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Technical Notes & Preliminary Communications

Core Ideas

Easy-to-use protocol captures carbon flux data on a mobile device.

Increases data storage, resolution, and setup flexibility compared with common practices.

Mobile devices can replace heavy equipment and increase useful time in the field.

Capturing Gas Fluxes on Your Phone: An iOS- and Android-based Data-Logging Setup for EGM-4 Environmental Gas Monitoring Systems

Henk Pieter Sterk,* Iain Detrey, Chris Marshall, Neil R. Cowie, Richard Payne, Jason McIlvenny, and Roxane Andersen

ABSTRACT

Mobile devices have become increasingly important for field monitoring to improve data capture efficiency, increase storage capacity, and replace heavy equipment. We introduce a quick and straightforward protocol to capture greenhouse gas (GHG) emission rates on mobile devices. We developed our setup on the widely used infrared gas analyzer (IRGA) EGM-4 by PP Systems. This IRGA has a limited internal storage capacity and requires an external device such as a laptop to conduct even modest field sampling. Furthermore, when raw data storage is required, carbon dioxide concentration resolution is reduced by the internal EGM-4 software settings, making the equipment less suitable for high-frequency measurements. Our protocol lets the user bring either an iOS or Android mobile device in to the field to connect to the EGM-4's data stream. For both platforms, a mobile console application was used to read, log, and share flux data. The raw data can be processed in either Python, R, or Matlab using the provided scripts that give the user flexibility to amend further postprocessing steps to obtain GHG fluxes. We demonstrate the flexible applicability of mobile devices for field recording and show that a cost-effective solution can enhance the operational life of superseded field equipment while also increasing the quality of the captured data.

MOBILE DEVICES have had a predominantly positive effect on field-based surveys due to their ability to produce, store, and back up large datasets that would otherwise be difficult to handle. It is now common for scientists to take their mobile devices into the field with them and create applications for environmental monitoring (Berger-Tal and Lahoz-Monfort, 2018), sharing and merging the data across digital platforms (Marvin et al., 2016). These handheld devices have considerable computing power and a range of sensors that have the potential to be exploited for scientific purposes (Teacher et al., 2013). The number of innovative solutions that take advantage of the abilities of mobile devices is increasing; examples include real-time GPS data provided by a smartphone (Lwin and Murayama, 2011), control of unmanned aerial vehicles (UAVs) by a smartphone app (Dixit et al., 2013), mobile device–based rice leaf color

measurement systems to estimate nitrogen levels in crops (Intaravanne and Sumriddetchkajorn, 2012), and apps such as eBird developed to record and help identify species during ecological surveys (Wood et al., 2011).

One common task in ecology and biogeochemistry is recording greenhouse gas (GHG) flux rates. While some modern gas analyzers have the built-in ability to output data to online servers and mobile devices, this is not the case for legacy devices currently in regular field use. We focus on the PP Systems EGM-4 infrared gas analyzer (IRGA) (PP Systems, 2009), which, while no longer in production, has been widely used and is still the most common measurement instrument for measuring soil CO_2 fluxes in field ecological laboratories. The EGM-4 has been a highly popular instrument because it is relatively robust and relatively inexpensive. However, it offers no built-in option for downloading to mobile devices, and the software has a number of significant limitations. The EGM-4 has limited storage capacity, and when the default settings are used, the internal logging software is incapable of using subminute time intervals for automated concentration logging. Due to these limitations, the equipment is not suitable for short measurement series, which are essential when there is buildup of gases inside measurement chambers (Lai et al., 2012). When chamber deployment is set for a short period, a higher number of data points available for regression functions is highly recommended (Kutzbach et al., 2007).

The EGM-4 can detect CO_2 concentration in the air at a parts per million (ppm) level ranging from 0 to 1000 ppm or even up to 100,000 ppm. Even though the instrument is able to store up to 1250 individual records, the EGM-4 operator has only two, mutually exclusive, options when using it as a Standalone CO_2 IRGA: manual internal storage with a key press or automatically storing actual CO_2 ppm measurements at a fixed interval rate (between 1 and 720 min). To overcome the inability to store measurements under the 1-min interval, manual recording of CO_2 ppm output values on a logging sheet has been a common practice, although mostly at 15-s intervals (Munir et al., 2015; Nwaishi et al., 2016). Alternatively, the EGM-4 can be used in a Closed System Soil Respiration mode, allowing it to store CO_2 ppm values at a 4.8-s interval but limiting storage to a maximum of 80 min of data, which is frequently insufficient for field monitoring. This is a particular problem as GHG projects often include several measurements per sampling occasion, for example, to capture the effect of solar radiation on fluxes throughout the day (Munir et al., 2015; Nwaishi et al., 2016; Green et al., 2018), and thus require sufficient storage capacity. The operator can alternatively bring a laptop in the field to have the EGM-4 dump or log its data straight to a hard drive, but this unfavorably increases the total weight of the setup and potentially decreases the available time in the field due to laptop battery limitations. The current standalone CO_2 IRGA setup is capable of having its internal memory emptied throughout the sampling period, but this still requires another mobile device, that can be connected to the EGM-4, to be taken into the field.

