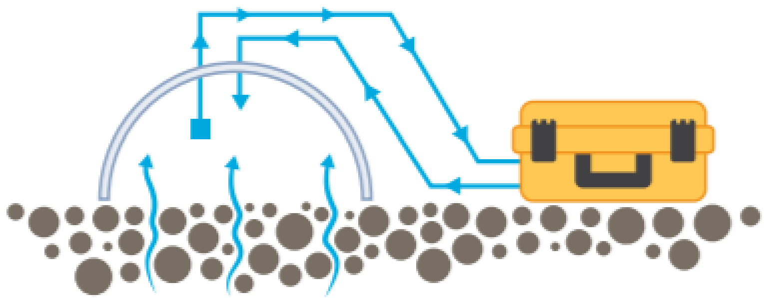


Theory and technique for gas exchange measurement at soil surface

Liukang Xu, Aug 26 2020

Outline

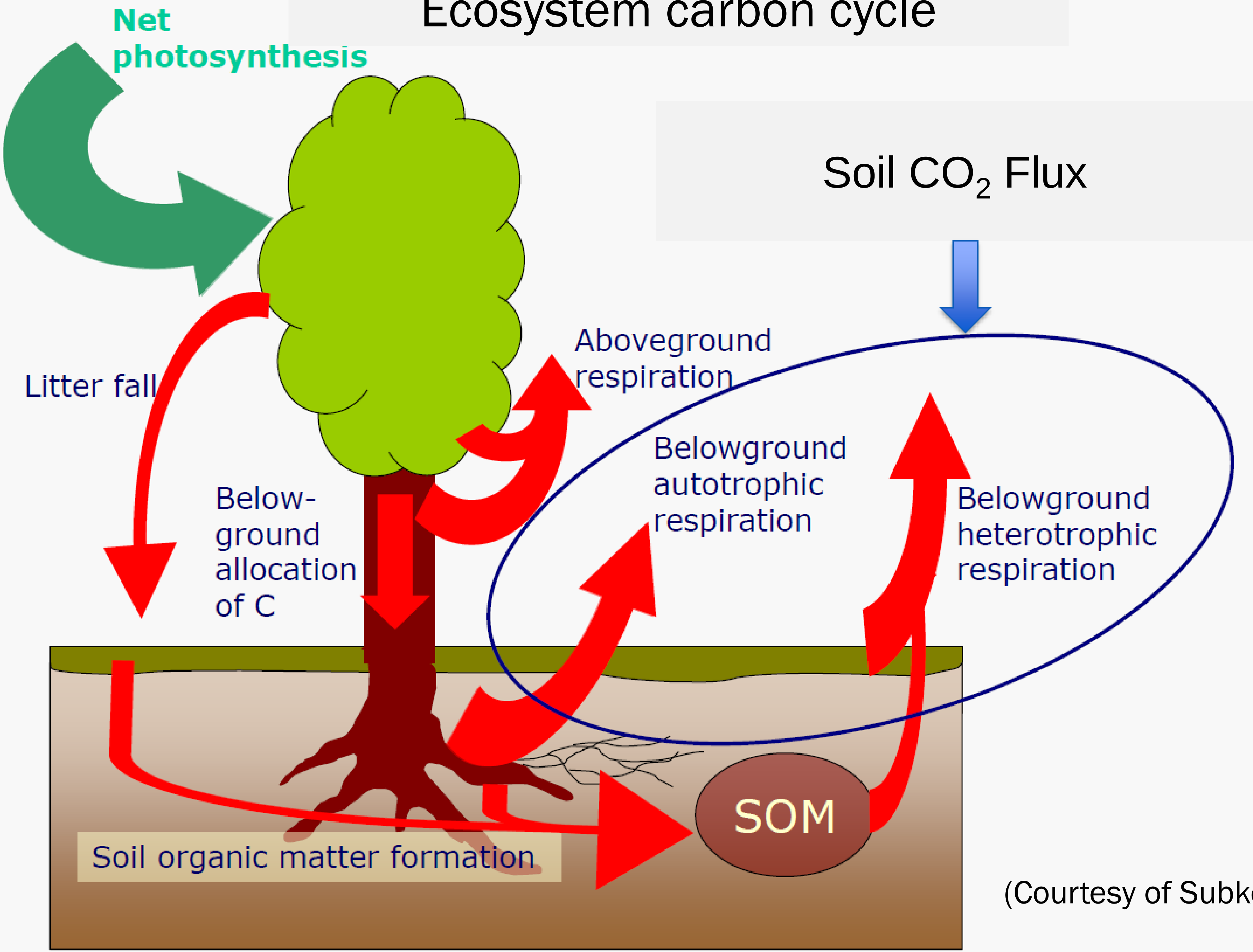
1. **Significance** of studying soil GHG (CO_2, CH_4 and N_2O) flux
2. **Theory and requirements** of chamber-based soil GHG flux measurement
3. **Production**: Biotic and abiotic control (CO_2 as an example)
4. Control of gas **transport** from soil to atmosphere

LI-COR®

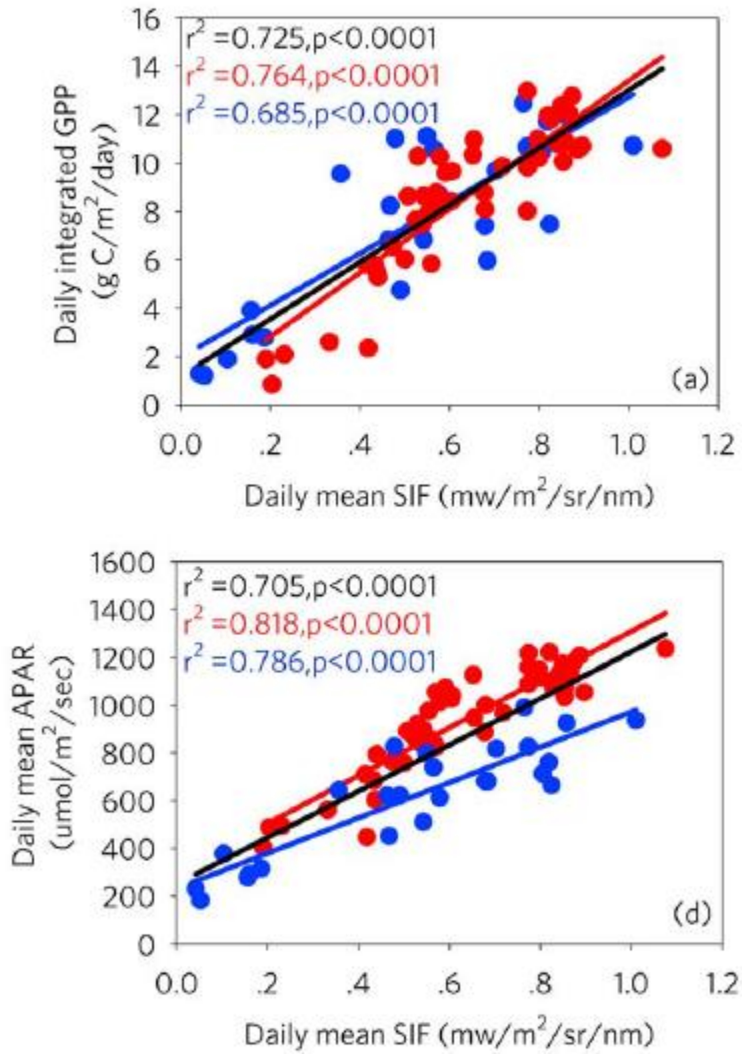
Three major greenhouse gases

Greenhouse Gas	Current Atmospheric Concentration	Atmospheric Lifetime (year)	Global Warming Potential	Radiative Forcing ($W\ m^{-2}$)
CO_2	405 ppm	50-200	1	1.66
CH_4	1852 ppb	12±3	21	0.48
N_2O	331 ppb	120	310	0.16

Ecosystem carbon cycle



(Courtesy of Subke)



GPP=NEE-Res

Yang et al., GRL 2015

Methanogenesis

Produced in anaerobic environments ,

Redox potential < -300 mv

$$C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4$$

LI-COR®

Methane Sinks

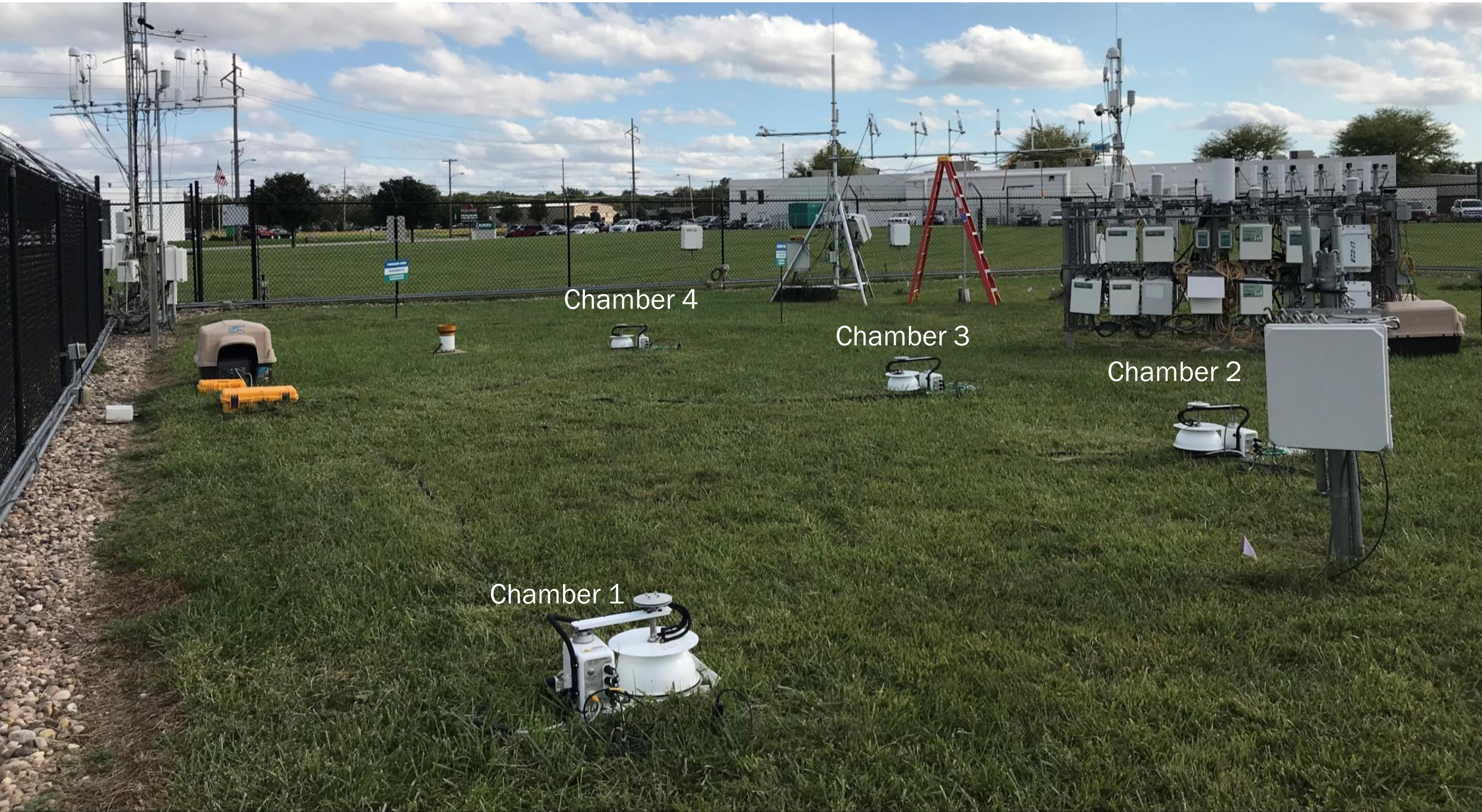
- Reaction with hydroxyl radical in troposphere and stratosphere (~95%)

