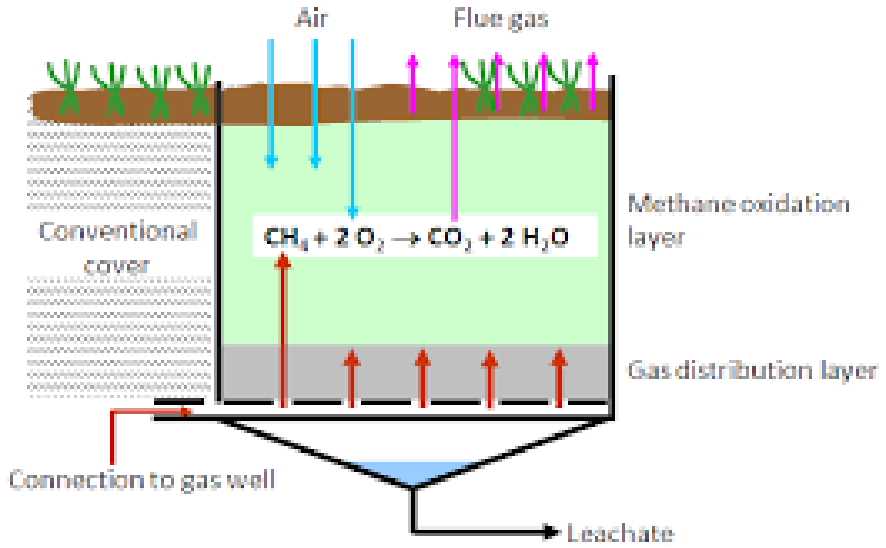
PTAC Biocovers Project Update Meeting – Preliminary Data

MEMS Research Project: Ian Hers, Aaron Cahill, Ian Mitchell

Jan 19, 2025

Project Overview

- Literature Review, study design and workplan
- Initial modeling
- Site attainment
- Biocell construction (compost testing, filling, instrumentation, gas injection)
- Baseline phase: Nov 2023 – Aug 14, 2024
- Gas injection phase: Aug 15 – Nov 27, 2024
- Continuous monitoring: gas flux (with some trials/gaps), temperature, weather, oxygen
- Discrete monitoring: soil gas composition, isotopes, fluxes (static chamber), microbes, soil properties, etc.
- Extensive / comprehensive data obtained – thousands of data pts (with some trials and challenges along the way)



Key statistics

Cell dimensions: 2.5 m by 3 m by 1 m thick bioactive compost media

Volume: 7.5 m3

Initial injection rate: 0.58 m3

Subsequent injection rate: 1.7 m3 About 90% CH_4

Above values to be checked

Project Overview

Automated EoSense CH_4 and CO_2 flux chamber

Gas cylinders and Alicat flow measurement device

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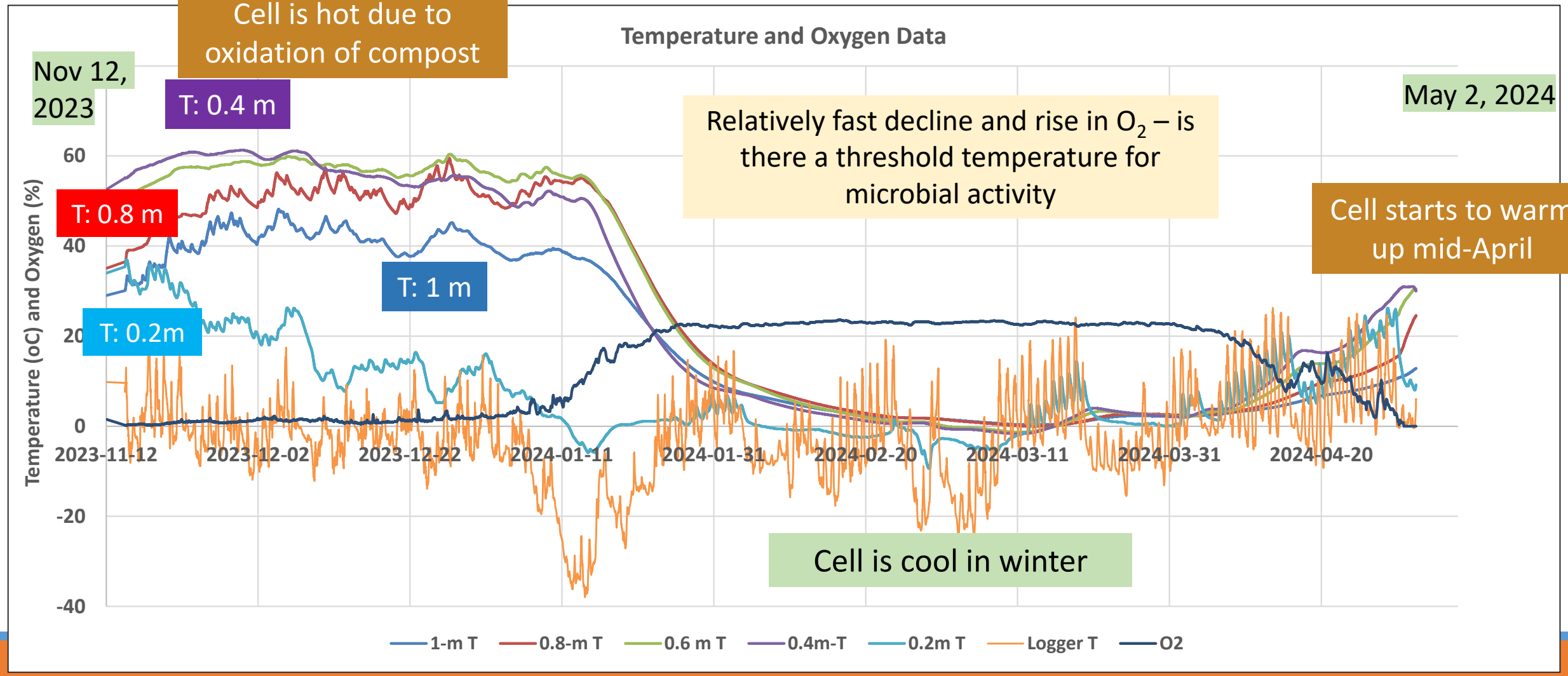
Baseline Soil Temperature & Oxygen: Nov 2023 - Apr 2024



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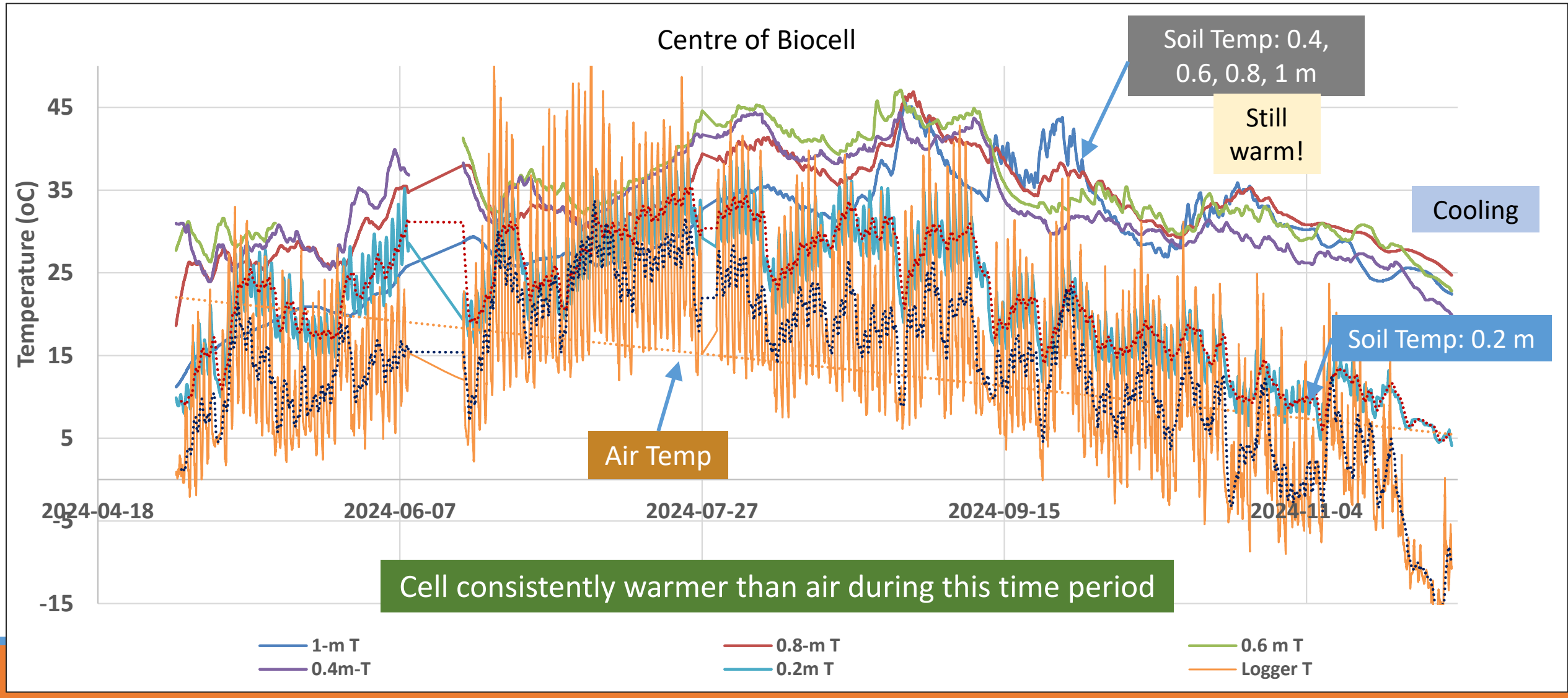
Soil and Air Temperature: May 5 - Nov 27



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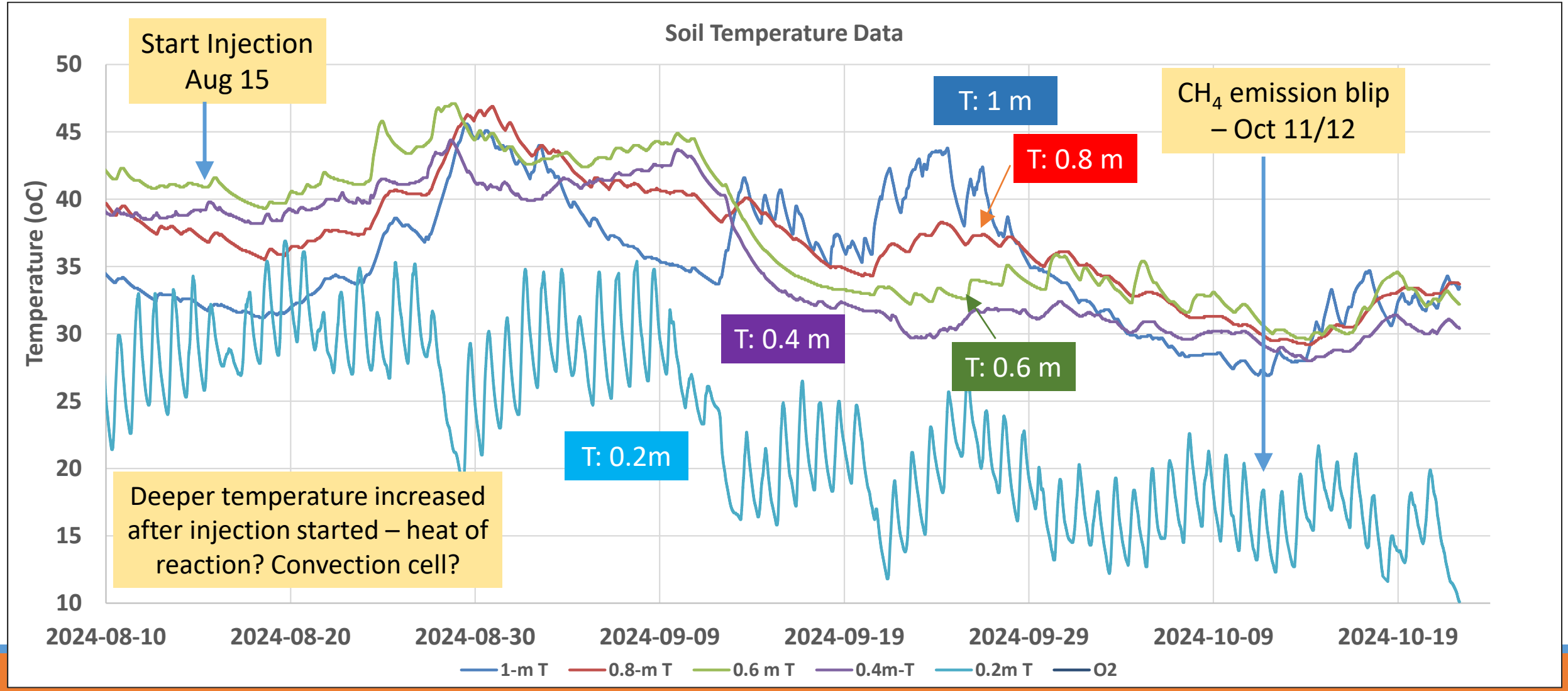
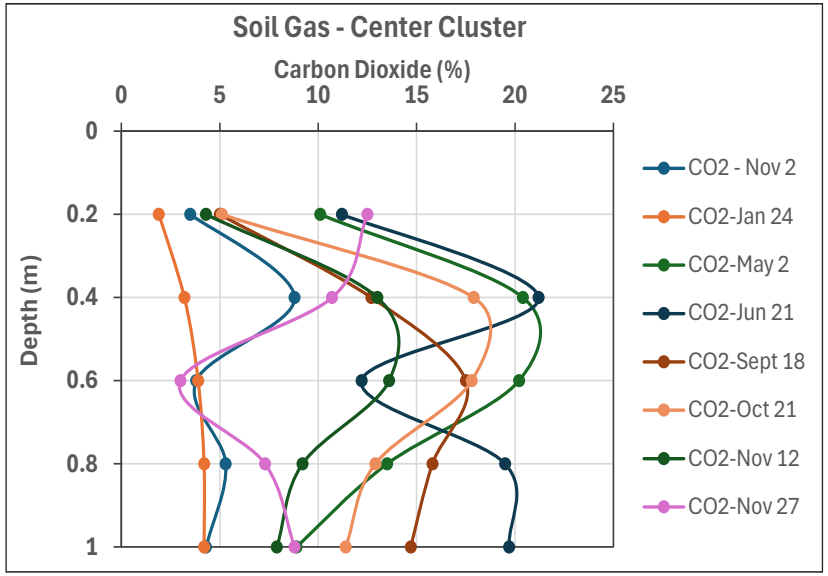
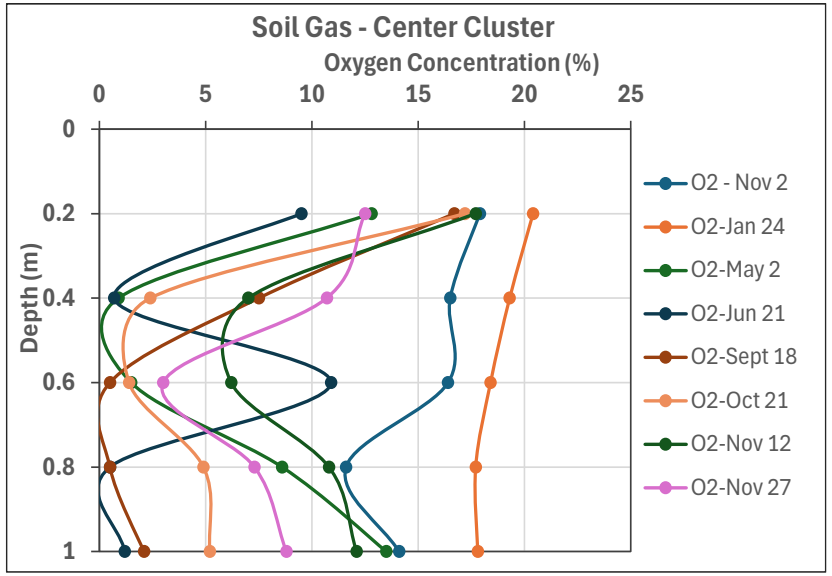
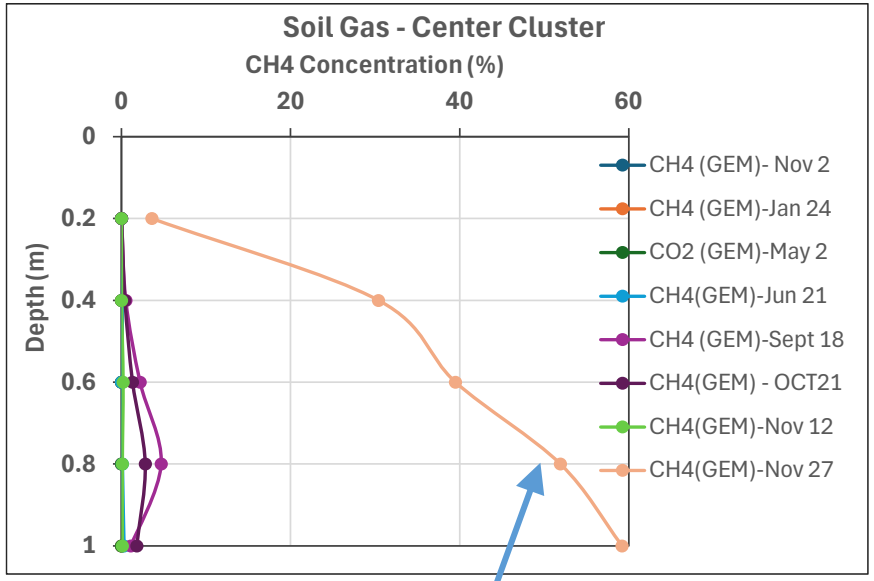
Soil Temperature: Aug 10 – Oct 22



