Measuring Greenhouse Gas Emissions in Alaska Wetlands

A user's guide for the Li-COR LI-7810 (CH4, CO2, H2O) portable gas analyzer

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Alaska Natural Heritage Program
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Introduction

This guide was developed for the Li-COR LI-7810 trace gas analyzer for use in Alaska wetlands (Figure 1) with a focus on boreal and temperate peatlands. The guidance we provide may not be appropriate for applications in different habitats or conditions. We intend this document to be dynamic and welcome your feedback. Please contact the lead author with ideas, suggestions, or corrections for incorporation to future versions. Technical support for the LI-7810, including the Instruction Manual referenced herein is available from the Li-COR website.

Figure 1. Using the LI-7810 unit with chamber and collar in a freshwater wetland near Happy Valley, Alaska in dry conditions (left) and in standing water (right). Note the plastic tote to protect the unit. In the left photo, a researcher is using a computer to monitor real time data. In the right photo, an extension chamber has been added to accommodate standing water and taller vegetation.

Wetland ecology

Wetlands are habitats that are able to support hydrophytic vegetation due to conditions of saturation or inundation during the growing season. Wetlands can be mineral or organic, with mineral wetlands such as swamps and marshes retaining very little organic matter due to frequent and large fluctuations in water level and/or high rates of mineral cycling and biodegradation. Tidal and riparian systems provide many good examples of mineral wetlands. Organic wetlands have relatively constant water levels, are often dominated by bryophytes and sedges, and accumulate organic matter as peat. These organic wetlands, or peatlands, can be further categorized as bogs or fens, with bogs experiencing lower rates of growth, decay, and water flow compared to more nutrient-rich fens.

Peat accumulates when the amount of photosynthetically produced organic matter exceeds the loss of organic matter through decomposition. The rate of organic matter gain or loss is primarily influenced by hydrology, chemistry, temperature, and vegetation, and is most sensitive to disturbances that alter the water regime or temperature of a system.

Influence of hydrology

Peat is a source of complex carbon that, under aerated soil conditions, is decomposed by aerobic metabolism, of which carbon dioxide (CO_2) is a byproduct. Under anoxic, or waterlogged soil conditions, decomposition occurs by anaerobic metabolism, of which both CO_2 and methane (CH_4) are byproducts.

Influence of chemistry and temperature

The chemistry and temperature of surface- and groundwater influence the direction and rate of biological processes in peatlands, and ultimately, the type of vegetation that can establish. In general, acidic conditions favor the growth of bog species such as dwarf shrubs and Sphagnum mosses, whereas circumneutral conditions favor the growth of fen species such as sedges, forbs, and true mosses. The rate of chemical reactions in peatlands is limited by low temperatures. Very little decomposition occurs at below freezing conditions, and decomposition during summer and shoulder seasons is often limited by a short period of above freezing temperatures and temperatures below thermal optima of soil microbes. Climate-induced warming, especially when coupled with drying, is expected to speed the rate of decomposition in Alaska peatlands.

Influence of vegetation

Peatland types form a continuum between minerotrophic fens and ombrotrophic bogs. Minerotrophic systems receive their nutrients through groundwater flow, while ombrotrophic systems receive their nutrients through rain and snowfall. Largely due to a greater flow of nutrient-rich groundwater through fens, faster growing sedges, forbs, and true mosses are more commonly associated with these systems. These herbaceous communities are characterized by greater primary productivity and labile peat. Conversely, bogs receive moisture from nutrient-poor precipitation, which encourages the growth of slow-growing plant species such as dwarf shrubs and Sphagnum mosses. Compared to fens, these woody bog communities are characterized by lower primary productivity and recalcitrant peat. The establishment of Sphagnum in particular, drives paludification and further acidification.

Ecosystem exchange of carbon

Globally, peatlands function as a repository for carbon. The gases most important to the carbon budget of peatlands are CO_2 and CH_4, which are chiefly released to the atmosphere through the cellular respiration of plants and the decomposition of organic material by microbes, respectively. The exchange of gas between the atmosphere and an ecosystem is referred to as flux. The flux of CO_2 is measured by net ecosystem exchange (NEE), which can be conceptualized as the difference between plants removing CO_2 from the atmosphere through photosynthesis and the ecosystem releasing CO_2 to the atmosphere through cellular respiration:

$$NEE = CO_2 \text{ fixed through photosynthesis} - CO_2 \text{ produced by respiration}$$

Net ecosystem exchange can be used as a measure of the capacity of an ecosystem to sequester carbon, with positive rates indicating the gain of carbon and negative rates indicating the loss of carbon.

Additional loss of carbon occurs from the release of CH_4 through the anaerobic decomposition of plant material by microbes. Because methanogenesis occurs exclusively in anoxic conditions, the release of CH_4 to the atmosphere is greater in saturated or inundated peatlands where soil pore space is occupied by water rather than air. As CH_4 is 28 times more potent as a greenhouse gas than CO_2 when fluxes are sustained over a 100-year period, the relative rates of CH_4 and CO_2 release are important to account for in the total carbon budget of a peatland.

Flux can be assessed on a global, regional, ecosystem, community, or organism level. Here we outline a procedure to estimate the greenhouse gas flux from a wetland ecosystem. We measure CO_2 and CH_4 flux during the growing season and under light and dark conditions at multiple locations within a wetland. These point-in-time measurements are used to interpolate the flux of our target gases over the course of a year. Interpolations are made more accurate by correlating ancillary point-in-time measurements of soil and air temperature, light intensity, and water level to continuous measurements of these same variables collected at the site (or peatland) level.

Chamber construction

The measurement of greenhouse gas emissions from a peatland are made within a purpose-built chamber, which allows the volumetric calculations of gases, prevents wind disturbance and atmospheric contamination, and provides an environment that can be darkened to simulate nighttime conditions (see visit-level section for a discussion on the utility of dark measurements). The chamber is placed on a collar installed at each sampling location. The collar is dug into the soil about 5-10 cm (ideally slightly below the elevation of the ground water table) such that during measurement the only gases entering the chamber are those produced by the plants and microbes that are enclosed by the chamber. Weather stripping is fixed to the bottom of the chamber to further reduce the mixing of atmospheric and chambered air (Figure 2). While the chamber moves with the Li-COR gas analyzer to each sampling location, the collars remain at the sampling location throughout the duration of the project.

We constructed our chamber from 0.64 cm (¼”) thick, 41 cm (16”) diameter, 63 cm high polyvinyl chloride (PVC) pipe. Collars were made from the same pipe, cut at approximately 30 cm height. We used a reciprocating saw to remove material so that light was transmitted and the weight of the chamber was reduced. Windows were sized to maximize light without compromising structural integrity (Figure 3).

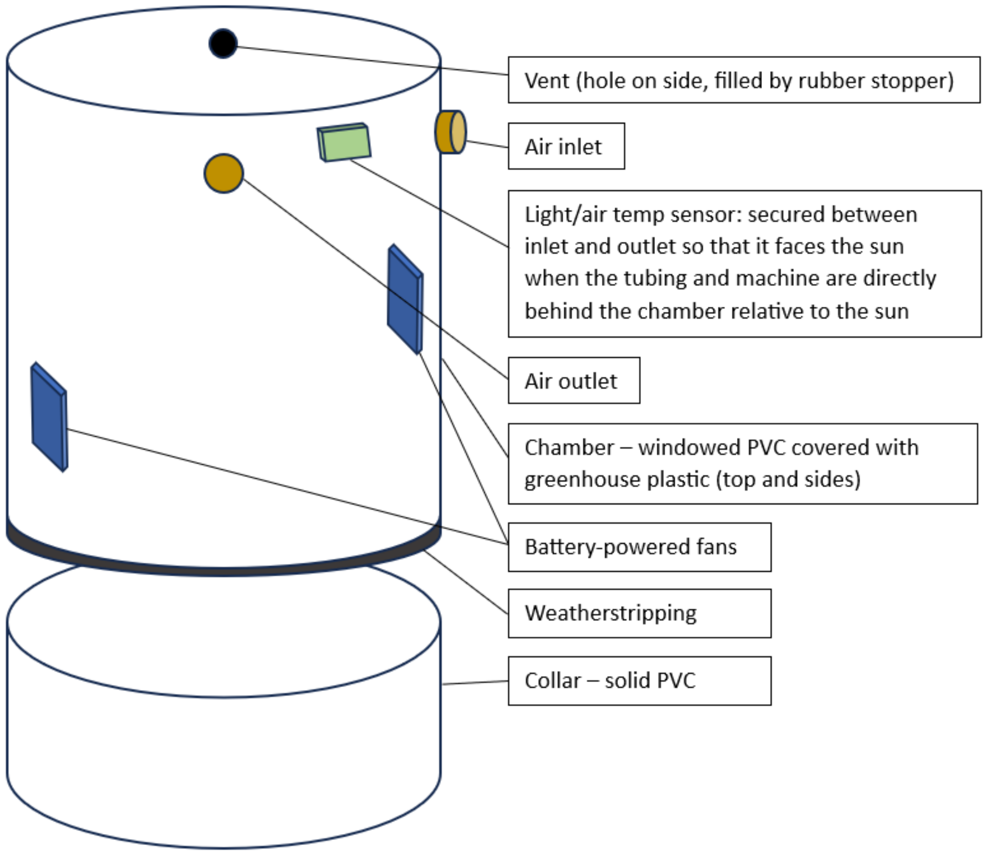

Figure 2. Schematic of constructed chamber and collar with accessories.

