Low cost field methane sensors for deployment in variable conditions worldwide

Overview

Methane (CH_4) emissions are increasing globally. Yet, partitioning different sources of methane emissions remains challenging due to the limited spatial and temporal scale of field measurements. Improving ground measurements of CH_4 flux will allow us to identify and quantify how different policy and management actions can reduce emissions. In order to increase ground measurements of CH_4 flux, we need affordable, rugged, and portable sensors that can be deployed for days to weeks at a time. We request funds to design, construct, and field test 10 prototype chambers to measure CH_4 and carbon dioxide (CO_2) flux from a variety of environments (e.g., manure, wetlands, lakes, agricultural fields). The development of these affordable, portable, rugged, and easy to use chambers will expand ground CH_4 flux measurements world-wide, ultimately providing much-needed science to inform carbon policy.

Background

Methane (CH_4) is a critical greenhouse gas (GHG) responsible for 16 - 25% of Earth's observed warming (Etminen et al. 2016), with emissions continuing to rise (Saunois et al. 2020). Much of this increase is attributed to wetland-climate feedbacks, agricultural practices, permafrost, and other non-industrial sources. Yet, the global CH_4 budget is incredibly uncertain, partly due to the limited spatial and temporal scale of on-the-ground measurements. For example, models suggest that tropical wetland emissions increase with climate warming, but actual data is sparse (Chang et al. 2023). The lack of empirical data impedes management decisions. For instance, changing manure management practices to use anaerobic digesters could reduce methane emissions in India, but the benefits are hard to judge as few data exist on current practices (Breitenmoser et al. 2019). Ultimately, more field CH_4 measurements will improve global models and management practices.

The challenge in globally expanding field CH_4 measurements is a practical one: we lack affordable, rugged, and portable CH_4 monitoring equipment. Current products on the market are limited to portable gas analyzers (e.g., Picarro GasScouter, LGR ultraportable or microportable, LI-COR trace gas analyzer), which cost over $35,000, and are not set up to be deployed for monitoring for more than a few hours. Typically, these analyzers are used to capture CO_2 and CH_4 fluxes for a few minutes in a few locations at a given study site. Another current approach is eddy flux towers, which continuously measure emissions over a given land footprint. But towers cost close to $100,000 and are expensive to maintain. Therefore, there is a critical need to develop affordable, rugged, and portable chambers that can be deployed for days to weeks at a time.

The technology to allow low-cost and portable GHG sensors has recently emerged. Bastivken et al. (2020) describe a low-cost sensor outfitted in a do-it-yourself flux chamber, which was modified by Sø et al. (2024a). **The goal of our project is to improve this design to create a turn-key, low-cost, and rugged portable GHG flux chamber** that can be distributed for use by collaborators globally.

Project Design

The do-it-yourself CH_4 flux chamber developed by Bastivken et al. (2020) uses low-cost CO_2 sensors (SenseAir Sweden), CH_4 sensors (Figaro, USA), and a temperature / humidity sensor connected to an Arduino to control sensors and record data. The CO_2 sensor is detected by non-dispersive infrared (NDIR) spectroscopy, which can detect CO_2 up to 10,000 ppm (Bastviken et al. 2015). The CH_4 sensor uses a metal oxide semiconductor sensing element. When CH_4 is present, it undergoes a chemical reaction with the sensor, causing a change in electrical resistance, which is measured by the sensor and can be converted to a CH_4 concentration. The sensor has a filter to eliminate interfering gases, however it is sensitive to changes in humidity and can be sensitive to sulfidic conditions (H_2S may interfere with the sensors). The sensor has very little drift: Eugster et al. (2020) found drift as low as 4-6 ppb per year after long-term measurements. The sensors are sold as modules to electrical boards, which must be soldered to add a power source and data communication devices. The sensor board is then installed inside of a chamber, which is outfitted with an air pump and battery to vent the chamber between sampling runs. The setup can be seen in Figure 1, taken from Sø et al. (2024a).

