Seasons of change: NSZD rates across 12 sites using new high-data density technology

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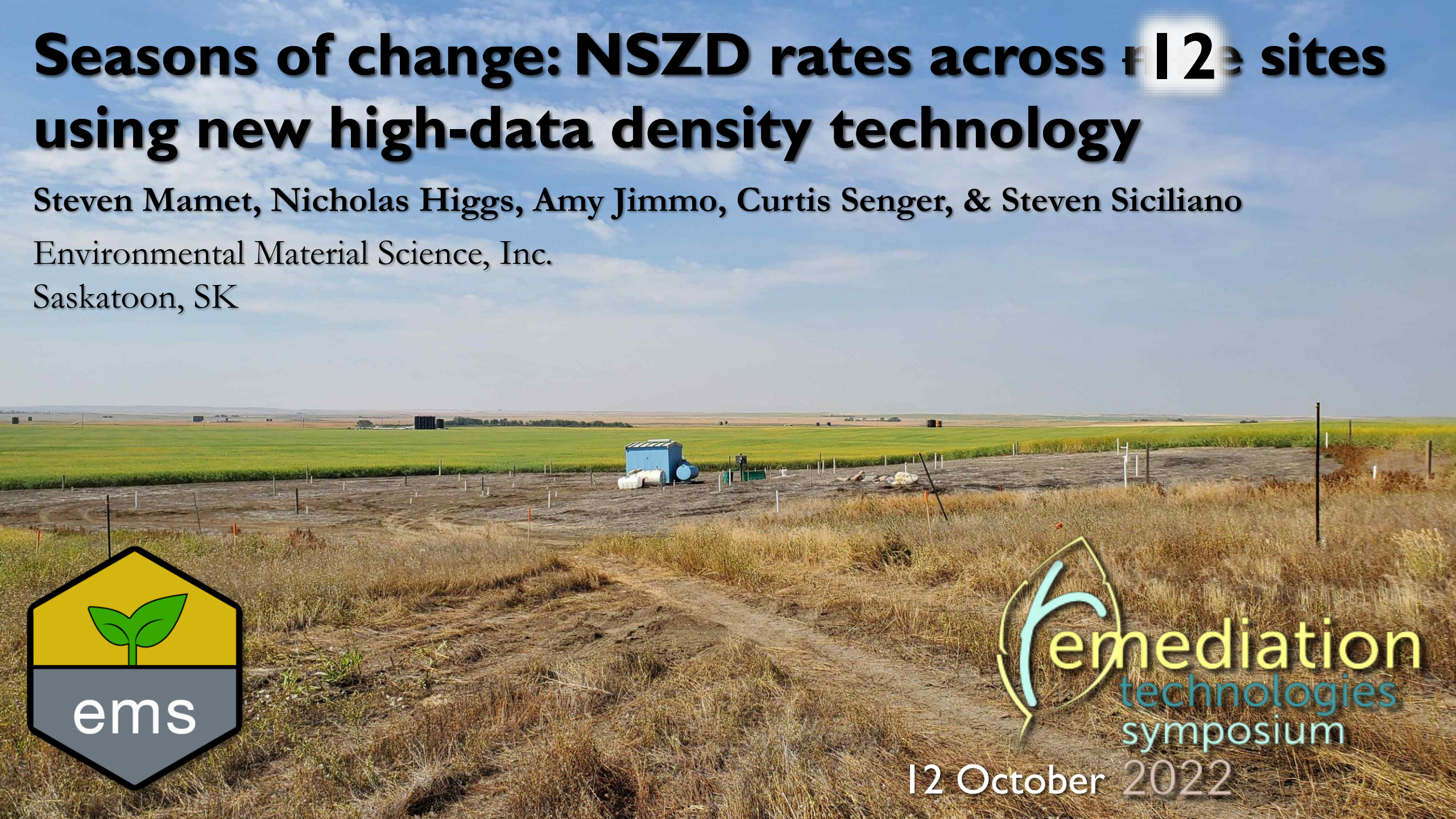


remediation technologies symposium

12 October 2022

Your roadmap for today

Site-specific stoichiometry

Pedotransfer and soil moisture

Continuous measurements Methane

Soil Sense

NSZD Overview

Natural Source Zone Depletion Explained

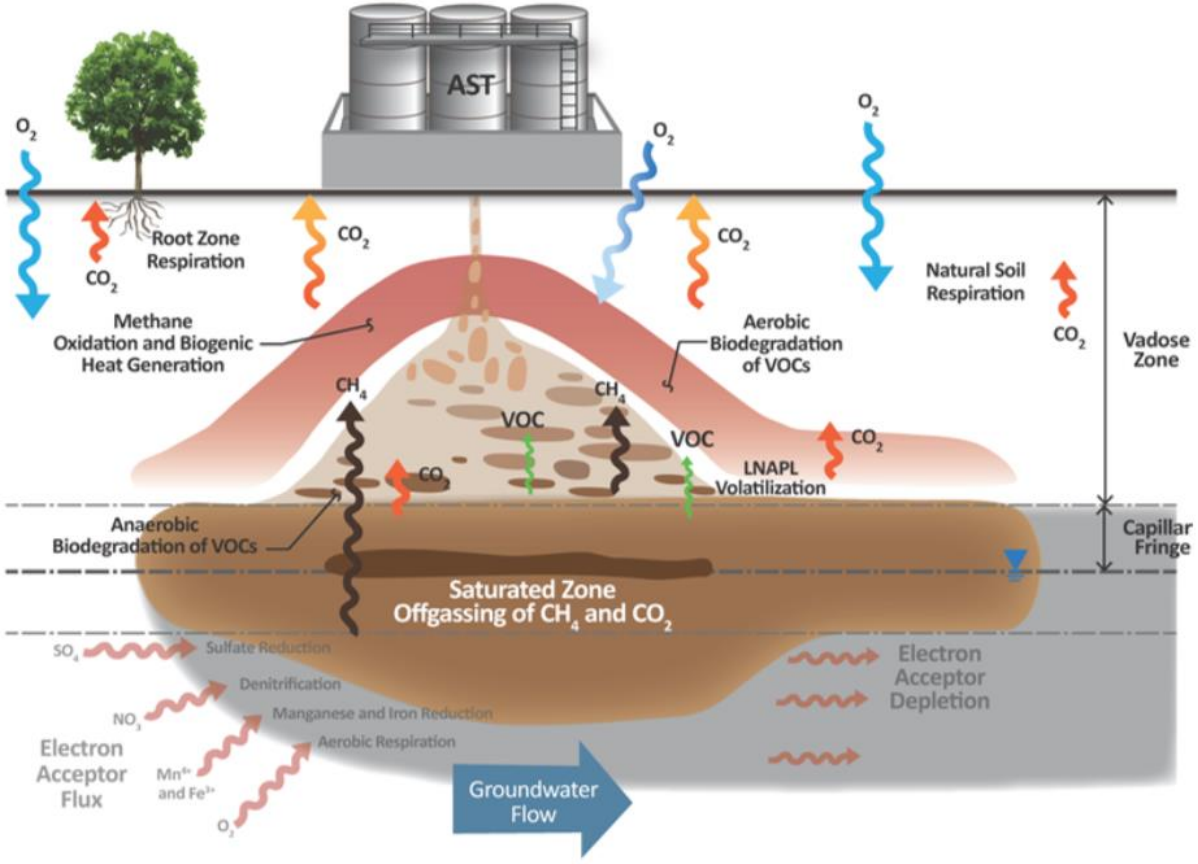


Figure 7: Conceptualisation of LNAPL NSZD processes (from API 2017)

Aerobic Transport

Methane Oxidation

$$CH_4 + 2O_2 \rightarrow CO_2\,(g) + 2H_2O$$

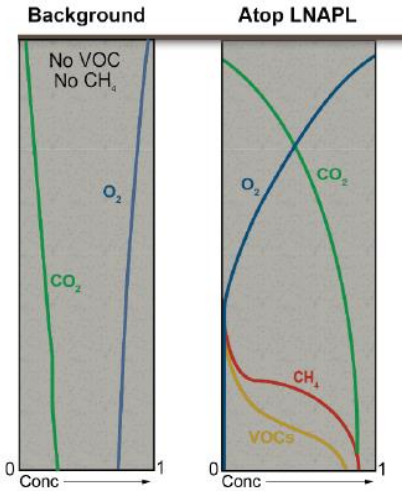
Methane Generation

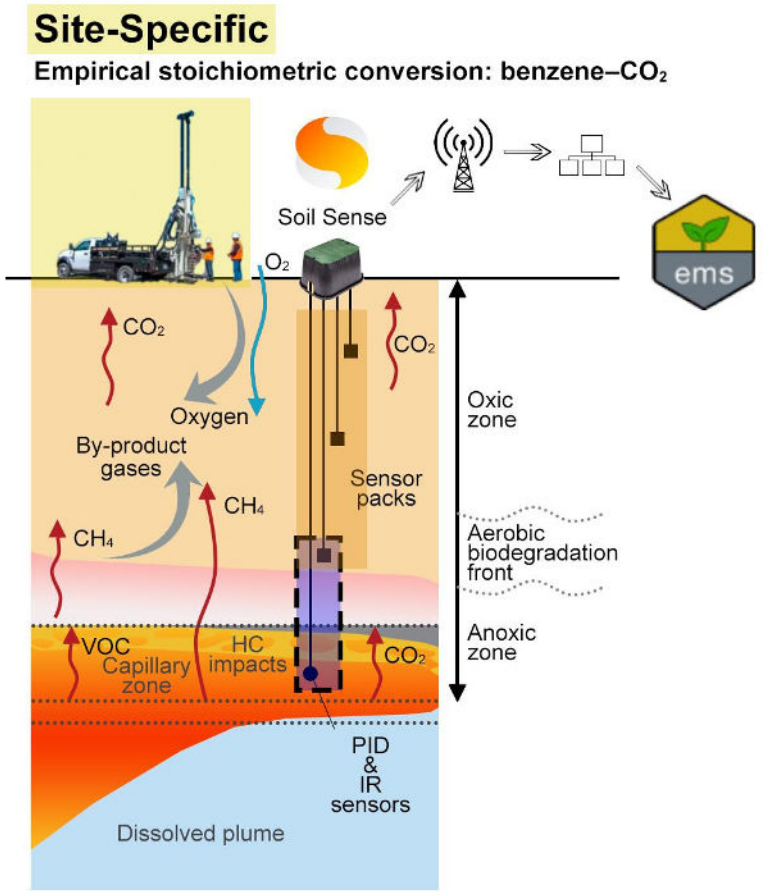
$$C_8H_{18} + 3.5\,H_2O \rightarrow 1.75\,CH_4\,(g) + 6.25\,CO_2\,(g)$$

CRC CARE Technical Report no. 46

The role of natural source zone depletion in the management of light non-aqueous phase liquid (LNAPL) contaminated sites

Concentration Gradient Method





Fick's First Law of Diffusion - rate of diffusion is proportional to the concentration and surface area

CRC Care 2018

1. $J = D_v^{eff}(\frac{dC}{dZ})$

J = steady state diffusive flux (g/m^2-soil/s)
D_v^{eff} = effective vapour diffusion coefficient (m^2/s)
$\frac{dC}{dZ}$ = soil gas concentration gradient (g/m^3-m)

2. $J_{impacted} - J_{background} = J_{corrected}$

3. **Theoretical stoichiometric conversion: benzene–CO_2**

$2C_6H_6 + 15O_2 \rightarrow 12CO_2 + 6H_2O$
$2C_6H_6$: 2*(12.011 g/mol*6 + 1.008 g/mol*6) = 156.223 g/mol
$12CO_2$: 12*(12.011 g/mol + 15.999 g/mol*2) = 528.096 g/mol

When 156 g of C_6H_6 are consumed, 528 g CO_2 are produced
$Stoich_{CO_2}$ = 156 / 528

4. **Natural Source Zone Depletion**

NSZD = $J_{corrected}$*$Stoich_{CO_2}$

Why CH_4 and why high data density?

