Biophysical controls on ecosystem-scale CO_2 exchange in a brackish tidal marsh in Northern California

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INTRODUCTION

Carbon (C) cycling in coastal wetlands is difficult to measure and model due to extremely dynamic atmospheric (vertical) and hydrologic (lateral) fluxes, as well as sensitivities to dynamic land- and ocean-based drivers. To date, few studies have begun continuous measurements of vertical and/or lateral C exchanges in these systems and as such our understanding of the key drivers of carbon cycling in coastal wetlands including inundation, soil and air temperature, radiation, and salinity remain poorly understood. Increasing the number of direct simultaneous measurements of vertical and lateral C fluxes is a critical first step to developing a better understanding of the drivers and sensitivities of C sequestration and greenhouse gas mitigation potential of coastal wetlands. Here we (1) investigate the biophysical drivers of whole ecosystem net CO_2 flux, and (2) asses the timescales at which the environmental drivers are influencing CO_2 exchange.

METHODS

STUDY SITE

Rush Ranch (RR) is located in the San Francisco Bay National Estuarine Research Reserve in Suisun Bay, CA, the most extensive marsh complex of the San Francisco Bay Delta, which itself is the largest estuary in the western U.S. The site is dominated by sedges (*Schoenoplectus* and *Typha* species), although it is increasingly influenced by an invasive perennial forb (*Lepidium latifolium L.*). Rush Ranch is classified as a high marsh, which the National Wetland Inventory estimates represents >58% of estuarine wetlands.

FLUX MEASUREMENTS

Biosphere-atmosphere exchange of CO_2 (NEE), water vapor (LE), and sensible heat (H) were measured using the eddy covariance method , with measurements beginning in March 2014. Meteorological instrumentation was deployed to accompany eddy covariance measurements, with sensors in the marsh installed in April 2016. In 2016, we also installed instrumentation to test the quantification of the lateral flux of carbon at First Mallard Slough, southwest of the flux tower. The equipment installed includes a YSI water quality meter and C-sense pCO2 probe.

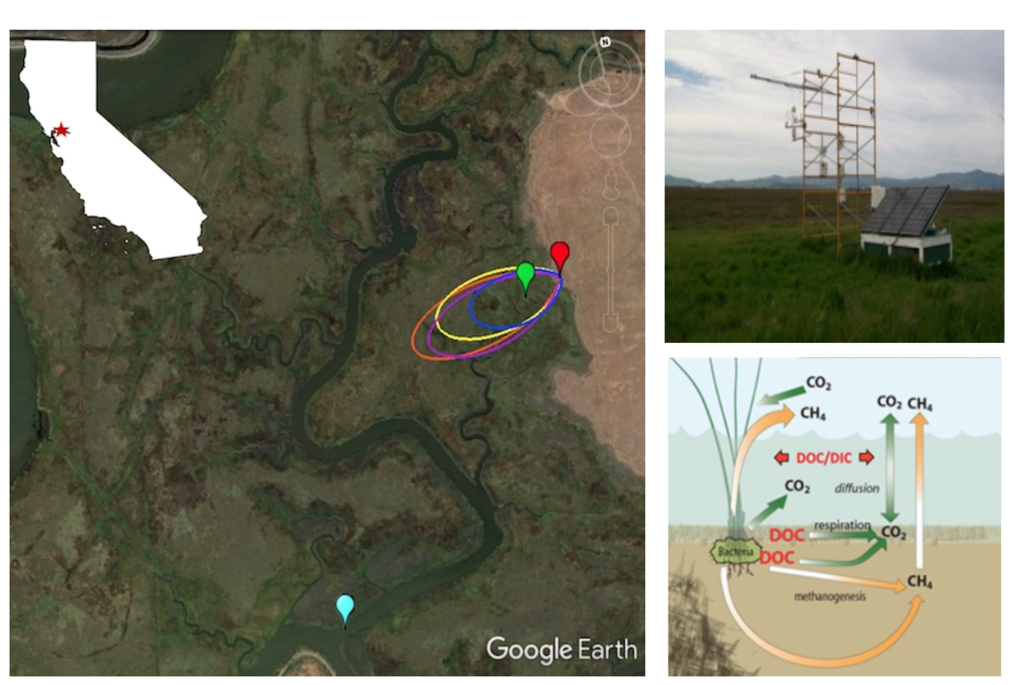
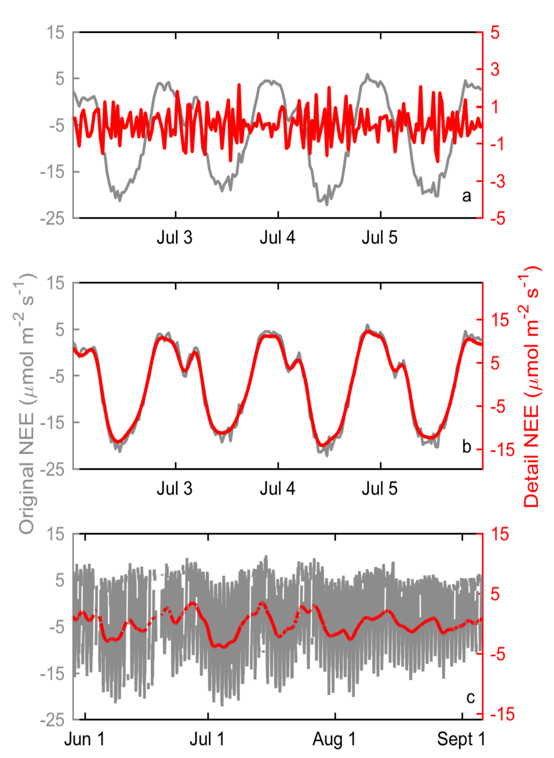


