CO2 / CH4 dynamic flux instrument: SOP
(Version: 12.12.2019)

1. Description of approach

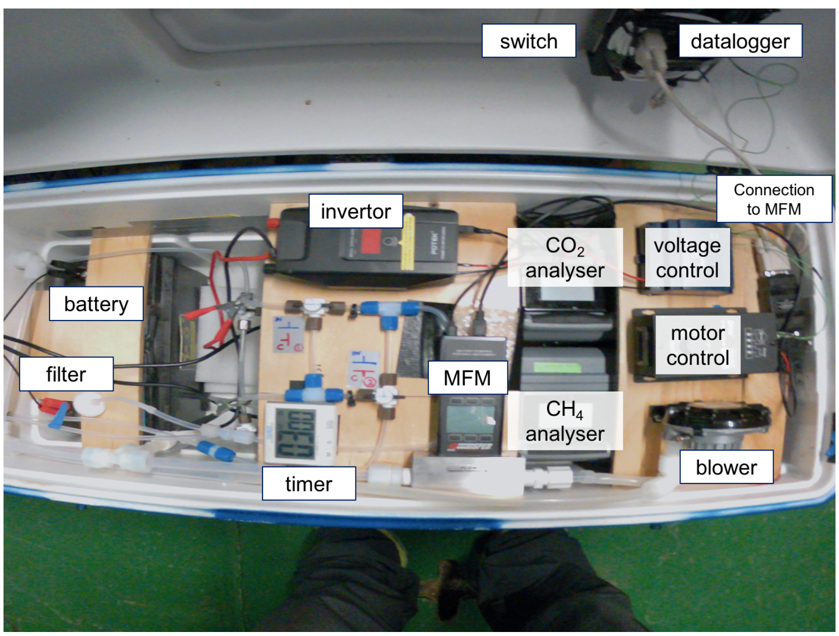
This is a dynamic flux chamber approach intended for short-duration surface flux measurements of CO_2, CH_4 and DMS at multiple locations with minimal disruption of the snow or ice surface. Ambient air is drawn through a chamber placed on the snow/ice. Exchange at the surface covered by the chamber is computed from gas concentrations measured in the air entering and exiting the chamber:

$F = Q * (C_{out}-C_{in}) / A$

, where F is the exchange rate, Q is the flow rate through the chamber, A is the area covered and C is the gas concentration. cPrimarily, the chamber measurements are intended to complement the EC-flux measurements by allowing us to develop an understanding of the contribution to the flux of the different surfaces types within the EC-footprint. Additionally, these measurements should allow us to relate gas fluxes to physicochemical and biological characteristics of the snow, ice and water. A static-chamber approach is also being used during MOSAiC (Nomura/Delille BGC group) to directly relate gas fluxes (CH_4 and CO_2) to biogeochemical characteristics of the ice. The two general aims – our interest in broader heterogeneity and developing a physical model of gas flux in a sea ice environment and their interest in the direct relationship between gas exchanges and ice biogeochemistry - are intended to be complementary. Direct comparison of the exchange rates measured by the two approaches will also be interesting.

2. Instruments / equipment

The system links a flux chamber to two portable, high precision analysers: a LICOR 7810 for CH_4 (CO_2 and H_2O) and a LICOR 7815 for CO_2 (and H_2O). The manuals for each analyser are in the bottom right-hand drawer in the instrument container.



An Ametek Minispiral blower draws air into and from the chamber through ½ inch Teflon tubing, via an Alicat mass flow meter (MFM) and then to an exhaust port on the side of the box.

Figure 1. Instrument layout in the 'blue box'.

The air for analysis is drawn by the analysers themselves, at about 250ml/min each, from the inlet and outlet of the chamber through ¼ inch Teflon tubing via several valves that allow switching between inlet and outlet sources. The ~ 500 ml/min flow is then added back into the main flow measured by the MFM.

Power is supplied by a 12-volt AGM battery. There is a Pro-Logix charger that has settings for AGM batteries and slow charging rates, outside the front of the instrument container. Power is supplied through a POTEK invertor (spare in ARCHER ATMOS 1) to a TDK-Lambda voltage regulator (also spare available) from which the Minispiral and datalogger are driven. A DC motor controller is used to vary the flow rate of the Minispiral. This power supply system is designed to maintain constant flow rates even when the battery voltage alters.