Figure 3. Chamber PVC skeleton (left) and collar (right).

To create an air-tight space, we recommend lining the chamber with 6 mil polyethylene film (greenhouse plastic), fixed in place with clear packing tape (Figure 4). Greenhouse plastic is ideal as it transmits the greatest range of photosynthetically active radiation (PAR). We also recommend sanding the sawed edges of the PVC to reduce abrasion of the plastic. The plastic is easiest to stretch and tighten if attached to the outside of the chamber. We recommend attaching weather stripping to the bottom of the chamber as a sealing strategy (we had success with Auto and Marine Rubber Weatherseal, sized to match the width of the PVC).

Figure 4. Chamber (top left, bottom) and extension chamber (top right) with greenhouse plastic and weather stripping. Scale shown in tenths of feet.

To create a closed loop of air flow between the chamber and the unit, we drilled a 1.3 cm (1/2") inlet and outlet in the chamber, fitted with 0.64 cm (1/4") ferrule and nut (Swagelok) connections. The inlet and outlets were placed at the top of the chamber and orthogonally to each other (rather than adjacent or opposite) to encourage air mixing within the chamber (Figure 5). Bev-A-Line 0.64 cm (¼") outer diameter polycarbonate tubing connected the unit inlet and outlet to the chamber inlet and outlet (Figure 6).

Figure 5. Orthogonal placement of vents.

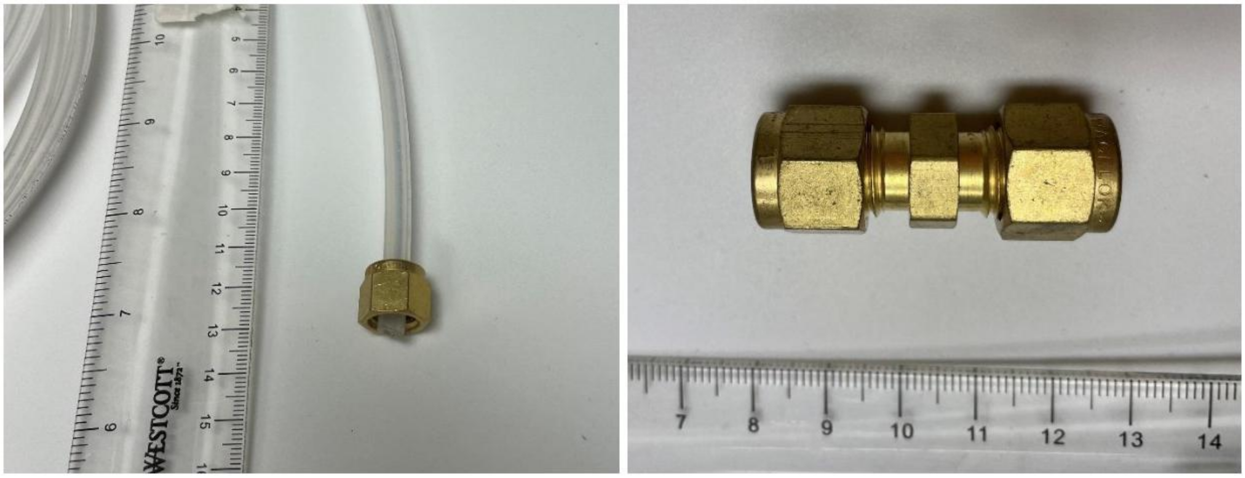

Figure 6. Photographs of 0.64 cm (¼") polycarbonate (Bev-A-Line) tubing and ferrule and nut (Swagelok) connectors.

We recommend using two small, battery powered fans on the sides of the chamber fixed with velcro, one towards the bottom and one further up the chamber. Both should face up so as not to interfere with the emission of gas from the ground surface. (Figure 7). These fans are available with either replaceable or rechargeable batteries; we have used both with equal success. During sampling, the flow of air between the unit and the chamber is driven by a fan internal to the Li-COR unit. Under ideal conditions in this closed loop system, neither positive nor negative pressure (relative to atmospheric pressure) is created within the chamber. Pressure can be inadvertently elevated by trapping air when setting the chamber over the collar, or may build if gases are actively diffusing. Positive pressures within the chamber can retard the natural flux of gas from vegetation and soil, leading to artificially low rates of gas emission. A vent can be installed at the top of the chamber so that pressure in excess of atmospheric pressure can be easily released before commencing measurement. The vent is simply a hole drilled in the chamber housing that can be closed with a rubber stopper. A vent is necessary when placing the chamber into standing water. However, this need can be eliminated by using an extension chamber: pressure can stabilize within this open system before the chamber is placed on top, which closes the system. Losing a black rubber stopper is very easy, so we recommend wrapping the stopper in flagging and taping it in during measurement sets where it's not necessary.

Figure 7. Battery powered fan: front, back, and attached with Velcro on the inside of the chamber.

We built an extension chamber to accommodate either taller vegetation or significant standing water. The extension chamber is constructed in a similar manner to the measurement chamber but is open on both ends, and does not include any data loggers or an inlet, an outlet, or a vent. The extension is also taller than the measurement chamber (91 cm vs 63 cm). Like the measurement chamber, it has weather stripping on the bottom and has two velcro fan placement points. We use four total fans when using the extension, unless the water is deep enough that one will be submerged. The extension chamber is placed between the collar and the measurement chamber at sites where the height of vegetation exceeds the height of the measurement chamber, or where water is deeper than ~10 cm above the collar (the exact cutoff for standing water is up to professional judgment). While not detailed here, floating chambers can be constructed for the measurement of gas emission in aquatic systems.

Both the measurement chamber and the extension chamber are fragile and require periodic maintenance. Holes can result from either woody vegetation when placing the chamber or abrasion on the PVC edges. Adding a small piece of packing tape, ideally to both sides of the plastic, is an effective short-term fix that works in the field. However, too much extra packing tape could affect the radiation that comes through the plastic. We recommend re-wrapping the chamber in plastic periodically as needed - e.g., once a year - and checking for holes regularly, particularly if there is reason to suspect one (spiky branches, unusual gas flux data). The weatherstripping is also fragile and wears down quickly. Worn weatherstripping can still provide an effective seal (ours has a few vertical layers separated by grooves). Still, we recommend replacing the weatherstripping at least once a year. Taking care when transporting, placing, and removing the chamber will minimize the amount of maintenance required. In particular, using a protective bag or backpack for either chamber (Figure 8) and transporting the measurement chamber in a tote can reduce wear and tear.

Figure 8. Custom-made backpack for carrying the measurement chamber (left) and extension chamber (right). This backpack was designed by Nomar in Homer, Alaska. It is water-resistant and has an insulating layer to protect against damage and a zipper to more easily take the chamber in and out.

Collar placement

We recommend installing collars approximately two weeks before data collection. The delay allows the soil and vegetation to regain stasis following the root and ground disturbance associated with collar installation. For site level measurements of flux, collars are located to capture the natural range of conditions (e.g., elevation, slope, vegetation, soil, hydrology) or as necessary to answer your research question of interest. Collars are embedded in the soil deep enough to prevent atmospheric air from entering or leaving the chamber. In wetlands, this depth should extend below the moss and duff layer and into the true organic soil. In more mesic habitats, collars should be installed about 5-10 cm into the soil. To install a collar deep enough, it may be necessary to cut through some roots using a hori-hori, bread knife, sawzall, or alternative tool. Loppers can be helpful for large roots, but be aware of what plants the large roots belong to - ideally root damage to the plants within the collar is minimized to the extent possible. The collar can be pounded in using a mallet; a 5 cm by 10 cm (2” x 4”) board placed over the collar can be helpful to avoid damage to the lip. Collars should be set into the ground as level as possible.