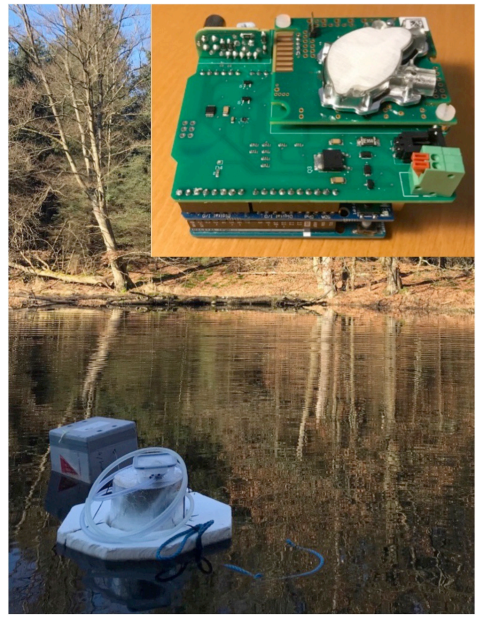

Figure 1*. A floating chamber (upside down bucket) on a pond, connected to a floating battery. The inset in the top right shows the sensor. Figure from Sø et al. (2024a).*

Between 2023 and 2024, the Holgerson Lab at Cornell built eight prototypes of this chamber, with each unit costing $450 in supplies. The units were used in waterbodies throughout New York in both years, and were effective. Yet, these chambers are not turn-key and would be challenging to distribute to collaborators globally. For instance, construction takes a novice ~6 hours and includes soldering, basic electronics, and coding the Arduino. Additionally, the CH_4 sensors have a calibration process to account for readings at different humidity levels and CH_4 concentrations. For the calibration, we use CH_4 standards in the lab and measure CH_4 concentrations with the DIY sensor and with a portable gas analyzer. After the chambers are setup and calibrated, the prototypes required maintenance when wires disconnected or batteries caught fire. Ultimately, it should be engineers (and not ecologists) who construct these chambers in a way that can be scalable and turn-key for a variety of end users.

Results from numerous studies show that these low-cost chambers are highly accurate and reliable compared to the expensive laser-based portable gas analyzers. The sensors show similar results to the portable analyzers, picking up steep increases of CH_4 (indicative of CH_4 bubbles) and fluxes at both low and high concentrations observed fluxing out of waterbodies (Bastviken et al. 2020, Sø et al. 2023, Sø et al. 2024). However, precision is lower, which may make it challenging to detect very low CH_4 fluxes. The number of chambers deployed per study will largely depend on the spatial variability of a site and the study goals. For instance, current studies on small waterbodies may deploy as few as 2 – 4 chambers (Ray and Holgerson 2023, Sø et al. 2024b), whereas another study that focused on spatial variability deployed 24 chambers rotating them around a small lake (Sø et al. 2023). Regardless of the study aims, the affordability of these sensors will allow for increased spatial replication compared to the alternative of sampling with portable gas analyzers.

Our project uniquely couples engineers, ecologists, and environmental practitioners to design, build, and test low-cost GHG flux chambers. We anticipate building the chambers for ~$250 each, and we will investigate the feasibility of reducing power needs, adding solar power and battery for nighttime measurements, adding N_2O, reducing power draw, and using satellite connectivity for data offloads. Much of this project will focus on the design and development of 10 prototypes by our engineers. The prototypes will be calibrated and field tested by our Cornell project team and external colleagues (e.g., Environmental Defense Fund [EDF], The Nature Conservancy) in a variety of environments that we currently work in to ensure that the chambers can be reliably transported and implemented by different end users. We envision testing on wetlands (including rice paddies) and ponds (Holgerson, Reid), estuaries (Cowen), coastal mangroves (EDF), manure lagoons (EDF, Cornell Dairy), near anaerobic digesters (Cornell Dairy), and abandoned oil and gas wells (Reid). We anticipate that by expanding beyond aquatic applications, we may need to adjust the chamber design, which is an important part of our process. Following field validation in a variety of environments, chambers will be shared with collaborators globally. We anticipate the international testing will take place in 2026, after the one-year grant ends.

Timeline and Team Member Roles

Over the one-year grant, we will design and build the GHG chambers, calibrate and field validate chambers (i.e., lab calibrations and field validation compared to a portable gas analyzer), and field test the chambers in a variety of environments (see below table for milestones and project leads). The design, production, and feedback process will adhere to the NASA systems engineering guidelines, which Dr. Adams has used for many of his previous projects. The engineering team will meet with the scientists to establish design requirements, and then design a device which adheres to those requirements. Before construction begins, the engineering team will present the design to the scientists for feedback. A single example of the device will be built and tested, any necessary design iterations will occur, and then the rest of the devices will be constructed based on the first. Each subsequent device will be subjected to acceptance testing to confirm that it is operating correctly before being deployed. When we calibrate and field validate the chambers, we will compare our design to a laser portable gas analyzer to ensure our approach is comparable or detect any shortcomings.