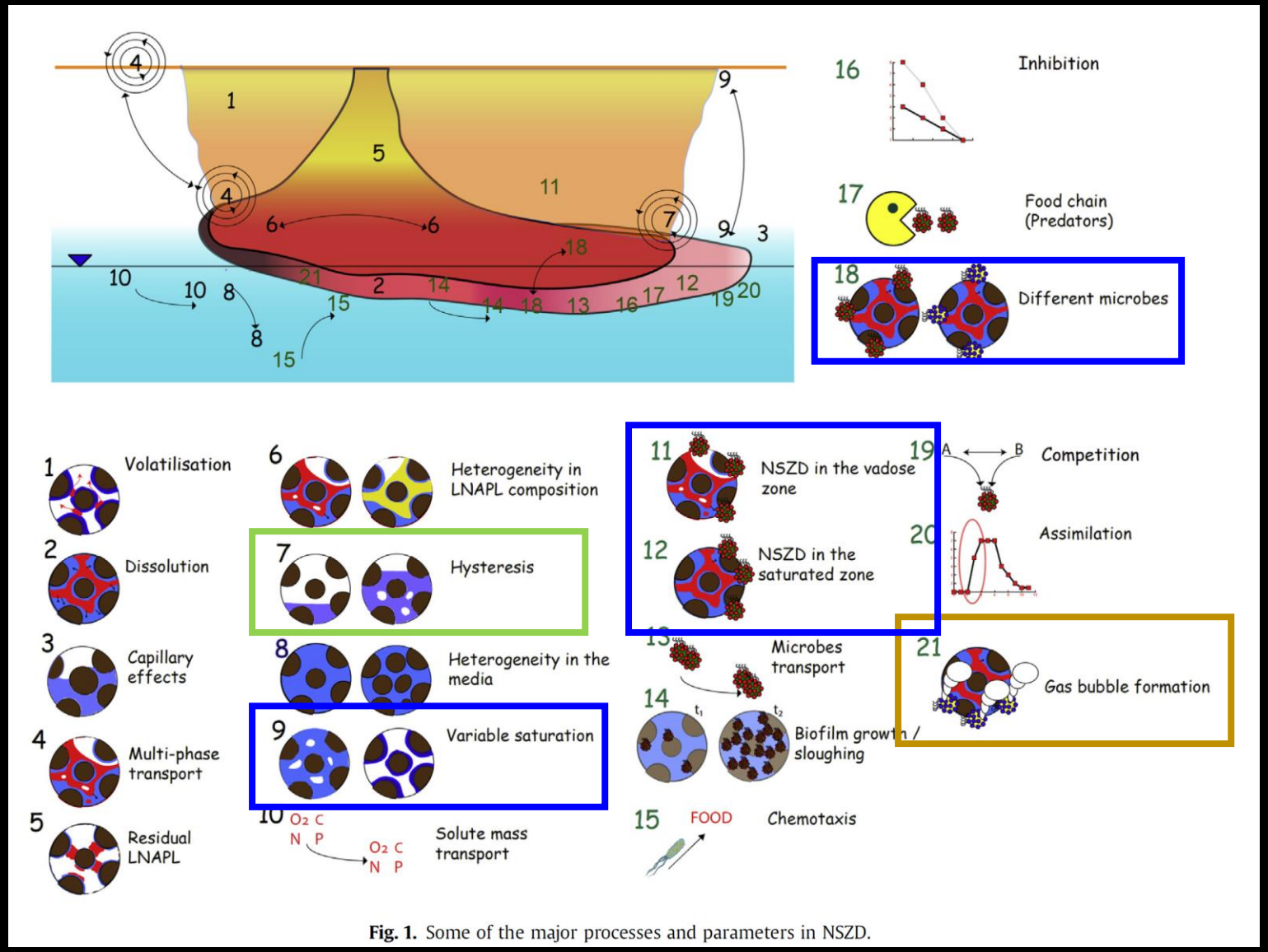
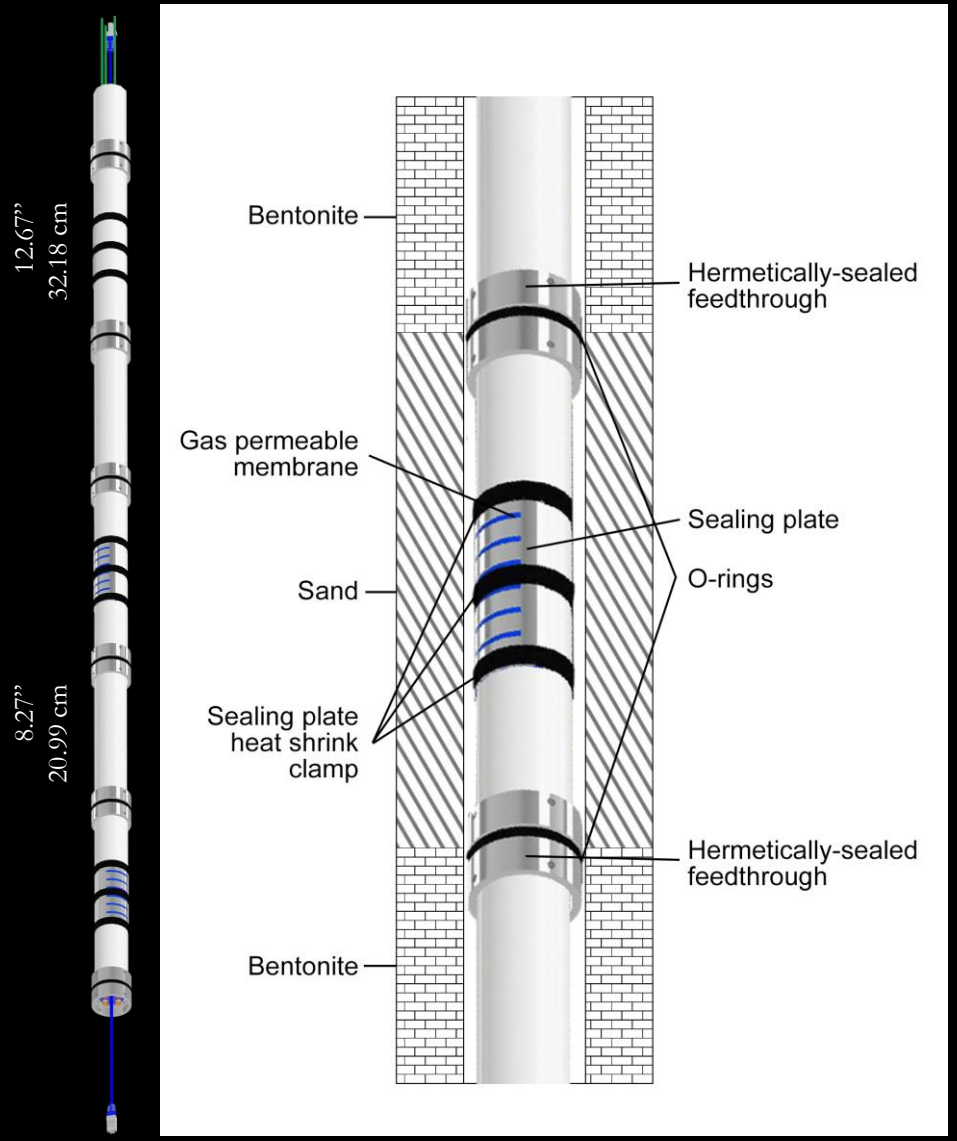


Fig. 1. Some of the major processes and parameters in NSZD.

- Early attenuation processes dominated by methanogenic degradation
- "Signal shredding"
- Lag between peak subsurface gas concentrations and peak surface efflux.

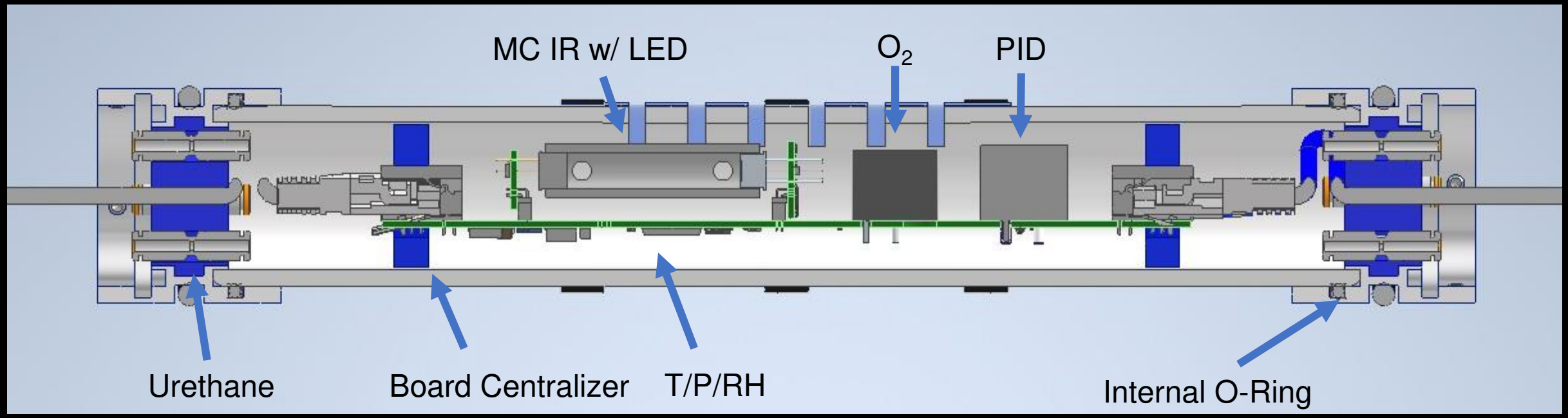
Lari et al., 2019. Water Research 157: 630-646.

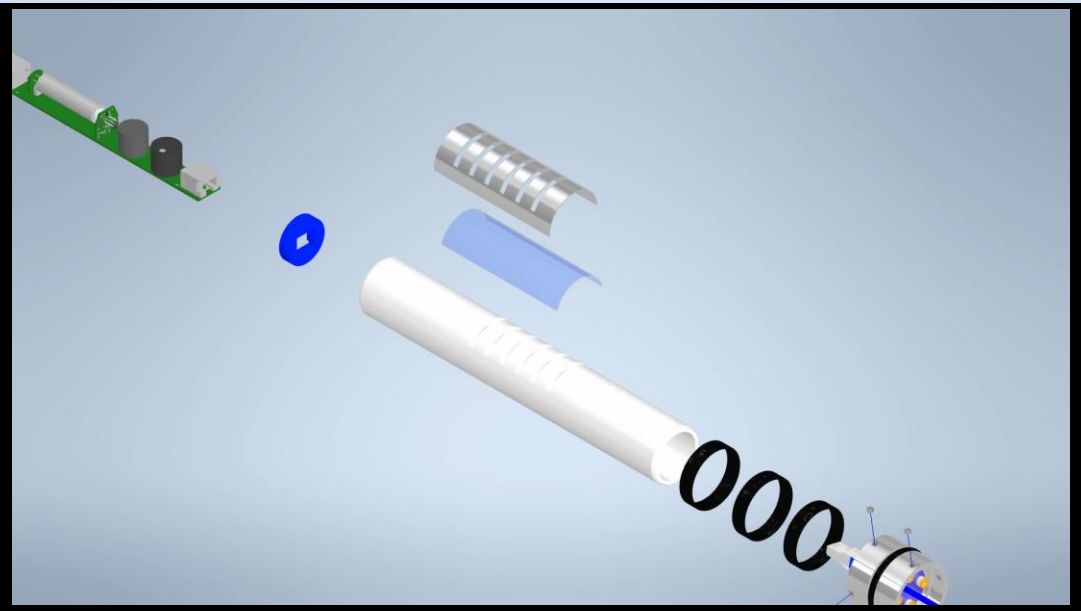
Soil Sense



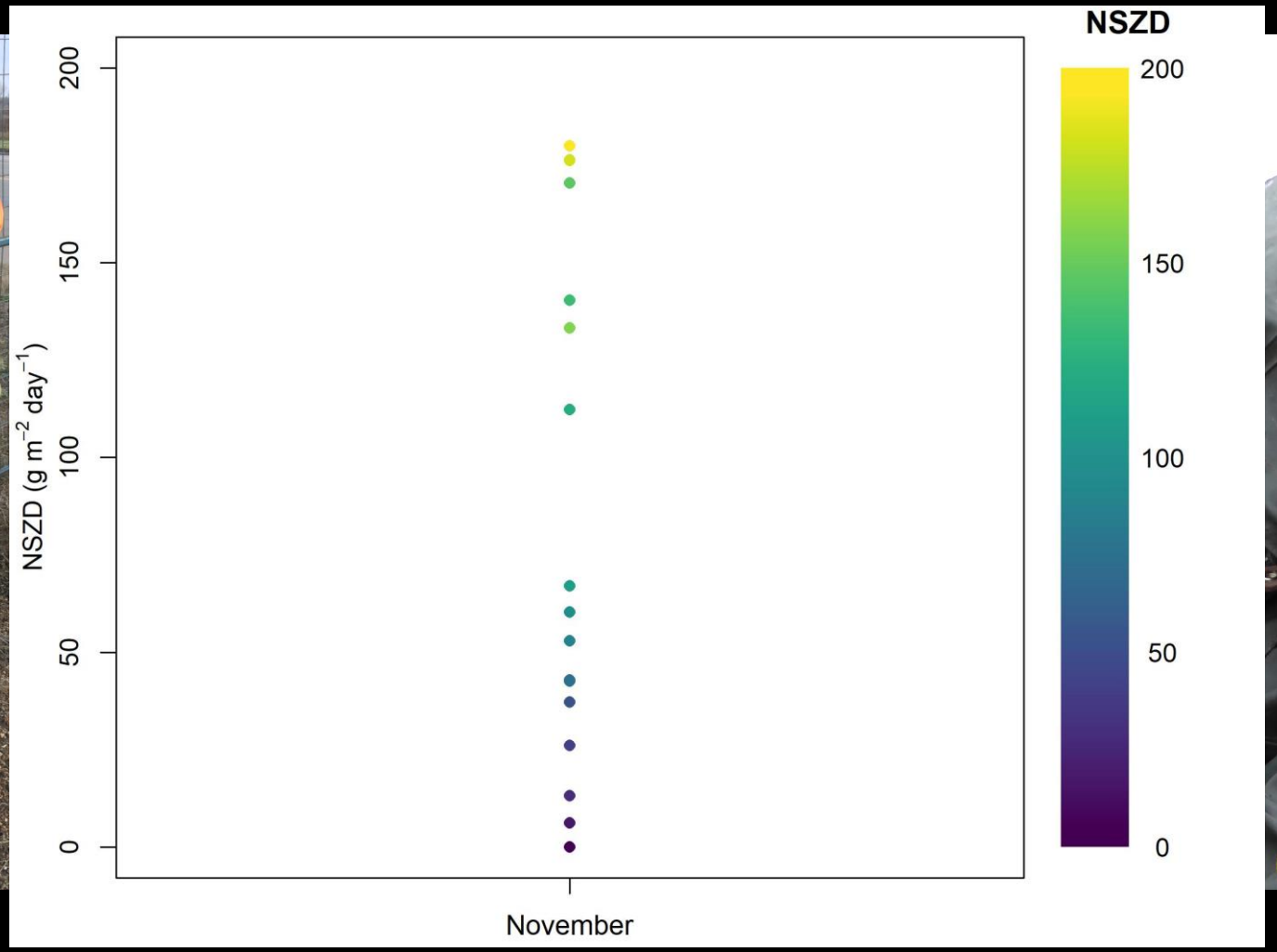
- Three solid-state sensor packs that provide constant soil feedback to EMS/client
- Continuously estimate within-soil **hydrocarbon vapours carbon dioxide, methane, oxygen,** temperature, barometric pressure, and **relative humidity**
- Features
  - NDIR technology
  - LoRa, LTEM, Satellite enabled
  - Fits into existing boreholes
  - Flush mount for active sites where Solar is not an option
  - Continuous remote data access
  - Single setup cost, no maintenance
- Soil Sense estimates **biological activity** and **hydrocarbon concentrations** every 30-mins
- Transmit data via LoRa gateways linked to cellular or satellite networks
- Can be used in remote areas (solar power) or developed areas (long-life batteries), with yearly servicing.

