Chamber-based soil gas flux measurement

Gas transport, theory, hardware, software and data analysis

Liukang Xu

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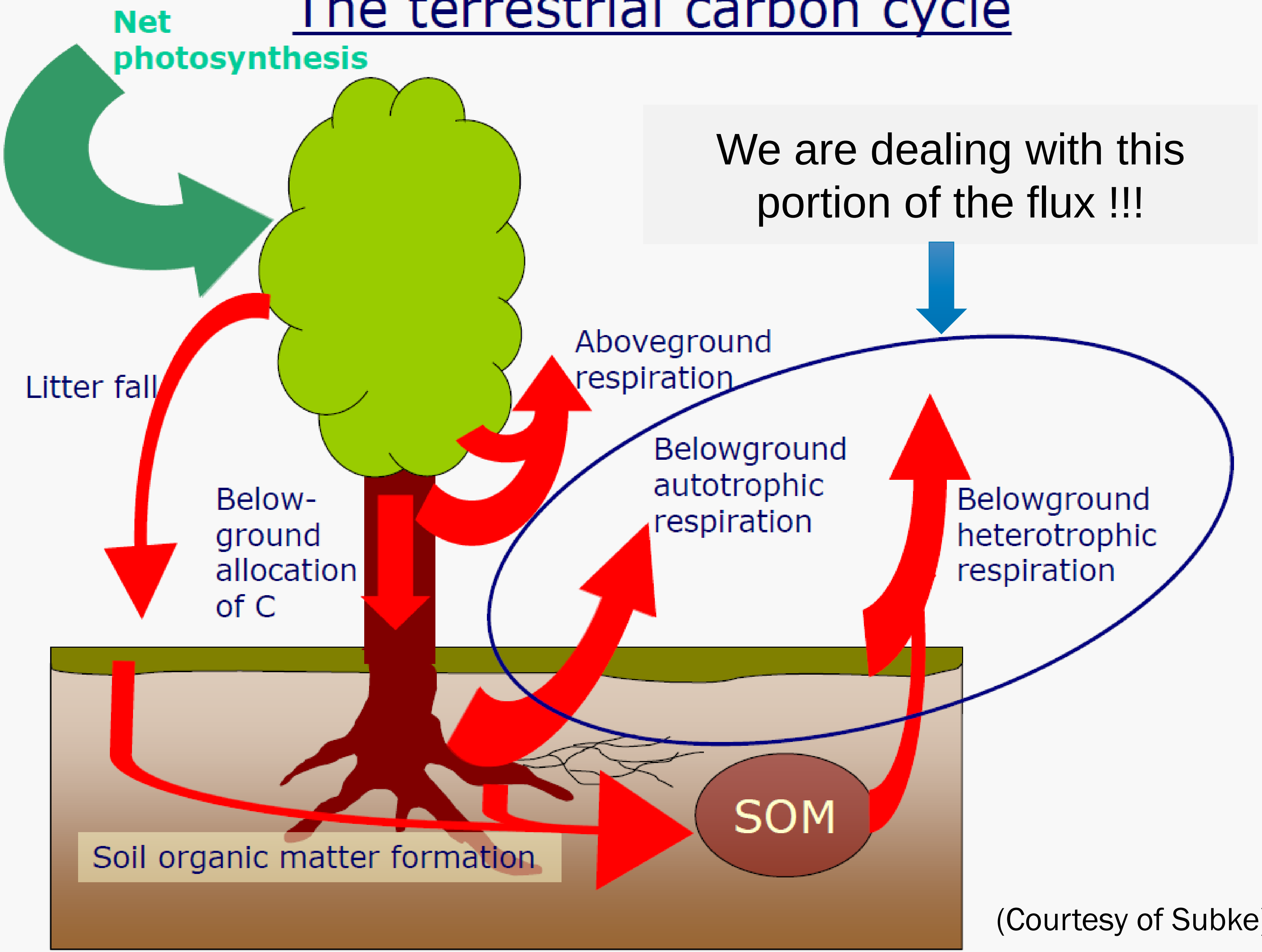
You can raise you hand anytime if you have a question !!!

Topics:

1) Control of gas transport across the soil surface
2) Theory of gas flux measurement across soil surface
3) Considerations for the closed-chamber method
4) Hardware: Smartchamber, LI-8250 system
5) Software
    - User interface (UI)
    - Data processing software (SoilFluxPro)
6) QA/QC
7) Other applications

The terrestrial carbon cycle



(Courtesy of Subke)

Transport mechanisms

Advection (Mass flow, convection)

This process is caused by the bulk motion of a fluid (like air), such as CO_2 or CH_4 molecules moves with the wind.

Diffusion

This process is caused by the random motion of individual molecule or particles and doesn't require bulk fluid (like air) motion. For example, diffusion can move CO_2 or CH_4 molecules along their concentration gradients.

Important equations

$$A = g \times (C_a - C_i)$$

$$E = g \times (e_i - e_a)$$

$$F_{CO_2} = g \times (CO_2^{soil} - CO_2^{air})$$

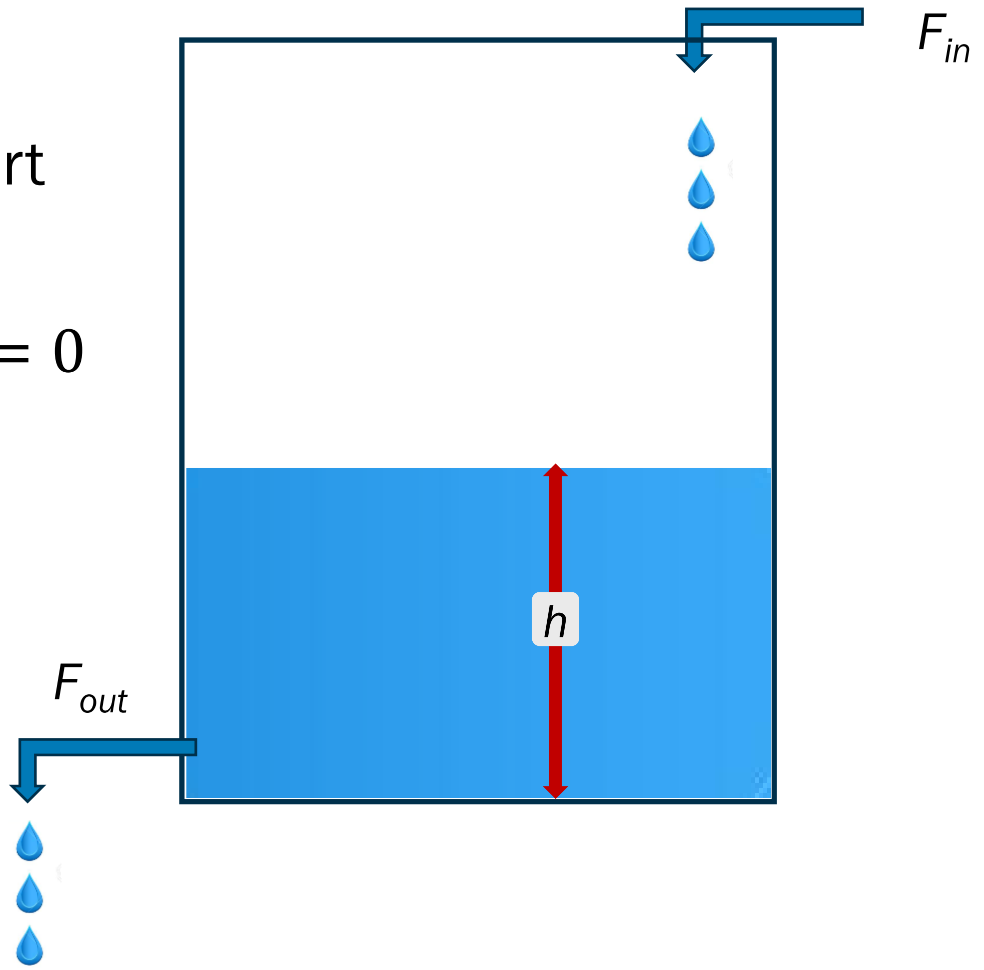
Gradient transport theory

Equation for advection transport

$$Flux = flowrate \times density$$

Steady state transport

$$F_{in} = F_{out} \quad \text{or} \quad \frac{dh}{dt} = 0$$



Non-steady state transport

$$F_{in} \neq F_{out} \quad \text{or} \quad \frac{dh}{dt} \neq 0$$

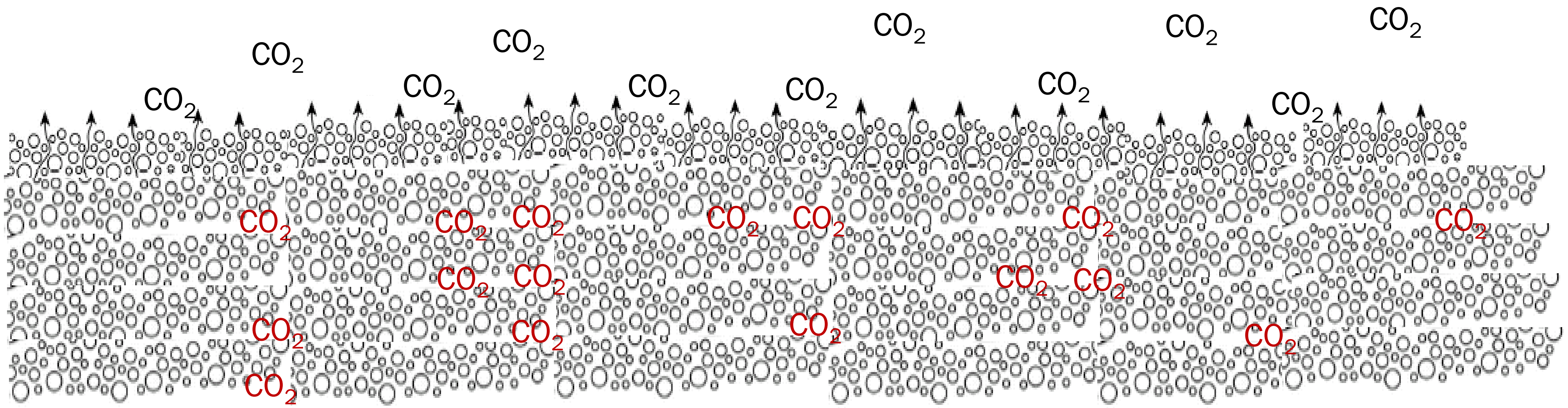
Soil Respiration
Production

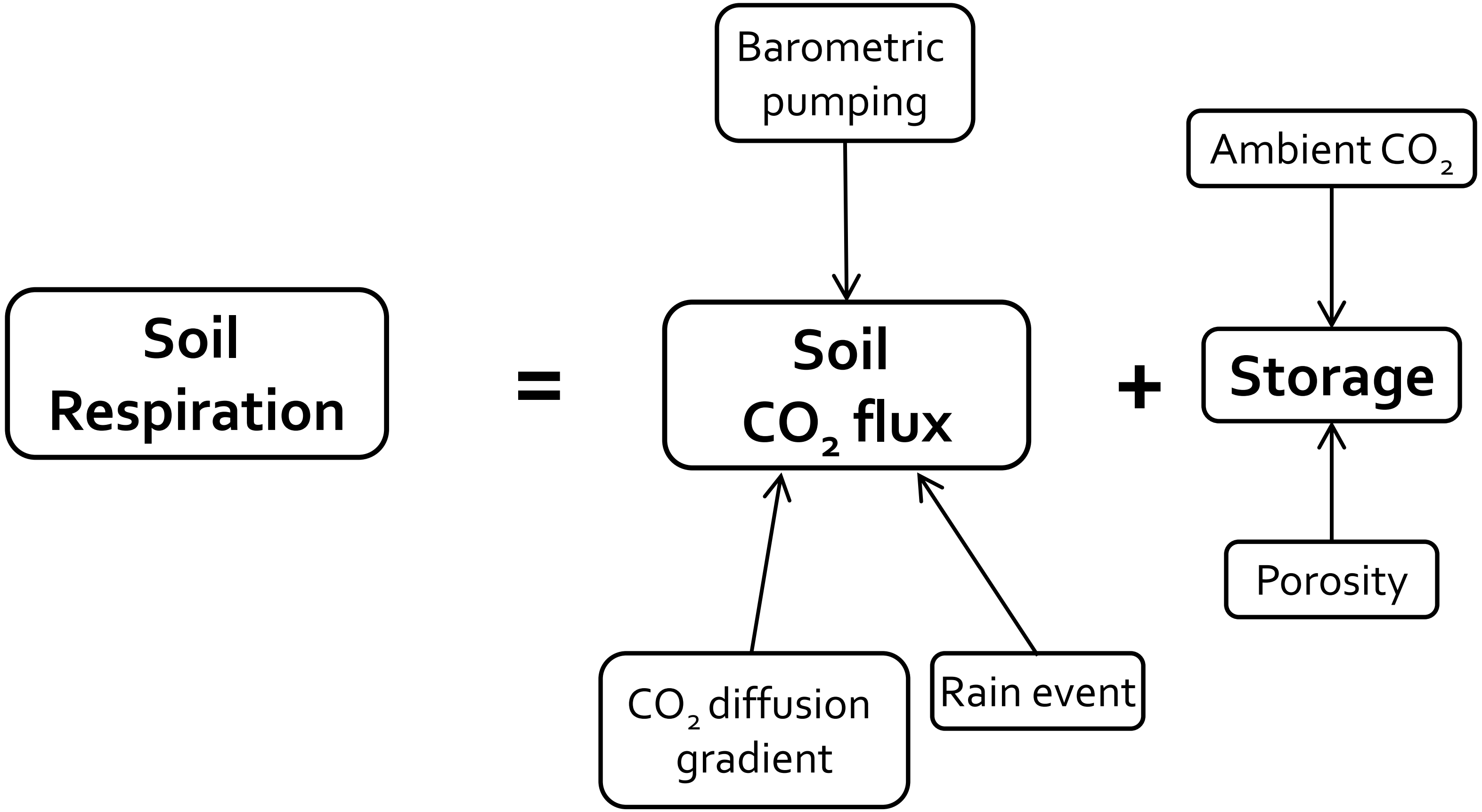
The amount of CO_2 produced from microbial activity in the soil

Soil CO_2 Flux
Transport

The amount of CO_2 transported out from soil to the atmosphere

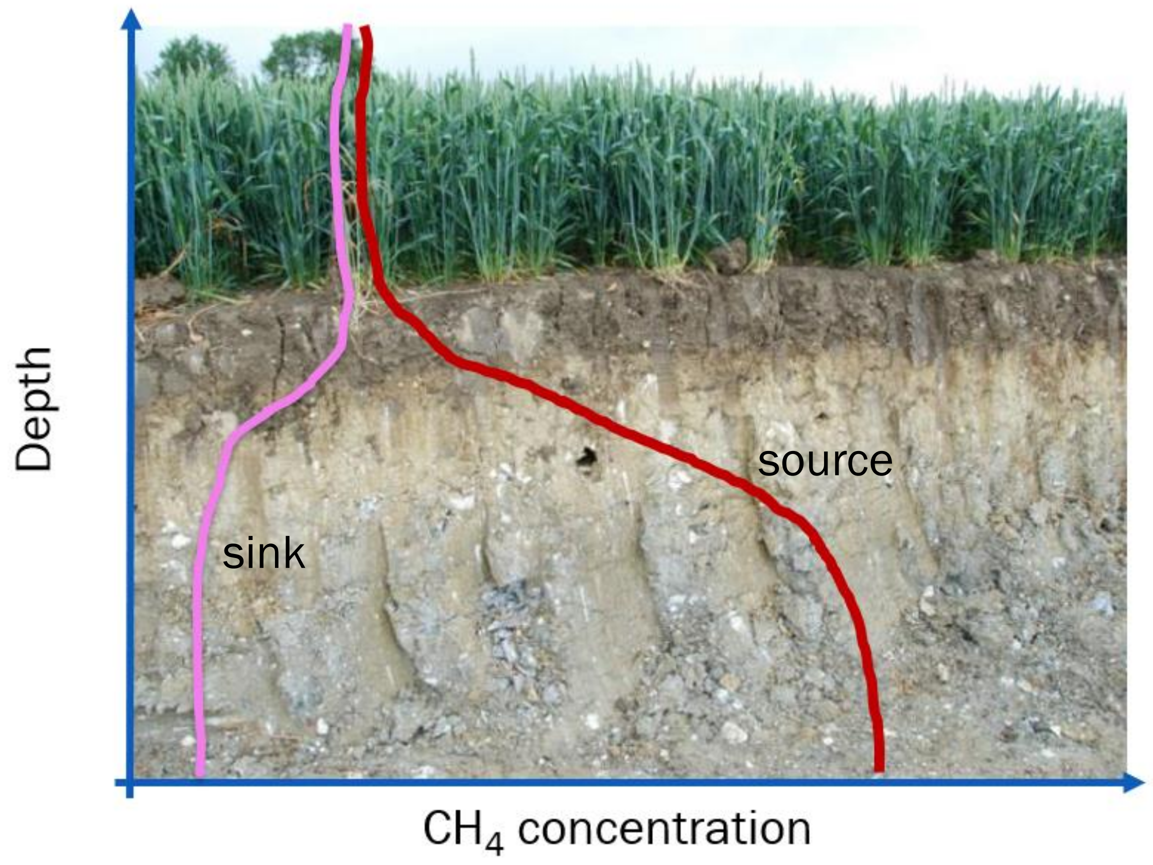
Question: Soil respiration = Soil CO_2 flux ?



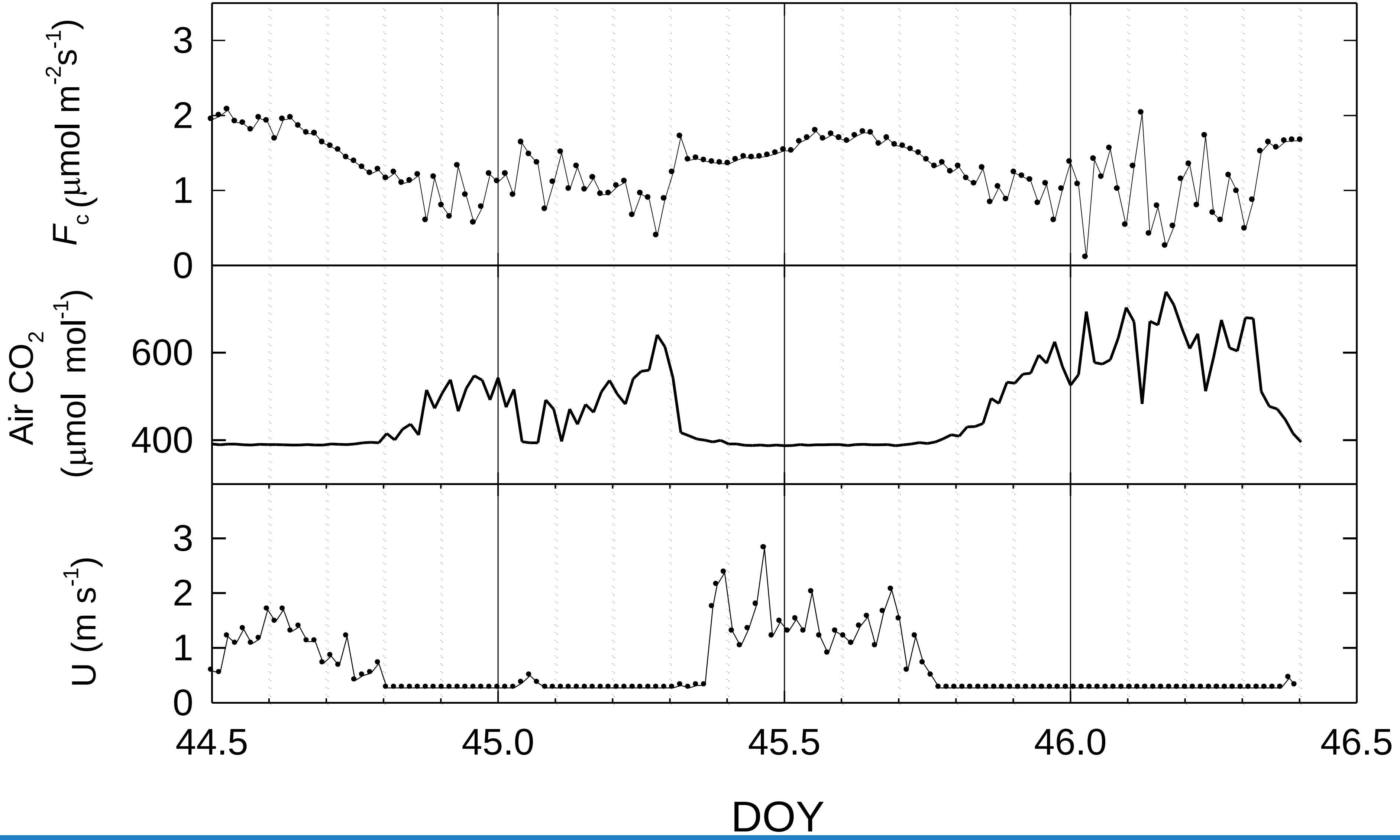


Only under steady-state condition, are soil respiration and soil CO_2 flux equal!

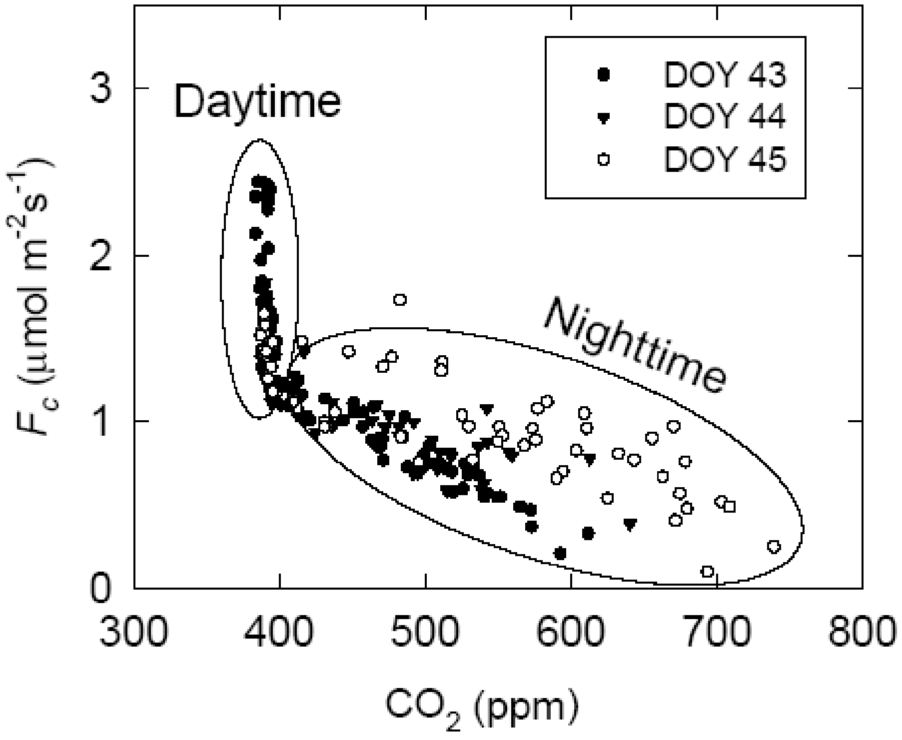
Control of gas transport from soil to atmosphere



Changing in diffusion gradient

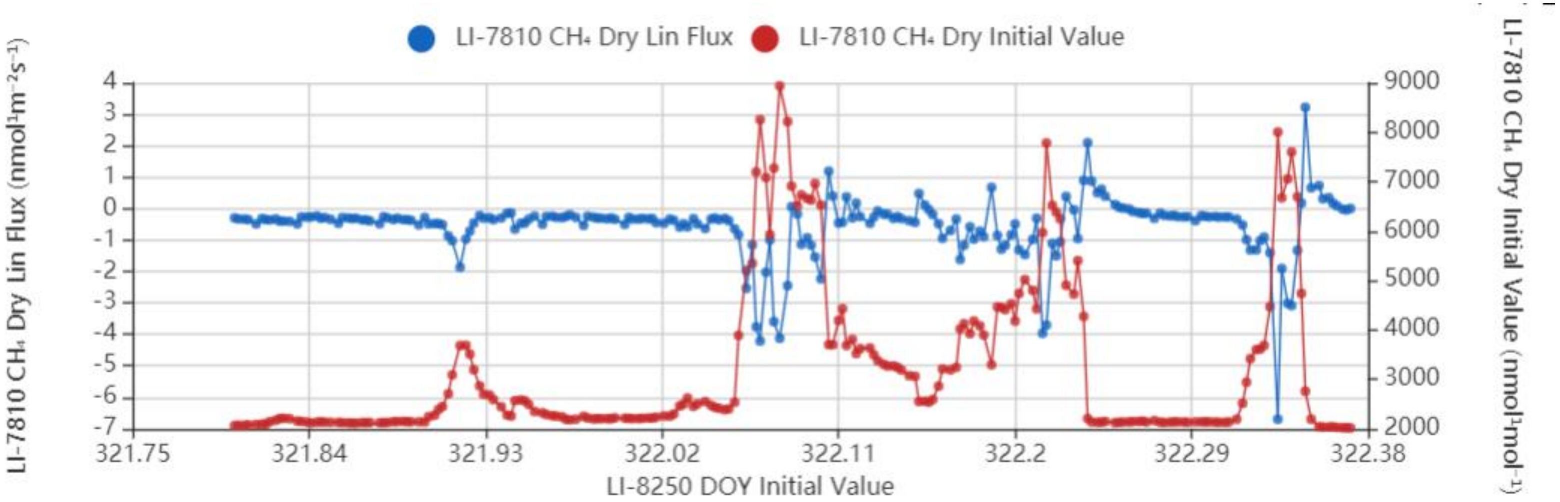


1: Transport



$$F_{CO_2} = g \times (CO_2^{soil} - CO_2^{air})$$

1: Transport



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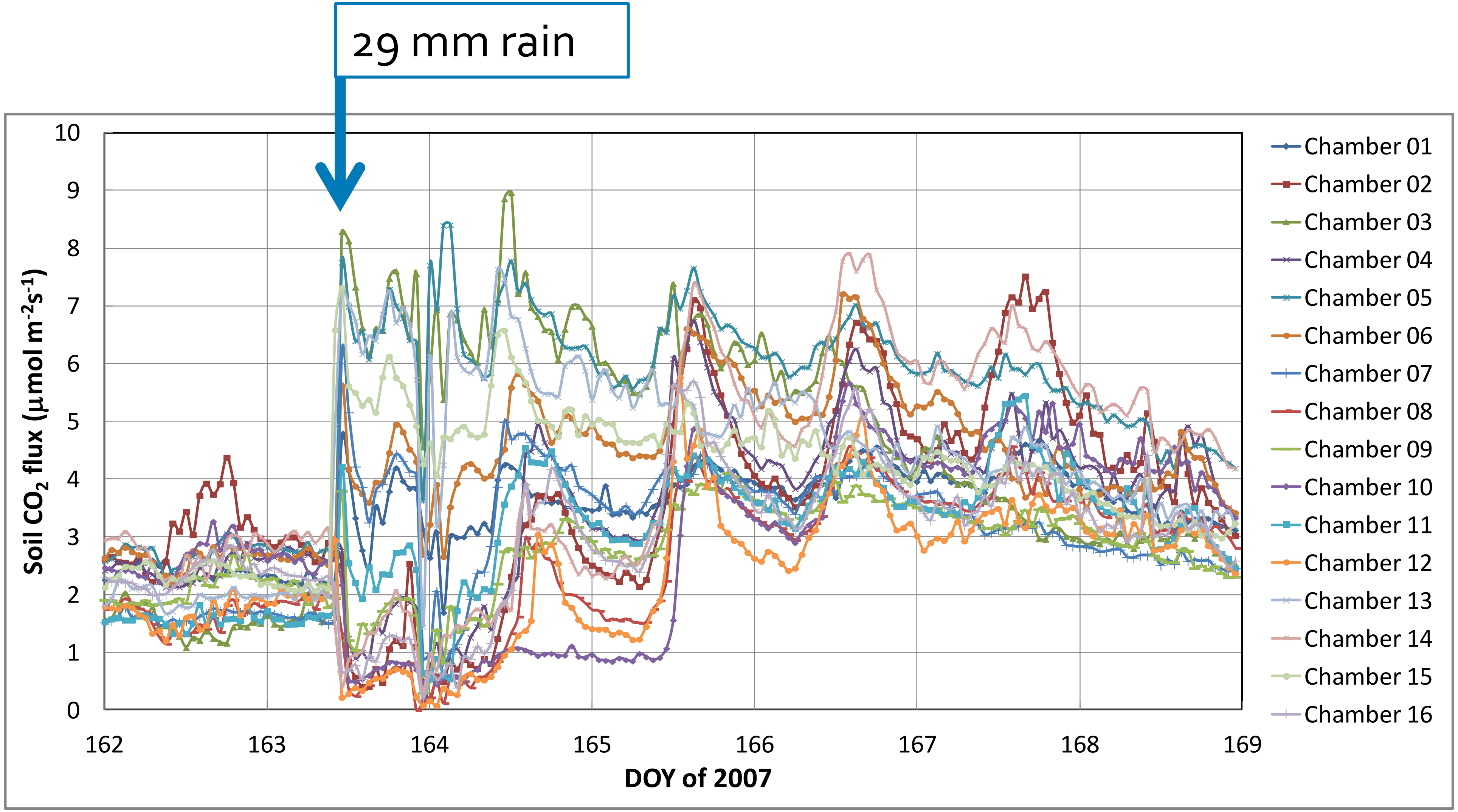
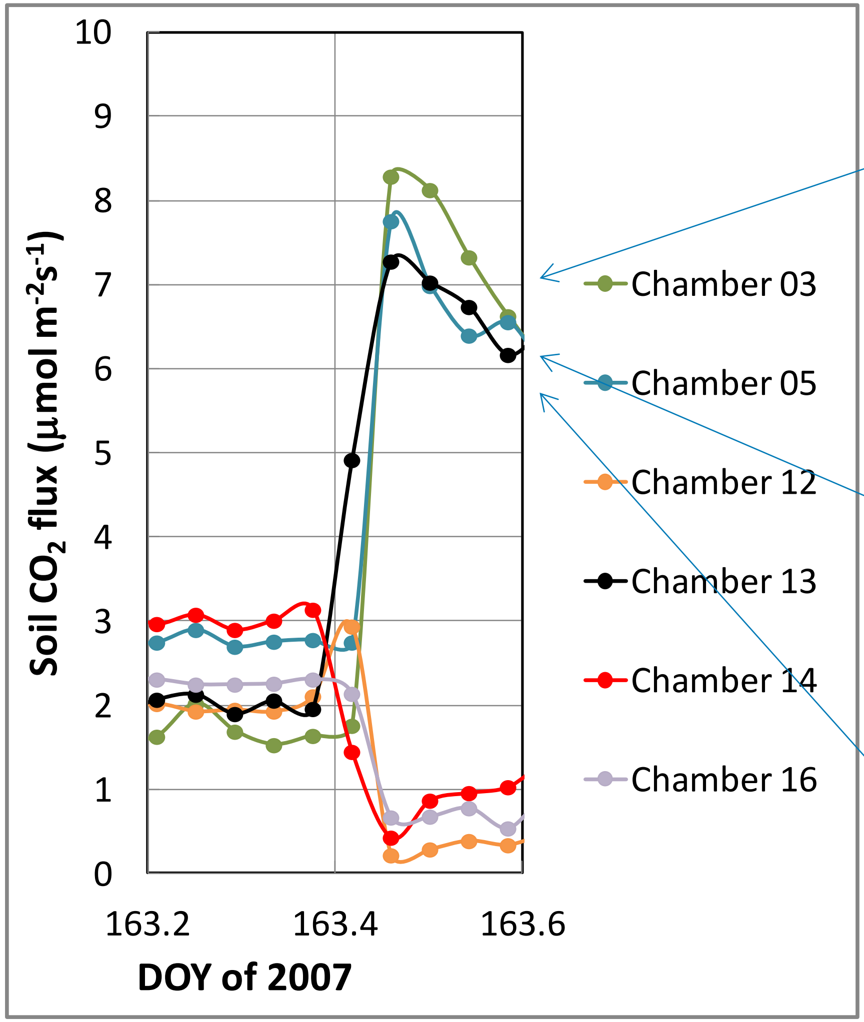
Changing in soil conductance



1: Transport



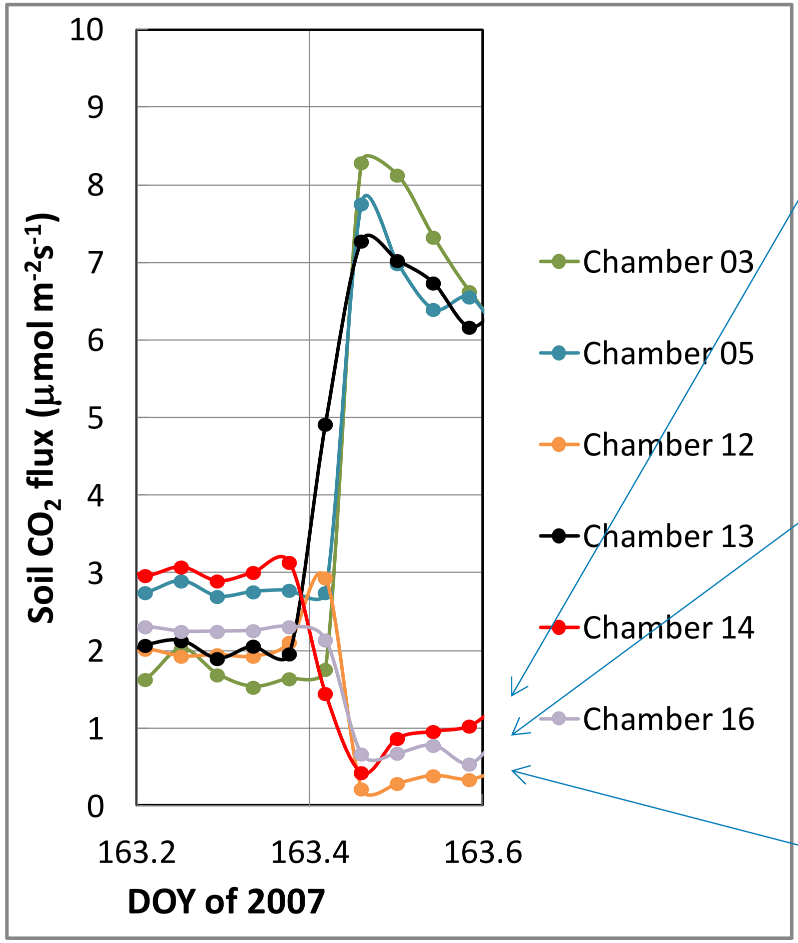
10
9
8
7
6
5
4
3
2
1
0
Soil CO2 flux (μmol m-2s-1)
163.2
163.4
163.6
DOY of 2007
Chamber 03
Chamber 05
Chamber 12
Chamber 13
Chamber 14
Chamber 16