  $CH_4 + OH \rightarrow CO_2 + H_2O$

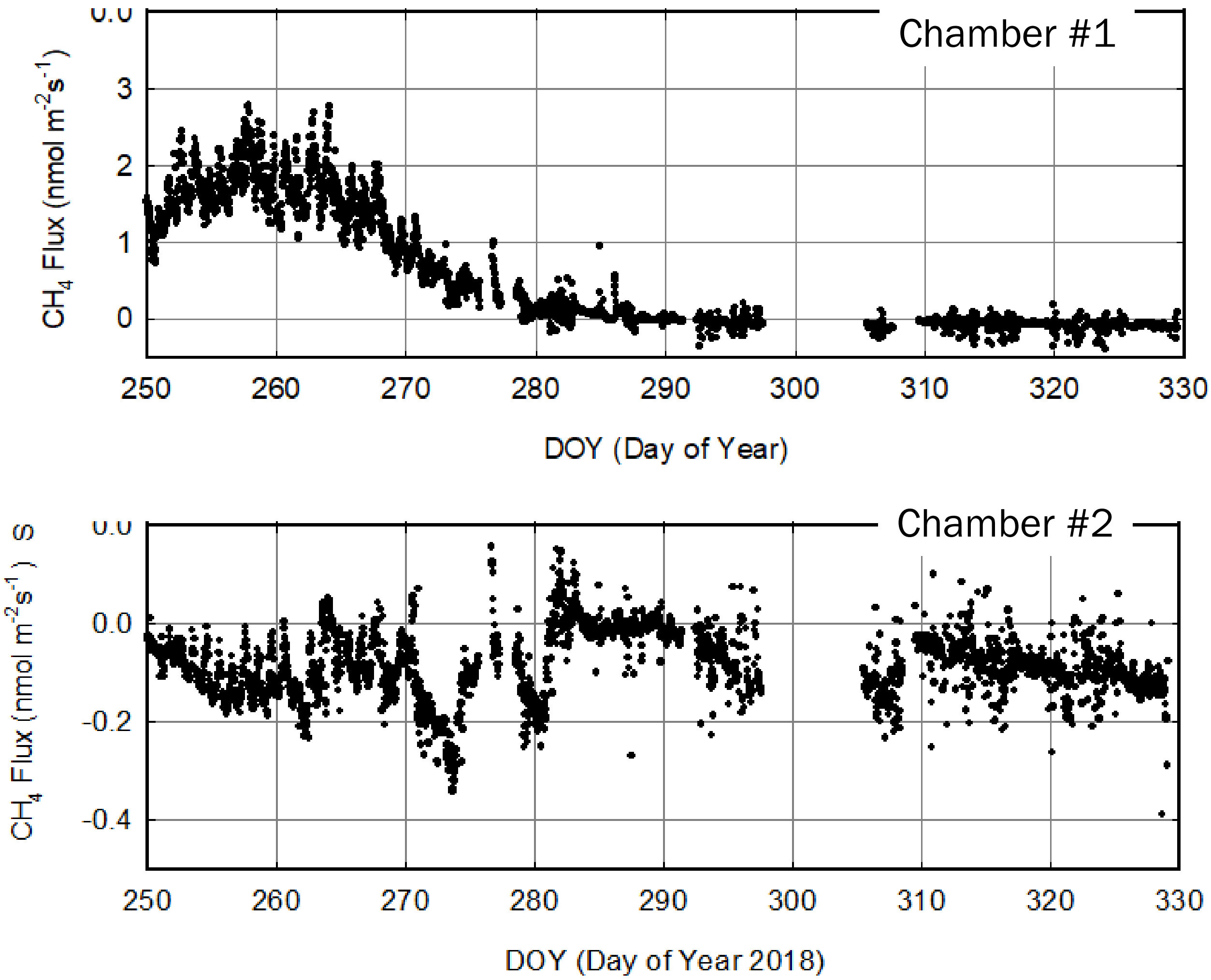
- Soil oxidation (~5%)

  $CH_4 + O2 \rightarrow CO_2 + H_2O$

Soil CO_2 and CH_4 fluxes



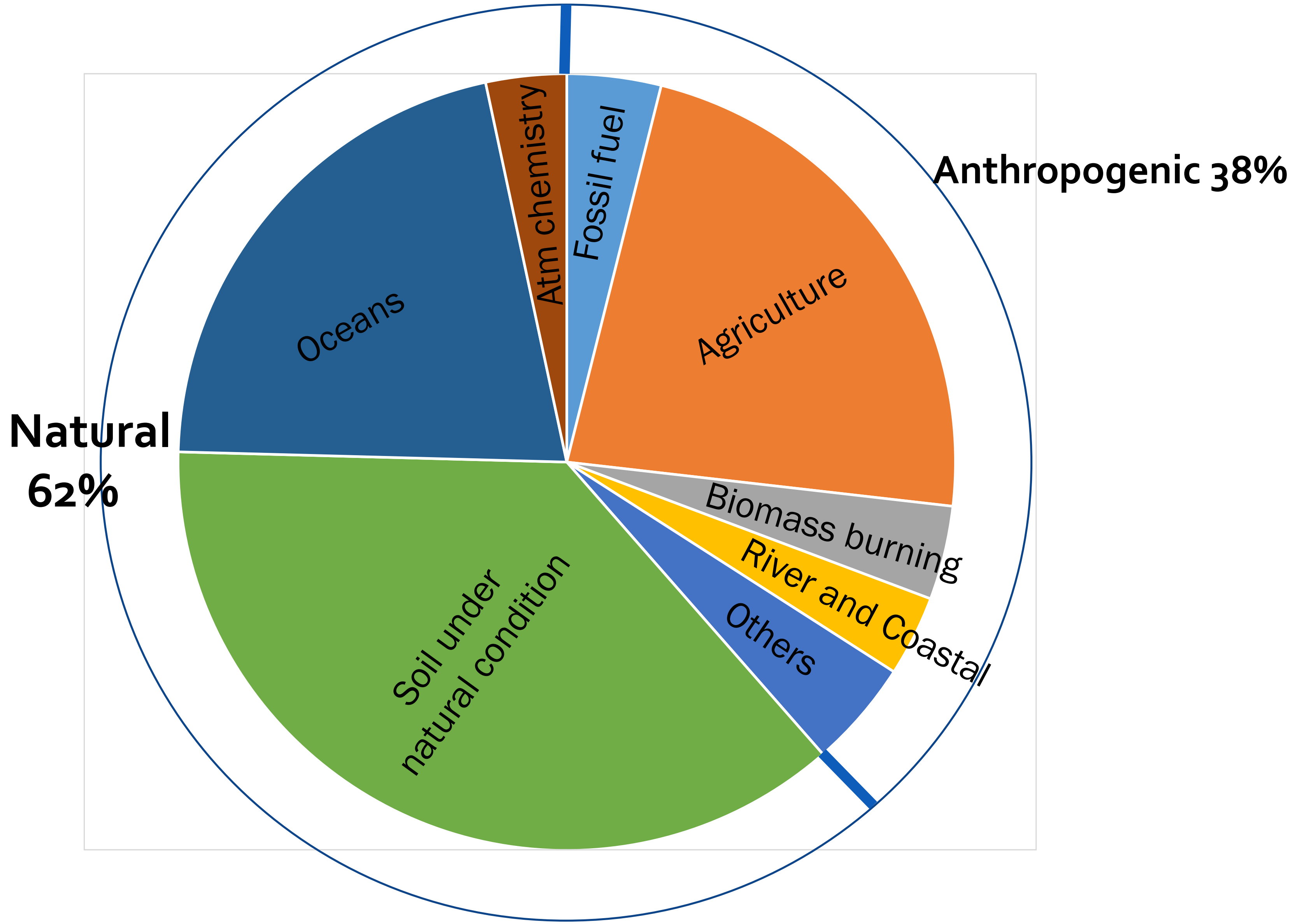
Urban lawn, CH4 sink or source?



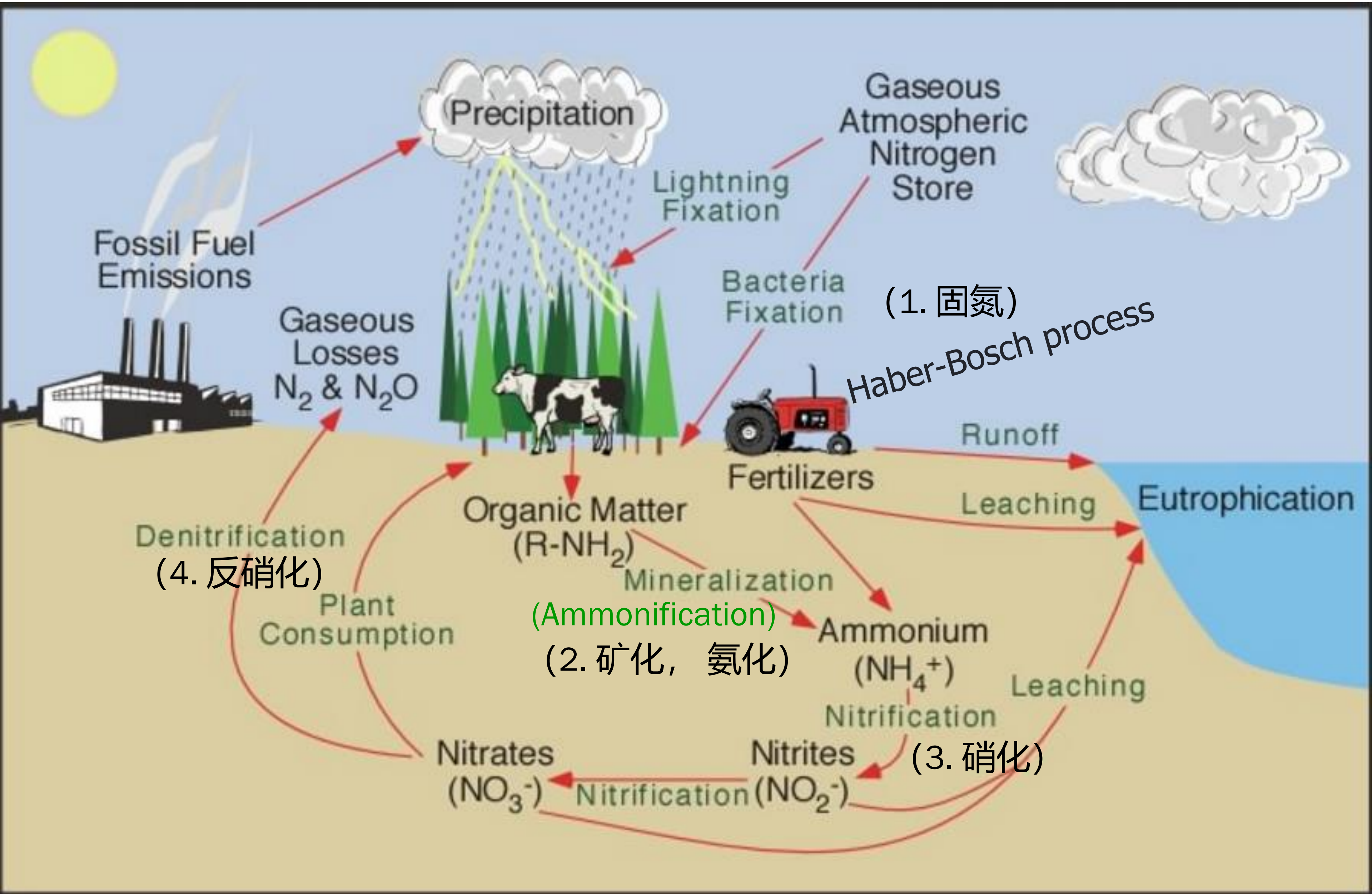
Published CH_4 flux for various sources

Ecosystem	CH_4 Flux		Study
	mg CH_4 $m^{-2}hr^{-1}$	nmol $m^{-2}s^{-1}$	
Peatland, Minnesota	1.5 - 8.0	26 - 139	Shurpali & Verma (1998)
Fen, Canada	1.5 - 12.0	26 - 210	Bubier et al (1993)
Fen, Finland	0 - 20.0	**0 - 347**	Peltola et al (2013)
Sugarcane, Australia	0.24	4	Denmead et al (2010)
Bog, Alaska	3.0 - 9.0	52 - 156	Moosavi et al (1996)
Pacific Mangroves, Baja California	2.3 - 4.4	40 - 76	LI-COR (unpublished)
Marsh, Nebraska	4.0 - 30.0	**69 - 521**	Kim et al (1998)
Wetland, California	0 - 17.3	0 - 300	Detto et al (2011)
Wetland, Florida	0 - 3.0	0 - 52	McDermitt et al (2011)
Alphine Wetland, China	4.0 - 12.0	69 - 210	Yu et al (2013)
Pasture, California	0 - 2.9	0 - 50	Detto et al (2011)
Pasture, UK	1.7 - 5.8	30 - 100	Dengel et al (2011)
Rice Paddy, Japan	0 - 11.5	0 - 200	Iwata et al (2013)
Rice Paddy, Japan	0.7 - 7.2	12 - 125	Miyata et al (2000)
Rice Paddy, Philippines	0 - 5.8	0 - 100	Alberto et al (2015)
Rice Paddy, California	0 - 8.6	0 - 150	Detto et al (2011)
Temperate Forest		± 3.5	Warner et al., (2017)
Temperate Forest		-3	Ueyama et al., 2015
Landfill, Tennessee	267.0 - 329.0	4600 - 5700	Hovde et al (1995)
Landfill, Lincoln	0 - 5760	0 - 100,000	Xu et al (2014)

