The relationship between sediment temperature and methane ebullition in a small eutrophic reservoir: insights from two years of intensive monitoring

Sarah Waldo[1]

[1]USEPA

November 23, 2022

Abstract

Reservoirs are a globally important source of methane (CH4) to the atmosphere, but measuring CH4 emission rates from reservoirs is difficult due to the spatial and temporal variability in emissions via the emission pathways of ebullition (bubbling) and diffusion. The dominant source of CH4 in reservoirs is production by methanogens in the reservoir sediment, a process that has been widely shown to have a positive correlation with temperature. However, oxidation of CH4 to carbon dioxide by methanotrophs, an important sink for CH4 within lakes, also scales with temperature. Understanding the relationship between reservoir CH4 emission (i.e. production – consumption) and temperature is made more complex by this dual feedback. This study presents results from multiple in-situ monitoring efforts at a small eutrophic reservoir in the Midwest US that look at how CH4 emissions vary with temperature across space and time. Using data sets from eddy covariance monitoring as well as inverted funnels, we found strong log relationships between daily average CH4 fluxes and daily average sediment temperature, with R2 values of 0.58, 0.45, and 0.7 for the eddy covariance data, the inverted funnel deployed at the 1.3-m site ("shallow"), and the inverted funnel deployed at the 8-m site ("deep"), respectively. The Q10 values for the shallow and deep site were 32 and 20, respectively, indicating a stronger dependence on temperature at the shallow site. However, both the shallow and deep sites had similar emission rates, scaling with relative maximum sediment temperature at each respective site. Sediment temperature was also found to be the second most important variable input to the artificial neural network used for gap-filling the eddy covariance CH4 fluxes (after wind speed). Improving our understanding of the temperature – methane emission feedback in freshwaters will enhance our ability to predict future global methane emissions.

Sediment temperature control on methane ebullition in a small eutrophic reservoir

www.epa.gov

Sarah Waldo[1], Jake Beaulieu[1], Will Barnett[2], and John Walker[1]

[1]US Environmental Protection Agency, Office of Research and Development, National Risk Management Research Laboratory
[2]Neptune and Company, Inc.

Sarah Waldo, PhD | waldo.sarah@epa.gov | 513-569-7747

AGU Fall Meeting 2018
Washington, D.C.
December 9-13
B41H-2805

Introduction: reservoirs and greenhouse gases

Background:

- Reservoirs are an important source of the greenhouse gas (GHG) methane (CH_4)
- Reservoirs can have higher CH_4 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 CH_4 from reservoirs are estimated to be 606.5 (413 -1036) Tg CO_2-eq CH_4 (Deemer et al., 2016)
- The rate of CH_4 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 CH_4 production over consumption**, leading to an increase in CH_4 emissions with increasing temperatures (Thanh Duc et al., 2010).

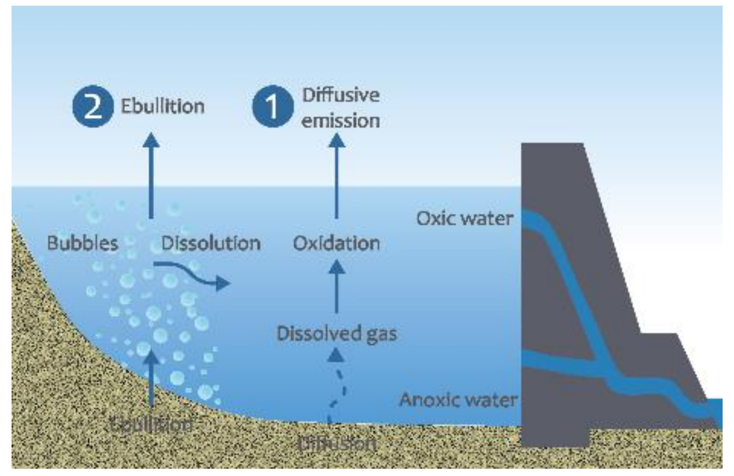


Figure 1: Gas dynamics in reservoirs

Objective:

Investigate the relationship between sediment temperature and CH_4 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 CH_4, carbon dioxide (CO_2), 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

