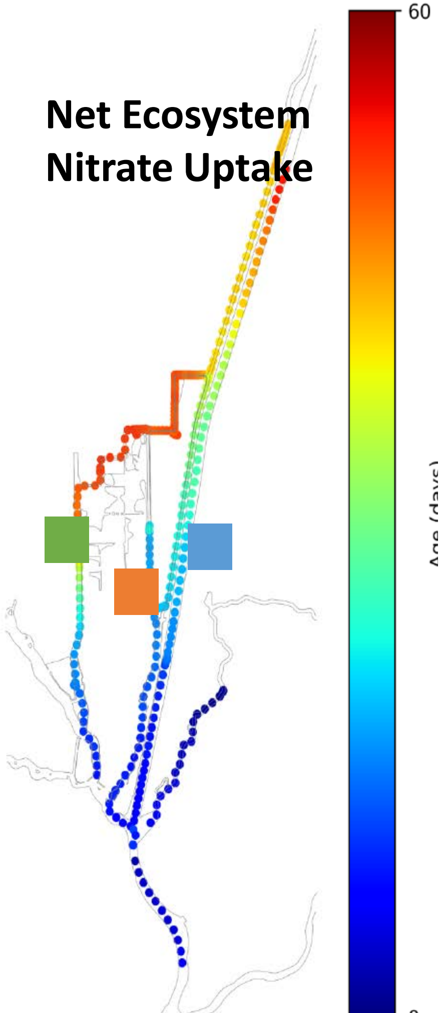
$$\tau = \frac{\%E \times D}{ETo \times 1.1}$$

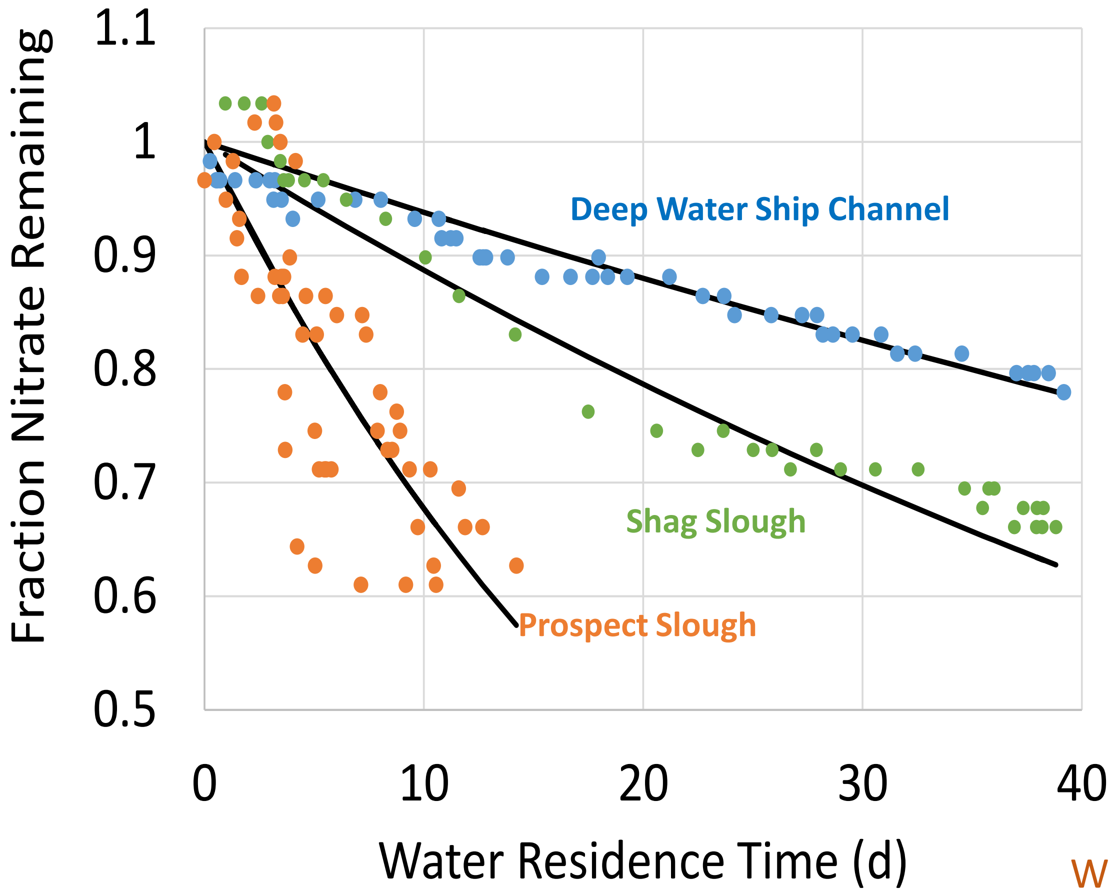
CIMIS ETo Data

Downing et al. ES&T (2016)

