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Sediment temperature control on methane ebullition in a small eutrophic reservoir

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Introduction: reservoirs and greenhouse gases

Background:

- Reservoirs are an important source of the greenhouse gas (GHG) methane (CH₄)
- Reservoirs can have higher CH₄ emission rates than natural lakes due to:
 - High ratio of catchment to reservoir area
 - Abundant organic matter from submerged vegetation
- Global annual emissions (and 95% confidence intervals) of CH₄ from reservoirs are estimated to be 606.5 (413 -1036) Tg CO₂-eq CH₄ (Deemer et al., 2016)
- The rate of CH₄ production and consumption by bacteria (methanogens and methanotrophs, respectively) are both positively affected by temperature (Fuchs et al., 2016).
- A study looking at lake sediments found that an **increase in temperature disproportionately effects CH₄ production over consumption**, leading to an increase in CH₄ emissions with increasing temperatures (Thanh Duc et al., 2010).

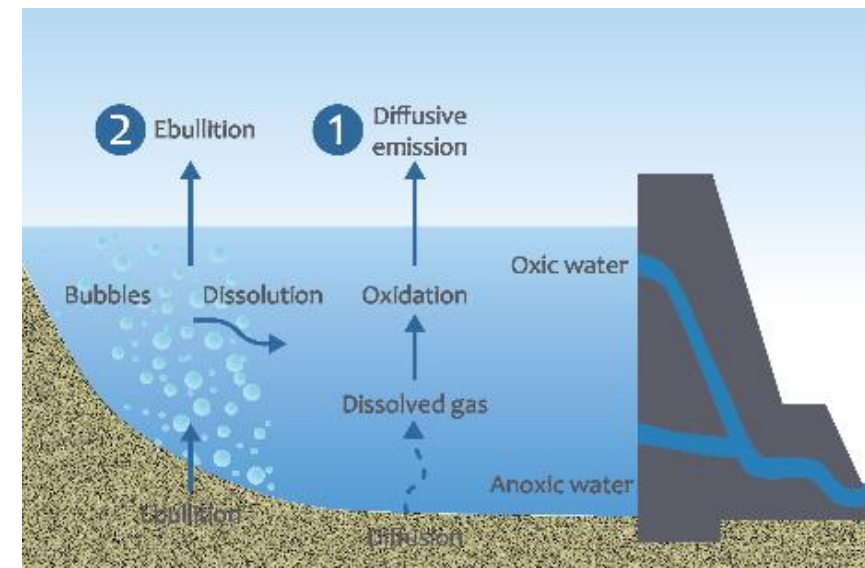


Figure 1: Gas dynamics in reservoirs

Objective:

Investigate the relationship between sediment temperature and CH₄ emission at a small eutrophic lake in southwestern Ohio, US over two years, from multiple locations and with multiple methods:

- continuous ebullition measurements at a shallow site
- continuous ebullition measurements at a deep site
- eddy covariance flux measurements over shallow waters

Methods: eddy covariance and inverted funnels

I. Eddy covariance

- Jan 2017 - April 2018: deployed off of a dock piling (~20 m from shore)
- April – Nov 2018: deployed off of an aluminum tower >200 m from shore
- Measuring fluxes of CH₄, carbon dioxide (CO₂), water vapor, and energy
- Auxiliary measurements: rainfall, net radiation, T, RH, and PAR
- Water temperature profiles measured near the shallow (1.3 m) and deep (8 m) sites