Soil Gas – Center Cluster







Elevated O2 concentrations in most of cell and low CH4 concentrations line of evidence for CH4 oxidation

Less CH4 oxidation Nov 27 event – cell rapidly; possibly convection cell, warm in core, cool in sides

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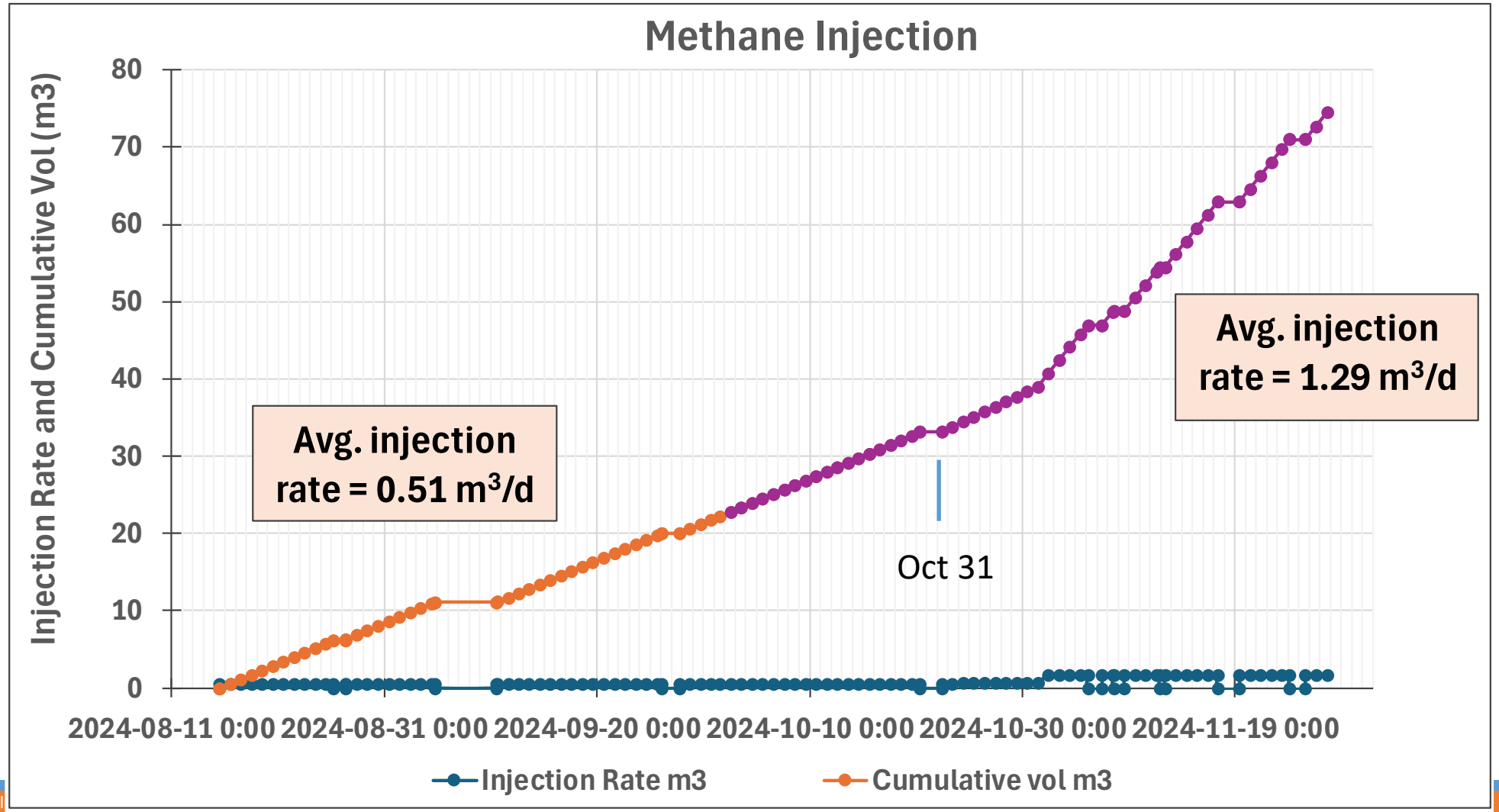
Methane Injection



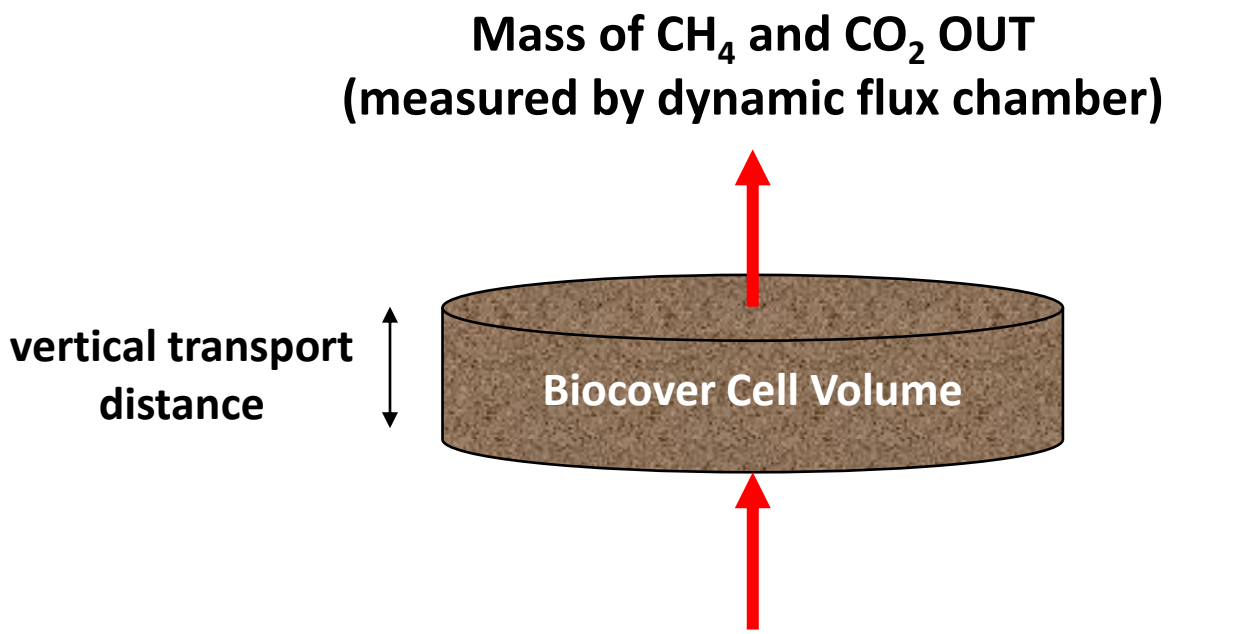
Example Key Flux Data October 2024

These data are just a small snapshot of what we have and will be working through to gain as much insight as possible.

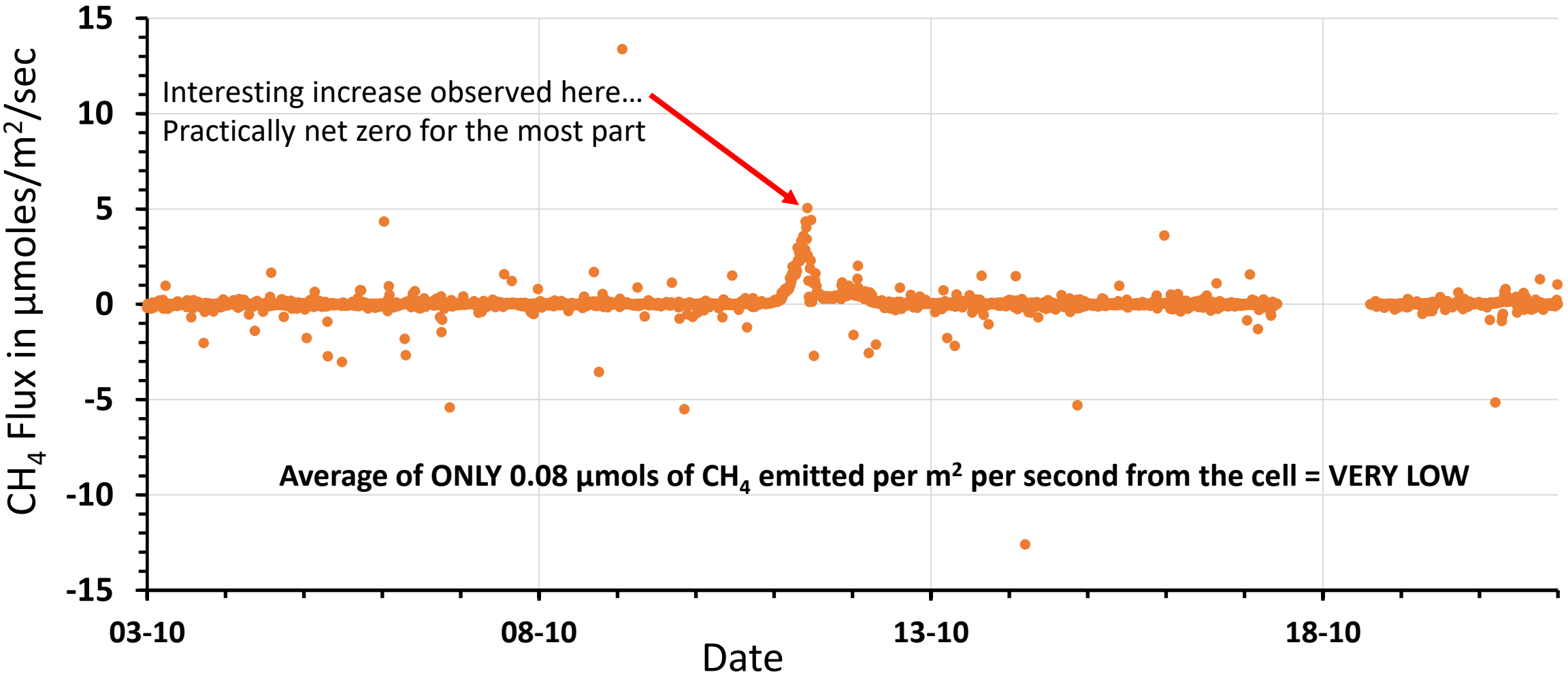
LOTS MORE INSIGHTS TO COME

What this snap shot shows is that the cell is able to fully oxidize 0.58 m3/day of methane injection except short blips when strong convective or advective gas gradients push methane up and limit oxidation (rate issue, bugs can’t degrade methane faster enough, but not overall significant limitation)…