Neither collars nor weatherstripping are necessary when the water table is at the soil surface and vegetation does not compromise the seal (e.g., tidal mud flats, floating bogs). Under these saturated conditions, the soil water provides an air-tight seal and the chamber can be placed directly on the ground surface. That being said, collars can still be helpful in these conditions to standardize the zone of measurement.

About the Gas Analyzer

The LI-7810 is a laser-based gas analyzer that uses absorption spectroscopy to measure gases in air (Figure 9). The analyzer reports and stores in its internal memory CH_4 and CO_2 dry mole fractions in air that are corrected for both the spectroscopic interferences and dilution due to H_2O, which is the main reason H_2O is measured. The unit is not waterproof – take care not to draw water into the air inlet.

Unit startup

Press the power button once to power on the unit. After powering on, the instrument will issue a series of status codes as it completes the startup cycle. The pump will start running when the optical bench (i.e., the internal gas absorption chamber) approaches 55 °C. If starting from room temperature, it will take about 30-35 minutes before the unit provides accurate measurements. If the instrument is cold, it will take longer to warm up. The startup process typically uses about 20% of the battery. However, you can save significant battery and startup time by running the unit while connected to power, then turning it off and restarting it when you get into the field. To make the most of your time, turn on the unit before you want to use it (e.g., before walking into the site); you can also connect the chamber and start ancillary measurements while you wait. Avoid keeping the caps on the inlet and outlet during startup, as the machine will interpret this as a plugged inlet and stop drawing in air. Store the caps in a secure location while using the machine.

The unit can be put in sleep mode between sampling sites and should be powered down at the end of the day. To enter sleep mode, press the power button twice within three seconds; to power down, press the power button three times within five seconds. Sleep mode shuts off the air pumps, which causes the unit to stop drawing in air. Because the heater remains powered in sleep mode, yet the fans do not, there is a risk of the unit overheating. Take care not to enter sleep mode if the air inlet or outlet is subject to positive or negative pressures (e.g., covered by waterproof fabric), and do not cover the vents while in sleep mode.

Figure 9. Schematic of the LI-7810 Trace Gas Analyzer (credit: LI-COR Environmental)

Connecting to the unit via Wi-Fi

Connection between the unit and a Wi-Fi-enabled device is made through a wireless local area network (WLAN); when enabled, the WLAN is indicated by the presence of a wireless network symbol on the unit display. To connect your PC or mobile device to the instrument's wireless network, first find the network in the list of networks presented on your device. The network name is the hostname (and serial number) of the instrument. For this specific unit the network shows as: tg10-01748. Select this network and enter the password 'licorenv' to connect. Enter the address http://tg10-01748.local into your web browser. The webpage shows graphs of CO_2, CH_4 and H_2O emissions similar to the interface shown in Figure 10 as well as a variety of other information, such as the time setting (modifiable), remaining battery, and startup codes and errors. See the LI-7810 manual for more details.

Figure 10. Example screen shot of the Li-COR webpage interface.

Connecting to the air inlet and outlet

Air is drawn in and purged from the unit as shown in Figure 10. Polycarbonate tubing (Bev-A-Line) with an outside diameter of 0.64 cm (¼") is connected to the Swagelok fitting using a nut and ferrule set, also shown in Figure 6. Using a crescent wrench, the nut should be turned ¼ turn beyond finger tight to ensure an air tight connection.

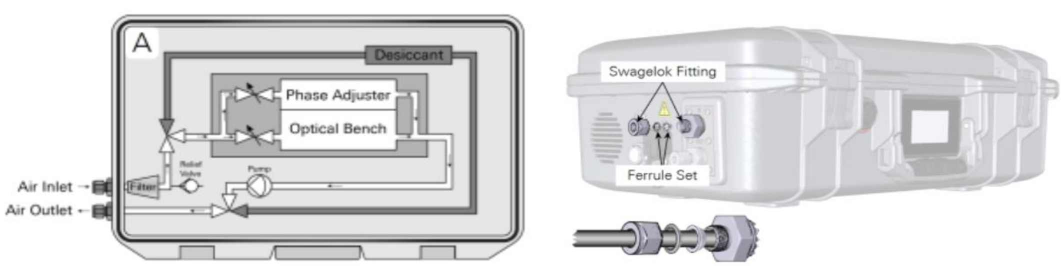

Figure 11. Simplified schematic of flow through the unit during measurement (left) and air inlet and outlet connections (right; credit: LI-COR Environmental)

Maintenance

The unit is factory calibrated. As this model has only been on the market for a few years, it is not known how often follow up calibration should occur. It is good practice to note if the unit is measuring within range of atmospheric concentrations, which are relatively constant, at startup.

Typical atmospheric levels for CH_4 and CO_2 are 2000 parts per billion (ppb) and 400-450 parts per million (ppm), respectively. If the unit is not reading close to these concentrations, you may want to check the desiccant (see below) or recalibrate with calibration gas. See the LI-7810 Instruction Manual for user calibration. It is worth noting that the atmospheric CO_2 concentration changes seasonally, dropping during the northern hemisphere spring and summer and rising again during fall and winter. This change is more extreme at more northern latitudes: Utqiagvik, Alaska sees an annual swing of about 20 ppm, as opposed to about 10 ppm at Mauna Loa, Hawaii.

The unit pumps air through the desiccant tube as it is powering down to purge the optics of water vapor. If the unit has been exposed to water or is reading out of range, you may want to replace or restore the desiccant. The silica gel beads are orange when new and green when saturated. The unit comes with replacement desiccant, however the silica beads can also be dried in an oven and reused. Air filters should also be replaced on a yearly basis (Figure 12). See the LI-7810 Instruction Manual for further direction.

Figure 12. Interior of the LI-7810 unit; desiccant tube filled with orange silica beads is shown in the upper right. Replacement desiccant and air filters and gaskets shown below.

Collecting Data

The type and frequency of data collected will depend largely on your research question. The following data collection recommendations are for the estimation of CO_2 and CH_4 annual emissions from an entire wetland (i.e., site-level assessment) and for this reason require the measurement of site- and collar-level parameters additional to the point-in-time measurements of gas flux.

Site-level Measurements

Site-level measurements of environmental variables are collected so that the point-in-time measurements of gas flux can be extrapolated to the site level. Site level measurements can be taken at a single, central location or averaged across a network of locations (Figure 12). Due to the large amount of data involved, continuous measurements of air and soil temperature, brightness, and water level can be logged every hour, or averaged over hour intervals.

Air temperature

Continuous air temperature can be measured at a single location. The continuous site-level measurement of air temperature is used to develop a relationship to the point-in-time measurements of air temperature made at each collar location during gas emission sampling.

Brightness

Continuous LUX can be measured at the same location as continuous air temperature. We opted to use LUX, a unit of illumination or brightness, as a proxy for photosynthetically active radiation (PAR), because the instrumentation for measuring LUX is less expensive, and LUX has a linear relationship with PAR for a given form of light. The continuous measurement of LUX can be converted to PAR or correlated to a local measurement of PAR. The continuous measurement of LUX or PAR is used to develop a relationship to the point-in-time measurements of LUX made at each collar location during gas emission sampling.

Water table

Continuous water table depth can be measured at a single location or across a network of permanent monitoring wells. If a single location is chosen, it is not necessary to collocate the well with the air temperature and LUX instrumentation. However, the location should be representative of site hydrology. The continuous measurement of water level is used to develop a relationship with the point-in-time measurements of water table depth made at each collar location during gas emission sampling.

Soil temperature

Continuous soil temperature can be measured at a single location or a network of locations (ideally next to collars) using buried data logger(s). Logger(s) should be buried at a depth consistent with visit-level data that approximates the root zone (ca. 10 cm). The continuous, site-level measurement of soil temperature is used to develop a relationship with the point-in-time measurements of soil temperature made at each collar location during gas emission sampling.