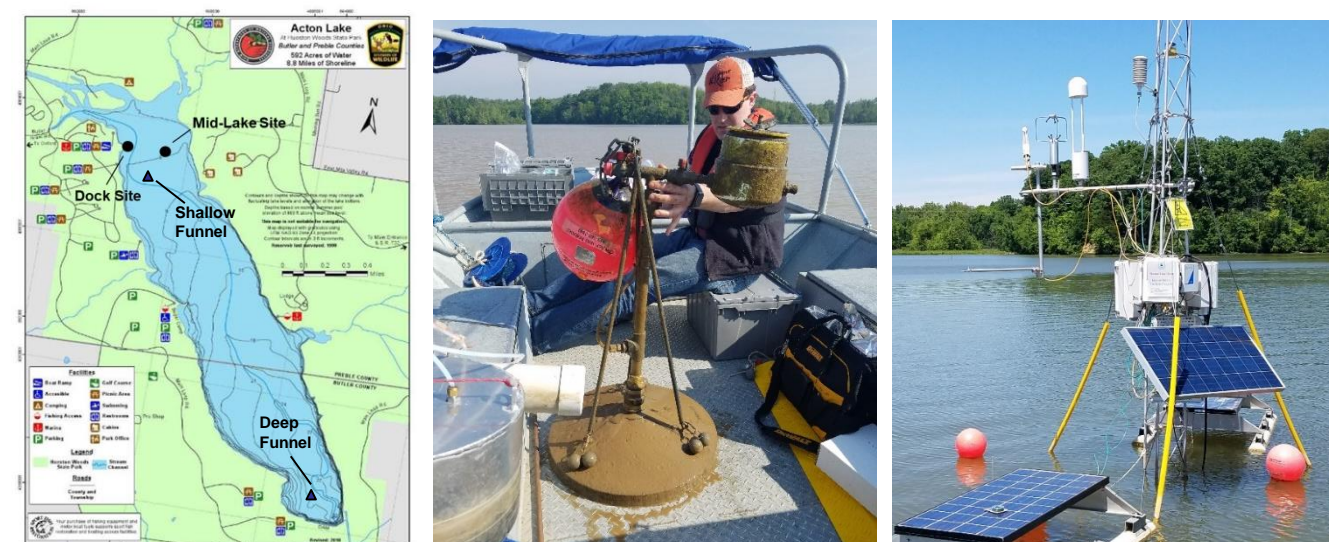
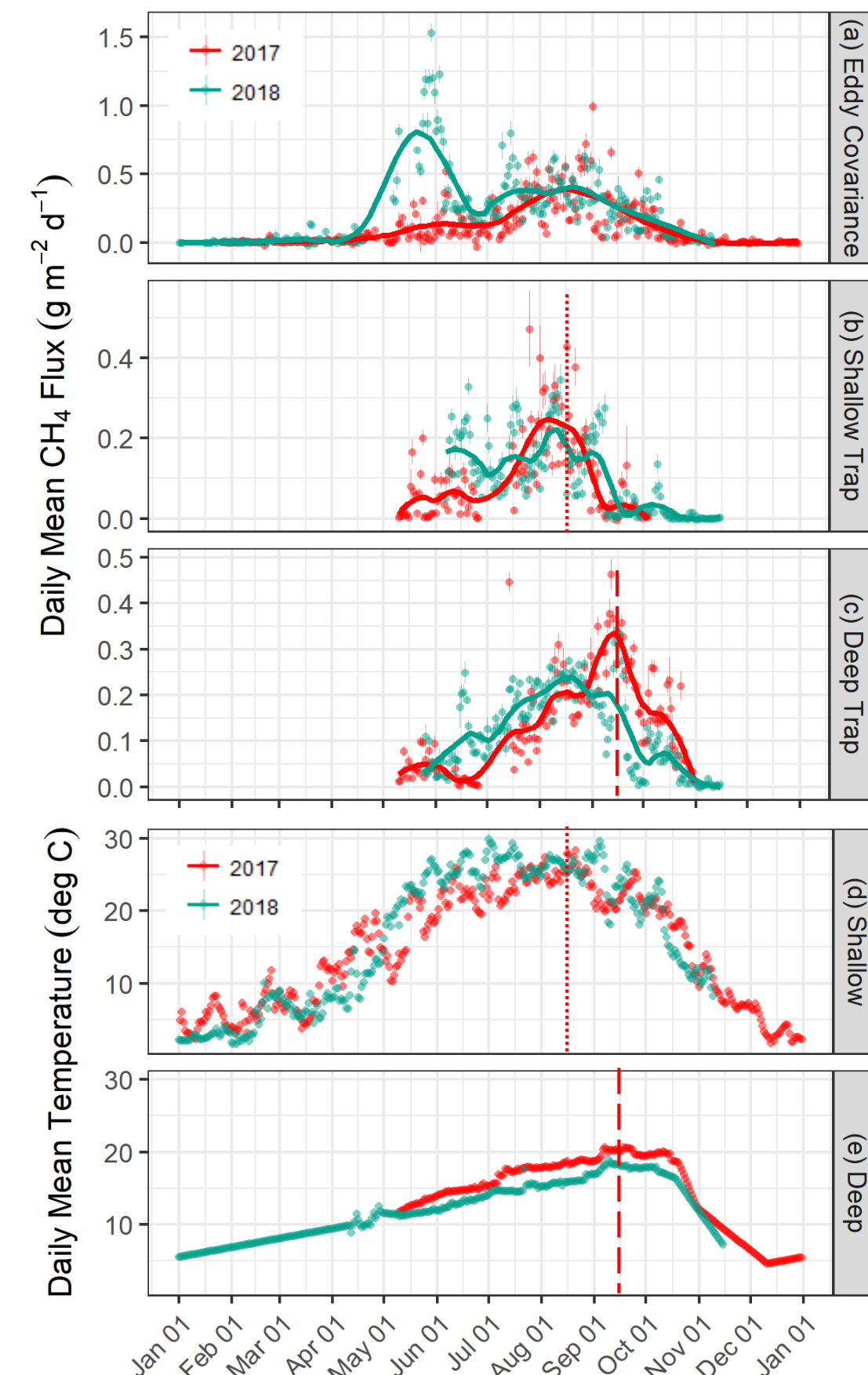