Nitrate uptake rates

Net Ecosystem Nitrate Uptake





Where rate (k): $\frac{dC}{dt} = kC$ ***and*** $C_t = C_0 e^{-kt}$ **:**

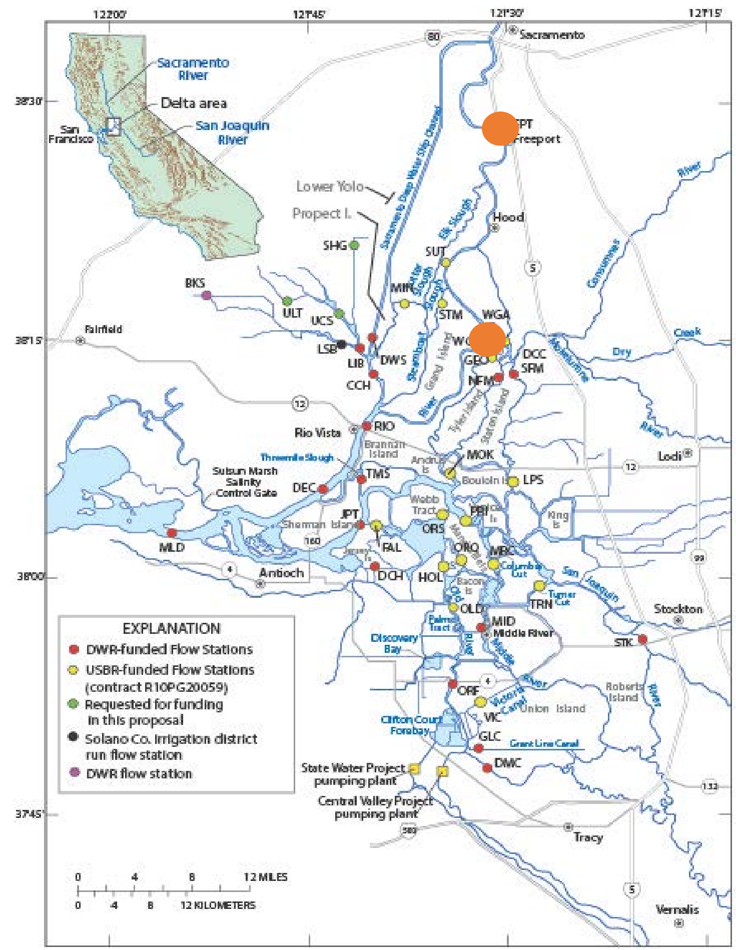
Whole-ecosystem uptake rates (k) ranged from 0.006 to 0.039 d^{-1}.

Why are rates different?