The AC power to the MFM is connected directly to the Invertor, although it also has its own internal battery that works fine. A count-down time is also mounted next to the valves inside the hatch – I keep a spare AAA battery in the red pouch that we take with us when deploying the instrument.

The analysers have their own internal Lithium battery power. The level of charging is displayed on the small screens and they need to be charged fully before deployment if possible. Full charge provides power for 3 to 4 h outside. It is possible to run them off the 12-volt battery supply by plugging them into the invertor. We've had to do that once when the AC charger supply was not plugged in properly overnight. Note, the analysers take ~ 30 mins to stablise once you've switched them on so do that well before you set out and ideally, while they are still on the ship supply.

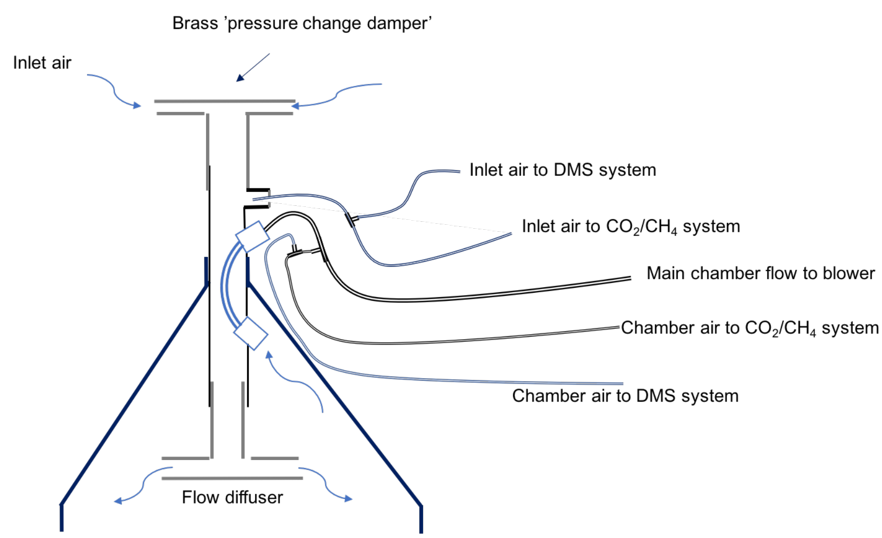


Figure 2. Chamber and plumbing. Note DMS fitting but not tubing attached at present.

3. Communication with instruments and data storage.

Analysers: Connection to the instruments is described in Section 2 of the manual. I have used the wireless route and once you've set it up it seems reliable and efficient. The instruments provide separate web servers and wireless networks. You may need to use the password 'licorenv' when you first set it up. It is also possible to use an Ethernet connection. The server is accessed via http://tg15-01011.local/ for the CO_2 system and http://tg10-01032.local/ for the CH_4 system. The instruments will provide an IP address that you may need to connect and they can throw out different IP addresses when you first start trying to connect. The IP address will show up at the top of the small screen. This may take some time to display when you initially try to connect. Once you've routinely established connection and bookmarked it etc., I've found that you can access data pretty soon after you've switched them on. It's still better to download the data before you switch them off after a session if possible.

The Datalogger: At present (Leg 1 and 2) we are using a Campbell Scientific XR1000 to record the output from the MFM, panel temperature, battery voltage and a timestamp (UTC as kept by the Bigelow Laboratory Dell 3450 Latitude). The XR1000 was loaned by Chris Cox – NOAA – and he will probably need it back for Leg 3. We will send a CR6 out with Leg 3, hopefully. We have a version of LoggerNet on the Dell 'Datalogger' laptop, from which it is possible to program the datalogger and to download data from it. 'Connect' to the datalogger via LoggerNet, from the Connect Screen you can either connect to the specific datalogger and download data via the 'Collect Now' tab. This allows you to add or retrieve data logger control programmes, to monitor what the system is recording and to download the data to the laptop.