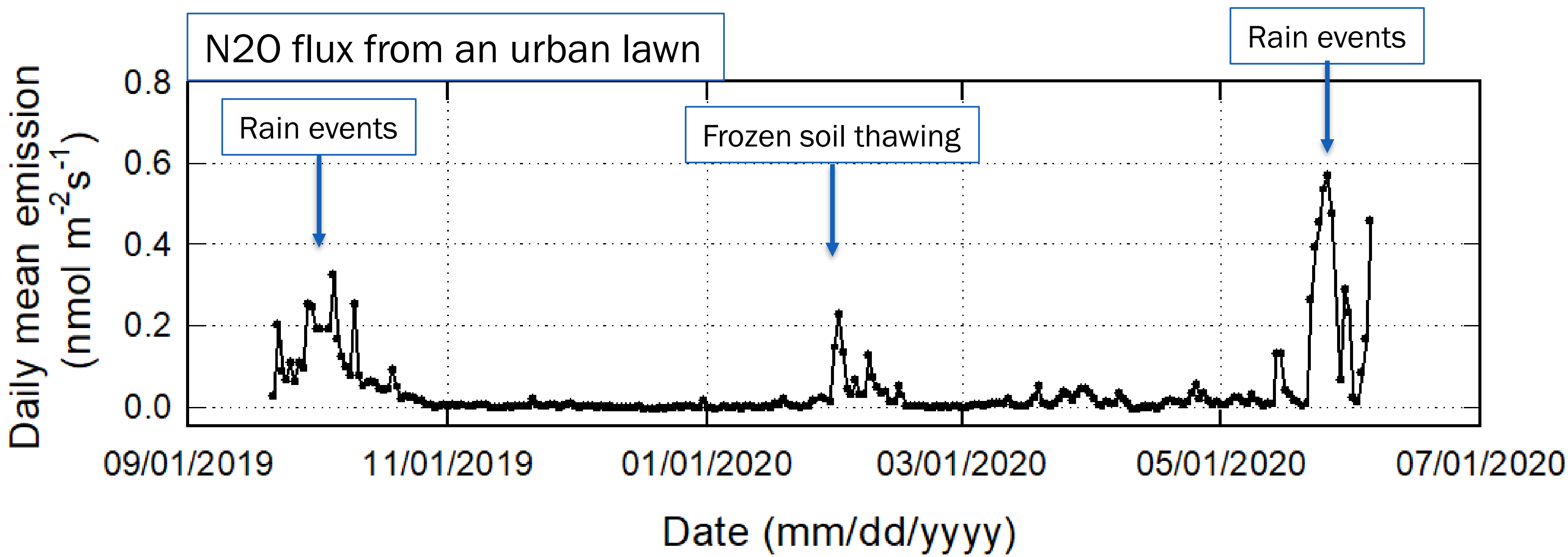
Global N_2O Sources



Nitrogen Cycle



N_2O emission has high temporal variation



Xu et al., unpublished

N2O flux (nmol/m2s)	N2O flux (mgN2O /m2hr)	Ecosystem	Author	Journal
9.921	1.571	Simulation for MN Crop field	Venterea at al.	SSSJ in press
0.595	0.094	moist tropic forest soil	Davidson et al.	GCB 2004
1.190	0.189	tropic agricultural field	Crill et al.,	GBC 2000
1.587	0.251	tropic agricultural field	Crill et al.,	GBC 2000
53.737	8.512	Managed ryegrass in Scotland	Dobbie et al.,	JGR 1999
1.637	0.259	drained agri valley, Mexico	Harrison et al.,	GBC 2003
24.266	3.844	drained agri valley, Mexico	Harrison et al.,	GBC 2003
0.064	0.010	Colorado shortgrass steppe	Mosier	GBC 1996
0.992	0.157	agri field	Mosier	Plant and Soil 1996
3.968	0.629	agri field	Mosier	Plant and Soil 1996
0.198	0.031	forest soil in N Europe	Pilegaard et al.,	Biogeosci 2006
0.357	0.057	fertilized grassland	Scanlon et al.,	GRL 2003
17.857	2.829	fertilized grassland	Scanlon et al.,	GRL 2003
39.683	6.286	grassland	Smith et al.,,	Phil Trans R. S 1995
0.357	0.057	Australian Sugarcane Soil	Denmead et al.	AFM 2009
17.857	2.829	Australian Sugarcane Soil	Denmead et al.	AFM 2009
0.893	0.141	dairy farm in Netherland	Kroon et al.,	Biogeosci 2007
5.357	0.849	dairy farm in Netherland	Kroon et al.,	Biogeosci 2007
0.020	0.003	agri field	Venterea at al.	J Env Quality 2005
0.694	0.110	agri field	Venterea at al.	J Env Quality 2005
0.200	0.032	agri field	Tallec et al.,	AFM 2019
8.929	1.414	agri field	Tallec et al.,	AFM 2019
0.794	0.126	Urban lawn	Hall et al.,	JGR 2008
1.40	0.222	Lincoln Lawn	Xu et al.,	unpublished
1.40	0.222	Lincoln Lawn	Xu et al.,	unpublished
0.04	0.007	Lawn	Bijoor et al.,	GCB 2008
0.41	0.065	Lawn	Bijoor et al.,	GCB 2008
0.10	0.016	Northern hardwood forest	Groffman et al.,	GCB 2013
0.50	0.079	Northern hardwood forest	Groffman et al.,	GCB 2013

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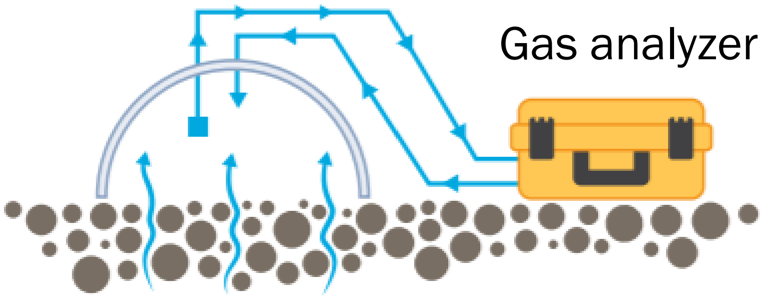
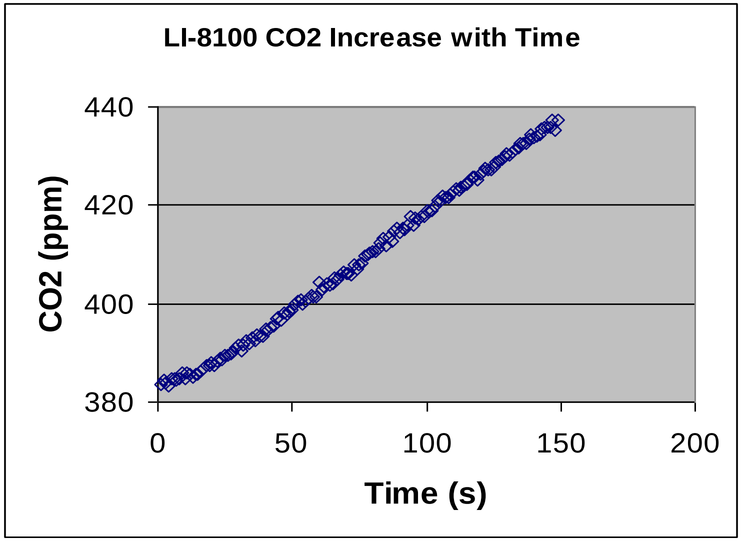
Theory of chamber-based soil GHG flux measurement

(Using CO_2 case as an example)



$$F_{CO2} = \frac{VP}{RST}\frac{dC}{dt}$$



V: Chamber volume, m^3

P: Pressure, kPa

R: Gas constant, Pa m^3 $k^{-1}mol^{-1}$

S: Soil area, m^2

T: Temperature, K

dC/dt: Slope, μmol mol^{-1} s^{-1}

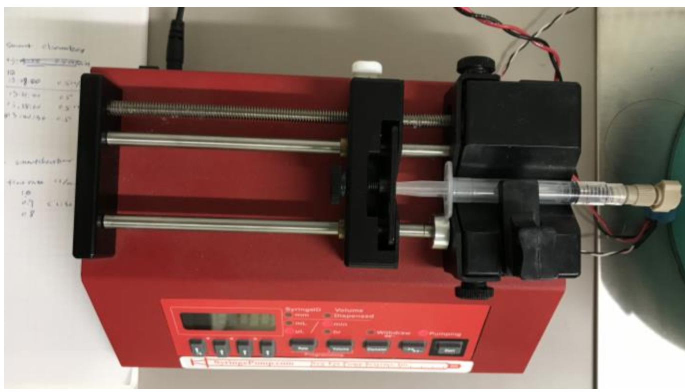
F_{CO2}: Flux, μmol $m^{-2}s^{-1}$

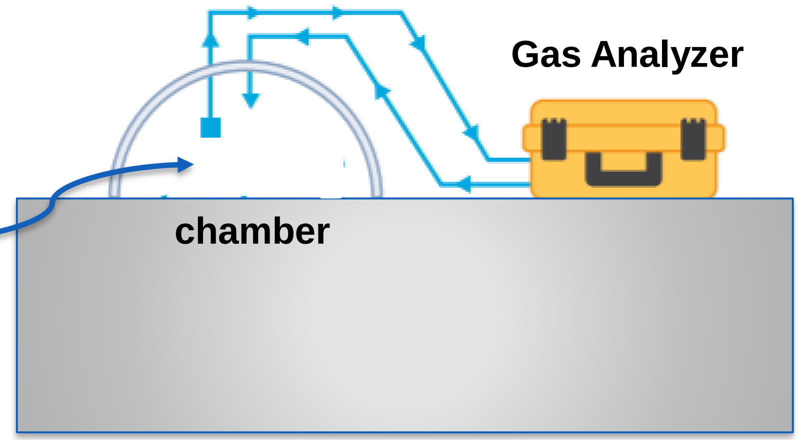
Requirements and considerations for chamber-based soil GHG flux measurement

1. Measure amount of GHG from the soil accurately
2. Minimize the influence on soil GHG “Transport”
3. Minimize the influence on soil GHG “Production”
4. Deal with temporal and spatial variation

Accurately measure amount of gas from the soil?