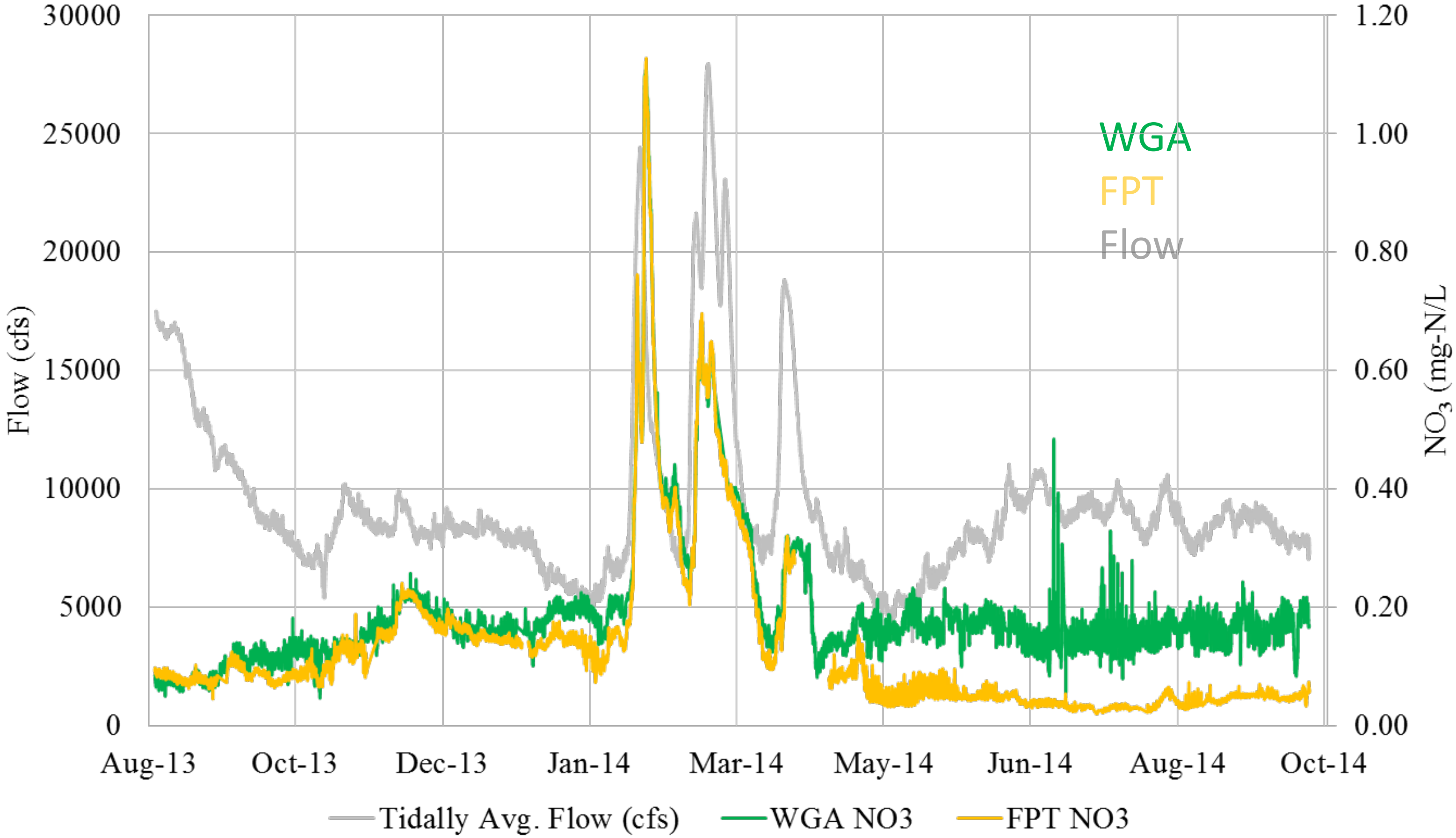
tidal wetlands
aquatic vegetation

Downing et al. ES&T (2016)

Rate determination using multiple continuous sensor deployments and hydrodynamic models



Estimating nitrification rates from nitrate changes down river



(Kraus et al., 2017)

Change in nitrate

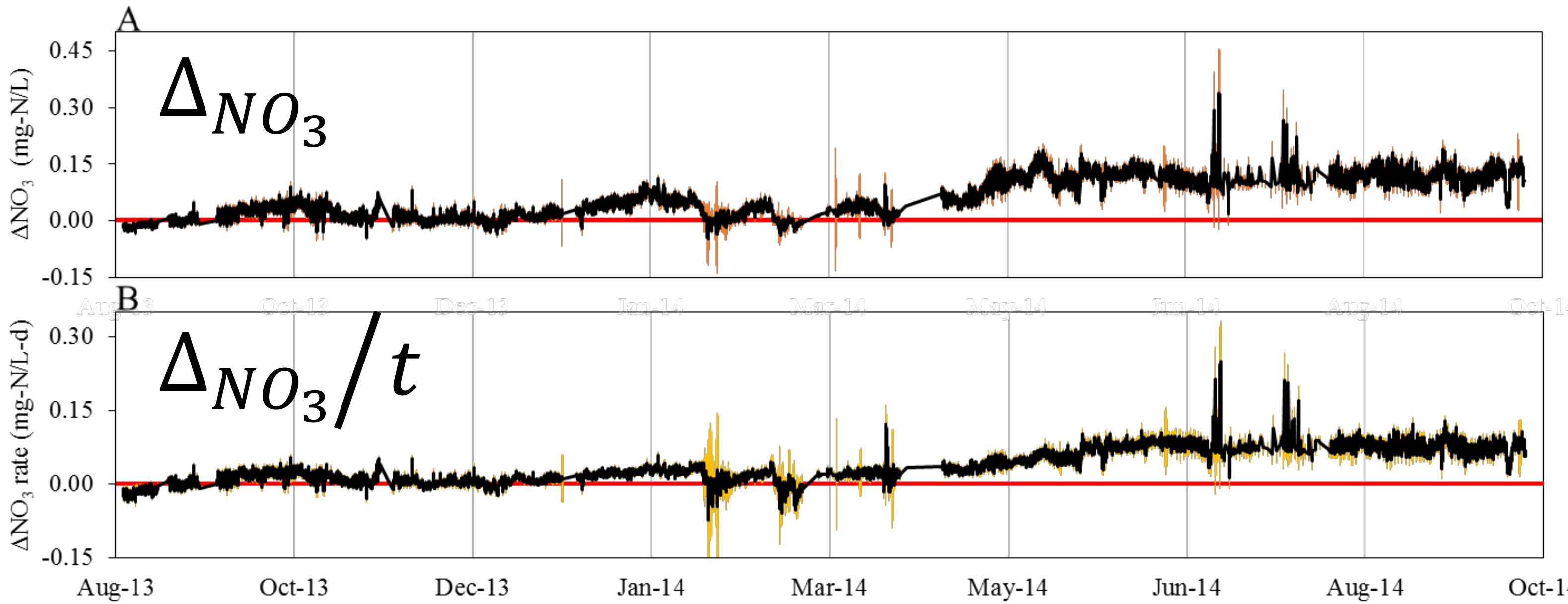


Figure 9. (A.) Net change in NO3 concentration calculated by subtracting concentrations at FPT from WGA, taking travel time between the two stations into account. Error bars showing standard deviation are indicated in orange and red delineates the 0 line associated with no change. (B.) Rate of NO3 change, calculated as the change NO3 divided by travel time. Error bars showing standard deviation are indicated in yellow, and red line delineates 0.