Figure 2: Map of Acton Lake measurement sites (a); photo of an inverted funnel ebullition trap (b); photo of the mid-lake eddy covariance flux tower (c)

II. Inverted funnels

- Deployed May – Dec 2017 and 2018
- Measure volumetric ebullition on a 5-minute timestep using a differential pressure sensor
- Concentration of CH₄ in the bubble gas determined via bi-weekly grab samples analyzed by GC-FID

Results I: seasonal patterns in methane emissions



I. 2017:

Red markers, red whiskers (\pm se), and red traces (loess smoothed, span = 0.3) in Figure 3 a-c:

- Gradual increase from background to peak emissions in late summer observed in 2017
- Maximum ebullition at the deep site (c) is shifted in time relative to the the shallow site (b), corresponding to an offset in maximum sediment T (e, d), illustrated by dashed and dotted lines, respectively

II. 2018:

Green markers, whiskers, and traces in Figure 3 a-c:

- Large emission event observed in late spring, kicking off a season characterized by flashy emission events
- This flashy emission profile is also present at the shallow site (b), but not the deep site (c)
- The elevated emissions in the late spring may have been driven, in part, by the warmer temperature compared to the prior year (Figure 3 d)

Figure 3: Time series of CH₄ emissions (a-c) measured via eddy covariance (a), inverted funnel traps at the shallow site (b), and deep site (c); and sediment temperature (markers) measured at the shallow (d) and deep (e) sites. Red indicates measurements from 2017, green from 2018. Dotted and dashed lines illustrate the timing of peak sediment temperature and peak ebullition at the two sites.