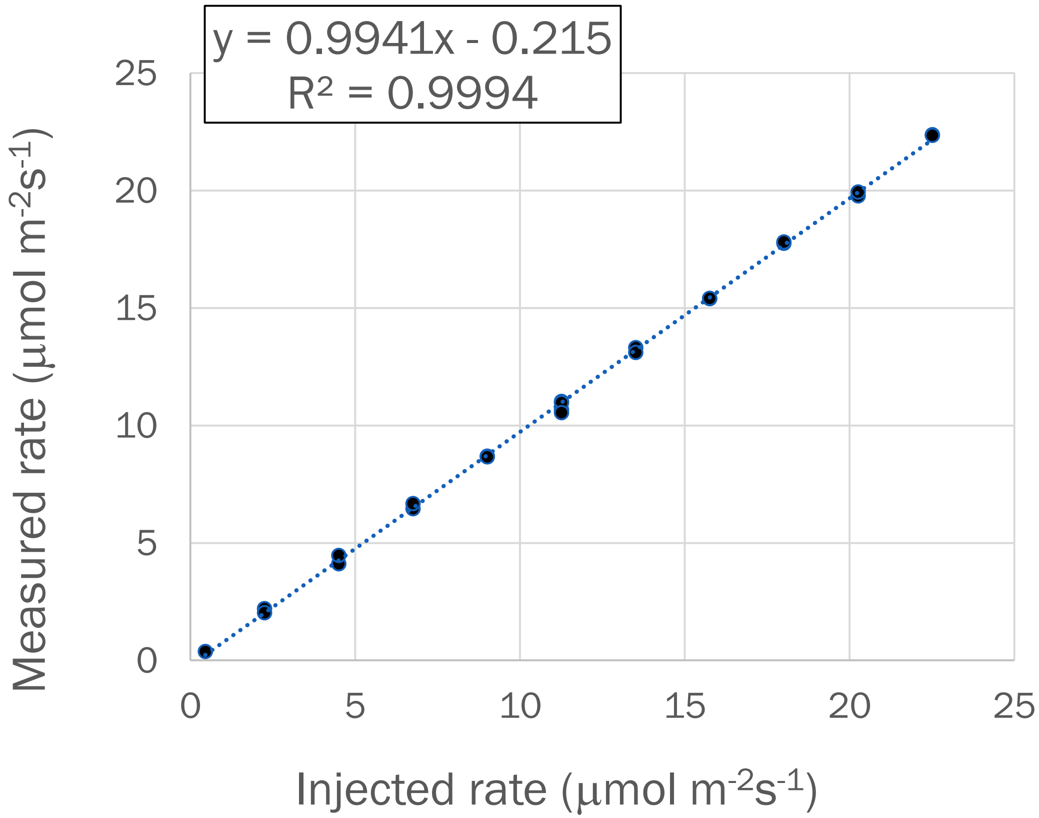
Syringe pump



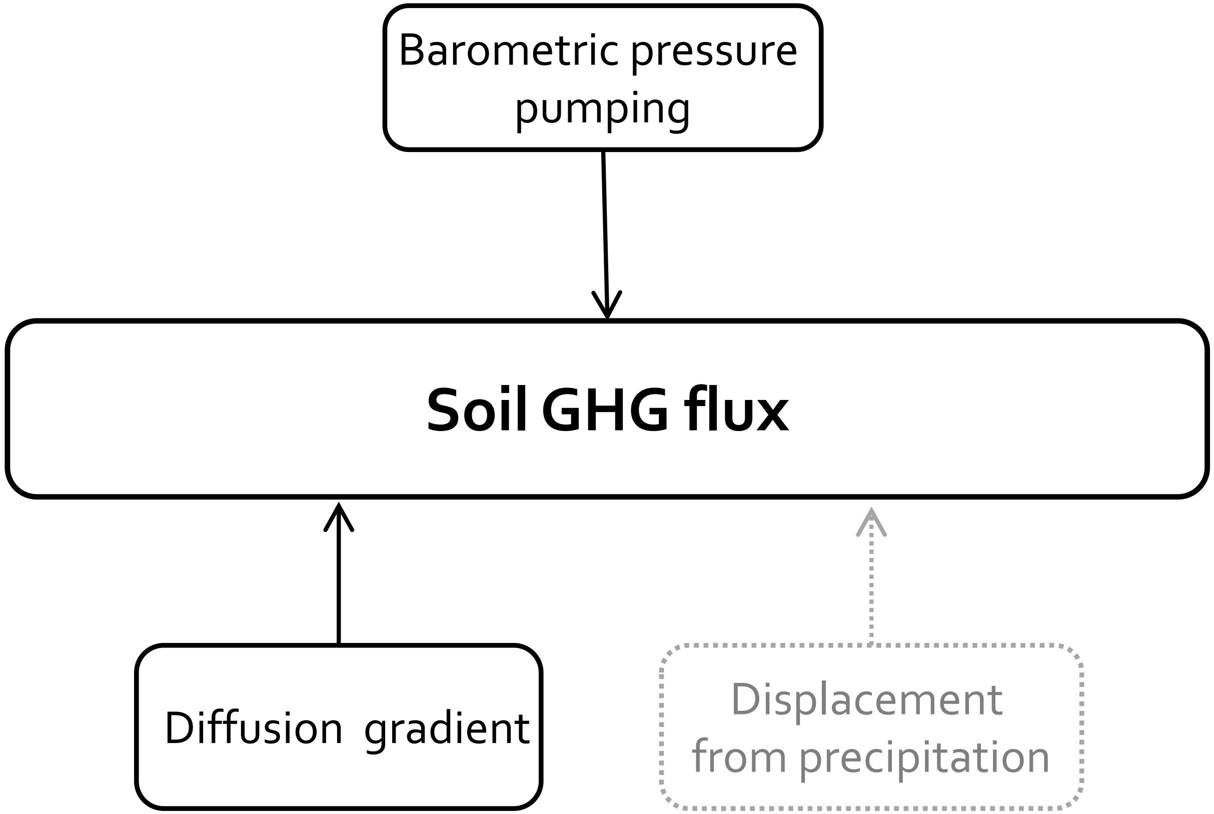


Inject known rate =? Measured rate

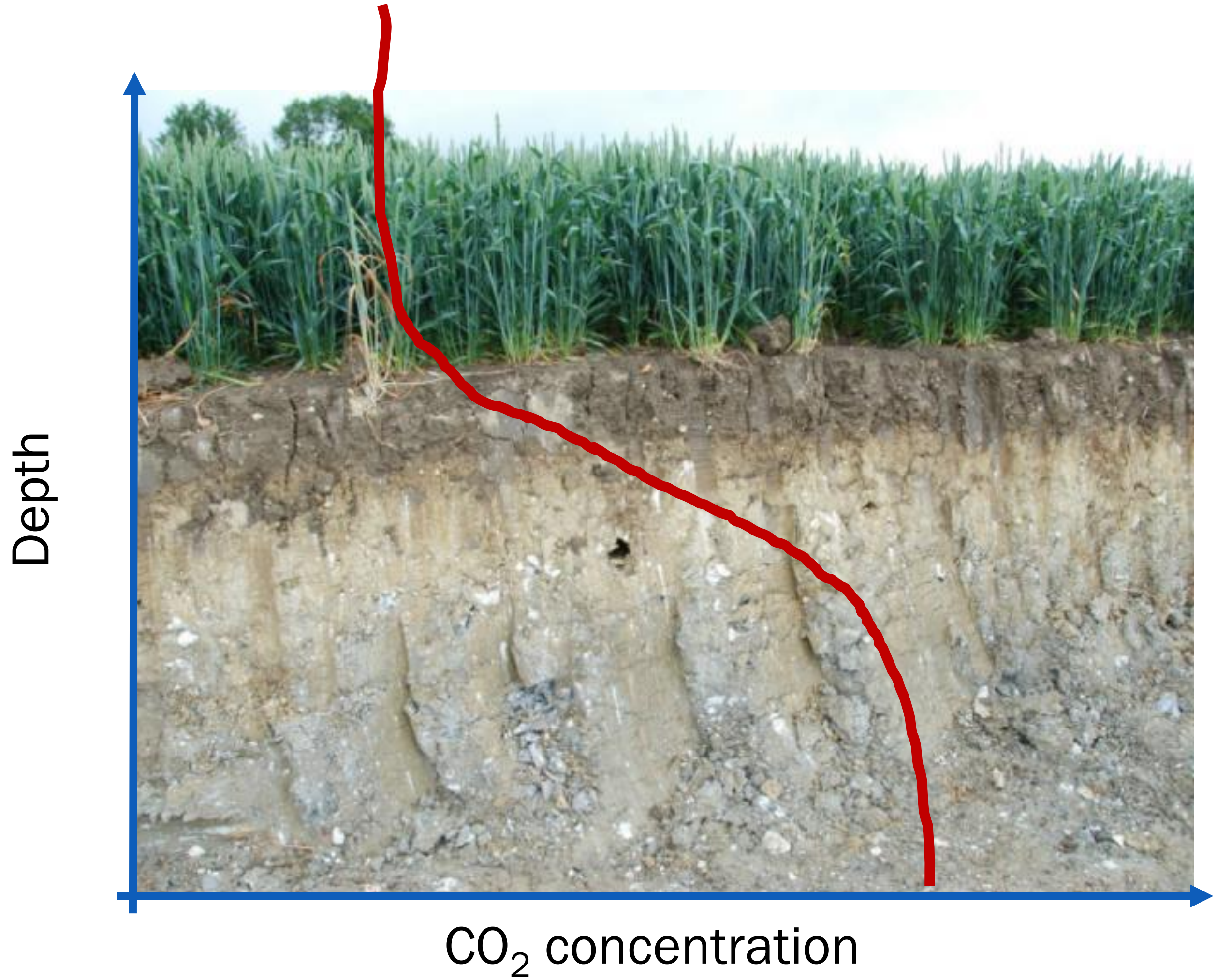
Accurately measure amount of gas from the soil?



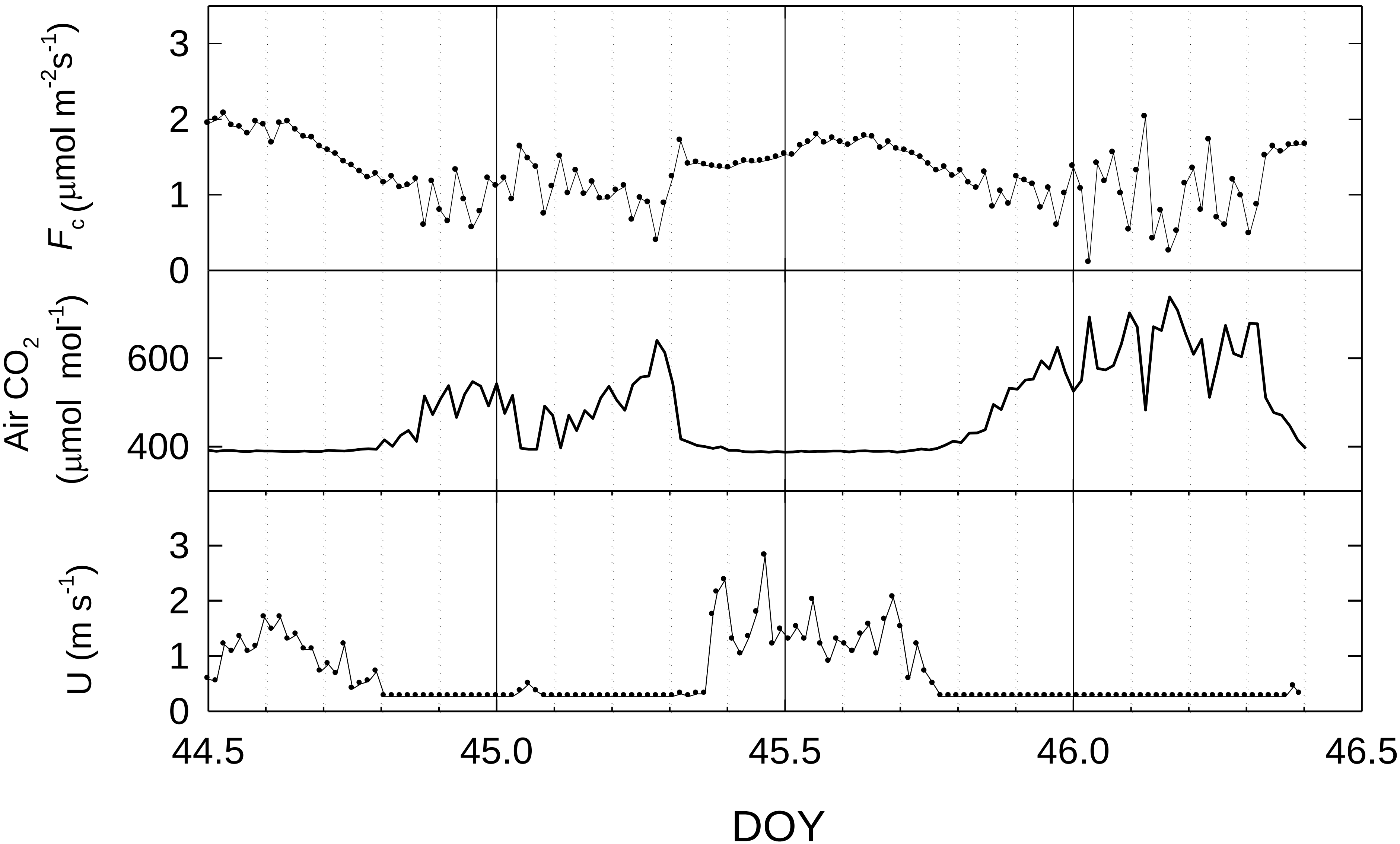
1. Accurately measure amount of GHG from the soil
2. Minimize the influence on soil GHG “Transport”
3. Minimize the influence on soil GHG “Production”
4. Deal with temporal and spatial variation

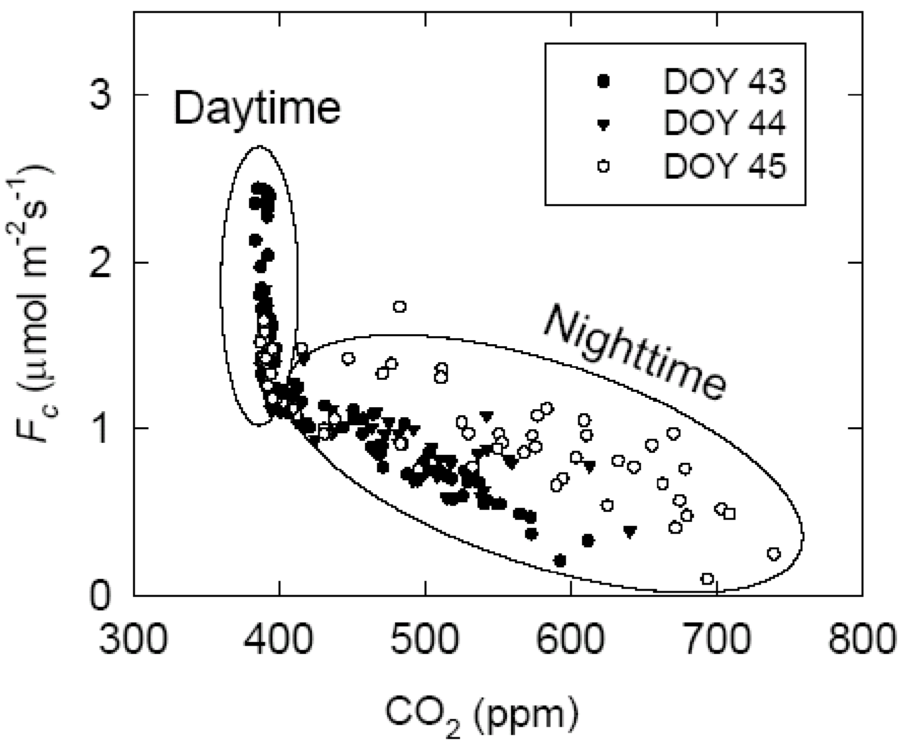

Barometric pressure pumping
Soil GHG flux
Diffusion gradient
Displacement from precipitation