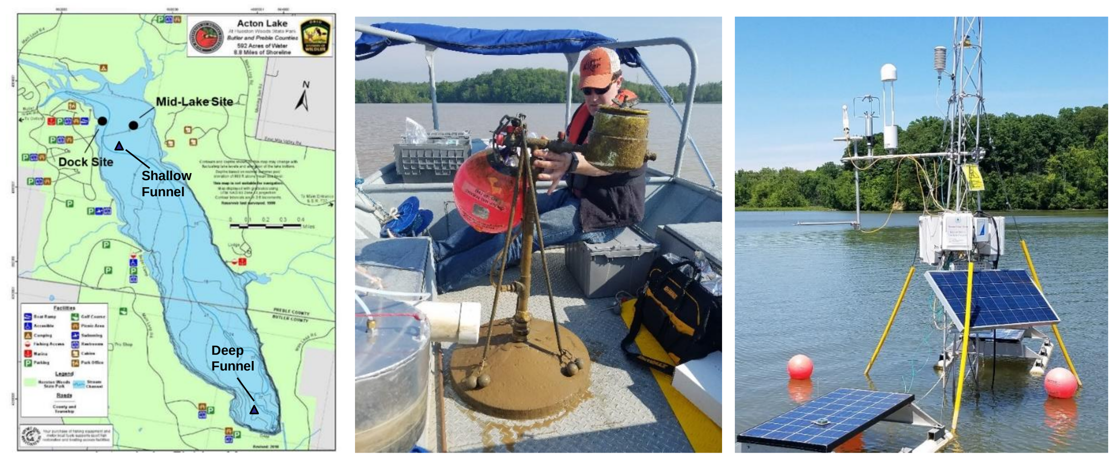
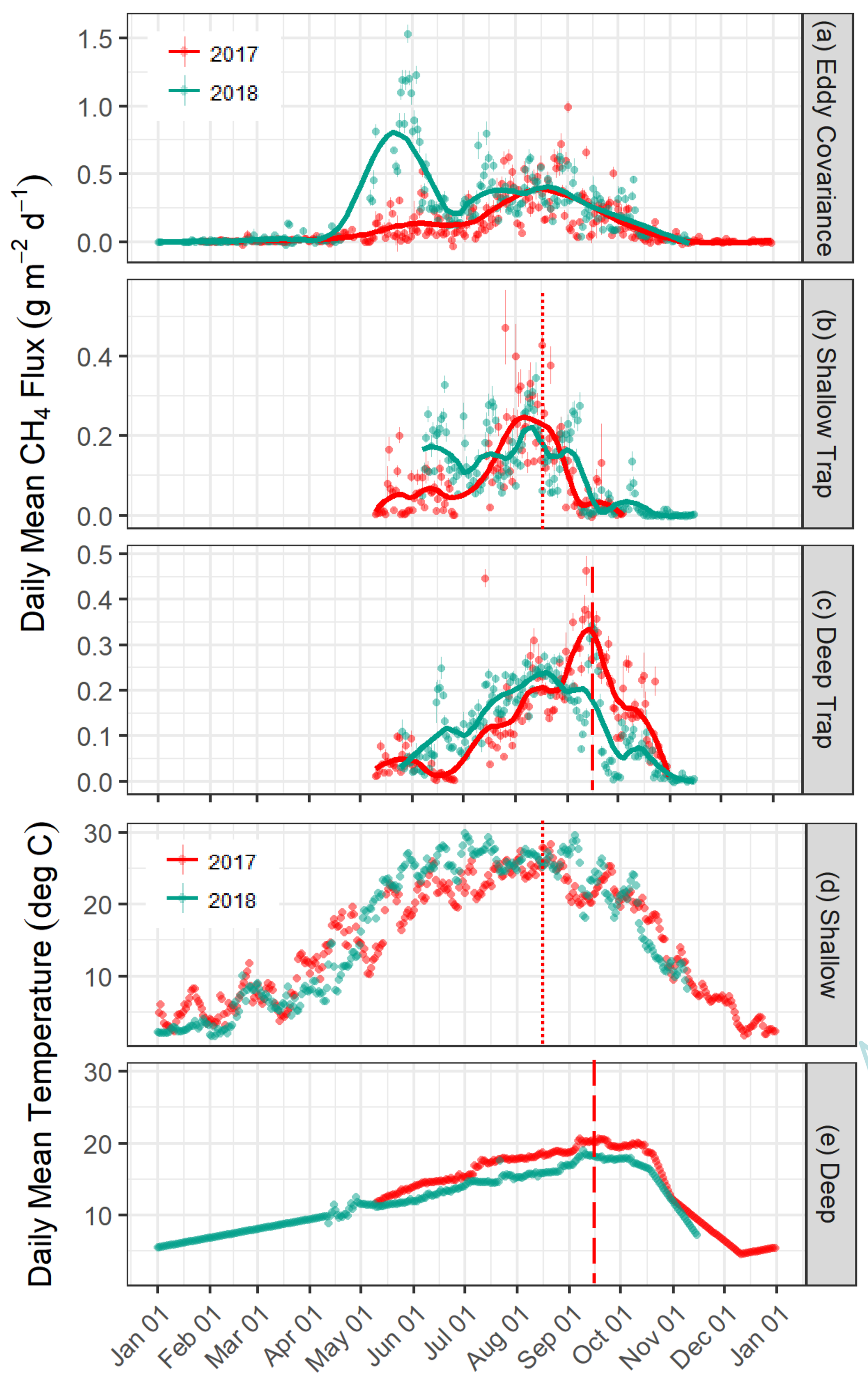