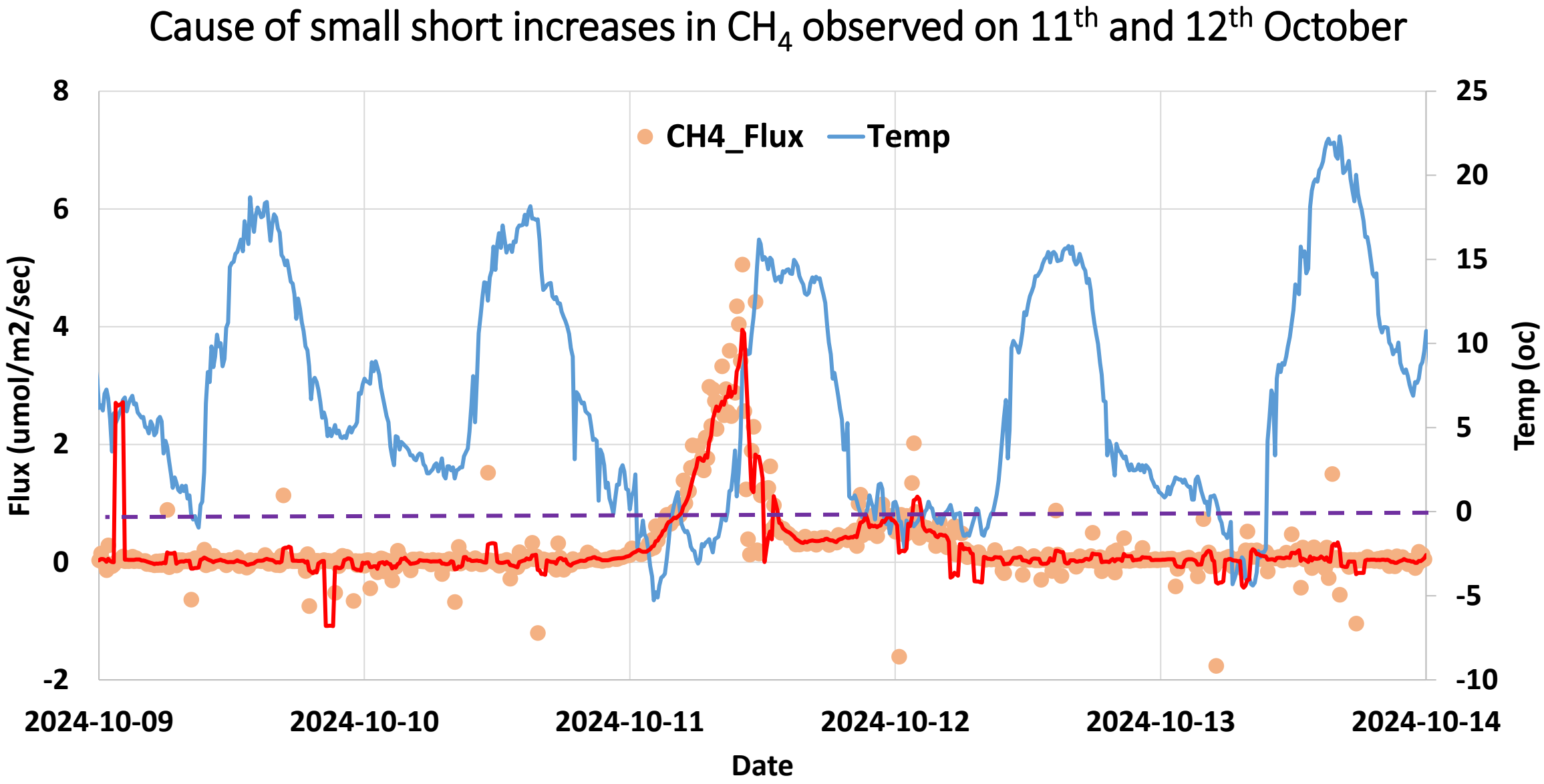
ALL SUBJECT TO QA/QC AND CHANGE – TENTATIVE ONLY


Mass of CH_4 and CO_2 OUT
(measured by dynamic flux chamber)
vertical transport distance
Biocover Cell Volume
Mass of CH_4 IN
(controlled/measured by mass flow meter)

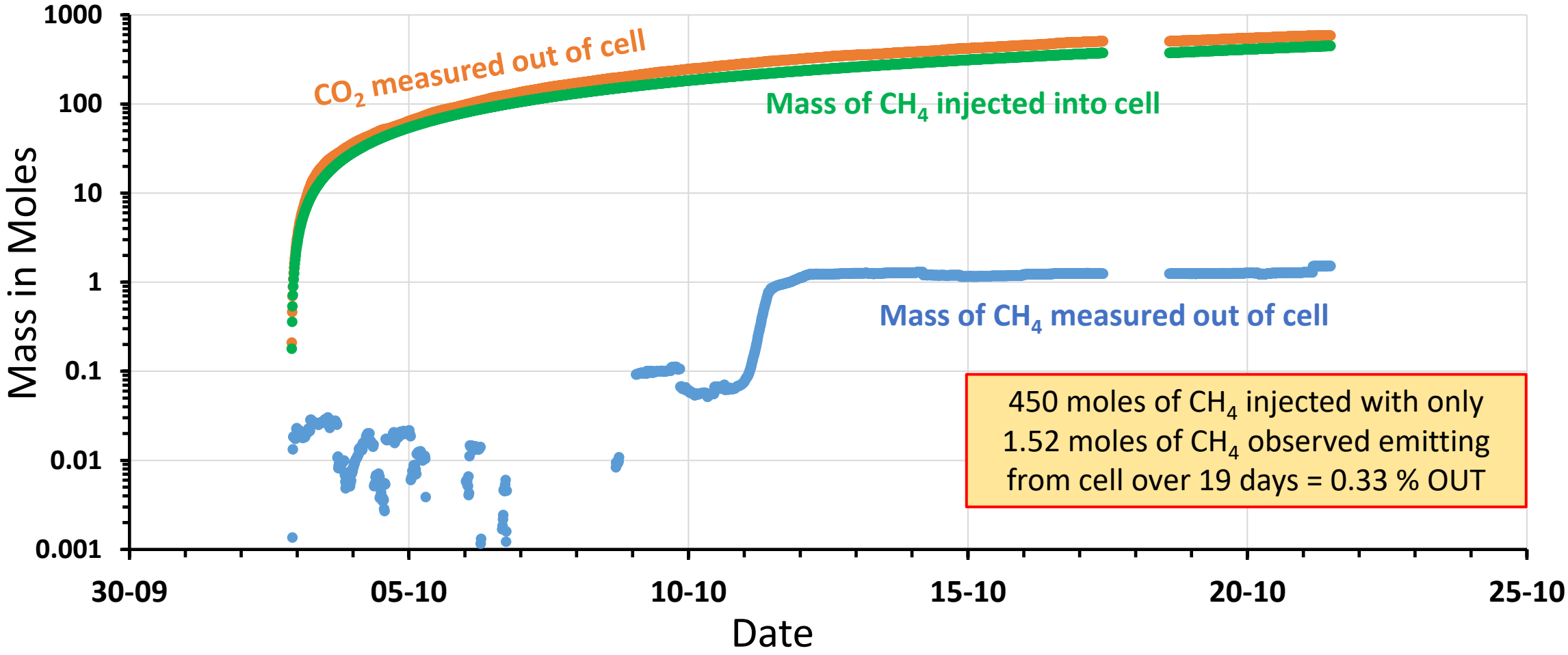
High resolution (10 minute interval) flux of CH_4 out of cell centre observed during key period in October



Early data review shows freezing conditions impacting oxidation rates:

