Making small-scale classroom greenhouse gas flux calculations using a handmade gas capture hood

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The emissions of various types of greenhouse gases (GHGs) from natural and industrial sources are undergoing a great deal of scrutiny around the world. The three main GHGs that are of most concern are carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). CO_2, N_2O and CH_4 are all efficient absorbers and emitters of thermal infrared radiation, and as a result, once they are emitted into the atmosphere, they can contribute directly to the greenhouse effect. One of the most popular GHG measurement techniques is near dispersive infrared (NDIR) gas analysis. This paper describes a high school Physics or general science practical exercise that uses an inexpensive NDIR based gas analysis unit combined with a gas capture hood to measure CO_2 gas flux from different water types and soil/fertiliser combinations. From this, students will gain an understanding of how GHGs are emitted from natural sources and how they are measured by scientists.

Introduction

Greenhouse gases

GHGs, particularly CO_2, are produced continuously in the natural environment. Freshwater lakes, streams and wetlands all measurably contribute to the emission of carbon (Schrier-Uijl et al., 2011). Currently, it is estimated that lakes alone release as much as 513 tonnes of CO_2 every year (Cole et al., 1994; Schrier-Uijl et al., 2011). CO_2 has a high solubility, and as a result, large amounts of CO_2 can group close to the water surface, which leads to an oversaturation and eventual ejection of the CO_2 out into the atmosphere (Schrier-Uijl et al., 2011). The production and emission of CO_2 can be modulated by various water quality parameters such as dissolved oxygen levels, water temperature, pH and electrical conductivity. Opposite to freshwater bodies, continental seas are absorbers (sinks) of CO_2 emissions on average, and as such they form an integral part of the world's carbon balance. Generally, subtropical and tropical systems provide a source of atmospheric CO_2, while mid and high-latitude systems provide a sink for atmospheric CO_2 (Borges, 2005; Borges et al., 2005, Borges et al., 2006; Kone et al., 2009). Shoreline ecosystems and waters (such as those that will be sampled in the practical exercise described in this manuscript) are usually positive emitters of CO_2 due to the regular inflow of carbon inputs from the mainland (Borges, 2005; Borges et al., 2005, Borges et al., 2006; Kone et al., 2009).

Carbon emitted from soils occurs generally in the form of CO_2 and is generated by soil respiration, which is usually either autotrophic (root respiration) or heterotrophic, a process occurring from the decomposition of soil organic matter (Berger et al., 2010). Soil respiration is the most substantial instigator of CO_2 emissions worldwide and delivers a yearly positive input approximately one magnitude larger than that produced by the use of anthropogenic fossil fuels (Raich et al., 2002; Berger et al., 2010). As a consequence of this, only small variations in soil respiration rates can have a measurable impact upon the level of atmospheric CO_2 (Berger et al., 2010). CO_2 emissions from soils can vary substantially with changes in soil type, temperature, management practices, introduction of organic and mineral fertilisers (such as those that will be analysed in the practical exercise detailed in this manuscript) and water content (Rogalski & Warminski, 2008).

Greenhouse gas measurement and NDIR gas analysis

The gas analysis performed in this exercise will follow a technique similar to that employed by Tremblay et al (2004) using a gas capture hood combined with a NDIR gas analyser for taking CO_2 measurements across large water bodies. Generally, for gas measurements in remote or isolated field locations, gas collection with a capture hood, combined with a NDIR gas analyser is the most appropriate. This is due to its relative ease of use and portability. Figure 1 shows a picture of a typical gas capture hood (Ac'Scent Flux Hood, www.fivesenses.com). Displayed in Figure 2 is a NDIR gas analysis unit (Horiba, VA 3000 Series) (top) coupled with a gas conditioning (water and dirt extraction) system (Horiba, VS 3000 Series) (bottom) prepared for deployment at a field site. An NDIR gas analyser is usually remotely connected to a gas capture hood via two rubber tubes (one for gas input and the other for gas output). However, in the practical exercise presented in this paper, the need for rubber tubing is removed as the NDIR gas analyser will be mounted inside the gas capture hood.

Figure 1: A gas capture hood designed to enclose GHGs from both solid and liquid surfaces.