(Kraus et al., 2017)

Travel time model for tidal system

$$t_t = t * \sum_{km=0}^{29} (v_{fpt} * t)\frac{d_{fpt}}{29} + (v_{wga} * t)\frac{d_{wga}}{29}$$

Nitrification

$$\Delta_{NO_3} = k_{NIT}\frac{NH_4^+ t}{V_t} + k_{ON}[ON]t - k_{U,NO_3^{-2}}[NO_3^{-2}]t - k_{DN,NO_3^{-2}}[NO_3^{-2}]t$$

Nitrification rates from the literature

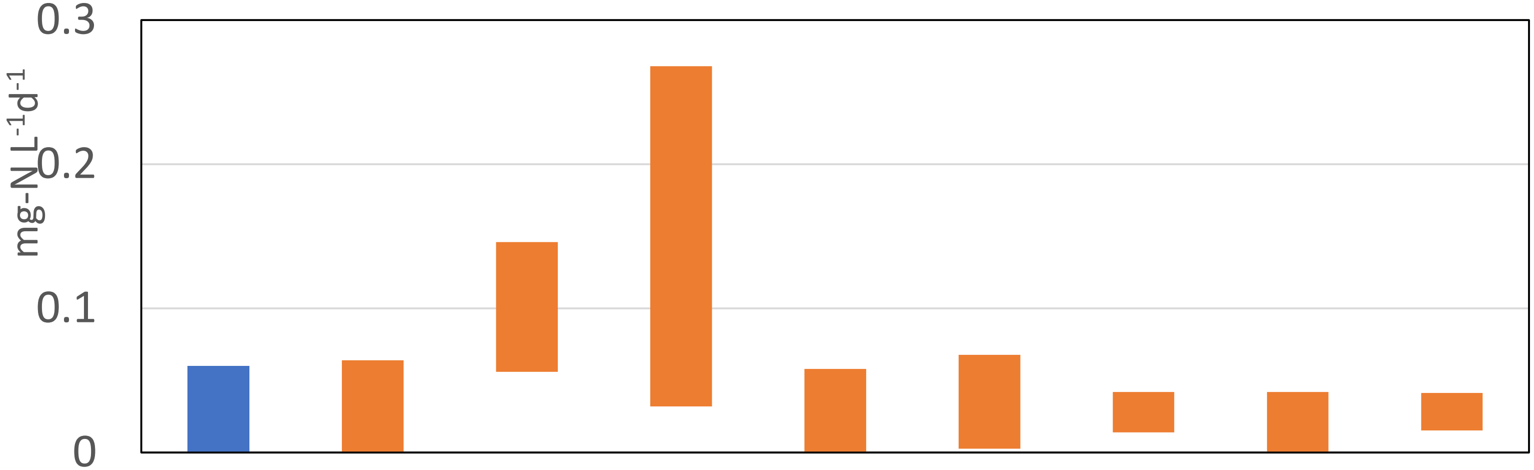
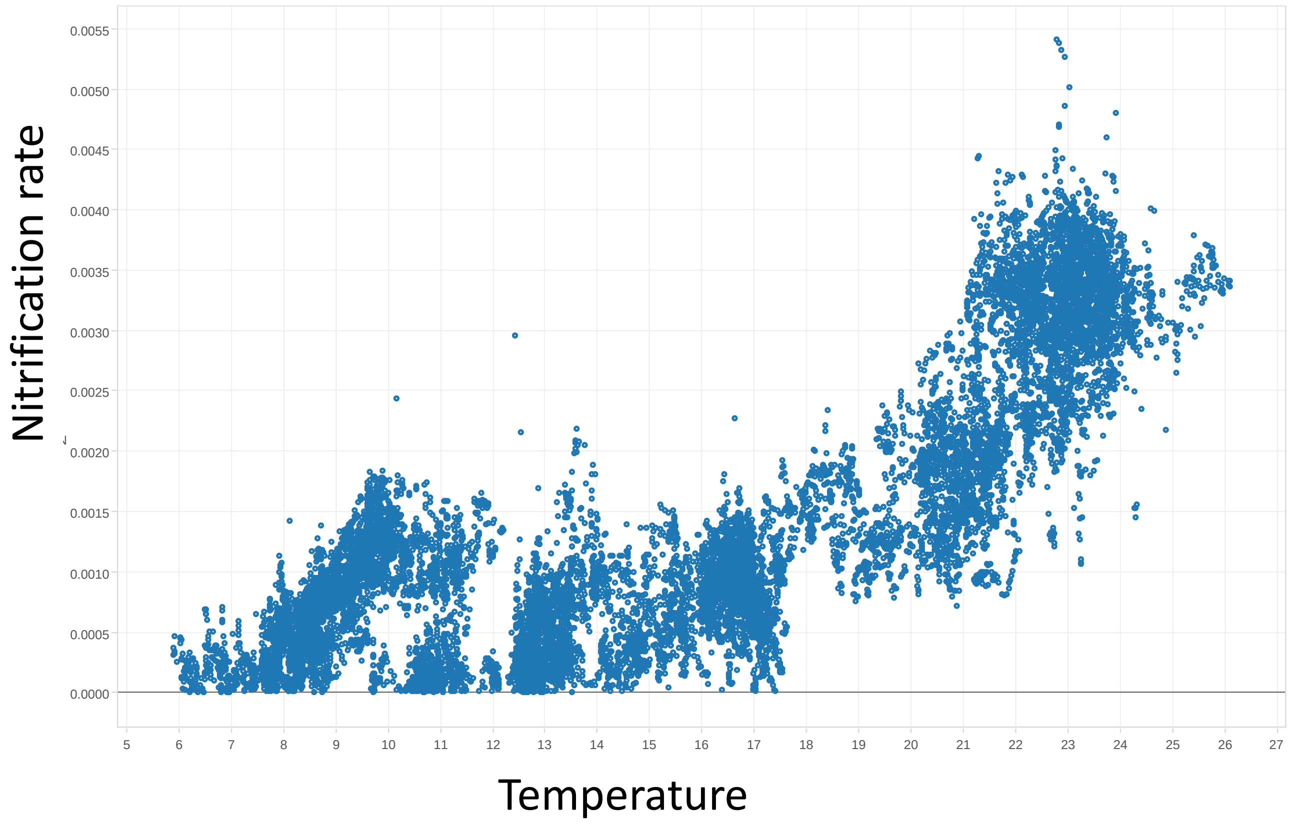