CO_2 profile in the soil



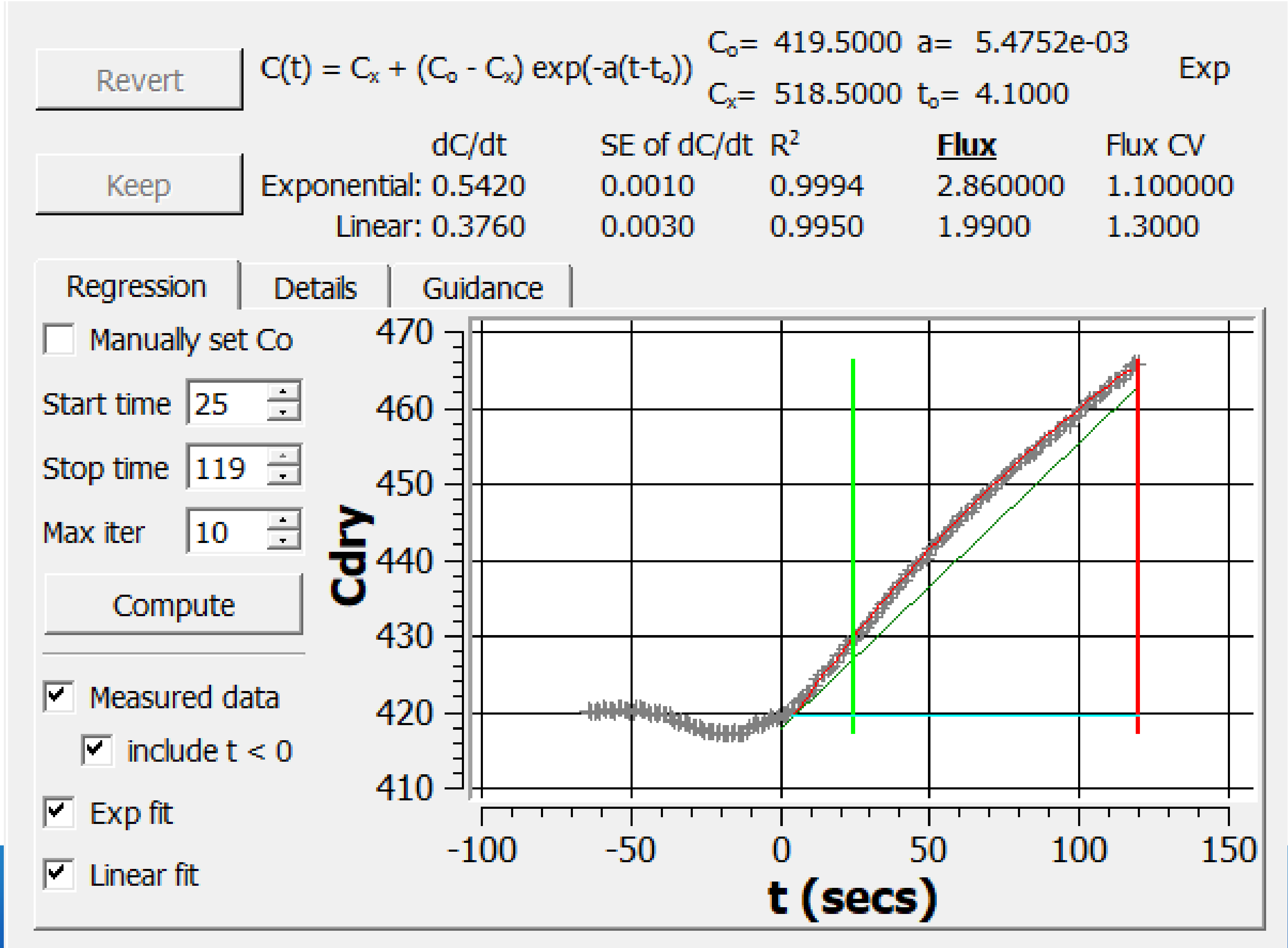
Changing in diffusion gradient

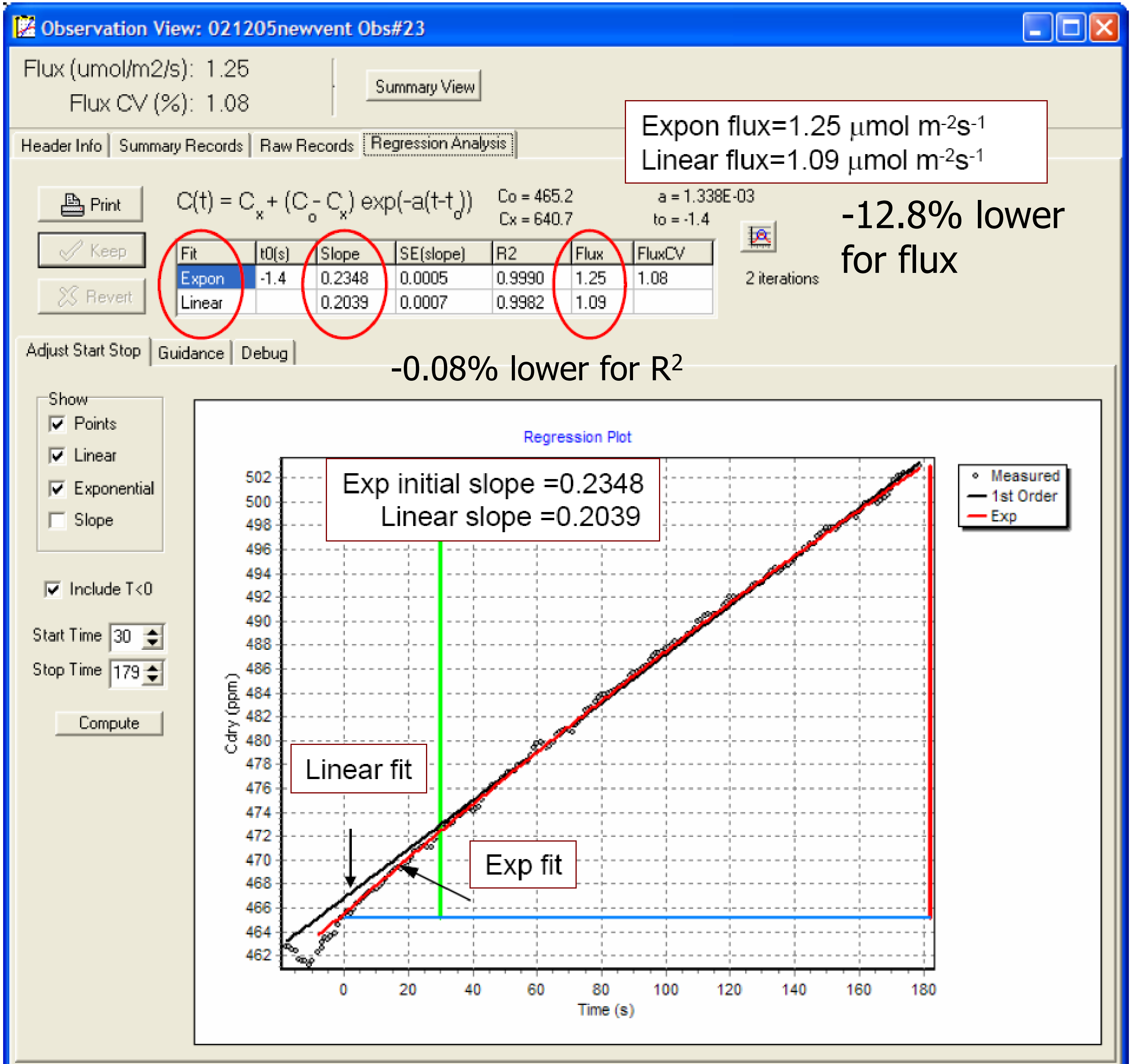




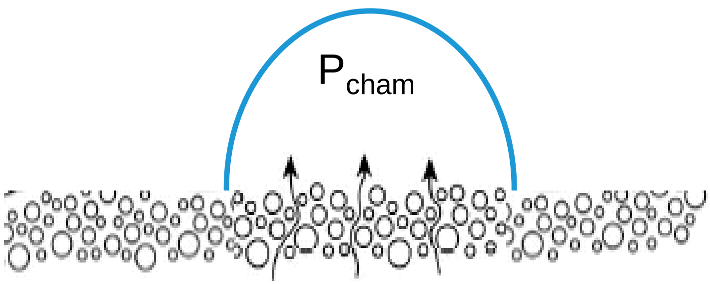
$$F_{CO2} = g \times (CO_2^{soil} - CO_2^{air})$$

Account for the change in CO_2 diffusion gradient inside the chamber



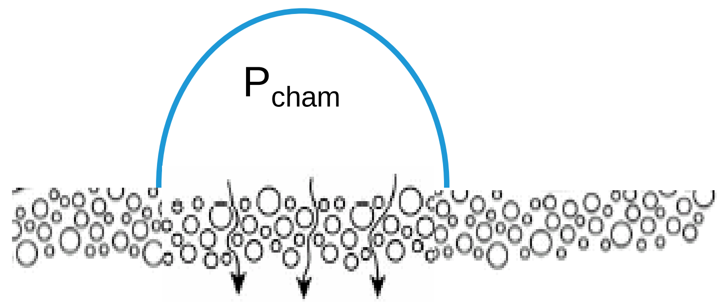

Observation View: 021205newvent Obs#23
Flux (umol/m2/s): 1.25
Flux CV (%): 1.08
Summary View
Expon flux=1.25 μmol m-2s-1
Linear flux=1.09 μmol m-2s-1
Header Info
Summary Records
Raw Records
Regression Analysis
Print
Keep
Revert
C(t) = Cx + (Co - Cx) exp(-a(t-to))
Co = 465.2
Cx = 640.7
a = 1.338E-03
to = -1.4
-12.8% lower for flux
Fit | t0(s) | Slope | SE(slope) | R2 | Flux | FluxCV
Expon | -1.4 | 0.2348 | 0.0005 | 0.9990 | 1.25 | 1.08
Linear | | 0.2039 | 0.0007 | 0.9982 | 1.09 |
2 iterations
Adjust Start Stop
Guidance
Debug
-0.08% lower for R2
Show
Points
Linear
Exponential
Slope
Include T<0
Start Time 30
Stop Time 179
Compute
Regression Plot
Exp initial slope =0.2348
Linear slope =0.2039
Measured
1st Order
Exp
Linear fit
Exp fit
Cdry (ppm)
Time (s)

Chamber pressure equilibrium



$P_{cham} < P_{atm}$

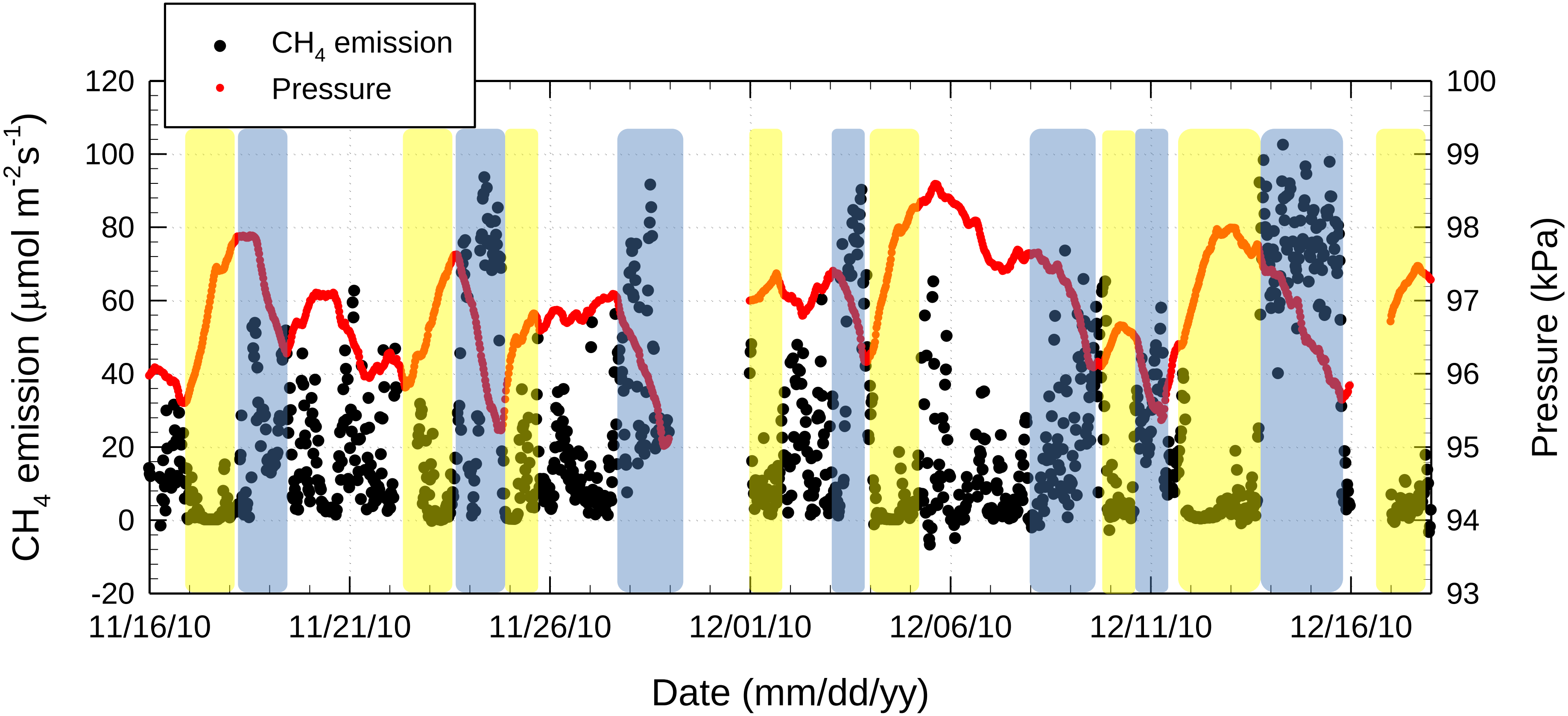
cause upward mass flow,
lead to a flux overestimation



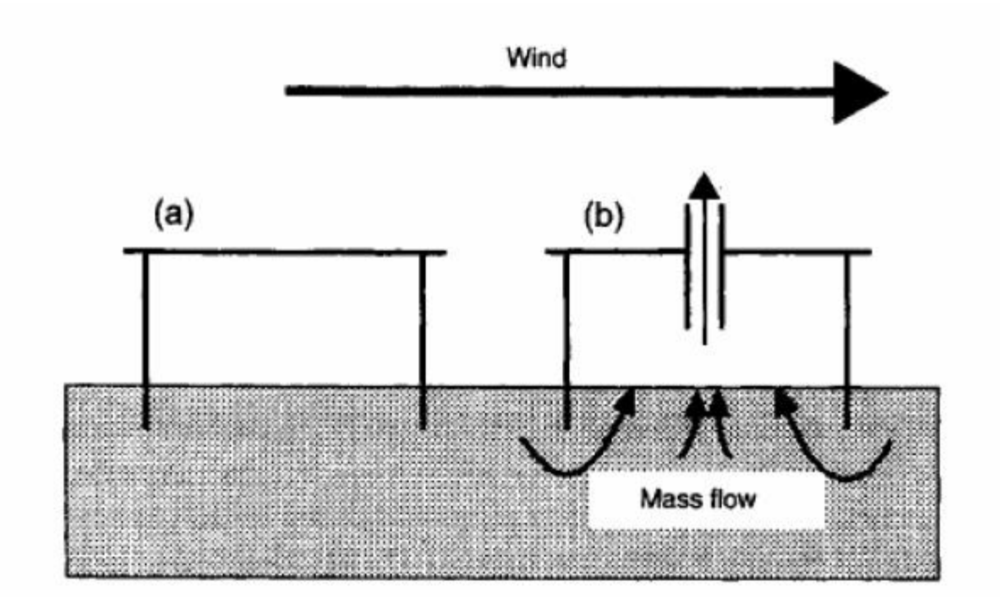
$P_{cham} > P_{atm}$

cause downward mass flow,
lead to a flux underestimation

Landfill F_{CH4} vs. changing in barometric pressure



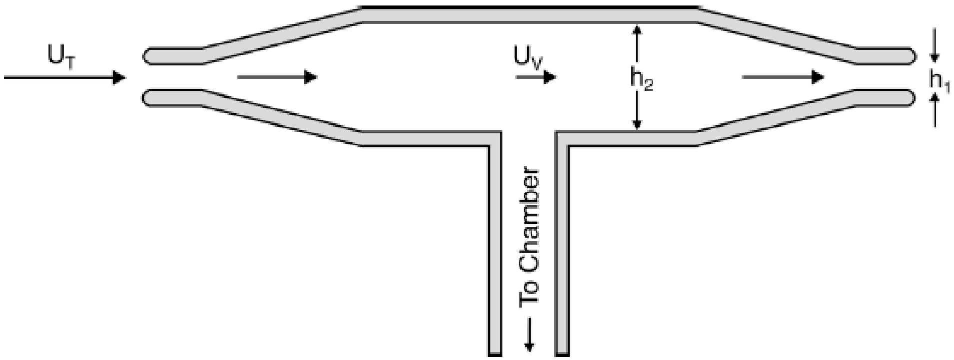
Xu et al., 2014. *Global Biogeochemical Cycle*.