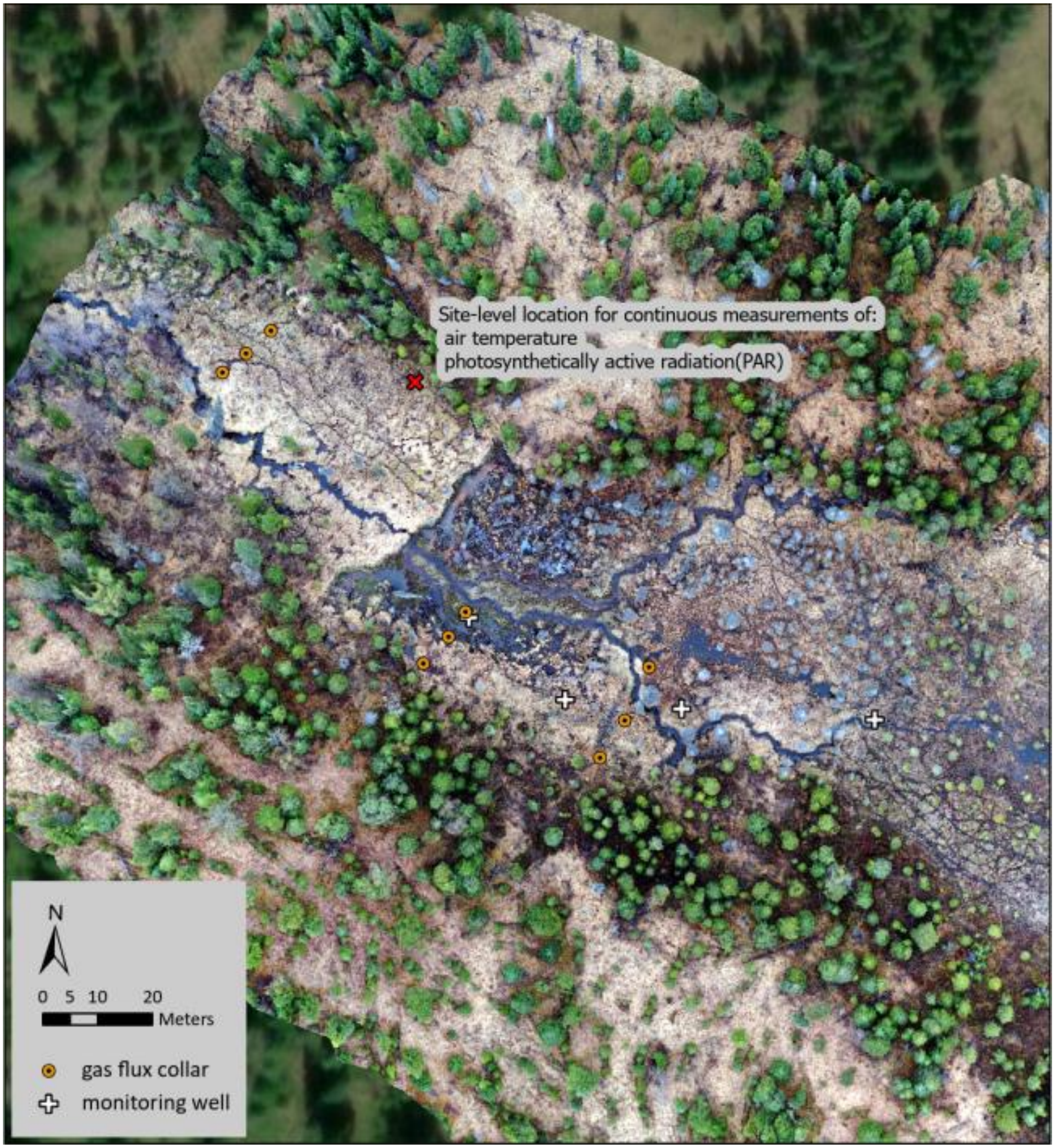

Figure 13. Example layout for the site-level estimation of annual gas flux across a beaver-influenced site showing locations of permanent monitoring wells, gas flux collars and an arbitrary, central location for the continuous measurement of variables.

Optional site-level Measurements

The following site-level measurements are not required, but can be made to estimate the volume of peat and the carbon content of a peatland or to account for the influence of vegetation type, abundance, and biomass in gas emissions.

Peat and carbon content

Soils can be characterized to estimate the carbon stock of a wetland. We recommend that the depth of organic soil be measured once during the life of the project, near each collar location using a tile probe, peat corer, or bucket corer. The probe or corer should be advanced until refusal or until a confining layer greater than 5 cm is encountered. For relatively shallow soil, we recommend at least coring periodically to determine whether soil being probed is actually organic. At a minimum, probing or coring provides depths of organic soil, from which a volume of soil organic matter can be estimated. At most, the cores can be assayed for carbon and bulk density, from which a carbon stock can be estimated. The number of core samples collected will depend on the size and heterogeneity of the system. Subsamples, representing each discernable soil horizon (i.e., change in soil color, texture, or density), can be extracted from each core. Subsamples are then assayed for organic carbon via loss on ignition, and characterized with respect to texture, pH, and bulk density. The total mass of carbon in the subsample is estimated by multiplying the percent organic carbon by the bulk density of the subsample and the volume of the subsample. Carbon stock is estimated for the site level by calculating an average carbon density for each soil horizon and multiplying that density by the interpolated volume occupied by that soil horizon. For landscape or regional scale estimates of carbon stock, efficiency can be gained by interpolating carbon storage from plant communities. Vegetation is an accurate proxy for soil type and hydrologic regime, which in turn are well-correlated to carbon content. Thereafter, the change in the volume of carbon over time can then be predicted from the flux of CO2 and CH4 estimated for the site.

The relative elevation change in a ground surface can be measured using a surface elevation table (SET). Relative elevation change can be interpreted as the rate of sedimentation or erosion at a site and in a wetland context, can be extrapolated to sequestration or degradation. When attached to a single or pair of vertical posts, the SET provides a constant reference plane in space from which the distance to the surface can be measured by using pins lowered to the sediment surface. Repeated measurements of elevation can be made with high precision if the orientation of the table in space remains fixed for each sampling. Surface Elevation Tables can be bought (expensive) or constructed (cheap). Construction requires a post installed on site that is not susceptible to vertical movement caused by, for example, frost or flooding. Possible methods of SET construction could use standing dead trees as a post or rebar installed below the depth of seasonal frost.

Vegetation type and abundance

Vegetation and abiotic ground cover can be measured once a year at full phenology (typically any time in July is appropriate) to develop a relationship between site level vegetation and point-in-time measurements of vegetation taken at each collar during gas emission sampling. We recommend that plant species and abiotic ground cover be measured using line point intercept techniques with point measurements occurring at a 0.5 m interval. Transect length can be variable yet sufficient to capture the natural variation in plant species and abiotic groundcovers present at the site. Using a laser pointer oriented vertically down, record the plant and groundcover types intersected by the beam at a set interval (e.g., 0.5 m, Figure 14). Vascular plants are recorded to the species level, and nonvascular plants are recorded to the finest level of taxonomic identification possible; occasionally this will be species, but more often genus or functional group. We recommend that plant species and ground covers be recorded using Alaska's Minimum Standards for Field Observation of Vegetation and Related Properties. Percent covers of plant species and abiotic ground cover types are estimated for the site by dividing the number of occurrences by the total number of points sampled along a transect, multiplied by 100. For example, if the laser encountered Species A at 25 of the 75 points sampled, then the cover of Species A is estimated to be (25/75)*100 = 33%. Because plant species differ in their primary productivity and morphological adaptations, their communities have a differential effect on the storage and release of carbon. The identification of plant communities and subsequent mapping of their extents at a site allows a more accurate approximation of annual carbon flux.

Vegetation biomass

The average height of woody and herbaceous plant species can be measured at least once a year at full phenology (typically any time in July is appropriate) to estimate biomass at the site level. Heights are measured along the vegetation transects at each sampling interval. We recommend measuring the second highest woody and herbaceous species located within a 15 cm radius of the sampling point; the second highest individuals are targeted to avoid measuring individuals with outlying heights. Height is measured using the elevation of the plant base as the zero line; herbaceous plants should be straightened for measurement, but woody plants should not be straightened.

Collar-level Measurements

Collar level measurements are made to calculate the volume of the chamber in which gas flux is measured and for geolocation of the sampling locations. Collars may be relocated if disturbed due to wildlife, flooding, frost action, or plant mortality. However, moving a collar will require remeasurement of depth to ground surface, geographic location, and photo documentation. We advise that data collection be paused for two weeks following the movement of a collar to allow for the environment inside the collar to regain stasis after disturbance.

Geographic location

Geographic location can be measured once during the life of the project, unless collars are moved. Collar locations should be recorded on a hand-held GPS with sub-meter accuracy. We recommend flagging and staking each location with rebar so that collars can be located under snow with the use of a metal detector.