Figure 2: Map of Acton Lake measurement sites (a); photo of an inverted funnel ebullition trap (b); photo of the mid-lake eddy covariance flux tower (c)

II. Inverted funnels

- Deployed May – Dec 2017 and 2018
- Measure volumetric ebullition on a 5-minute timestep using a differential pressure sensor
- Concentration of CH_4 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 (± 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 CH_4 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: CH_4 emissions as a function of sediment T

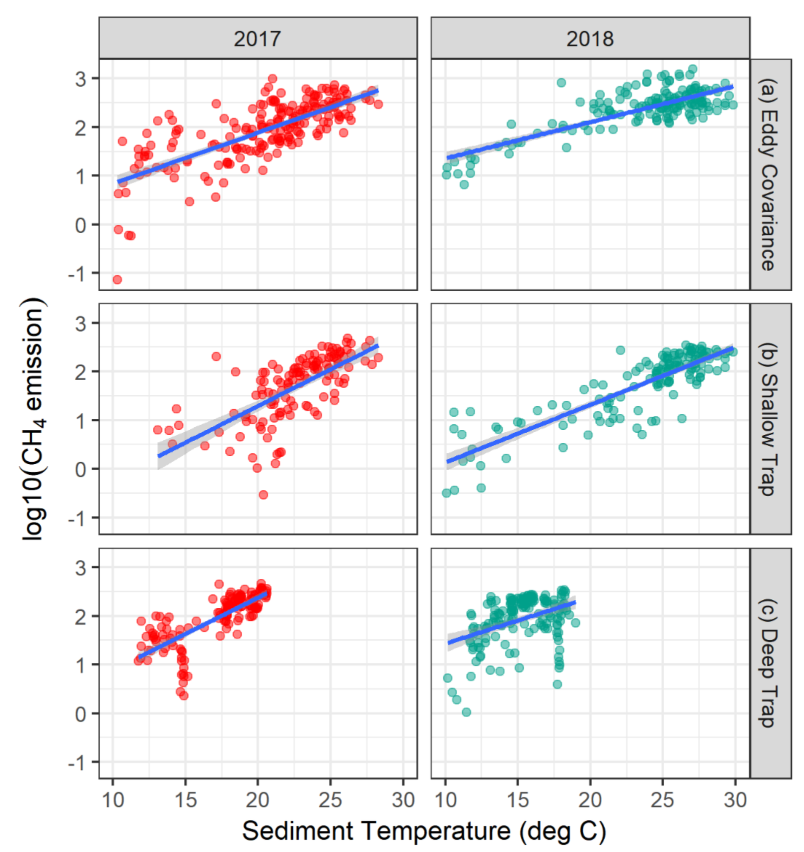


Figure 5: Linear regression of the log transformed daily average CH_4 emissions vs. the sediment temperature