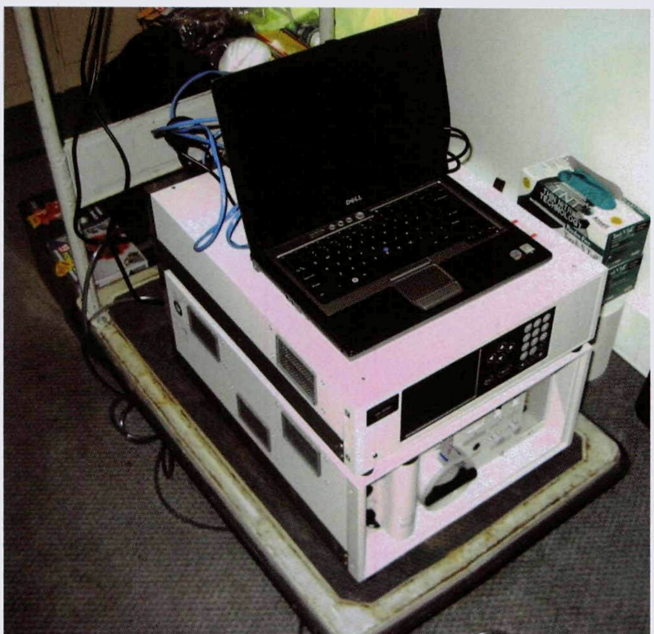

Figure 2: A typical NDIR gas analysis system (Horiba VA/VS 3000) prepared for work in a field environment.

NDIR gas analysers consist of four main components: an infrared source, a reference tube, a sample tube and a detector. The reference tube contains either an enclosed, or free flowing reference gas (such as nitrogen), while the sample tube takes in gas sampled externally at a stable flow rate. Inside the analyser, two identical infrared beams are sent through the reference tube and sample tube simultaneously. The detector measures the difference between the infrared absorption occurring in the reference tube and the infrared absorption occurring in the sample tube. Specifically, in the sample tube, the amount of infrared absorbed is proportional to the concentration of sampled gas. The exact concentration of CO_2 in the sample tube can be accurately calculated by positioning an optical filter in front of the detector that is opaque to all infrared wavelengths, apart from the exact wavelength absorbed by CO_2 (RAE Systems, N.D).

Objective

The following exercise documented in this paper can be used in high school Year 11 and Year 12 Physics classes or in advanced sciences classes for students in Year 10 and above. Specifically, this exercise employs an inexpensive NDIR gas analysis unit combined with a gas capture hood to measure CO_2 gas flux from different water types, soils and fertilisers. From this exercise, the students will obtain a good understanding of how CO_2 is naturally emitted from typical sources such as sea water, creek water, soils and fertilisers and will also learn how they are measured in real-time in field environments by scientists. It is estimated that the entire exercise should take no more than 1 hour to 1.25 hours to complete. In some schools, classes may run for less than an hour, so the exercise described in the manuscript may take slightly too long. Consequently, the exercise may be completed and presented by students in science fairs and science competitions, or teachers may wish to modify its content for use as a take home assignment project.

Materials and Methods

In order to successfully complete this practical exercise, several items are required:

- A rectangular water container capable of holding >= 40 L of water;
- Access to a supply of sea water and fresh water sourced from a dam, creek or river. In the example experiments shown in this manuscript, the authors obtained coastal sea water and flowing creek water;
- A bag (or several bags) of fresh nitrogen-based fertiliser and access to an open soil area. Three types of fertiliser were chosen by the authors for use in the example experiments: Richgro Basics Rose and Citrus fertiliser (Total Nitrogen = 7.5%; Total Phosphorus = 1.5%), Richgro Basics Vegetable and Herb fertiliser (Total Nitrogen = 8%; Total Phosphorus = 1.6%) and Richgro Basics Garden Complete fertiliser (Total Nitrogen = 8%; Total Phosphorus = 1.6%);
- In order to induce aeration in the water inside the tank, a simple water aeration/bubble plume system may be used. If a water aeration/ bubble plume system is not available, a simple water pump/bubbler device can be used as an alternative to recirculate the aerated water instead. These systems are readily available from aquarium stores and are inexpensive. In the example provided in this manuscript, the authors used a Sera Precision 550 R plus aquarium air pump (9.2 L min-1 flow rate);
- One to two empty and clean regular-sized ice cream containers;
- High strength masking tape or duct tape;
- Sticking putty;
- Scissors;
- Four empty water bottles;
- A NDIR CO_2 measurement meter (TIM10 CO_2 Meter, Indoor Air Quality Products). This CO_2 measurement meter can be purchased from http://www.co2meter.com for approximately $149.95 US (excluding shipping);
- An extension power lead.