Soil Sense

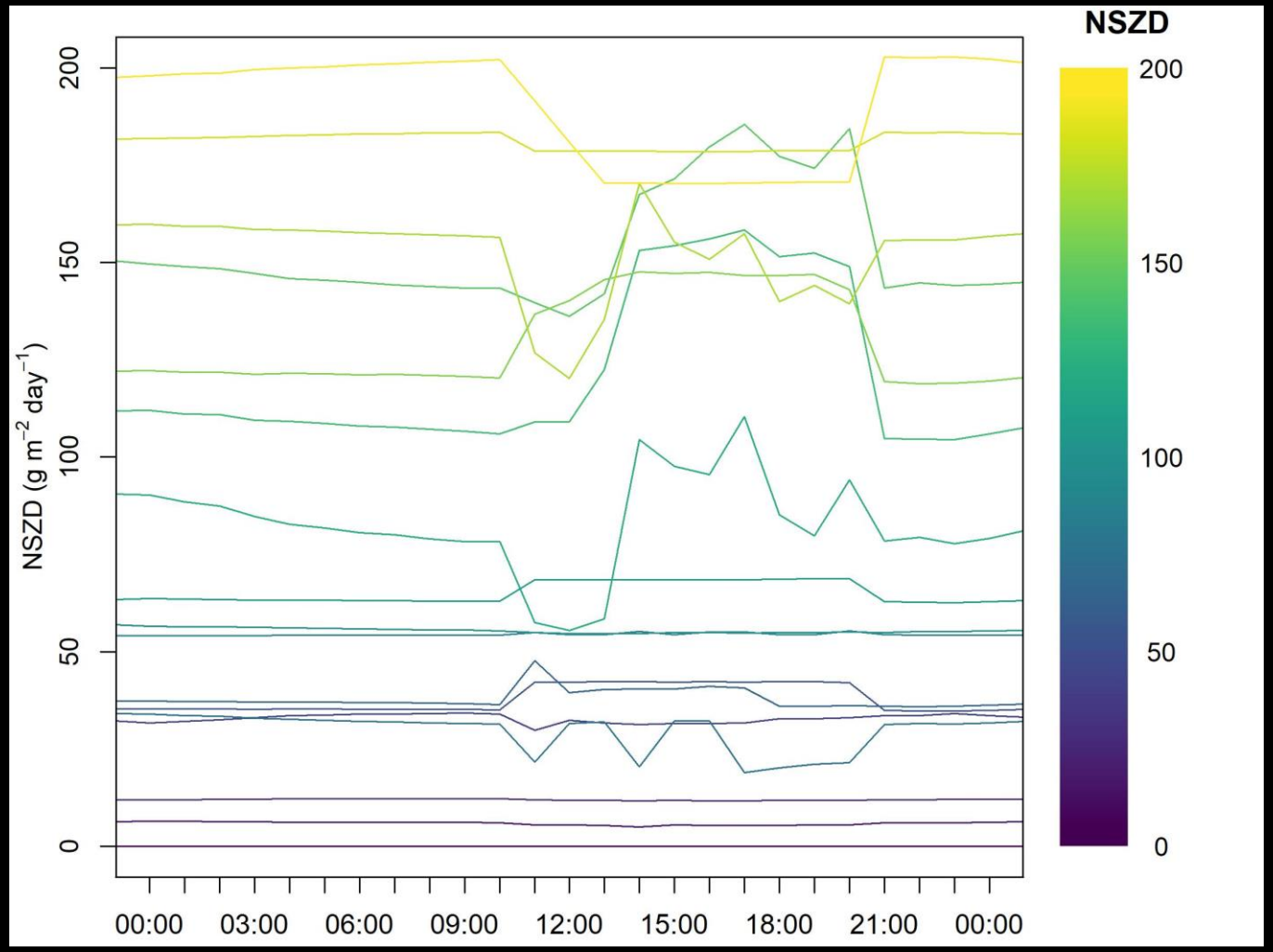

MC IR w/ LED
O_2
PID
Urethane
Board Centralizer
T/P/RH
Internal O-Ring


OOO

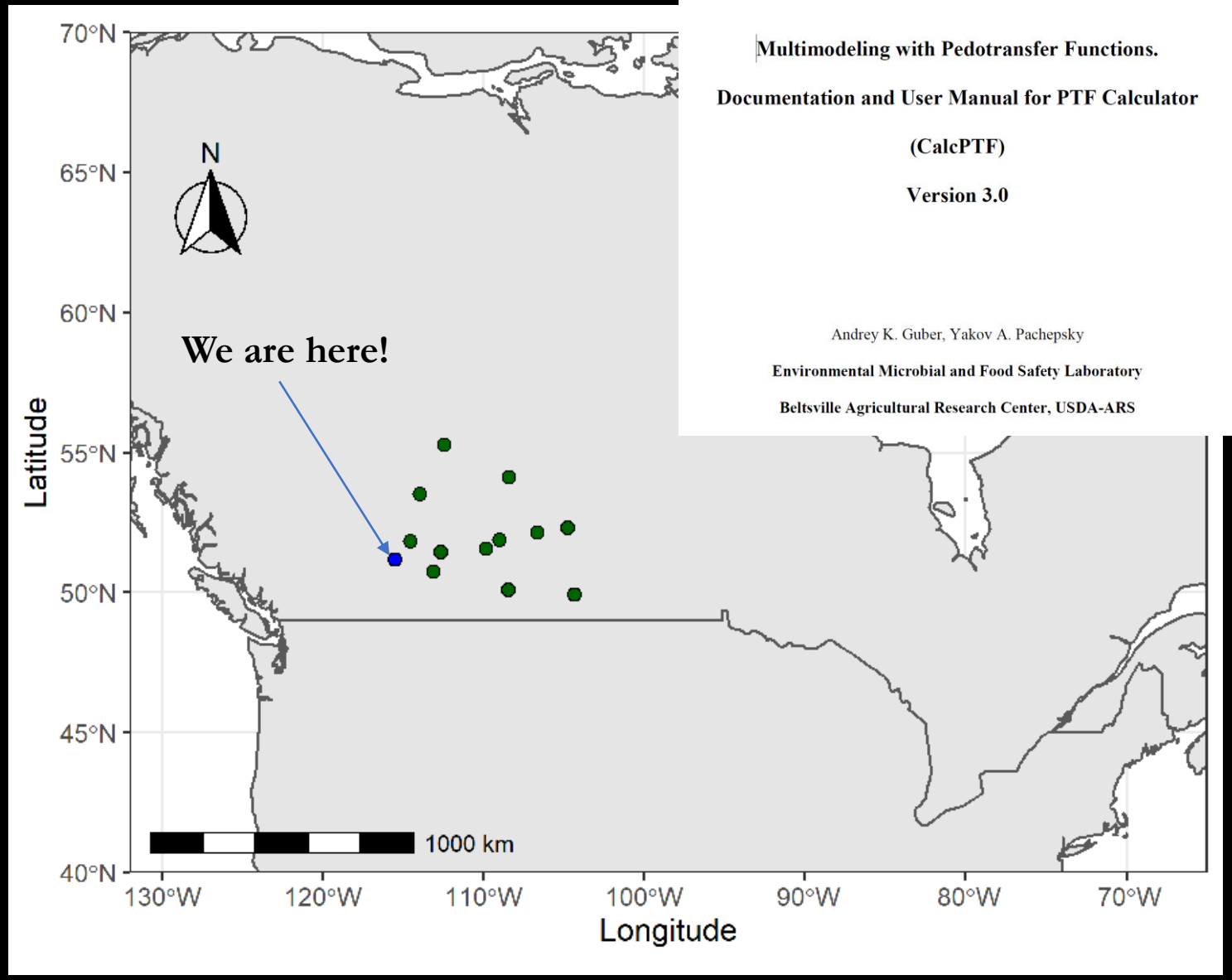
Low sampling frequency (point-in-time is the "pits")



Soil Sense collects 48 measurements per day



The Sites



USDA

Multimodeling with Pedotransfer Functions.

Documentation and User Manual for PTF Calculator

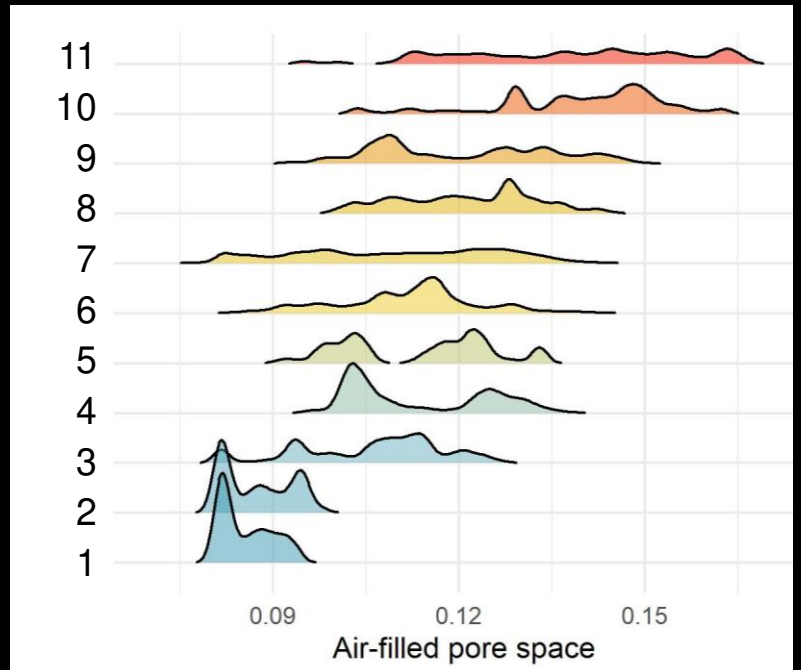
(CalcPTF)