Collar volume

Collar volume is remeasured once a year to provide a volume of the chamber in which gas flux is measured. The average depth from the collar top to the ground surface can be estimated by dropping a ruler from five intersections on the vegetation sampling grid (see visit-level measurements) and averaging the depths. The ground surface is conceptualized as the elevation at which there is a significant change in bulk density. This average depth should be multiplied by the area of the collar opening to calculate a collar volume. The chamber volume, which is constant, is then added to the collar volume to calculate the concentration of gases.

Photo documentation

Photo documentation can be captured at least once a year during full phenology (typically any time in July is appropriate). We recommend labeling each collar (e.g., on the side of the collar in permanent marker) and taking photos in cardinal directions with the collar in each shot and directly over the collar to capture the vegetation growing within the area of measurement. We recommend using a photo board, showing the direction, date, and site and collar number; the photo board does not need to be included in the ground shot (Figure 15). Photographs help relocate sites, reconcile data quality issues, and verify plant identity, abiotic ground cover types and percent covers.

Figure 14. Example of line point intercept methodology using a vertically-mounted laser pointer.

Figure 15. Example photographs showing a gas exchange collar from a cardinal direction (left) and from overhead (right).

Optional Collar-level Measurements:

The following collar-level measurements are not required, but can be made to more accurately account for the influence of vegetation and ground surface type, abundances, and plant biomass in gas emissions.

Vegetation and abiotic ground surface covers

Vegetation and abiotic ground surface covers can be measured at least once each year to correlate the occurrence of plant species within the collar to the vegetation community at the site level. We recommend using a grid of 25 evenly spaced points constructed to fit over the collar aperture and oriented parallel to the cardinal directions so that the points intersect the same ground surface location during each sampling event (Figure 16). Similar to the site-level survey of vegetation, species and ground cover occurrence can be multiplied by four to estimate percent cover. We recommend that plant species and ground covers be recorded using Alaska's Minimum Standards for Field Observation of Vegetation and Related Properties.

Woody and herbaceous vegetation height

Similarly, height of woody and herbaceous vegetation can be measured to correlate the heights of plant species within the collar at the time of sampling to heights of the vegetation community at the site level. We recommend measuring the second highest woody and herbaceous species located within the collar to avoid measuring individuals with outlying heights. Height can be measured using the elevation of the plant base as the zero line. Plants should not be straightened for measurement.

Biomass

At the end of a project, destructive harvests of biomass within collar footprints can be made to investigate how the type and abundance of plant material influences gas emissions.

Visit-level Measurements

Visit-level measurements are the basis for interpolating flux over time and extrapolating flux to the site level. In addition to the core measurement of gas flux, we suggest taking ancillary measurements of water level, air and soil temperature, brightness (LUX), and maximum plant height. These measurements are used as covariates to model CO_2 and CH_4 gas flux; this model can then be extrapolated site-wide and across time using continuous site-level data. We recommend collecting visit-level measurements once every two weeks to month during the snow-free season, defined as the period from ground thaw to ground freeze. We also recommend an early, mid, and late winter visit in the first year to establish winter flux. If gas exchange is documented to occur under snow or when the ground is frozen, winter monitoring should be continued at a frequency appropriate to the research.

Gases are released to the atmosphere via diffusion, ebullition (release of bubbles), and/or plant tissue. In general, emission is hampered by impermeable subsurface layers such as frozen ground and solid peat. Importantly, as the unit is measuring the emission rather than production of CO_2 and CH_4 within the chamber, flux can be influenced by a multitude of external factors such as people pushing gas from the subsurface when walking close to the collar, exhaling CO_2, shading the chamber, etc. Be mindful of your actions before and during gas measurement. In saturated or muddy habitats, constructing a simple boardwalk as shown in Figure 1 can help distribute the weight of the field workers and minimize the compaction of soil pore space and subsequent release of gases to the atmosphere. In these scenarios, it is important to stay as still as possible, either on a boardwalk or on relatively solid ground (though you may be standing in water). In some cases, slowly and carefully stepping away can be effective. In all cases, monitoring the data in real time will tell you whether gas emissions are jumping or spiking to unreasonable levels, and you can adjust your methods accordingly.

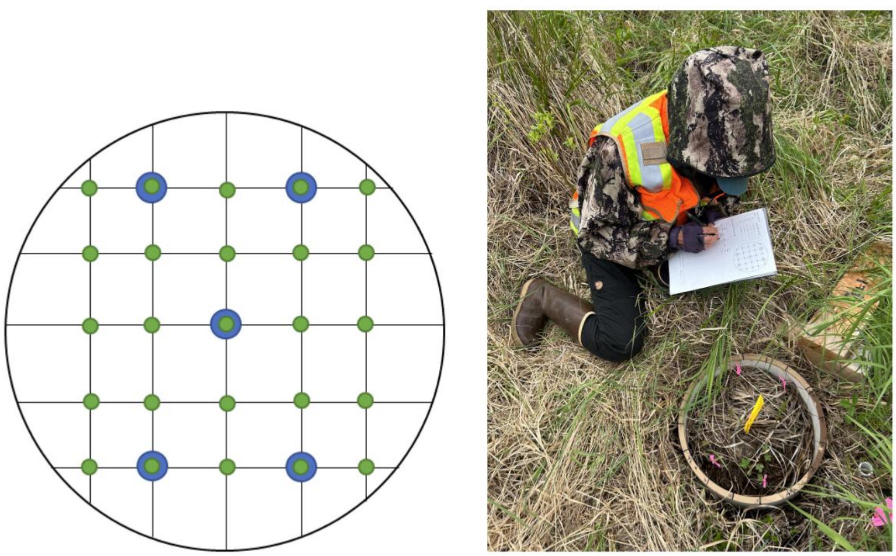

Figure 16. Top-down schematic of a vegetation sampling grid (left), and implementation of this grid in the field (right). Smaller green circles are vegetation sampling locations, and larger blue circles are depth to ground surface measurement locations (see Collar Level Measurements).

As the LI-7810 unit is water-sensitive, and is by far the most expensive piece of equipment involved in gas flux work, keeping water out of the unit (particularly the tubing) is the top priority during fieldwork. We use a clear plastic tote to transport the unit. The chamber may also be carried in this tote for transport between collars. Take care not to set the chamber sideways on flooded ground, as this is an easy way to get water into the intake tubing. The tote can be floated out to a flooded site, though it is unstable when the chamber is inside; keep a hand on the floating tote, especially when you are also transporting the chamber. Because the LI-7810 unit is protected by a pelican case, drops of water from a damp chamber or plastic bags are not a huge concern; the main points of vulnerability are the inlet and outlet (covered by tubing during use) and the power port (we keep this covered by duct tape). That being said, we avoid direct rain exposure. A very light drizzle is okay, but we avoid taking measurements if there's enough rain to warrant a raincoat. While waiting out a rain shower, place plastic bags over the tote. We anticipate that adding a tote lid would make the system more resilient to rain, but that tote lid would need to be raised for air exchange so the unit doesn't overheat.

Figure 17. Gas flux light reading (left) and dark reading (right) in a freshwater wetland near Happy Valley, AK. The dark reading makes use of an extension chamber due to flooded conditions; note that four plastic bags are used (two for chamber, two for extension) to fully block the light.

Typical atmospheric levels for CH_4 and CO_2 are 2000 parts per billion (ppb) and 400-450 parts per million (ppm), respectively. The unit should be reading within range of these values before the chamber is placed for data collection.

The flux of CO_2 and CH_4 is measured in dark and light (Figure 17) to simulate nighttime and daytime conditions. Nighttime conditions for CO_2 represent ecosystem respiration, whereas daytime conditions represent net ecosystem exchange (photosynthesis minus ecosystem respiration). Some species of plants have active ventilation of CH_4 during photosynthesis, in which case light/dark conditions will affect CH_4 fluxes. Otherwise, CH_4 fluxes are typically similar under light and dark conditions and can be averaged. Flux is calculated from the change in concentration of a given gas over time, which is represented by the slope of the line relating gas concentration to time. Approximately 3-4 minutes of linear data are necessary to extract a slope for the gas being measured. Often the 15 to 30 seconds of measurements need to be discarded because of pressure differences from placing the chamber and other human impacts. However, the measurement period should start as soon as possible after chamber placement so that gas concentrations begin close to atmospheric concentrations. For the light measurements, it is not ideal for the headspace CO_2 measurements to get so low that photosynthesis is inhibited. For dark measurements it is not ideal for headspace concentrations of CO_2 and CH_4 to get high enough to inhibit emission into the headspace. We recommend beginning with the light measurement, then removing the chamber from the collar so that it can re-equilibrate with the atmosphere prior to the dark measurement. Holding the chamber into the wind can make this process faster. If the evaporation rate is high, consider wiping condensation out of the chamber during this transition.