4. Making measurements

4.1. Preparations
1. overnight: make sure the system is charged – i.e. the 12-volt battery and the LICOR analysers. I plug the power supplies and battery charger into the orange extension and plug that into the van power socket on the left of the doorway.
2. check the tubing on the chamber is intact and that the PVC piping that makes up the inlet and outlet is firm and fixed to the funnel. A ½ inch Teflon tube runs from inside the top of the chamber through the PVC piping to the ½ inch connection on the chamber outlet. That top connection is sealed with silicon glue but can work loose, allowing air in to the inlet pipe. That won't have much impact on the system but it'll be better to try to keep it sealed.
3. you'll need a pulka, strap(s) for securing the blue box to the sled, bungies for securing the chamber, red pouch with correct sized wrench (9/16th at least), a small container for the swagelock plugs and caps, a pencil and paper booklet. Make sure the countdown timer is in the blue box. I usually add some spare fittings in case something gets lost on the way.
4. ½ h before departing: switch on the LICOR analysers to let them warm up. They take atleast ½ h hour to do so. Make sure they are drawing air through the tube with the filter on in the blue box. remember to reattach the actual inlet before starting measurements.

4.2. Actual deployment
Transport. We use a pallet jack to transport the blue box from the container to the working deck. Once you get it on the working deck, we've found sitting the blue box in a pulka and sliding it down (and up) the gangway works fine. We usually use a yellow (i.e. not too long) rachet strap to attach the blue box to a Nansen sled and put the pulka with chamber etc. on the sled too. Keep the bungies and strap in some sort of bag.

Once you get on site, you want to try to position yourselves upwind of anyone else or any skidoo traffic, if possible. The less disturbance of the ambient CO_2 and CH_4 levels the better. Windless days make it pretty difficult to make good measurements.

4.3. Set-up

1. Attach the chamber tubing to the blue box and make sure you swop-out the filter from the inlet line. Double check no fittings have come apart in transport, on both the chamber and in the blue box.
2. Connect the battery if not done already and switch on the invertor – 1 long press. Pressing it briefly again will give you the battery voltage. Make sure the MFM display is on, adjust the flow rate on the blower to something like 7.5 SLPM and make sure the valves are on the 'inlet' setting (see Figure 3).
3. Place the chamber on undisturbed snow/ice, upwind of where you are set-up and press it into the snow if possible.
4. Making the measurement: 1 tau = chamber volume / flushing rate, 4 x tau is about the time it takes for the air in the chamber to be fully replaced. The chamber is ~ 40 L, so at a flow rate of 7 – 8 SLPM, 1 tau is about 5 – 6 mins. We usually sit the chamber on the ice and set a flow rate of 7 to 8 SLPM and then start the following measurement sequence:

10 mins – on 'inlet' mode

3 mins – 'chamber'

3 mins – 'inlet' , etc. normally we do 5 of each mode, finishing with the 3 mins of 'inlet'. if you get pressed for time, shorten the intervals to 2 min but keep the first 10 mins on 'inlet'

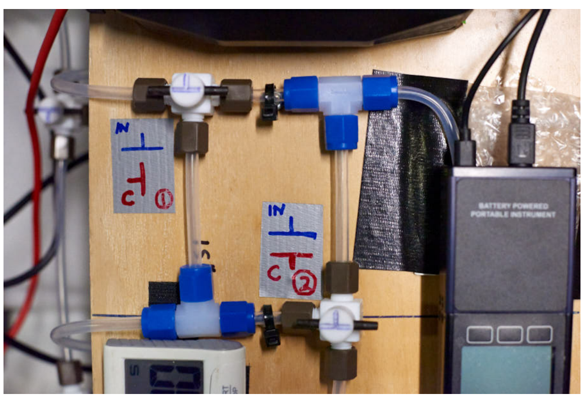


Figure 3. Two x 3-way valves are used to swop between 'inlet' and 'chamber' air flows to the two analysers. This set-up is designed to reduce changes in pressure in the flow entering the analysers. Earlier tests found that this could alter the concentration measurements enough to obscure the low signals we are trying to measure. The way it is set-up now means there is always some flow to each analyser – almost. The analysers use a cavity-ringdown type system and so rely on having a constant pressure in their internal chamber. Valve 1 is always switched first, then in quick succession, Valve 2. We use the countdown timer, as it can be heard when the box hatch is closed. At the same time as switching the valves, we also switch the datalogger switch to provide a voltage/time stamp of the flow sequences. So, for consistency if I'm transitioning between modes, I open the hatch, press the countdown timer to restart the next 3 mins, toggle the switch and then do the valves.