Chamber 03

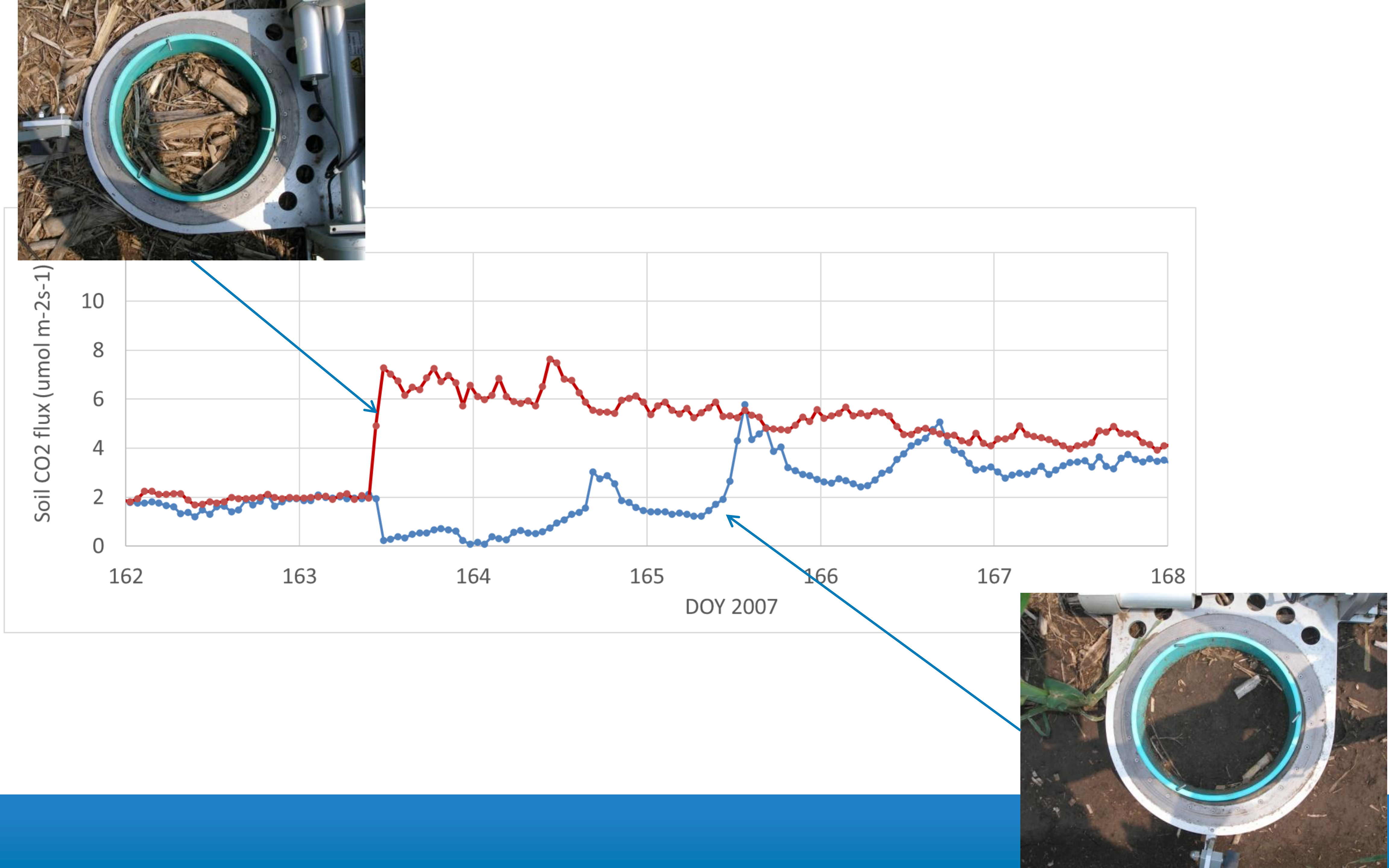
Chamber 05

Chamber 13

1: Transport

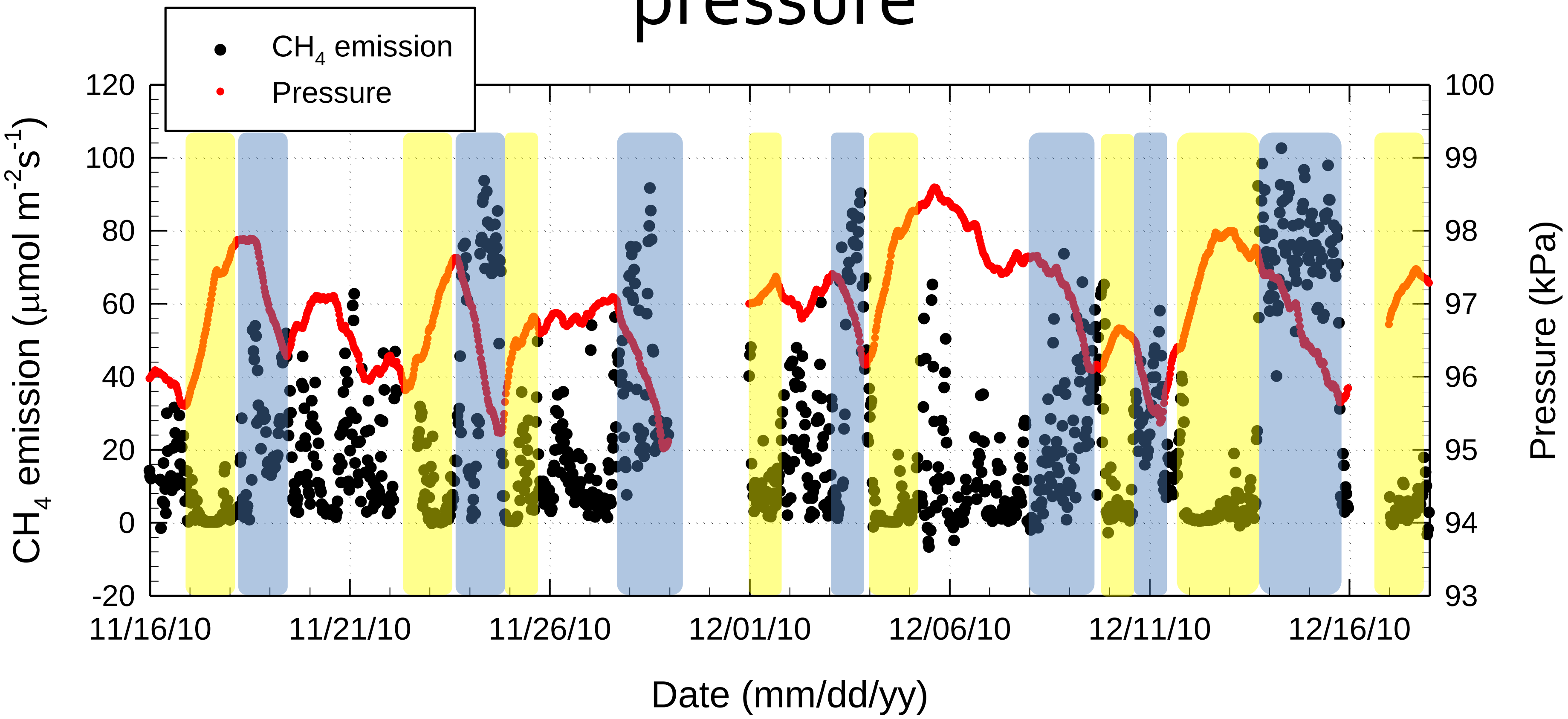


$$F_{CO_2} = g \times (CO_2^{soil} - CO_2^{air})$$



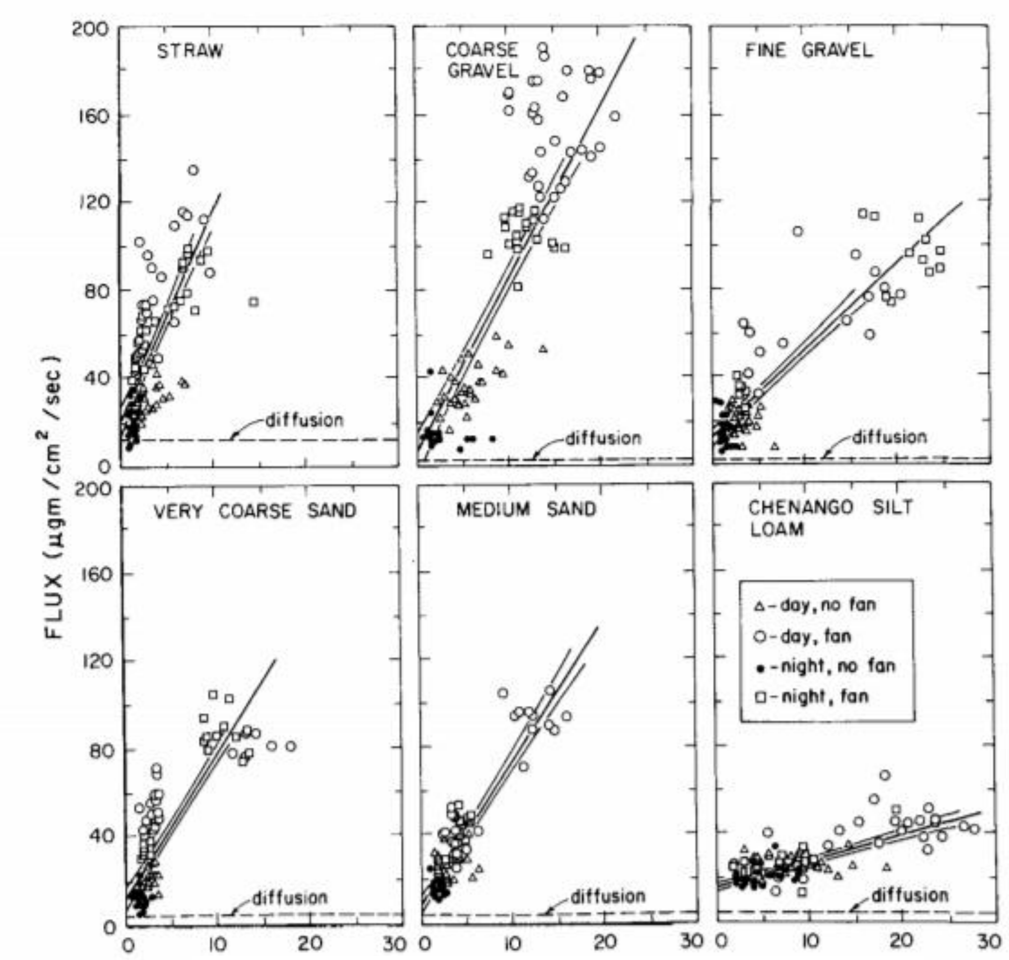
Soil CO2 flux (umol m-2s-1)
0
2
4
6
8
10
162
163
164
165
166
167
168
DOY 2007

Landfill F_{CH_4} vs. changing in barometric pressure



Xu et al., 2014. *Global Biogeochemical Cycle*.

Pressure variation



Standard deviation of Pressure (μbar)

Fig. 2—Flux of heptane evaporation from beneath 2-cm surface coverings of various porous media plotted against root mean square pressure fluctuation for 1-min time periods.

Kimball and Lemon, SSSAJ, 1971

Topics:

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3. Considerations for the closed-chamber method
4. Hardware: Smartchamber, LI-8250 system
5. Software:
    a. User interface (UI)
    b. Data processing software (SoilFluxPro) Demo
6. QA/QC
7. Other applications

Techniques for measure the soil CO_2 flux

I. Gradient methods

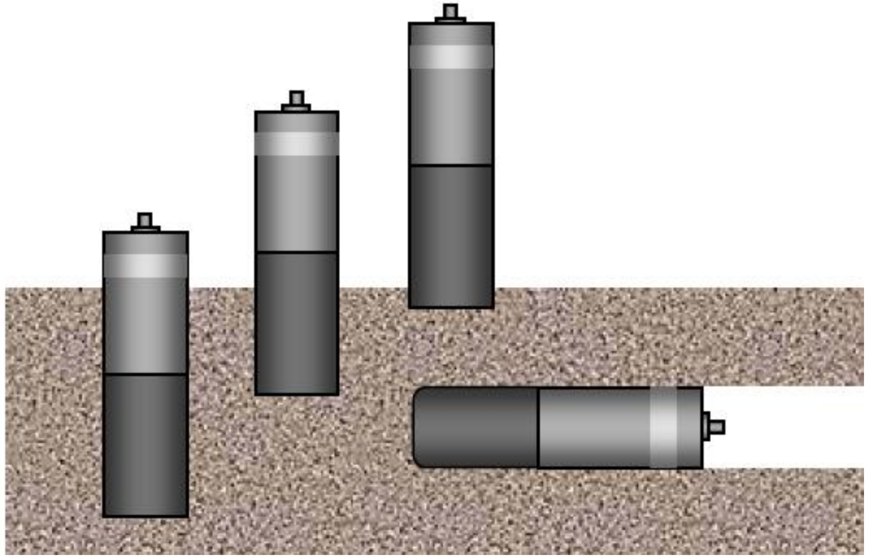
II. Chamber methods

1. Steady-state open chamber
2. Non-steady-state closed chamber

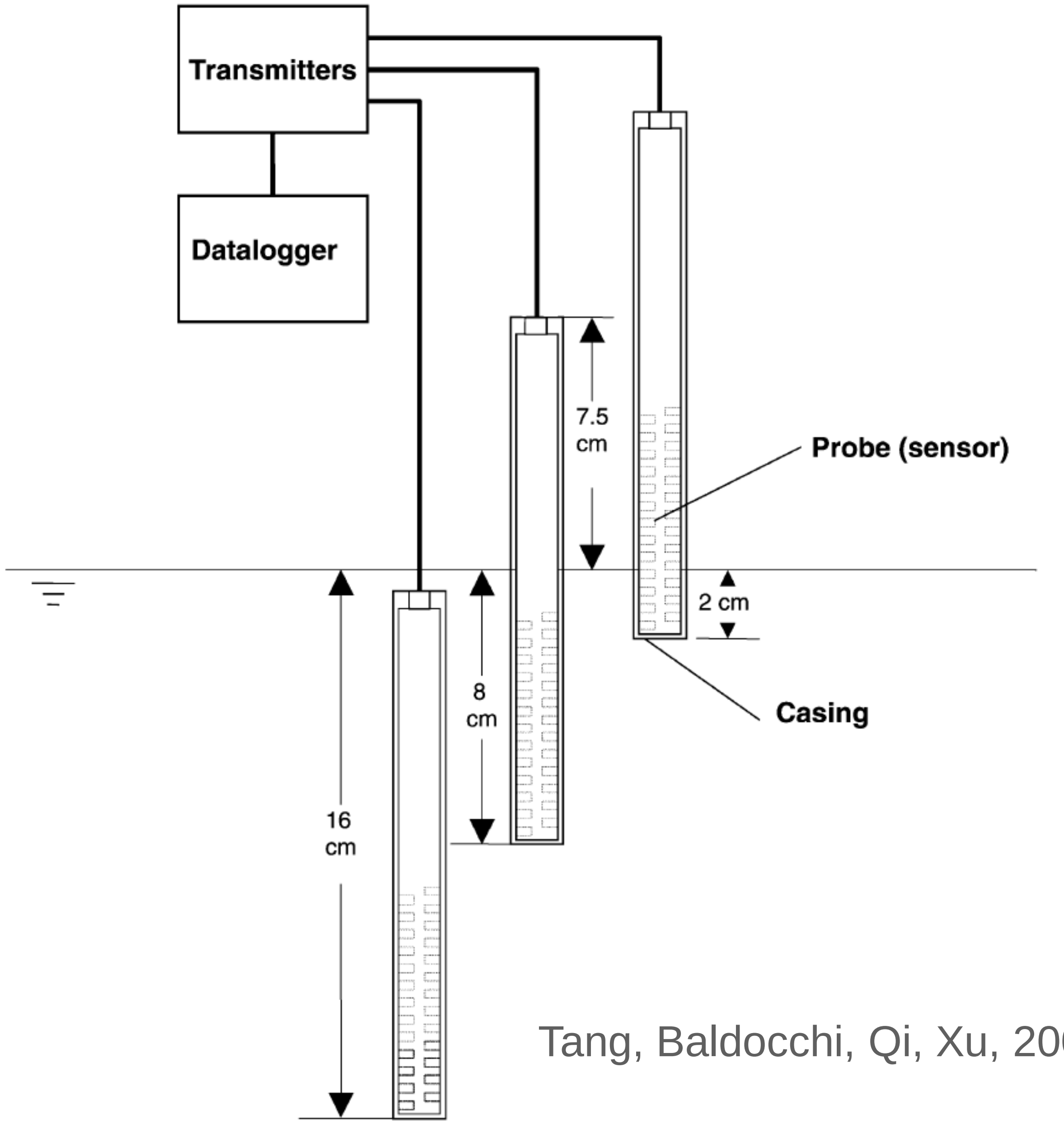
How is soil CO_2 flux measured?

1. Gradient methods

$$F_{CO2} = -D\frac{\partial C}{\partial z}$$

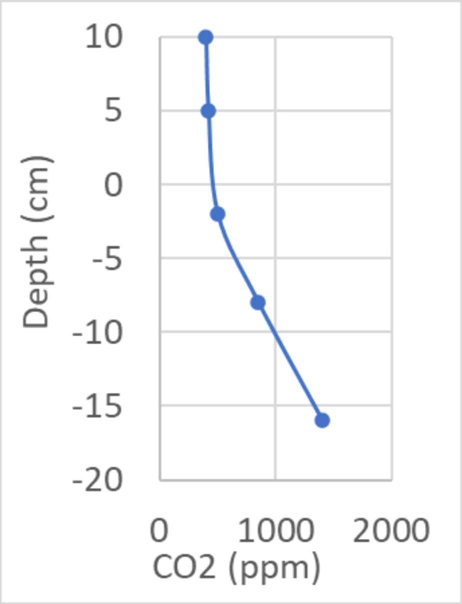


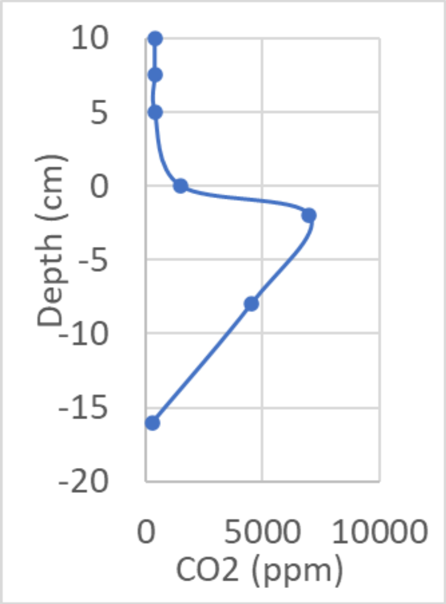
It will be very difficult to estimate D.

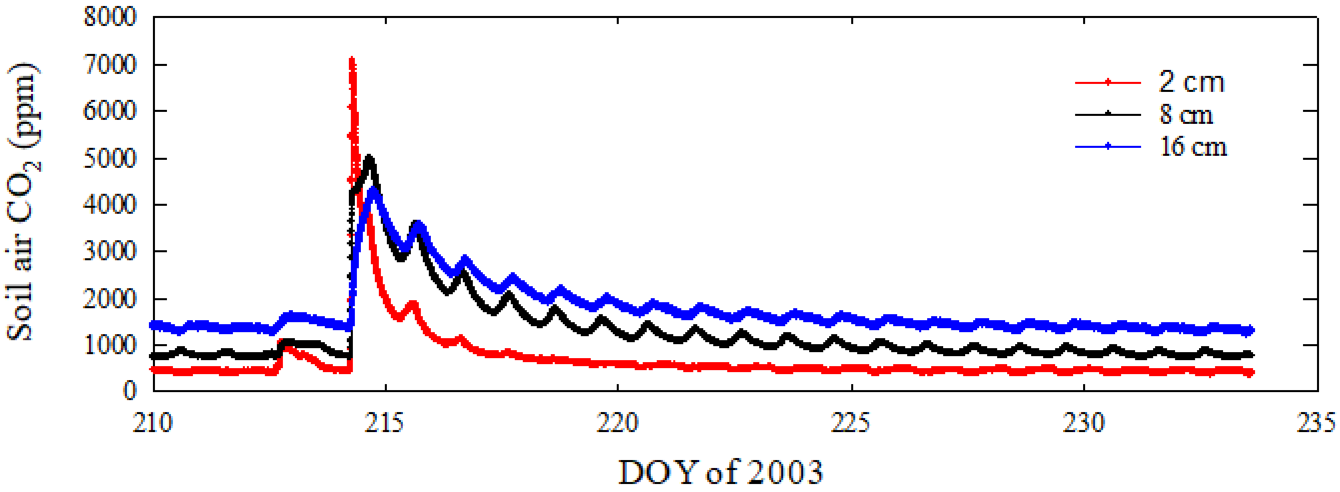


Tang, Baldocchi, Qi, Xu, 2003 AFM

Issues with the gradient method



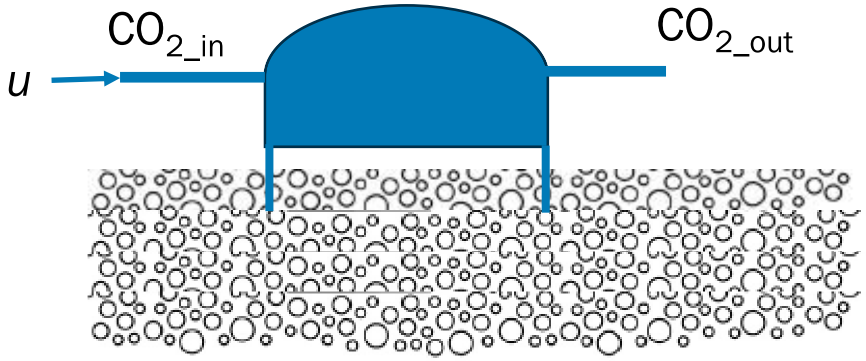




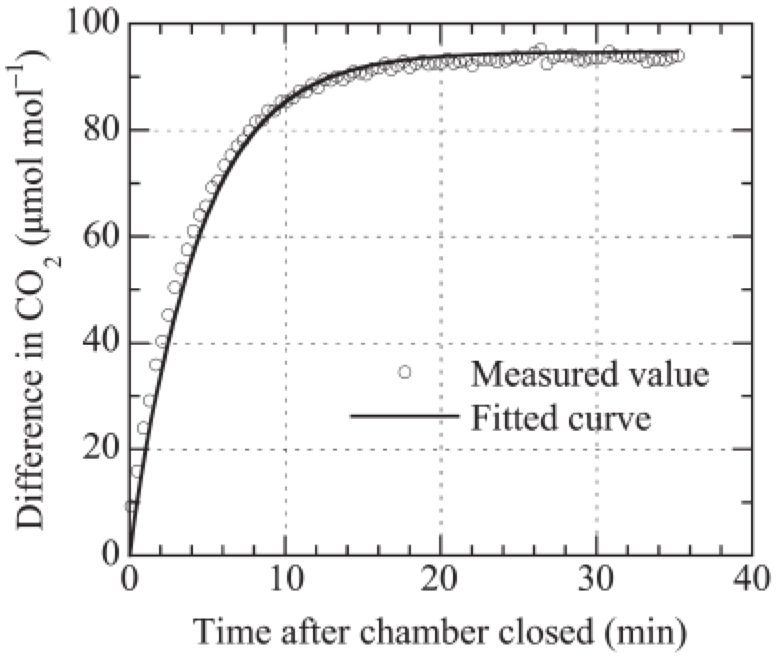
Xu, Baldocchi, Tang, 2004 GBC

Technique: Chamber methods 1.

Steady-state open chamber



$$F_{CO2} = \frac{u}{S} \times (CO_{2\_out} - CO_{2\_in})$$



- Disturbing the diffusion gradient
- Need longer time to do measurement

Technique: Chamber methods 1.

Steady-state open chamber

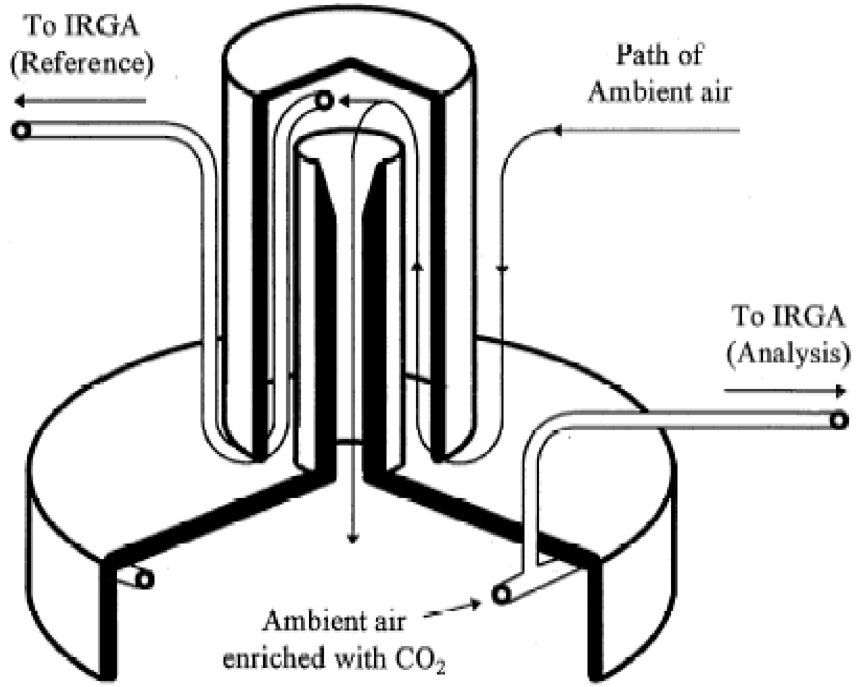


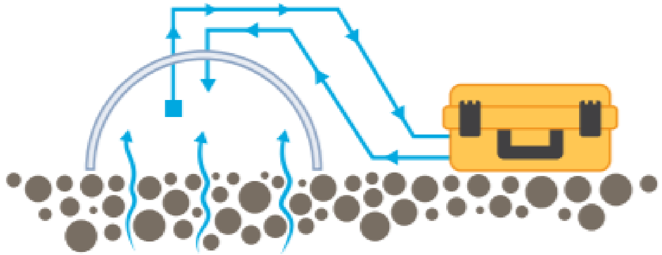
Figure 1. Schematic diagram of a section through an open system soil CO_2 efflux chamber.

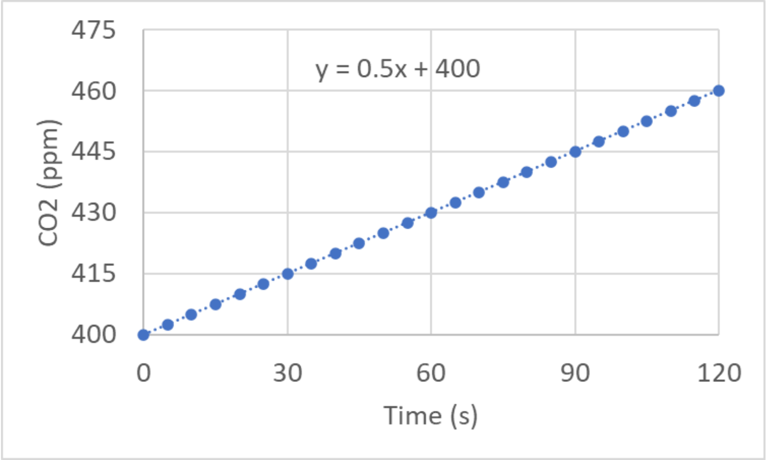
$$F_{CO2} = \frac{u}{S} \times (CO_{2\_out} - CO_{2\_in})$$

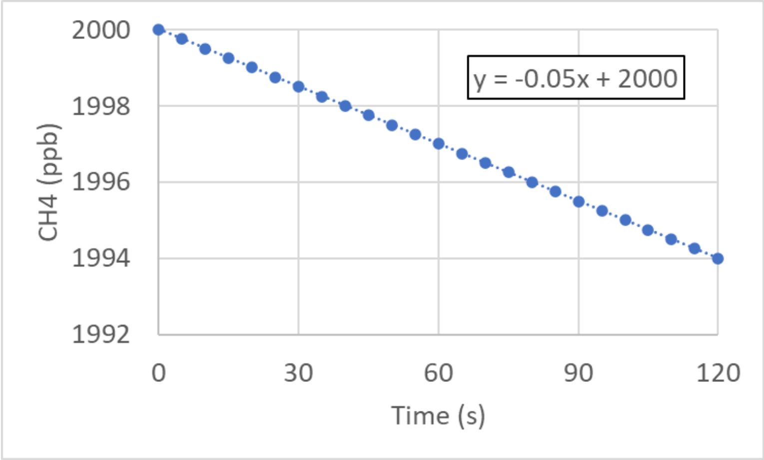
Rayment and Jarvis. 1997. An improved open chamber system for measuring soil CO2 effluxes in the field. *J Grophysics Res*, 102: 28779-28784

2: Theory

Non-Steady-state closed chamber method







$$F_{CH4} = \frac{VP_o(1 - W_o)}{RS(T_o + 273.15)} \frac{dC'}{dt}$$

V:	Chamber volume	m^3
P_o:	Pressure	Pa
R:	Gas constant	Pa m^3 $k^{-1}mol^{-1}$
S:	Soil area	m^2
T_o:	Temperature	^oC
$\frac{dC'}{dt}$	Slope	nmol $mol^{-1}s^{-1}$
W_o	H_2O	mol mol^{-1}
F_{CH4}:	Flux	nmol $m^{-2}s^{-1}$

$$F_{CH4} = \frac{n}{S}\frac{dC'}{dt} = \frac{mole}{m^2}\frac{nmol}{mol \cdot s} = \frac{nmol}{m^2 \cdot s}$$

$$n = \frac{PV(1 - \mathrm{W})}{RT} = \frac{Pa \cdot m^3}{Pa \cdot m^3 k^{-1} mole^{-1} \cdot k}$$

$$F_{CH4} = \frac{P_o V(1 - W_o)}{RS(T_o + 273.15)}\frac{dC'}{dt}$$

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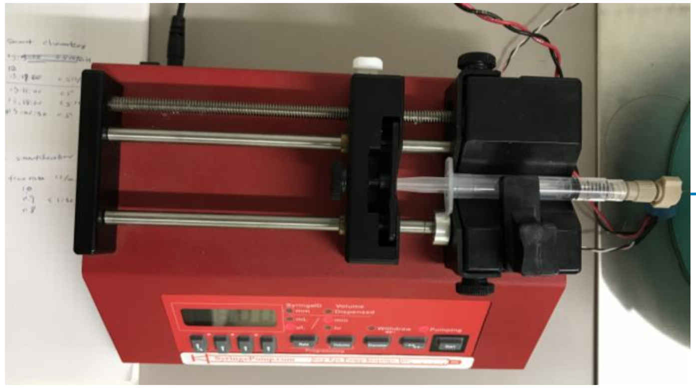
Consideration: Questions need to be answered

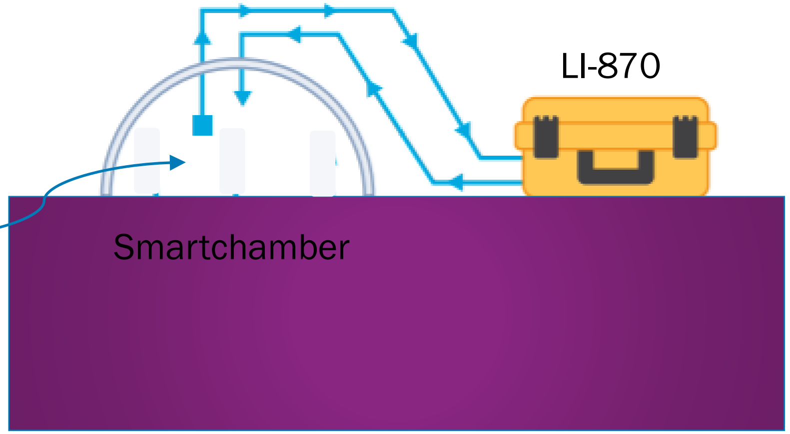
1. Accurately measure amount of GHG from the soil
2. Minimize the influence on soil GHG “Transport”
3. Minimize the influence on soil GHG “Production”
4. Mixing

3: Considerations

Accurately measure amount of gas from the soil?

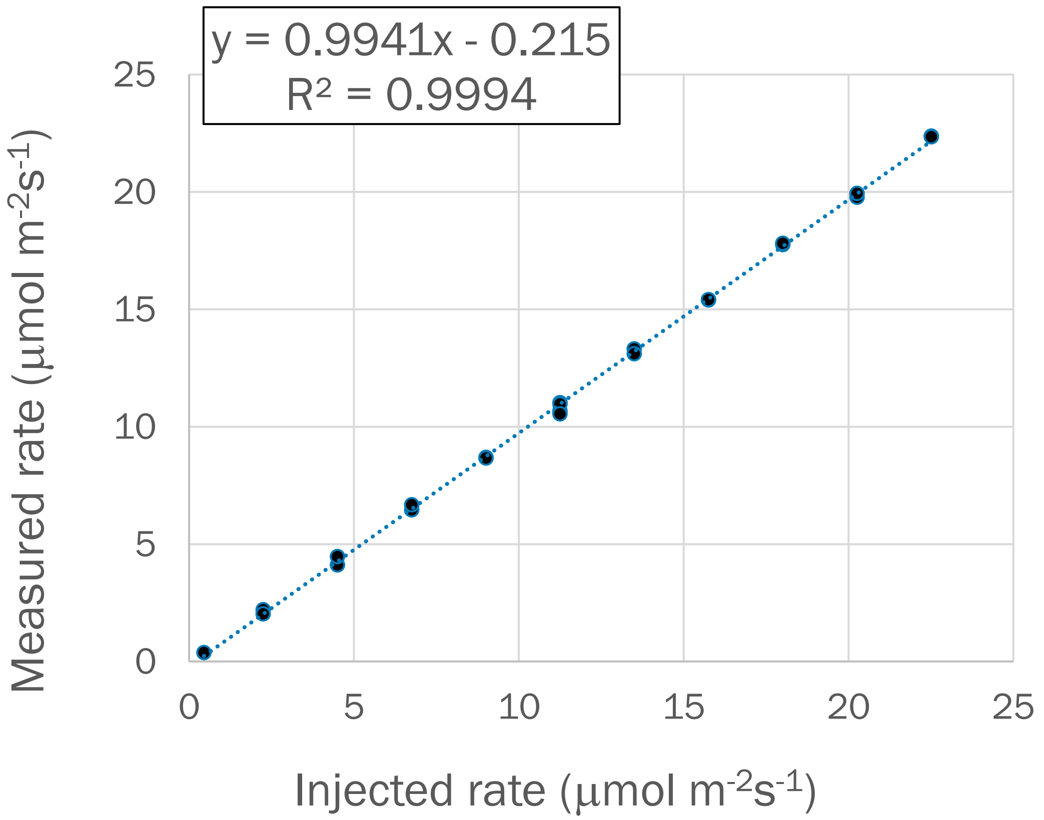
Syringe pump





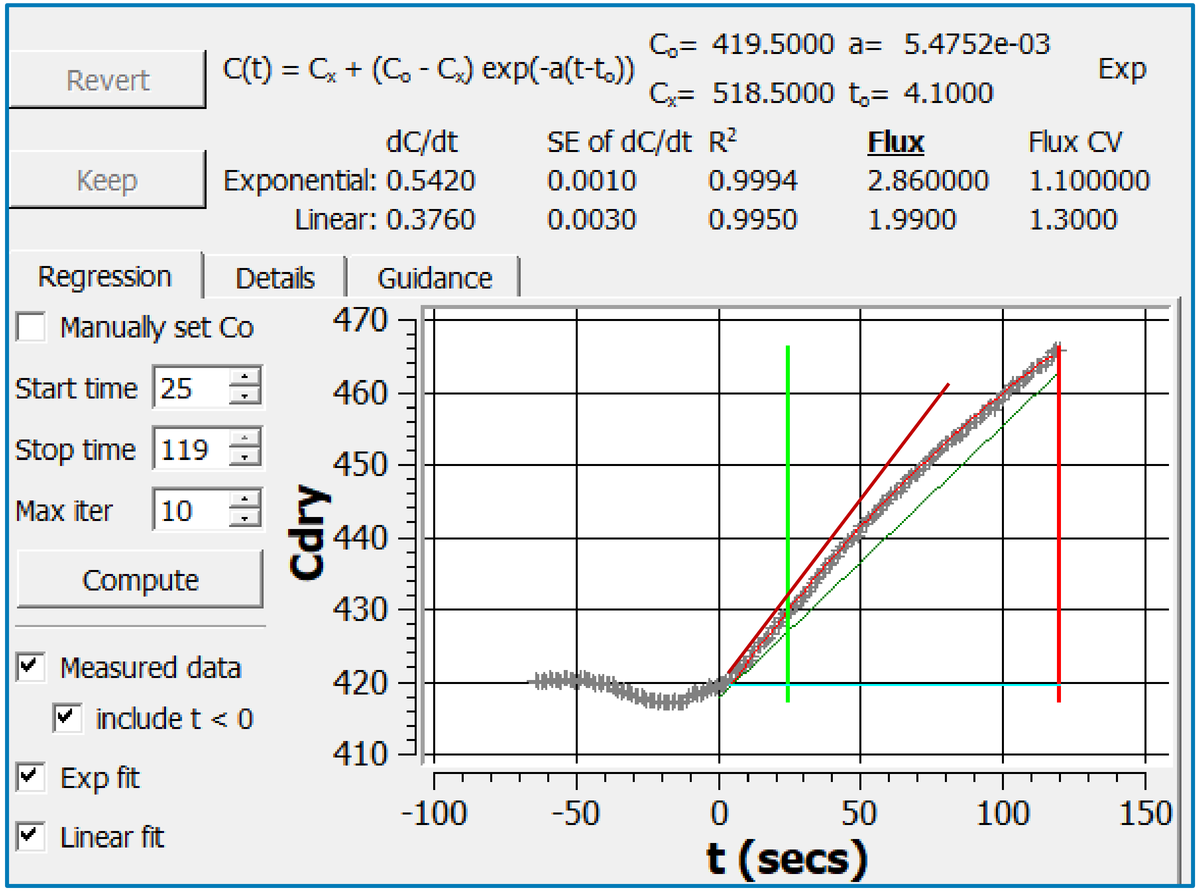
Inject known rate $\stackrel{?}{=}$ Measured rate

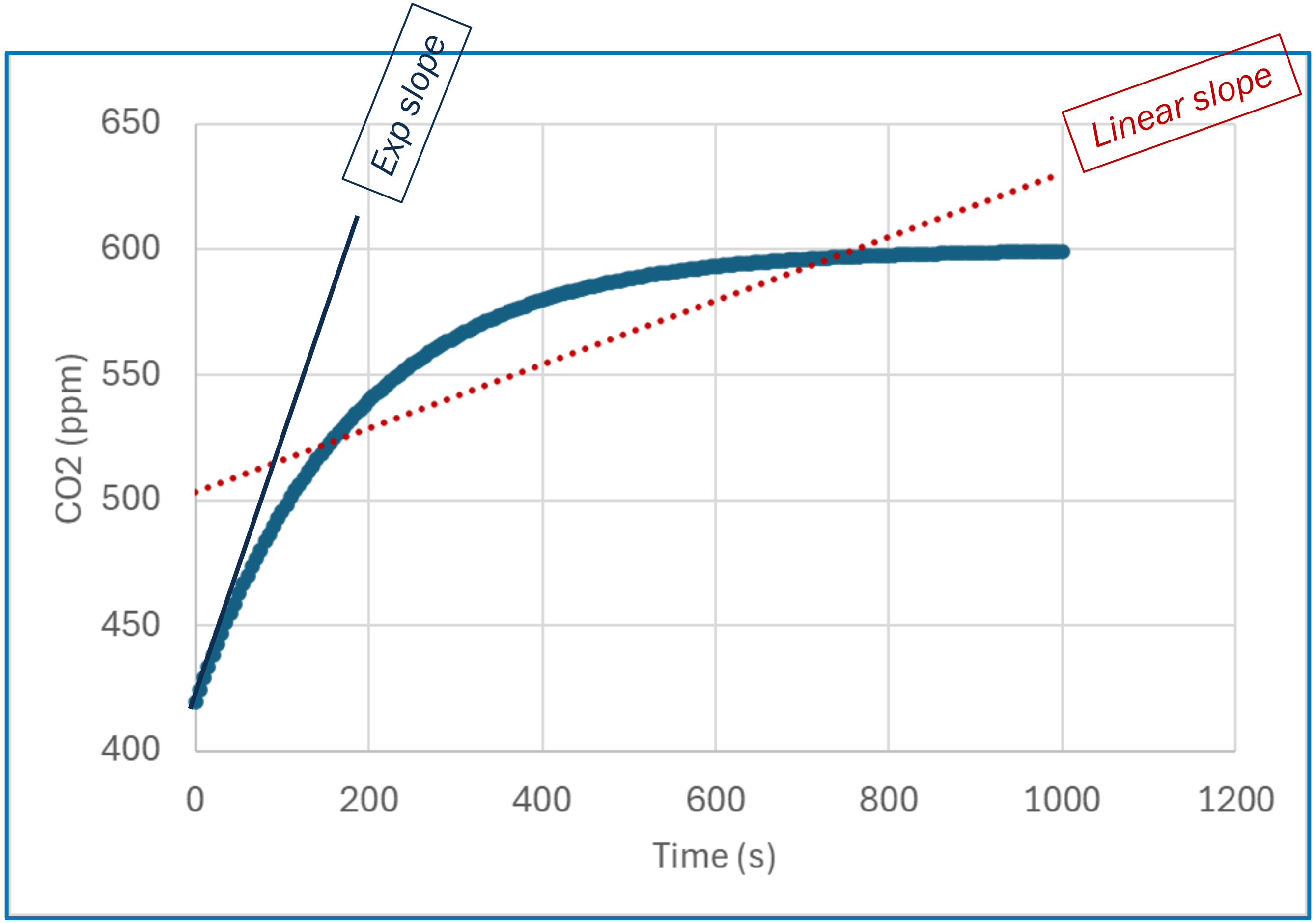
Accurately measure amount of gas from the soil?