In this paper, we provide the information to capture the serial output from an EGM-4 and list the required cables and serial connections settings for the console applications to connect the EGM-4 to an iOS (Apple) or Android (Google) device. Basic scripts, which for maximum flexibility are presented in each of Python (https://www.python.org/), R (https://www.r-project.org/), and Matlab (MathWorks, https://www.mathworks.com/products/matlab.html), are presented to run initial postprocessing of CO_2–flux data and add metadata to the output files. The

aim is to provide the scientific community with a cost-effective, lightweight mobile solution for a widely used gas analyzer to increase both its operational lifespan and its data output quality.

MATERIALS AND METHODS

Here we describe our proposed solution (Fig. 1) to the issues identified above and the steps needed to connect the EGM-4 to a compatible smartphone or tablet. We state the hardware requirements, followed by a detailed workflow on both iOS- and Android-based mobile devices, and conclude with a single postprocessing scripts section. In this case, we assume that the reader is familiar with the setup for the standalone CO_2 IRGA setting according to the EGM-4 Operator's Manual (PP Systems, 2013). The same familiarization process applies to the mobile devices used. Even though the output files at the end of the protocol are generally small, we recommend a minimum of 4 GB of available storage on the mobile device.

The EGM-4 is equipped with a 9-pin digital serial communication port set to the international RS-232 communication standard. The port's purpose is to dump data from the EGM-4's internal memory to a PC or laptop running the PP Systems Windows (Microsoft)–based software program Transfer. The RS-232 port is also capable of streaming data produced by the EGM-4 if the machine is put in its record mode (1REC in the main display). Due to different connection ports on iOS and Android devices, each requires a different adaptor cable for the mobile-to-EGM-4 connection. Detailed walk-throughs on setup, logging, and exporting data from the EGM-4 using either iOS or Android mobile devices can be found in the Supplemental Material.

Hardware and Application for iOS Devices

To set up a connection between the EGM-4 and a mobile iOS device, the Get Console application, available from the Apple App Store, is required, along with the Redpark Lightning Console Cable (L2-RJ45V-A). This adaptor cable connects an Ethernet plug (wired per Cisco console port specifications) and an Apple iOS device with a lightning port (introduced for iPhones, iPads, and iPods in 2012). The connection also requires another DB9 adaptor to connect the Ethernet plug to the RS-232 9-pin port of the EGM-4. For older iOS device models with a 30-pin port, another Redpark serial cable (C2-DB9V) can be used to connect the device to the RS-232 port; however, these devices are unlikely to be able to run the required iOS version. The minimal iOS version compatible with the Get Console (version 2.48) application is iOS 8.4 or higher. After installation, system settings have to be altered based on the operator's manual for the EGM-4 to log the output from the gas analyzer (see the Supplemental Material).

Hardware and Application for Android Devices

To augment the application possibilities, mobile devices using the Android operating system with a micro-USB can be used as well. A variety of micro-USB to RS-232 cables are on the market; here, we used the StarTech.com Micro USB to RS232 DB9 Serial Adaptor Cable for Android with USB Charging-M/M. Similar to the iOS setup, an application has to be downloaded to read the serial output from the EGM-4. The adaptor cable is equipped with a FTDI USB UART chip support, required to interpret the serial signal from the EGM-4. The free FTDI AOA HyperTerm (version 1.0) was used from the Google Play store to run on Android

(version 3.2 or higher) and is designed to deal with the adaptor's output signal. After installation, signal detection settings have to be adjusted to receive and log the EGM-4 data stream.

Postprocessing in Python, R, or Matlab

Logged files are stored as .txt files, each line consisting of a string of 61 characters without spaces (see Supplemental Material: Example Dataset). The range of values (e.g., Plot No. range 0–99 and Rec No. range 0–9999) can influence the number of digits used for a record. The solution provided does not require manual or automated alteration of Plot No. or Rec No. values as this option is not used during data collection. After the log files are transferred to a desktop (i.e., shared as an email attachment), they are processed into the format (Fig. 2, Step 3) stated in the EGM-4 Operator's Manual (PP Systems, 2013).