We try to get two full measurements done per trip as they take almost an hour each, once you have set things up and taken it apart again.

5. Hopefully, you've come to terms with the Floe-Navi system. It'll be very useful in the long-run if we record an entry for each location sampled using the flux chambers.

4.4. Downloading the data

Once connected to the software of the LICOR analysers, you can download the data for each set of measurements by defining a specific date and time period. You can also connect to the datalogger via the RS232 to USB cable (blue cable, in plastic bag on the shelf below the DMS system) and download the data from that. So, you should end up with 3 files for each deployment; something like:

> 2019-12-02T090000.data (CH_4 analyser)
> TG15-01011-2019-11-30T044500.data (CO_2 analyser)
> CR1000_FLOW.dat (datalogger)

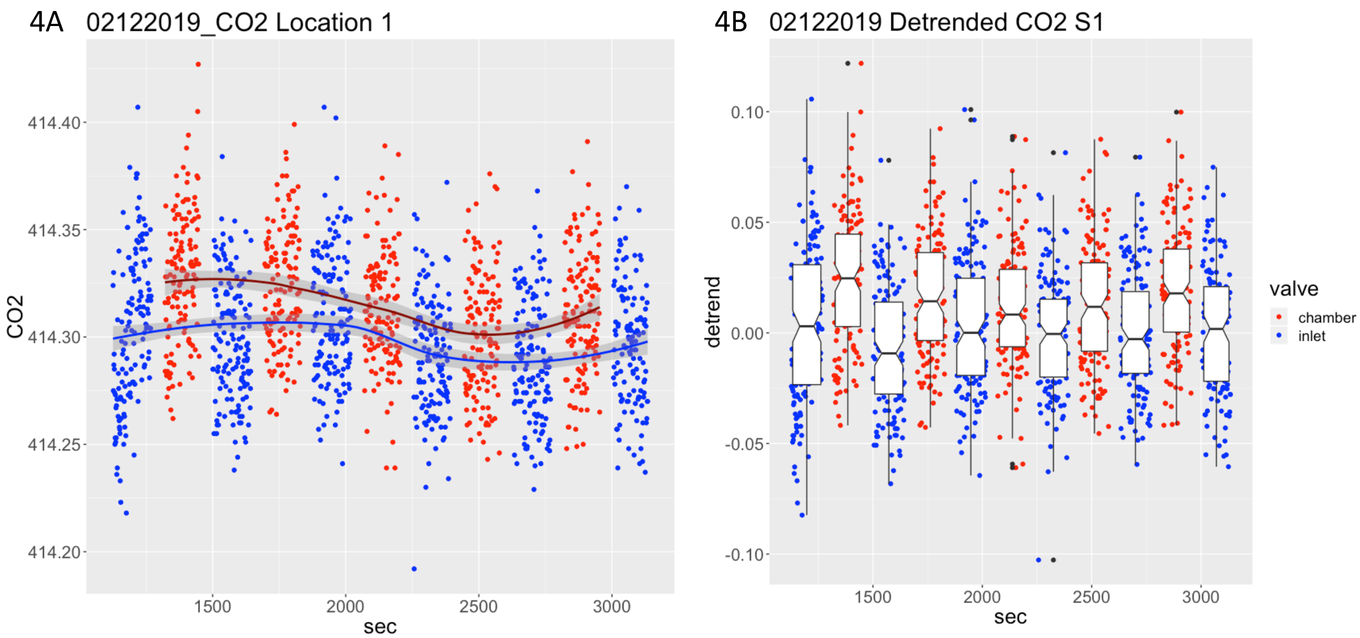
Obviously, you will have your own approaches to handling these files and interpreting the data. At minimum, these three files should be stored on the MCS database, once the Floe-Navi entry has been loaded, and on the 'Flux Group Mac'.
Supporting data. If possible, obtain an ice depth and snow depth measurement as close to the chamber location as possible, we've borrowed the 2 inch auger, drill and tape or got some of the 'professional ice-corers' to do it for us, if they are around.