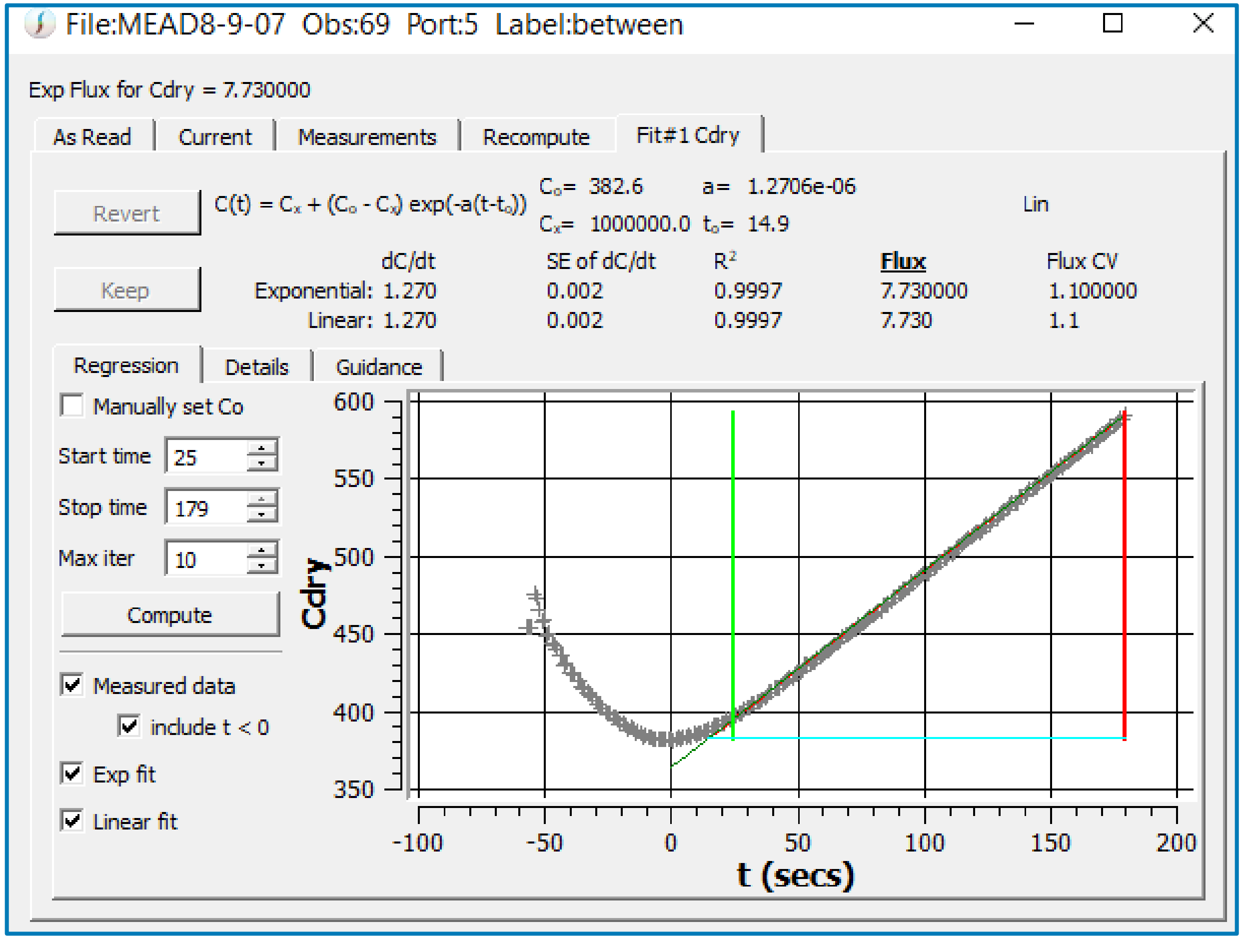
3: Considerations

Account for the change in CO_2 diffusion gradient inside the chamber





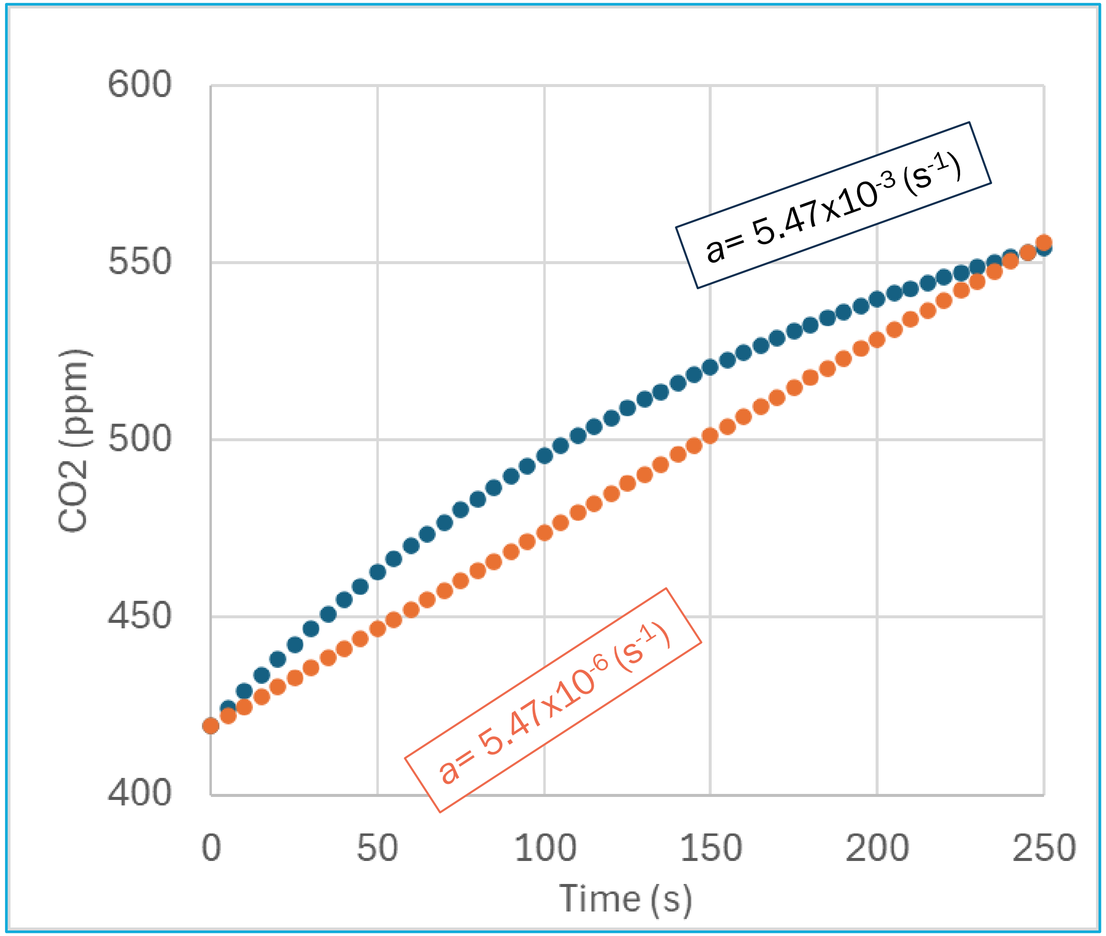
Account for the change in CO_2 diffusion gradient inside the chamber



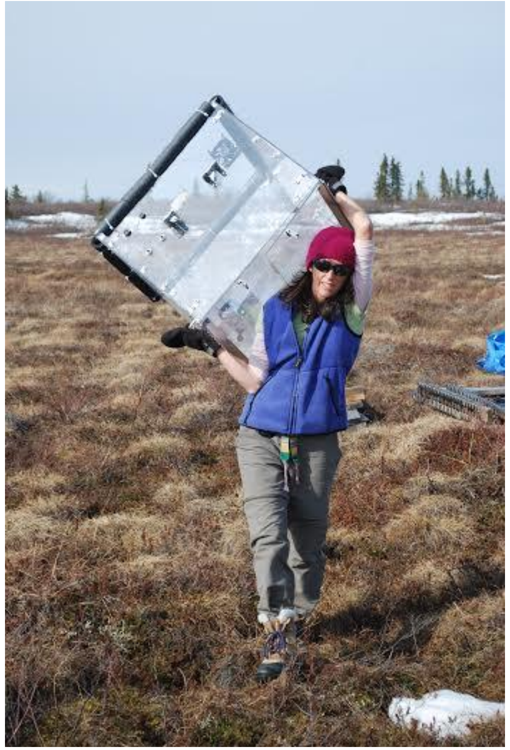
Curvature of the time series

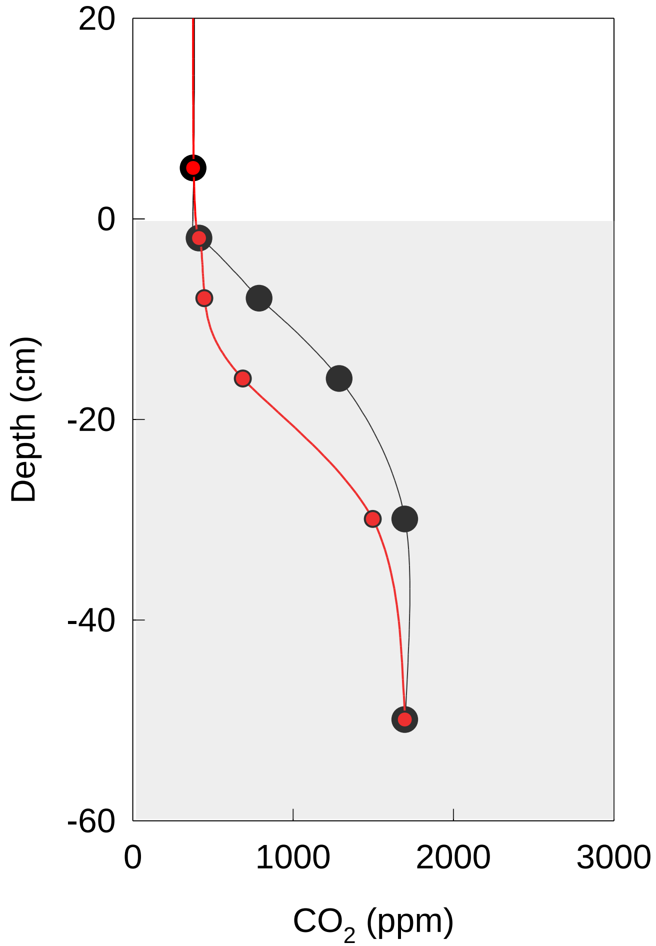
$$C_t = C_x + (C_o - C_x) \cdot exp^{-a \cdot t}$$

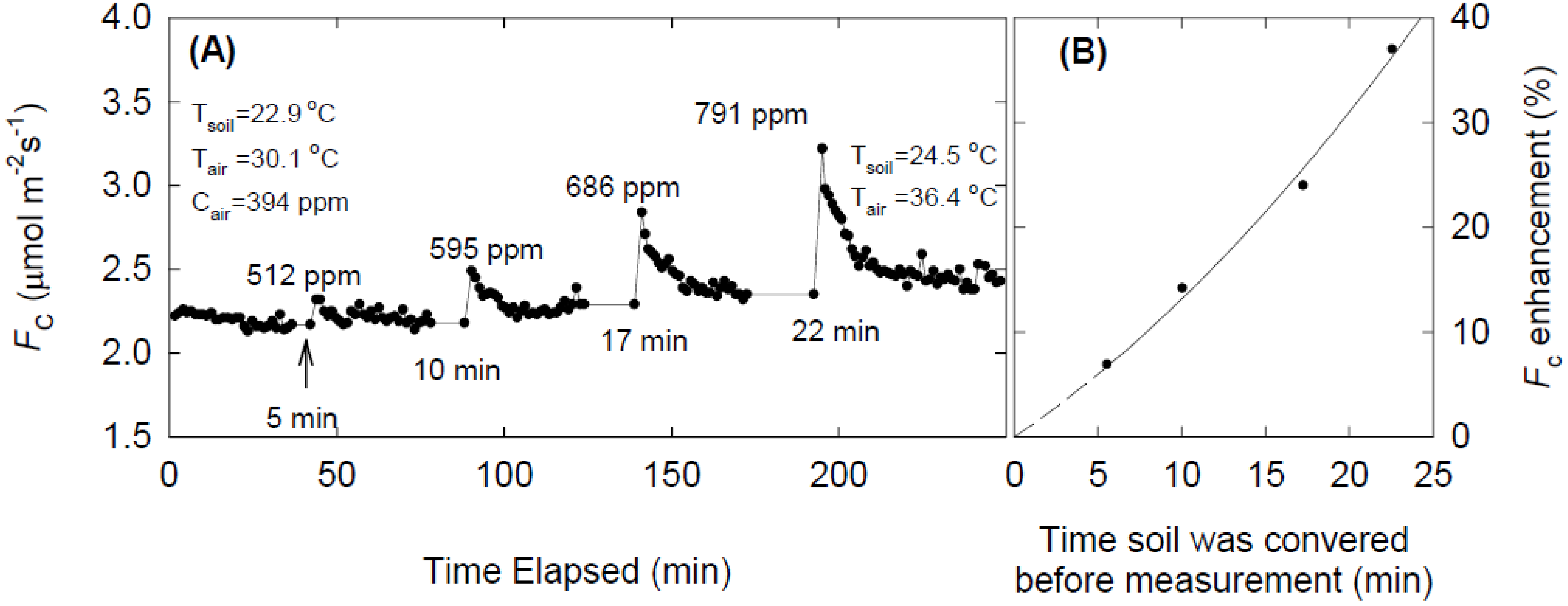
$$a = \frac{g \cdot S}{V}$$

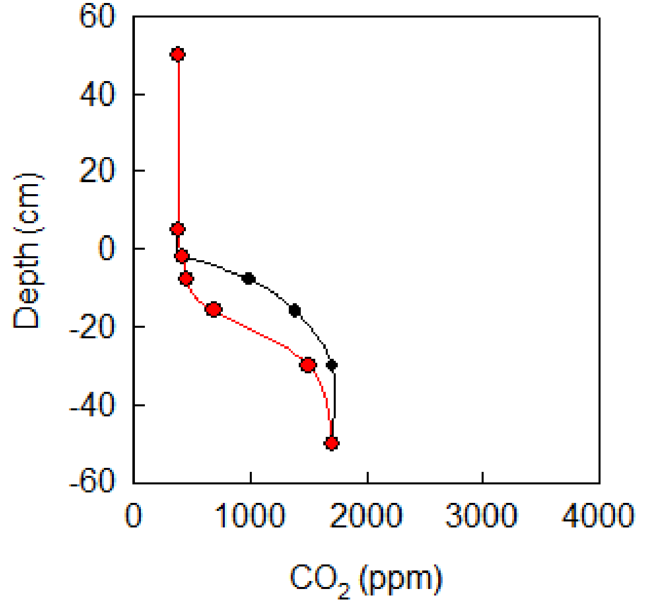


No disturbance to CO_2 diffusion gradient inside the soil profile



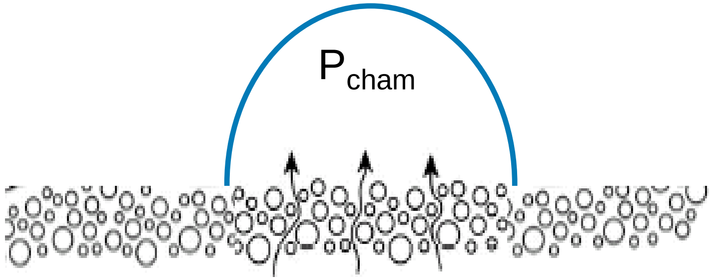






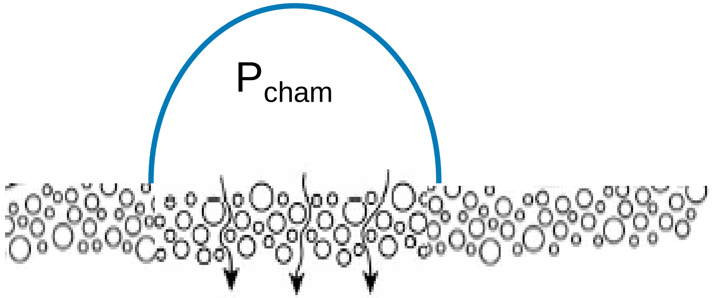
Caution: Be aware of this when repeat the measurement on the same collar !

Chamber pressure equilibrium



$P_{cham} < P_{atm}$

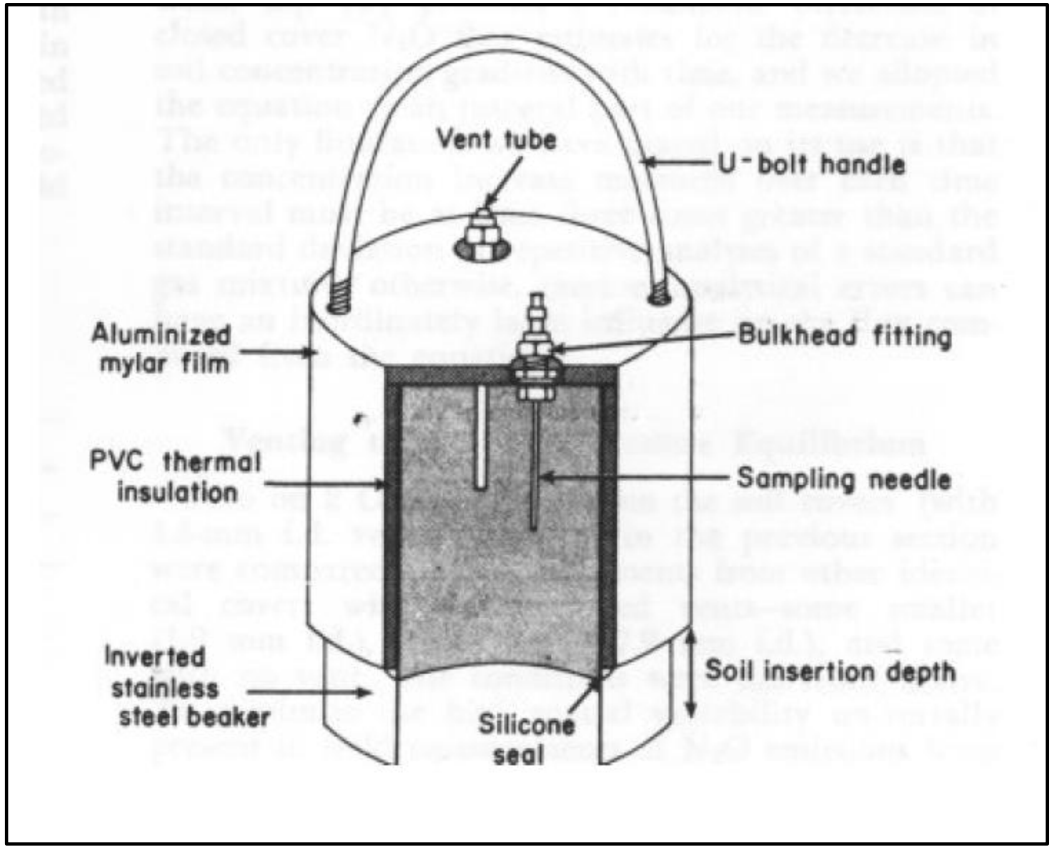
cause upward mass flow,
lead to a flux overestimation

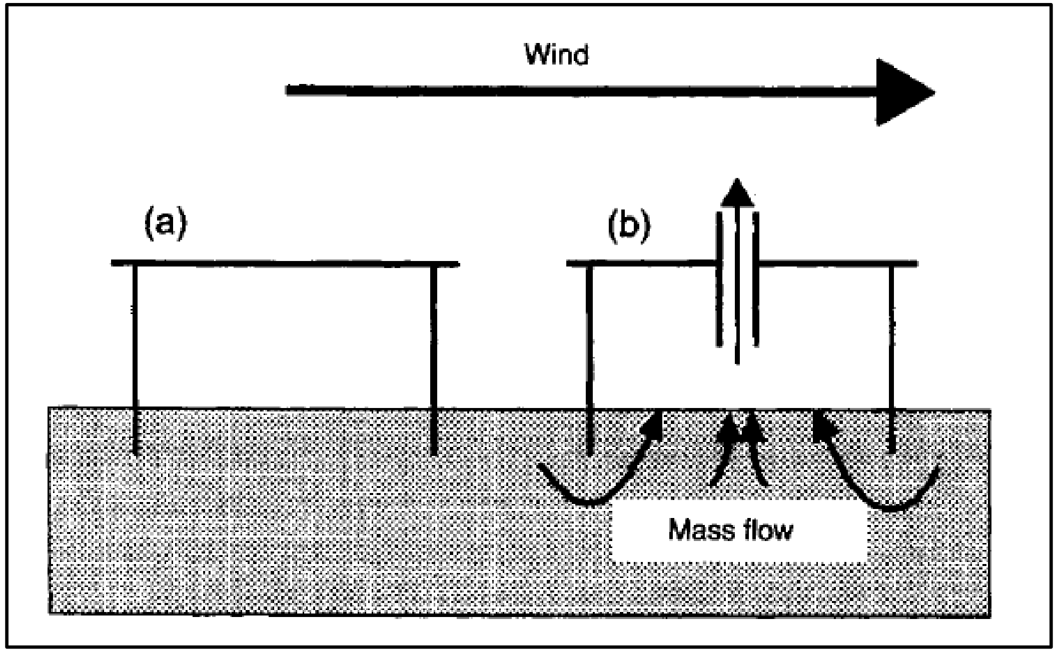


$P_{cham} > P_{atm}$

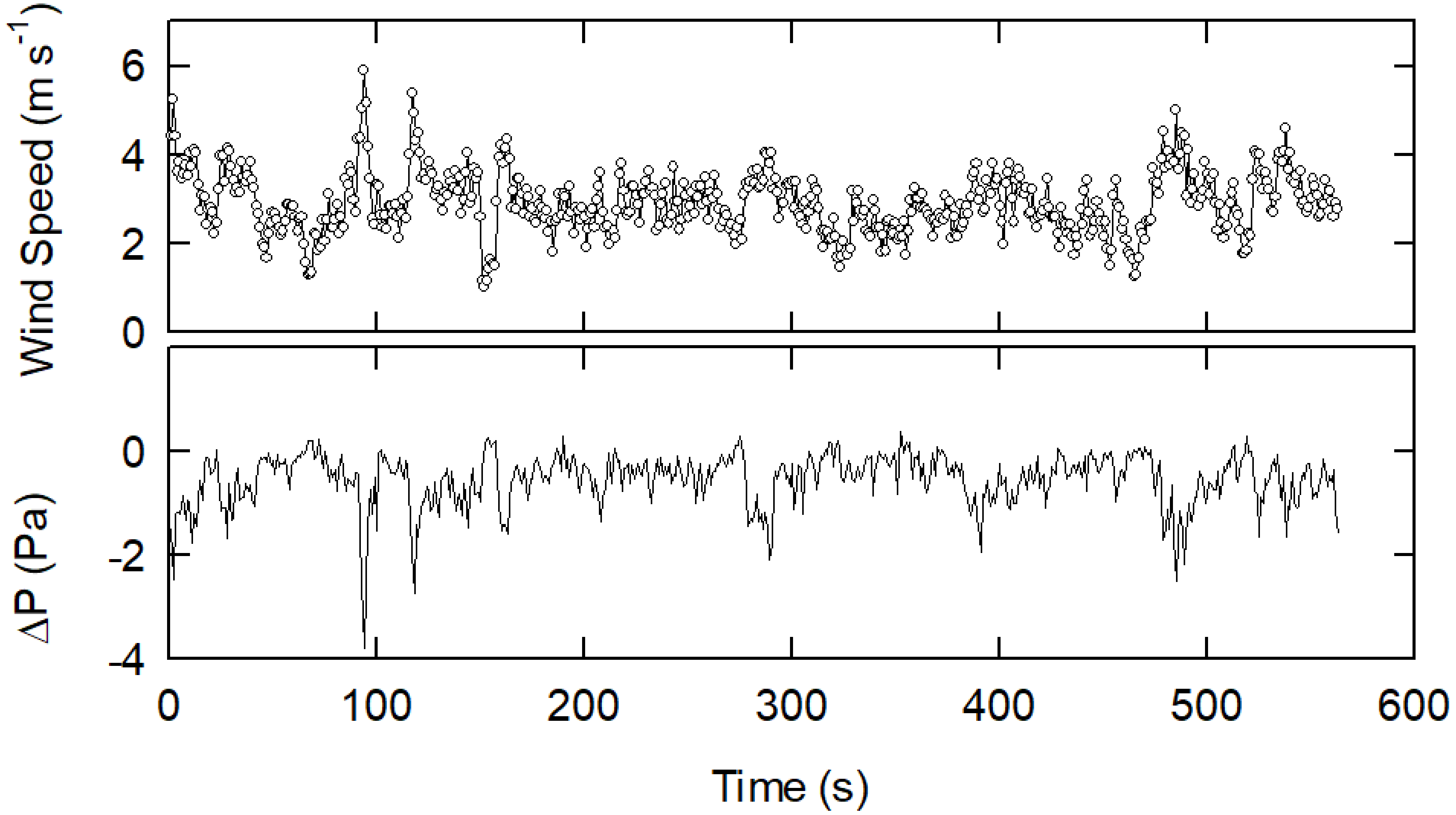
cause downward mass flow,
lead to a flux underestimation

Minimize the influence on soil GHG "Transport"





Conen and Smith 1998. Eur. J of Soil Sci. 49: 701-707



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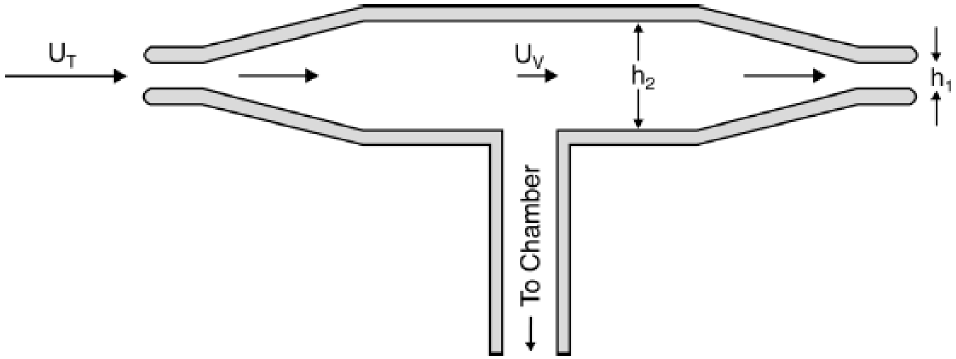
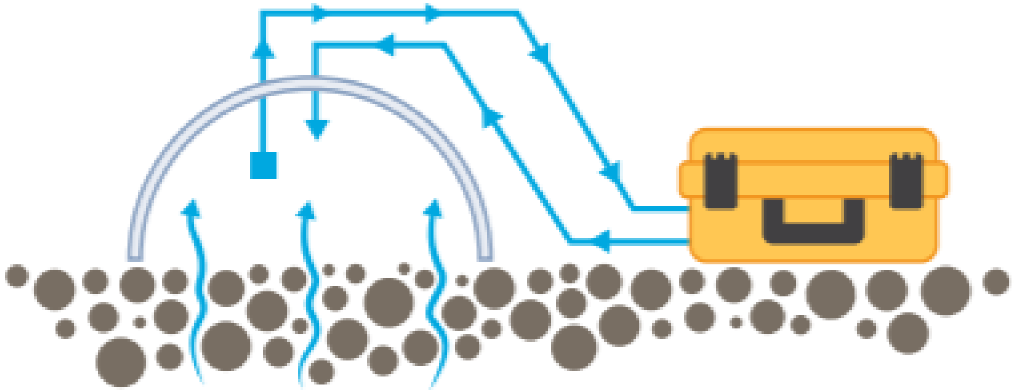
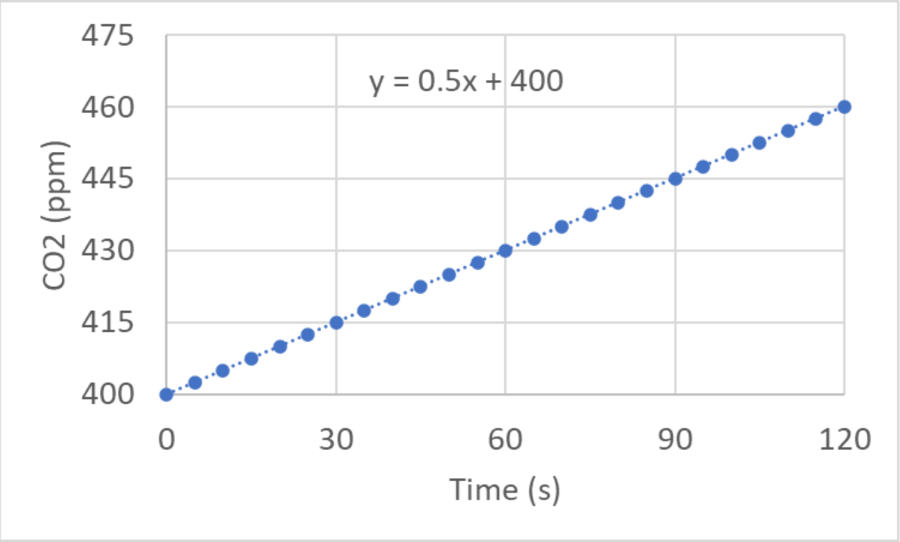
Minimize the influence on soil GHG "Transport"

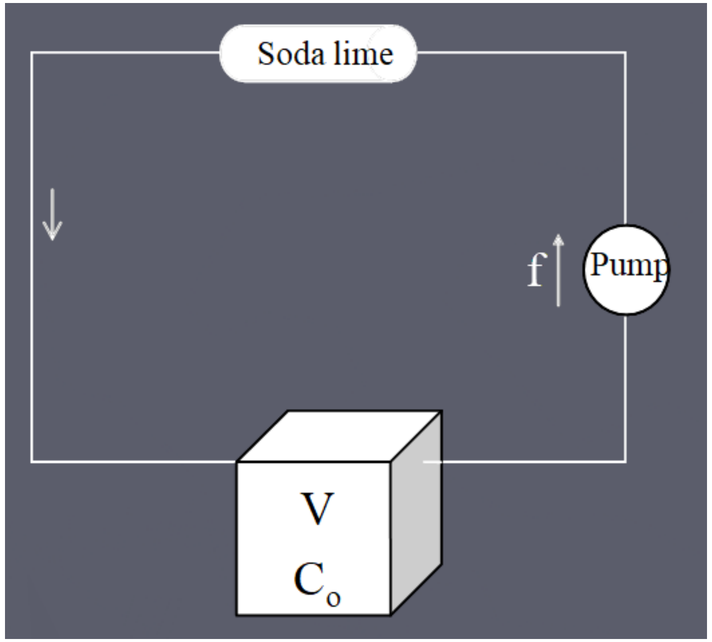


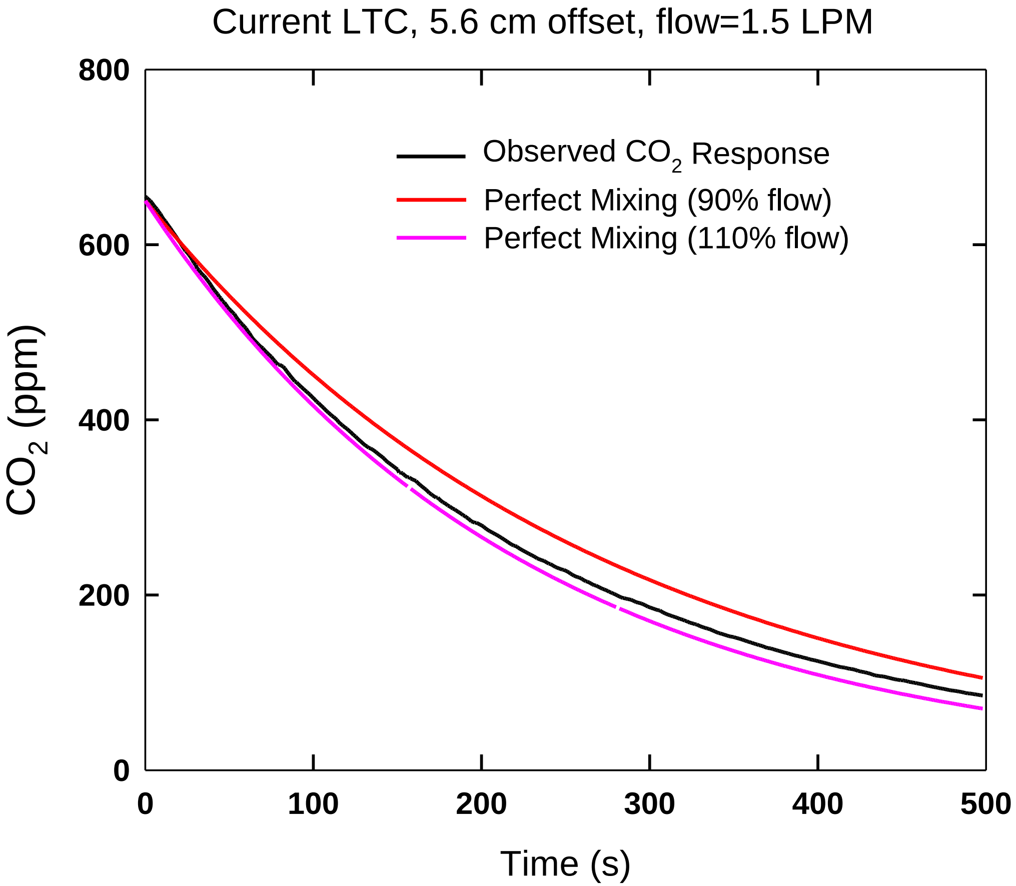
Why do we need to have a good mixing inside the chamber?