The text-read and export to CSV file steps are shared in Python, R, and Matlab in the Supplemental Material. Each script was tested on a set of over 500 log files stored together in a user-defined directory. The scripts can handle individual folders containing the saved log files and will iterate over the files to process each log file individually. Using the EGM-4 in the stand-alone IRGA setting can result in calibration "zero checks" being logged, creating gaps in the record. In all scripts, this problem is taken into account by including an additional column ("Sec") to include the seconds since the start of the record and subsequently removing the zero check lines from the log. Furthermore, the scripts include code to extract filenames into the dataset for additional metadata (column "File") and for the output file to be named after the input file. For all scripts, user-defined directories (for input and output location) have to be assigned accordingly.

RESULTS AND DISCUSSION

All postprocessing steps in Python, R, and Matlab are based on the same structure: data import, data cleanup, and data export to a CSV file. In theory, all data processing can be done manually for each file, but the advantage of the scripts is their ability to process as many files as workstation's memory can handle. The supplemented scripts can be changed and augmented to meet specific needs from the user. Additional data output from the standalone CO_2 IRGA setting of the EGM-4 can be stored through the described logging setup: when probes are added to the EGM-4, the RS-232 port will also stream this data in columns A to G (Fig. 2) according to the probe type (PP Systems, 2013). Depending on the usage of the data, these columns can be included or omitted in further data-processing steps.

High-frequency flux data are highly valuable to calculate rates with a range of regression analysis techniques and software packages. Short chamber deployment times require more data points to determine whether a linear regression underestimates actual fluxes, and nonlinear regression models should be used (Kutzbach et al., 2007). Additionally, the high-resolution concentration data allow for precise study of nonlinear—or curvilinear—behavior of the fluxes (Pirk et al., 2016), essential to properly quantifying the net gaseous carbon balance. When using standard PP Systems chambers (e.g., SRC-1 or CPY-4) in the closed system soil respiration mode, the output resolution is limited to 4.8 s when a full dataset is saved, that is, no rates calculated using the PP Systems algorithm are stored internally. With this default setup, the

internal storage is capable of recording 80 min worth of continuous data, ready for regression analyses later (PP Systems, 2013). As mentioned previously, while the operator can bring a laptop in the field to have the EGM-4 dump or log its data straight to a hard drive, this increases the total weight of the setup, and laptop battery limitations potentially decrease the available time in the field. The proposed mobile-to-EGM-4 connection removes this data storage barrier, especially if data are transferred to data repositories through email during a field sampling campaign. Battery life will thus be the only limiting factor remaining for both the EGM-4 and mobile device used for logging.

New generation gas analyzers are capable of recording gas changes at a 1-s resolution (EGM-5 Operation Manual; PP Systems, 2018) and give the operator more data storage and processing power in the field. These new devices require large investments and are frequently unavailable. Furthermore, in theory, all gas analyzers with a RS-232 port, including older PP Systems models (e.g., SBA-1, WMA-1, EGM-3), should be able to use the above method, with changes to the mobile application settings with reference to the device operation manual, something outside the scope of this paper.

Our study provides an example of how readily available connectors combined with simple postprocessing can improve the practicality and data quality of the EGM-4 infrared gas analyzers. The use of mobile devices in science is increasingly important, as they can replace additional heavy field equipment to record data and makes possible quick data sharing, allowing for uploading of raw data enhanced with metadata into the cloud and enabling operators to begin data processing remotely while in the field.

SUPPLEMENTAL MATERIAL

The first part of the supplemental material includes the mobile application settings for mobile devices running on either iOS or Android. The second part contains solutions to common errors that can occur during operation. The third part includes the data processing scripts to be used in respectively Python, R or Matlab. Each script has been tested and is provided with explanations for all sections help the user select and change the code for their own use (e.g. to change directory names). The fourth and final part is an example dataset (in txt format) of the EGM-4 output captured with either iOS or Android setup. It allows the user to test the scripts and examine the script's output.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Fig. 1. EGM-4 to mobile device diagram, including handheld and application requirements, sharing options, and postprocessing choices.

Fig. 2. Data processing: raw output data from Get Console and FTDI AOA HyperTerm applications in text-file (.txt) format to comma-separated values (.csv) files.