Light measurements

Place the chamber on the collar and note the time that the chamber is sealed. For some collars, one person may need to hold the vegetation in place while the other person places the chamber - for example, if there is significant herbaceous growth over the top of the collar, or a willow with wide branches. While vegetation disturbance should generally be avoided, it is also important to place the chamber relatively quickly, so it's fine if a few small herbaceous plants get caught between the chamber and collar as long as they do not affect the seal. In areas with substantial vegetation within the collar, CO_2 concentrations will typically decrease over time. After 3-4 minutes of linear data, remove the chamber and note the unseal time. The exact measurement period to be extracted for analysis may either be determined and written down in the field or determined retrospectively when processing the data.

Dark measurements

To simulate nighttime conditions, cover the chamber with two contractor-grade black trash bags so that PAR is blocked (one bag still lets out a bit of light). Bags can be placed at the end of the light measurement before removing the chamber, or during the air-out period between measurements. If you are using the extension, cover it with two trash bags cut so that they are open on both ends. Note that when placing the chamber in standing water without the extension, you will need to place the chamber and put the stopper back in before adding the trash bags. Otherwise, follow the light measurement procedures. CO_2 concentrations should increase over time.

Patterns to look for during gas flux measurements

- Where live vegetation occurs within a collar, the emission of CO_2 should always be higher in the dark than the light due to the elimination of photosynthesis.
- Where CO_2 concentration decreases, the contribution of cellular respiration is likely overridden by photosynthesis. CO_2 will be flat under conditions of equilibrium between photosynthesis and respiration.
- If CO_2 "jumps" at the beginning of the measurement, you probably breathed into the chamber.
- CH_4 fluxes are often less predictable than CO_2 fluxes because of the complicated controls of CH_4 production, consumption, and transport in ecosystems.
- CH_4 emissions will be higher from wet, anoxic sites because methanogens are strict anaerobes. CH_4 emissions will be lower (or even negative) from mesic, aerobic sites where CH_4 is being consumed in the soil.
- The emission of CH_4 is directly related to temperature and pH, that is as temperature and pH increase so will the emission of CH_4.
- If CH_4 "jumps" during the measurement, your movement likely caused the release of methane bubbles.
- If either gas is non-linear - especially non-monotonic - check for a leaky chamber. If either gas is fluctuating wildly, check for malfunctioning fans. Pay attention to the y-axis: a seemingly wild fluctuation or non-linearity in the graph could just be the result of a small overall change in concentration.

Additional environmental measurements

Water level

Water level is measured in a piezometer installed adjacent to the collar. We use 2.6 cm diameter PVC, drilled with holes to allow water flow in the subsurface portion of the pipe. The pipe should be installed deep enough to reach the lowest seasonal level of ground water. Measurements can be simplified if the piezometer top is level with the collar top. In this way, the average depth from collar top to ground surface can be subtracted from the water level depth as measured from the top of the piezometer to calculate the depth to water from the ground surface (Figure 18). If using this scheme, check to make sure that the piezometer and collar remain level over time.

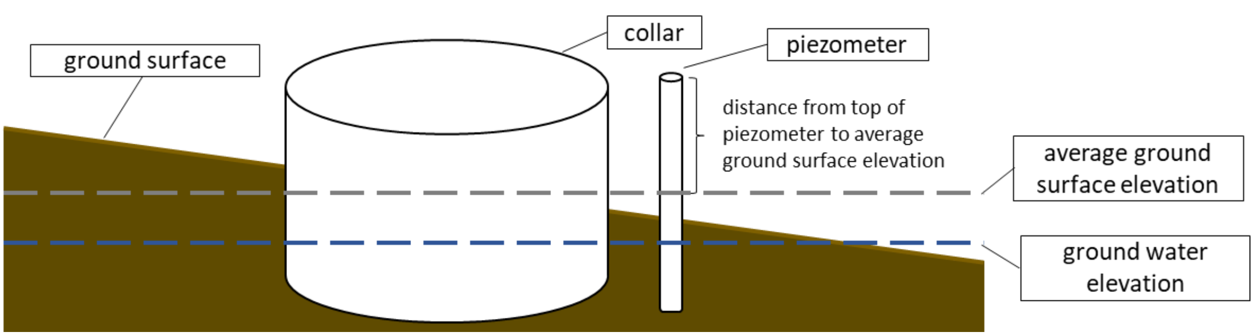

Figure 18. Schematic of collar placement relative to piezometer and ground surface.

Air temperature and brightness

Air temperature and LUX, a unit of brightness, are measured within the chamber during each gas flux measurement. We use a HOBO pendant logger that captures both temperature and light, and we take measurements every 10 seconds. At the start of a day of measurements, the logger is launched from our field computer and then secured on the inside of the chamber, facing outward, near the top of the PVC frame using two pieces of packing tape (being careful not to cover the specific points where light and temperature are sensed). The sensors should directly face the sun; placing the logger between the inlet and outlet tubing allows us to position the tubing and the tote directly behind the chamber (relative to the sun), where they will not shade the chamber (Figure 2). For analysis, we calculate the average LUX and temperature for each measurement period. If the LI-7810 time and the computer time are not aligned when the logger is launched, we note the time offset for data processing.

Soil temperature

Soil temperature is measured with a waterproof soil thermometer at a depth that approximates the root zone (ca. 10 cm) at a set location outside of the collar, for example, 5 cm north of the piezometer.

Vegetation height

The maximum heights of herbaceous and woody vegetation are measured for each collar using the same procedure as the collar-level measurements. For each height, we record the species. We also take a photo of each collar on a visit-level basis.

Downloading and Processing Data

Downloading data

While connected to the unit via a WLAN or ethernet connection, click Options > Export. Specify a date range and time period. Dates are displayed as YYYY-MM-DD. Time options are given in a 24-hour clock (00:00 through 24:00). Click Export. The web browser will prompt you to save or open the file, and then provide a text file with the requested data. The file has a .data extension. Measurements are recorded as tab-delimited text that can be opened in a text editor or spreadsheet application. The unit can store approximately 62 days of continuous data, after which records are overwritten. We recommend downloading all relevant data after each sampling event.

As an alternative to downloading data, the LI-7810 unit can communicate directly with devices using the Message Queuing Telemetry Transport (MQTT) protocol. See the LI-7810 Instruction Manual for a basic example describing how to read and save data from the unit in a terminal program such as macOS or Windows.

We have been processing the LI-7810 Data using a combination of Microsoft Excel and R. Data could be processed using alternative spreadsheet and coding applications. We will detail our analysis steps here as an example. Our code can be viewed on GitHub.

Preparing data

The first step is to open the downloaded data as a spreadsheet. You may need to copy the tab-delimited data from a text file into Excel. To prepare for data processing in R, remove the text-only rows (leaving the headers). We also suggest removing measurements with diagnostic errors (see Figure 19) by sorting the DIAG column from largest to smallest and removing all rows with non-zeros. DIAG shows the sum of the codes for the diagnostic errors. Each error type has a code represented by a power of two (1, 2, 4, 8, etc.; see the LI-7810 manual for more details). Save this file as a .csv.

You will also need to enter any data you collected on the data sheet (see ours in Appendix 1). This includes site-level metadata (e.g., date, people involved), collar-level covariate data (e.g., soil temperature, water table depth), and the time periods you will target for gas flux analysis. We collect all field data and calculated data in a master spreadsheet (Figure 20), with a metadata sheet that explains each column.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
1	Model:	LI-7810																				
2	SN:	TG10-01748																				
3	Software '	2.3.8																				
4	Timestam	6/17/2024 10:20																				
5	Timezone	US/Alaska																				
6	DATAH	SECONDS	NANOSEC	NDX	DIAG	REMARK	DATE	TIME	H2O	CO2	CH4	CAVITY_P	CAVITY_T	LASER_PH	LASER_T	RESIDUAL	RING_DO\	THERMAL_	PHASE_ER	LASER_T_!	INPUT_VC	CHK
7	DATAU	secs	nsecs	index	diag		date	time	ppm	ppm	ppb	kPa	°C	kPa	°C		µsecs	°C	counts	°C	V	CHK
8	DATA	1718648400	7.89E+08	8465	0		6/17/2024	10:20:00	11347.52	458.8571	2080.482	40.0982	54.9278	30.827	36.5758	0.002568	11.3272	54.4752	-222	-0.02072	15.6637	75
9	DATA	1718648401	7.89E+08	8469	0		6/17/2024	10:20:01	11368.49	457.6872	2083.257	40.0962	54.9286	30.8221	36.5758	0.002555	11.3256	54.4759	-158.75	-0.02072	15.6637	38
10	DATA	1718648402	7.89E+08	8473	0		6/17/2024	10:20:02	11377.92	458.0288	2083.23	40.0946	54.9293	30.818	36.5758	0.002563	11.326	54.4767	-271.5	-0.02072	15.6641	24
11	DATA	1718648403	7.89E+08	8477	0		6/17/2024	10:20:03	11378.51	458.213	2082.102	40.0933	54.9301	30.8126	36.5752	0.002557	11.3261	54.4775	-201.75	-0.02152	15.6645	235
12	DATA	1718648404	7.89E+08	8481	0		6/17/2024	10:20:04	11384.04	457.2666	2083.015	40.0909	54.9309	30.8069	36.575	0.002558	11.3262	54.4781	-258.75	-0.02152	15.6653	209