Requirement: **Mixing**



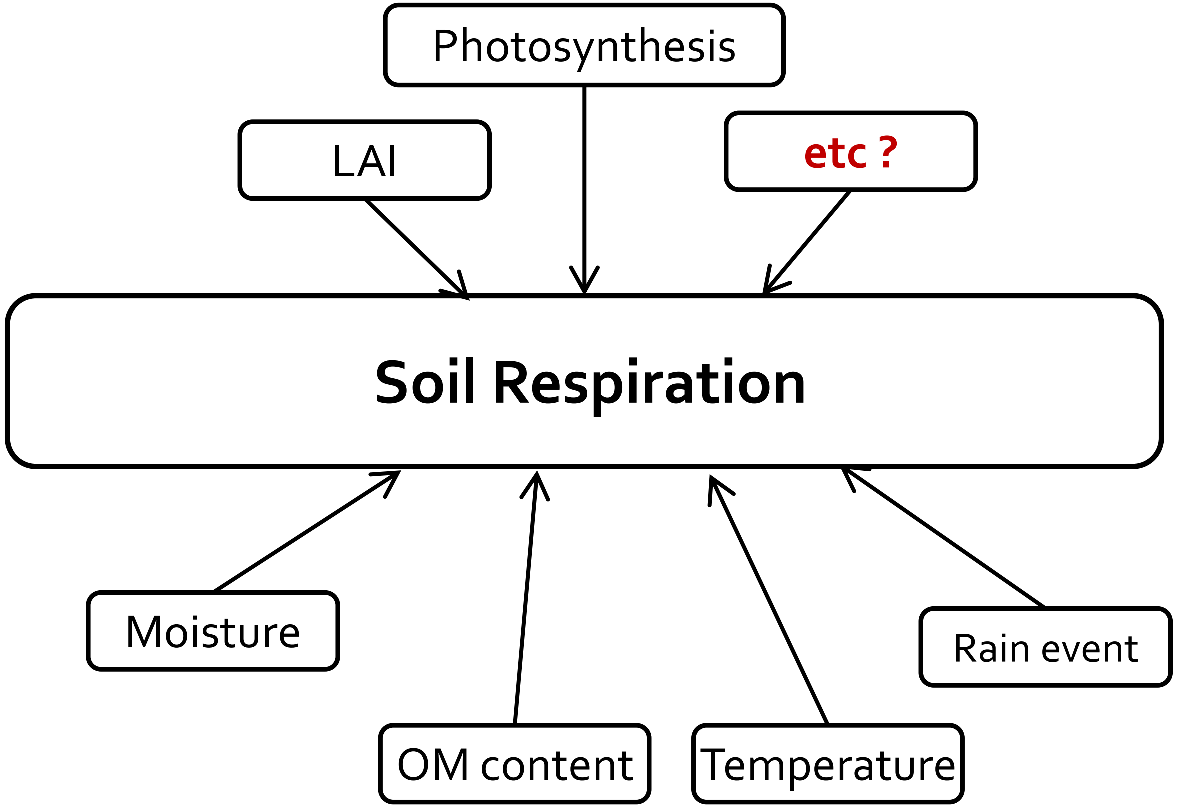


$$C_t = C_o e^{-\frac{f}{V}t}$$

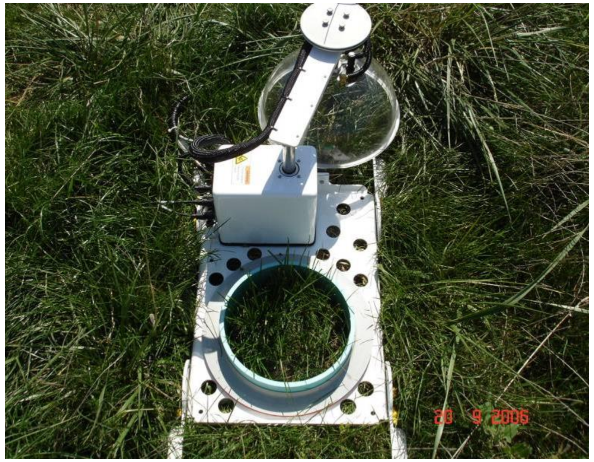
$$\frac{dC}{dt} = \frac{f}{V}(C_{in} - C) = -\frac{f}{V}C \qquad \frac{dC}{C} = -\frac{f}{V}dt$$

$$\ln C = -\frac{f}{V}t + C_o \qquad C = e^{-\frac{f}{V}t + C_o} = C_o e^{-\frac{f}{V}t}$$

Understanding control of soil respiration



Minimize the disturbance to production, esp. for long-term automated chamber deployment



Minimize biological disturbance

3: Considerations

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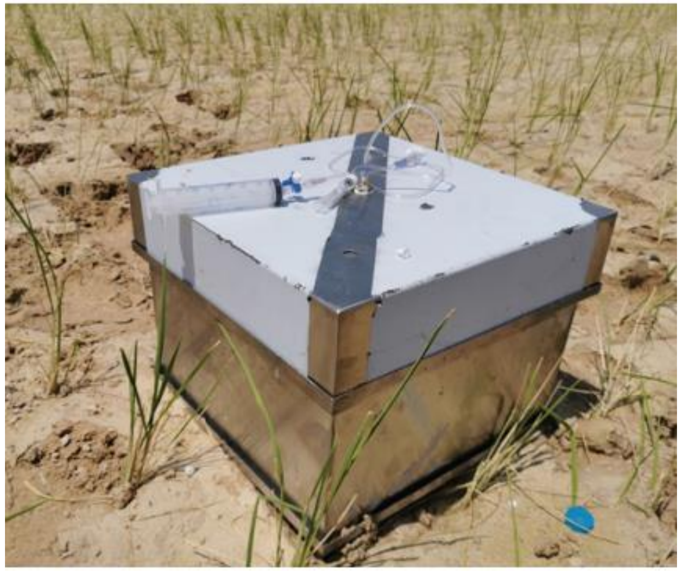
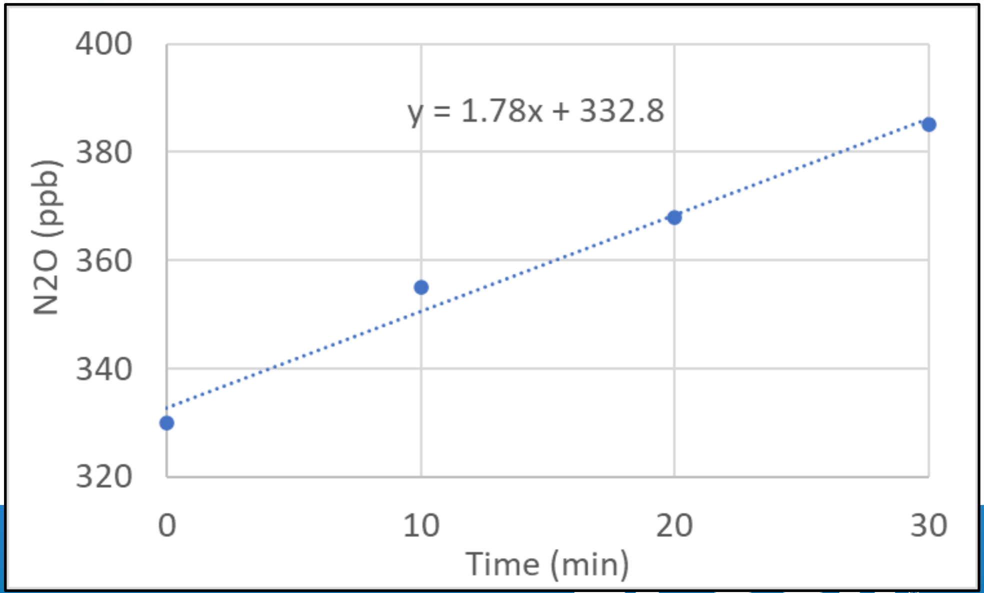
Hardware: Manual chamber





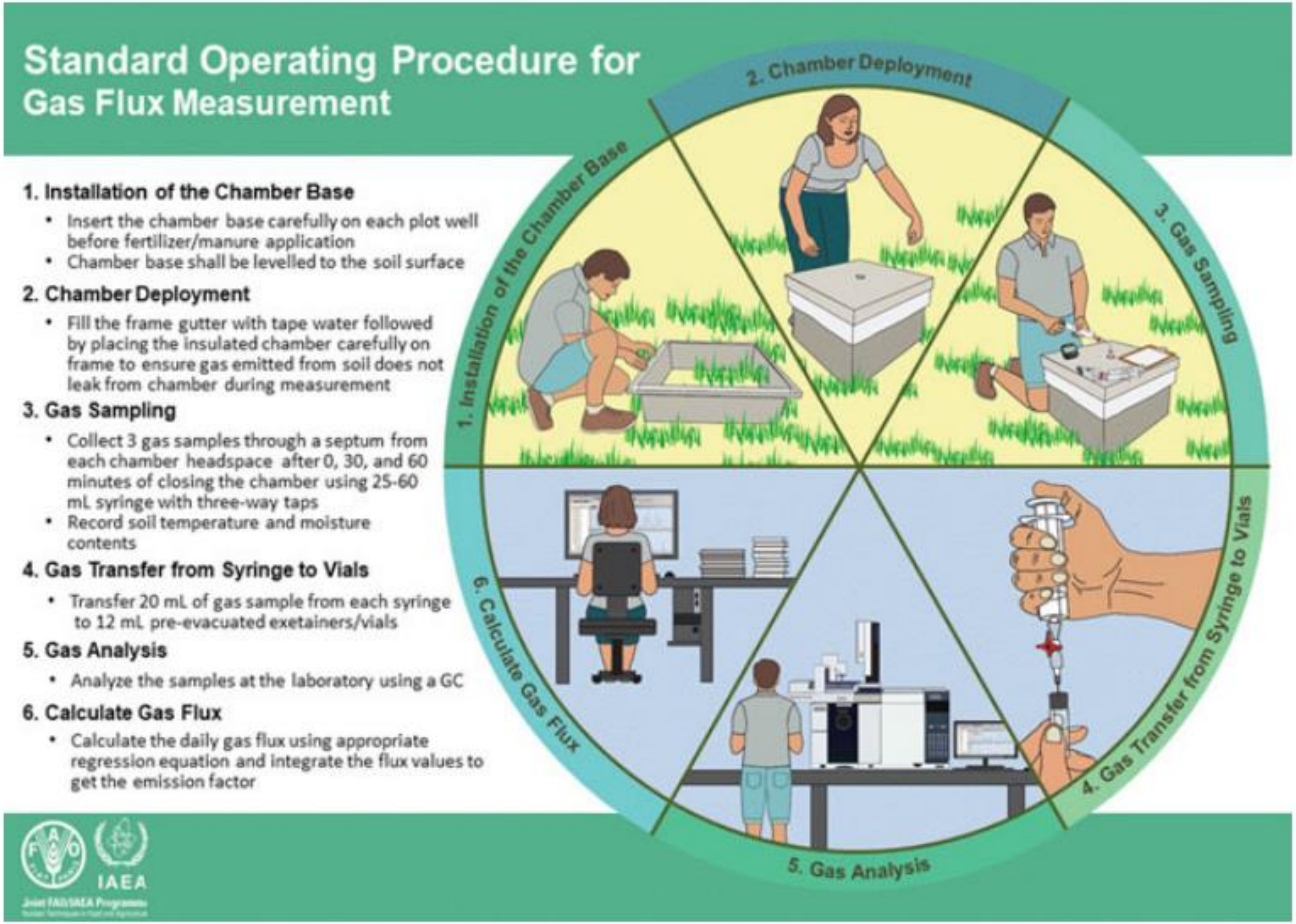


Plate 2.16 A schematic representation of gas sampling, analysis, and interpretation (© FAO/IAEA Mohammad Zaman)

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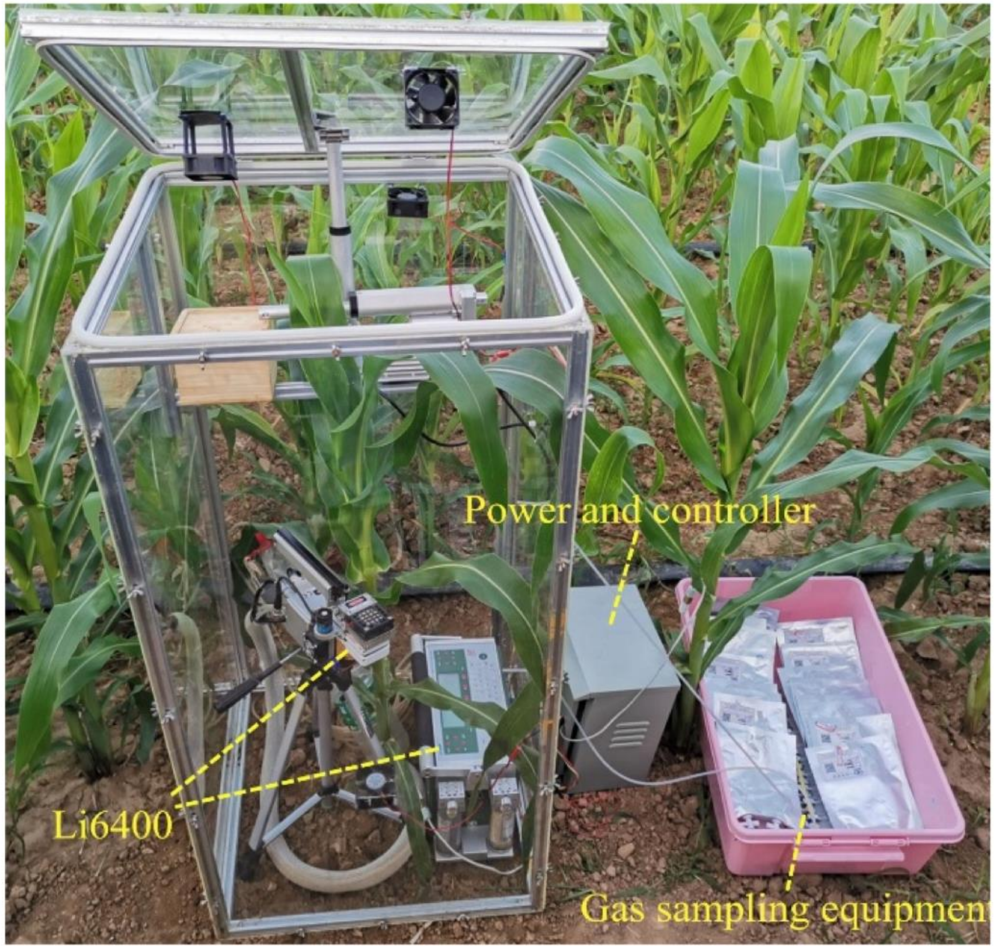
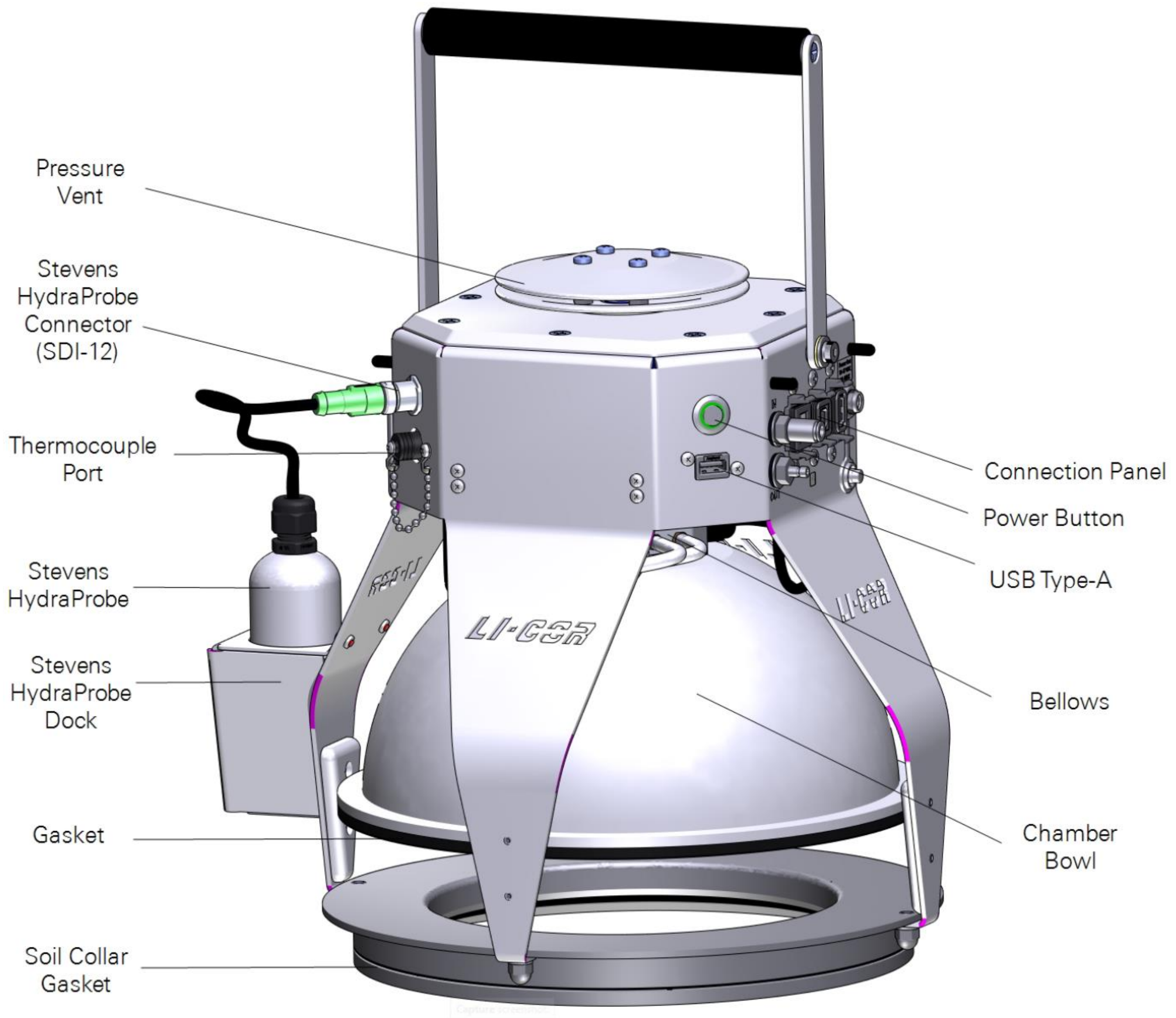

Power and controller
Li6400
Gas sampling equipment

Survey chamber: Smart Chamber

A word about Stevens Hydraprobe
for soil temperature measurement



Survey system (8200-01S)

LI-870SC

LI-7810SC; LI-7820SC

Survey system (8200-01S)

LI-870SC+LI-7820

LI-7810SC+LI-7820

Long-term system (LI-8250)

LI-8250 Multiplexer Hardware

- Slightly smaller than the LI-8150 Multiplexer
  - 38.5 cm L x 52 cm W x 18.5 cm H
- Tested to IEC IP55 standard
- Temperature operating range: -20 to 45 °C
- Power consumption

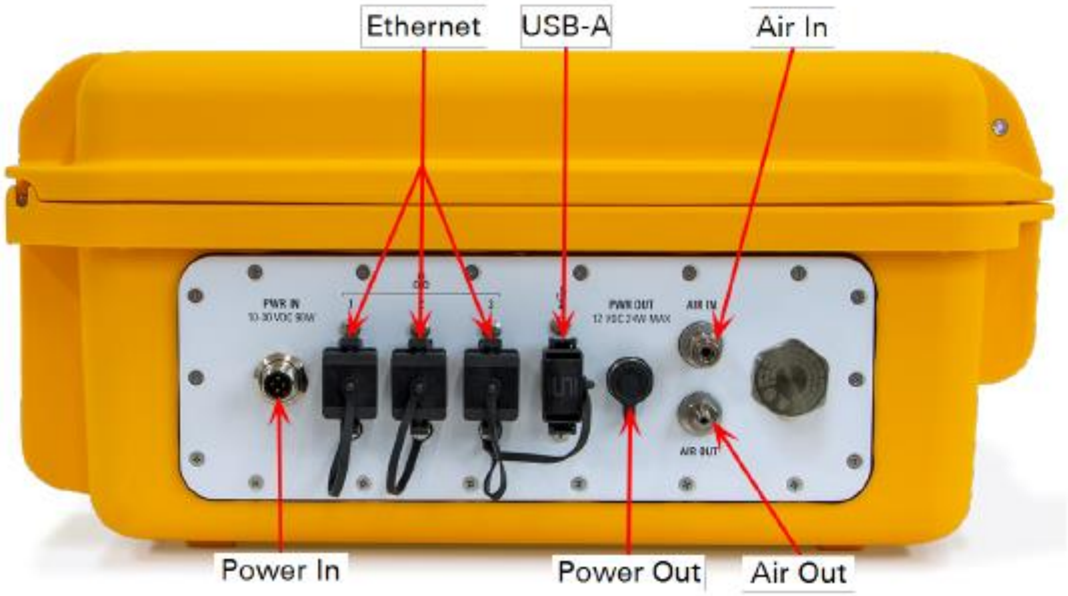
	Idle	Sampling/Moving	Maximum
• LI-8250	4.4 W	16.1 W	19.5 W
• 8200-104	0.3 W	7.5 W	N/A

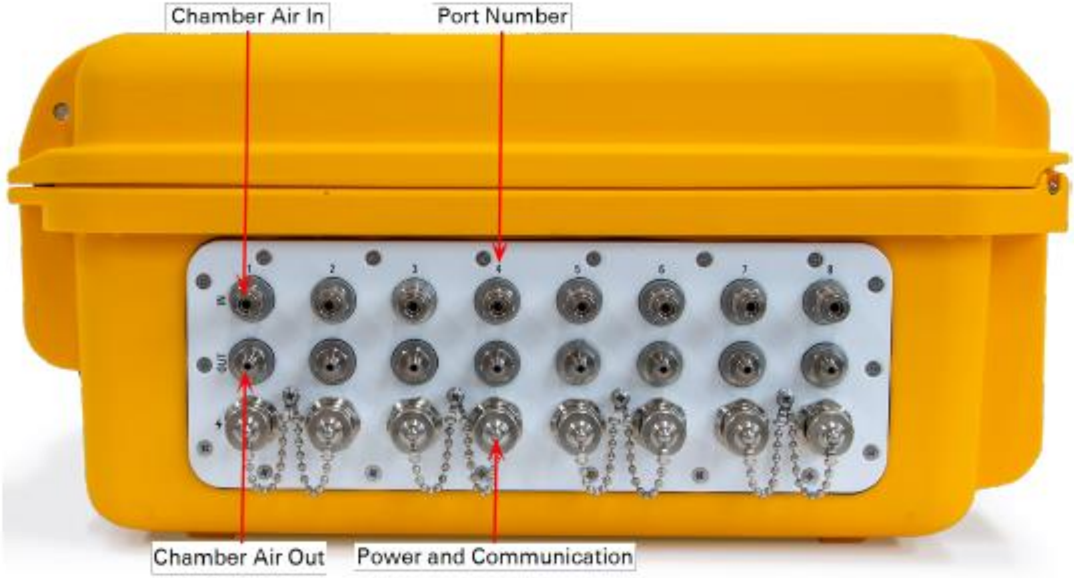
LI-8250 Multiplexer Hardware

- Slightly smaller than the LI-8150 Multiplexer
  - 38.5 cm L x 52 cm W x 18.5 cm H
- Tested to IEC IP55 standard
- Temperature operating range: -20 to 45 °C
- Power consumption

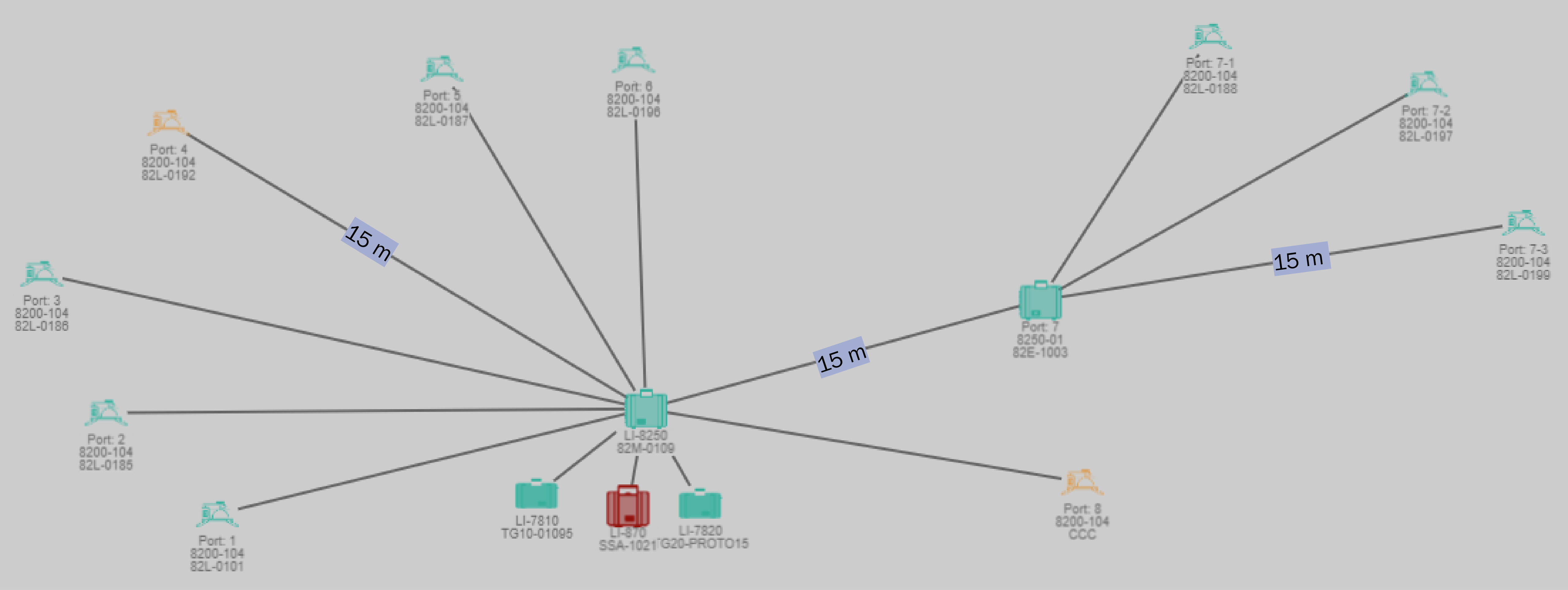
	Idle	Sampling/Moving	Maximum
• LI-8250	4.4 W	16.1 W	19.5 W
• 8200-104	0.3 W	7.5 W	N/A

LI-8250 –Multiplexer

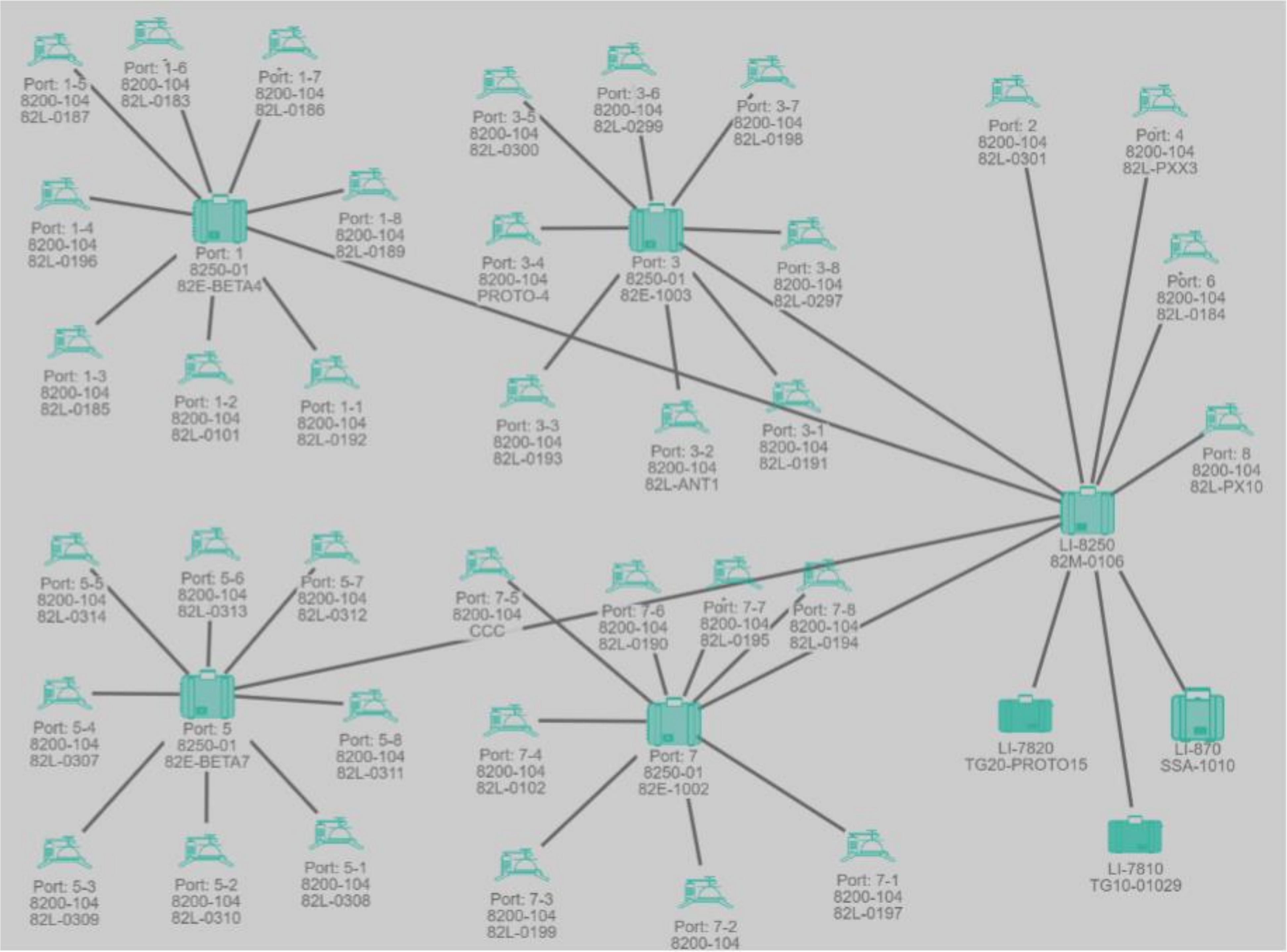




4: Hardware


Port: 5
8200-104
82L-0187
Port: 6
8200-104
82L-0196
Port: 7-1
8200-104
82L-0188
Port: 7-2
8200-104
82L-0197
Port: 4
8200-104
82L-0192
15 m
Port: 3
8200-104
82L-0186
15 m
Port: 7-3
8200-104
82L-0199
Port: 7
8250-01
82E-1003
15 m
Port: 2
8200-104
82L-0185
LI-8250
82M-0109
LI-7810
TG10-01095
LI-870
SSA-1021
LI-7820
TG20-PROTO15
Port: 8
8200-104
CCC
Port: 1
8200-104
82L-0101

4: Hardware


Port: 1-5
8200-104
82L-0187
Port: 1-6
8200-104
82L-0183
Port: 1-7
8200-104
82L-0186
Port: 1-4
8200-104
82L-0196
Port: 1
8250-01
82E-BETA4
Port: 1-8
8200-104
82L-0189
Port: 1-3
8200-104
82L-0185
Port: 1-2
8200-104
82L-0101
Port: 1-1
8200-104
82L-0192
Port: 3-5
8200-104
82L-0300
Port: 3-6
8200-104
82L-0299
Port: 3-7
8200-104
82L-0198
Port: 3-4
8200-104
PROTO-4
Port: 3
8250-01
82E-1003
Port: 3-8
8200-104
82L-0297
Port: 3-3
8200-104
82L-0193
Port: 3-2
8200-104
82L-ANT1
Port: 3-1
8200-104
82L-0191
Port: 2
8200-104
82L-0301
Port: 4
8200-104
82L-PXX3
Port: 6
8200-104
82L-0184
Port: 8
8200-104
82L-PX10
LI-8250
82M-0106
Port: 5-5
8200-104
82L-0314
Port: 5-6
8200-104
82L-0313
Port: 5-7
8200-104
82L-0312
Port: 5-4
8200-104
82L-0307
Port: 5
8250-01
82E-BETA7
Port: 5-8
8200-104
82L-0311
Port: 5-3
8200-104
82L-0309
Port: 5-2
8200-104
82L-0310
Port: 5-1
8200-104
82L-0308
Port: 7-5
8200-104
CCC
Port: 7-6
8200-104
82L-0190
Port: 7-7
8200-104
82L-0195
Port: 7-8
8200-104
82L-0194
Port: 7-4
8200-104
82L-0102
Port: 7
8250-01
82E-1002
Port: 7-3
8200-104
82L-0199
Port: 7-2
8200-104
Port: 7-1
8200-104
82L-0197
LI-7820
TG20-PROTO15
LI-870
SSA-1010
LI-7810
TG10-01029

2a: Long-term system (LI-8250)

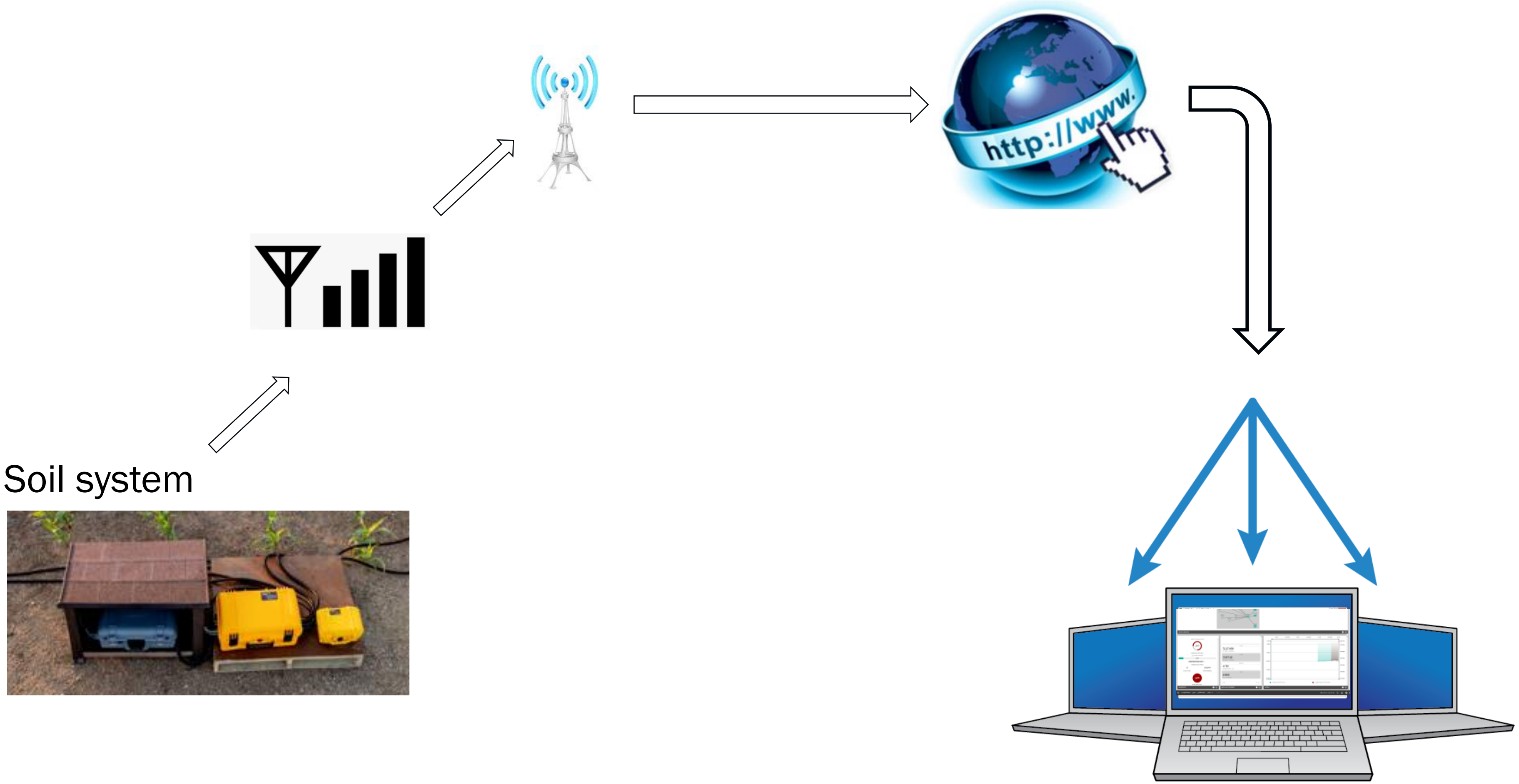
8200-104 Long Term Chamber – What’s New

- Update to enclosure
- Chamber thermistor redesign
- SDI-12 Connection: soil temperature and soil moisture sensor
- Easier integration of LI-COR light sensors

8200-104C Clear Long-Term Chambers

- For measuring Net Carbon Exchange (NCE)
- Upgrade kits available for converting between opaque and clear chambers