$$P_{Chamber} = -0.5\,\rho U^2$$

Conen & Smith, *European Journal of Soil Science.* 1998

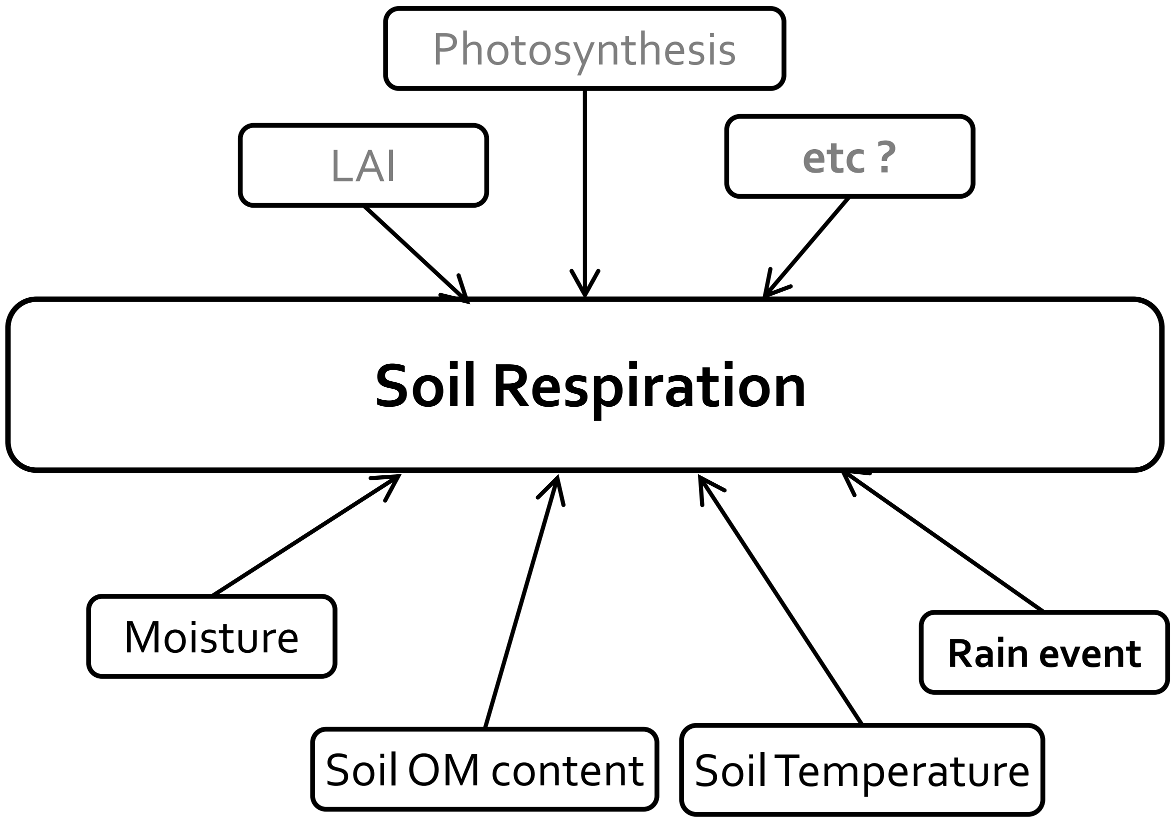
Minimize the influence on soil GHG "Transport"



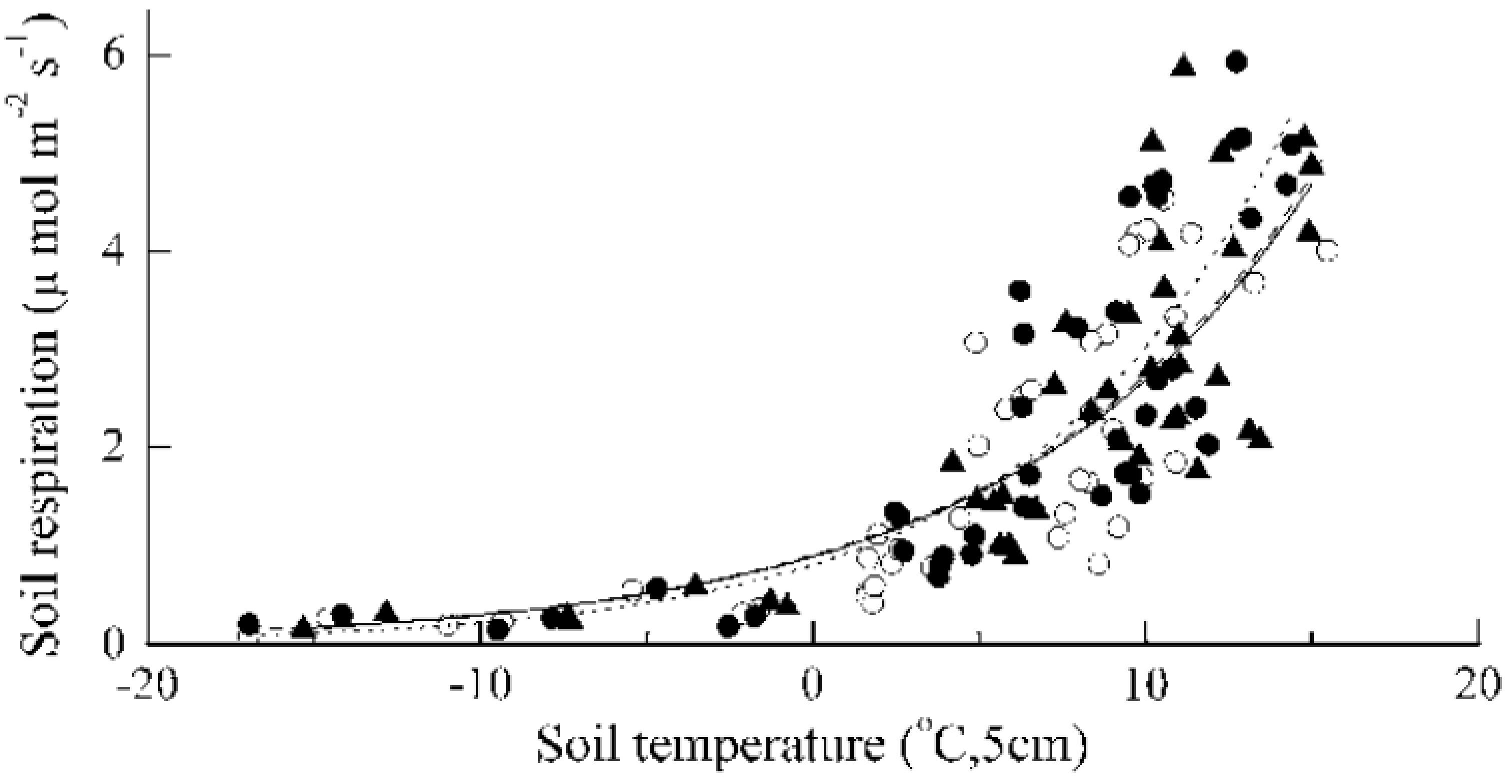
Xu et al., Journal of Geophysical Research-Atmosphere, 2006

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. Deal with temporal and spatial variation

Understanding control of soil respiration

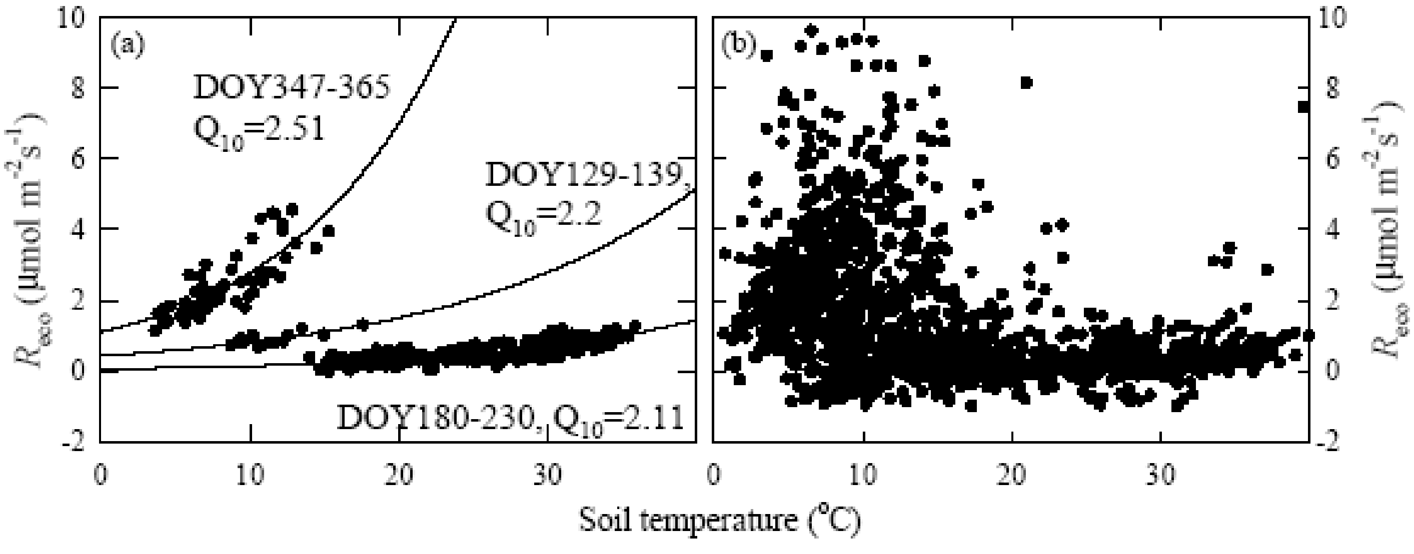


Temperature dependence of soil respiration



Temperature dependence of soil respiration

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



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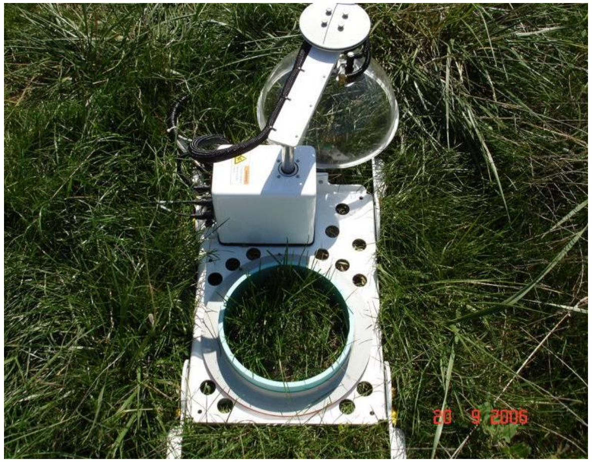
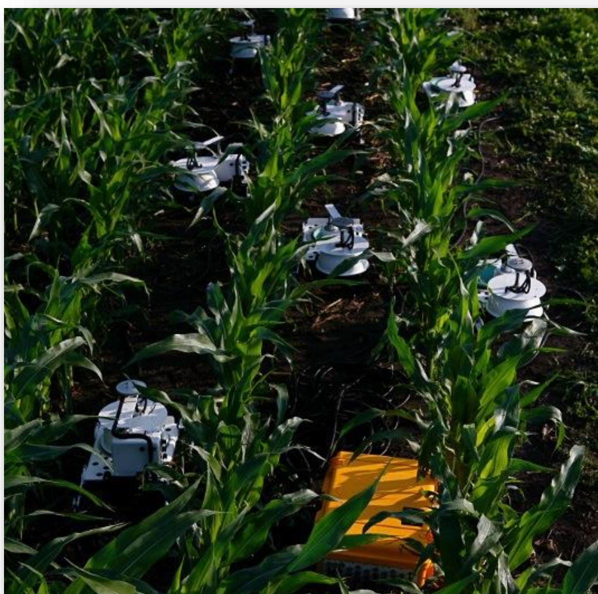
Minimize the disturbance to production, esp. for long-term automated chamber deployment