Results II: CH₄ emissions as a function of sediment T

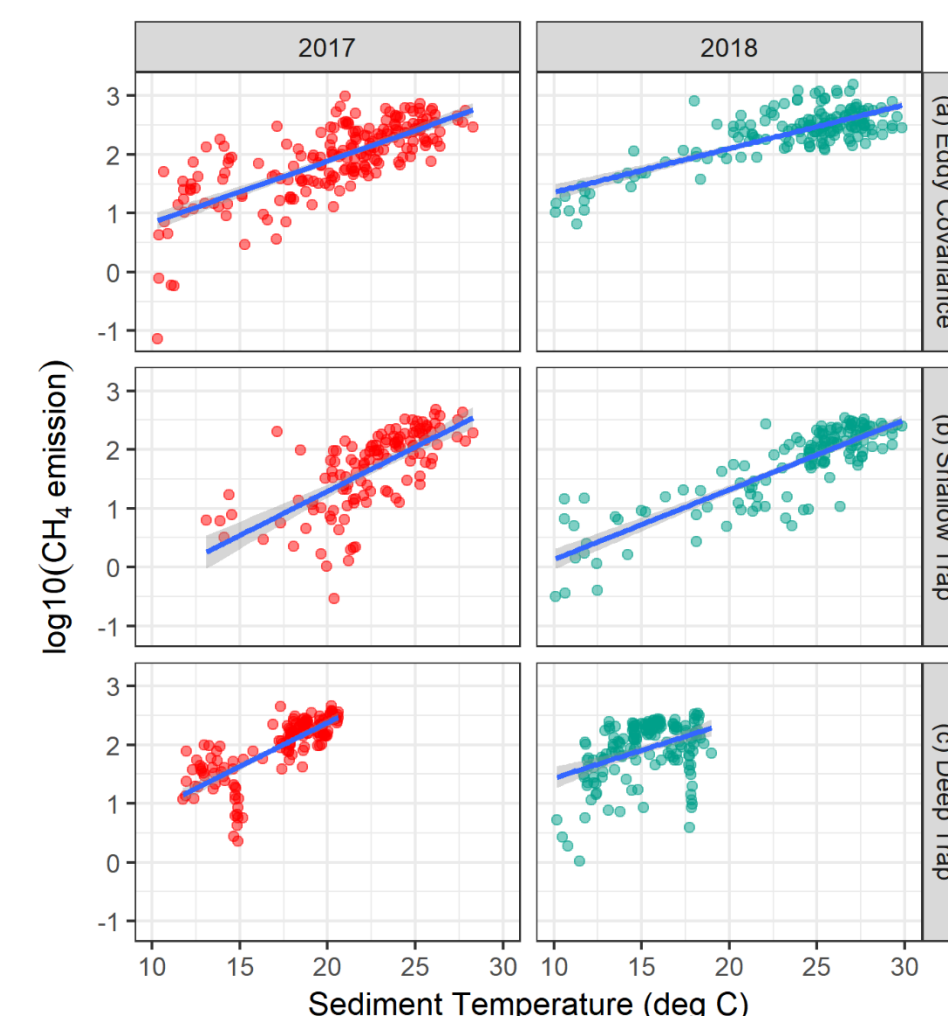


Figure 5: Linear regression of the log transformed daily average CH₄ emissions vs. the sediment temperature

- Sediment temperature was a strong driver of daily average CH₄ emissions during both monitoring seasons across all modalities, except for the deep trap in 2018 (R² values between 0.45 and 0.72, Table 1)
- The similar slopes observed between the three measurement modalities suggests the important role of temperature on CH₄ emission at multiple sites across the lake
- The ecosystem Q₁₀ values span the range of what has been reported in the literature (c.f. DelSontro et al., 2016).

Method	Year	R ²	Slope	Q ₁₀
EC	2017	0.75	0.10	9.4
EC	2018	0.79	0.08	6.3
ST	2017	0.45	0.15	32
ST	2018	0.75	0.12	15
DT	2017	0.60	0.148	31
DT	2018	0.33	0.13	20