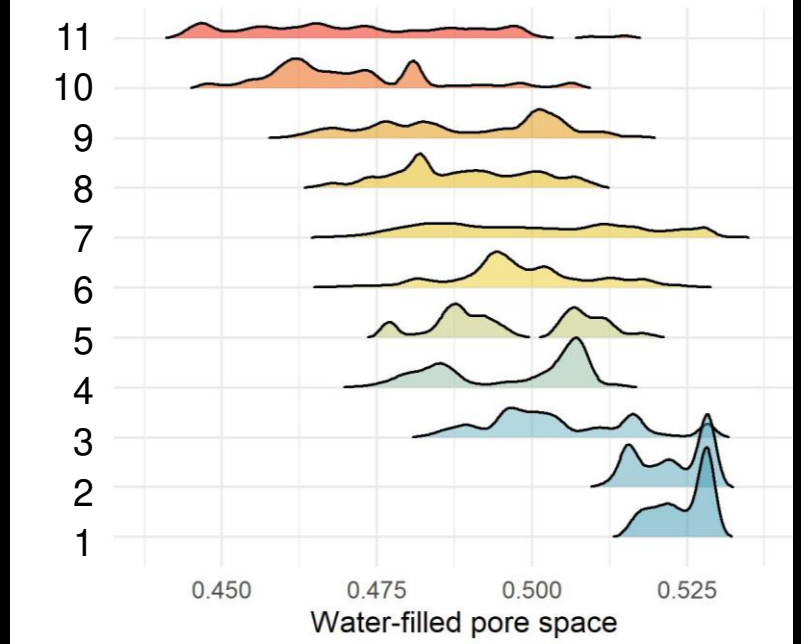
Version 3.0

Andrey K. Guber, Yakov A. Pachepsky

Environmental Microbial and Food Safety Laboratory

Beltsville Agricultural Research Center, USDA-ARS

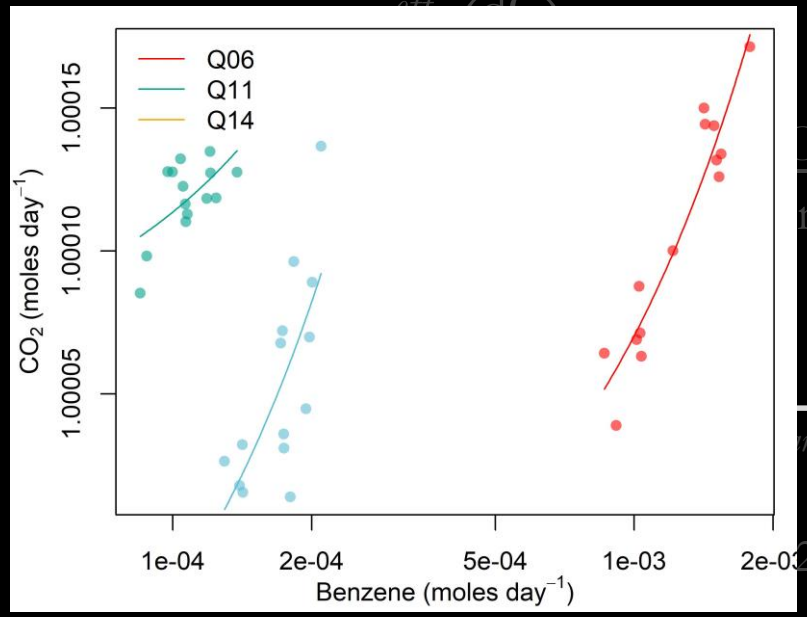


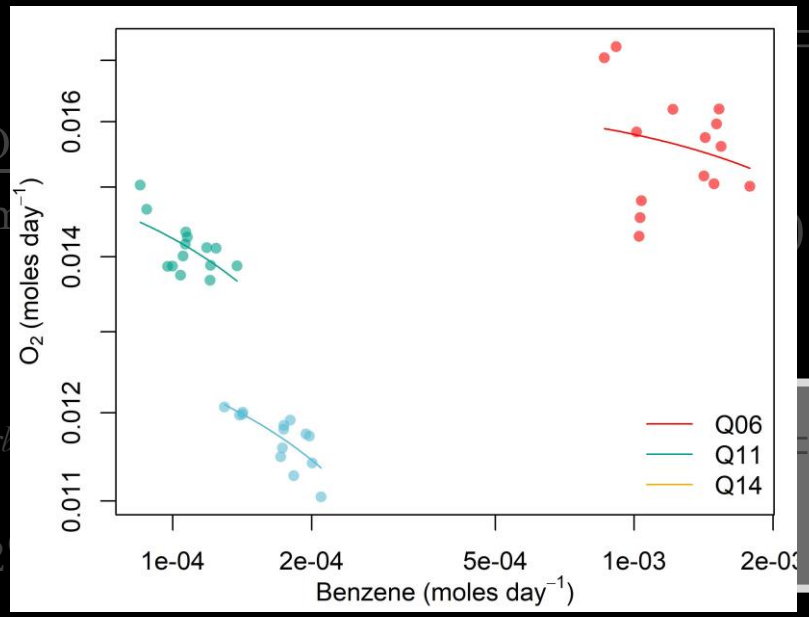


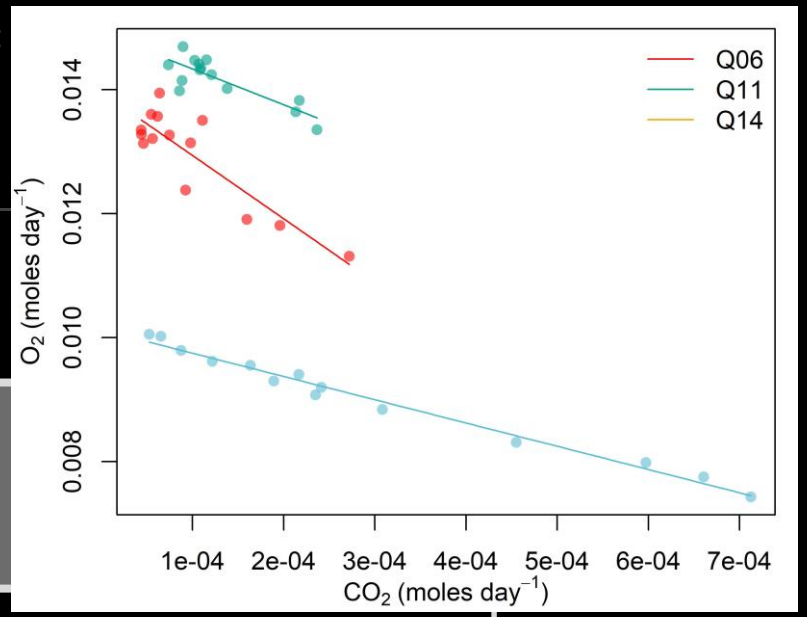
Guidance values

Convert Flux to Hydrocarbon Depletion (GUIDANCE)

CONVERT FLUX TO HYDROCARBON DEPLETION (SITE-SPECIFIC)







$$\text{Molar Ratio} = \frac{78.11\ \frac{g C_6H_6}{mol}}{44.11\ \frac{g CO_2}{mol}} \quad 2\ mol C_6H_6$$

Ratio	Guidance (mass)	Site-specific (mass)
C_6H_6:CO_2	0.296	0.329
C_6H_6:O_2	0.325	0.179
C_6H_6:CH_4	1.038	1.038

Adapted from CRC CARE 2018

Convert Flux to Hydrocarbon Depletion (GUIDANCE)

CONVERT FLUX TO HYDROCARBON DEPLETION (SITE-SPECIFIC)

$$J = D_v^{eff} \left(\frac{dC}{dZ}\right)$$

$$J = 3.8 \times 10^{-7} \frac{m^2}{s}$$

$$J = 2.43 \times 10^{-}$$

Convert to g – *Repres*

$$2C_6H_6 + 15O_2 \rightarrow 12$$

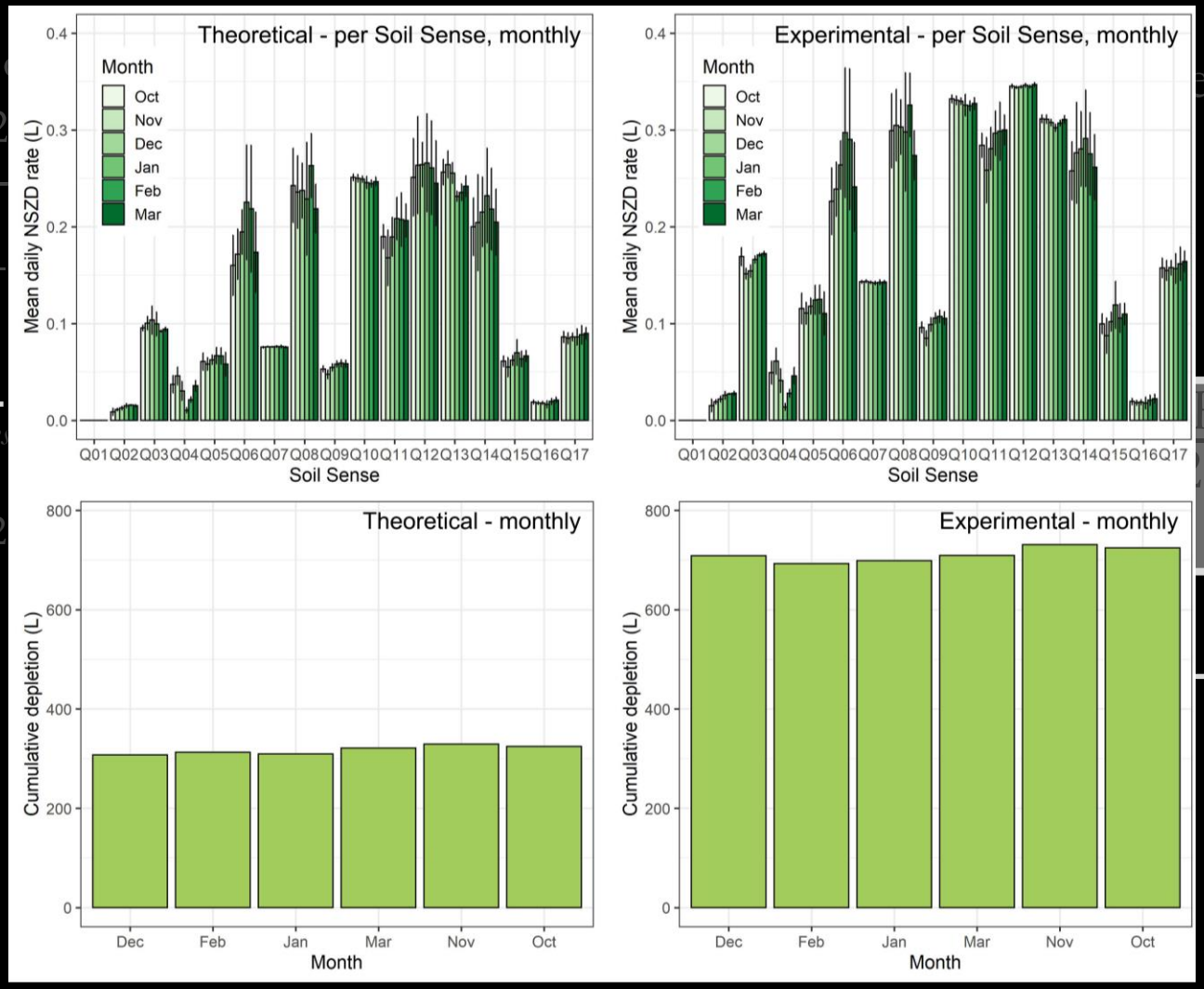
$$\text{Molar Ratio} = \frac{78.11 \frac{gC_6H_6}{mol}}{44.11 \frac{gCO_2}{mol}}$$