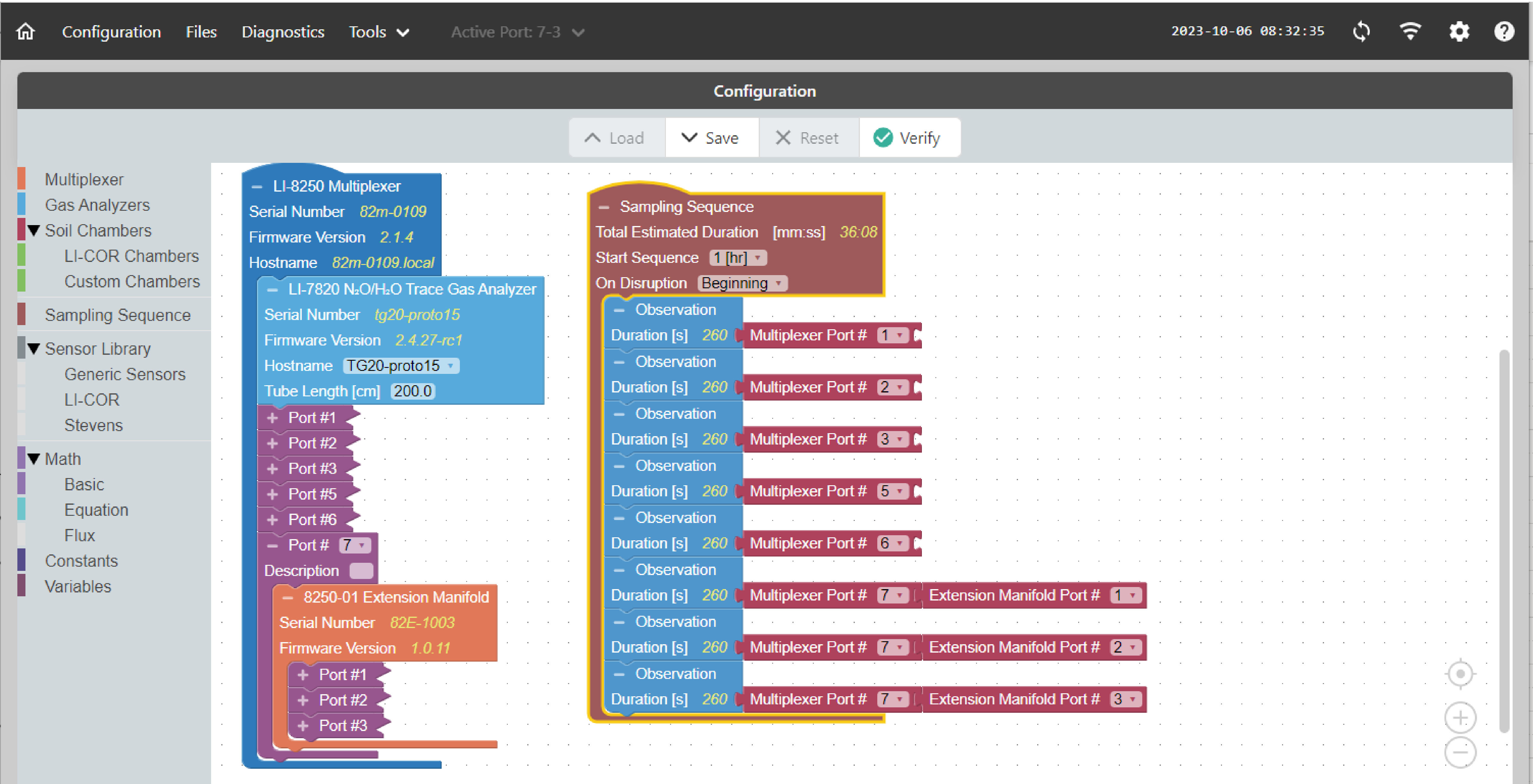
Long-term system (LI-8250)



Topics:

1. Control of gas transport across the soil surface
2. Theory of gas flux measurement across soil surface
3. Considerations for the closed-chamber method
4. Hardware: Smartchamber, LI-8250 system
5. Software:
   a. User interface (UI)
   b. Data processing software (SoilFluxPro) Demo
6. QA/QC

5: Software (UI, LI-8250)



5: Software (UI, Smartchamber)

5: Software (SoilFluxPro)

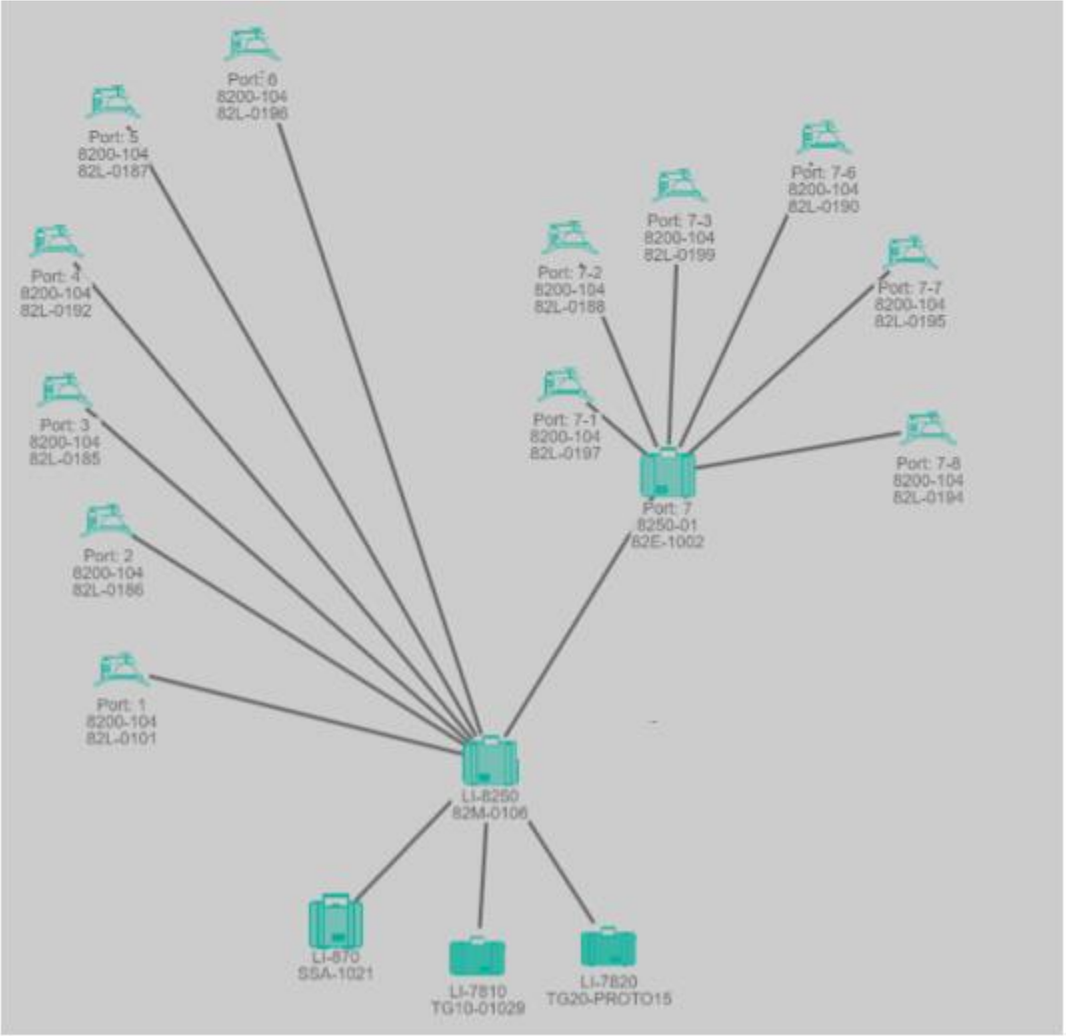
SoilFluxPro™

The ultimate in data processing simplicity

Main features of SoilFluxPro (SFP)

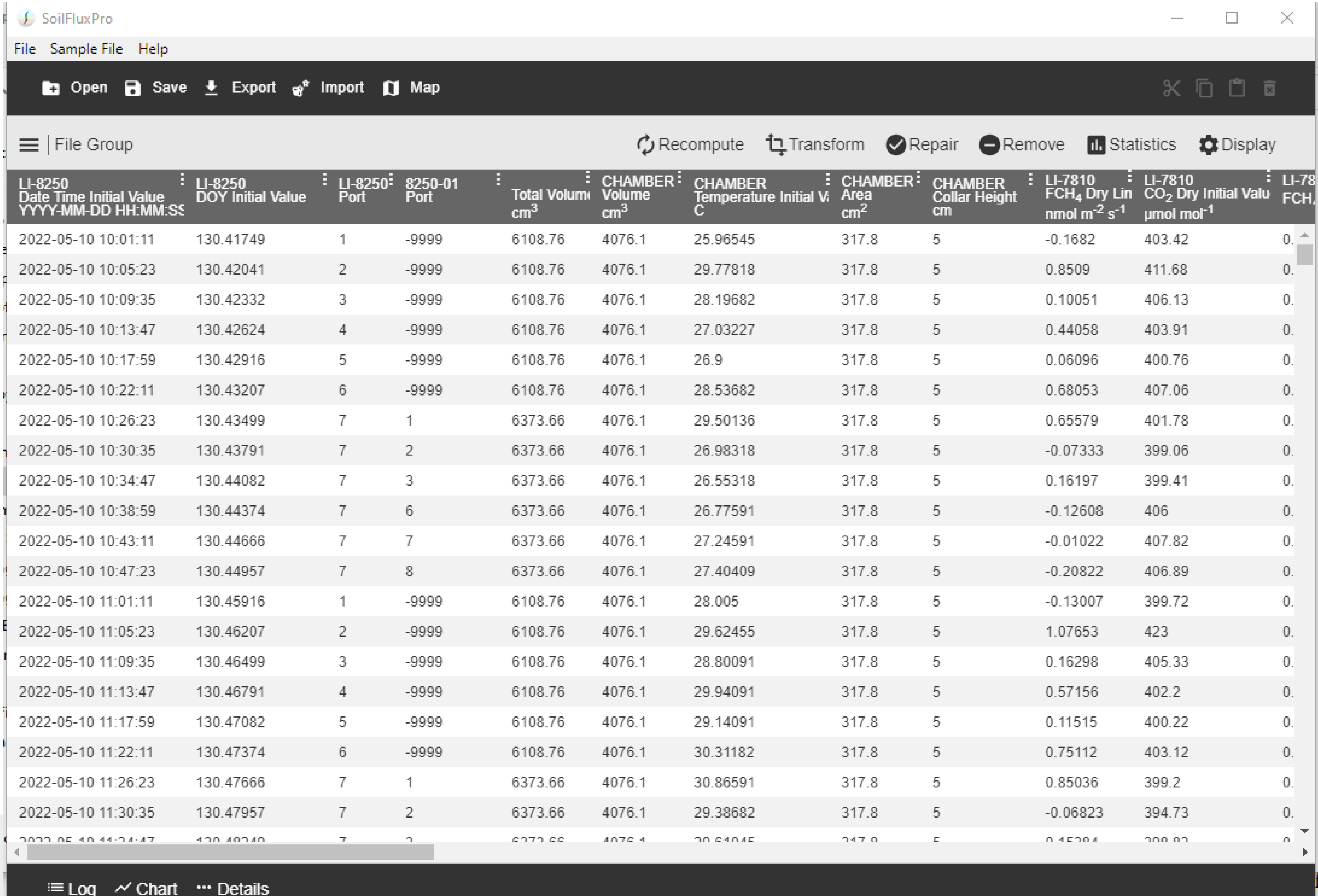
- Recompute
- Transform
- Repair
- Export
- Import
- Display
- Chart, Details, etc.

SoilFluxPro Demo



Chamber
P.1
P.2
P.3
P.4
P.5
P.6
P.7-1
P.7-2
P.7-3
P.7-6
P.7-7
P.7-8

SFP demo



LI-8250 Date Time Initial Value YYYY-MM-DD HH:MM:SS	LI-8250 DOY Initial Value	LI-8250 Port	8250-01 Port	Total Volum cm^3	CHAMBER Volume cm^3	CHAMBER Temperature Initial V C	CHAMBER Area cm^2	CHAMBER Collar Height cm	LI-7810 FCH_4 Dry Lin nmol m^{-2} s^{-1}	LI-7810 CO_2 Dry Initial Valu µmol mol^{-1}	LI-78 FCH
2022-05-10 10:01:11	130.41749	1	-9999	6108.76	4076.1	25.96545	317.8	5	-0.1682	403.42	0.
2022-05-10 10:05:23	130.42041	2	-9999	6108.76	4076.1	29.77818	317.8	5	0.8509	411.68	0.
2022-05-10 10:09:35	130.42332	3	-9999	6108.76	4076.1	28.19682	317.8	5	0.10051	406.13	0.
2022-05-10 10:13:47	130.42624	4	-9999	6108.76	4076.1	27.03227	317.8	5	0.44058	403.91	0.
2022-05-10 10:17:59	130.42916	5	-9999	6108.76	4076.1	26.9	317.8	5	0.06096	400.76	0.
2022-05-10 10:22:11	130.43207	6	-9999	6108.76	4076.1	28.53682	317.8	5	0.68053	407.06	0.
2022-05-10 10:26:23	130.43499	7	1	6373.66	4076.1	29.50136	317.8	5	0.65579	401.78	0.
2022-05-10 10:30:35	130.43791	7	2	6373.66	4076.1	26.98318	317.8	5	-0.07333	399.06	0.
2022-05-10 10:34:47	130.44082	7	3	6373.66	4076.1	26.55318	317.8	5	0.16197	399.41	0.
2022-05-10 10:38:59	130.44374	7	6	6373.66	4076.1	26.77591	317.8	5	-0.12608	406	0.
2022-05-10 10:43:11	130.44666	7	7	6373.66	4076.1	27.24591	317.8	5	-0.01022	407.82	0.
2022-05-10 10:47:23	130.44957	7	8	6373.66	4076.1	27.40409	317.8	5	-0.20822	406.89	0.
2022-05-10 11:01:11	130.45916	1	-9999	6108.76	4076.1	28.005	317.8	5	-0.13007	399.72	0.
2022-05-10 11:05:23	130.46207	2	-9999	6108.76	4076.1	29.62455	317.8	5	1.07653	423	0.
2022-05-10 11:09:35	130.46499	3	-9999	6108.76	4076.1	28.80091	317.8	5	0.16298	405.33	0.
2022-05-10 11:13:47	130.46791	4	-9999	6108.76	4076.1	29.94091	317.8	5	0.57156	402.2	0.
2022-05-10 11:17:59	130.47082	5	-9999	6108.76	4076.1	29.14091	317.8	5	0.11515	400.22	0.
2022-05-10 11:22:11	130.47374	6	-9999	6108.76	4076.1	30.31182	317.8	5	0.75112	403.12	0.
2022-05-10 11:26:23	130.47666	7	1	6373.66	4076.1	30.86591	317.8	5	0.85036	399.2	0.
2022-05-10 11:30:35	130.47957	7	2	6373.66	4076.1	29.38682	317.8	5	-0.06823	394.73	0.

Topics:

1. Control of gas transport across the soil surface
2. Theory of gas flux measurement across soil surface
3. Considerations for the closed-chamber method
4. Hardware: Smartchamber, LI-8250 system
5. Software:
   a. User interface (UI)
   b. Data processing software (SoilFluxPro) Demo
6. QA/QC
7. Other applications

1. QA/QC
   - Uncertainty of the measured flux
   - All the variables in the flux equation have reasonable values?
   - All gas concentrations have reasonable values?
   - chamber open/close properly? Use CO_2 as an indicator
   - Gas analyzer diagnostic?
   - Flow rate?
   - R^2, etc.
2. A word about *Flux_lin* vs. *Flux_exp*

N_2O Measurements

Measurement Range: 0 to 100 ppm

Response Time (T_{10}-T_{90}): $N_2O \leq 2$ seconds, 0 to 330 ppb

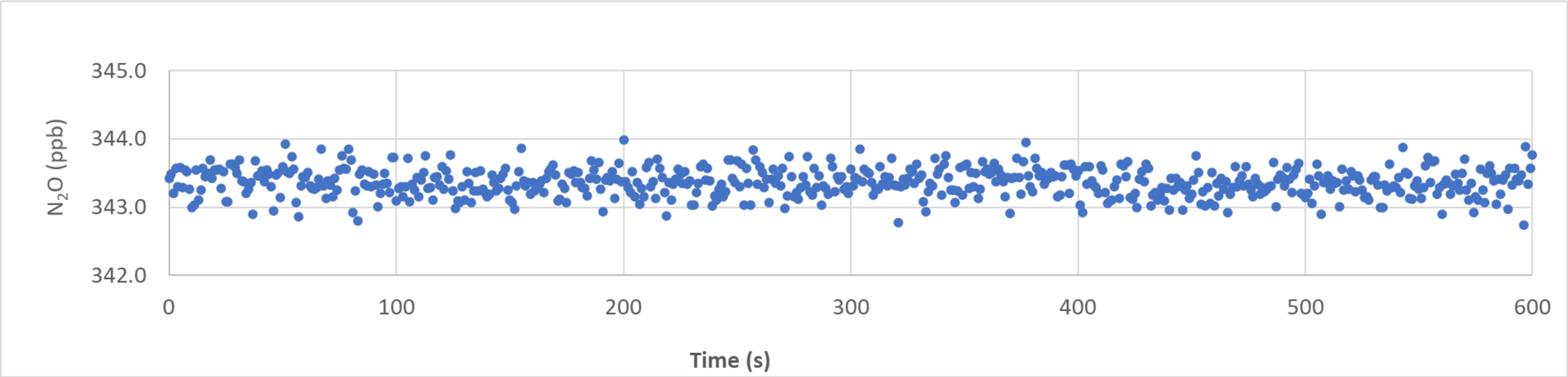
Precision (1σ):

0.40 ppb at 330 ppb with 1 second averaging

0.20 ppb at 330 ppb with 5 second averaging

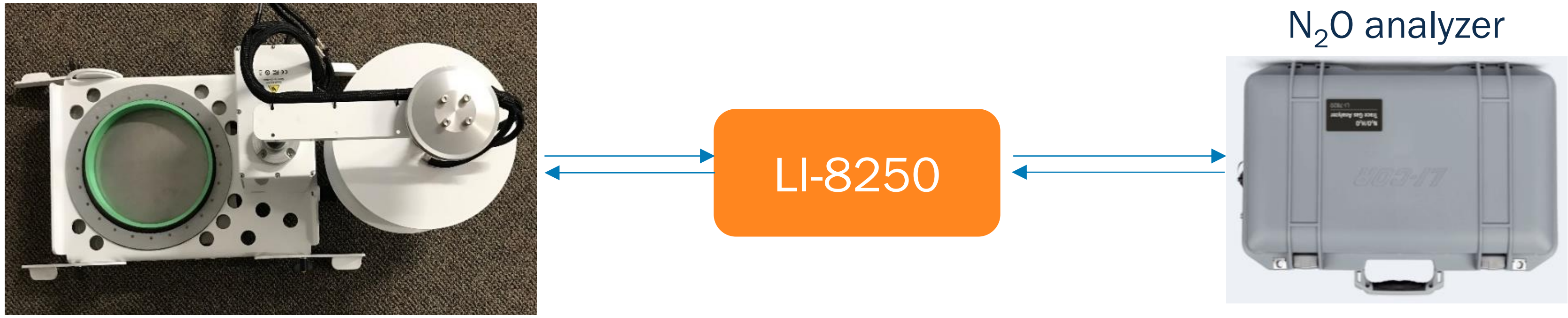
6: QA/QC

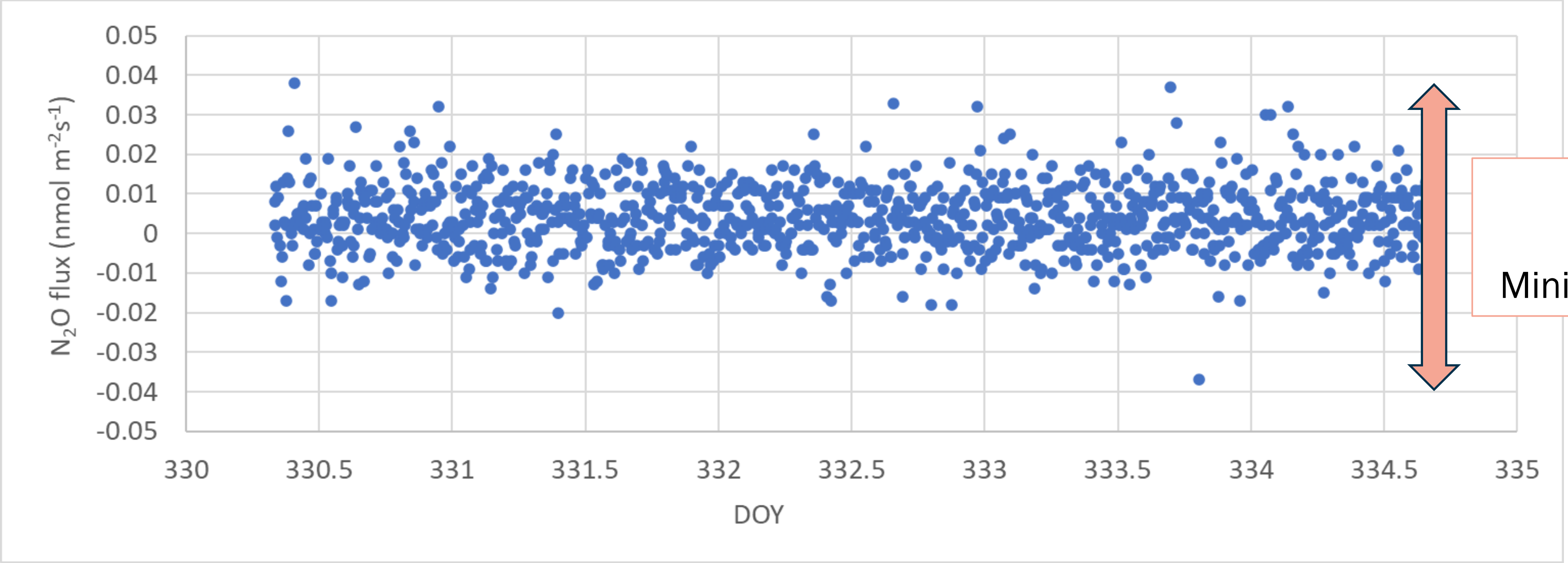
Precision, RMS, Standard Deviation $\sigma = \sqrt{\frac{\sum (x_i - \mu)^2}{N}}$



Precision = 0.25 ppb for this dataset

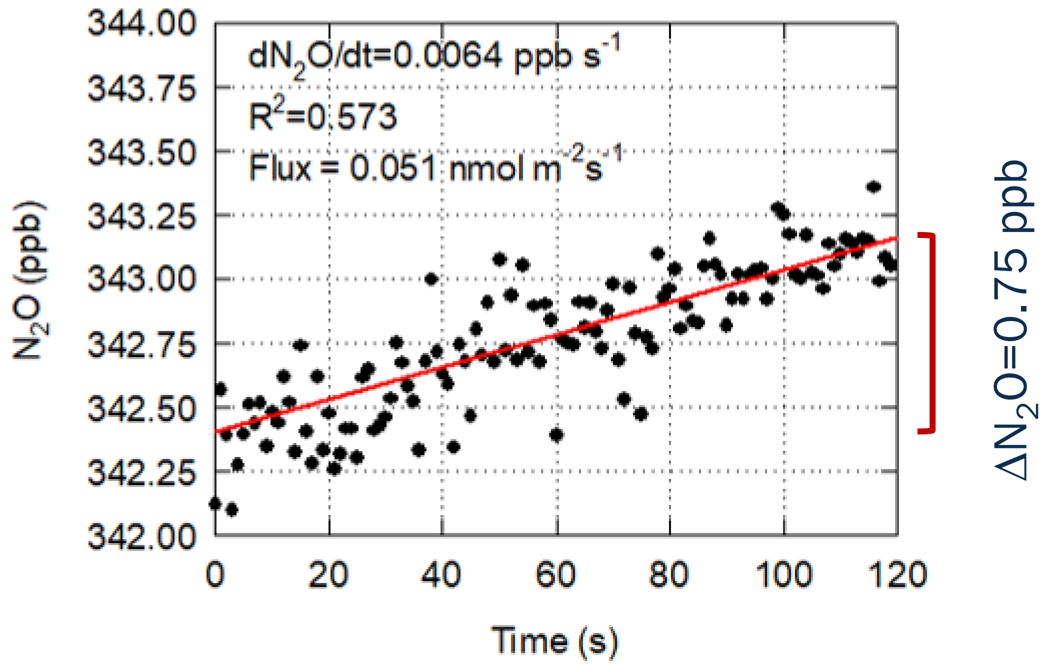
6: QA/QC





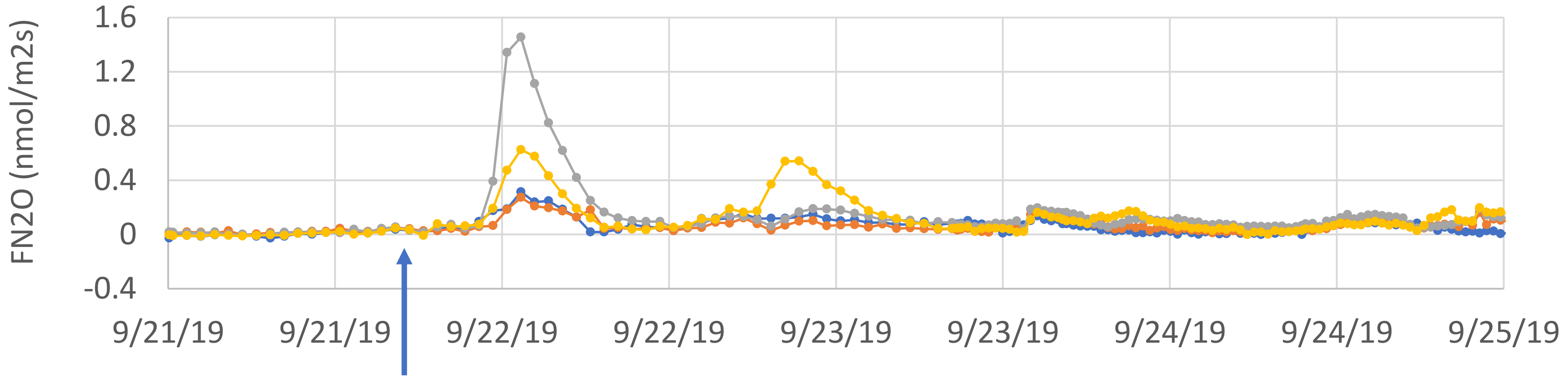
Uncertainty in Flux,
±0.03 nmol $m^{-2}s^{-1}$
Minimum Detectable Flux (MDF)

It is always a good idea to do a zero-flux test !!!

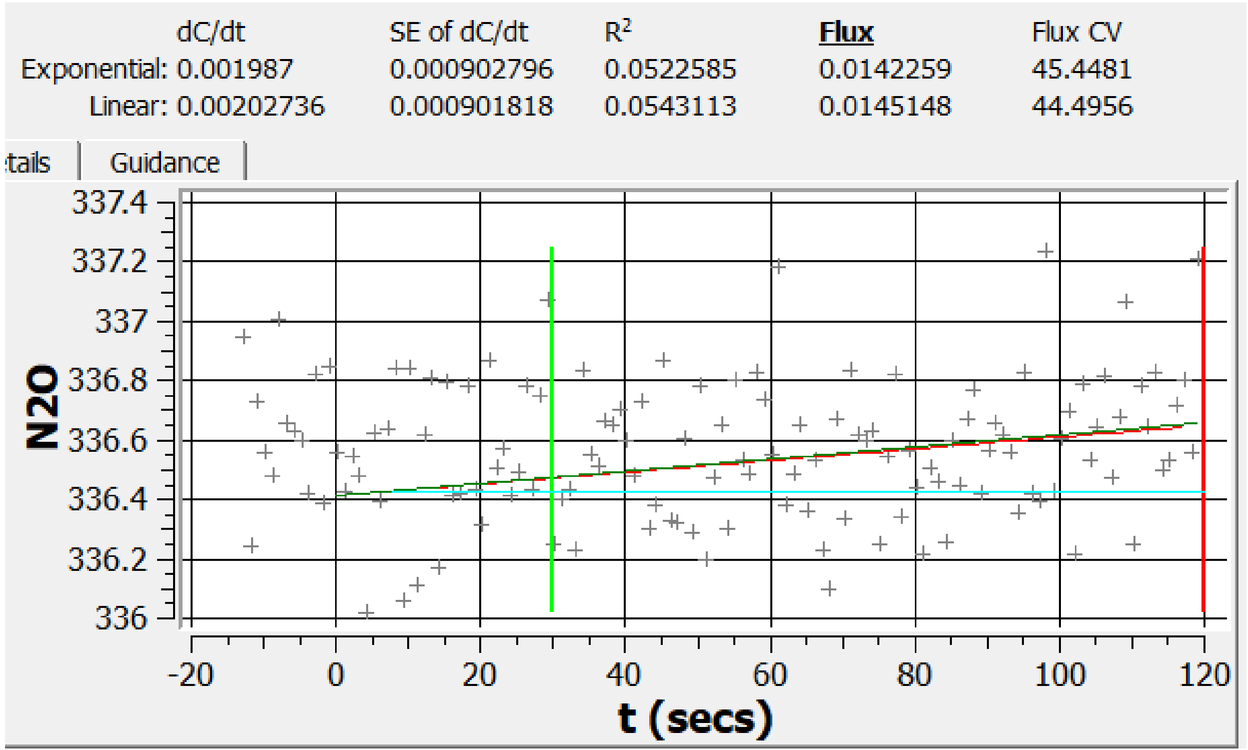


$$F_{N_2O} = \frac{VP}{RST}\frac{dN_2O}{dt}$$

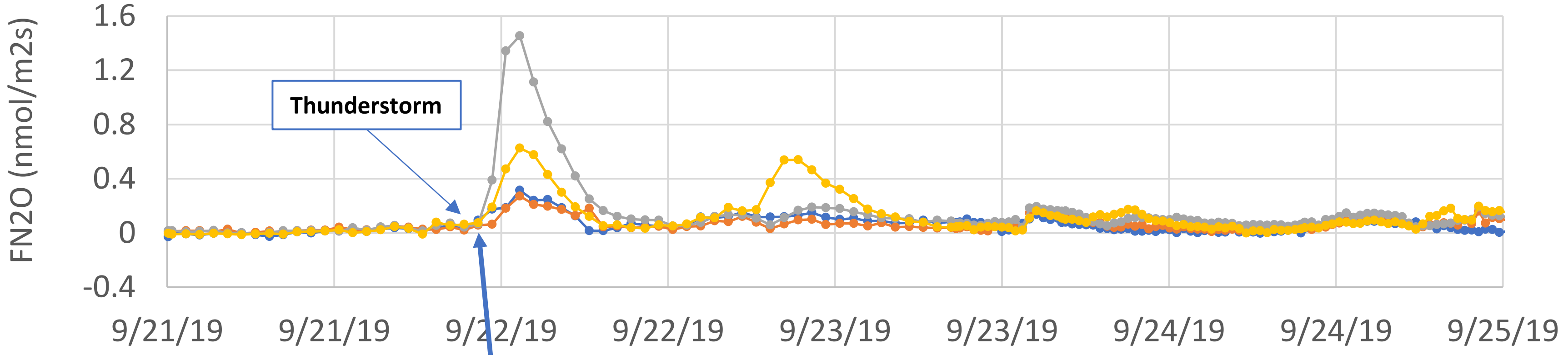
Minimum detectable flux (MDF) = 0.05 nmol m^{-2} s^{-1}



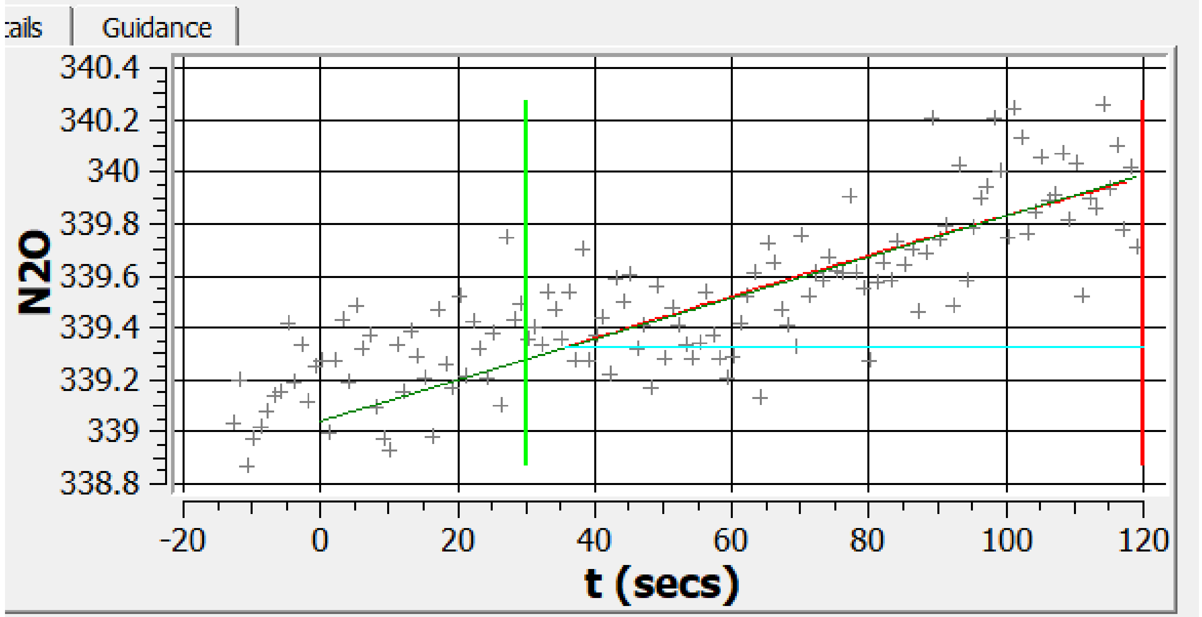
FN2O (nmol/m2s)
1.6
1.2
0.8
0.4
0
-0.4
9/21/19
9/21/19
9/22/19
9/22/19
9/23/19
9/23/19
9/24/19
9/24/19
9/25/19

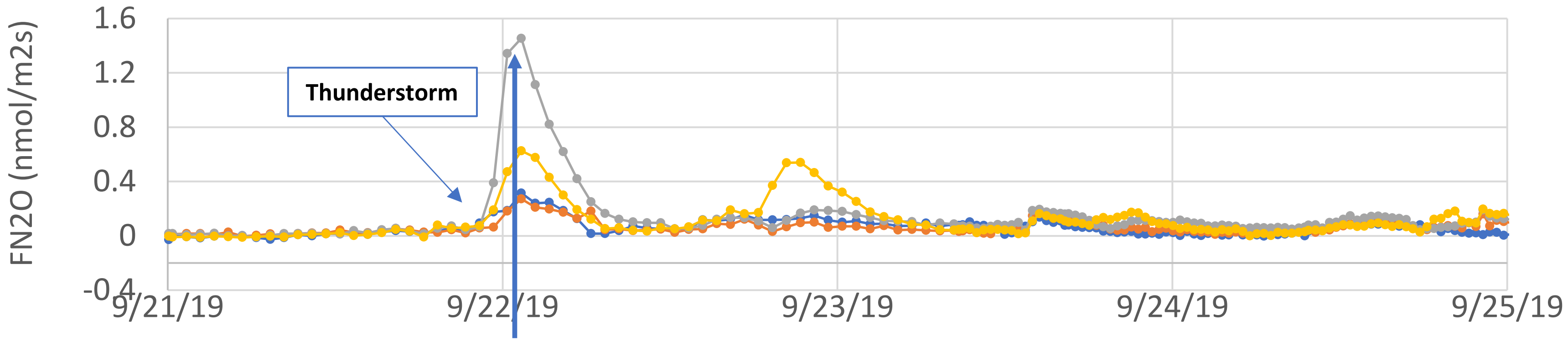


dC/dt
SE of dC/dt
R2
Flux
Flux CV
Exponential: 0.001987
0.000902796
0.0522585
0.0142259
45.4481
Linear: 0.00202736
0.000901818
0.0543113
0.0145148
44.4956
Guidance
N2O
337.4
337.2
337
336.8
336.6
336.4
336.2
336
-20
0
20
40
60
80
100
120
t (secs)

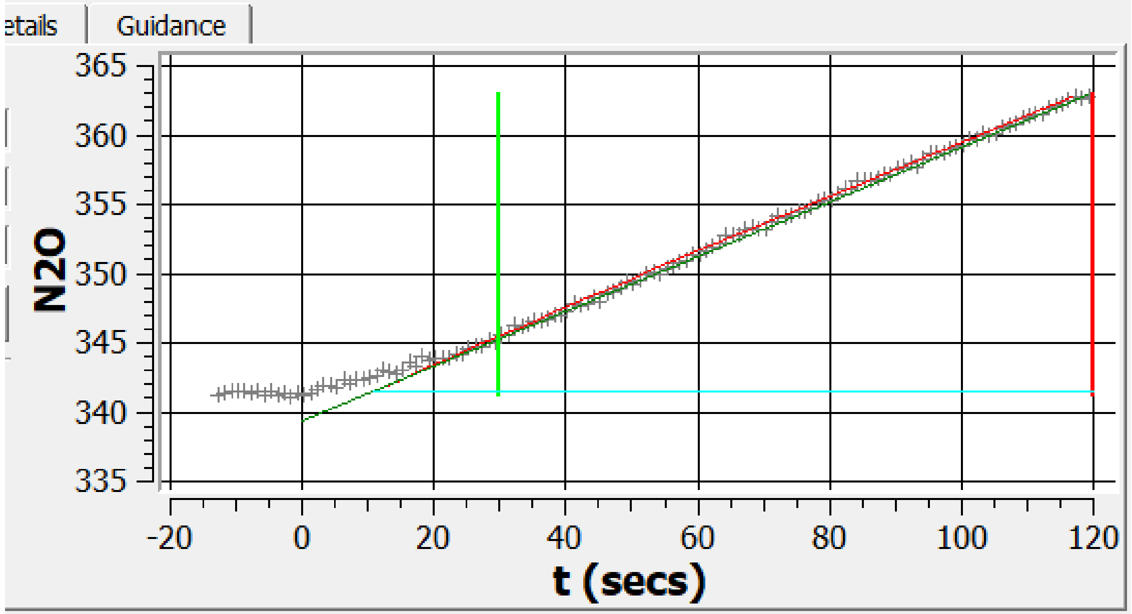


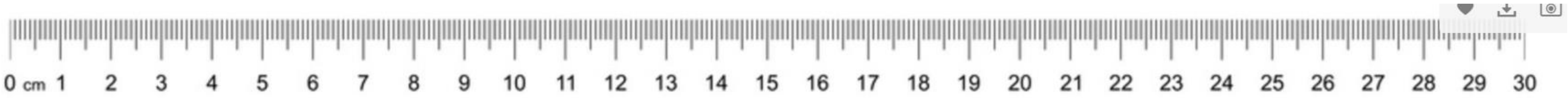
	dC/dt	SE of dC/dt	R^2	**Flux**	Flux CV
Exponential:	0.0083001	0.000736705	0.563307	0.0605698	8.94219
Linear:	0.00788035	0.000732905	0.567801	0.0575067	9.36374





	dC/dt	SE of dC/dt	R^2	**Flux**	Flux CV
Exponential:	0.212968	0.000736993	0.998779	1.56698	1.14211
Linear:	0.19772	0.000799228	0.998564	1.45479	1.16106