Results III: diurnal patterns in methane emissions

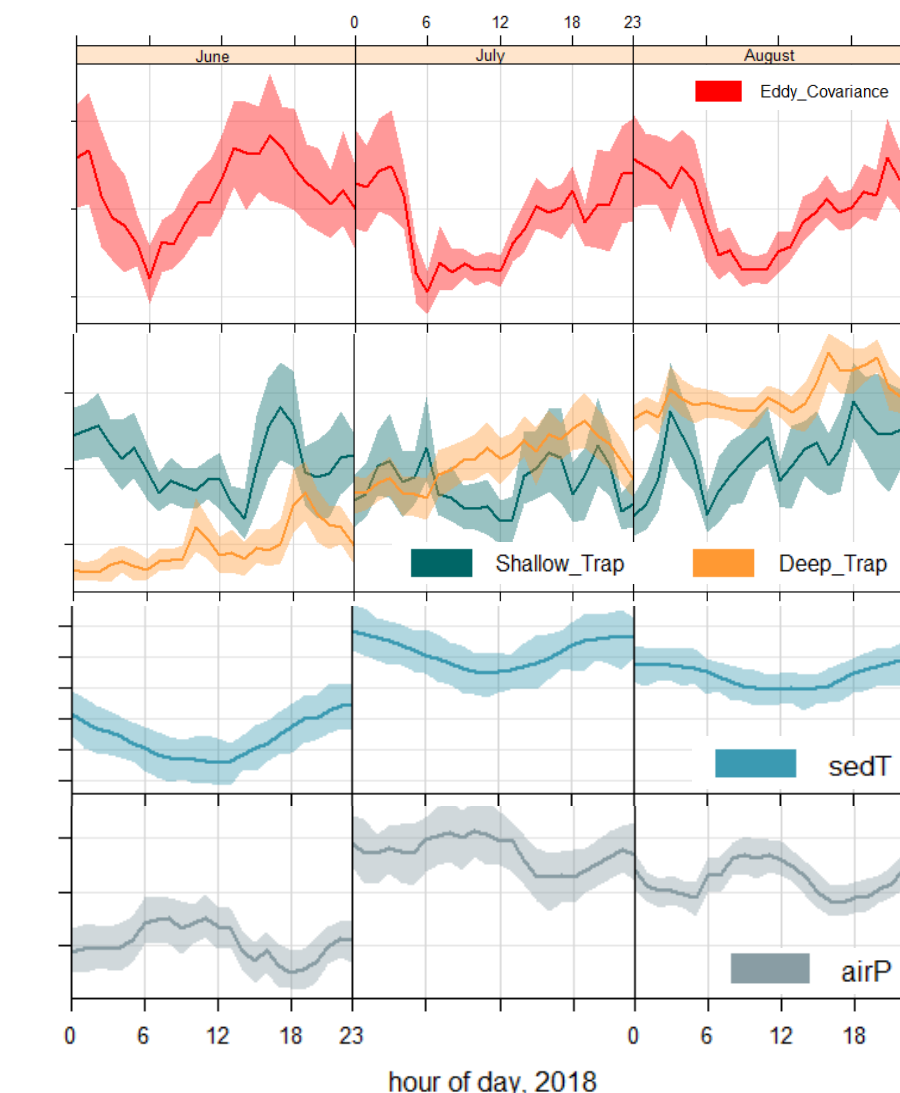


Figure 6: Diurnal plots of normalized methane emissions measured by EC (a) and funnels (b). Diurnal plots of environmental drivers sediment temperature (c) and air pressure (d) measured at the shallow site.

- Diurnal patterns in CH₄ emissions from the eddy covariance monitoring during summer 2018 show:
 - minimum emissions in the morning
 - peak emissions in the afternoon (June) or at night (July and August)
- The diurnal patterns measured by the shallow trap are not as clear, which could be due to site-specific controls on methane ebullition (e.g. ebullition history, sediment composition, microbial community)
- The deep ebullition trap displayed a different pattern: emissions peaking in the afternoon, followed by a sharp decrease, then building from the early morning over the course of the day
- The diurnal pattern in air pressure has a stronger relationship with the diurnal CH₄ emission pattern than that of sediment T
- Timescales: sediment T is an important determinant of CH₄ emissions on seasonal timescales, while air pressure controls sub-daily variability

Conclusions and future work

I. The role of temperature

- We saw a strong relationship between sediment temperature and CH₄ emissions at Acton Lake in 2017, but that relationship was not as strong in 2018
- The 2018 season had higher temperatures and larger emissions than 2017, but there was a weaker relationship between sediment temperature and daily emissions
- Other environmental conditions (e.g. substrate availability, pressure, or wind speed) may have been more important drivers than sediment temperature during 2018

II. Future work: other drivers and non-linear interactions

- We are using an artificial neural network to gap-fill and analyze biophysical drivers of CH₄ emissions
- Investigate relationship between CH₄ emissions and:
 - Synoptic weather events via their impact on air pressure, wind speed (c.f. Liu et al., 2016)
 - Energy input via net radiation, latent heat flux (c.f. Wik et al., 2014)

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