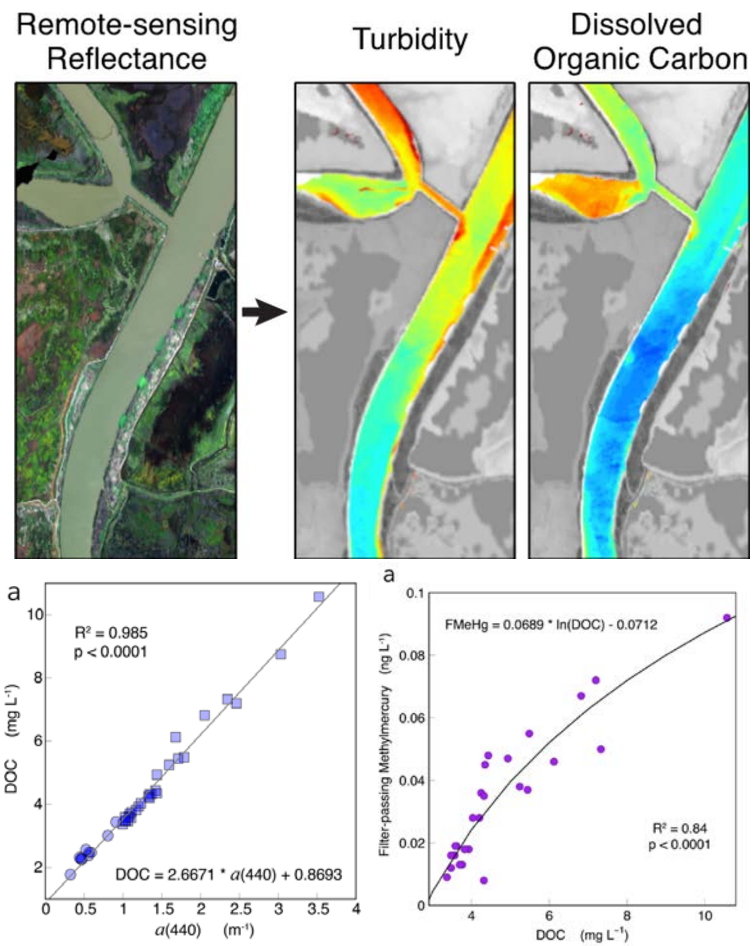
Table 6. Nitrification rates reported in the literature.