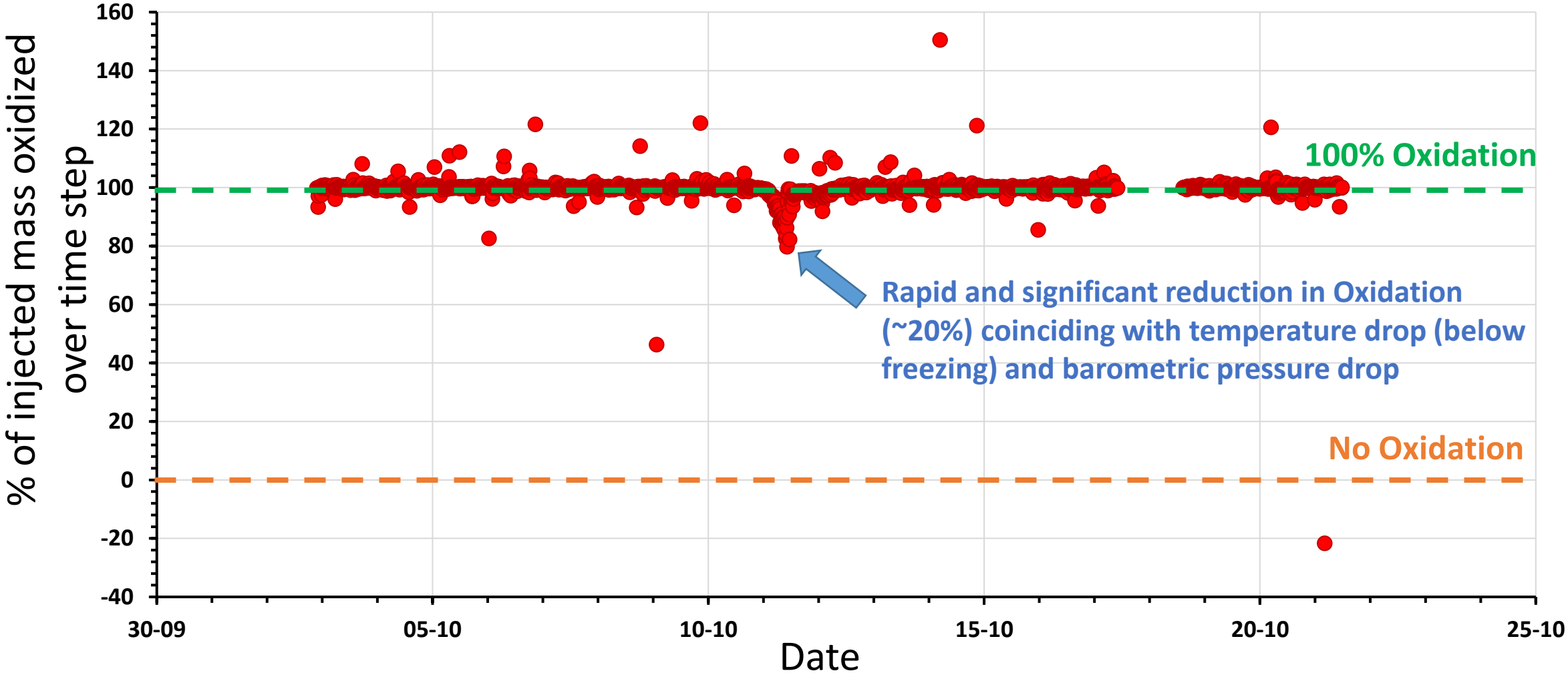


Mass Balance: Compare inflow to outflow

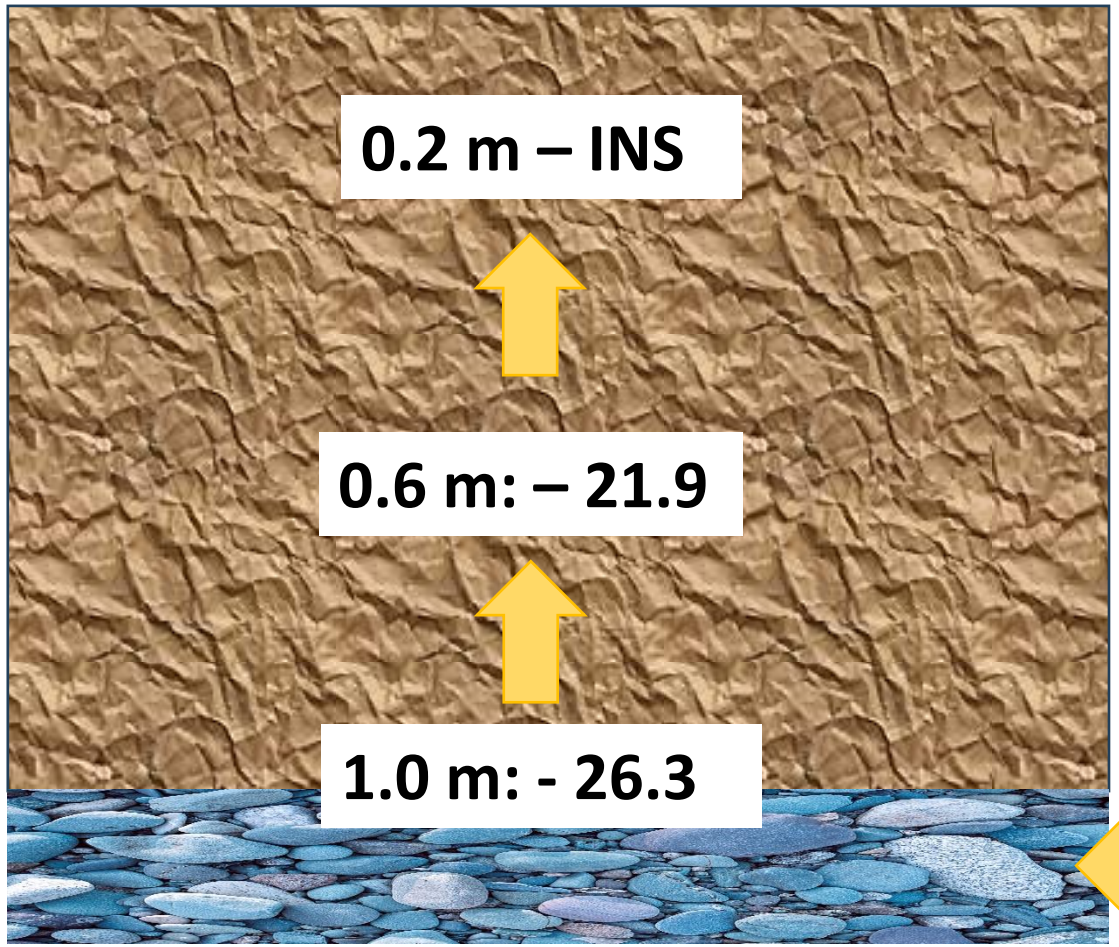


Shows cell effectively removed CH_4 and prevented emissions to atmosphere

High level of efficiency when above freezing…



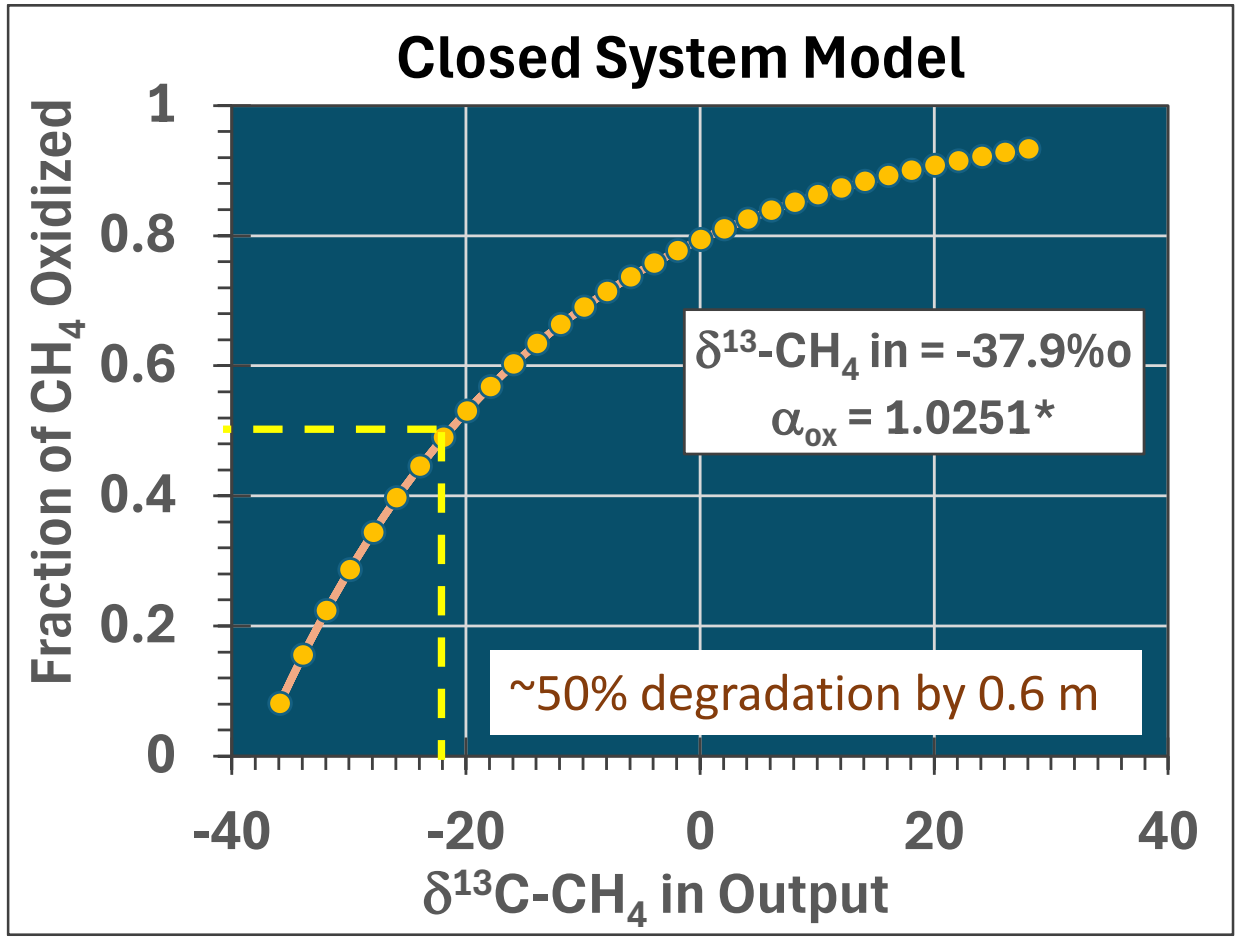
Stable Carbon Isotope Analysis – Line of Evidence for Biodegradation



$\delta^{13}C$-CH_4 Results (‰) During Injection (Sept 2024)

As CH_4 is transported, $\delta^{13}C$-CH_4 becomes less negative. This is consistent with faster biodegradation of ^{12}C vs. ^{13}C.

Stable Carbon Isotope Analysis – Line of Evidence for Biodegradation



* α_{ox} avg. of Powell et al. (2007) (1.0244) and Capanema and Cabral (2012) (1.0258). Can obtain from lab incubation studies

Rayleigh Fractionation Model Assuming Closed System, Advective Transport

$$f_{oxir} = 1 - \left(\frac{\delta_{out} + 1000}{\delta_{in} + 1000}\right)^{\alpha_{ox}/1-\alpha_{ox}}$$

$$\delta^{13}C = 1000\left(\frac{R_{sam}}{R_{std}} - 1\right)$$

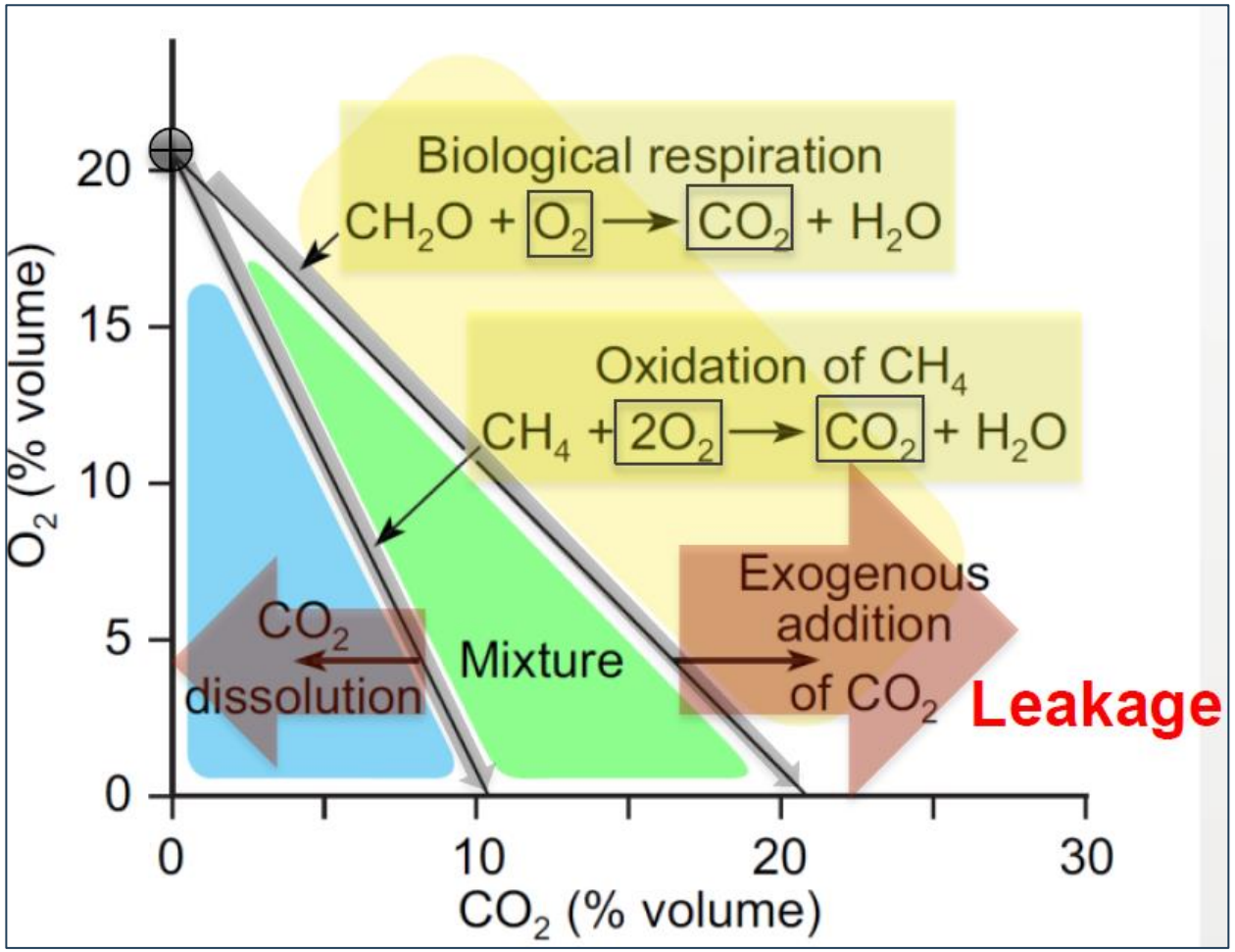
Rayleigh Fractionation Model Assuming Open System, Advective & Diffusive Transport

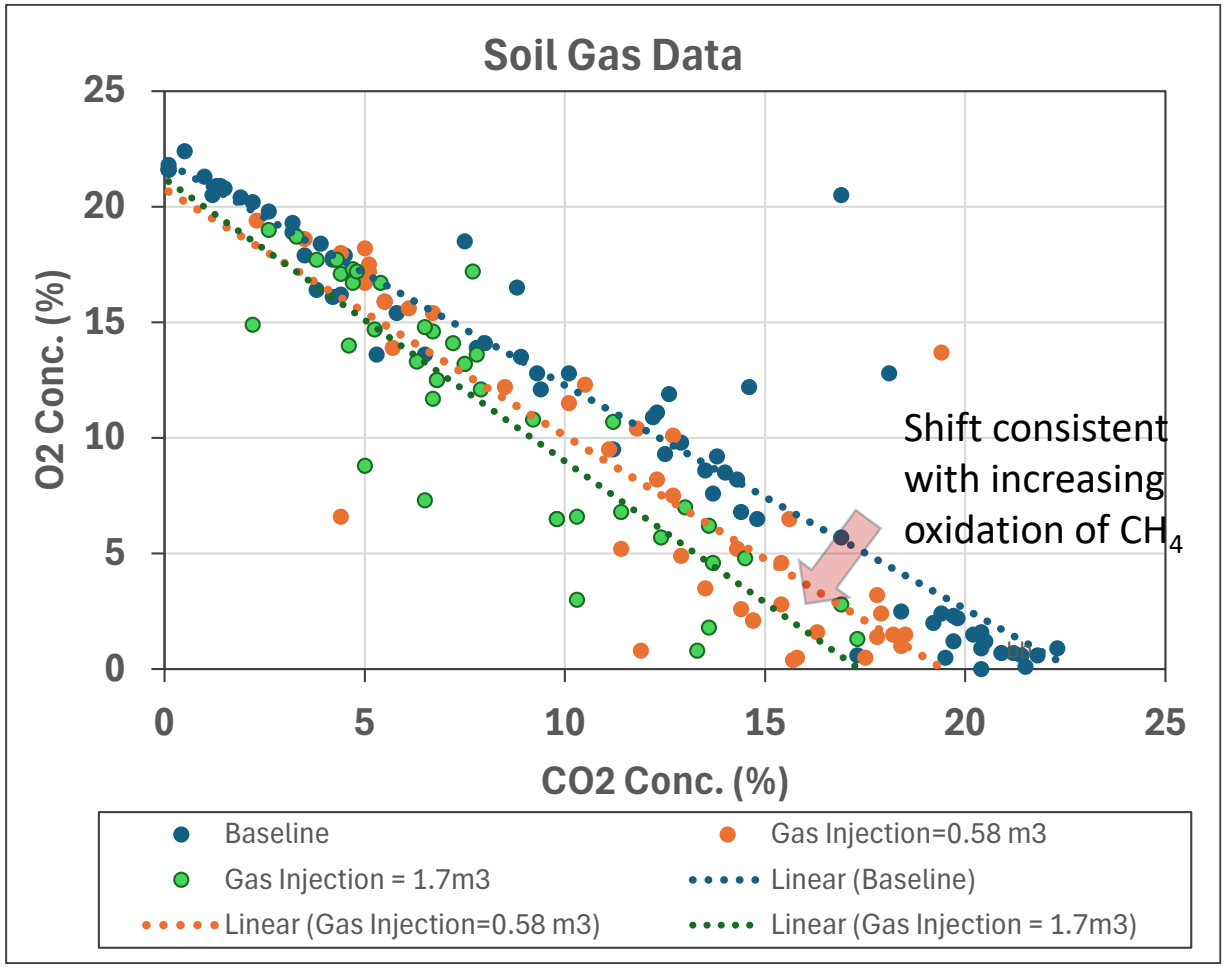
$$f_{oxio} = \frac{\delta_{out} - \delta_{in}}{1000(\alpha_{ox} - \alpha_{trans})}$$

Diffusing ^{12}C-CH_4 will migrate slightly faster than ^{13}C – added complexity

where δ_{in} and δ_{out} are standard carbon isotope ratios of input and output, α_{ox} is isotope fractionation, R_{sam} is $^{13}C/^{12}C$ ratio of sample, R_{std} is ratio for standard Vienna Peedee Belemnite (0.01124).

Process Based Analysis of Oxidation – Line of Evidence for Biodegradation





From Romanuk et al. (2012)

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Initial Take Homes

- Cell highly effective and able to easily oxidize CH4 load injected except when significant cooling occurred in late November, not unexpected based on thermal shock and gradients
- Appears to have 100% efficiency for almost all of 19-day period in October
- Short methane emission blip when temperature dipped < 0 degrees – could be from increased thermal gradient and barometric pressure drop
- Cell able to store and release mass intermittently
- Massive potential to reduce emissions at live wells – needs temperature control/insulation efforts as well as other controls to optimize
- Think a 60 – 80% efficiency could be achieved annually….
- Needs field trial next with robust monitoring program
- More insights to be gained from full data analyses….