Figure 1. Vertical and lateral flux measurements at the site.

WAVELET DECOMPOSION & INFORMATION THEORY

We used a combination of wavelet analysis and information theory to analyze interactions between whole-ecosystem NEE and biophysical drivers. Figure 2 illustrates the wavelet detail reconstruction for hourly, diel, and multi-day scales.



Then the relative mutual information (I^R) between NEE and biophysical drivers was computed within each time scale over a range of time lags (Sturtevant et al., 2015). I^R represents a normalized measure of statistical dependence of Y on X, with higher values indicating greater dependence. The power of mutual information lies in the lack of parametric assumptions about the relationship between X and Y and thus is able to identify linear and nonlinear interactions alike.

Figure 2. Example NEE variation isolated with wavelet decomposition at the hourly, diel, and multiday time scales. Gray lines are original half-hourly measurements. The red line indicates the wavelet detail reconstruction.

RESULTS

ATMOSPHERIC FLUXES & ENVIRONMENTAL CONDITIONS

Meteorological variables and fluxes exhibited a strong seasonal pattern superimposed with notable variability at the multiday and diel scales. Inundation of the marsh only occurred during spring tides, and only high spring tides caused flooding, which at this site currently occurs near midnight in the summer months. Water and air temperature were higher during neap tides than during spring tides. H, LE, and NEE were influenced by the fortnightly tidal cycle and NEE showed strong variability at the multiday and diel scales (Figure 2 and Figure 3d).