5. Data interpretation

The aim is to determine whether there is a significant ∂C between the ambient (inlet) air and the air that has passed through the chamber. The 3 min duration for each sequence was chosen based on how quickly the analysers 'recovered' from switching between modes and sufficient data points to establish a statistically robust estimate of concentration, i.e. about 100 data points per sequence generally gives < 1% coefficient of variation. The general approach I've used is:

1. The instruments and datalogger have been set at close to UTC.
2. I pick a specific starting time point (i.e. the start of the 10 min – 'inlet' mode) and make that zero seconds and then add a time line in seconds to each data file.
3. Then use the switch voltage to determine the time of the transition points between inlet and chamber modes ('inlet' has been 5000 mV, 'chamber' has been 0 mV) in the datalogger file.
4. Then use those time points to constrain each 'inlet' and 'chamber' sequence in the LICOR data.
5. I then cut-out about 25 s of the data before the transition and 25 s after it, so that any affect the switching has on the analysers is removed from the interpretation. You can check whether those cut-out periods are sufficient.
6. I then plot the 'inlet' and 'chamber' data separately versus time and fit a polynomial/loess fit to the 'inlet' data (Figure 4A).
7. This is then used to 'detrend' the data, in order to account for changes in the ambient air concentration. The fit is subtracted from both the 'inlet' and 'chamber' data to produce detrended values (Figure 4B).
8. The detrended data is then tested for signficant differences – as a first approach, I've used a two-tailed T-test, assuming similar variance between datasets. So far, I've used the pooled data from the inlet vs. chamber sequences to determine significance and if significant, used the difference between average values to

calculate a flux rate. Obviously, if you have some disruption to the sample record - e.g. a skidoo passing by – then you can legitimately remove the affected 3 min sequences from the analysis and use fewer than the 11 sequences for the comparison. For the equation $F = Q * (C_{out}-C_{in}) / A$, I've averaged Q from the datalogger output over the duration of the 11 sequences. So far, the flow rate has remained pretty constant and doing this does not introduce much additional uncertainty. A, the area of the base of the funnel is calculated from a diameter of 26.05 ", and works out at 0.3438 m^2.



6. General sampling plan:

We have tried to initiate four time series of flux measurements that we hope will provide flux information from a variety of surfaces and be useful for interpreting the EC measurements. The three locations are:

1. *Ice transect South (including BGC 3).* This region is currently to the south of the ship and southeast of Met City and possibly lies in the footprint of the EC systems on both towers, when the wind is in the correct sector. This is primarily a 1st year ice area. Ice depths in December are about 80 cm and the ice and snow cover is relatively homogenous in the area. Within the region we have sampled from three locations, two sites just south of the transect, marked by green flags and a site used by BGC team for ice core sampling. High spatial resolution ice and snow thickness measurements are routinely made along the transect. BGC group also provide more detailed temperature profiles and vertical profiles of a range of biogeochemical measurements at their site.

2. *Met City.* We've carried out a number of measurements close to the base of the tower on the 1st year ice to the south. This region has been modified by ice movement quite a bit but there is still some accessible 1st year ice. The location has a couple of

advantages, it is easily accessed because an Atmos team is often working out there and a bear guard will be around and it is often in the footprint of the Met City EC system. The downsides are that other peoples' activities might contaminate the measurements and that no ice-property measurements are being carried out by other groups.

3. *The Dark Side*. This is the location where the ECO/BGC team do their major ice sampling each week. It is primarily a 1st year ice location. It is probably not in the EC system footprints but does have the big advantage of the extensive supporting information. We have found that the best times to work out there are when few other groups are around. A downside is that because it is a long way out, you require two skidoos and an effective bear guard. Even here, you need to check the ice depth after each sampling session unless others have done so very close to the location. It can be highly variable.

4. *BGC 2*. This is a more complex, multi-year ice site close to Balloon Town. The BGC team are interested because it suits the methane-story that they are keen on. We have been sampling it for that reason and because it is where the Nomura/Delille chamber has been being deployed and so allows some good intercomparisons of the approaches. It is prone to contamination due to skidoo/people traffic. So try to work upwind of other groups, the road and Balloon Town.

Obviously, things are going to change over the year, and some of these locations will become more or less accessible and new, better locations may show up. The key points are relation to the EC flux footprints and level of supporting information.