Next Steps

- Controlled injection Study
  - Wind-down field monitoring in November 2024
  - Conduct additional data analysis and prepare project report in Winter 2025
  - Key recommendations/proposals on potential for roll out at scale in “live” environments captured in proposal submitted on Jan 19, 2025

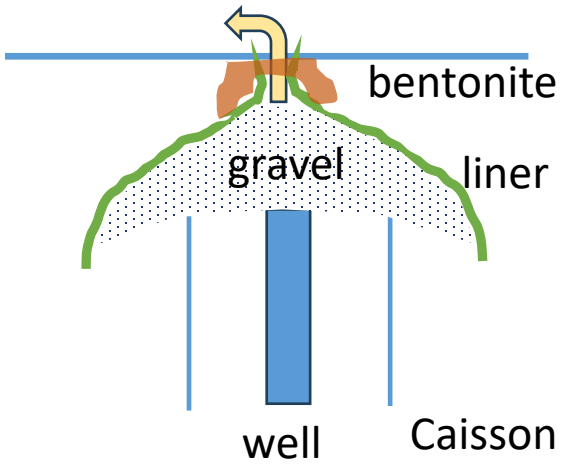
Proposed Field Demonstration Project

- **Goals**: are to demonstrate technology at “live” sites, establish basis for technology adoption, obtain cost and performance data
- **Objectives**: obtain additional data on key factors including 4-season data, refine biocell design and monitoring
- **Approach**: re-use biocell / instrumentation at 1st site, test biocover concept at 2nd site

Possible use of CNRL well sites (Turner Valley, Bonnyville) – to be determined

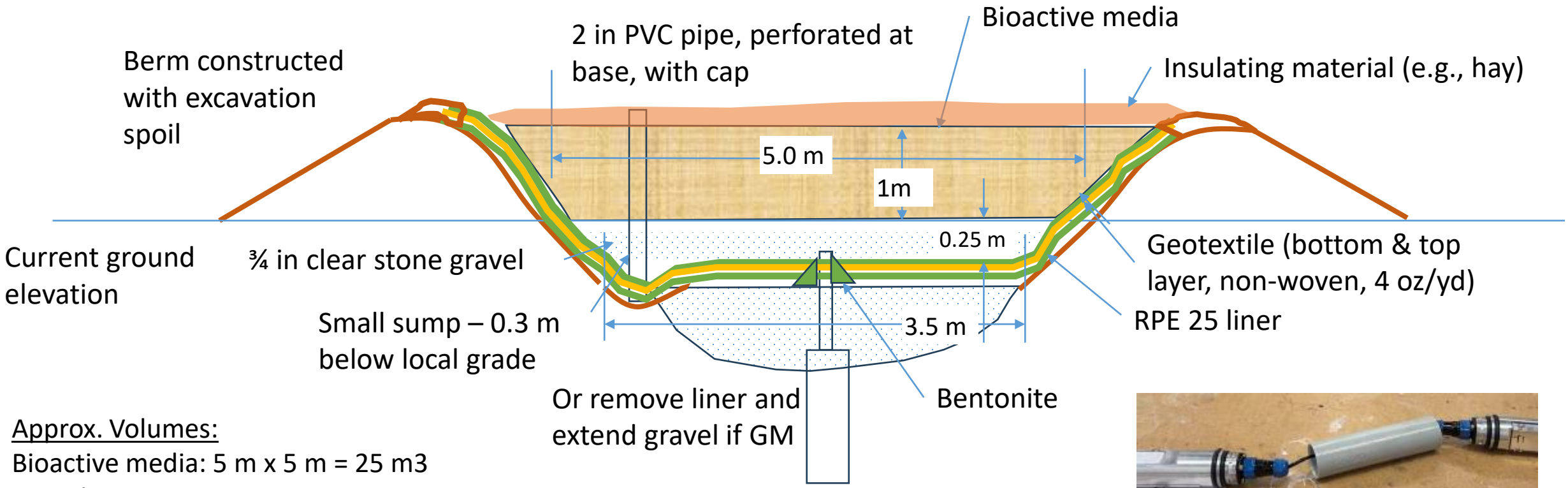
- **An extensive and detailed proposal has been prepared building on lessons learned for an efficient approach**

Field Demonstration – Site 1 – Biocell Concept



- Intended for SCVF where can pipe CH4 to biocell
- Re-use of biocell and existing instrumentation

Field Demonstration – Site 2 – Biocover Concept



Approx. Volumes:
Bioactive media: 5 m x 5 m = 25 m3
Gravel: 3.5 m x 3.5 m x 0.25 m = 3.1 m3

Bioactive media design:
57% woodchips (2-inch size 14.2 m3), 35% compost AMS Greencart (8.8 m3)
8% biochar (2 m3)

EMS CH4/CO2/O@/temp/pressure sensors - low CH4 conc. possible

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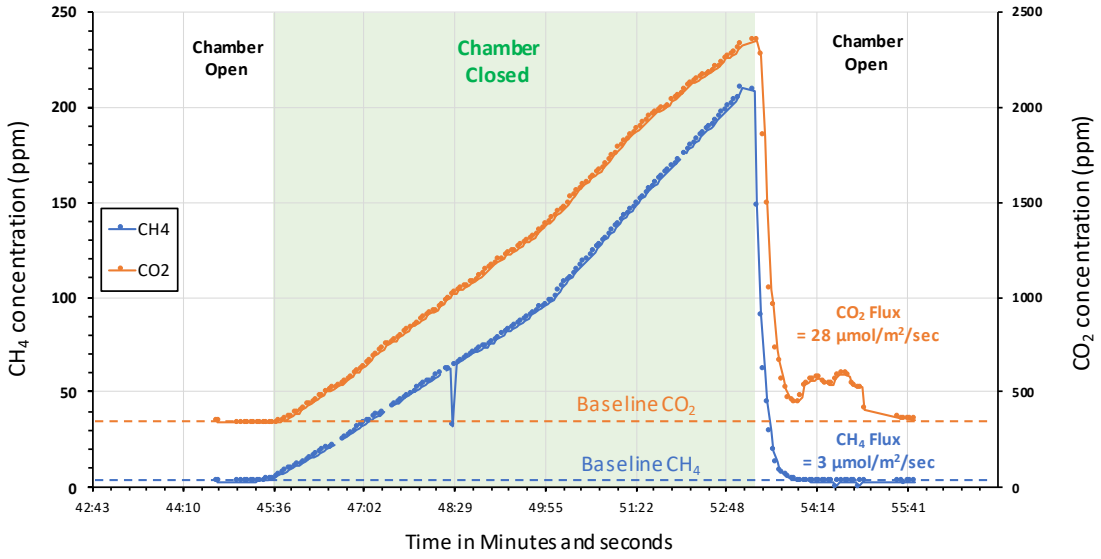
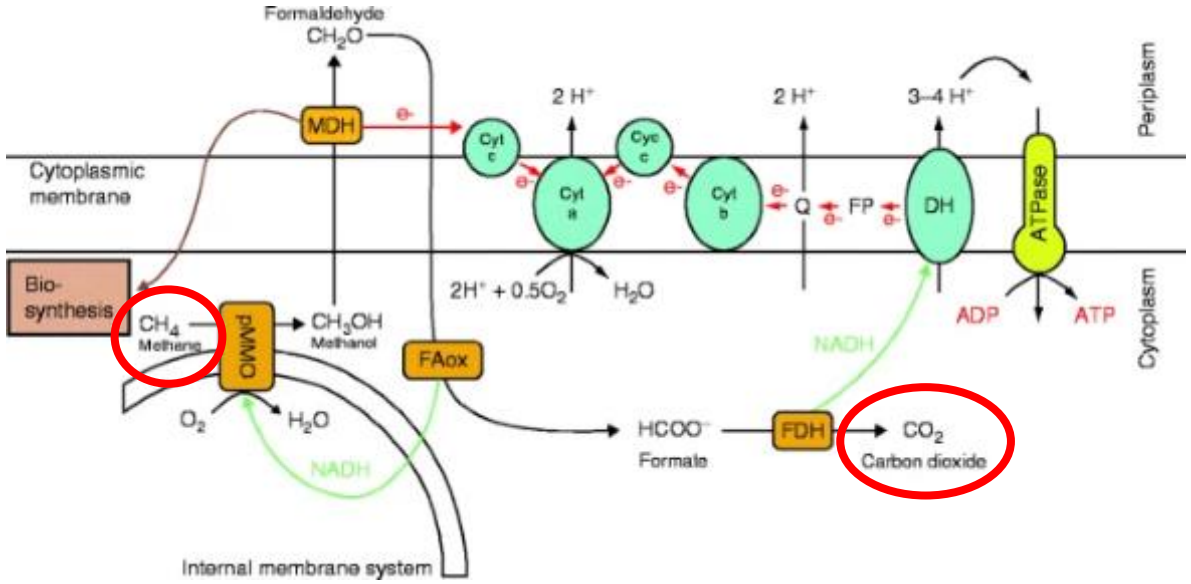
Extra Slides

Porous Media CH_4 oxidation has great potential to aid management and mitigation of well leakage





- Potential reduction in GHG emissions of up to 97% (over 20 years) if full conversion from CH_4 to CO_2 is achieved.
- BUT: it's not magic – a fairly complicated, multi step process…
- Lots of controlling parameters and factors affect rates and extents…
- A need for enhanced understanding of the process…

Need to understand “who” is eating the methane…

(Literature Search and evaluation of potential methods of Microbial Analysis)

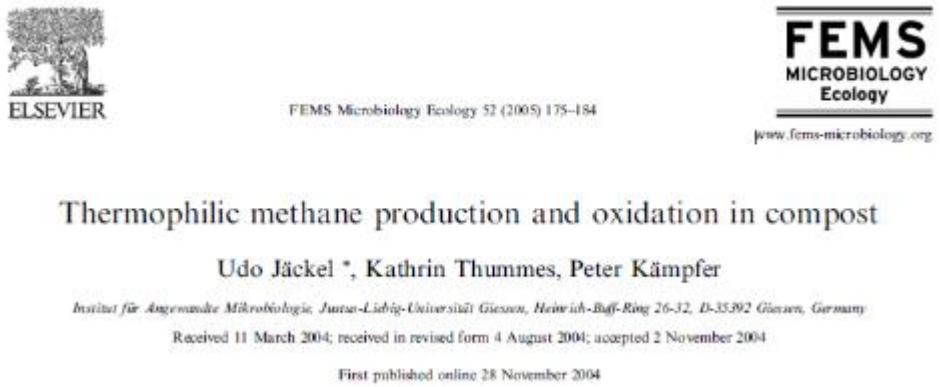
J. Microbiol. Biotechnol. 2021. 31(6): 803–811
https://doi.org/10.4014/jmb.2103.03005

JMB
Journal of Microbiology and Biotechnology

Characterization of the Bacterial Community Associated with Methane and Odor in a Pilot-Scale Landfill Biocover under Moderately Thermophilic Conditions

Hyoju Yang[1], Hyekyeng Jung[1], Kyungcheol Oh[2], Jun-Min Jeon[2], and Kyung-Suk Cho[1]*

[1]Department of Environmental Science and Engineering, Ewha Womans University, Seoul 03760, Republic of Korea
[2]Green Environmental Complex Center, Suncheon 57992, Republic of Korea



ELSEVIER

FEMS Microbiology Ecology 52 (2005) 175–184

FEMS MICROBIOLOGY Ecology
www.fems-microbiology.org

Thermophilic methane production and oxidation in compost

Udo Jäckel *, Kathrin Thummes, Peter Kämpfer

Institut für Angewandte Mikrobiologie, Justus-Liebig-Universität Giessen, Heinrich-Buff-Ring 26-32, D-35392 Giessen, Germany

Received 11 March 2004; received in revised form 4 August 2004; accepted 2 November 2004

First published online 28 November 2004

- Bacterial genera (DNA) were identified using qPCR testing under temperatures ranging from moderately thermophilic (40-50oC) to mesophilic (30oC) conditions
- Major methane oxidizing species were Methylocaldum spp. during t-philic and Methylobacter spp. during m-philic conditions.
- Diversity of bacterial community in the biocover during t-philic did not decrease significantly compared to m-philic (Halet et al. 2010 found diversity was less during thermophilic phase)

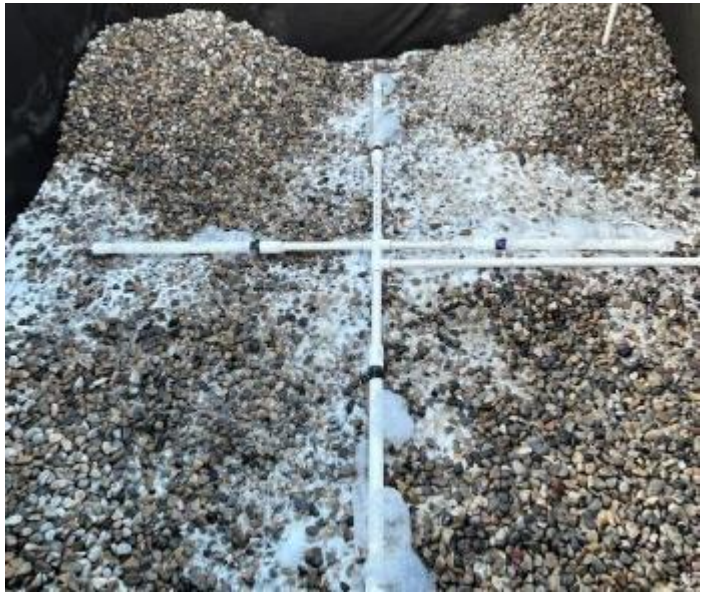
- Methane oxidation demonstrated under thermophilic conditions; optimal temperatures were 45-55oC
- Methylocaldum main strain isolated
- Short lag times of about a day

https://www.cell.com/molecular-cell/pdf/S1097-2765(18)30271-5.pdf

Numerous other papers summarized

Biocell Construction and Instrumentation

Biocell consisted of wooden box of approx. dimension 2.5 m by 3 m by 1.3 m. Foamboard insulation (DuraSpan 1” thick, R3.75) was installed. A 25 RPE polyethylene liner overlain by 4 oz/yd non-woven polyethylene geotextile was placed over the insulation.



Gas injection piping - uniformity of gas injection promoted through 4 porous (20 um) Shumaprobe air sparge points (1” diameter, 20” long). System was tested by injecting air using small air pump and soap bubbles.