0 cm 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30

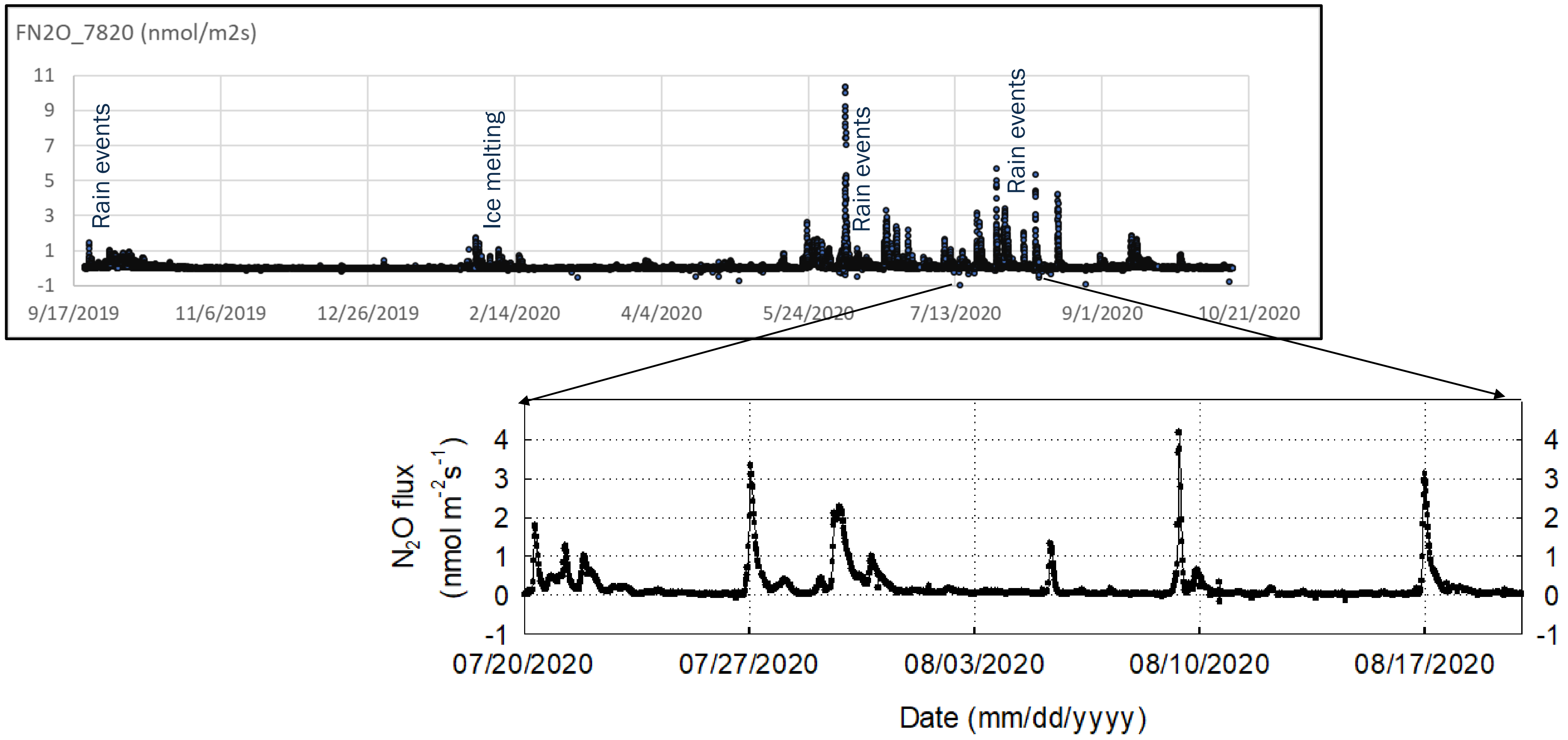

250
200
150
100
50
0

Key Points

- Small MDF can tell the small difference in flux between your field treatments
- Small MDF can give you fine temporal flux variations

Long-term soil chamber system (LI-8250)

Can give you fine temporal variation

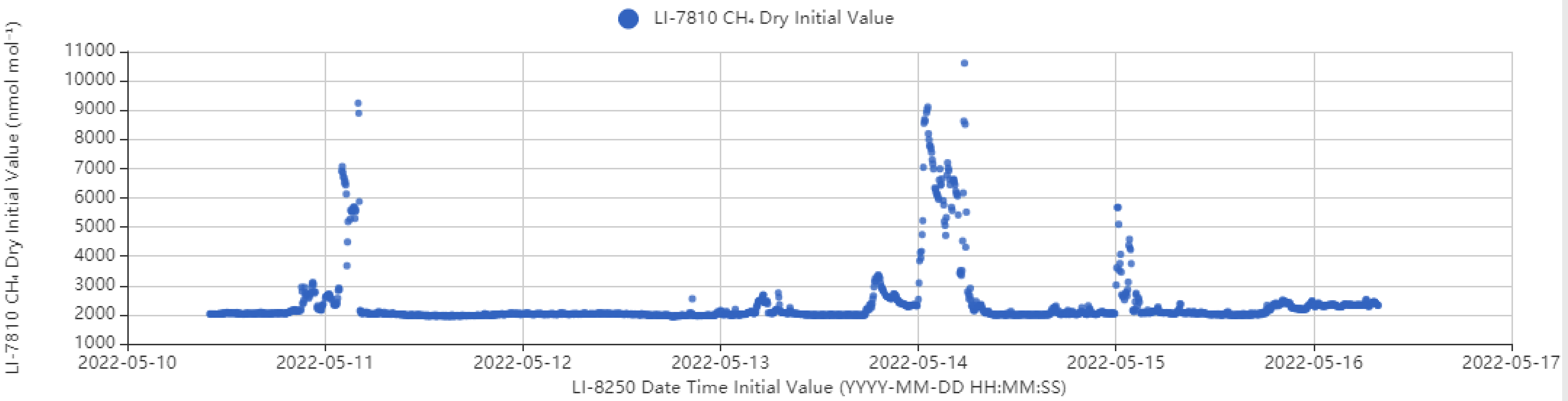


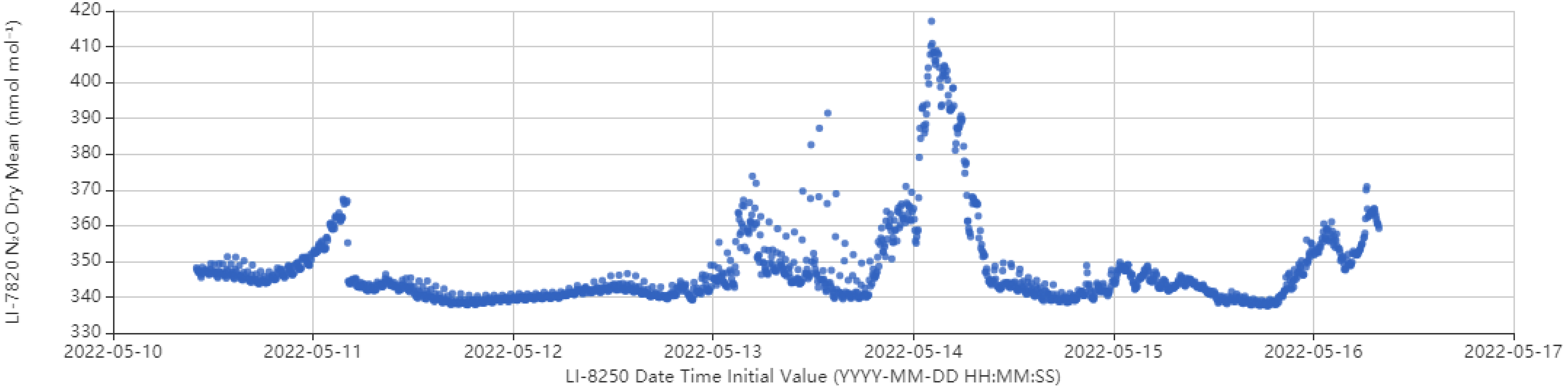
All variables in the flux equation have reasonable values?

$$F_{CO2} = \frac{VP_o(1-W_o)}{RS(T_o+273.15)}\frac{dC'}{dt}$$

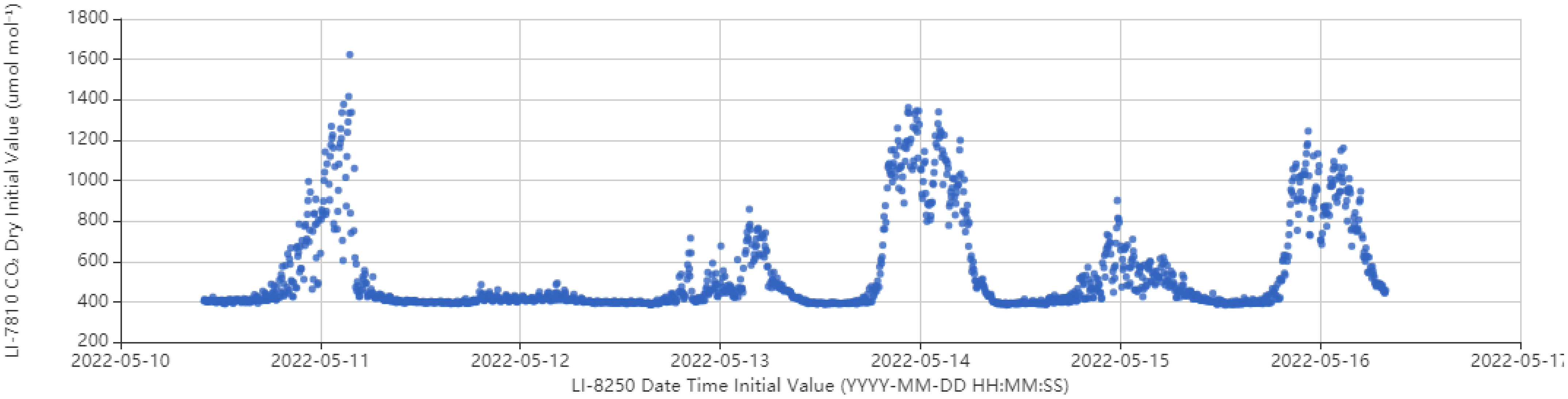
LI-8200 Date Time Initial Value YYYY-MM-DD HH:MM:SS	Total Volume cm^3	LI-8200 Pressure Initial Val kPa	LI-7820 H_2O Initial Value mmol mol^{-1}	CHAMBER Area cm^2	CHAMBER Temperature Initial V C	CHAMBER Collar Height cm	LI-7820 FN_2O Dry Lin dC/dt nmol mol^{-1} s^{-1}	LI-7820 FN_2O Dry Lin nmol m^{-2} s^{-1}	LI-7820 N_2O Dry Initial Value nmol mol^{-1}	LI-7820 FN_2O Dry Lin r^2
2021-06-23 11:21:57	5881.06	96.77	14.807	318	23.75705	5	0.03027	0.2162	352.569	0.87909
2021-06-23 11:27:12	5881.06	96.72	13.142	318	21.71712	5	0.02629	0.18933	352.16	0.84444
2021-06-23 11:32:28	5881.06	96.77	12.162	318	20.97371	5	0.02936	0.21224	351.955	0.85424
2021-06-23 11:37:44	5881.06	96.75	11.768	318	20.61039	5	0.02835	0.20528	351.892	0.8672
2021-06-23 11:43:00	5881.06	96.76	11.382	318	20.07271	5	0.02814	0.20423	351.437	0.86598
2021-06-23 11:48:16	5881.06	96.72	13.735	318	20.6672	5	0.02896	0.20914	351.808	0.83787
2021-06-23 11:53:32	5881.06	96.77	14.911	318	21.3171	5	0.02524	0.18177	352.306	0.84962
2021-06-23 11:58:47	5881.06	96.71	14.826	318	21.9506	5	0.02363	0.16968	352.869	0.75045
2021-06-23 12:04:03	5881.06	96.76	14.583	318	22.28158	5	0.02136	0.15334	353.139	0.75092
2021-06-23 12:09:19	5881.06	96.72	14.446	318	22.50053	5	0.02408	0.17273	353.042	0.83223
2021-06-23 12:14:36	5881.06	96.76	15.256	318	22.3933	5	0.0262	0.18787	352.257	0.854

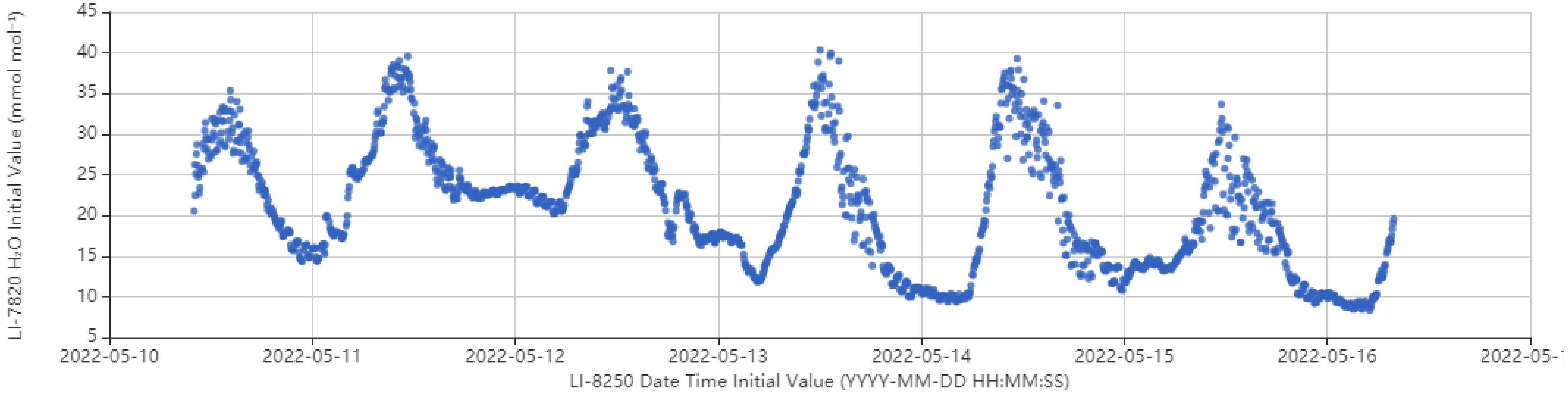
All gas concentrations have reasonable values?





All gas concentrations have reasonable values?





6: QA/QC

1. QA/QC: Gas analyzer diagnostic (LI-8250, LI-7810, LI-7820, LI-870)

LI-8250 Date Time Initial Value YYYY-MM-DD HH:MM:SS	LI-8250 Port	LI-7810 Diagnostic Ir	LI-7820 Diagnostic Initial	LI-870 Cell Temperature C	LI-870 Cell Pressure Ini kPa	LI-8250 Temperature Initi C	LI-8250 Pressure Initial Value kPa	LI-8250 Flow Initial Value L M^{-1}
2022-05-10 10:01:11	1	0	0	51.31	96.54	36.36044	97.23	2.93
2022-05-10 10:05:23	2	0	0	51.3	96.53	37.79581	97.21	2.89
2022-05-10 10:09:35	3	0	0	51.31	96.53	38.55114	97.23	2.89
2022-05-10 10:13:47	4	0	0	51.31	96.53	38.63707	97.23	2.92
2022-05-10 10:17:59	5	0	0	51.31	96.52	39.59588	97.22	2.81
2022-05-10 10:22:11	6	0	0	51.31	96.52	40.4691	97.23	2.89
2022-05-10 10:26:23	7	0	0	51.31	96.52	40.913	97.25	3.44
2022-05-10 10:30:35	7	0	0	51.31	96.52	41.44886	97.27	3.47
2022-05-10 10:34:47	7	0	0	51.31	96.52	41.35369	97.27	3.43
2022-05-10 10:38:59	7	0	0	51.31	96.52	41.62819	97.28	3.39
2022-05-10 10:43:11	7	0	0	51.31	96.52	41.92472	97.29	3.37
2022-05-10 10:47:23	7	0	0	51.31	96.52	41.98651	97.28	3.35
2022-05-10 11:01:11	1	0	0	51.3	96.52	42.53622	97.29	2.95
2022-05-10 11:05:23	2	0	0	51.31	96.52	42.55079	97.3	2.92
2022-05-10 11:09:35	3	0	0	51.31	96.53	42.6907	97.29	2.91

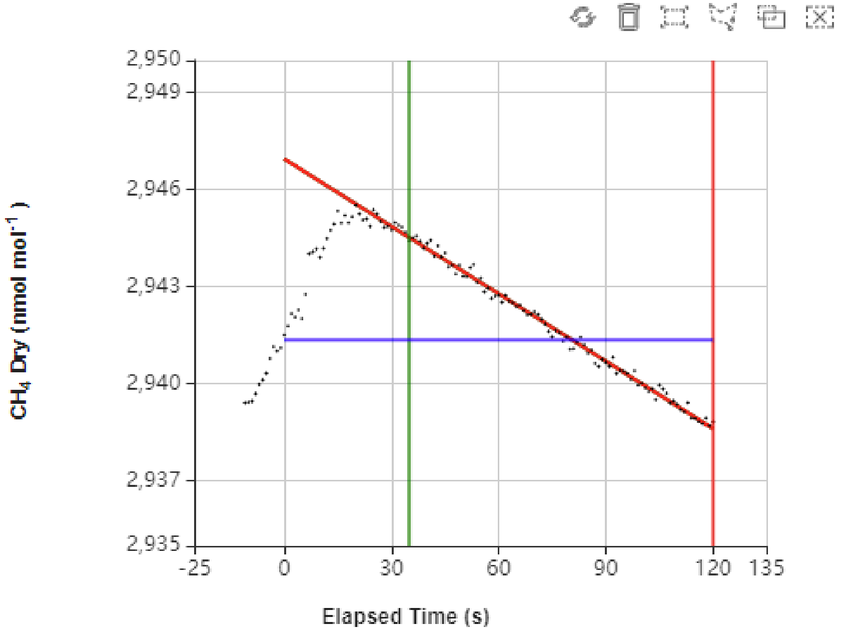
6: QA/QC

Chamber open/close properly?

When CH_4 flux is not small, the time series of CH_4 can be the evidence.

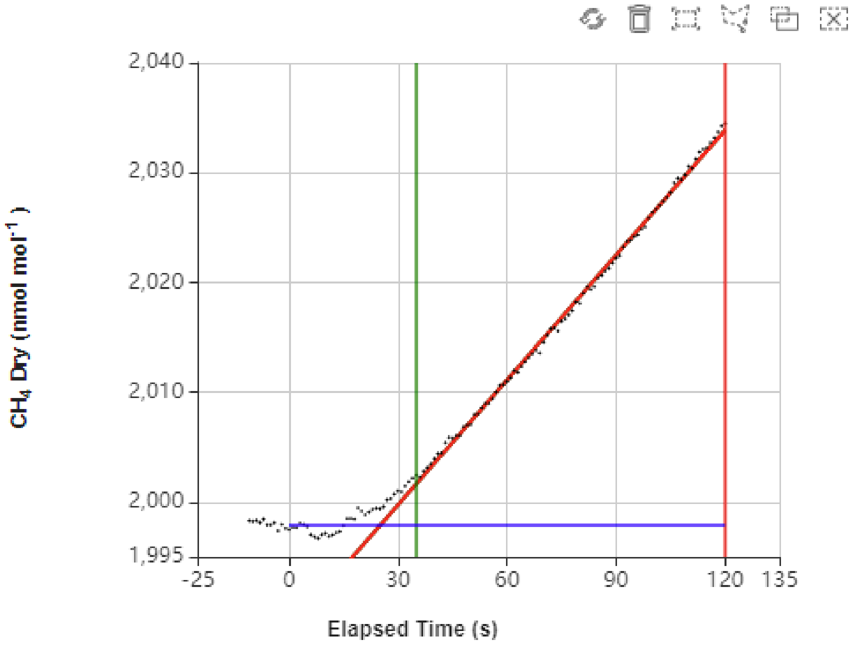
C_o	C_x	a	t_o
2941.36082	0	0.00002	0

	dC/dt	SE of dC/dt	r^2	Flux	Flux CV
Exponential	-0.06942	0.00071	0.99135	-0.55359	1.49075
Linear	-0.06942	0.00071	0.99135	-0.55359	1.49075



C_o	C_x	a	t_o
1997.89082	1000000	0	0

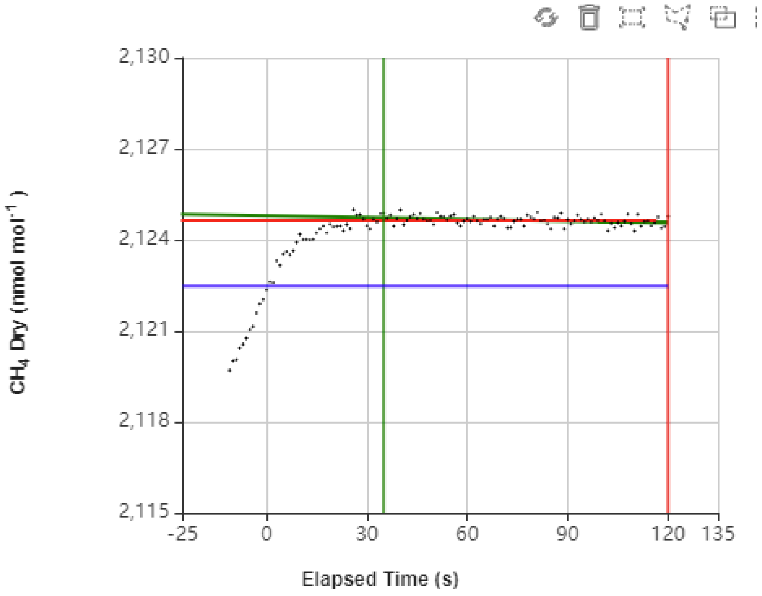
	dC/dt	SE of dC/dt	r^2	Flux	Flux CV
Exponential	0.37926	0.00169	0.99834	2.65363	1.17662
Linear	0.37926	0.00169	0.99834	2.65363	1.17662



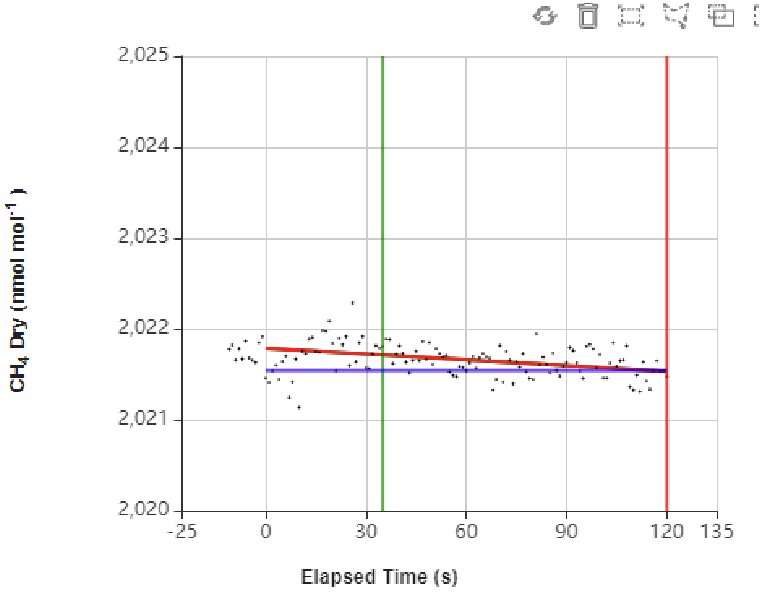
6: QA/QC

When CH4 flux is around zero, use CO_2 as an indicator to see whether the chamber is closed properly or not

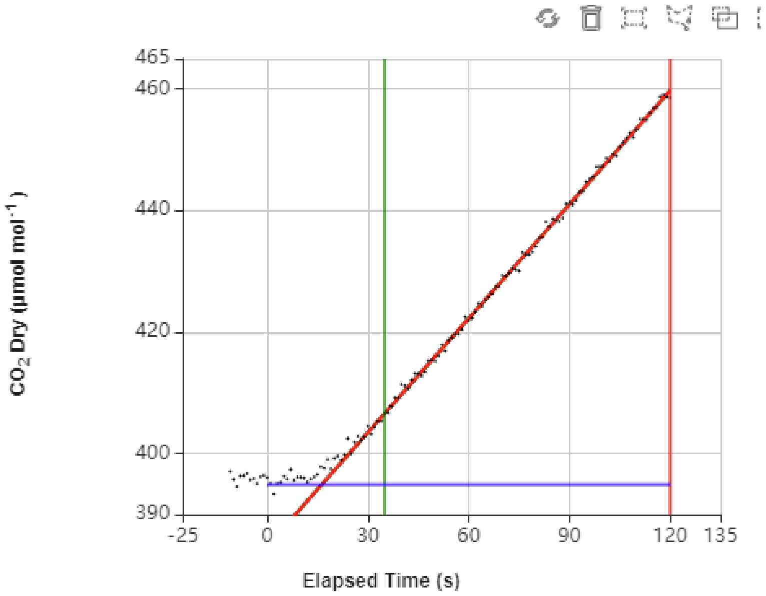
	dC/dt	SE of dC/dt	r^2	Flux	Flux CV
Exponential	-0.00192	0.00063	0.10015	-0.01501	32.72311
Linear	-0.00192	0.00063	0.10015	-0.01501	32.72311



	dC/dt	SE of dC/dt	r^2	Flux	Flux CV
Exponential	-0.00211	0.00059	0.1323	-0.01584	27.96384
Linear	-0.00211	0.00059	0.1323	-0.01584	27.96384

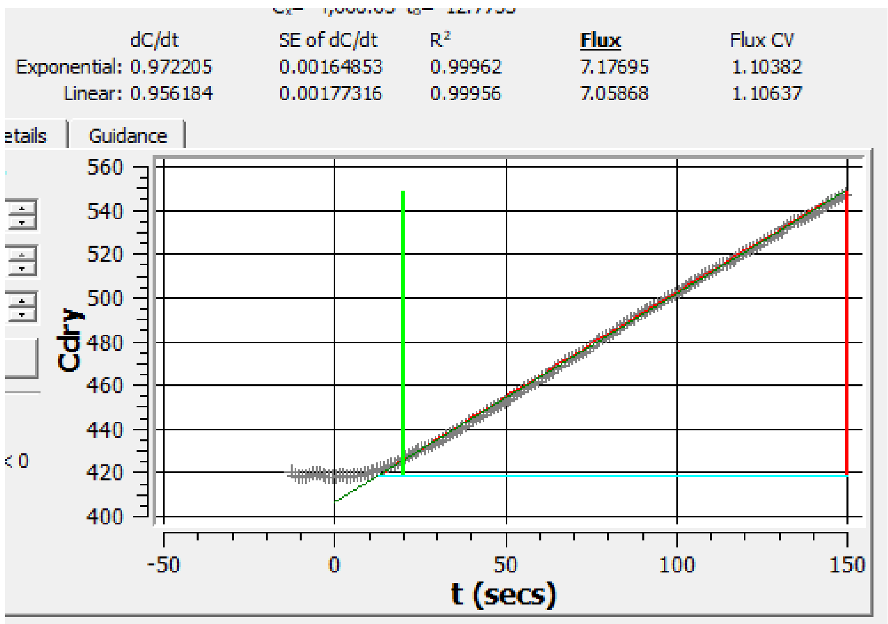


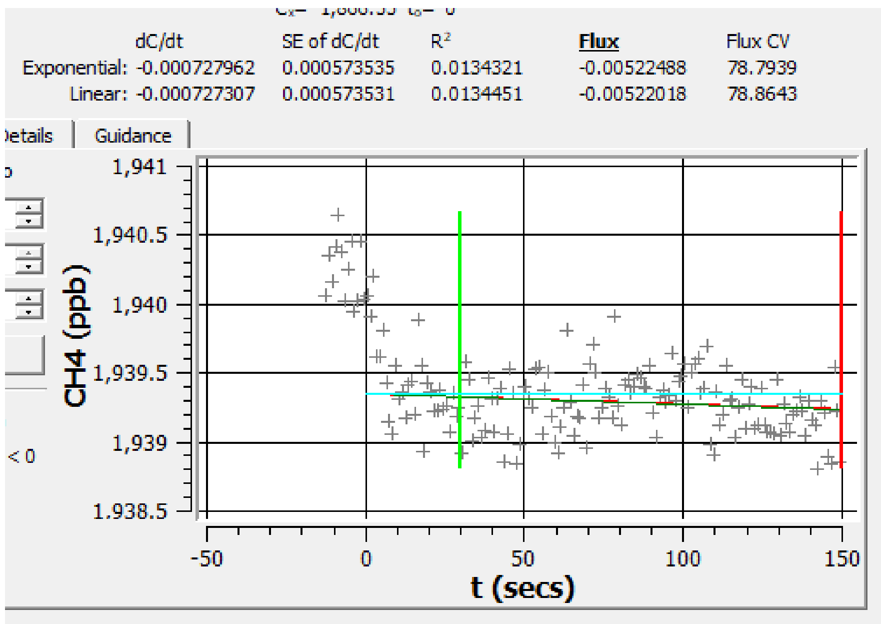
	dC/dt	SE of dC/dt	r^2	Flux	Flux CV
Exponential	0.62521	0.00276	0.99836	4.68388	1.1732
Linear	0.62521	0.00276	0.99836	4.68388	1.1732

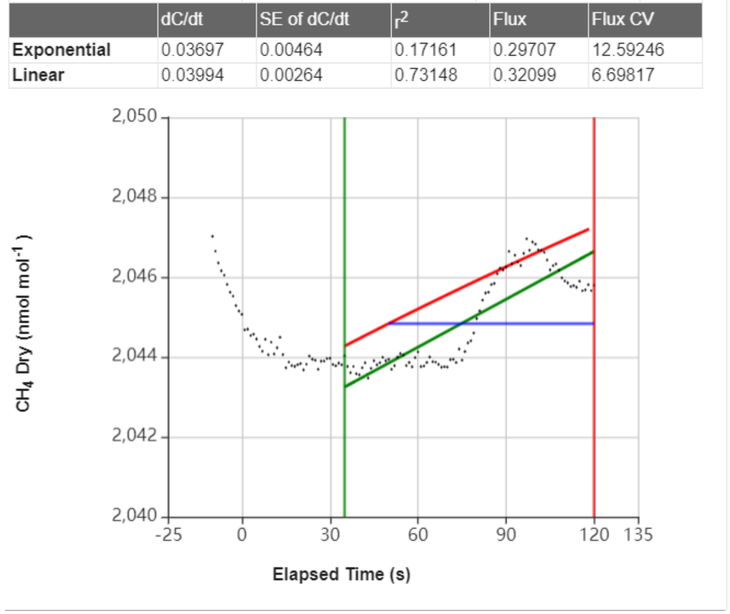


6: QA/QC

R^2? This depends on the magnitude of the flux!



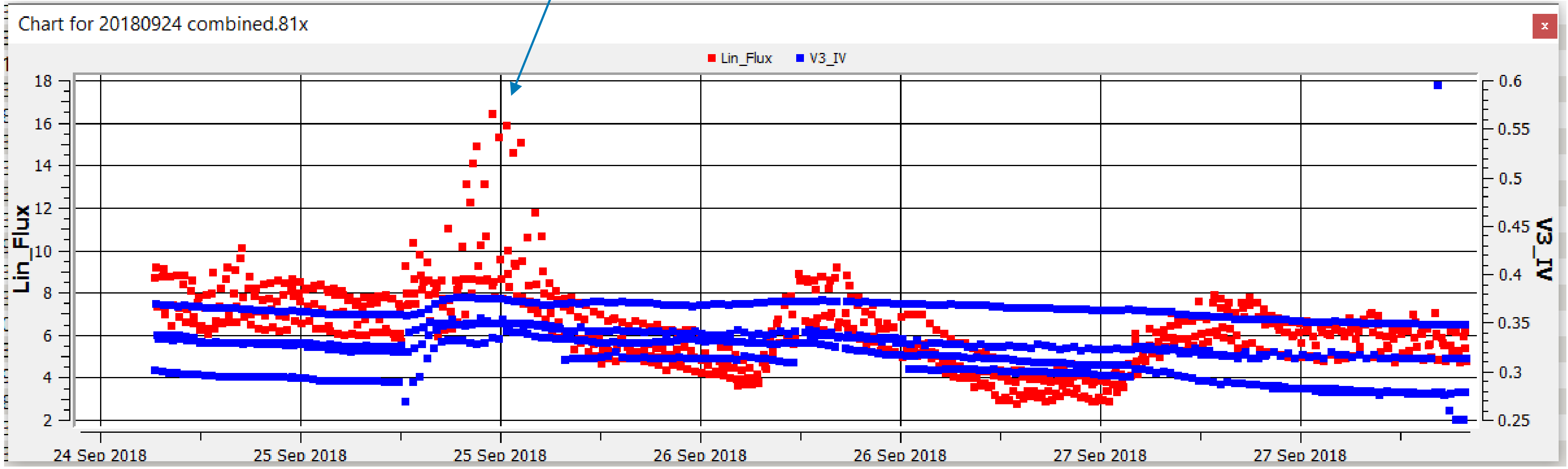




6: QA/QC

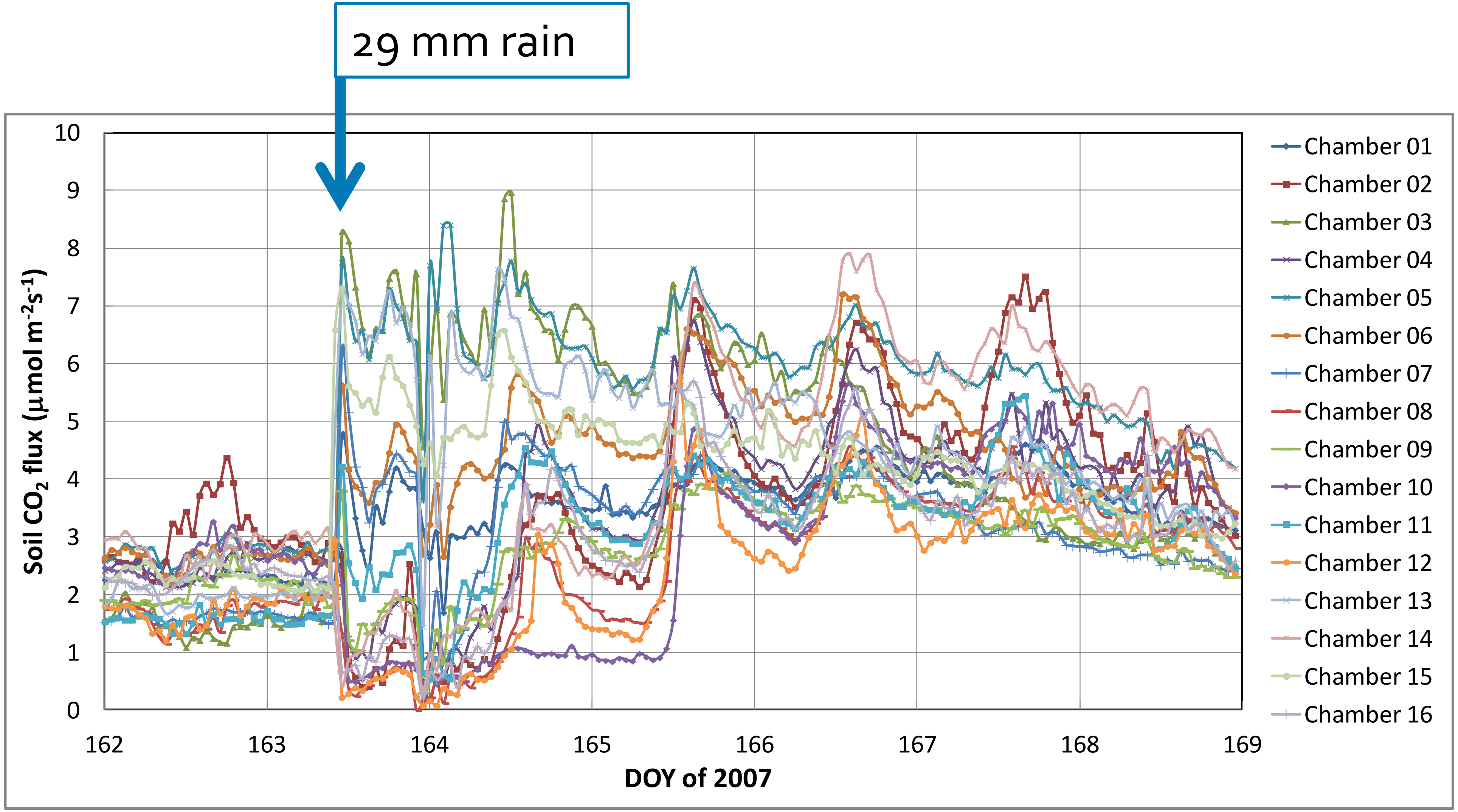
Bad outliers or good outliers?