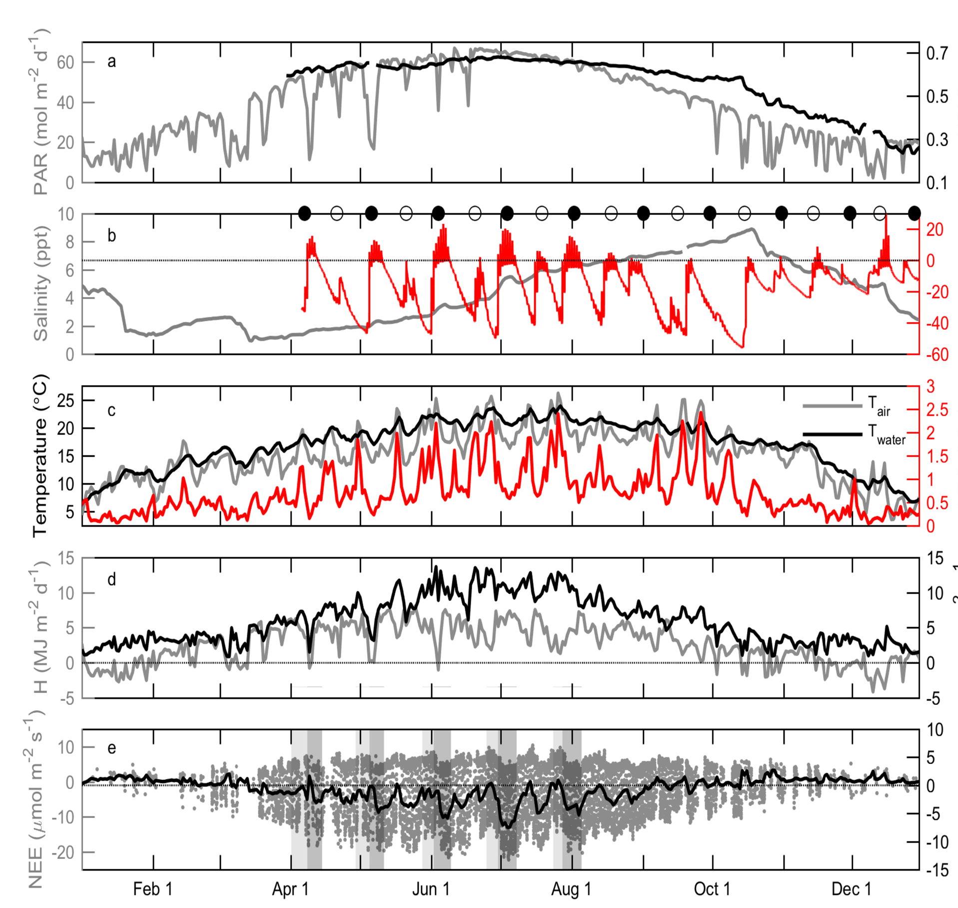


Figure 3. Daily average or half-hourly environmental conditions and NEE at the site in 2016.

INTERACTIONS BETWEEN NEE & BIOPHYSICAL VARIABLES

Figure 4 indicates the most significant eco-atmosphere interactions at each time scale, which is indicated by the length of the bars, and whether a lead or lag was involved in the process, as indicated by colored extensions to the bars.

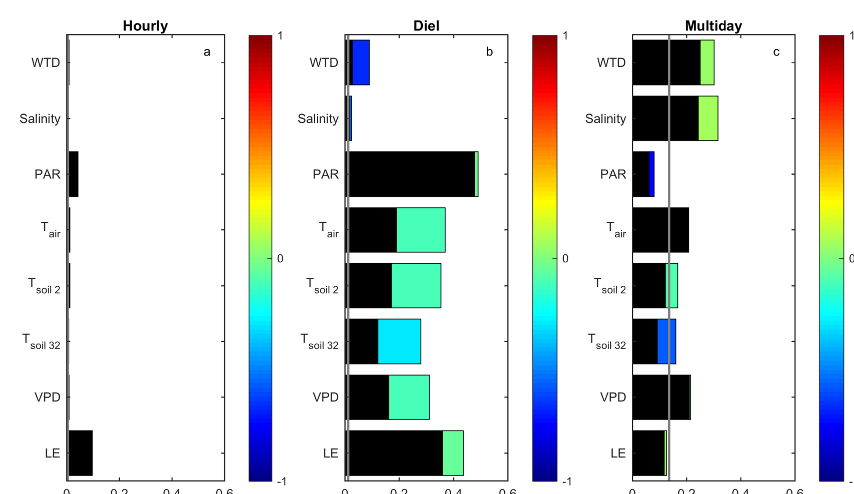


Figure 4. Relative mutual information ($I^R_{X,NEE}$) between NEE & biophysical variables (X = each variable on the y axis) from hourly to multi-day time scales.