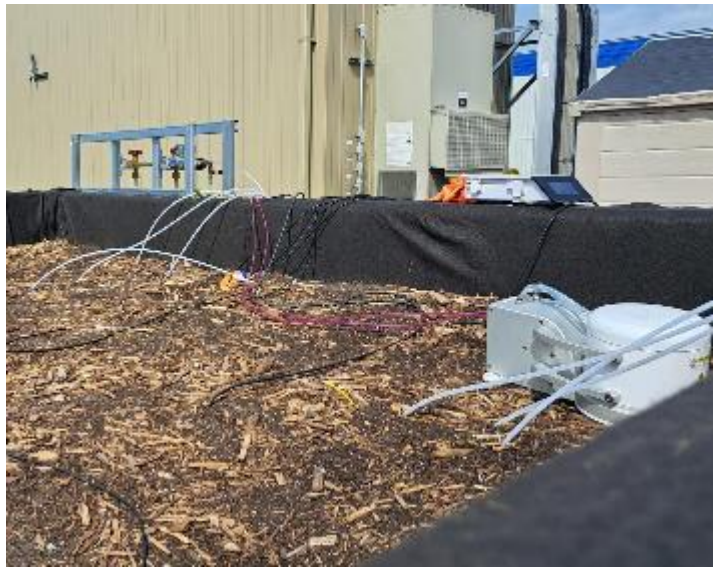
Gas injection layer consisted of 0.25 m thick ¾ inch clear gravel. Capped 1-inch PVC pipe with screen at base of gravel installed to enable monitoring of potential water ingress.

TEROS 12 soil temperature and soil moisture sensors were installed in middle of cell at 0.2, 0.4, 0.6, 0.8 and 1 m depth

Biocell Construction and Instrumentation

AMS soil gas probe tips were installed at 21 locations within cell

Static chamber used to measure surface fluxes of CO2 using VAISALA VM-70 (CO2) and CH4 (SEM-5000)



Automated EoSense CH4 and CO2 flux chamber

Gas cylinders and Alicat flow measurement device

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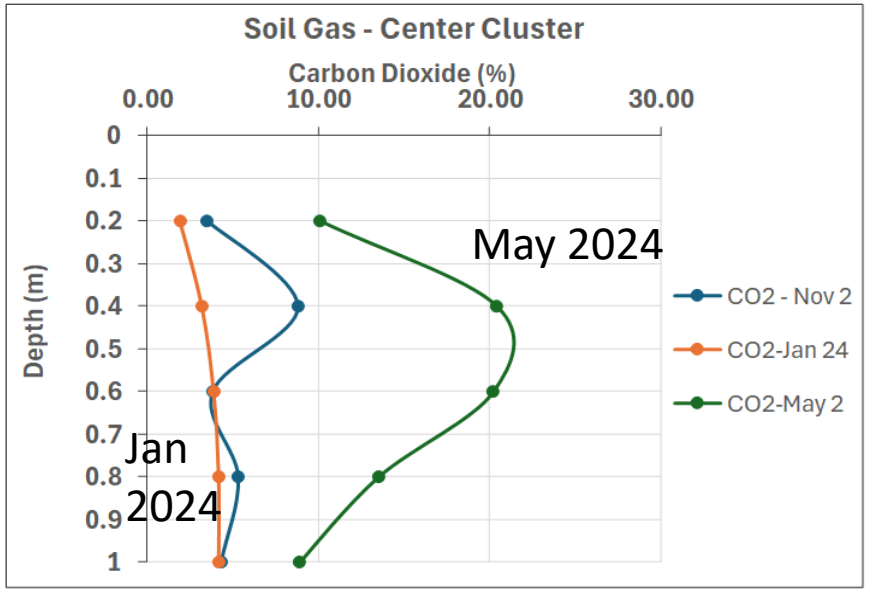
Compost Respiration Data

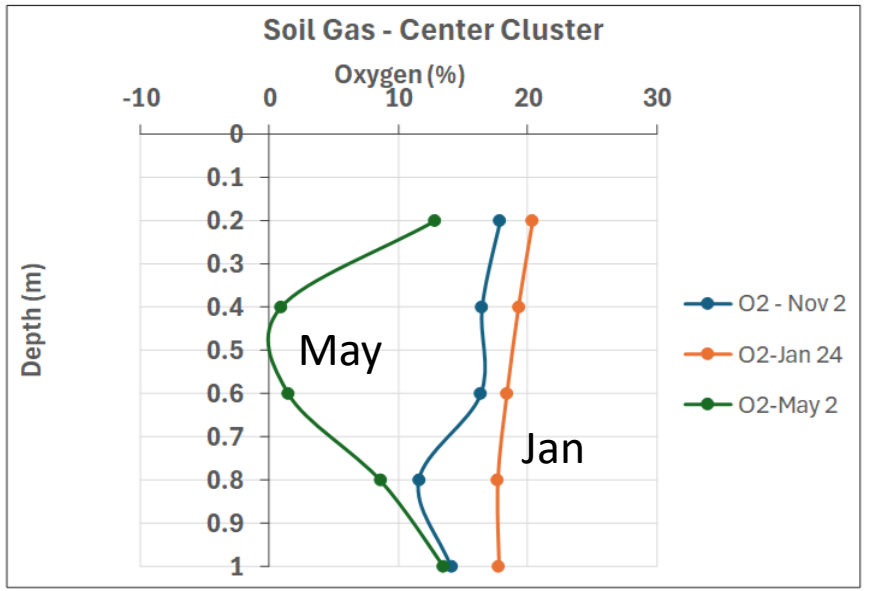
Sample	Respiration Rate (mgCO2-C/g OM/d	Respiration Rate (mgCO2-C/g TS/d	Compost Stability Index
Compost Only – As Received at Site October 2023			
Composite 1	4.7	2.9	6
Composite 2	6.4	3.9	5
Average	5.5	3.4	5.5
Compost and Wood Chips Mixture – November 2023			
Shallow (0.2 m)	5.4	3.4	6
Deep (0.6 m)	3.4	2.3	7
Average	4.4	2.85	6.5

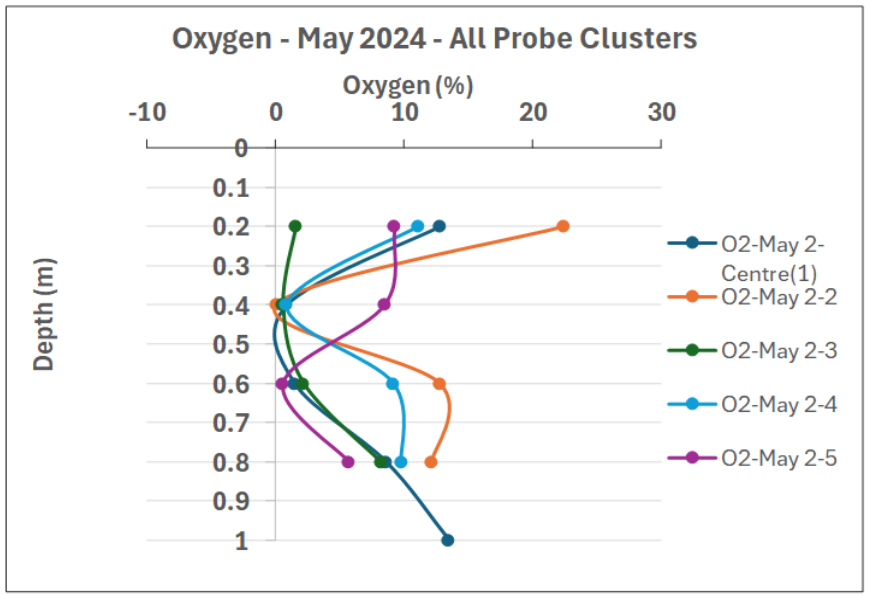
Compost/wood chips between “curing” and “well-aged” compost on Solvita Scale

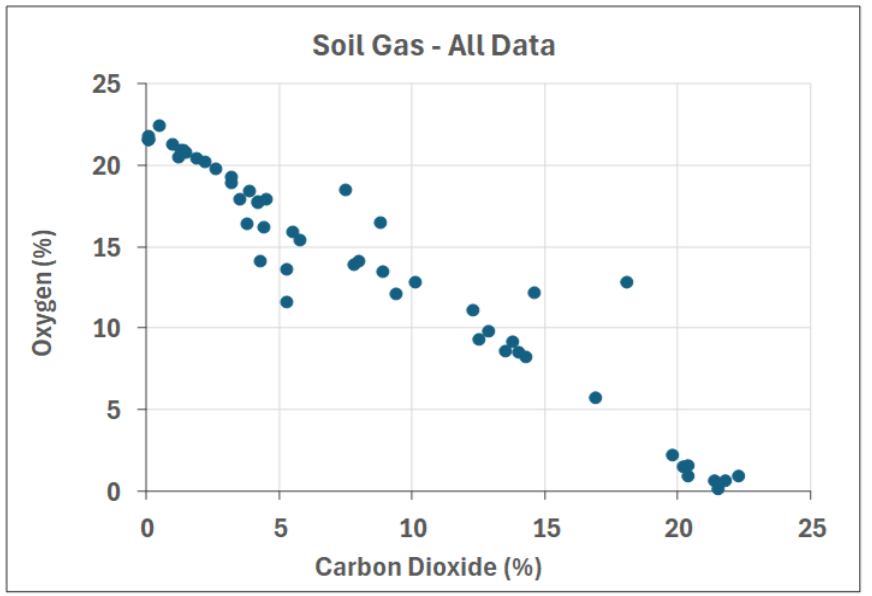
Note AIM Group (supplier of compost) provided data for compost Respiration = 0.8 mgCO2-C/g-OM/d

Baseline Soil Gas Monitoring







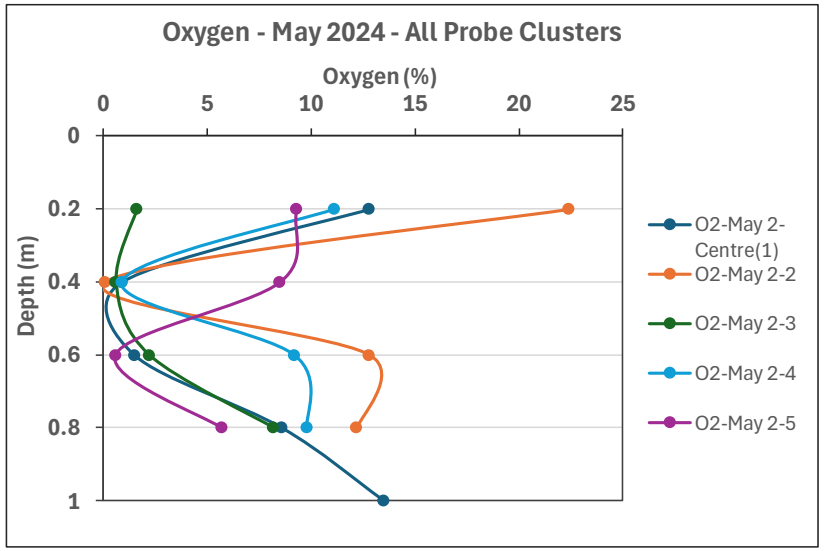


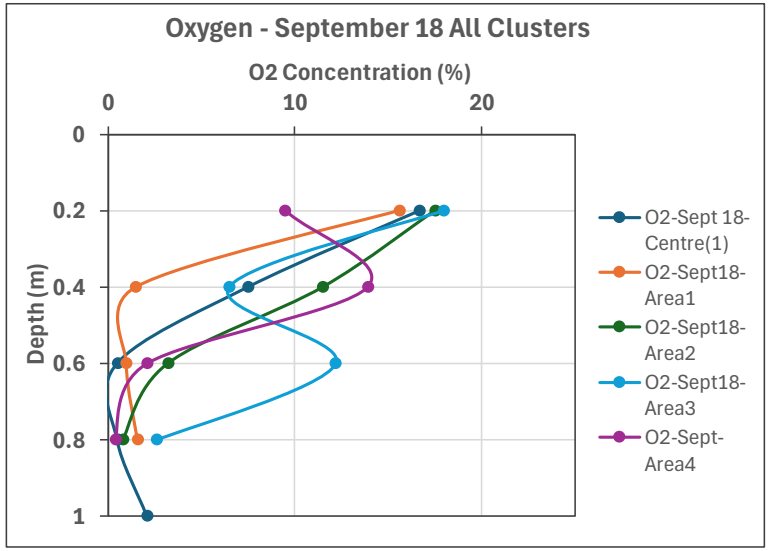
CO_2 and O_2 inversely correlated in May

CO_2 and O_2 from respiration should fall on a straight line – can be used as a QC check