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
1	DATAH	SECONDS	NANOSEC	NDX	DIAG	REMARK	DATE	TIME	H2O	CO2	CH4	CAVITY_P	CAVITY_T	LASER_PH	LASER_T	RESIDUAL	RING_DO\	THERMAL_	PHASE_ER	LASER_T_!	INPUT_VC	CHK
2	DATA	1718660522	2.74E+08	56953	372		6/17/2024	13:42:02	6854.278	1886.256	3920.38	82.8866	55.0003	83.4995	36.5128	0.241053	-1161.58	54.5004	3914.25	-0.08371	14.3596	144
3	DATA	1718660526	2.74E+08	56969	372		6/17/2024	13:42:06	8506.463	883.5076	2627.611	83.2626	54.9995	83.8874	36.5128	0.689502	11.4103	54.5042	278.5	-0.08371	14.3647	33
4	DATA	1718660527	2.74E+08	56973	372		6/17/2024	13:42:07	7165.047	-13743.7	830.0457	83.332	54.9995	83.9567	36.5128	1.29832	11.3417	54.5046	593.5	-0.08371	14.3647	241
5	DATA	1718660529	2.74E+08	56981	372		6/17/2024	13:42:09	-13066.5	4683.269	4269.292	83.444	54.9995	84.0712	36.5128	0.929795	11.5066	54.5059	996.5	-0.08371	14.3674	4
6	DATA	1718660530	2.74E+08	56985	372		6/17/2024	13:42:10	-20099.3	3390.966	15191.04	83.4913	54.9995	84.1201	36.5128	1.41935	11.5058	54.5061	-565.25	-0.08371	14.3682	85
7	DATA	1718660541	2.73E+08	57029	372		6/17/2024	13:42:21	8042.246	-5683.75	-146357	83.7815	55.0003	84.416	36.5128	0.499296	11.5133	54.5075	-6930.25	-0.08371	14.3729	143
8	DATA	1718660587	2.71E+08	57213	372		6/17/2024	13:43:07	11614.17	9302.975	110.7808	83.9616	55.0001	84.602	36.5128	0.801212	11.5124	54.5021	-7424.25	-0.08371	14.3709	54
9	DATA	1718660645	2.69E+08	57445	372		6/17/2024	13:44:05	4982.828	9344.765	-424649	83.9727	55.0003	84.6118	36.5128	0.817667	11.5123	54.5005	-7437.75	-0.08371	14.369	192
10	DATA	1718660670	2.68E+08	57545	372		6/17/2024	13:44:30	-13657.3	-3548.17	-73508.4	83.9707	55.0003	84.6114	36.5128	0.688938	11.5117	54.5013	-7363.5	-0.08371	14.367	190
11	DATA	1718660705	2.66E+08	57685	372		6/17/2024	13:45:05	-9322.27	-4385.72	2701.801	83.9711	55.0003	84.6102	36.5128	0.766783	11.5105	54.5009	-7438	-0.08371	14.365	229
12	DATA	1718660735	2.65E+08	57805	372		6/17/2024	13:45:35	-6430.15	-2235.11	46487.71	83.9699	54.9995	84.6094	36.513	0.522948	11.5112	54.5005	-7419	-0.08371	14.3635	14
13	DATA	1718660747	2.65E+08	57853	372		6/17/2024	13:45:47	-4450.87	-1650.88	91863.06	83.9686	55.0003	84.609	36.5128	0.310204	11.5105	54.5005	-7476.25	-0.08371	14.3639	202
14	DATA	1718660490	2.75E+08	56825	356		6/17/2024	13:41:30	58083.33	-84679.5	-21166.5	42.1957	55.001	35.815	36.5128	10.38	11.3578	54.5013	941.5	-0.08371	14.3466	71

Figure 19. Raw LI-7810 gas flux data before any manipulation (top) and after removing rows of text besides the headers (bottom).

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	CollarID	Light_Dark	Date	Site	Dam_YN	People	Flag	Weather	Time_Seal	Time_Unseal	Time_Start_Mea	Time_End_Meas	Extension_YN
2	TEH1	Light	6/15/2024	East	N	SJ_LF_RG		Sunny	11:30:41	11:36:00	11:31:01	11:34:01	N
3	TEH1	Dark	6/15/2024	East	N	SJ_LF_RG		Sunny	11:42:40	11:48:20	11:43:00	11:46:00	N
4	TEH2	Light	6/15/2024	East	N	SJ_RC		Sunny	12:26:07	12:31:14	12:26:27	12:29:27	N
5	TEH2	Dark	6/15/2024	East	N	SJ_RC		Sunny	12:35:36	12:43:02	12:35:56	12:43:02	N
6	TEH3	Light	6/15/2024	East	N	SJ_RC		Sunny	12:53:27	13:01:27	12:53:47	12:56:47	N
7	TEH3	Dark	6/15/2024	East	N	SJ_RC		Sunny	13:08:04	13:18:56	13:08:24	13:11:24	N
8	TEM1	Light	6/17/2024	East	N	SJ_RC_LM		Partly Sunny	10:32:24	10:40:58	10:32:44	10:35:44	N
9	TEM1	Dark	6/17/2024	East	N	SJ_RC_LM		Partly Sunny	10:49:59	10:55:19	10:50:19	10:53:19	N
10	TEM2	Light	6/17/2024	East	N	SJ_RC_LM		Partly Sunny	11:06:18	11:13:21	11:07:23	11:10:23	N
11	TEM2	Dark	6/17/2024	East	N	SJ_RC_LM		Partly Sunny	11:17:35	11:23:53	11:18:02	11:21:02	N
12	TEM3	Light	6/17/2024	East	N	SJ_RC_LM		Partly Sunny	11:36:32	11:42:40	11:36:56	11:39:56	N
13	TEM3	Dark	6/17/2024	East	N	SJ_RC_LM		Partly Sunny	11:48:30	11:56:15	11:48:50	11:51:50	N
14	TEL1	Light	6/17/2024	East	N	SJ_RC_LM		Partly Sunny	12:34:44	12:39:56	12:35:04	12:38:04	N
15	TEL1	Dark	6/17/2024	East	N	SJ_RC_LM		Partly Sunny	12:44:12	12:49:50	12:44:32	12:47:32	N
16	TEL2	Light	6/17/2024	East	N	SJ_RC_LM		Partly Sunny	12:56:25	13:03:02	12:56:45	12:59:45	N

Figure 20. Example portion of master visit-level data sheet for combined gas flux and covariate data. This sheet contains direct measurements and calculated values. Most of the columns are not shown.

Once you have your .csv file(s) for the gas flux data, read the data into R. You will also need to read in the master sheet that contains the start and end times for the gas flux measurement periods. Using R, plot CO_2 and CH_4 concentrations for each measurement period (preferably next to each other). If you have already determined the measurement periods, check to make sure that these measurement periods make sense (roughly linear data representing a base rate of gas emission or drawdown with no clear sign of human interference). If you are determining measurement periods retrospectively, plot each seal-unseal period to see what makes sense. While it is important to look at each graph individually to remove anomalies, we recommend using a somewhat standardized procedure to avoid cherry picking data. Our procedure is to automatically remove the first 20 seconds (most likely period of human interference, anomalies often present), then take the following 3 minutes of data unless there are any clear anomalies ("stair-stepping", sudden change in slope) that likely represent human interference (e.g., releasing methane by stepping around collar). If there are anomalies, choose the soonest acceptable 3-minute period of data, or the longest period of acceptable data if you don't have 3 minutes. Choosing the soonest data helps minimize the effects of changing partial pressures and other changes from the base conditions. Enter these measurement periods into the master sheet.