ed * Molar Ratio

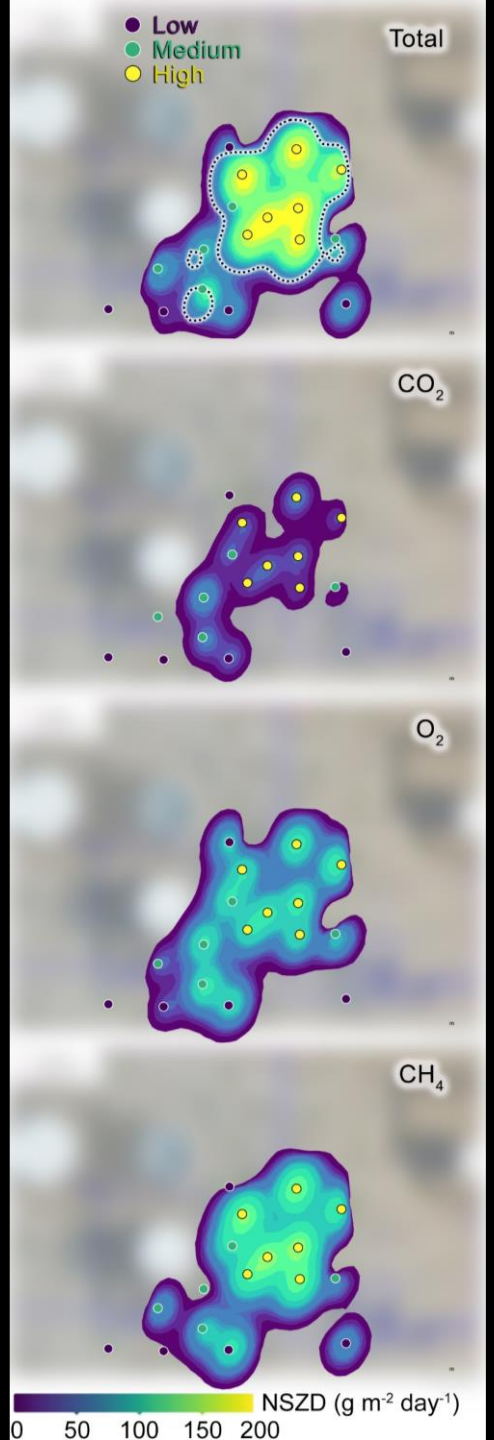
* 0.3 * 86400

H_6

d

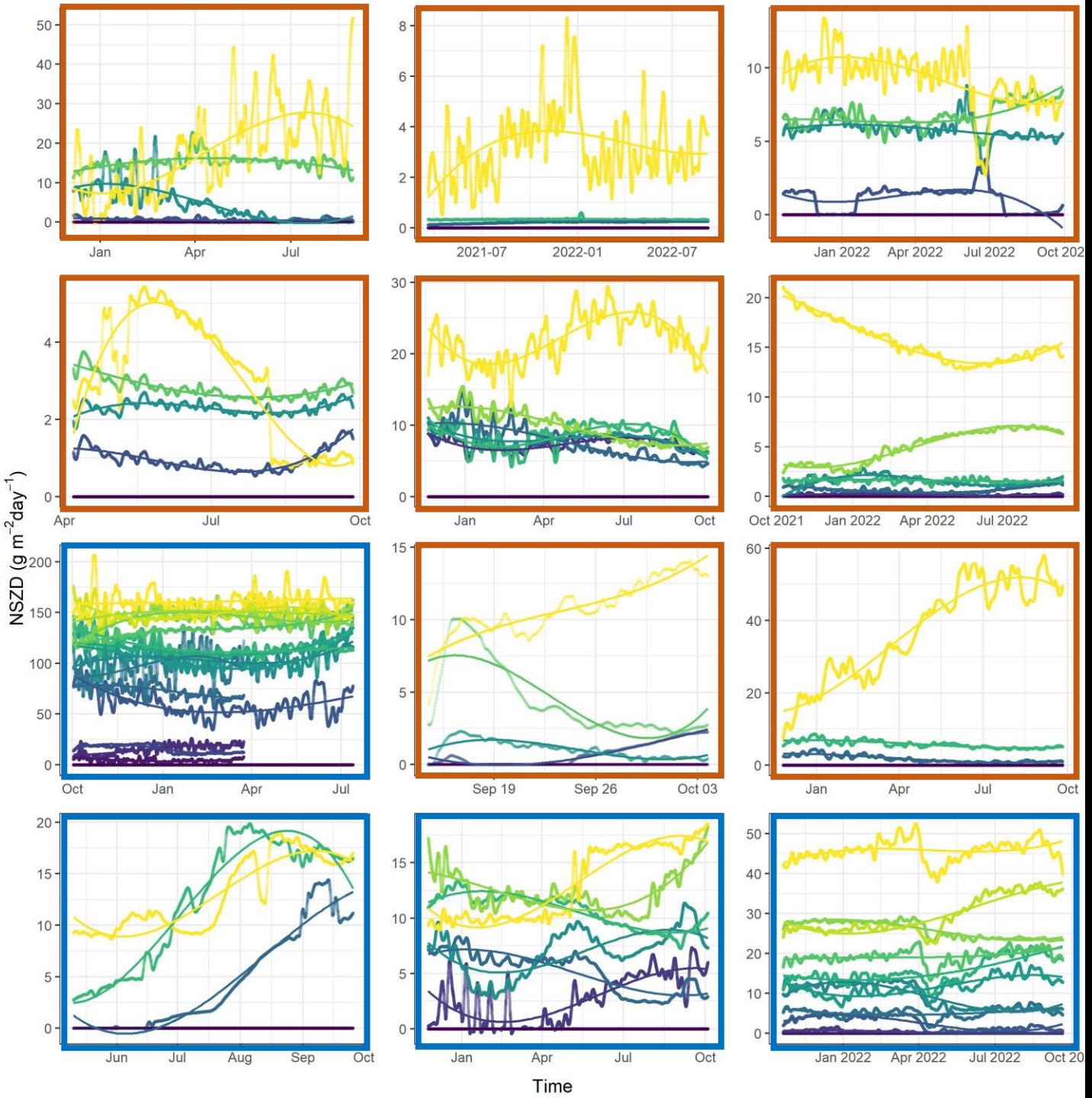


Adapted from CRC CARE 2018



NSZD through space

- NSZD estimates incorporate methane and paired CO_2 production/O_2 consumption
- More representative estimates of biological activity.