Soil Gas – Oxygen – All Clusters

May 2
Baseline

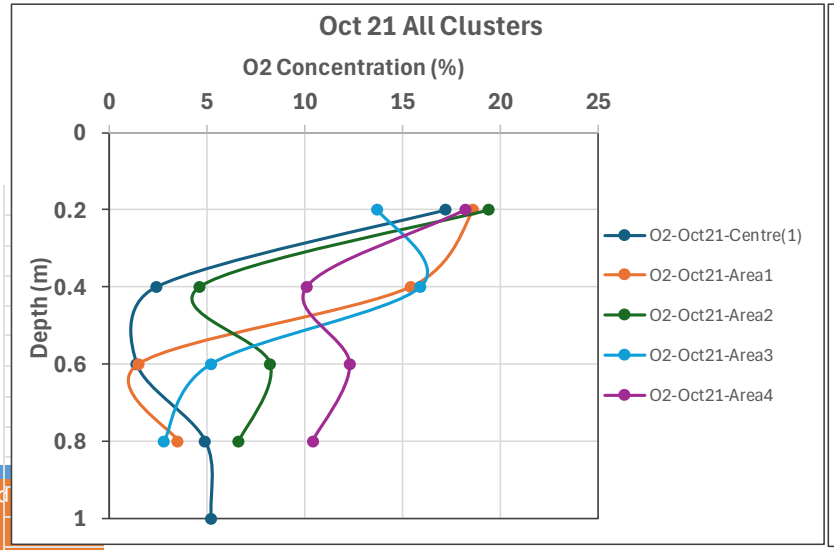


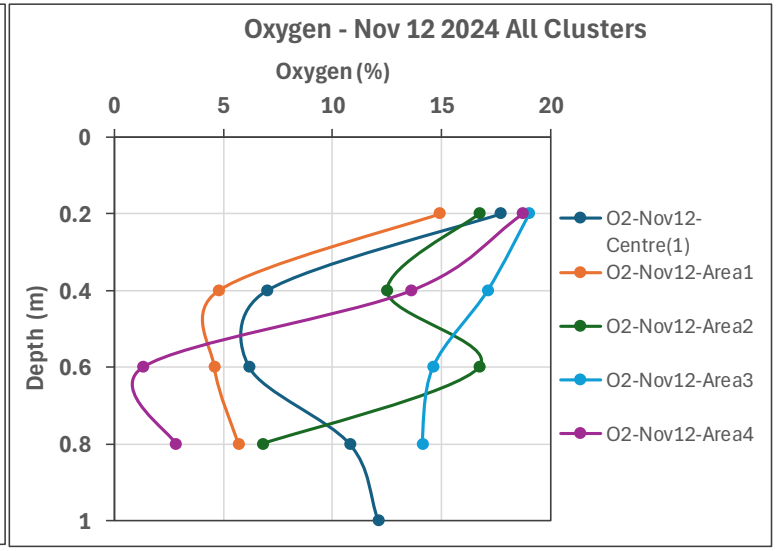


Sept 18
CH4
Injection

Elevated O2 in most of cell another line of evidence for CH4 oxidation

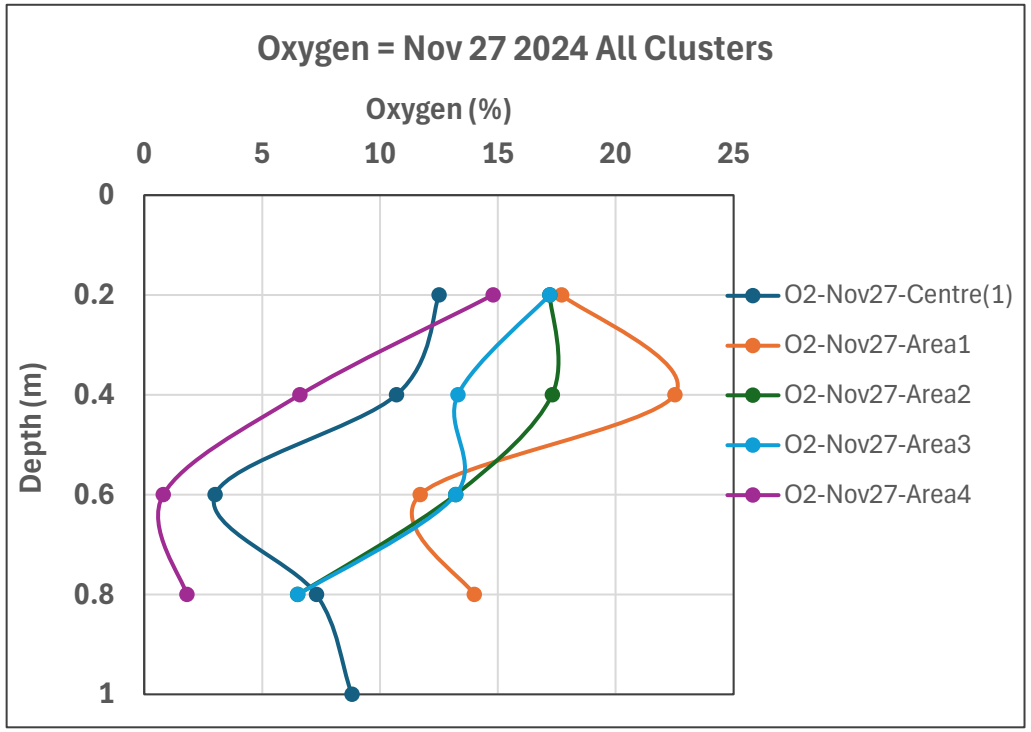
Oct 21
CH4
Injection

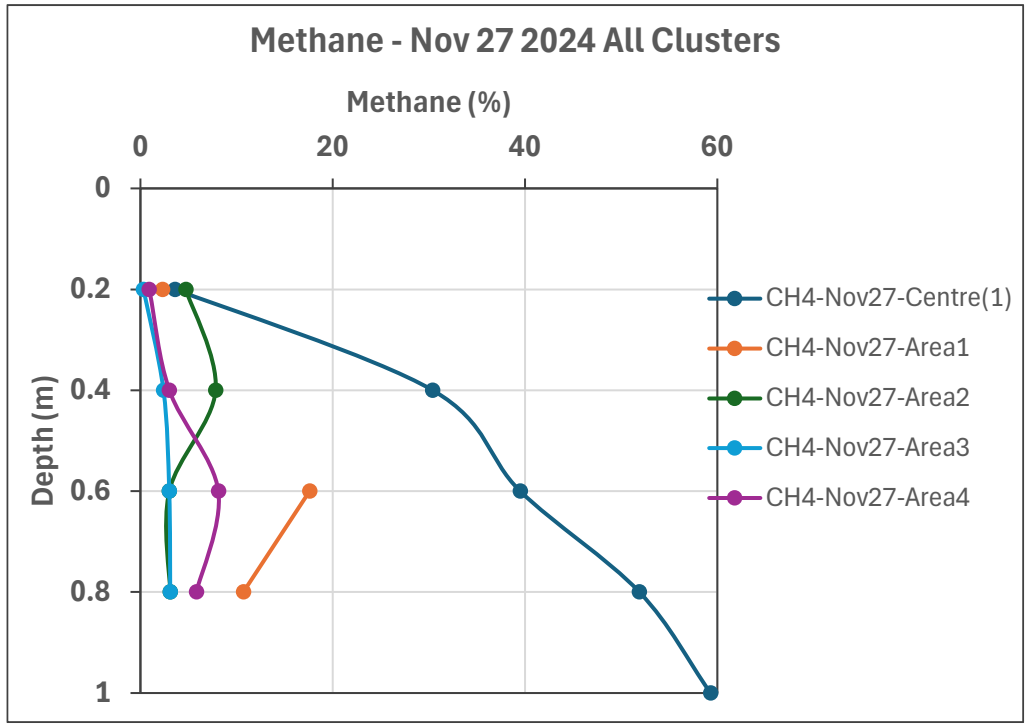




Nov 12
CH4
Injection

Soil Gas – Oxygen and Methane – Nov 27, 2024 – All Clusters





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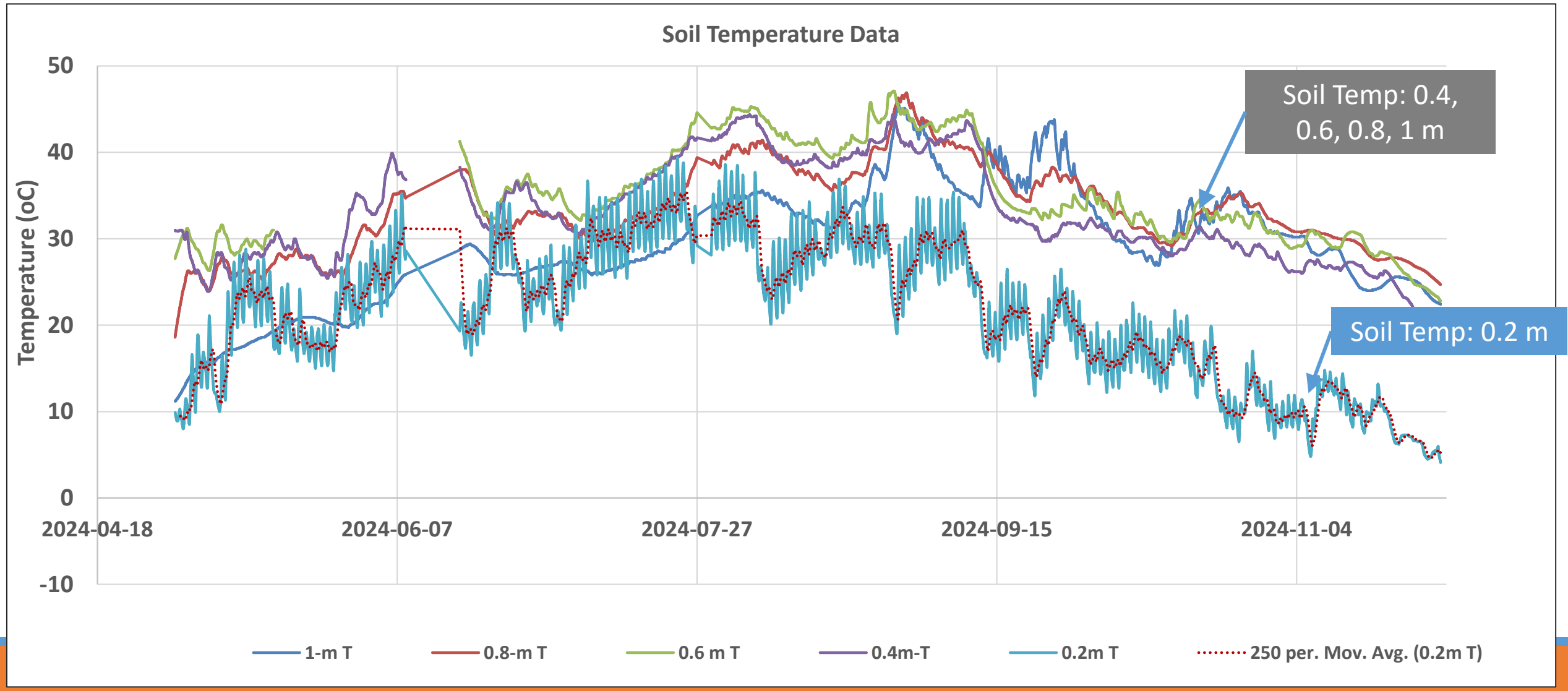
Soil Temperature: May 5 - Nov 27



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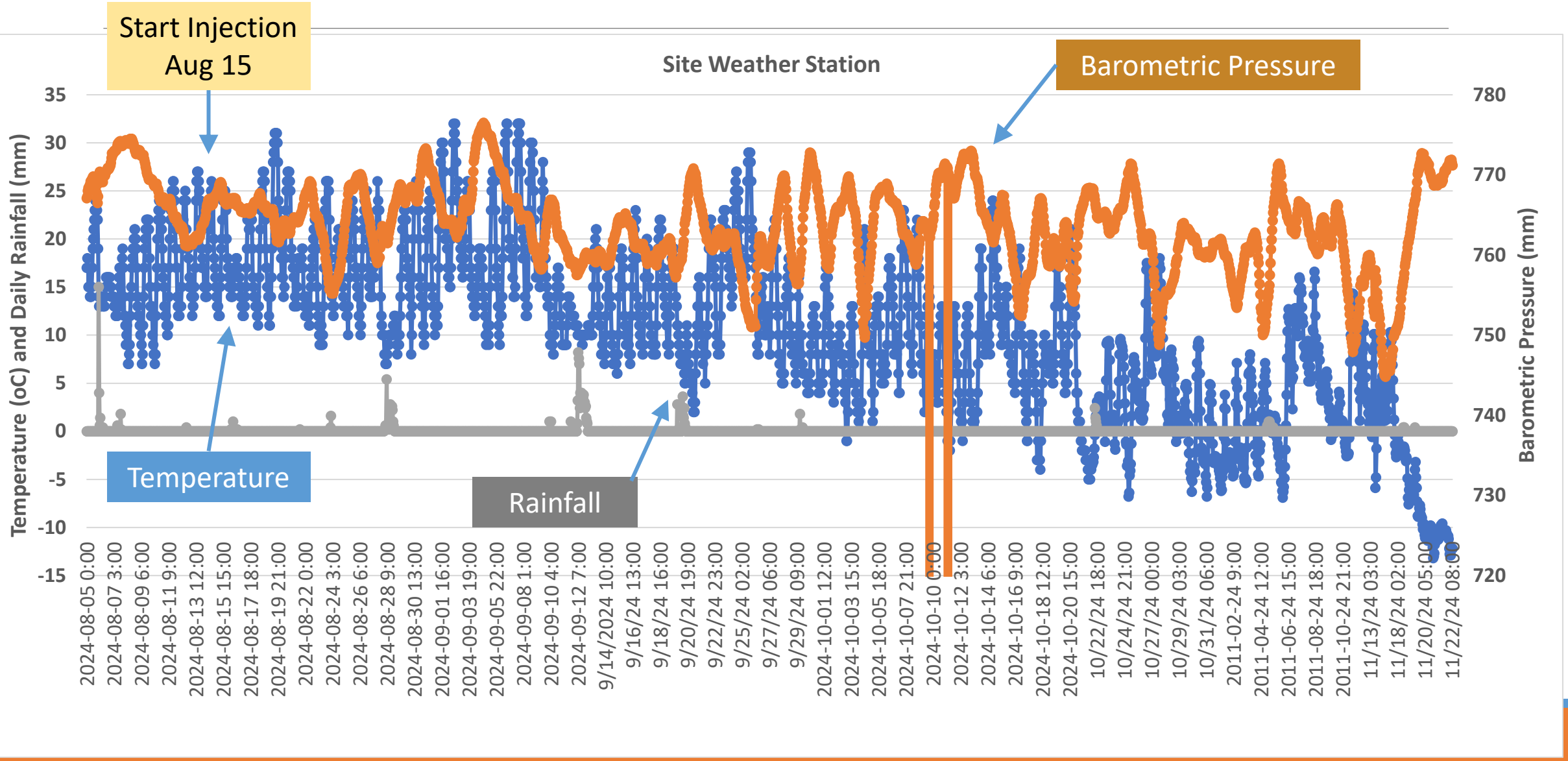
Site Weather – Aug 5 to Nov 22 2024