Gas capture hood construction

1. Using the CO_2 measurement meter as a template, use a permanent marker to draw out a line around the bottom of an empty medium sized ice cream container;
2. Cut all the way around the marked line to create a circular hole in the bottom of the ice cream container;
3. Slide the CO_2 measurement meter into the hole making sure that the LCD display faces outwards and not into the ice cream container. The circular groove located just beneath the LCD display and the settings buttons allow the CO_2 measurement meter to lock into place;
4. Use either high-strength masking tape or duct tape to seal the CO_2 measurement meter to the ice cream container. The tape should be applied in a liberal manner around both the front and the back of the ice cream container in order to ensure that the CO_2 measurement meter does not fall out and that an air tight seal is made. A picture of the CO_2 measurement meter attached to the ice cream container is displayed in Figure 3;
5. Using a pair of scissors, carefully punch a hole into the side of the ice cream container. Slide the CO_2 measurement meter power cord through this hole and connect it into the meter. Figure 4 shows where the hole should be made in the side of the ice cream container in order to allow the power cord to pass through;
6. To make the gas capture hood capable of taking water surface gas measurements, it must be modified so it can float. To do this, obtain four empty lightweight water bottles. Place the water bottles (with their lids still attached) around each side of the ice cream container;
7. Attach the bottles to the sides of the ice cream container using duct tape. Ensure that the water bottles are attached asymmetrically around the ice cream container. This helps to improve buoyancy around the entirety of the hood. Figure 5 shows an example of how the water bottles can be attached to the outside of the ice cream container;
8. Make sure to loop the tape several times around the ice cream container and the bottles. Doing this prevents the bottles from falling off the sides of the ice cream container after splash down;
9. Test the buoyancy of the gas capture hood in a small water tank or in a sink. If the gas capture hood looks like it is about to sink, quickly remove it from the water and make modifications to improve the buoyancy as required.

Figure 3: Top view of the gas capture hood with the CO_2 measurement meter fixed into the centre.

Figure 4: Underneath view of the gas capture hood with the CO_2 measurement meter fixed into the centre. The power cord exit hole can be clearly seen in this picture.

Figure 5: Top view of the gas capture hood with the CO_2 measurement meter fixed into the centre and the empty water bottles attached to the outside.

Gas concentration measurement method (water surface)

1. Take a measurement of the background (ambient) CO_2 concentration with the CO_2 measurement meter;

2. Place the flux hood/CO_2 measurement meter on top of the water surface. Make sure that the ice cream container sits flush on top of the water surface so that no air can flow in or out;

   NOTE: Take great care not to submerge or splash any substantial amount of water on the CO_2 measurement meter. Doing this may damage the sensitive internal sensor electronics.

3. Record an initial CO_2 concentration measurement as shown on the LCD display of the CO_2 measurement meter;

   NOTE: Make sure to keep the flux hood/CO_2 measurement meter in the same position on the water surface throughout each gas concentration measurement. Failure to do so may introduce errors into the gas concentration readings.

4. Using a stop watch or digital timer, wait for 10 seconds and record another CO_2 concentration measurement;

5. Continue recording CO_2 concentrations every 10 seconds for a further two minutes. This will give a total of 12 CO_2 concentration measurements;

6. Upon the conclusion of each two minute CO_2 concentration measurement, remove the flux hood/CO_2 measurement meter from the water surface and wait for the CO_2 concentration to drop down to the background (ambient) CO_2 concentration as measured in step 1;

7. If necessary, empty the tank out and fill it up with another type of water. The measurements can be completed quicker if multiple tanks are filled up with each different type of water before the start of the exercise;

8. Repeat steps 1 through to 8 for each water type;

9. Once all static water CO_2 gas concentration measurements have been made, insert the air flow tube/s from the air bubbler into the tank. Turn on the air bubbler and let it run for two minutes to allow the water to become fully aerated. For this, make sure the air bubbler is set to provide its highest flow rate. Use spheres of sticking putty as ballast to prevent the air flow tubes from moving around under the water surface;

10. Repeat steps 1 through to 8 again for each water type with the air bubbler in full operation. From this, it will be seen if aeration has any influence upon the amount of CO_2 emitted from each water type.