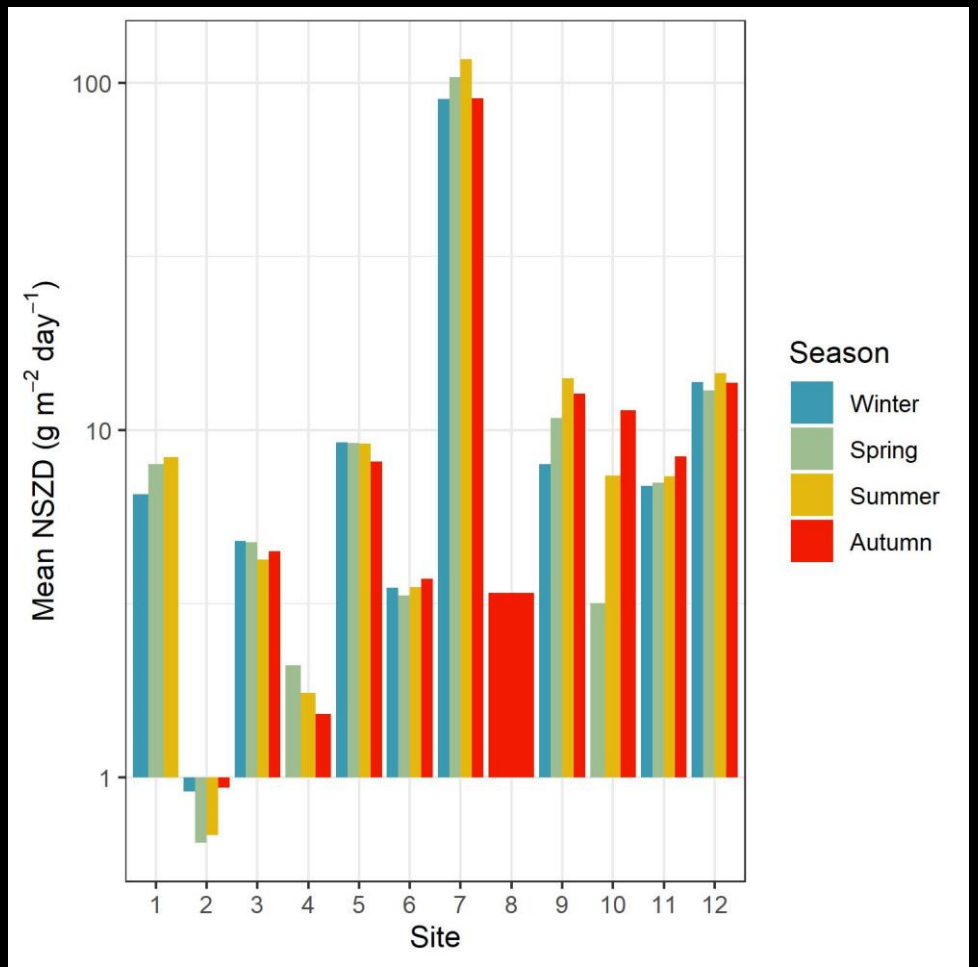


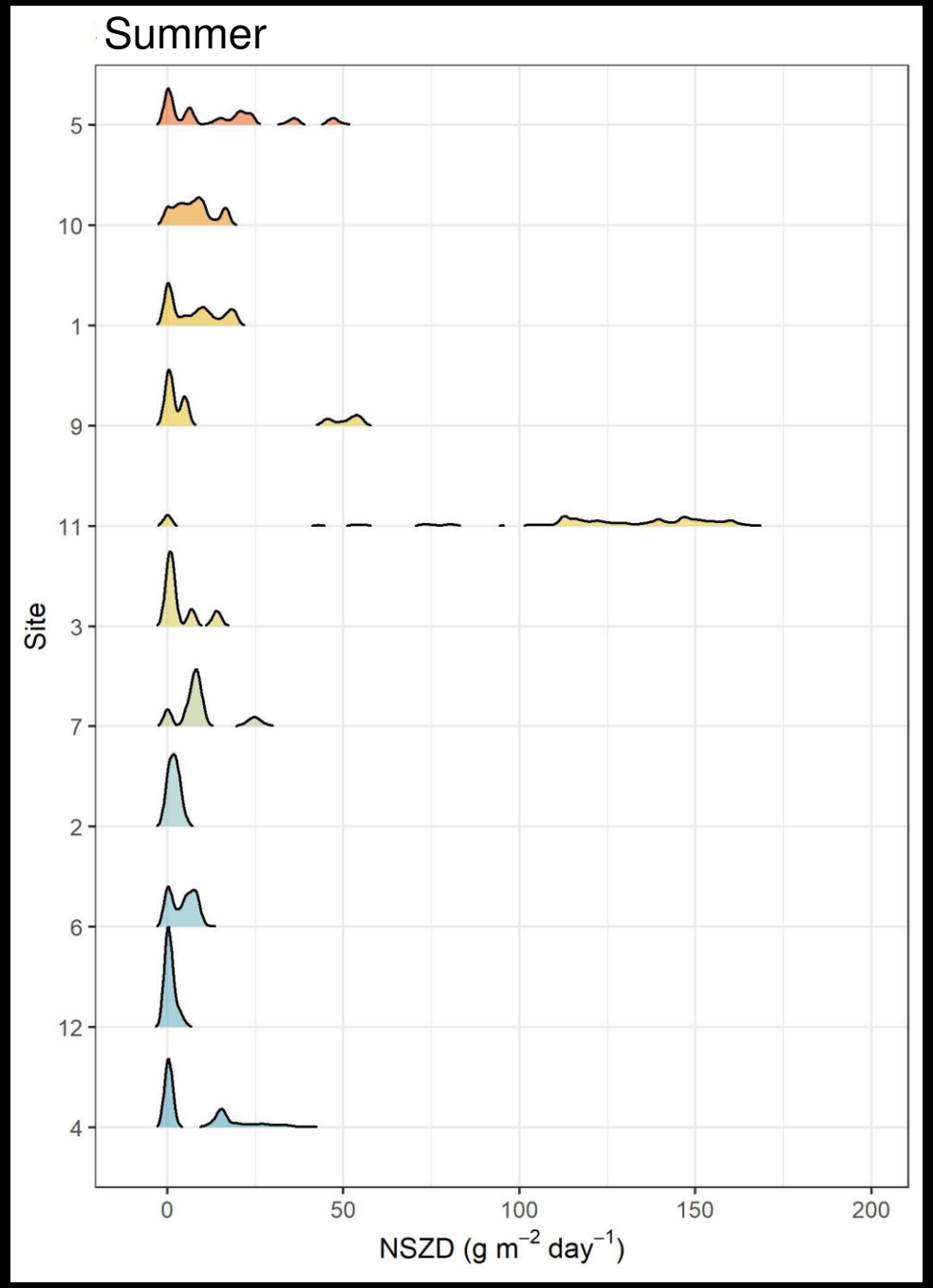
12 sites

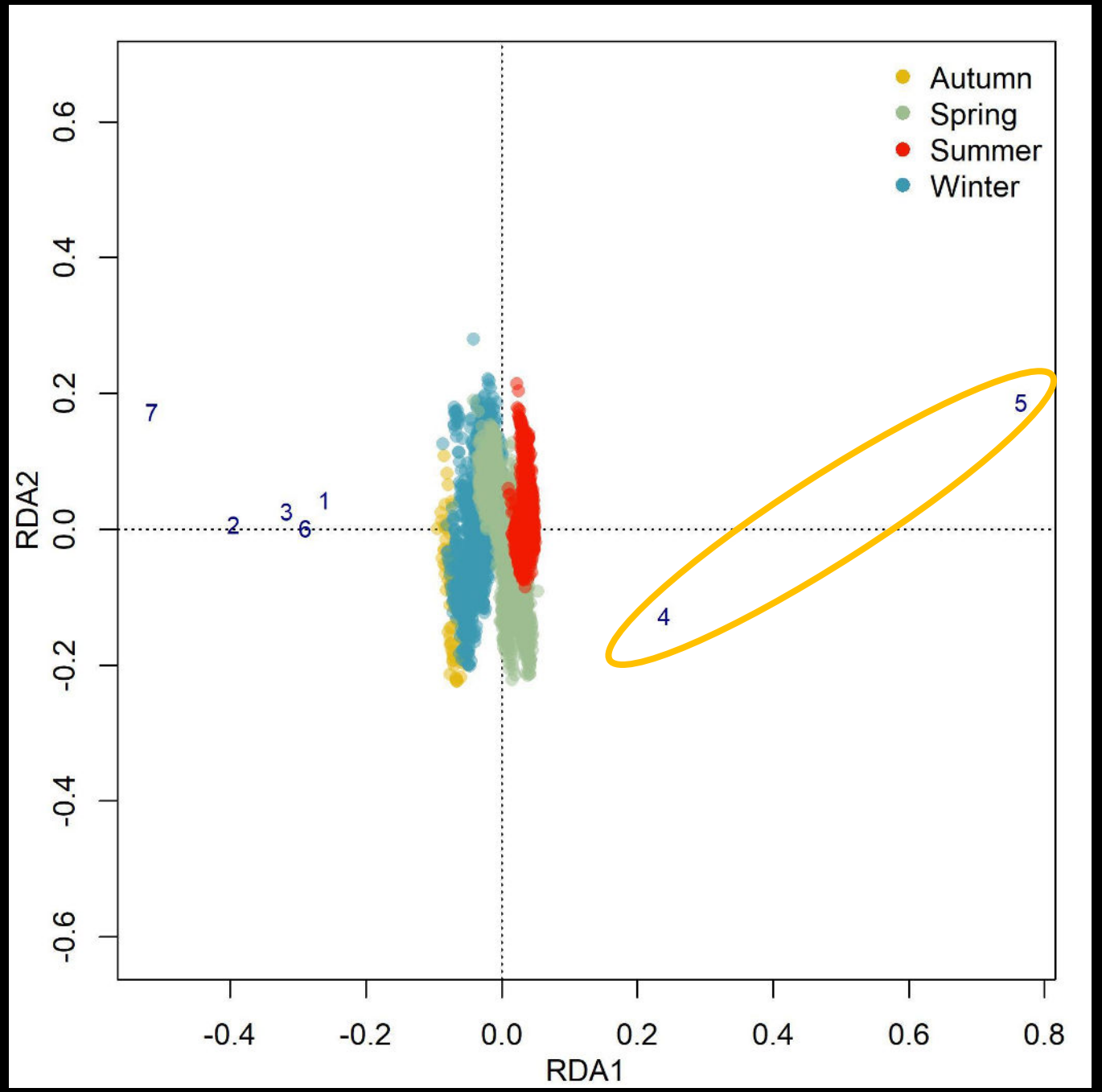
76 Soil Senses

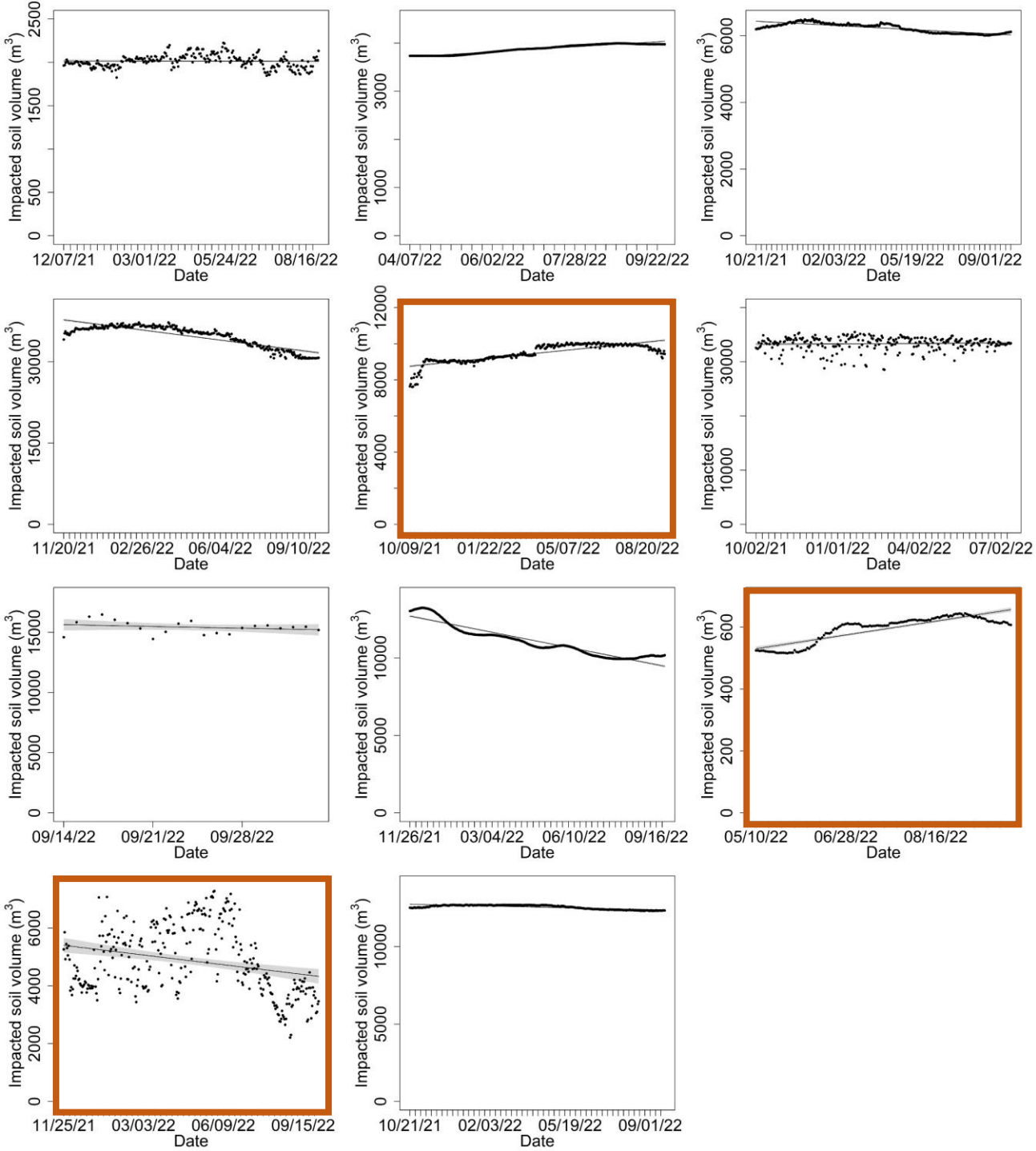
228 Sensor packs

92,662,066 data points!




Summer
Site
5
10
1
9
11
3
7
2
6
12
4
0
50
100
150
200
NSZD (g m^{-2} day^{-1})


Autumn
Spring
Summer
Winter
RDA2
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
RDA1
-0.4
-0.2
0.0
0.2
0.4
0.6
0.8
7
2
3
6
1
5
4

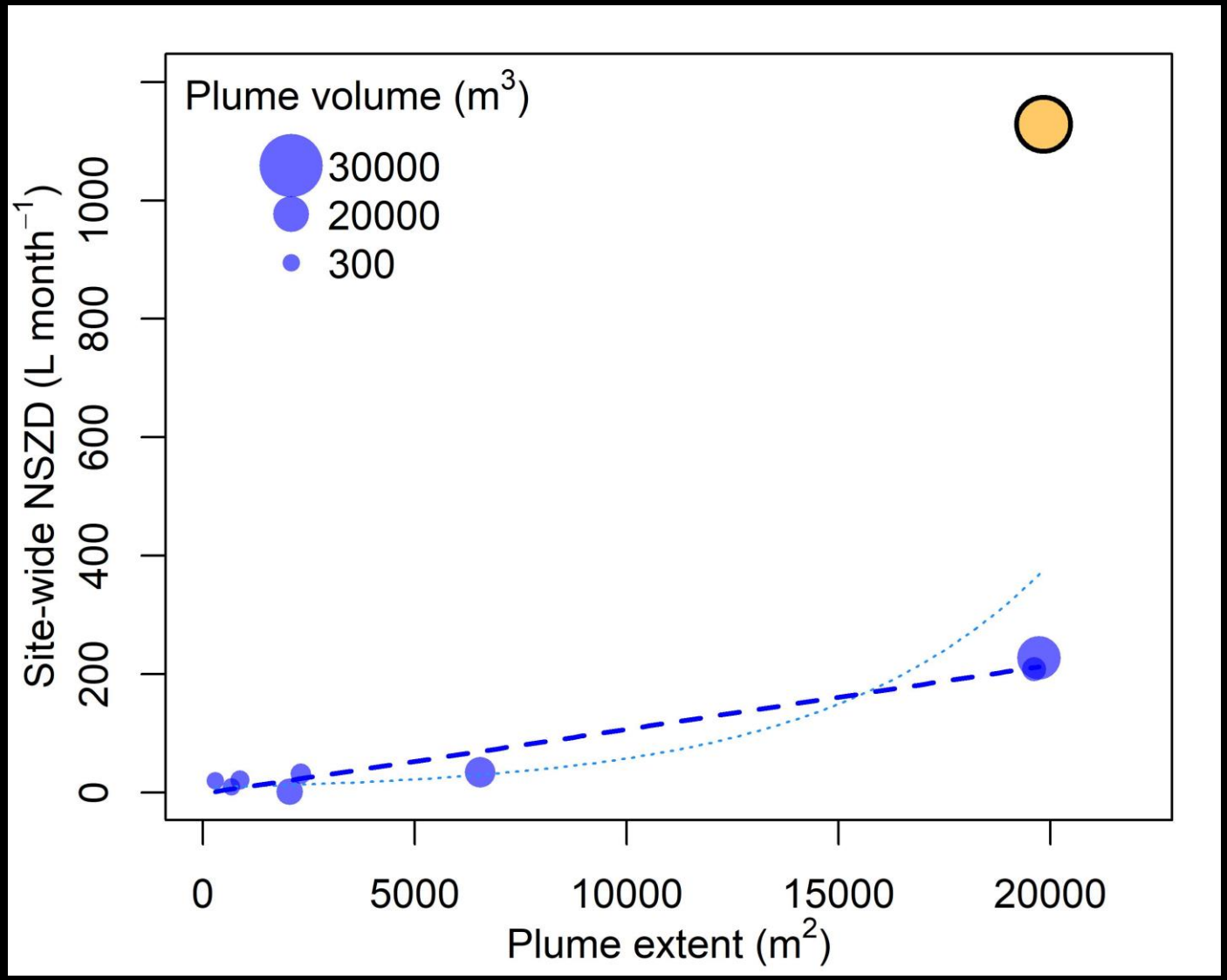


Plume volume

Typically stable over seasons

- Active site
- Additional sensor install and equilibration
- Site with high-water table and fall ice-up.

How do sites compare?

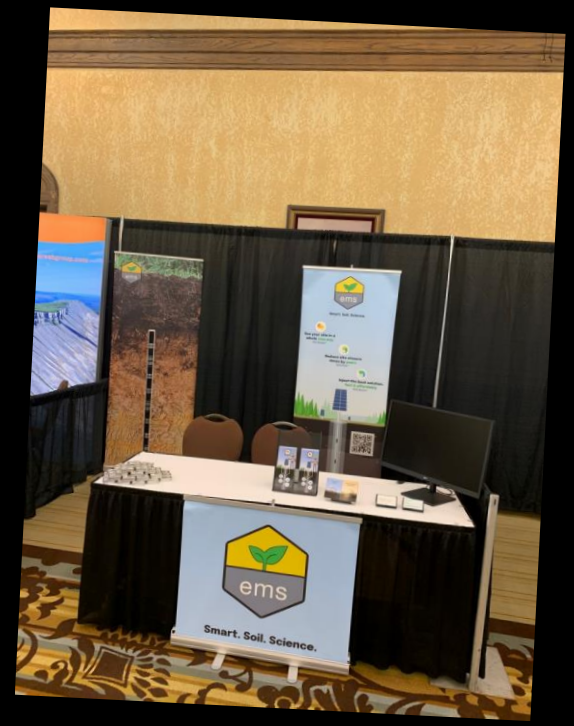



I DON'T ALWAYS KNOW THINGS
BUT
WHEN I DO, I KNOW NOTHING
quickmeme.com

Where are we now?

- High density continuous measurements
  - Diurnal and seasonal nuances, site-driven variation
  - CH_4 may make up the bulk of NSZD in some sites
- Soil moisture
  - Implications for fluid transfer and PHC distributions
- Site-specific estimates
  - Theoretical stoichiometry may not represent site processes
- Stay-tuned for next year!
  - FEA
  - Bayesian prediction networks
  - AgTech
  - Winter is coming.

Check us out at booth #6!