Multiday variation in NEE was most strongly linked to water table (WTD). NEE varied nearly synchronously with WTD, with higher net CO_2 uptake when water levels were higher. Similarly, there was a synchronous, although slight weaker, linkage between NEE and T_{air}, with higher net CO_2 uptake when temperatures were cooler (i.e. spring tides).

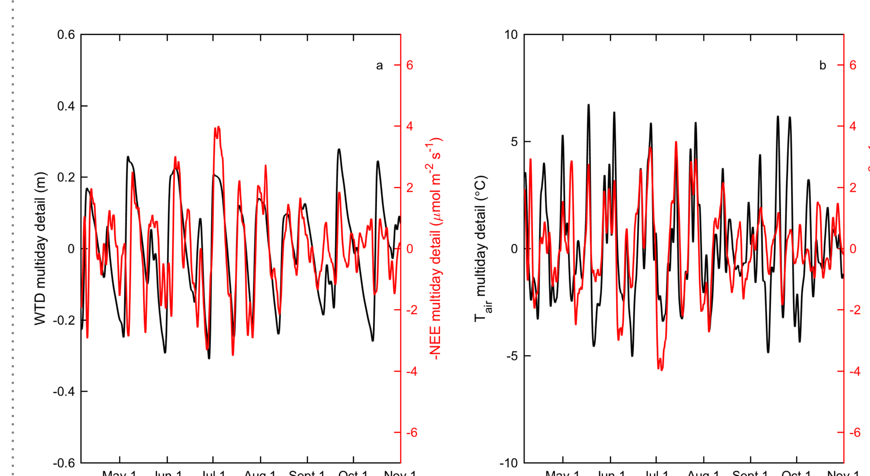


Figure 5. Multi-day wavelet detail reconstructions of (a) NEE and WTD, and (b) NEE and T_{air} during the 2016 growing season.

At the diel scale, NEE was dominantly and largely synchronously linked to PAR. However, there was also a significant interaction between NEE and WTD, with nighttime high tides resulting in an instantaneous drop in respiration, despite incoming warmer waters causing an increase in soil temperature (Figure 6).

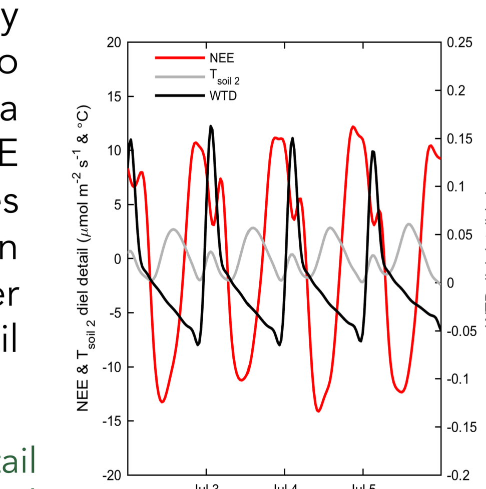


Figure 6. Diel wavelet detail reconstructions of NEE, WTD, and soil temperature at 2cm depth (TS 2cm).