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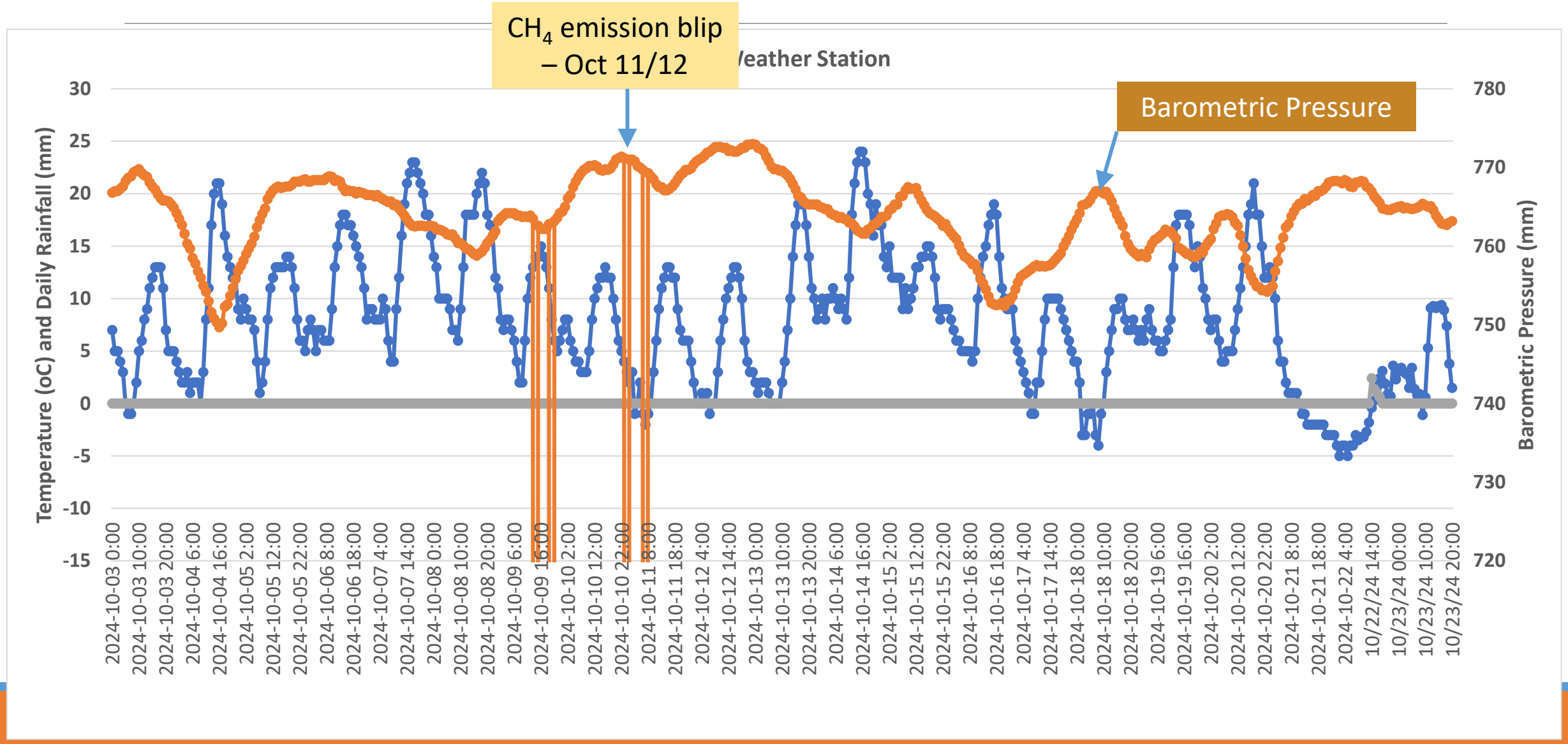
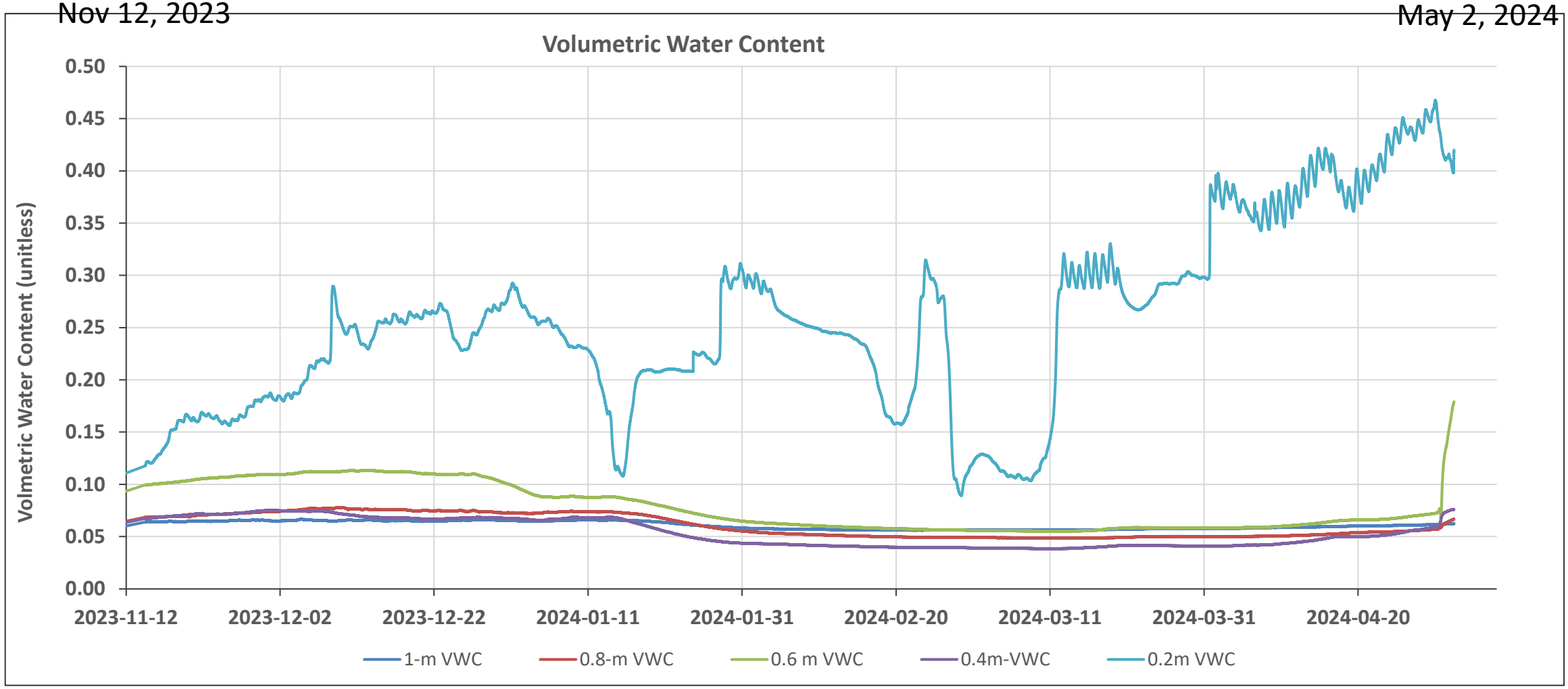
Site Weather: Oct 3 to Oct 23 2024



Baseline Volumetric Water Content: Nov 2023 – Apr 2024

Nov 12, 2023

May 2, 2024



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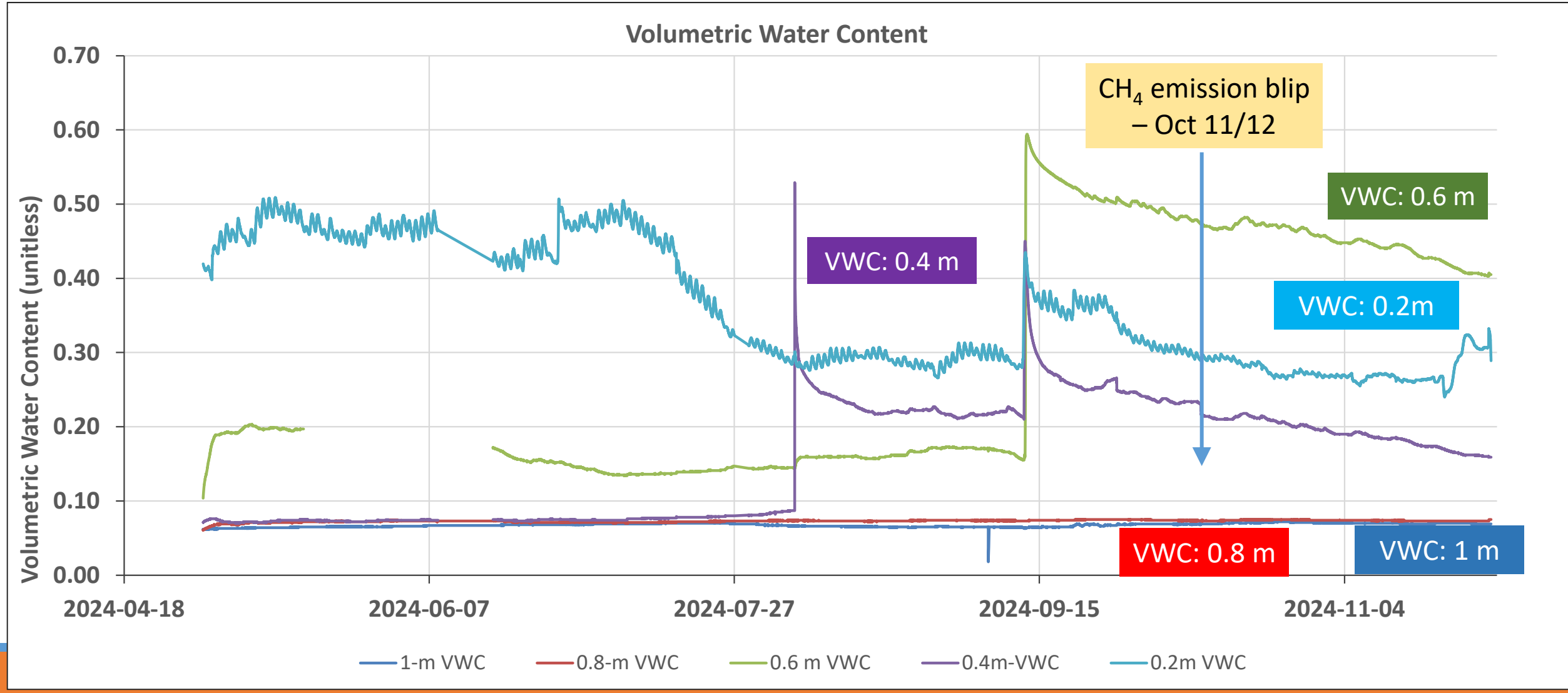
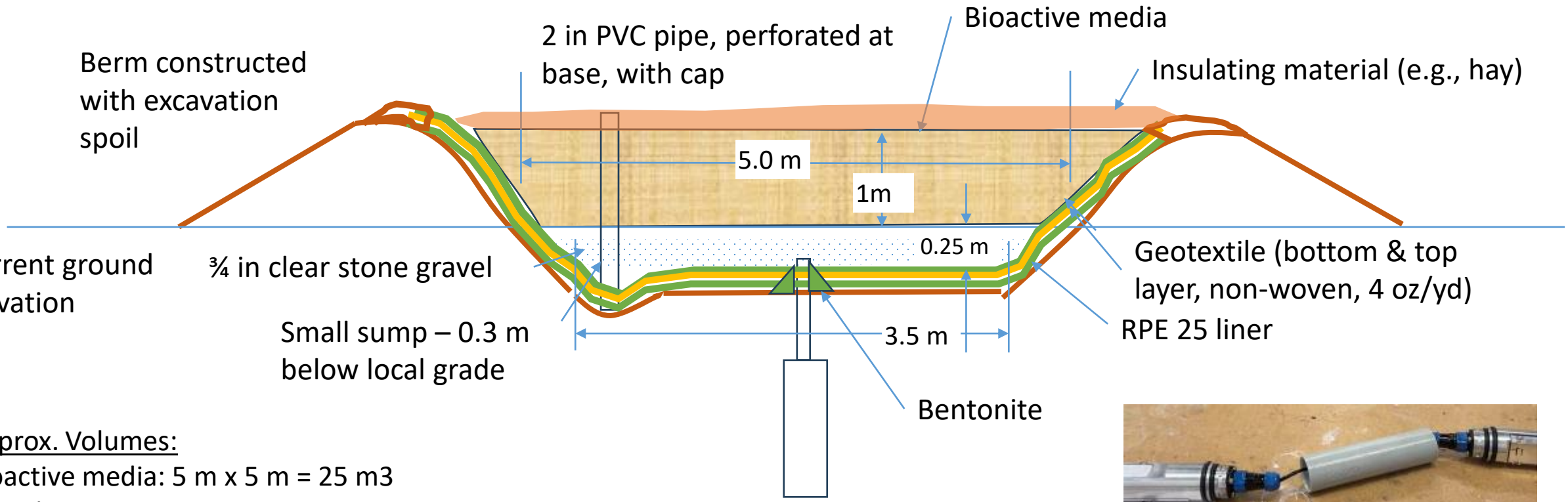
Volumetric Water Content: May 5 – Nov 27 2024



Field Demonstration – Site 2 – Biocover Concept



Approx. Volumes:
Bioactive media: 5 m x 5 m = 25 m3
Gravel: 3.5 m x 3.5 m x 0.25 m = 3.1 m3

Bioactive media design:
57% woodchips (2-inch size 14.2 m3), 35% compost AMS Greencart (8.8 m3)
8% biochar (2 m3)

EMS CH4/CO2/O@/temp/pressure sensors - low CH4 conc. possible

References

Chanton, J. P., Powelson, D. K., Abichou, T. and Hater, G. 2008. Improved Field Methods to Quantify Methane Oxidation in Landfill Cover Materials Using Stable Carbon Isotopes. Environmental Science & Technology,VL - 42
IS - 3 M3 - doi: 10.1021/es0710757

Powelson, D. K., Chanton, J. P., Abichou, T. 2007. Methane Oxidation in Biofilters Measured by Mass-Balance and Stable Isotope Methods. Environmental Science & Technology, VL = 41, IS = 2, doi: 10.1021/es061656g

Capanema, M.A., Cabral, A.R. Evaluating Methane Oxidation Efficiencies in Experimental Landfill Biocovers by Mass Balance and Carbon Stable Isotopes. *Water Air Soil Pollut* **223**, 5623–5635 (2012). https://doi.org/10.1007/s11270-012-1302-6