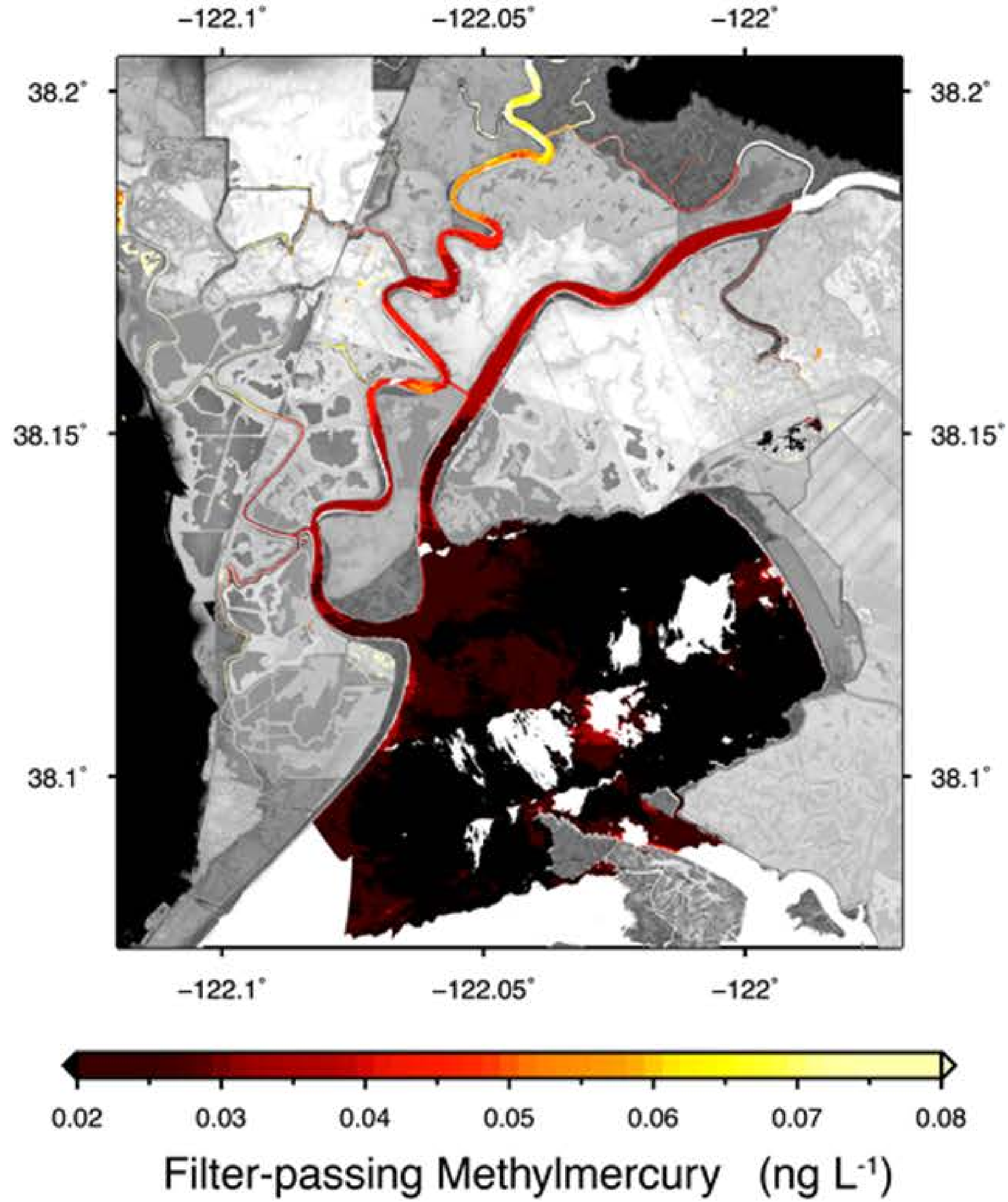
Region	Method	Nitrification Rate (mg-N/L-d)	Season	Reference
Sacramento River, California	Net Transformation	0.026 ± 0.011-0.045 ± 0.012	September 2013 - September 2014	This study 2015
Puget Sound, Washington	15-N	0.000112-0.00581	May, August, October, December	Urakawa et al. 2014
Chang Jiang River, China	15-N	up to 0.064	August, after typhoon	Hsiao et al. 2014
San Francisco Bay Delta, California	Net Transformation	0.056 (net transformation) 0.090 (nitrification factor)	March-April 2009	Parker et al. 2012
Scheldt Estuary, France	15-N	0.032-0.236	January, April, July, October 2003	Andersson et al. 2006
Rhone River, Northwest Mediterranean Sea	14-C	up to 0.058	November 1991-October 1992	Bianchi et al. 1999
Urdaibai Estuary, Spain	14-C	0.00028-0.065	August 1994	Iriarte et al. 1996
Rhone River, Northwest Mediterranean Sea	14-C	0.014-0.028	May 1992	Fliatra and Bianchi 1993
Tamar Estuary, England, UK	14-C	up to 0.042	May-August 1982	Owens 1986
Delaware River, New Jersey	15-N	0.0154-0.0266	July and September 1983	Lipschultz et al. 1986

Nitrification rate and Temperature



Connecting to Remote Sensing





Fichot, C. G., B. D. Downing, B. A. Bergamaschi, L. Windham-Myers, M. Marvin-DiPasquale, D. R. Thompson, and M. M. Gierach (2015), High-Resolution Remote Sensing of Water Quality in the San Francisco Bay–Delta Estuary, *Environmental Science & Technology*, doi:10.1021/acs.est.5b03518.