This collaborative project would not be possible without bringing together ecologists, field engineers, computer engineers, and environmental practitioners. Our interdisciplinary team will have monthly Zoom calls and frequent inter-lab interactions, including an in-person meeting to train external partners and Cornell users on the new chamber design.

Project Step	Timeline	Project leads
Design & build GHG chambers	9/24 - 4/25	Dr. Adams and Cornell Engineering MS students, with input from rest of team
Calibrate & field validate chambers	3/25 - 5/25	Dr. Adams, Dr. Holgerson
Field testing chambers; followed by data analysis	5/25 - 9/25	Drs. Holgerson, Reid, Cowen, external partners
Global testing	2026	Drs. Holgerson, Reid, Cowen, external partners

Impact & Long-term Vision

Our research is incredibly scalable through the development of a low-cost, rugged, and portable GHG measuring system, that is not commercially available. We will publish and share an open-source design of our chambers, so that researchers can reproduce our design for use globally. Project-specific data will be shared when we publish our results. We will continue collecting data for numerous Cornell and external projects, ranging from wetlands to manure to oil and gas applications. We will preliminarily scope (though not directly test in this round) chamber improvements, for instance increasing deployment length, adding N_2O as cheap sensors become available, or applying to space technology (e.g., monitoring CH_4 lakes of Saturn's moon, Titan). We will explore the potential for wireless data transfer to allow real-time data exploration (otherwise, data is only available via manual data offloads). There is also potential to use data collected by these chambers to field validate new CH_4 satellite observations. Lastly, our chambers can launch community science initiatives to collect local measurements (e.g., suspected gas leaks from CH_4 transport infrastructure, monitoring local ecosystems). In short, the technology we develop will be user-friendly, rugged, and affordable, transforming CH_4 monitoring. With increased diversity of CH_4 emissions represented, this science can ultimately inform climate-smart policy.

References

Bastviken, D., I. Sundgren, S. Natchimuthu, H. Reyier, and M. Gålfalk. 2015. Technical note: Cost-efficient approaches to measure carbon dioxide (CO2) fluxes and concentrations in terrestrial and aquatic environments using mini loggers. Biogeosciences 12: 3849-3859.

Bastviken, D., J. Nygren, J. Schenk, R. Parellada Massana, and N. T. Duc. 2020. Technical note: Facilitating the use of low-cost methane (CH4) sensors in flux chambers – calibration, data processing, and an open-source make-it-yourself logger. Biogeosciences **17**: 3659–3667.

Breitenmoser, L., T. Gross, R. Huesch, J. Rau, H. Dhar, S. Kumar, C. Hugi, and T. Wintgens. 2019. Anaerobic digestion of biowastes in India: Opportunities, challenges and research needs. Journal of Environmental Management **236**: 396-412.

Chang, K.Y., W.J. Riley, N. Collier, G. McNicol, E. Fluet-Chouinard, S.H. Knox, K.B. Delwiche, R.B. Jackson, B. Poulter, M. Saunois, and N. Chandra. **2023**. Observational constraints reduce model spread but not uncertainty in global wetland methane emission estimates. Global Change Biology **15**:4298-4312.

Etminan, M., G. Myhre, E. J. Highwood, and K. P. Shine. 2016. Radiative forcing of carbon dioxide, methane, and nitrous oxide: A significant revision of the methane radiative forcing. Geophysical Research Letters **43**: 12,614-12,623.

Eugster, W., J. Laundre, J. Eugster, and G.W. Kling. 2020. Long-term reliability of the Figaro TGS 2600 solid-state methane sensor under low-Arctic conditions at Toolik Lake, Alaska. Atmospheric Measurement Techniques 13: 2681–2695.

Saunois, M., A. R. Stavert, B. Poulter, et al. 2020. The Global Methane Budget 2000–2017. Earth Syst. Sci. Data **12**: 1561–1623.

Sø, J. S., K. Sand-Jensen, K.T. Martinsen, E. Polauke, J. E. Kjær, K. Reitzel, and T. Kragh. 2023. Methane and carbon dioxide fluxes at high spatiotemporal resolution from a small temperate lake. Science of The Total Environment **878**: 162895.

Sø, J. S., K. Sand-Jensen, and T. Kragh. 2024a. Self-made equipment for automatic methane diffusion and ebullition measurements from aquatic environments. JGR Biogeosciences: 10.1029/2024JG008035.

Sø, J. S., K.T. Martinsen, T. Kragh, and K. Sand-Jensen. 2024b. Hourly methane and carbon dioxide fluxes from temperate ponds. Biogeochemistry: https://doi.org/10.1007/s10533-024-01124-4.