Probably good outliers, because of rain



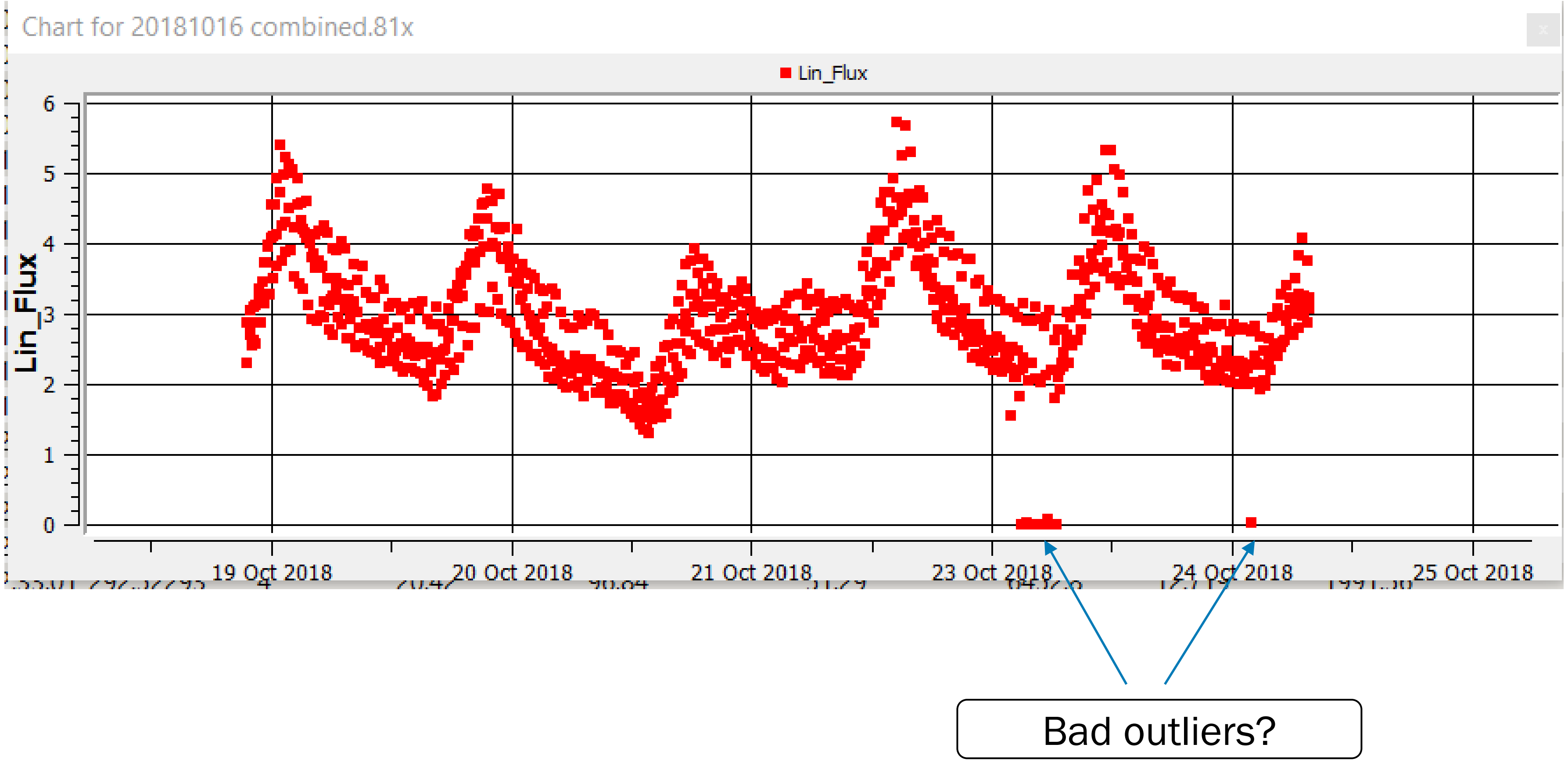
6: QA/QC

1. QA/QC: bad outliers or good outliers?



6: QA/QC

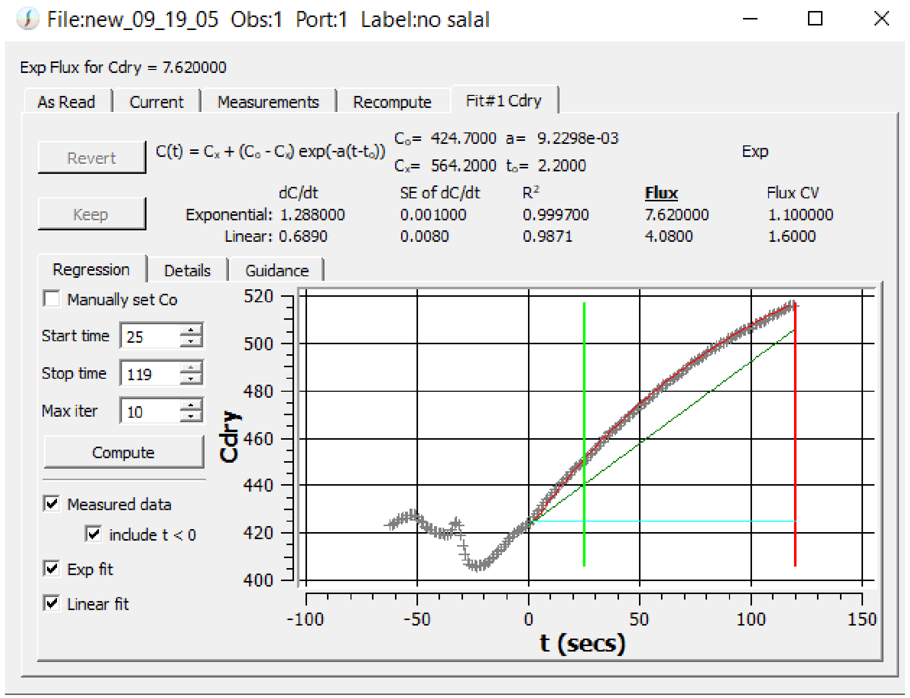
Bad outliers?



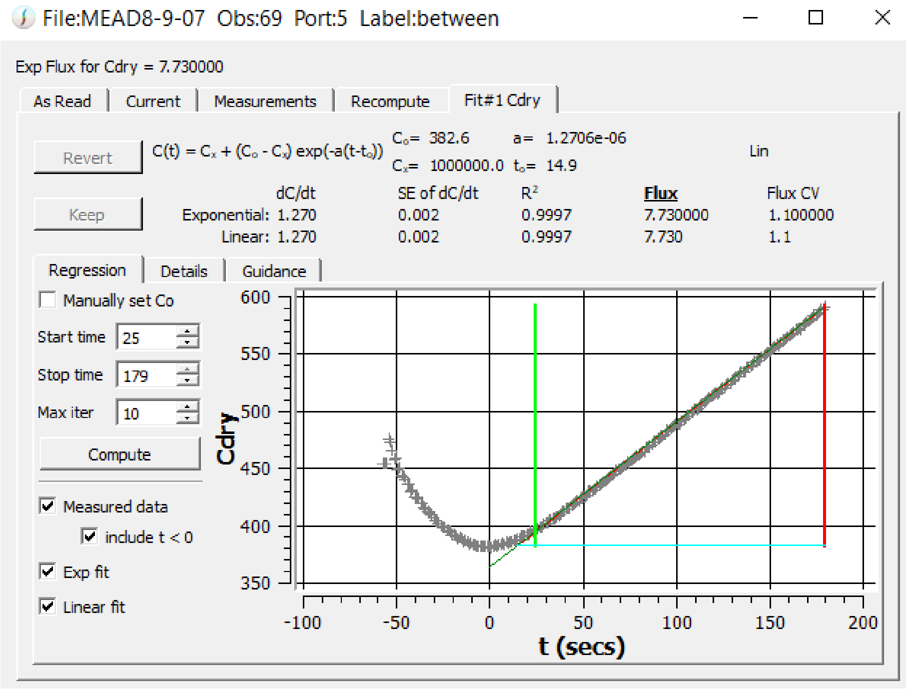
6: QA/QC

A word about *Flux_lin* vs. *Flux_exp*

Forest light soil



Heavy clay soil

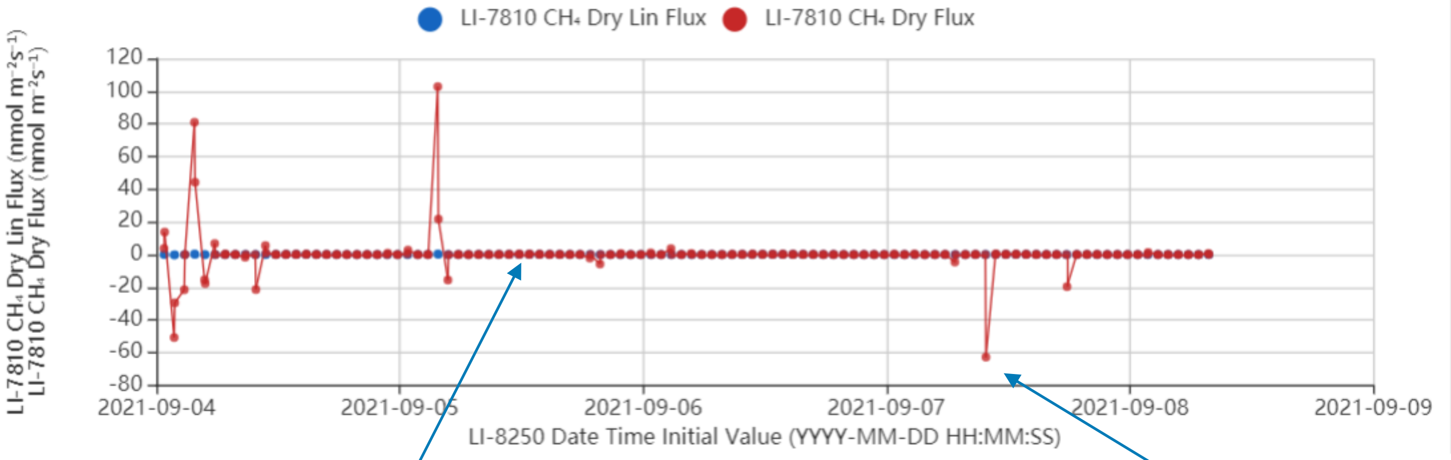


$$C'(t) = C_x' + (C_0' - C_x')e^{-a(t-t_0)}$$

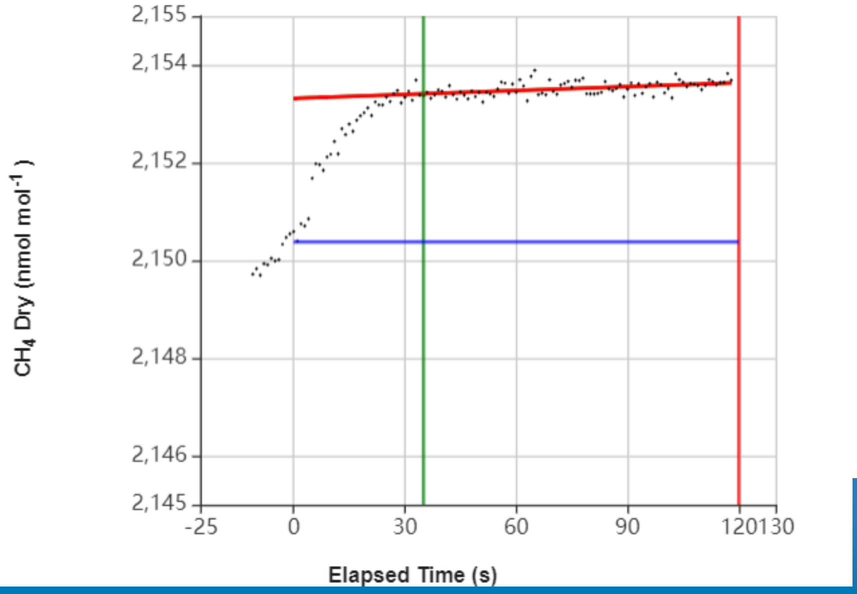
$$a = \frac{S \cdot g}{V}$$

A word about *Flux_lin* vs. *Flux_exp*

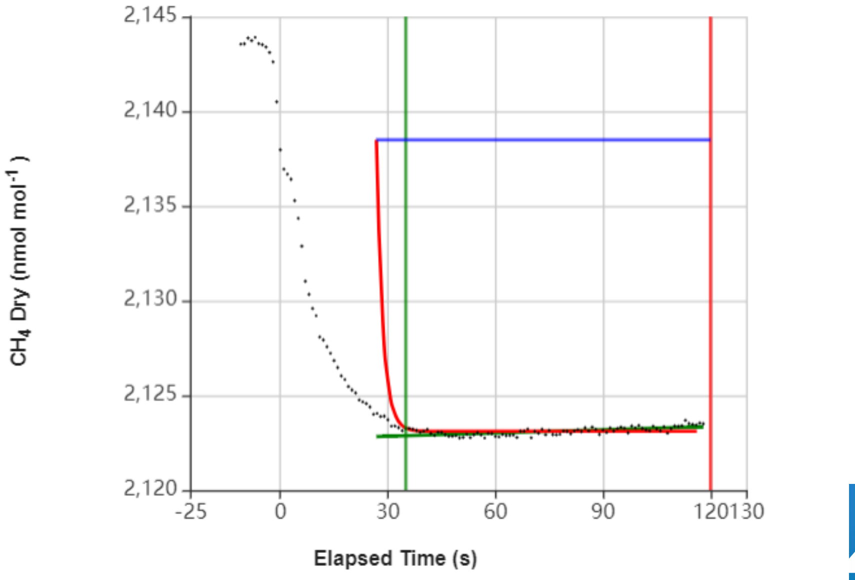
2. A word about *Flux_lin vs. Flux_exp*



	dC/dt	SE of dC/dt	r^2	Flux	Flux CV
Exponential	0.00266	0.00057	0.21278	0.0212	21.26887
Linear	0.00266	0.00057	0.21278	0.0212	21.26887



	dC/dt	SE of dC/dt	r^2	Flux	Flux CV
Exponential	-8.41317	0.00095	0.01143	-62.71444	1.0854
Linear	0.00573	0.00072	0.43508	0.04269	12.6303



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Data Analysis

A word about Flux_*lin* vs. Flux_*exp*

When the flux is small, Lin flux is always better.

F_{CO2}<0.5 μmol $m^{-2}s^{-1}$

F_{CH4}<0.2 nmol $m^{-2}s^{-1}$

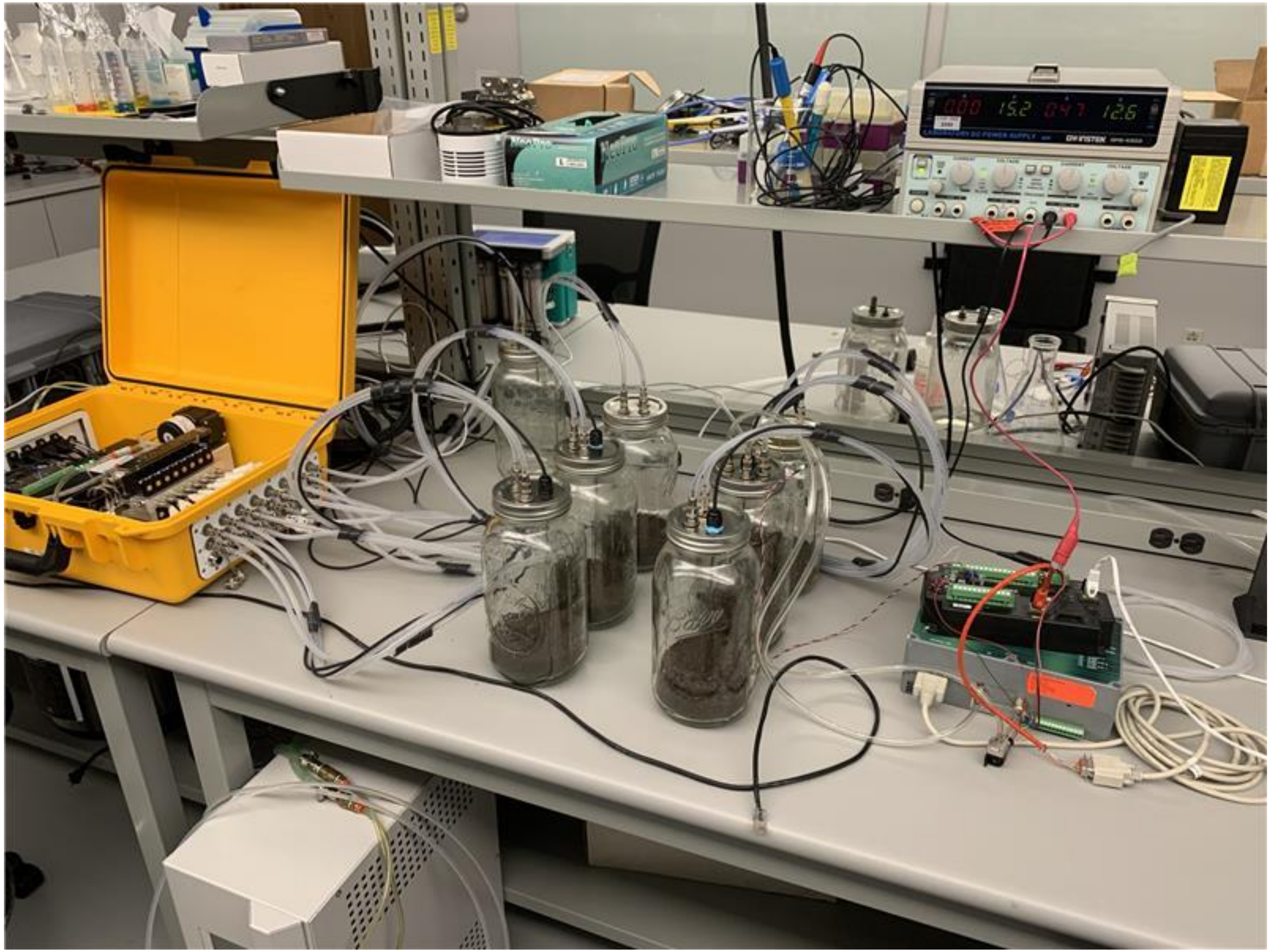
F_{N2O}<0.2 nmol $m^{-2}s^{-1}$

Take a look at the time series first before making the judgement

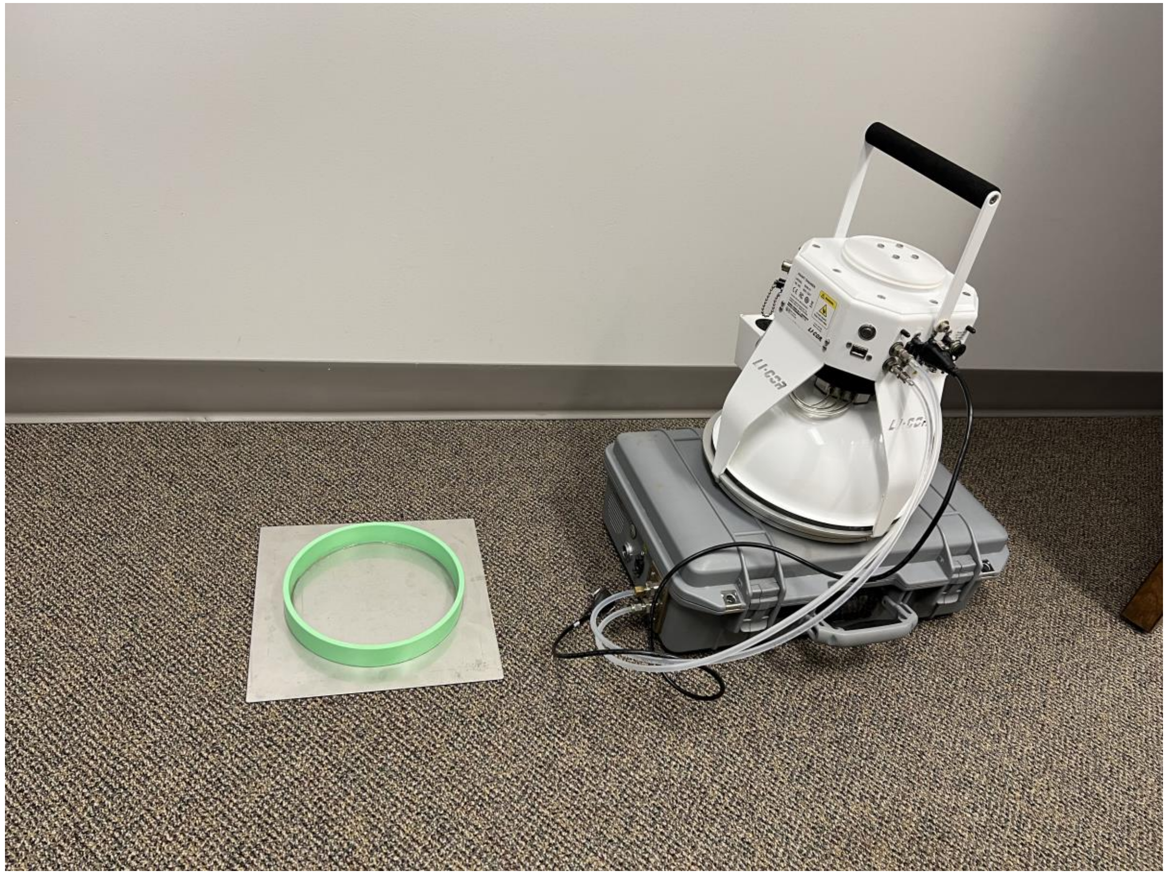
Topics:

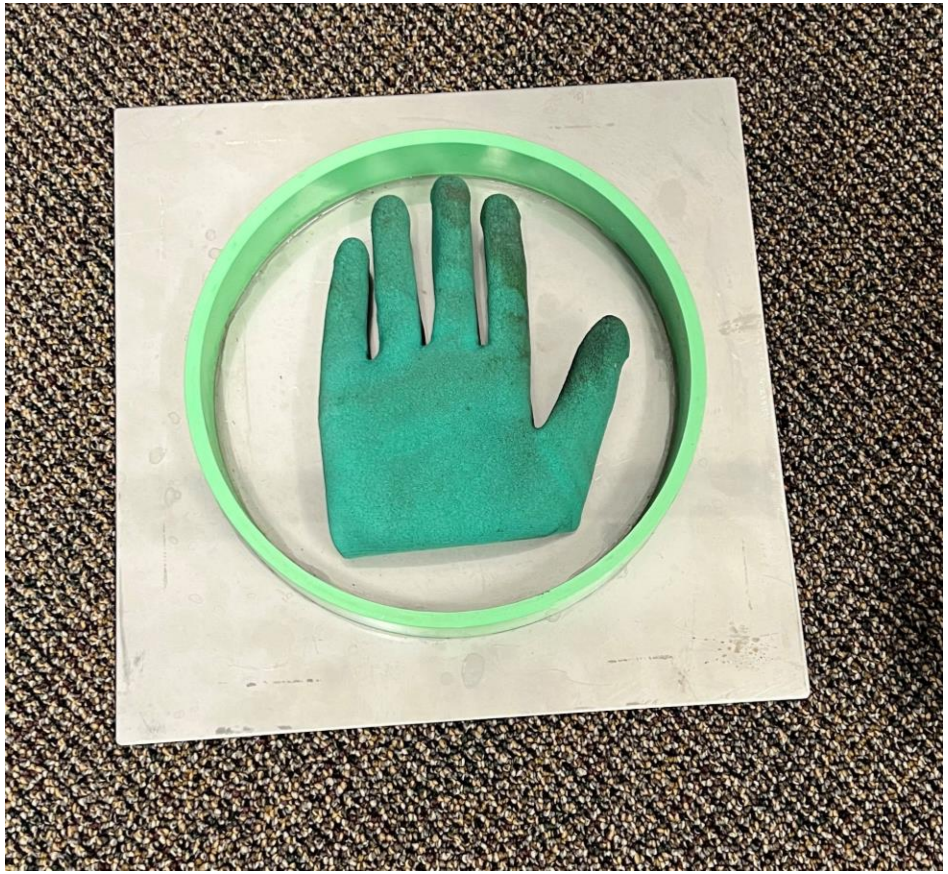
1. Control of gas transport across the soil surface
2. Theory of gas flux measurement across soil surface
3. Considerations for the closed-chamber method
4. Hardware: Smartchamber, LI-8250 system
5. Software:
    a. User interface (UI)
    b. Data processing software (SoilFluxPro) Demo
6. QA/QC
7. Other applications

Flask Sampling



Study the decomposition of any material





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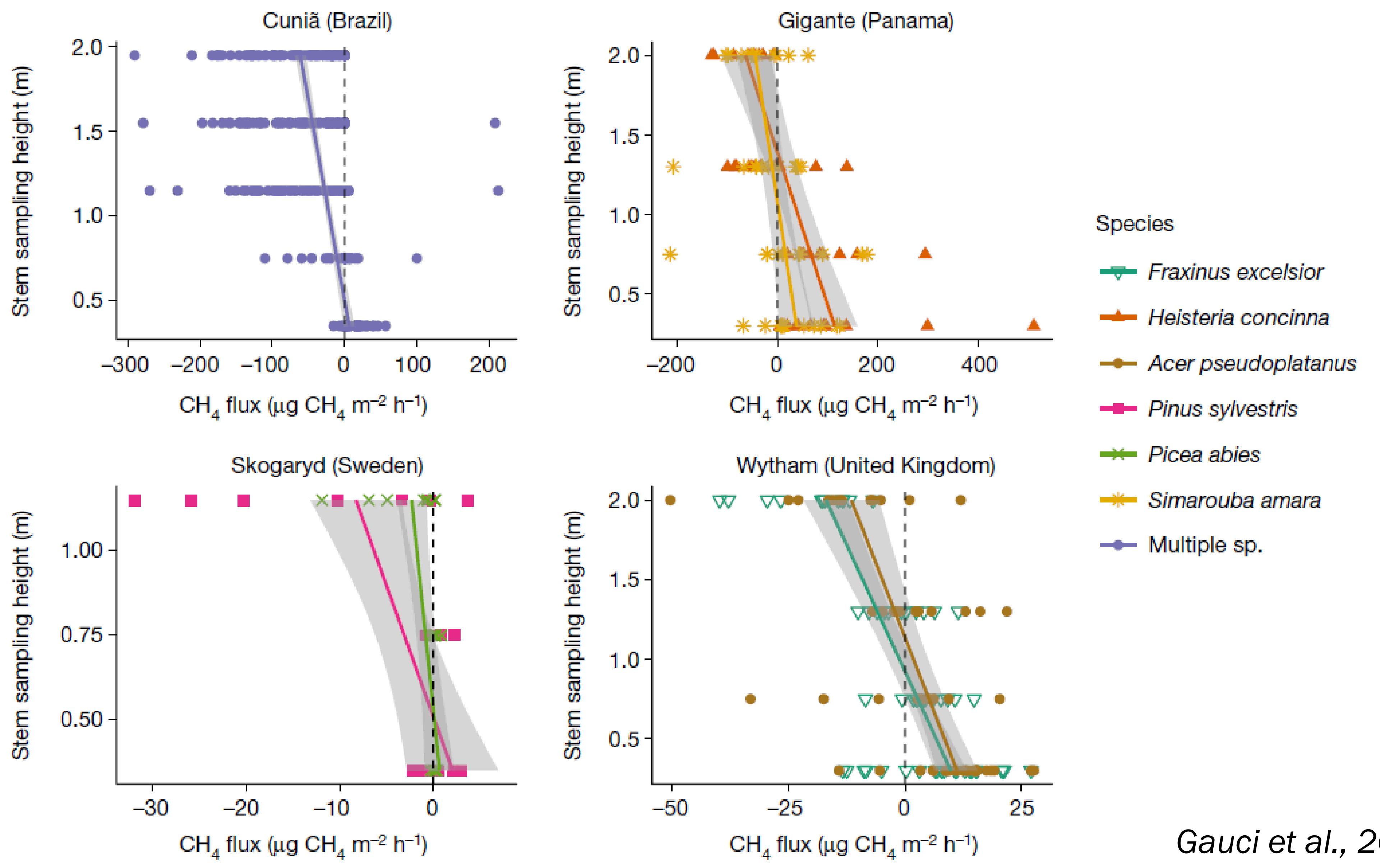
GHG flux over wastewater surface

5. Other applications

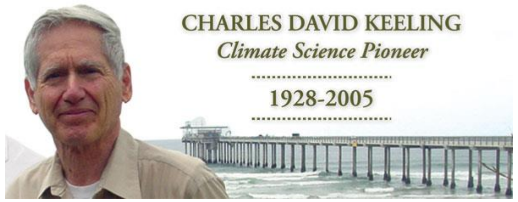
GHG flux over water surface

Tree stem GHG flux measurement



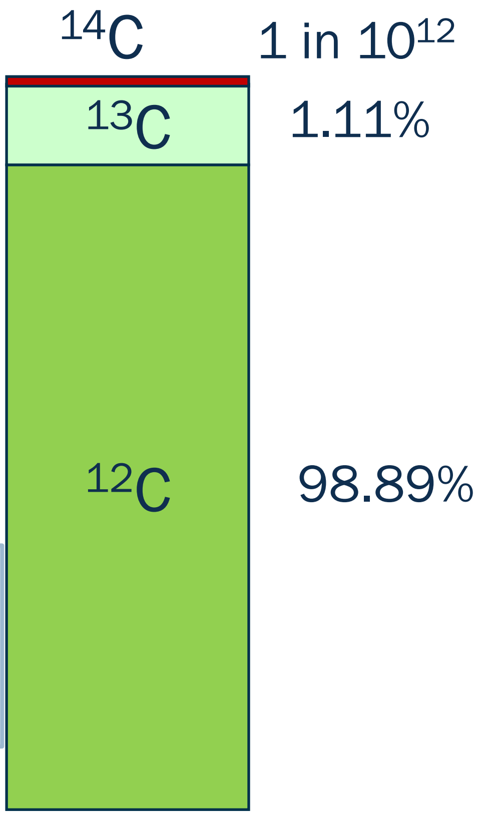
Gauci et al., 2024 Nature.

The closed chamber method can be used to estimate the $\delta^{13}C$ of any source with keeling plot.



Carbon Isotopes

Isotope	Protons	Electron	Neutrons
^{12}C	6	6	6
^{13}C	6	6	7
^{14}C	6	6	8



- ^{12}C and ^{13}C are stable isotopes
- ^{14}C is radioactive with half life of 5730 years

Definition of $\delta^{13}C$

$$\delta\ {}^{13}C = \left(\frac{\left(\frac{{}^{13}C}{{}^{12}C}\right)_{sample}}{\left(\frac{{}^{13}C}{{}^{12}C}\right)_{standard}} - 1 \right) * 1000\ ‰$$

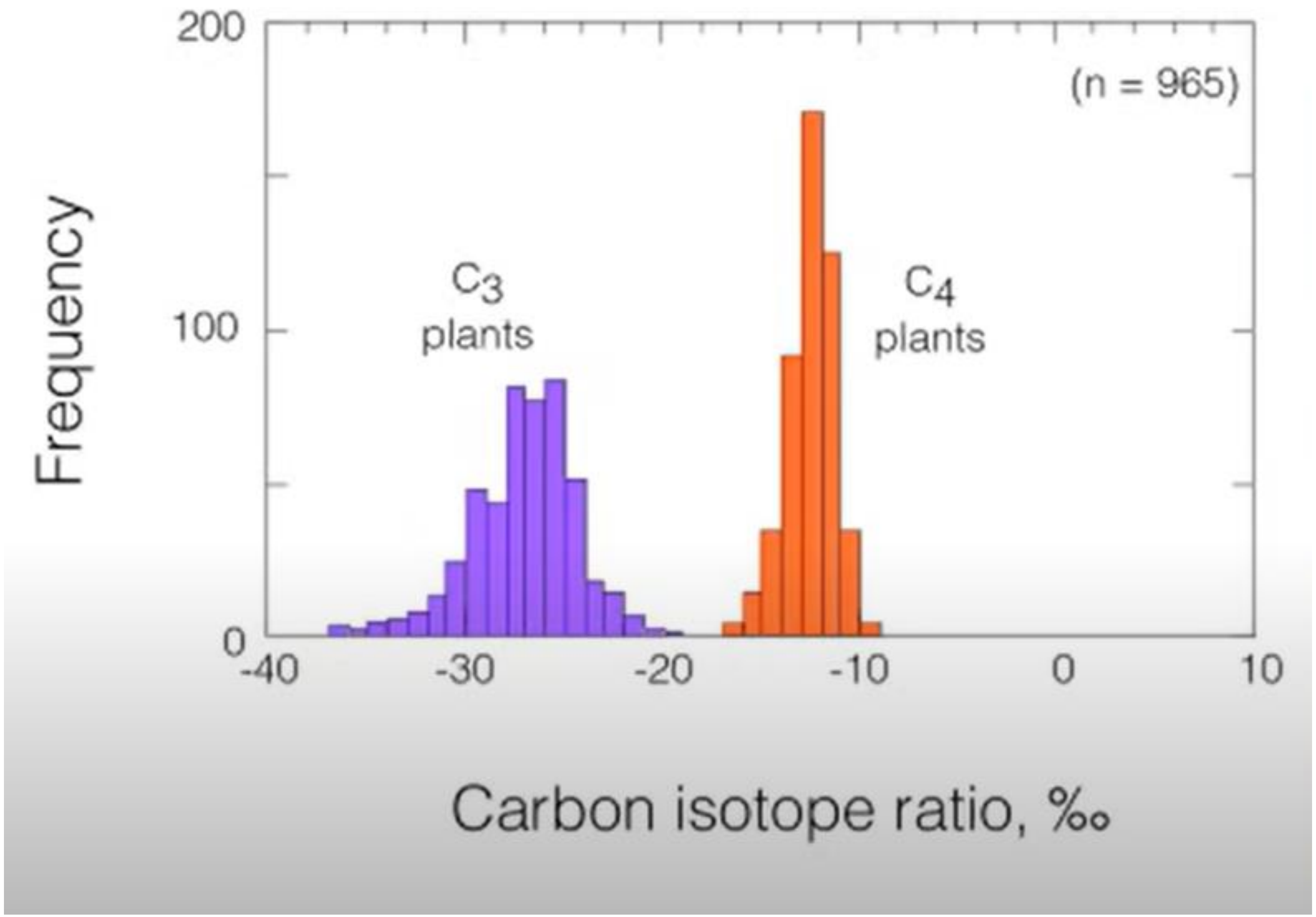
VPDB Standard; Vienna Pee Dee Belemnite standard $^{13}C/^{12}C=0.01118$

The relationship between R ($^{13}C/^{12}C$) and $\delta^{13}C$, assuming CO_2 of 400 ppm

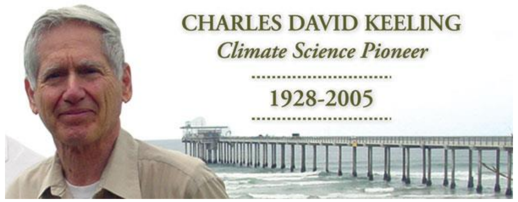
More positive
Less positive
Enriched in the heavy isotope

Less positive,
More negative,
Depleted in the heavy isotope

C13/C12	C12 (ppm)	C13 (ppm)	δ13C (per mil)	
0.01132	395.5227	4.4773	12.52	
0.01128	395.5383	4.4617	8.94	
0.01124	395.5540	4.4460	5.37	
0.01120	395.5696	4.4304	1.79	
0.01118	395.5774	4.4226	0.00	R_{std}=0.01118
0.01116	395.5853	4.4147	-1.79	
0.01112	395.6009	4.3991	-5.37	
0.01108	395.6166	4.3834	-8.94	← Ambient Air
0.01104	395.6322	4.3678	-12.52	← C_4 Plant Biomass
0.01100	395.6479	4.3521	-16.10	
0.01096	395.6635	4.3365	-19.68	
0.01092	395.6792	4.3208	-23.26	
0.01088	395.6948	4.3052	-26.83	← C_3 Plant Biomass
0.01084	395.7105	4.2895	-30.41	
0.01080	395.7262	4.2738	-33.99	


(n = 965)
C3 plants
C4 plants
Frequency
200
100
0
-40
-30
-20
-10
0
10
Carbon isotope ratio, ‰

The closed chamber method can be used to estimate the $\delta^{13}C$ of any source with keeling plot.