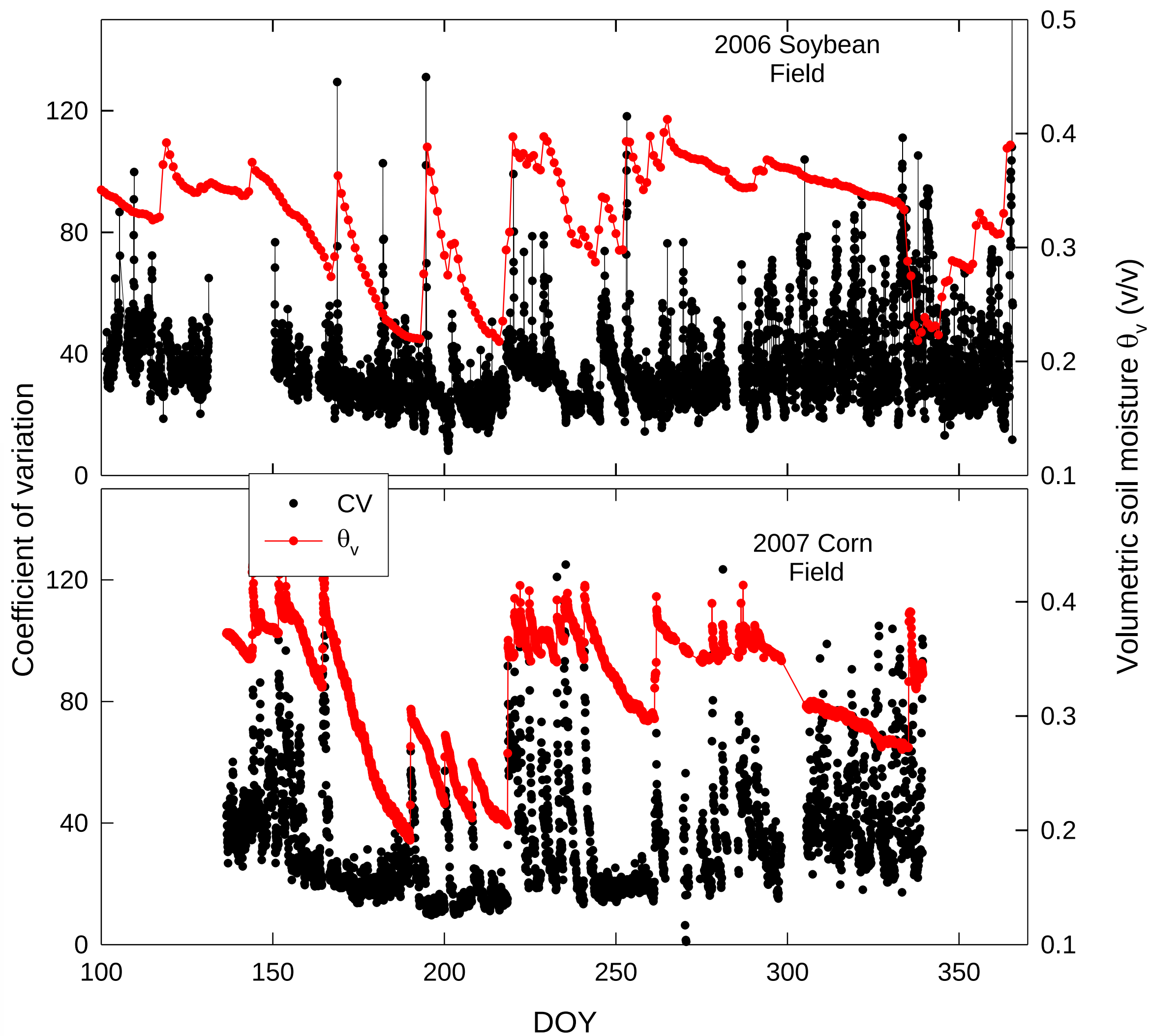


Minimize the disturbance to environment

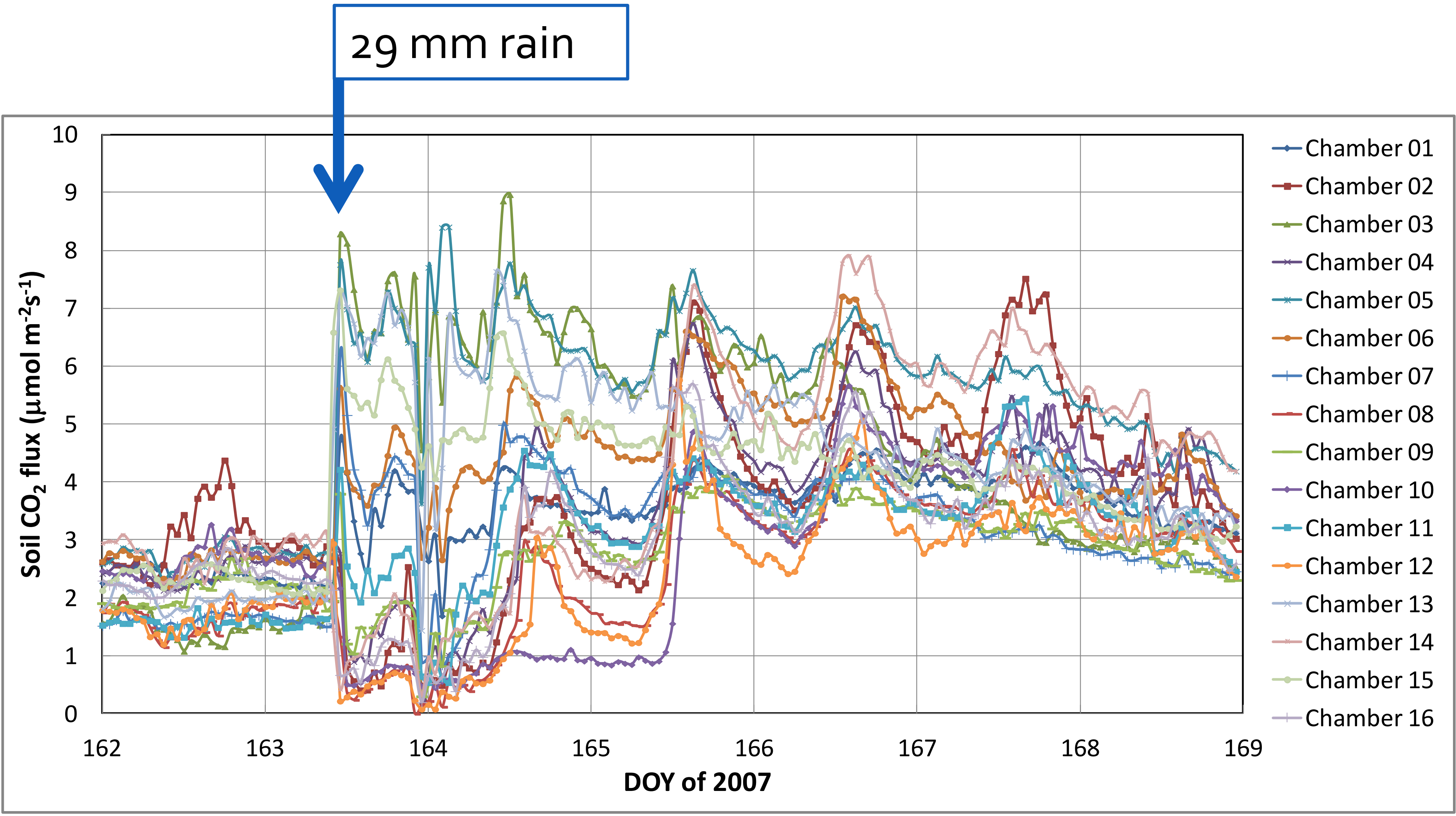
1. Accurately measure amount of GHG from the soil
2. Minimize the influence on soil GHG "Transport"
3. Minimize the influence on soil GHG "Production"
4. Deal with temporal and spatial variation

Characteristics: Large spatial variation





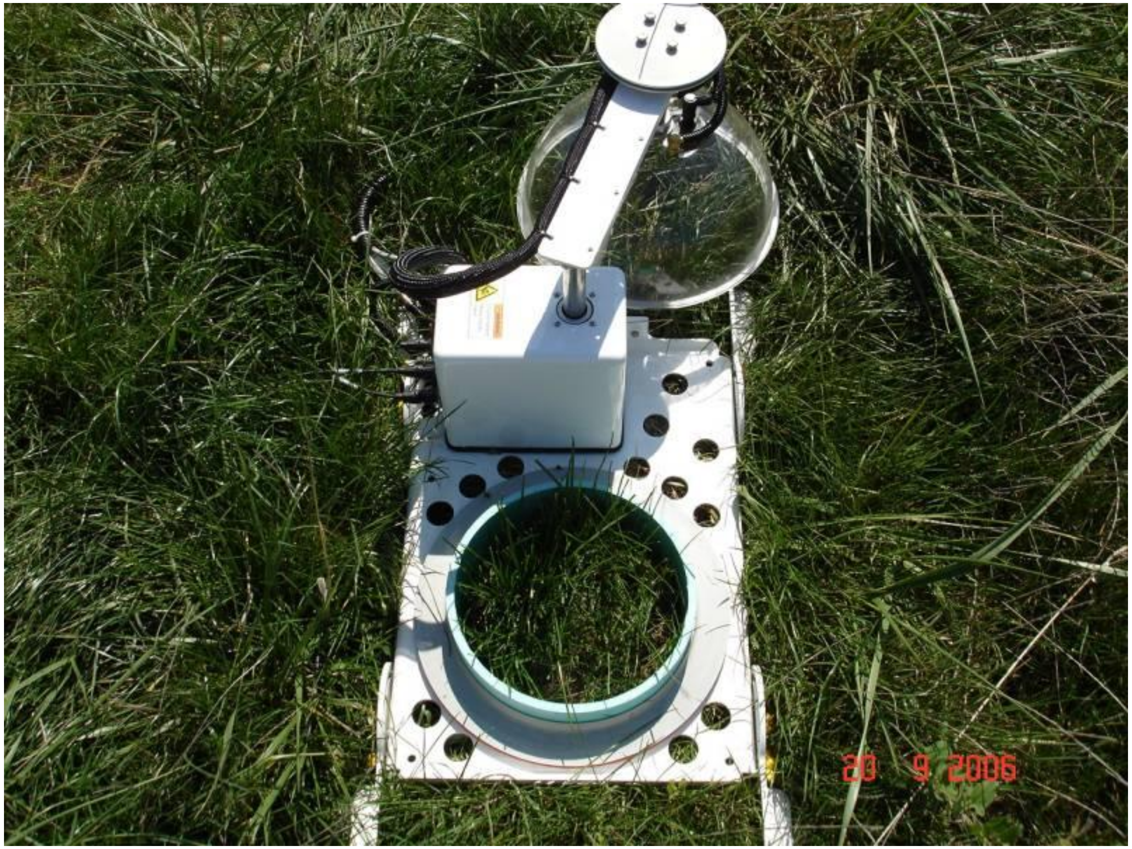
Solution: Long-term continuous measurement with multiple chambers