Gas concentration measurement method (soil and fertiliser surface)

1. Sprinkle roughly 2.5 kg of each type of fertiliser separately across an estimated 4 m x 4 m outdoors area. Make sure to leave an even spacing of 1 m between each fertiliser type.

2. Make sure to mix in the fertilisers consistently with the top soil.

3. Place the flux hood/CO_2 measurement meter on top of the soil/fertiliser surface. Ensure that the ice cream container sits tightly on top of the soil so that no air can flow in or out;

4. Record an initial CO_2 concentration measurement as shown on the LCD display of the CO_2 measurement meter;

   NOTE: As with the water surface measurements, make sure to keep the flux hood/CO_2 measurement meter in the same position on the soil/fertiliser surface throughout each gas concentration measurement.

5. Using a stop watch or digital timer, wait approximately 10 seconds and take another CO_2 concentration measurement;

6. Continue measuring the CO_2 concentration every 10 seconds for a further two minutes. This will provide 12 CO_2 concentration measurements;

7. Upon the conclusion of each two minute CO_2 concentration measurement series, remove the flux hood/CO_2 measurement meter from the soil/fertiliser surface and wait for the CO_2 concentration to fall back to the background (ambient) CO_2 concentration originally measured in step 3;

8. Repeat steps 3 through to 10 for each different type of soil/fertiliser mix;

9. Once the dry soil/fertiliser CO_2 concentration measurements are complete, pour roughly 5 L of water over each type of soil/fertiliser mix;

10. Repeat steps 1 through to 8 again for each soil/fertiliser mix observing whether water saturation has any influence on the CO_2 emissions generated

Results

Gas flux calculation and data analysis

Students can complete the graphing and modelling work required for this exercise on paper or by using Microsoft Excel. The data analysis phase may be completed in the following order:

1. Graph a plot of gas concentration (in parts per million (ppm)) versus time (in seconds) for each of the different water types and soil types that were analysed. Set a linear trend line to each of the plots. Also make sure to note the R^2 value. An example of how CO_2 concentration data should look after the completion of the experiments is depicted in Figure 6 (A) for the two example water types and Figure 6 (B) for the three example soil and fertiliser mixes. Linear regression is a part of the Australian Mathematics Curriculum. As a result, this exercise provides a crossover between both physical science and mathematics, allowing students to gain extra practice in an important statistical skill set that is frequently used in practical scientific applications (particularly at the tertiary education level and above);

2. Calculate the slope (m) for each of the trend lines;

3. Gas flux is to be calculated using the following equation (Tremblay et al 2004):

$$\mathit{Flux} = \frac{m \times V \times \alpha \times \beta}{A \times \gamma}$$

where: m is slope (ppm/sec); V is volume under the hood (m^3); α is a concentration conversion factor; β is a temporal conversion factor; A is the area under the flux hood (m^2) and γ is a magnitude conversion factor. Flux is given in mg/m^2/d. V and A can be calculated by the students using a ruler and a calculator before the exercise begins. The value for a is given as 1798.45 μg m^{-3}, the value for α is given as 86400 sec d^{-1} and β is given a value of 1000 μg mg^{-1}. Figure 7 shows the CO_2 flux estimates as calculated for each of the example water and fertiliser/soil types by the authors.