INFLUENCE OF TIDES ON NEE, GPP, and R_{eco}

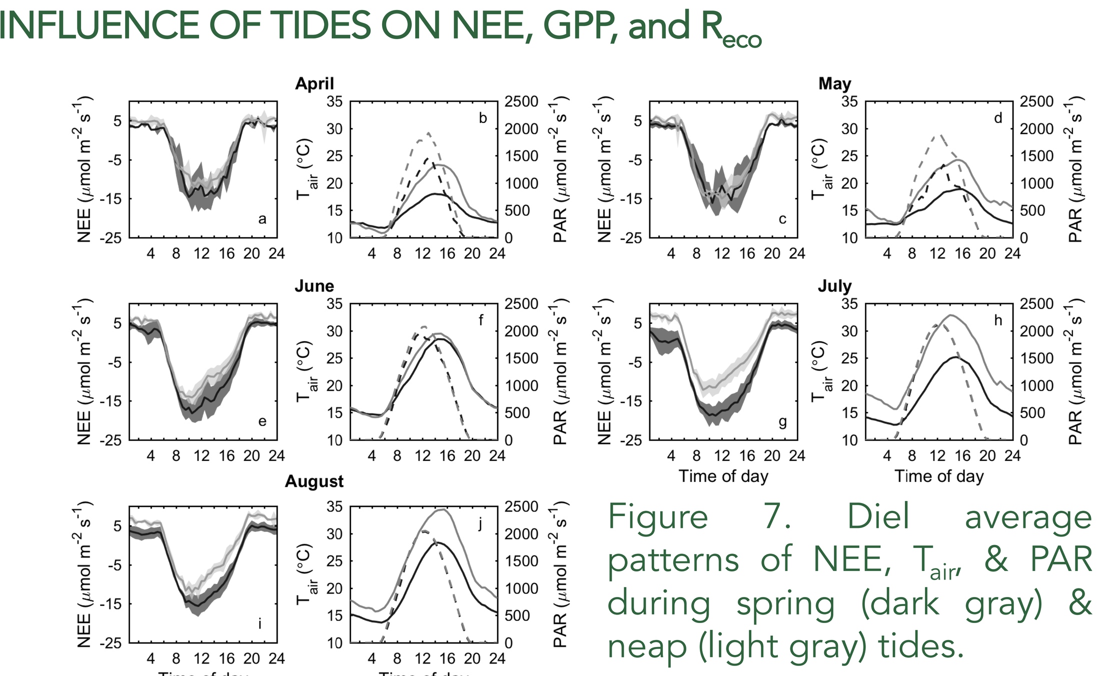


Figure 7. Diel average patterns of NEE, T_{air} & PAR during spring (dark gray) & neap (light gray) tides.

INFLUENCE OF TIDES ON NEE, GPP, and R_{eco} (CONT.)

Large variations in environmental conditions made it difficult to assess the direct and indirect influence of tides on NEE, photosynthesis (GPP), and respiration (R_{eco}) (Figure 7). However, with respect to R_{eco}, nighttime temperatures in April and June were not significantly different between neap & spring tides, while R_{eco} did differ significantly; R_{eco} was 21% (April) to 33% (June) lower under higher water levels, indicating the importance of water levels in modulating NEE.

A simple modeling exercise was conducted to help further examine the confounding influence of temperature and WTD on R_{eco} during spring versus neap tides.

$$R_{eco} = r b \exp\left(E_0\left(\frac{1}{T_{ref}-T_0} - \frac{1}{T_{air}-T_0}\right)\right)$$

Modeled R_{eco} was 24 to 27% lower when water levels were higher, and flooding appeared to have a larger influence on R_{eco} than temperature.

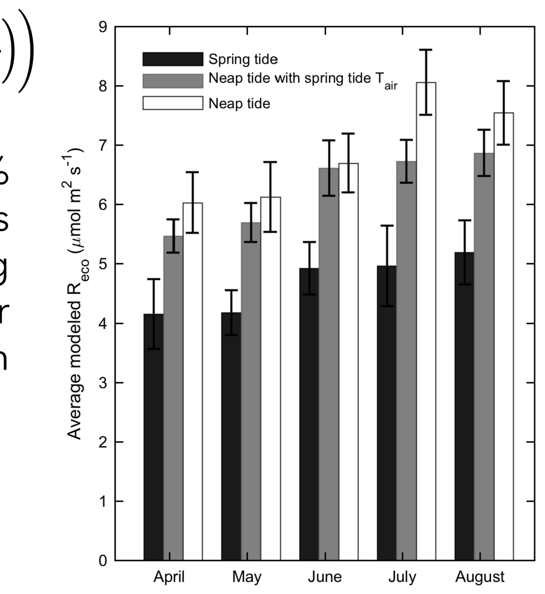


Figure 7. Average modeled R_{eco} for spring & neap periods.

$$NEE = -\frac{A_{max}\alpha \mathrm{PAR}}{A_{max}+\alpha \mathrm{PAR}} + R_{eco}$$