Benthic fluxes

Benthic chamber – real time flux measurements

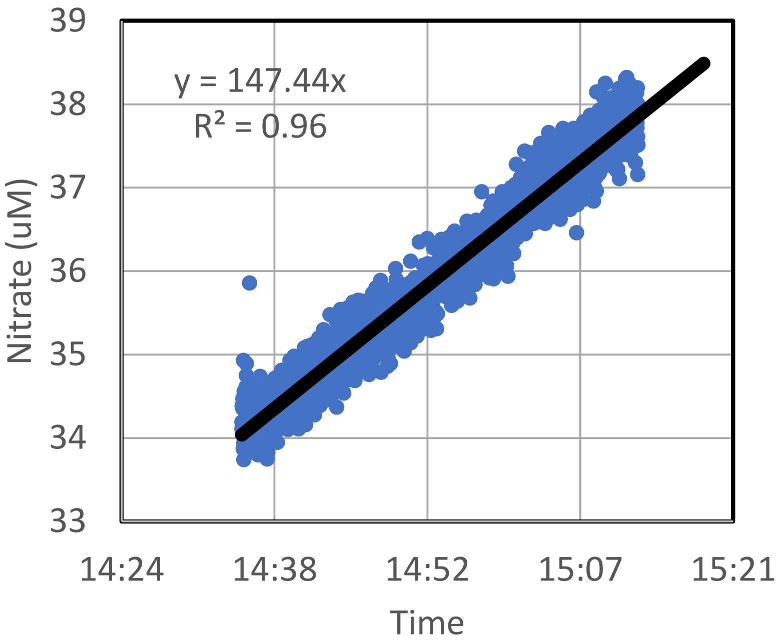


Figure 3. Graph showing change in nitrate concentration over time.

Final Thoughts

- New innovative methods are needed to understand the coupling of wetlands with pelagic aquatic systems
  - *Many improvements are needed in current methods*
  - *Especially to improve scalability and transferability*
- New instrumentation provides new opportunities
  - *We need to be creative in their use*
- High resolution data is needed to bound variability
  - *Continuous measurements are necessary*
  - *tidal systems are dynamic – cannot extrapolate from one or a few tides and get the right answer*
- Water age/residence time is an important driver of biogeochemical processes in wetlands
  - *Should include in our studies*
- Systematic methods are needed for scaling from plot-based to landscape-scale assessments
  - *Typological models of wetland geomorphology and hydrodynamics*
  - *Need many additional studies using common techniques*

THANKS!

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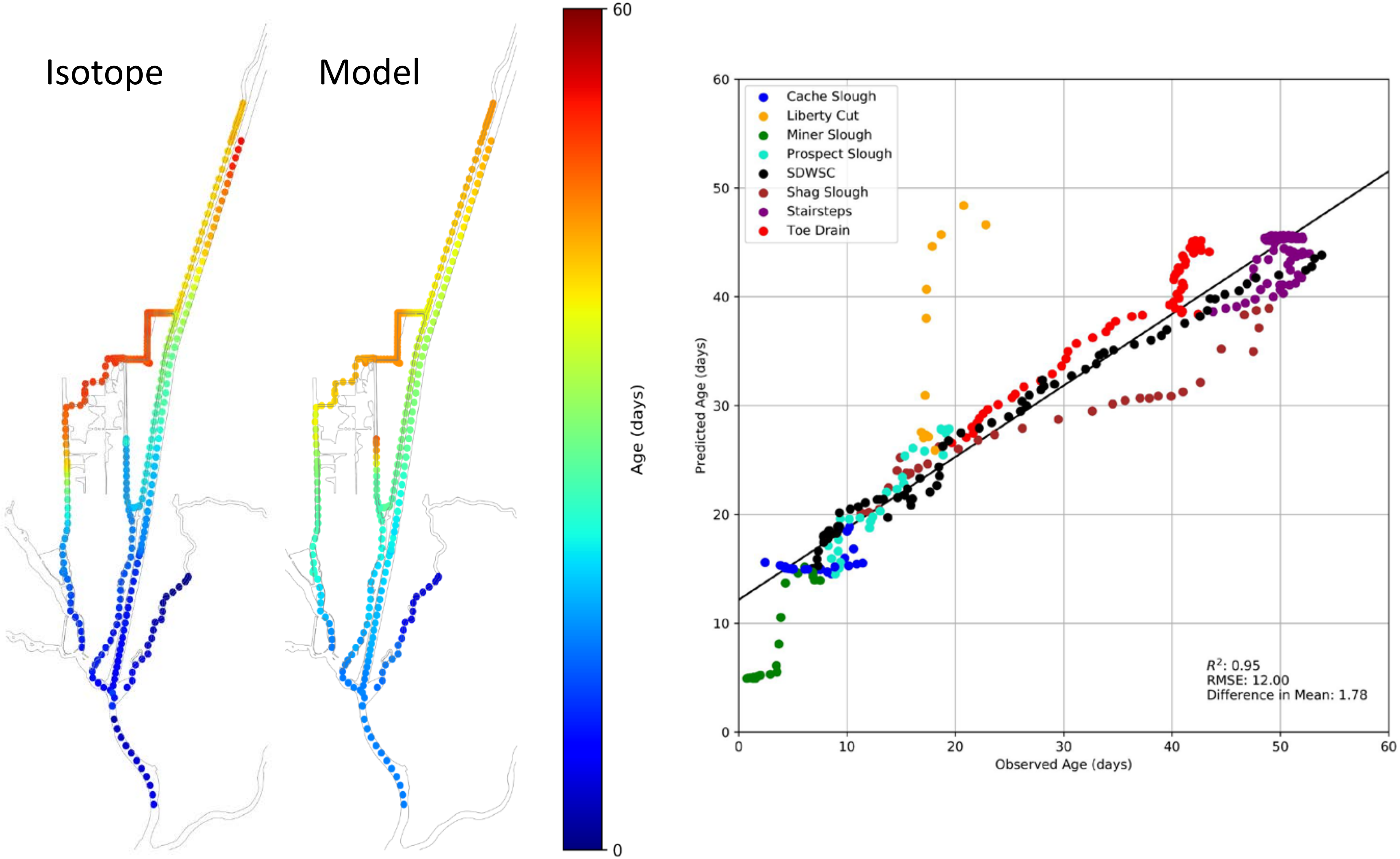
papers available at: http://profile.usgs.gov/bbergama/