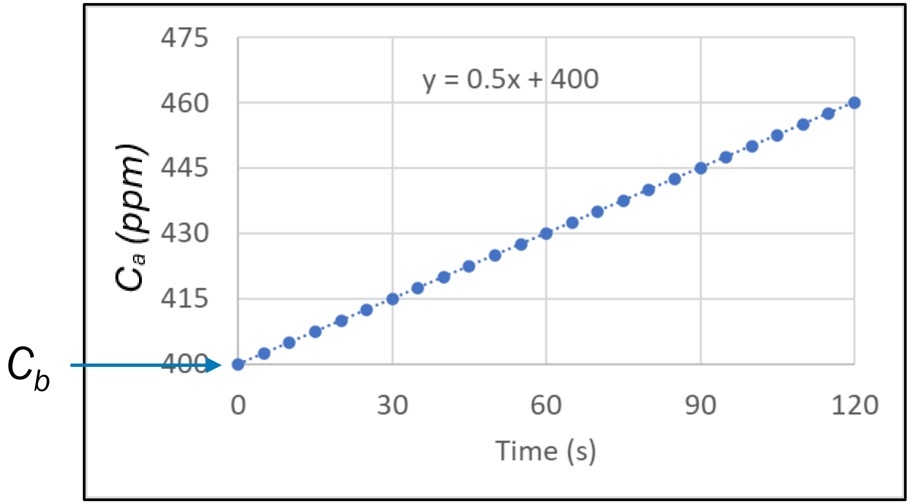


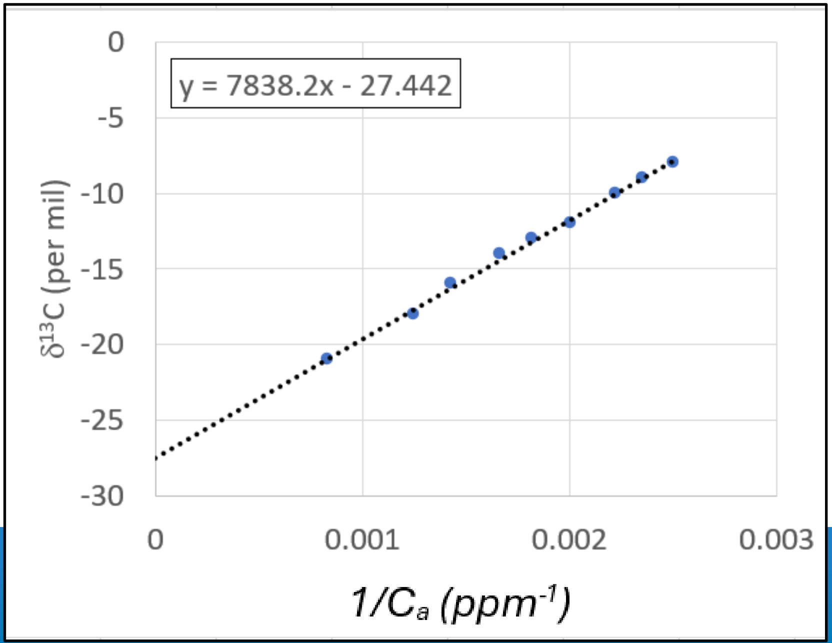
$$c_a = c_b + c_s$$

$$\delta^{13}C_a c_a = \delta^{13}C_b c_b + \delta^{13}C_S c_S,$$

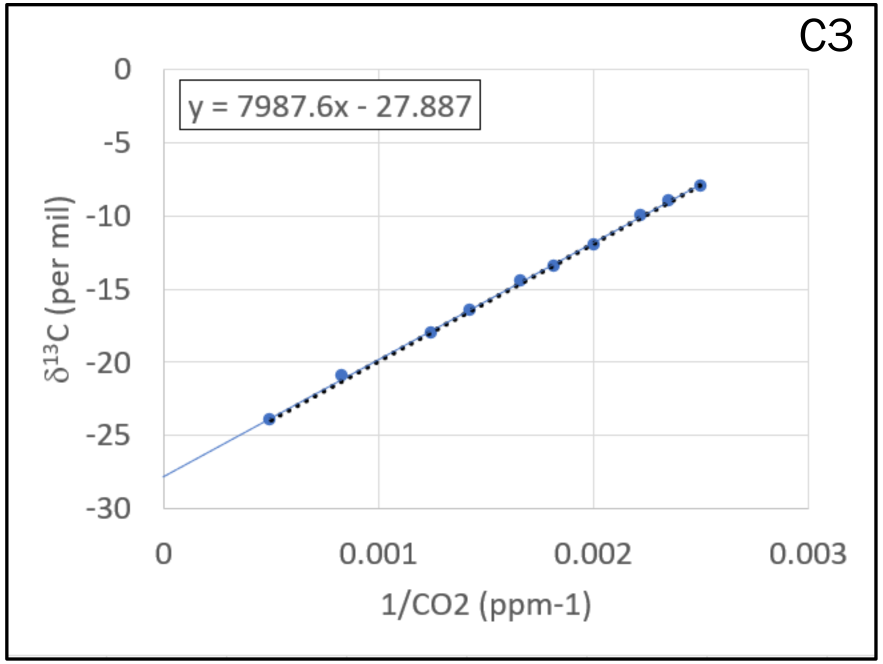
$$\delta^{13}C_a = c_b\left(\delta^{13}C_b - \delta^{13}C_S\right)(1/c_a) + \delta^{13}C_S,$$

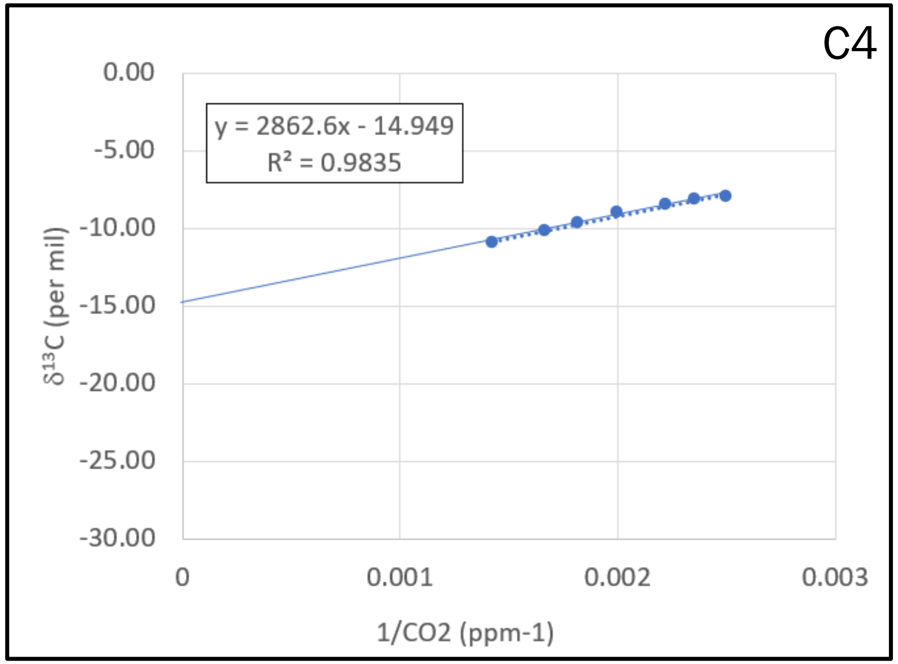
A simple linear mixing model





Keeling plots for CO_2 respired from the C_3 and C_4 biomass



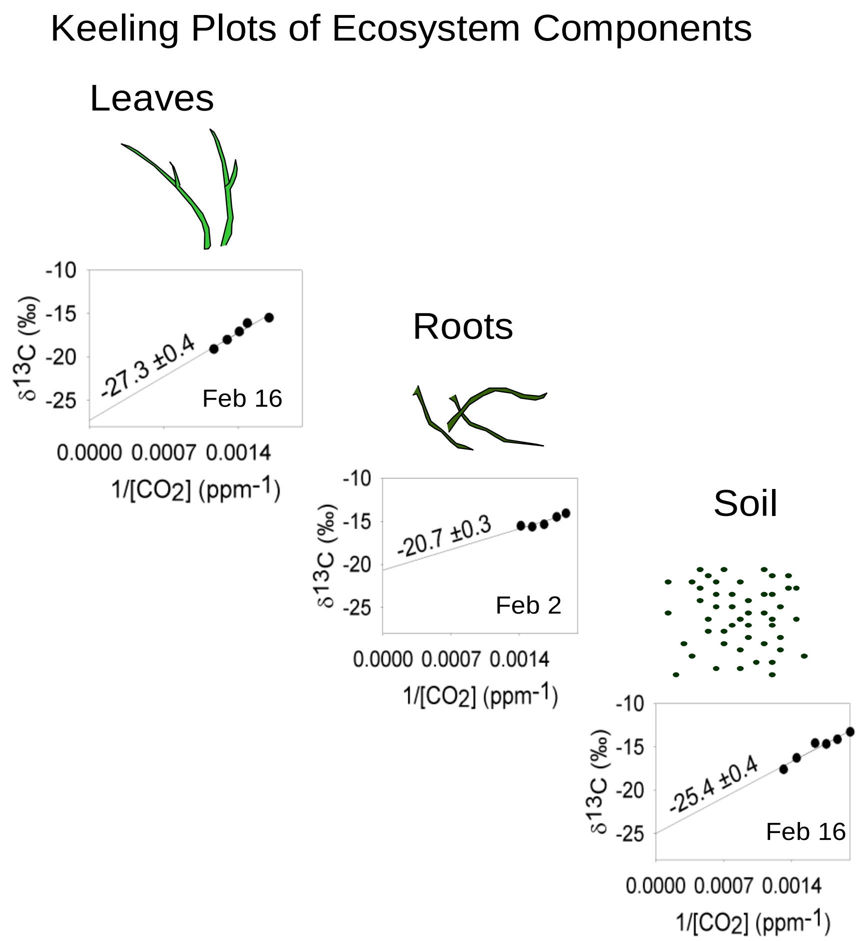


Partitioning soil respiration into auto- and heterotrophic respiration

$$\delta^{13}C_{below} = \delta^{13}C_{root} \times f_{root} + \delta^{13}C_{soil} \times (1 - f_{root})$$

Partitioning ecosystem respiration into below and above ground component

$$\delta^{13}C_{ecosystem} = \delta^{13}C_{below} \times f_{below} + \delta^{13}C_{shoot} \times (1 - f_{below})$$



Advantages of chamber method

1. Simple theory

    Pay attention to considerations

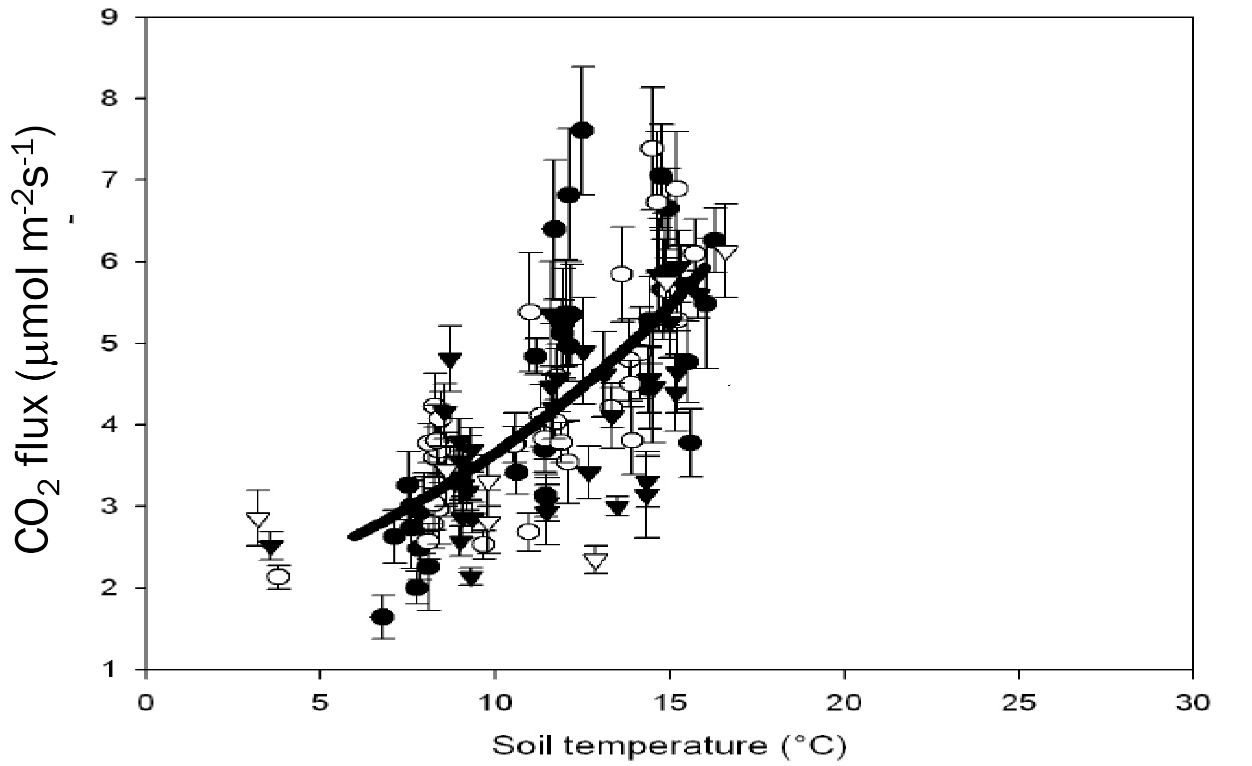
2. Can measure very small flux
3. Relatively easier to process the data
4. Can be used over small plots
5. Can be used over a wide range of field topography
6. Automated and long-term continuous measurement

Challenges remain:

1. Boundary layer disturbance
2. Spatial coverage
3. Chamber size limitation

Most common issue in manuscript

Caution: with whole growing season dataset



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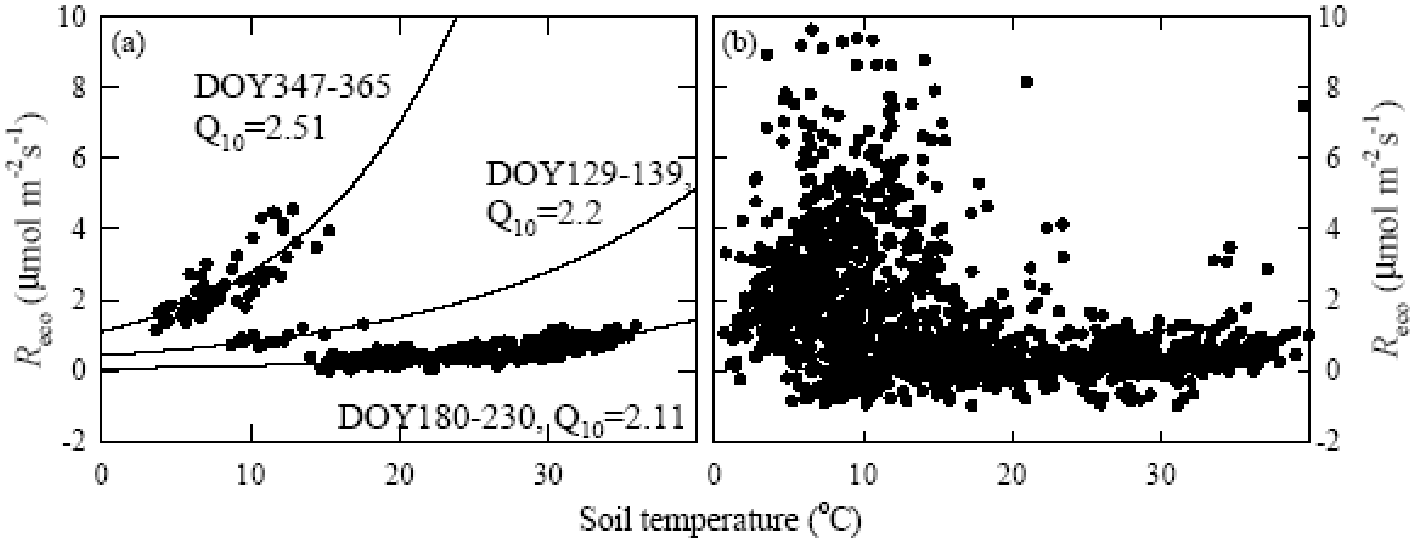
Most common issue in manuscript

Temperature dependence of soil respiration

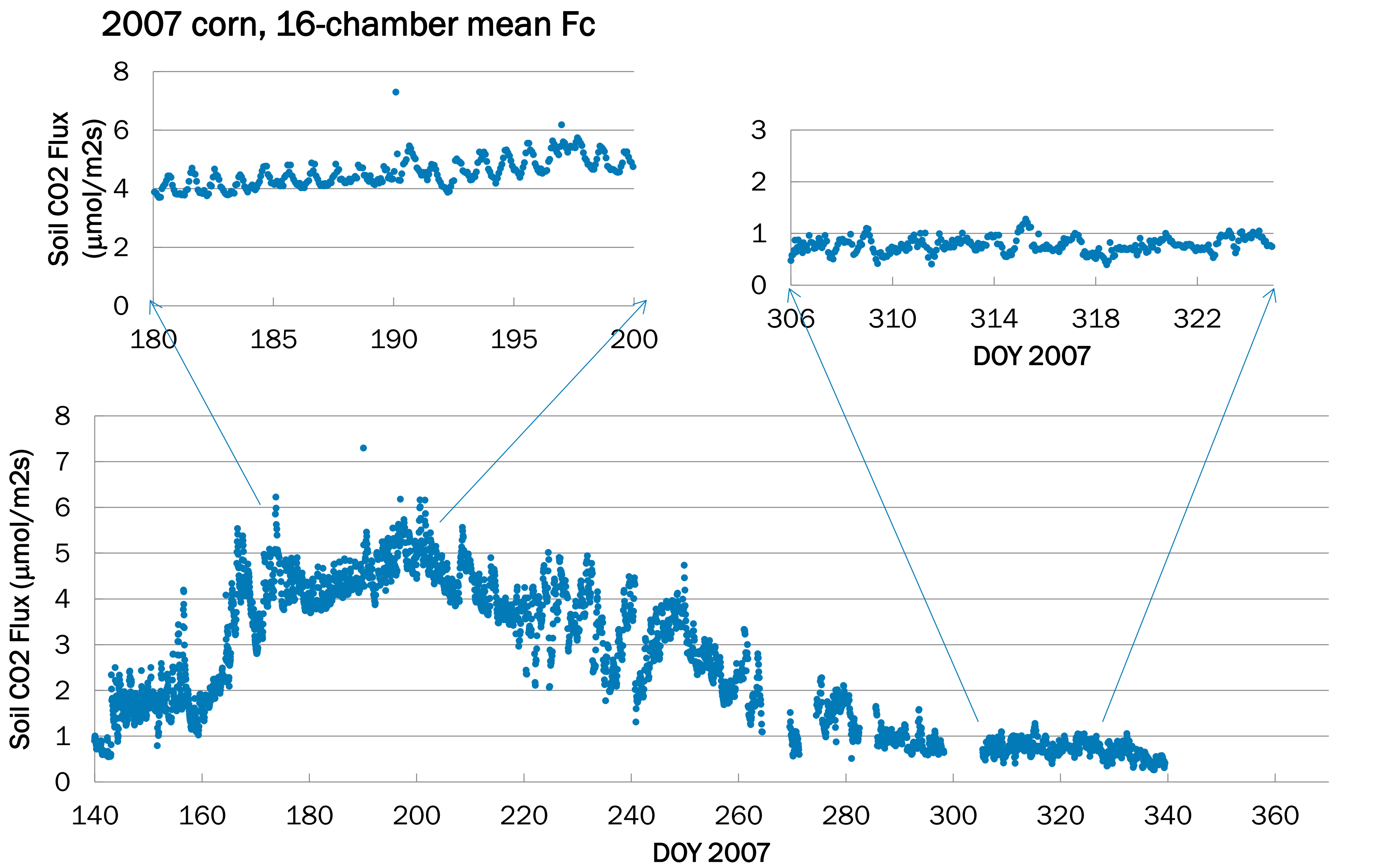
L. Xu, D.D. Baldocchi / Agricultural and Forest Meteorology 1232 (2004) 79–96

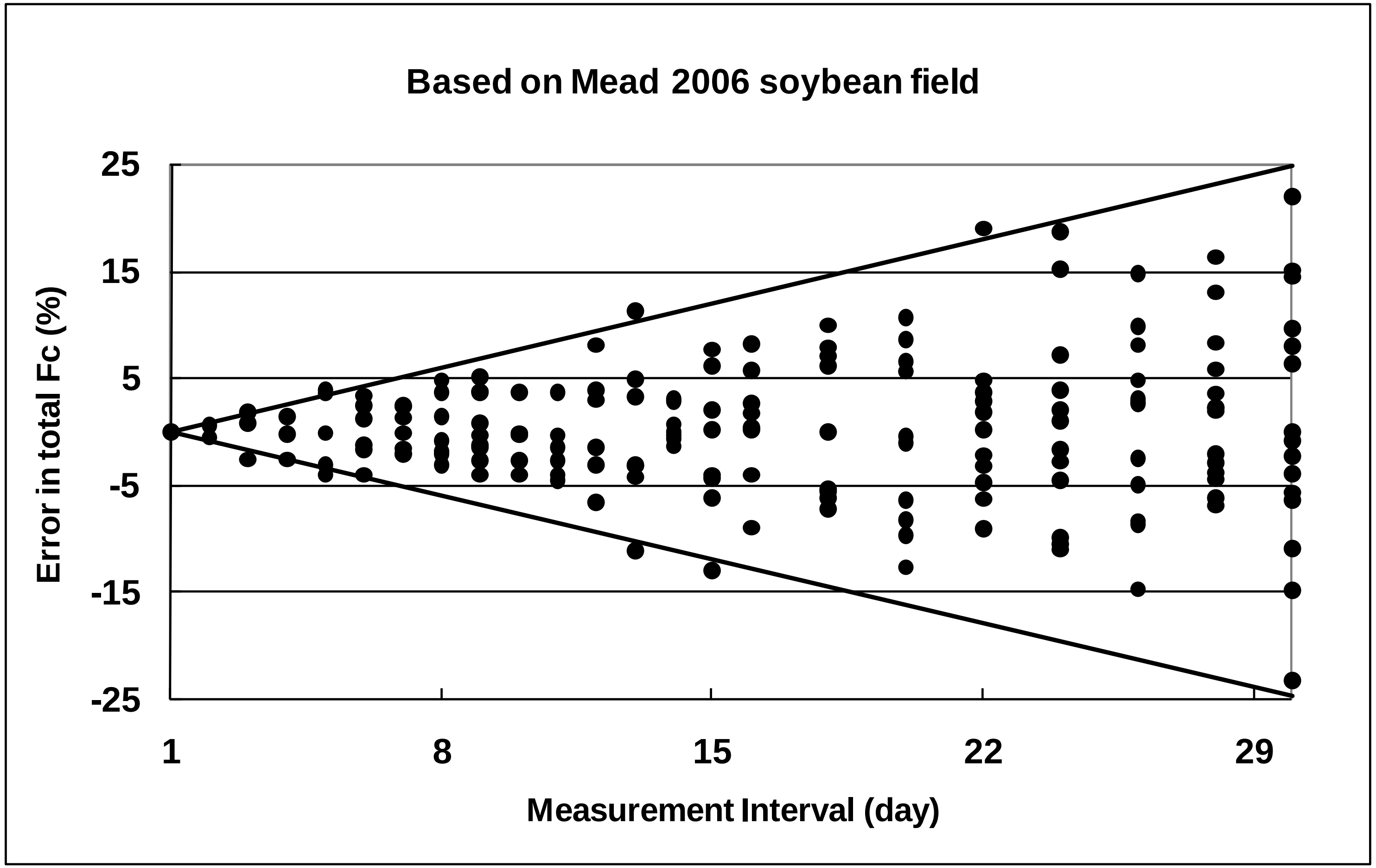


Most common issue in manuscript

Using the data from the field measurement at certain intervals to estimate the seasonal total flux !

Most common issue in manuscript




Based on Mead 2006 soybean field
25
15
5
-5
-15
-25
Error in total Fc (%)
1
8
15
22
29
Measurement Interval (day)

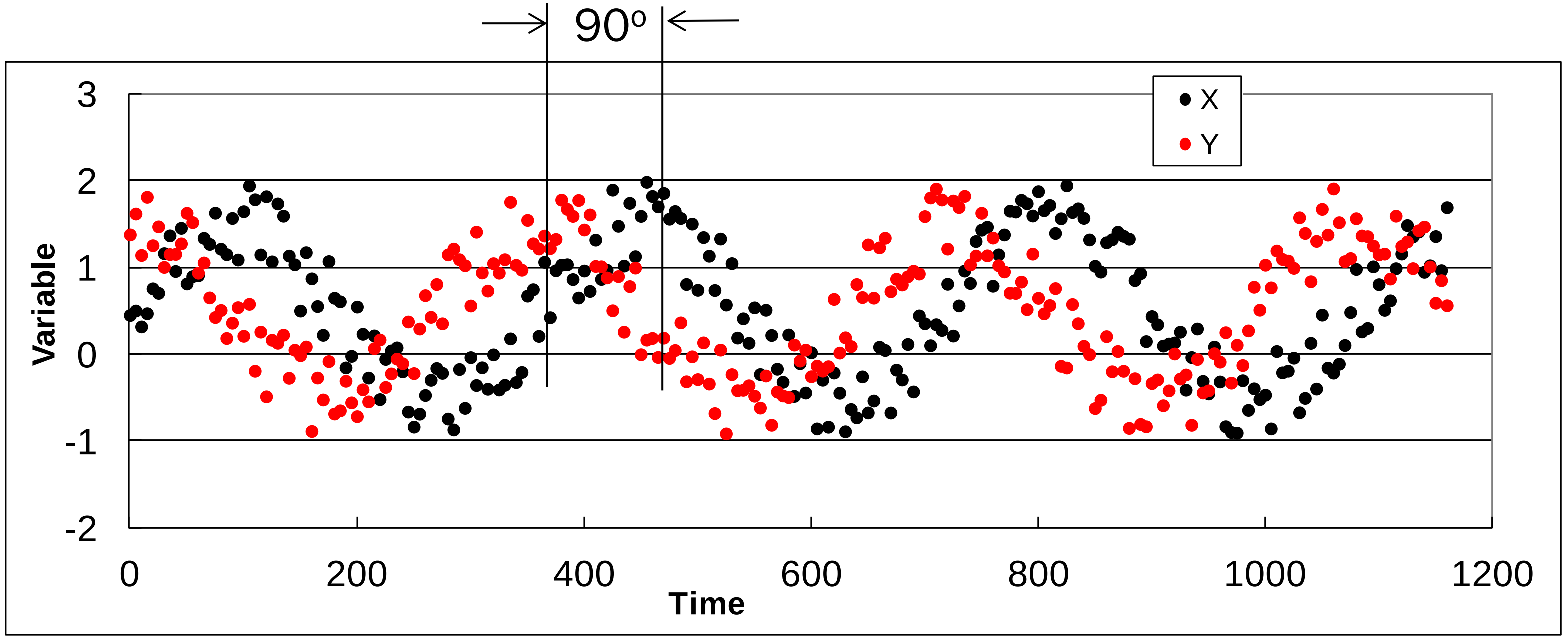
Most common issue in manuscript

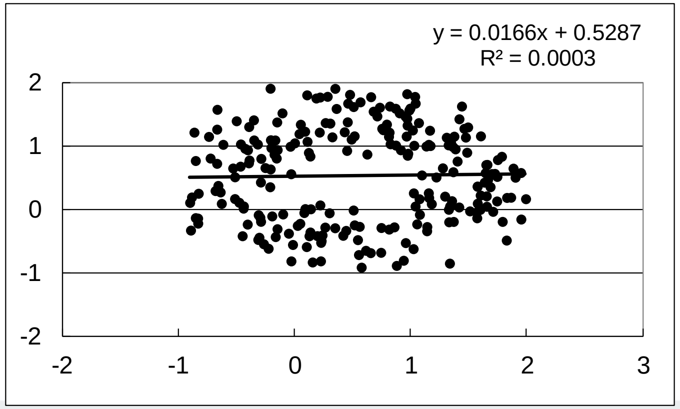
Abuse the linear regression

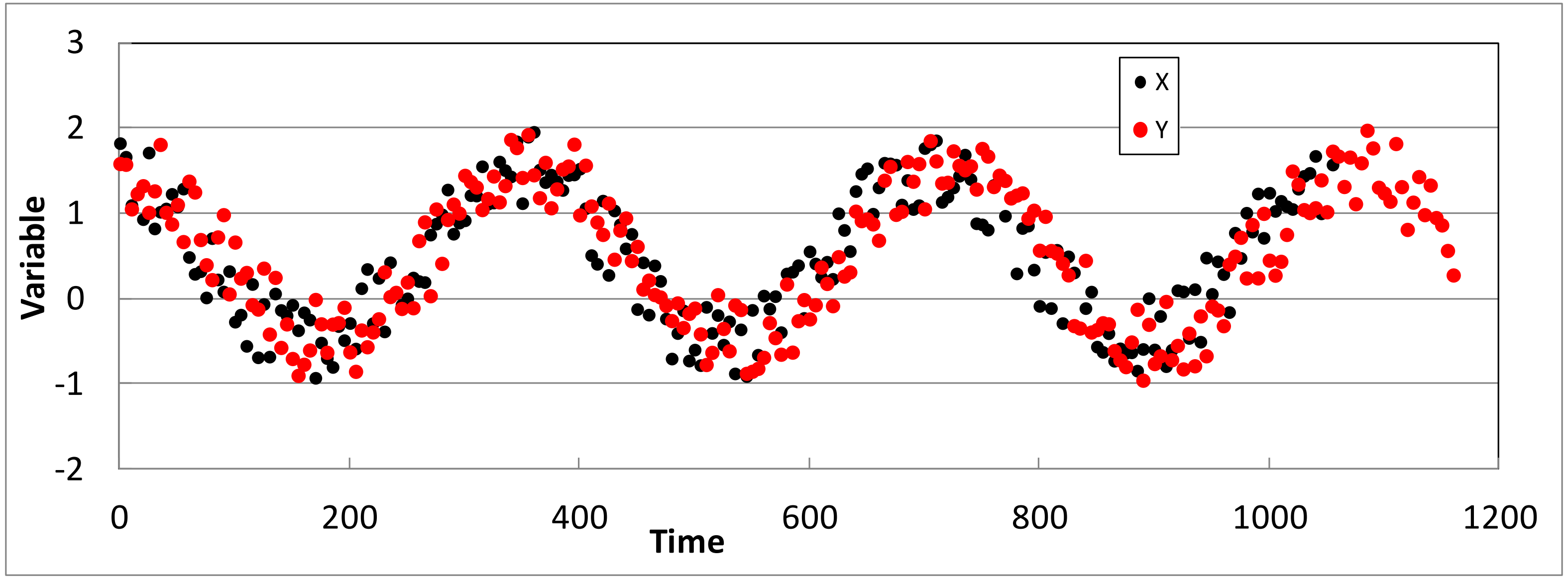
Table 1
Linear regression analyses between half-hourly CH_4 flux (umol m^{-2} s^{-1}) and environmental variables [air temperature (*Ta*), floodwater temperature at 2.5 cm above the soil (Tfw 2.5), soil temperature at 2.5 cm depth (Ts 2.5), soil temperature at 5 cm depth (Ts 5), net radiation (*Rn*), soil heat flux (*G*), sensible heat flux (*H*), latent heat flux (LE), and net ecosystem CO_2 exchange (NEE)] during the different growth stages of the rice plant (pre-planting, vegetative, reproductive, ripening, and fallow). All the data in each growth period were sorted into 10 bins and averaged within each bin. Analyses were performed for daytime and nighttime data separately. R^2 = coefficient of determination, ρ = significance

Variables	Pre-planting		Vegetative		Reproductive		Ripening		Fallow	
	R^2	ρ	R^2	ρ	R^2	ρ	R^2	ρ	R^2	ρ
Daytime										
Ta (C)	-0.01	0.8210	0.88	0.0001	0.91	0.0001	0.89	0.0001	-0.12	0.3373
Tfw 2.5 (C)	-0.13	0.2995	0.93	0.0001	0.85	0.0002	0.66	0.0045	-0.55	0.0140
Ts 2.5 (C)	-0.16	0.2470	0.92	0.0001	0.96	0.0001	0.77	0.0008	-0.43	0.0387
Ts 5 (C)	-0.13	0.2995	0.83	0.0003	0.91	0.0001	0.89	0.0001	-0.24	0.1446
Rn (MJ m^{-2})	0.01	0.7466	0.97	0.0001	0.92	0.0001	0.84	0.0002	-0.77	0.0006
G (MJ m^{-2})	-0.08	0.4204	0.97	0.0001	0.94	0.0001	0.78	0.0008	-0.69	0.0028
H (MJ m^{-2})	-0.25	0.1407	0.98	0.0001	0.87	0.0001	-0.04	0.5818	-0.50	0.0206
LE (MJ m^{-2})	0.65	0.0051	0.97	0.0001	0.95	0.0001	0.94	0.0001	-0.78	0.0006
NEE (umol m^{-2} s^{-1})	-0.79	0.0006	-0.26	0.1323	-0.90	0.0001	-0.67	0.0038	0.83	0.0003
Nighttime										
Ta (C)	-0.20	0.1922	-0.51	0.0208	0.74	0.0015	-0.27	0.1210	0.02	0.6949
Tfw 2.5 (C)	-0.02	0.6769	-0.29	0.1095	0.34	0.0791	-0.21	0.1806	0.10	0.3886
Ts 2.5 (C)	-0.06	0.5001	0.24	0.1535	0.39	0.0533	0.65	0.0045	0.32	0.0881
Ts 5 (C)	-0.02	0.6769	0.10	0.3697	0.56	0.0132	0.81	0.0004	0.51	0.0192
Rn (MJ m^{-2})	-	-	-0.07	0.4677	0.08	0.4527	0.16	0.2550	0.01	0.8648
G (MJ m^{-2})	-0.01	0.9109	0.18	0.2407	0.23	0.1662	-0.03	0.6107	0.22	0.1711
H (MJ m^{-2})	-0.32	0.0861	-0.89	0.0001	-0.80	0.0005	-0.34	0.0792	-0.72	0.0020
LE (MJ m^{-2})	0.04	0.5954	0.76	0.0009	0.68	0.0036	0.24	0.1491	0.36	0.0682
NEE (umol m^{-2} s^{-1})	0.03	0.6153	0.99	0.0001	0.79	0.0006	0.04	0.5855	0.85	0.0001

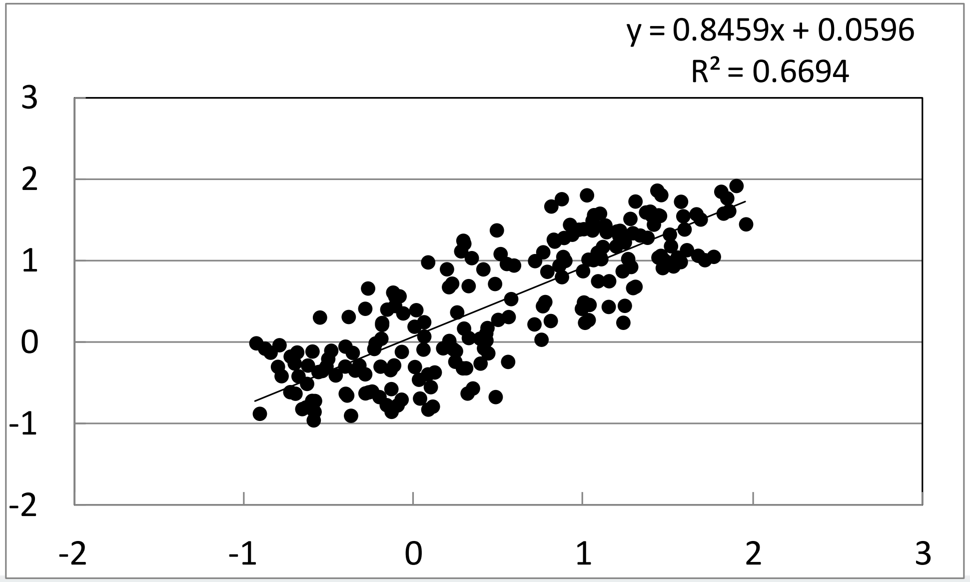
Caution on simple linear regression: Abuse







3
2
1
0
-1
-2
Variable
0
200
400
600
800
1000
1200
Time
X
Y



y = 0.8459x + 0.0596
R² = 0.6694
3
2
1
0
-1
-2
-2
-1
0
1
2
3

Topics we covered:

1. Control of gas transport across the soil surface
2. Theory of gas flux measurement across soil surface
3. Considerations for the closed-chamber method
4. Hardware: Smartchamber, LI-8250 system
5. Software:
    a. User interface (UI)
    b. Data processing software (SoilFluxPro) Demo
6. QA/QC
7. Other applications

- It is very important to understand the theory of the measurement and how the GHG flux is calculated, what variables are used in the equation etc. This is very helpful for trouble shooting and data QA/QC.

- Try to look at your data as soon as you download from the instrument. If you see something wrong, try to fix the issue. Otherwise, you could lose more data.

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Q & A