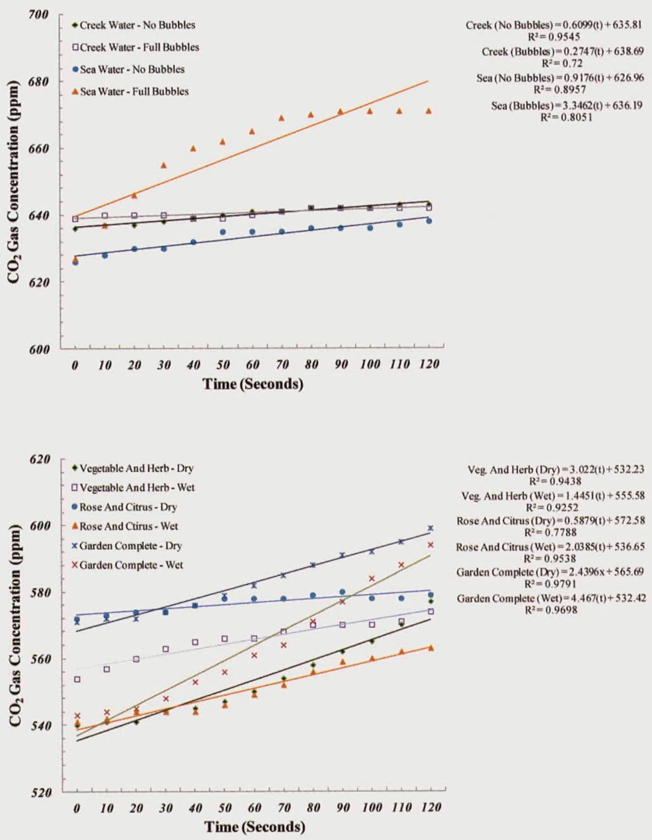

Figure 6: CO_2 gas concentration data measured over time for each particular water (A) and soil/fertiliser (B) type. Regression equations and R^2 values for each trend line are displayed on the graph.

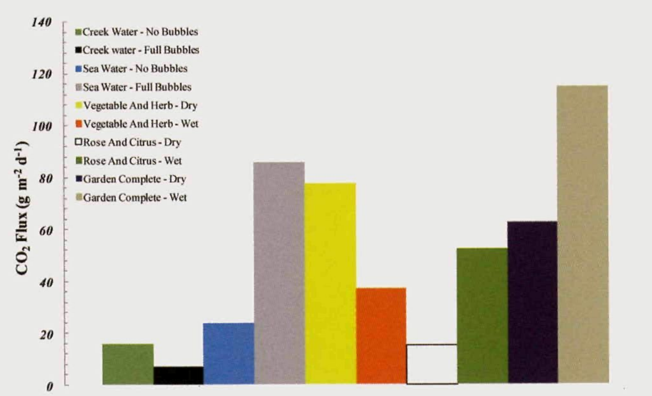

Figure 7: CO_2 flux estimates as calculated for each of the water and fertiliser/soil types.

Discussion and Conclusions

From the final CO_2 flux measurements shown in Figure 7, it can be clearly seen that all of the chosen water and soil/fertiliser types did emit CO_2 gases at varying levels in the example experiments performed by the authors. In particular, the highest emitters were the wet Garden Complete soil/fertiliser mix and the aerated sea water. Upon completing the practical exercise, students should be encouraged to do further research (possibly as a homework activity) to evaluate why soil/fertiliser mixes and water types may emit higher amounts of CO_2 gases under damp and aerated conditions. Students should also be asked to perform basic error analysis to determine a percentage error estimate for each of the final CO_2 flux measurements. Educators can also take their students to perform this practical exercise in the real-world at a local dam or creek. If time permits, students should be encouraged to ask and attempt to answer several questions related to the operation of the gas flux hood, the NDIR gas analyser and the results from the gas emissions measurements. Such questions could include: What are some of the possible sources of both instrumental and measurement error in the experimental procedure? How could these errors be minimised or eliminated? Why do some of the water types and fertilisers emit more CO_2 in comparison to the others? Do other environmental factors, such as air temperature, influence the CO_2 emissions? Answers to these questions can be obtained by the students as a homework activity.

Connection to the curriculum

The activity presented here provides clear links to studies of the environment, ecology, and modern atmospherics as a physical and chemical science. The influence of human activity on the production of GHGs through the production of fertilisers, livestock loading and land clearing can be studied relative to GHG production through increased sediment loads reaching runoff areas and making their way into streams and waterways. This enhances student understanding of the influence of human activity on the natural systems they inhabit. The natural breakdown of submerged detritus and subsequent release of GHGs can be studied relative to natural cycles in the environment. Past, present and future climates experience different atmospheric compositions and concentrations of organic gases. The techniques presented here demonstrate measurement techniques used by scientists today to study modern and past climatic conditions and thus reinforce the learning of science as a study of measurement. In addition to these benefits, students gain experience through the completion of this activity in the cogent application of the scientific method, by making predictions, performing experiments and drawing conclusions from the evidence collected. Greenhouse gas flux measurements are not currently a part of the national curriculum. However, it is a senior science exercise (there is no national curriculum for that as every state has its own distinct curriculum in place). As such, the exercise should be regarded as an 'experimental investigation' which provides children with real word science practical and analysis skills. The exercise could also be regarded 'extension work' for students in science fairs and science competitions.

Acknowledgements

The lead author would like to thank CSIRO Land and Water for providing postdoctoral funding to assist in the completion of this manuscript.

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