- Sediment temperature was a strong driver of daily average CH_4 emissions during both monitoring seasons across all modalities, except for the deep trap in 2018 (R^2 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 CH_4 emission at multiple sites across the lake
- The ecosystem Q_{10} 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

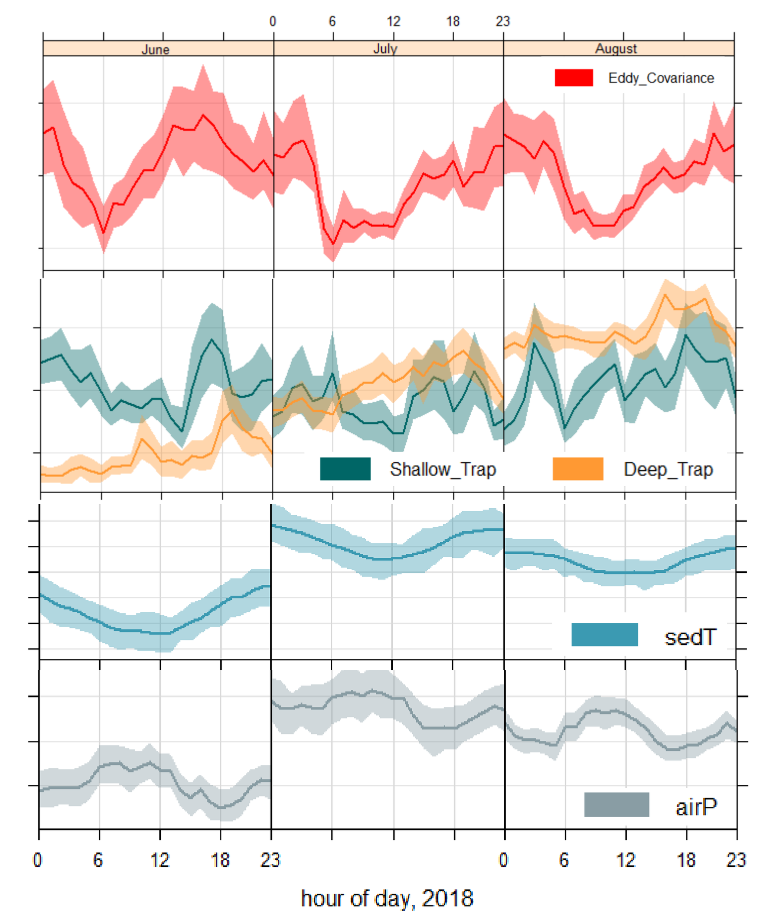


Figure 6: Diurnal plots of normalized methane emissions measured by EC (a) and funnels (b). Diurnal plots of environmental drivers sediment temperature (c) and air pressure (d) measured at the shallow site.

- Diurnal patterns in CH_4 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 CH_4 emission pattern than that of sediment T
- Timescales: sediment T is an important determinant of CH_4 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 CH_4 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 CH_4 emissions
- Investigate relationship between CH_4 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)

References:

- Deemer, B., et al. (2016). "Greenhouse Gas Emissions from Reservoir Water Surfaces: A New Global Synthesis." Bioscience.
- DelSontro, T., et al. (2016). "Methane ebullition and diffusion from northern ponds and lakes regulated by the interaction between temperature and system productivity." Limnology and Oceanography.
- Fuchs, A. et al., (2016). "Effects of increasing temperatures on methane concentrations and methanogenesis during experimental incubation of sediments from oligotrophic and mesotrophic lakes." JGR Biogeosciences.
- Liu, H., et al. (2016). "Large CO_2 effluxes at night and during synoptic weather events significantly contribute to CO_2 emissions from a reservoir." Environmental Research Letters.
- Thanh Duc, N., et al., (2010). "Implications of temperature and sediment characteristics on methane formation and oxidation in lake sediments." Biogeochemistry.
- Wik, M. et al. (2014). "Energy input is primary controller of methane bubbling in subarctic lakes." Geophysical Research Letters.