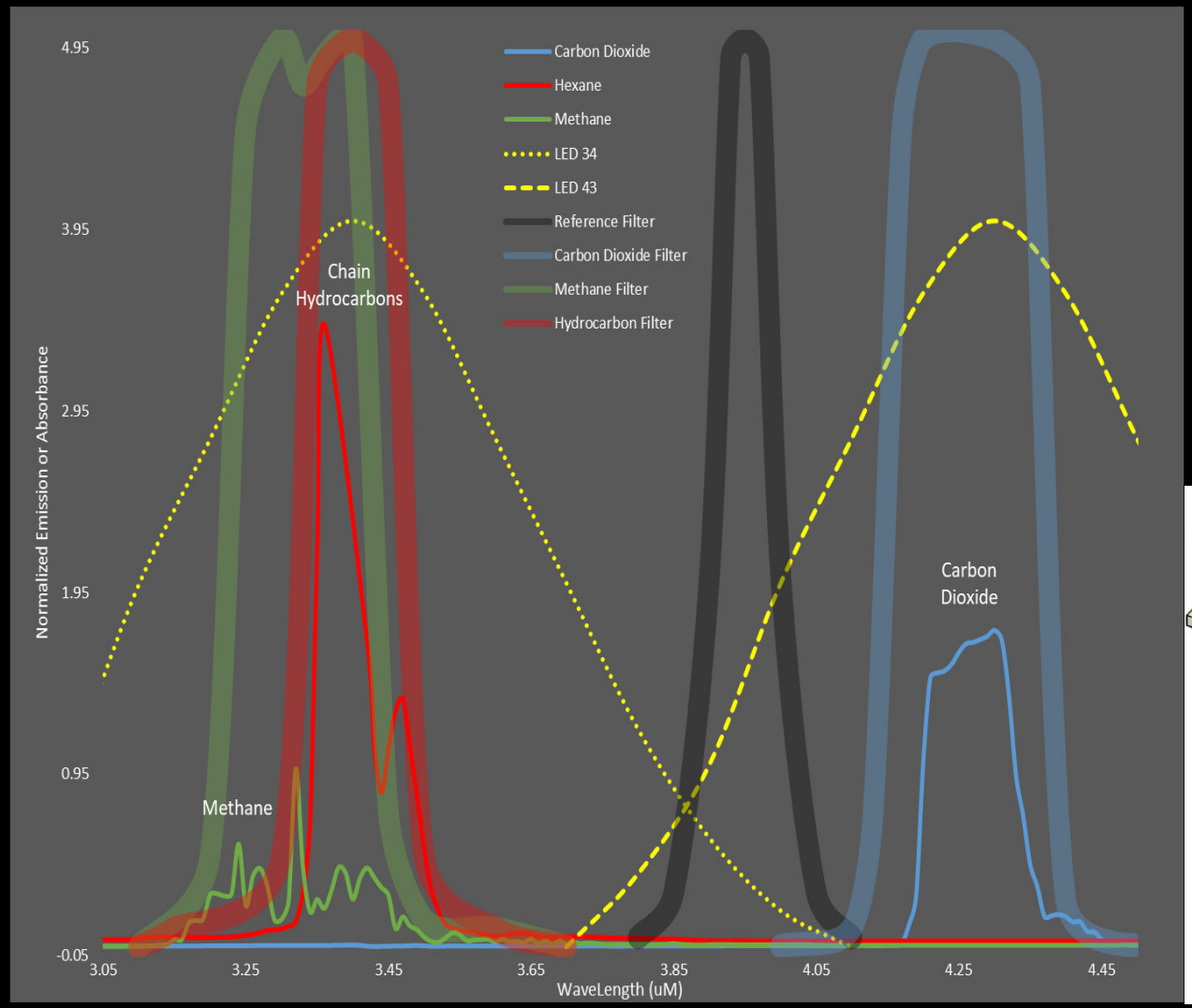


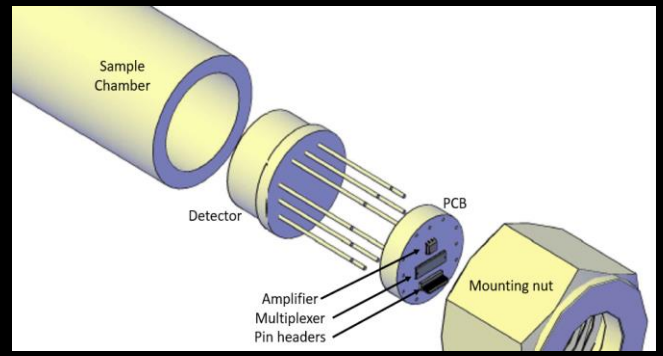
Thank you!

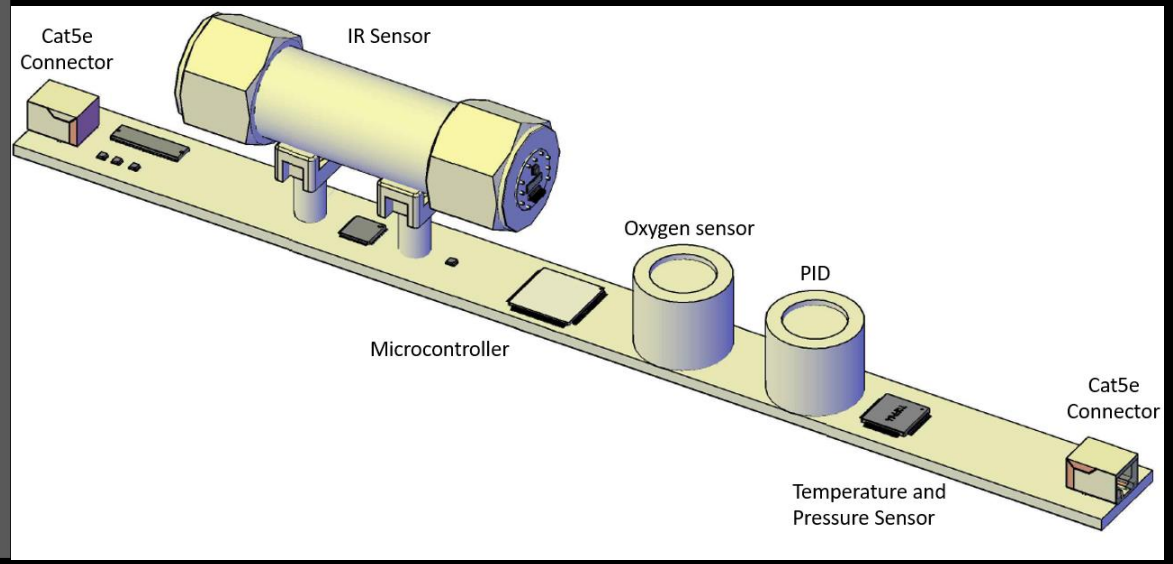
SUSTAINABLE DEVELOPMENT TECHNOLOGY CANADA

TECHNOLOGIES DU DEVELOPPEMENT DURABLE CANADA

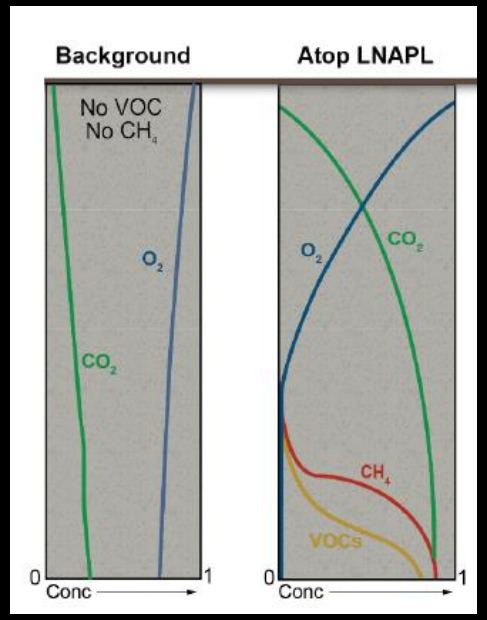
Pyroelectric Infrared Detectors in Soil Sense



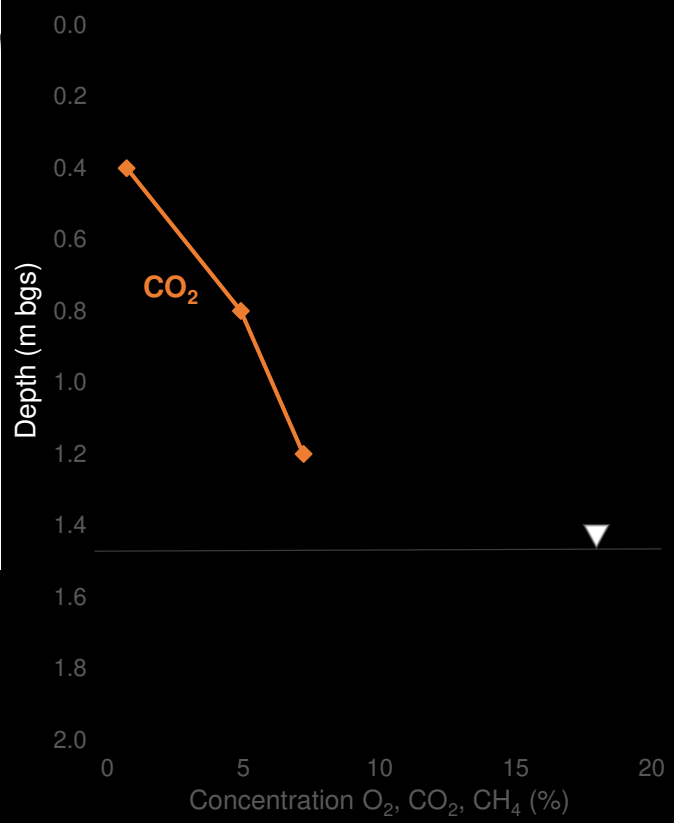




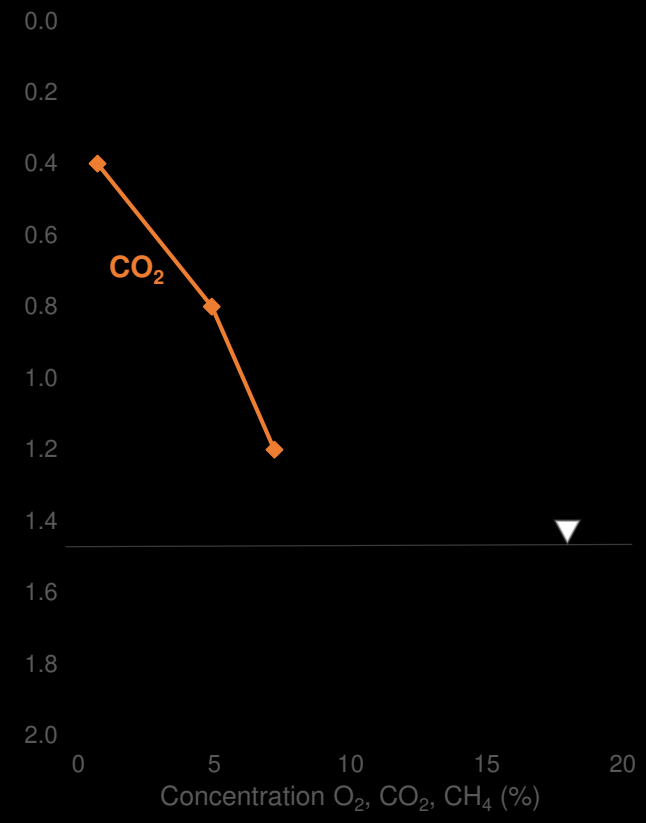
CONCENTRATION GRADIENT METHOD ("CGM") – CLASSIC SITE