Calculating covariates

To calculate values for the rate and concentration of carbon dioxide and methane gas efflux, you will need to perform the following steps in R:

Step 1. Gas concentration slopes for each measurement: Pull the CO_2 and CH_4 concentrations from the measurement period to determine Δ(PPM or PPB)/s. You may also want to calculate confidence intervals for these slopes and pull out the start and end concentrations for each measurement period.

Step 2. In-chamber average temperature and brightness: read in .csv data from the loggers, isolate data from each measurement period (apply time offset if necessary), and calculate averages.

Step 3. Chamber volume: add the volume of the main measurement chamber to the extension (if necessary) and the volume within the collar. Subtract any standing water volume. You may want a collar-level master sheet with measurements like depth to ground surface (Figure 16); this sheet can then be joined with the visit-level master sheet by Collar ID.

Step 4. Gas flux for each measurement: Use the ideal gas law (PV = nRT) to determine the moles of gas (n) in the chamber. Use the average temperature in the chamber (in Kelvin) and assume a pressure of one atmosphere (unless you are measuring pressure onsite). Use the calculated chamber volume. Then calculate gas flux using Equation 1. Note that if you are using $\Delta PPB/s$, you will need to either divide by 1000 or use nmol of gas instead. This method makes some simplifications - assuming the pressure, temperature, and moles of gas are constant - that we know are not fully accurate. However, given that both CO_2 and CH_4 are trace gases, and the measurement periods are short, we would expect the errors to be small.

Step 5. Any other covariates of interest - e.g., water level (using water depth in piezometer and depth from collar to ground surface), day of the year (or days since thaw), or change in max vegetation height across the year.

Equation 1

$$\frac{\mu mol\ CO_2\ or\ CH_4}{m^2 * s} = \Delta PPM/s\ * n\ moles\ *\ (basal\ area\ of\ collar\ in\ m^2)^{-1}$$

Model development

Next, build a model relating the environmental covariates to CO_2 and CH_4 gas flux. So far, we have been using generalized additive models (GAMs). Other researchers studying wetland CH_4 flux have had success using boosted regression trees. The details of the modeling will depend on your study system, your experimental setup, and the data you have available.

Use the best models from the previous step to build an annual carbon budget for your study system. We have not reached this step yet, but we anticipate that a grid approach would make sense: use the site-level data loggers and vegetation data to estimate or model each covariate at each point in space and time across the year, then use the models to estimate gas flux at each point in space and time. If you are measuring vegetation, the grid should have the same level of resolution as the manually delineated extents of plant communities. Multiply flux rates by grid unit area and the change in time to get a total CO_2 and CH_4 flux for each unit during each time period. Add all of these estimates together to get a sitewide budget for the year.

Appendix 1. Field Equipment List

This list covers the KBNERR/ACCS gas flux setup. Note that for others doing gas flux work, some of the specifics may differ.

- ☐ Li-COR LI-7810 unit
- ☐ Project binder with permits, Li-COR user guide, etc.
- ☐ Li-COR Instruction Manual
- ☐ Measurement chamber (in Nomar bag)
- ☐ Clipboard with data sheets
- ☐ Extension chamber
- ☐ black contractor grade trash bags for dark readings: two normal bags, two more cut bags for extension chamber, extra bags as backup
- ☐ Four fans (two are rechargeable - make sure they are fully charged)
- ☐ extra batteries for:
    - LI-7810 (we have two extra - make sure these are charged)
    - Fan (AA)
- ☐ Large tote for Li-COR unit (clear "Licor Lifeboat"; also bring a rain cover, if built)
- ☐ backpack for unit to carry to the sites and between sampling locations; consider sledding gear in wintertime
- ☐ 0.79 cm (5/16") crescent wrench for Swagelok fittings
- ☐ Packing tape
- ☐ Tablet, phone, or (preferably) computer to read data from unit; Bluetooth-enabled device if using HOBO pendant MX loggers
    - SWMP computer if available (ruggedized)
- ☐ HOBO/Onset base station with USB cord, connector(s) to logger(s)
- ☐ Extra pendant logger with sufficient battery to use in unit: launch using USB-enabled computer in field or in the office before leaving
- ☐ Pelican case for accessories
- ☐ level to assess collar and piezometer alignment; mallet(s) for adjustments
- ☐ Fold-out ruler for measuring vegetation height and piezometer water depth
- ☐ Chalk for measuring piezometer water depth
- ☐ Soil thermometer - silver one from ACCS and long, wired one from Scott Bridgham
- ☐ Extra velcro and weather stripping
- ☐ Optional: external charger(s) and cord(s) for computer, tablet or phone, or Licor/Licor batteries

If surveying vegetation:

- ☐ Appropriate plant species checklists and floras
- ☐ Ziplock bags of various sizes for voucher specimens of plant species not identifiable in the field
- ☐ Hand lens
- ☐ Hori-hori or other digging tool for collecting plants

For remote settings (no lab/office access for repairs):

- ☐ Extra air filters, o-rings, and screws for LI-7810 unit
- ☐ Extra desiccant
- ☐ Extra Bev-A-Line tubing and Swagelok fittings
- ☐ Repair toolkit (screwdriver, etc.)
- ☐ Gloves and clean surface (e.g., paper towels)

Personal Gear List

Clothing:

- ☐ Boots, and waders for flooded sites
- ☐ Rain jacket/pants
- ☐ Gloves
- ☐ Bug shirt/spray

Safety:

- ☐ InReach satellite communication device
- ☐ Bear spray, air horn
- ☐ First aid kit

Additional:

- ☐ Water and food/snacks
- ☐ Optional:
    - Bivy and/or tent
    - Full KBNERR field pack with tent, stove, etc.

Appendix 2: Example Data Sheet

Beaver Project: Visit Level Measurements

Transect data:

Date (yyyy-mm-dd):________________________ Observer/Recorder:__________________________

Transect ID:____________________________ Time offset (sec; HOBO minus Li-Cor): ______________

Weather: Sunny Partly Sunny Overcast Rainy (circle one; note if this changes for each reading)

Notes:

Collar data:

Collar ID: _____________ Extension: Yes No (circle one) Soil Thermometer: Silver Wire Other

Depth to groundwater from top of piezometer (cm):________________ Soil Temp (C): ____________

Tallest Woody: _______________________ Tallest Herbaceous: _________________________

Max Height (cm): _____________ Max Height (cm): _____________

Light measurement

START: ***(hh:mm:ss)****	**CO_2 (ppm)**	**CH_4 (ppb)**

STOP: ***(hh:mm:ss)****	**CO_2 (ppm)**	**CH_4 (ppb)**

Dark measurement

START: ***(hh:mm:ss)****	**CO_2 (ppm)**	**CH_4 (ppb)**

STOP: ***(hh:mm:ss)****	**CO_2 (ppm)**	**CH_4 (ppb)**

Notes:

*Timestamp when chamber is sealed/unsealed in Li-Cor time (AKST +/- some seconds)

Collar ID: ______________ Extension: Yes No (circle one) Soil Thermometer: Silver Wire Other

Depth to groundwater from top of piezometer (cm): ______________ Soil Temp (C): ______________

Tallest Woody: ______________ Tallest Herbaceous: ______________

Max Height (cm): ______________ Max Height (cm): ______________

Light measurement

START: *(hh:mm:ss)**	**CO_2 (ppm)**	**CH_4 (ppb)**

STOP: *(hh:mm:ss)**	**CO_2 (ppm)**	**CH_4 (ppb)**

Dark measurement

START: *(hh:mm:ss)**	**CO_2 (ppm)**	**CH_4 (ppb)**

STOP: *(hh:mm:ss)**	**CO_2 (ppm)**	**CH_4 (ppb)**

Notes:

Collar ID: ______________ Extension: Yes No (circle one) Soil Thermometer: Silver Wire Other

Depth to groundwater from top of piezometer (cm): ______________ Soil Temp (C): ______________

Tallest Woody: ______________ Tallest Herbaceous: ______________

Max Height (cm): ______________ Max Height (cm): ______________

Light measurement

START: *(hh:mm:ss)**	**CO_2 (ppm)**	**CH_4 (ppb)**

STOP: *(hh:mm:ss)**	**CO_2 (ppm)**	**CH_4 (ppb)**

Dark measurement

START: *(hh:mm:ss)**	**CO_2 (ppm)**	**CH_4 (ppb)**

STOP: *(hh:mm:ss)**	**CO_2 (ppm)**	**CH_4 (ppb)**

Notes:

*Timestamp when chamber is sealed/unsealed in Li-Cor time (AKST +/- some seconds)