Residence time (τ)



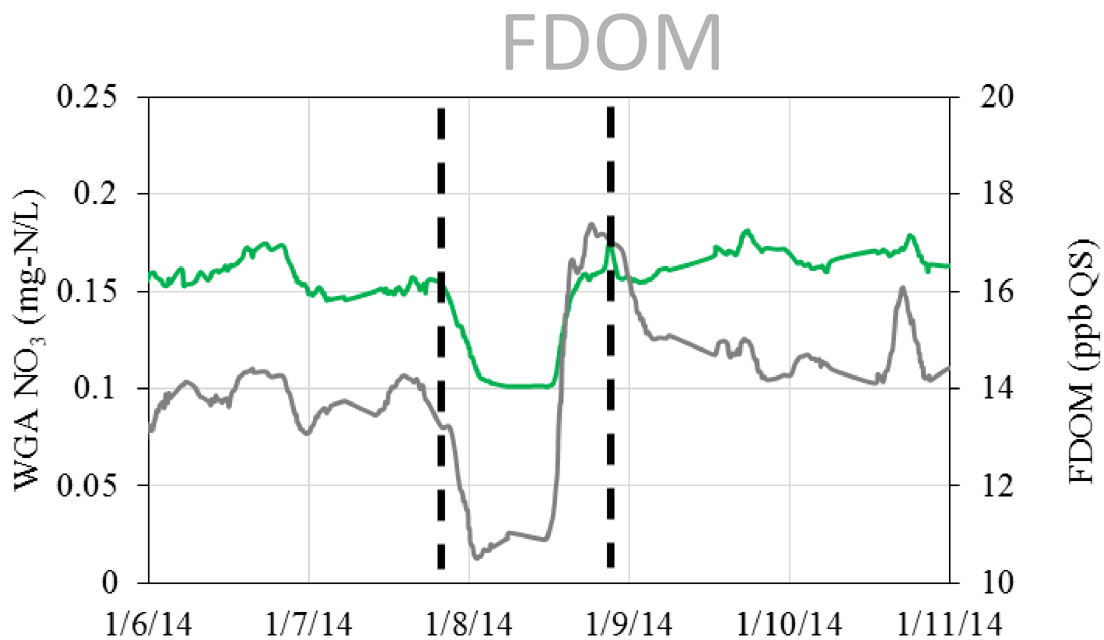
Downing et al., 2016

Gross et al., 2018 (in prep)

Ed Gross, 2018. RMA

Presence and Absence of Wastewater

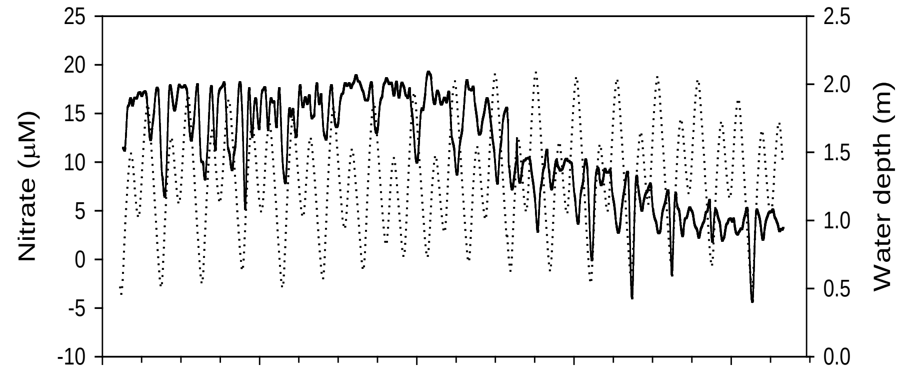
- Multiple WW holds during study period
  - ~30 holds
  - >7 hours
  - ~ 5 km parcel of wastewater free water



Areas needing improvement

- Better constraints on yield area
  - Soil drainage rates
  - Improved calculations
  - Model integration
- Longer records from different systems
  - Magnitude of variability
  - Modes and drivers of variation
- Models
  - Wetland typology
  - Critical characteristics

Why measure in HD?



HIGH DEFINITION

- Because you need to
  - even for loads……C:Q often doesn't work.
  - In tidal systems……….fuhgetaboutit
- Separate among multiple modes of variability in ecological drivers
- Understand and **quantify** fluxes and process rates
- Identify long term trends
- IMPROVE DISCRETE SAMPLING
  - Identify appropriate sampling timing and frequency
  - Establish linkages between discrete samples
  - Place discrete sampling to environmental and hydrologic context and relate to antecedent conditions