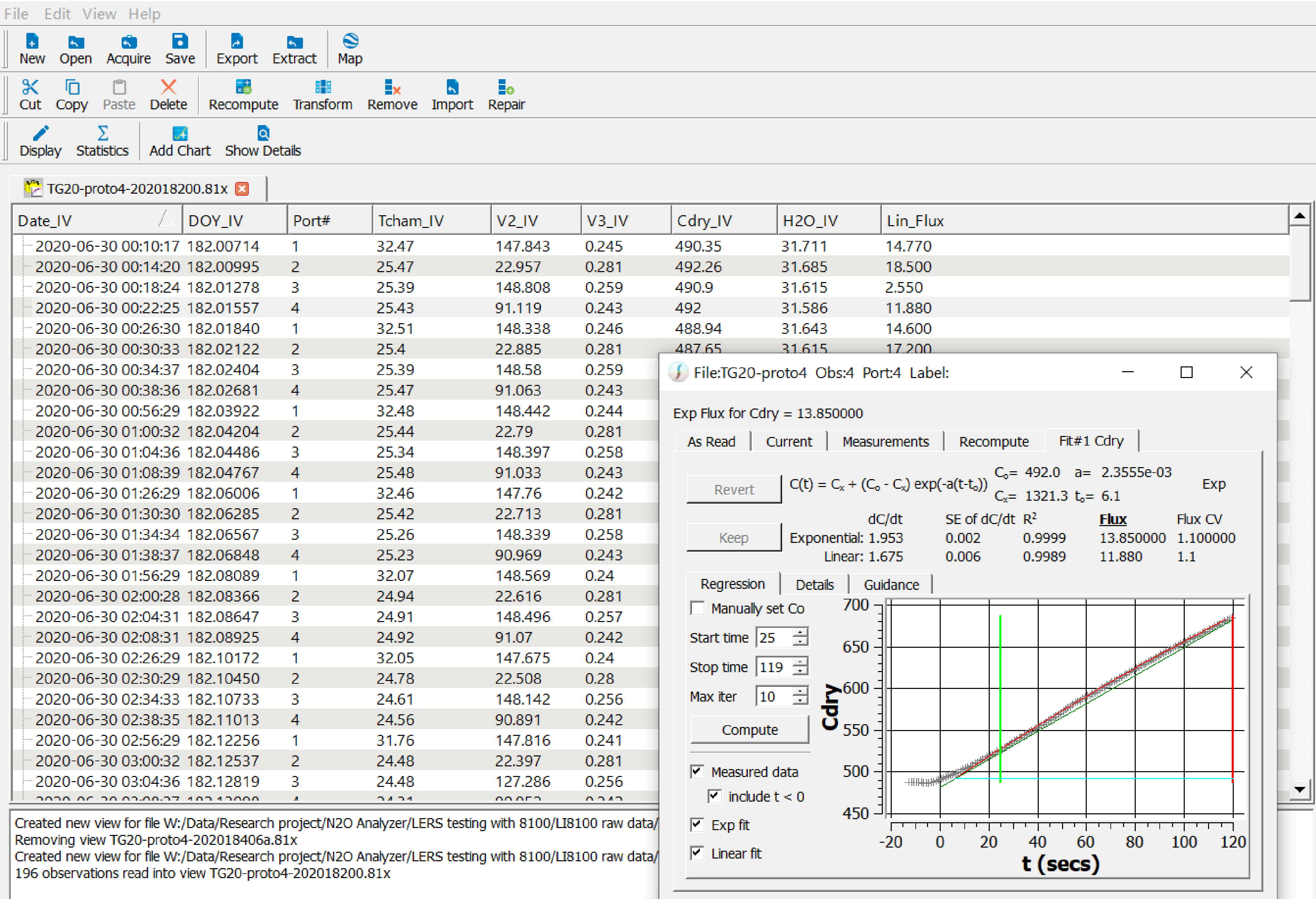
Survey Chamber

Long-term chamber system

Clear chamber for net ecosystem CO_2 exchange

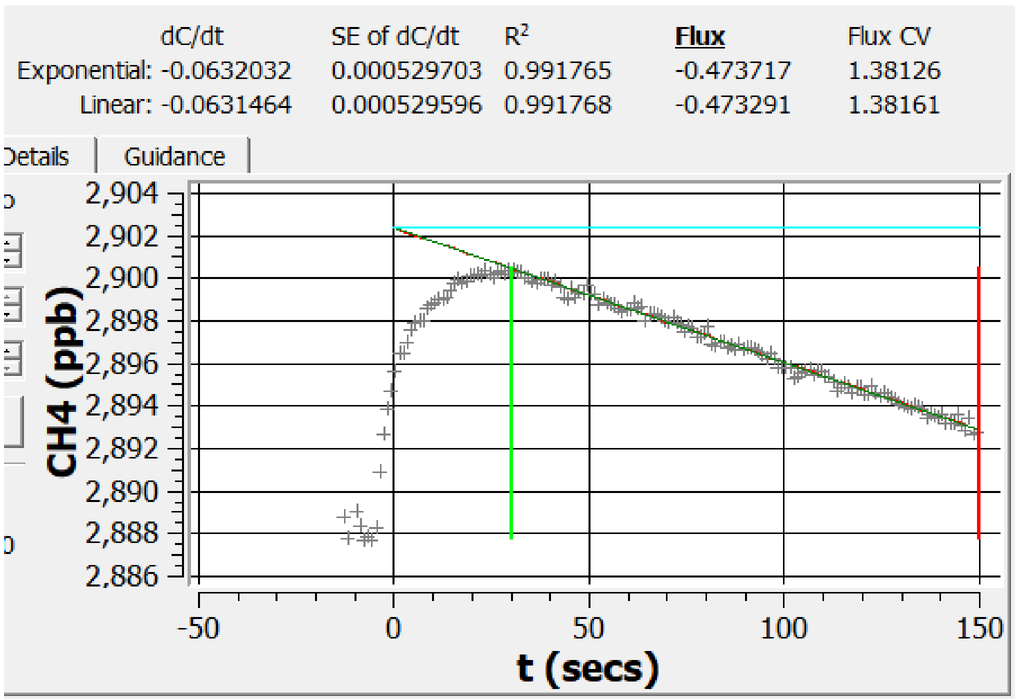


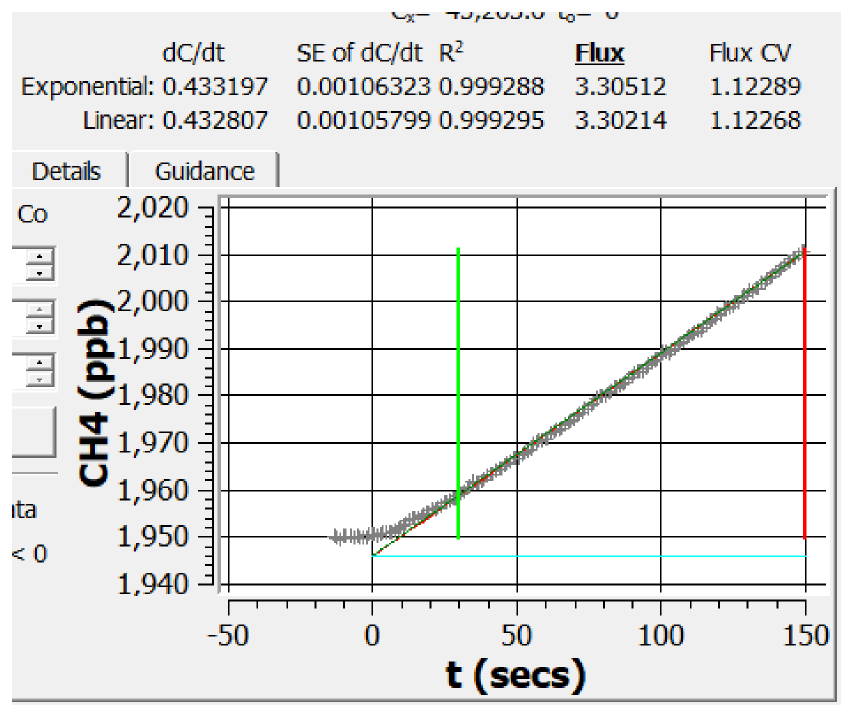
Data processing software; SoilFluxPro



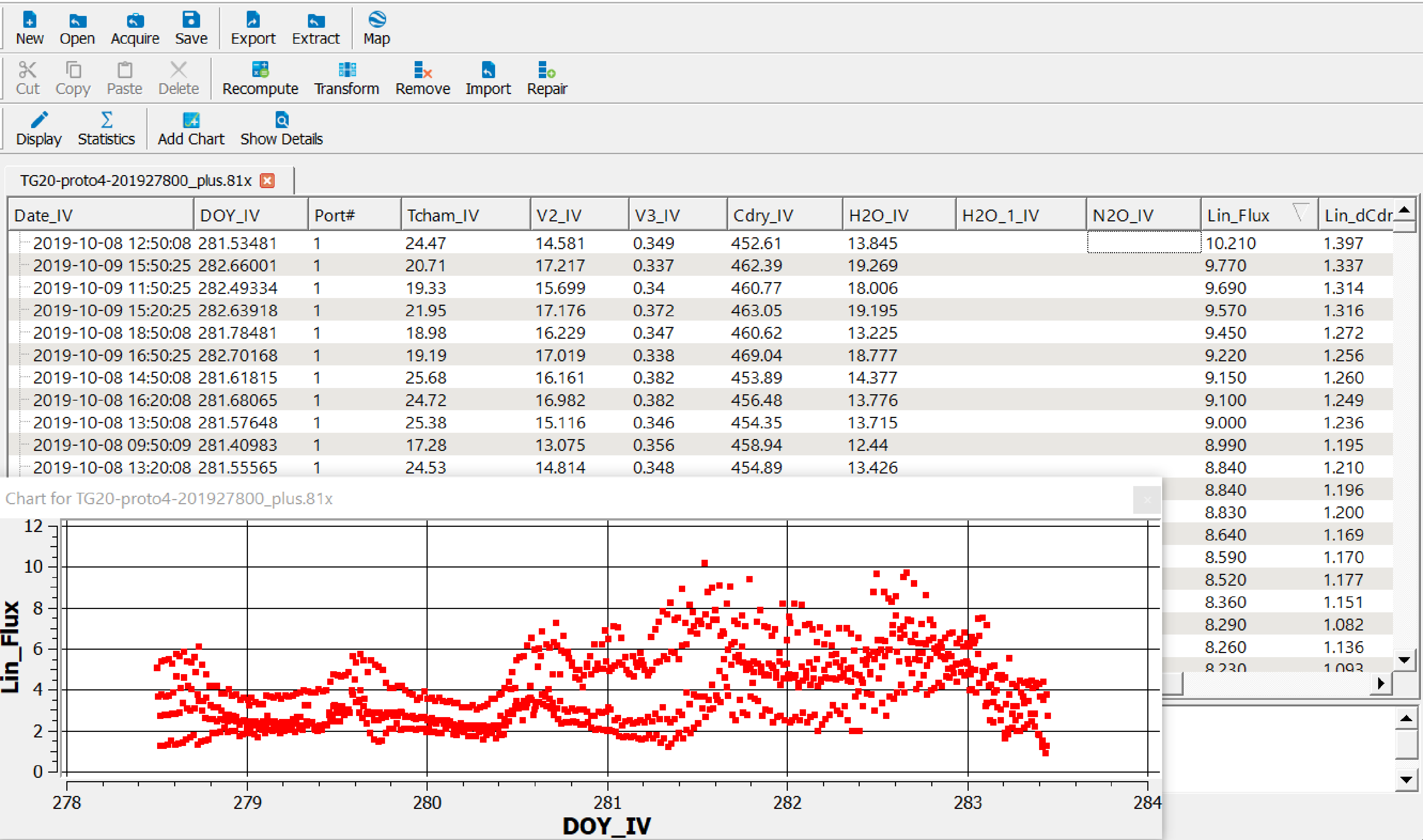
Date_IV	DOY_IV	Port#	Tcham_IV	V2_IV	V3_IV	Cdry_IV	H2O_IV	Lin_Flux
2020-06-30 00:10:17	182.00714	1	32.47	147.843	0.245	490.35	31.711	14.770
2020-06-30 00:14:20	182.00995	2	25.47	22.957	0.281	492.26	31.685	18.500
2020-06-30 00:18:24	182.01278	3	25.39	148.808	0.259	490.9	31.615	2.550
2020-06-30 00:22:25	182.01557	4	25.43	91.119	0.243	492	31.586	11.880
2020-06-30 00:26:30	182.01840	1	32.51	148.338	0.246	488.94	31.643	14.600
2020-06-30 00:30:33	182.02122	2	25.4	22.885	0.281	487.65	31.615	17.200
2020-06-30 00:34:37	182.02404	3	25.39	148.58	0.259			
2020-06-30 00:38:36	182.02681	4	25.47	91.063	0.243			
2020-06-30 00:56:29	182.03922	1	32.48	148.442	0.244			
2020-06-30 01:00:32	182.04204	2	25.44	22.79	0.281			
2020-06-30 01:04:36	182.04486	3	25.34	148.397	0.258			
2020-06-30 01:08:39	182.04767	4	25.48	91.033	0.243			
2020-06-30 01:26:29	182.06006	1	32.46	147.76	0.242			
2020-06-30 01:30:30	182.06285	2	25.42	22.713	0.281			
2020-06-30 01:34:34	182.06567	3	25.26	148.339	0.258			
2020-06-30 01:38:37	182.06848	4	25.23	90.969	0.243			
2020-06-30 01:56:29	182.08089	1	32.07	148.569	0.24			
2020-06-30 02:00:28	182.08366	2	24.94	22.616	0.281			
2020-06-30 02:04:31	182.08647	3	24.91	148.496	0.257			
2020-06-30 02:08:31	182.08925	4	24.92	91.07	0.242			
2020-06-30 02:26:29	182.10172	1	32.05	147.675	0.24			
2020-06-30 02:30:29	182.10450	2	24.78	22.508	0.28			
2020-06-30 02:34:33	182.10733	3	24.61	148.142	0.256			
2020-06-30 02:38:35	182.11013	4	24.56	90.891	0.242			
2020-06-30 02:56:29	182.12256	1	31.76	147.816	0.241			
2020-06-30 03:00:32	182.12537	2	24.48	22.397	0.281			
2020-06-30 03:04:36	182.12819	3	24.48	127.286	0.256			

CH_4 release or uptake





View time series of soil GHG flux data with SoilFluxPro



Date_IV	DOY_IV	Port#	Tcham_IV	V2_IV	V3_IV	Cdry_IV	H2O_IV	H2O_1_IV	N2O_IV	Lin_Flux	Lin_dCdr
2019-10-08 12:50:08	281.53481	1	24.47	14.581	0.349	452.61	13.845			10.210	1.397
2019-10-09 15:50:25	282.66001	1	20.71	17.217	0.337	462.39	19.269			9.770	1.337
2019-10-09 11:50:25	282.49334	1	19.33	15.699	0.34	460.77	18.006			9.690	1.314
2019-10-09 15:20:25	282.63918	1	21.95	17.176	0.372	463.05	19.195			9.570	1.316
2019-10-08 18:50:08	281.78481	1	18.98	16.229	0.347	460.62	13.225			9.450	1.272
2019-10-09 16:50:25	282.70168	1	19.19	17.019	0.338	469.04	18.777			9.220	1.256
2019-10-08 14:50:08	281.61815	1	25.68	16.161	0.382	453.89	14.377			9.150	1.260
2019-10-08 16:20:08	281.68065	1	24.72	16.982	0.382	456.48	13.776			9.100	1.249
2019-10-08 13:50:08	281.57648	1	25.38	15.116	0.346	454.35	13.715			9.000	1.236
2019-10-08 09:50:09	281.40983	1	17.28	13.075	0.356	458.94	12.44			8.990	1.195
2019-10-08 13:20:08	281.55565	1	24.53	14.814	0.348	454.89	13.426			8.840	1.210
										8.840	1.196
										8.830	1.200
										8.640	1.169
										8.590	1.170
										8.520	1.177
										8.360	1.151
										8.290	1.082
										8.260	1.136
										8.230	1.093

Data processing software

- Soil gas flux data analysis software
- Recompute dataset
- QA/QC
- View time series of soil GHG flux data
- Compute statistics
- Export results for further analysis

SoilFluxPRO™

The theory for soil chamber sounds easy ! In reality, it is very challenging to get accurate result

1. Accurately measure amount of GHG from the soil

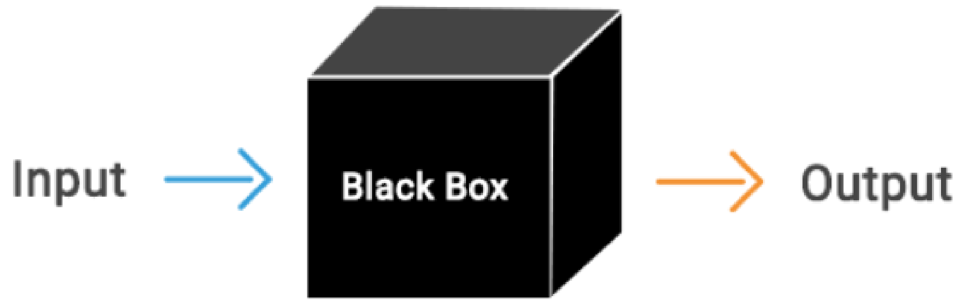
2. Minimize the influence on soil GHG “Transport”

3. Minimize the influence on soil GHG “Production”

4. Deal with temporal and spatial variation

An important advice

- Understanding the theory of the technique you are using in your research will help you to get much better experimental data.
- Don’t treat your instrument as a black box.



Summary

- **Significance** for CO_2, CH_4 and N_2O
- Chamber-based **method**; theory and requirement
- **Production:** Soil temperature, soil moisture, SOM, photosynthesis, LAI etc.
- **Transport**
  - Molecular diffusion due to the concentration gradient
  - Mass flow due to the pressure variation

Q & A