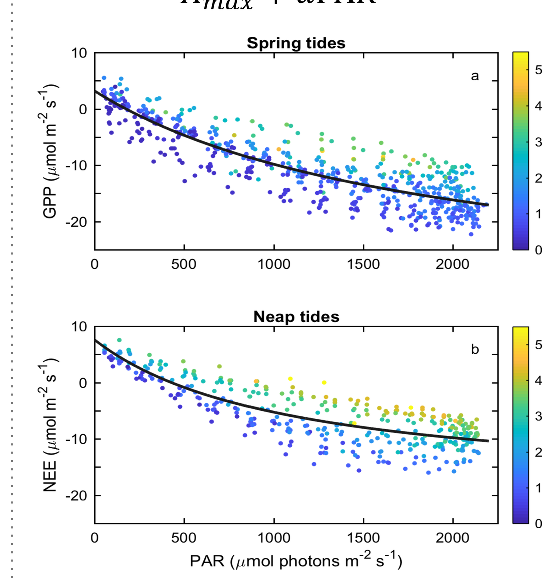


Figure 8. Daytime NEE as a function of PAR.

A_{max} was significantly lower during neap tides than spring tides, when T_{air} and VPD were higher but salinity was lower. LUE decreased significantly with T_{air} and VPD, but not salinity.

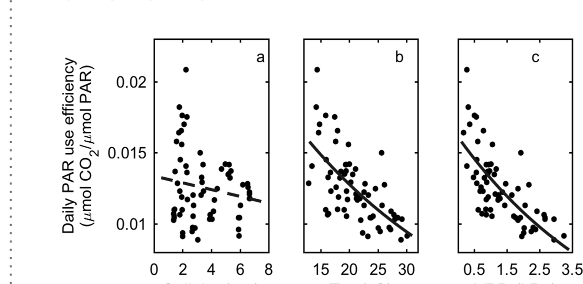
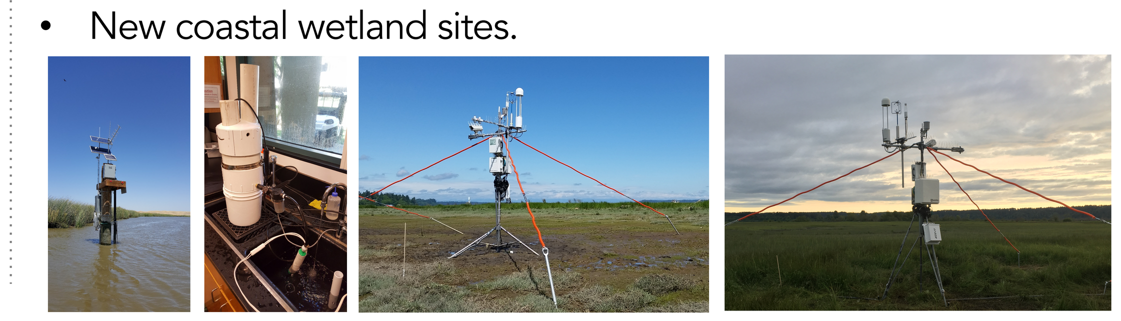


Figure 9. LUE a function of daytime average (a) salinity, (b) T_{air}, and (c) VPD.

CONCLUSIONS & FUTURE DIRECTIONS

- NEE showed considerable variability at the diel and multi-day scales.
- Episodic flooding significantly influenced R_{eco}, likely due to the suppression of CO_2 efflux from the soil as the water creates a physical barrier against gas diffusion.
- The effect of tides on T_{air} and VPD influenced GPP, with higher GPP during cooler spring tides.
- Further research on lateral C transport is key to investigating the influence of tides on the role of coastal wetlands as C sinks or sources.
- New coastal wetland sites.



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References: Sturtevant, C., B. L. Ruddell, S. H. Knox, J. Verfaillie, J. H. Matthes, P. Y. Oikawa, and D. Baldocchi (2016), Identifying scale-emergent, nonlinear, asynchronous processes of wetland methane exchange, J. Geophys. Res. Biogeosci., 121, 188–204, doi:10.1002/2015JG003054; Lasslop, G., et al. "Separation of net ecosystem exchange into assimilation and respiration using a light response curve approach: critical issues and global evaluation." *Global Change Biology* 16.1 (2010): 187-208.