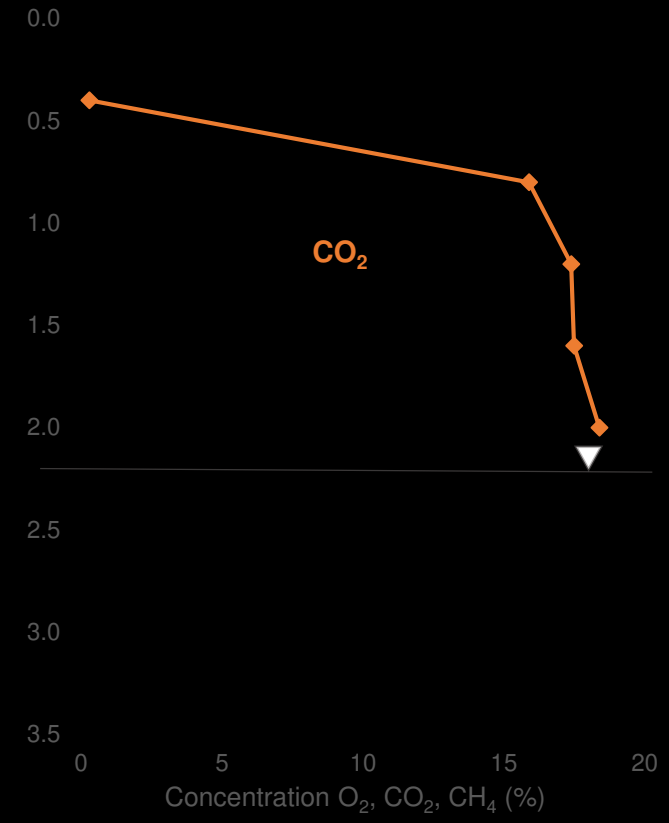
Background



Source 1

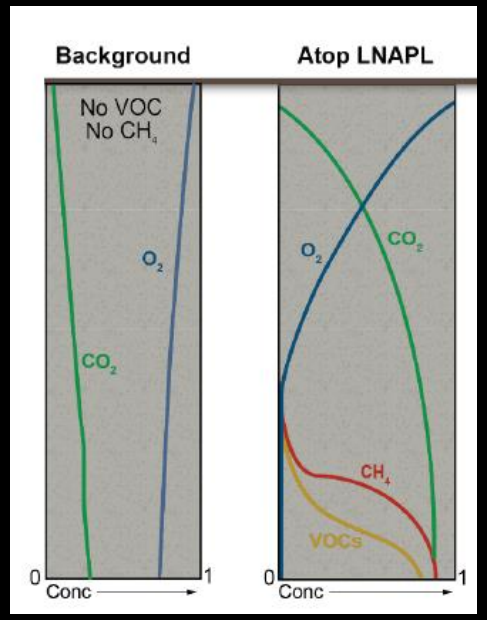


Source 2

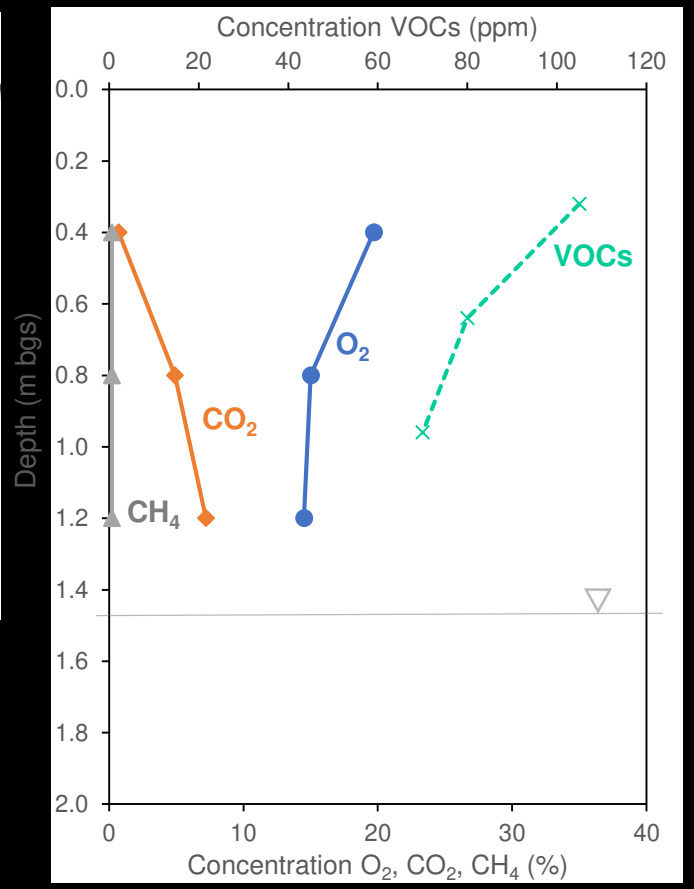


Adapted from CRC CARE 2018

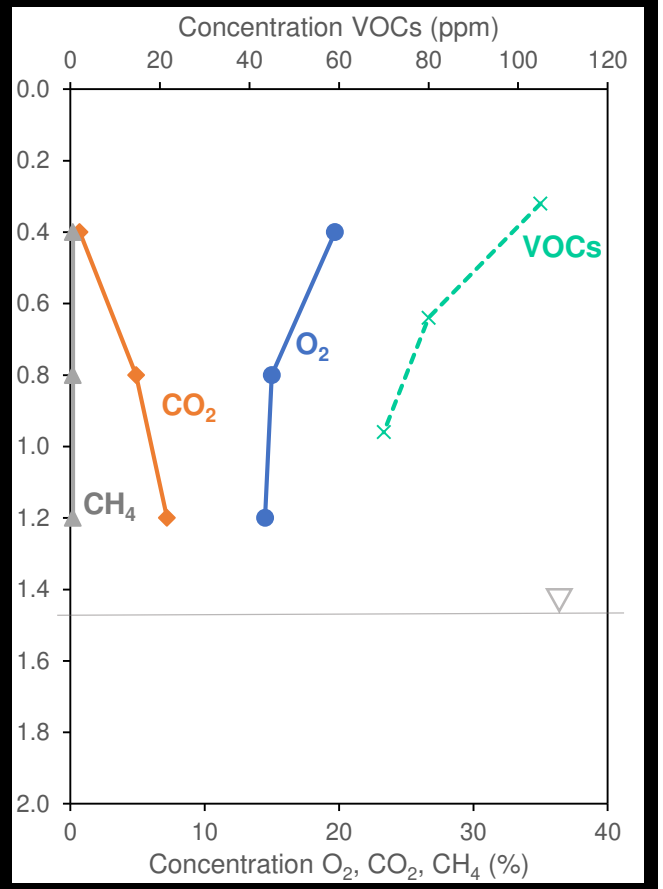
Concentration Gradient method ("CGM") – classic site



Background



Source 1



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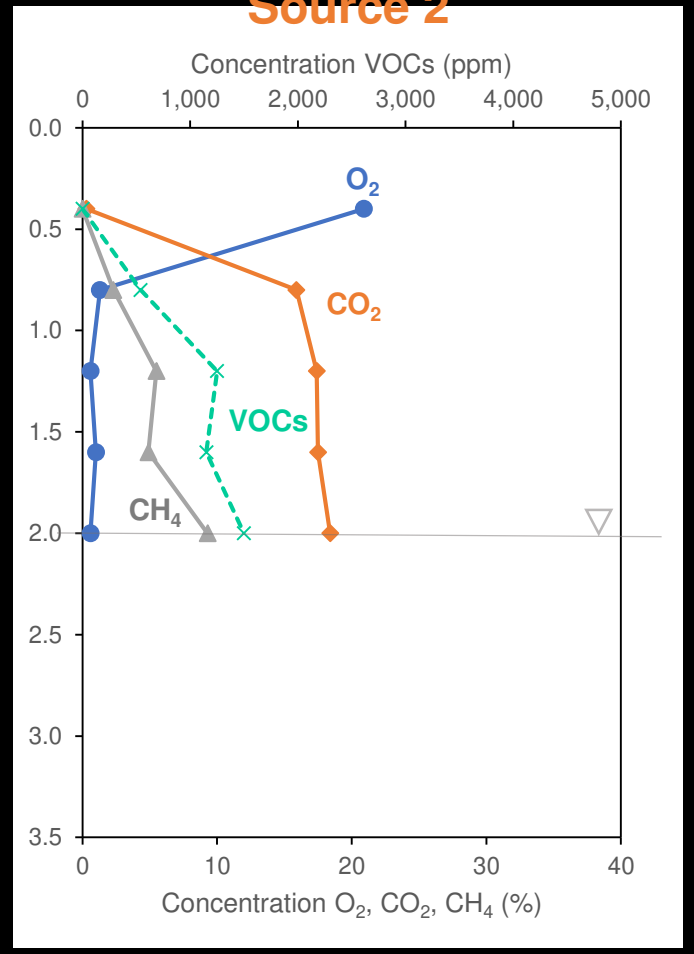
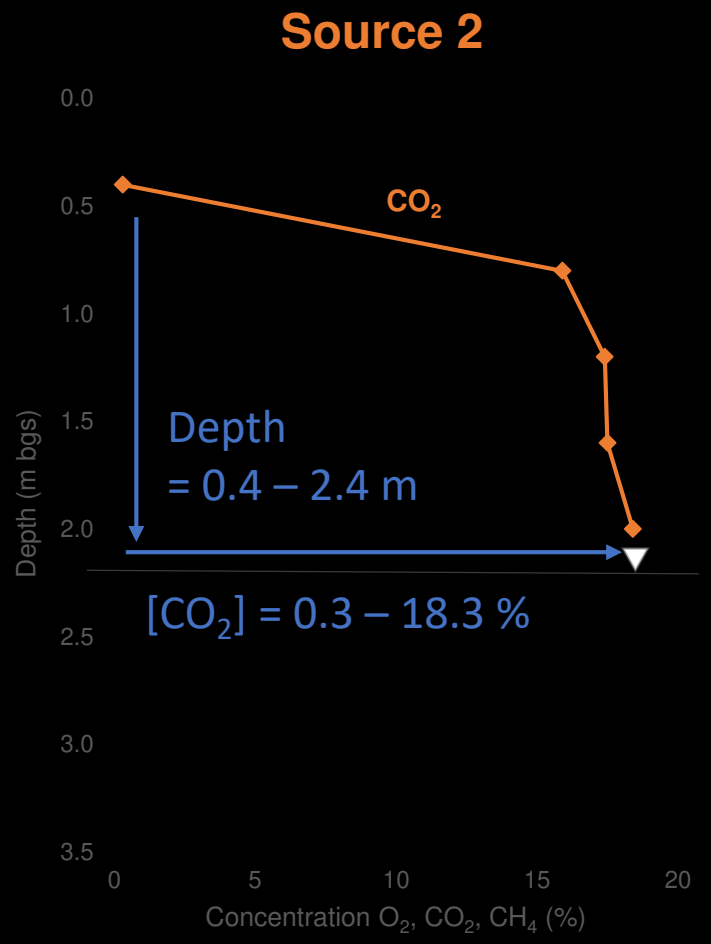


CGM – Step 1: Calculate Flux from Soil



$$J = D_V^{eff}\left(\frac{dC}{dZ}\right)$$

$$\left(\frac{dC}{dZ}\right)_{impacted} = \frac{C_2 - C_1}{Z_2 - Z_1} = \frac{\frac{mg}{m^3}}{m} = \frac{18.3\% - 0.3\%}{\square} = \square \ \frac{g_{CO_2}}{m^3 m}$$

$$\left(\frac{dC}{dZ}\right)_{corrected} = \left(\frac{dC}{dZ}\right)_{impacted} - \left(\frac{dC}{dZ}\right)_{background}$$

$$\left(\frac{dC}{dZ}\right)_{corrected} = \square \ \frac{g_{CO_2}}{m^3 m} - \square \ \frac{g_{CO_2}}{m^3 m} = \square \ \mathbf{\frac{g_{CO_2}}{m^3 m}}$$

Adapted from CRC CARE 2018

CGM– Step 2: Convert Flux to Hydrocarbon Depletion (GUIDANCE)

$$J = D_V^{eff} \left(\frac{dC}{dZ}\right) \text{corrected}$$

$$J = 3.8 \times 10^{-7} \frac{m^2}{s} * 64 \frac{g_{CO_2}}{m^3 m}$$

$$J = 2.43 \times 10^{-5} \frac{g_{CO_2}}{m^2 s}$$

Convert to g – *Representative Hydrocarbon*

$$2C_6H_6 + 15O_2 \rightarrow 12CO_2 + 6H_2O$$

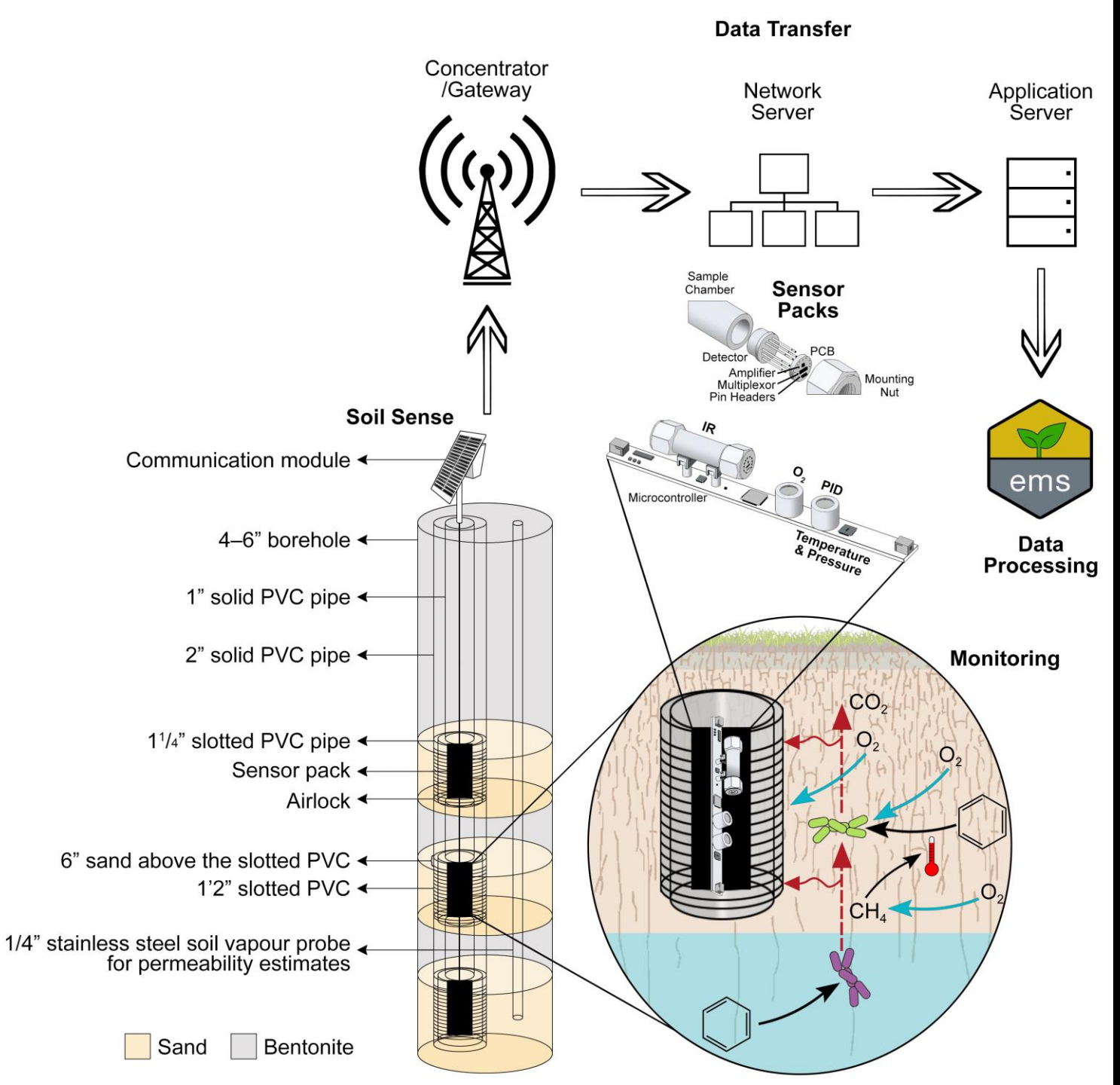
$$\text{Molar Ratio} = \frac{78.11 \frac{g_{C_6H_6}}{mol}}{44.11 \frac{g_{CO_2}}{mol}} * \frac{2 \text{ mol}_{C_6H_6}}{12 \text{ mol}_{CO_2}} = 0.3$$

$$NSZD_{point} = J_{corrected} * \text{Molar Ratio}$$

$$= 2.43 \times 10^{-5} \frac{g_{CO_2}}{m^2 s} * 0.3 * 86400$$

$$= 0.63 \frac{g_{C_6H_6}}{m^2 d}$$

Adapted from CRC CARE 2018



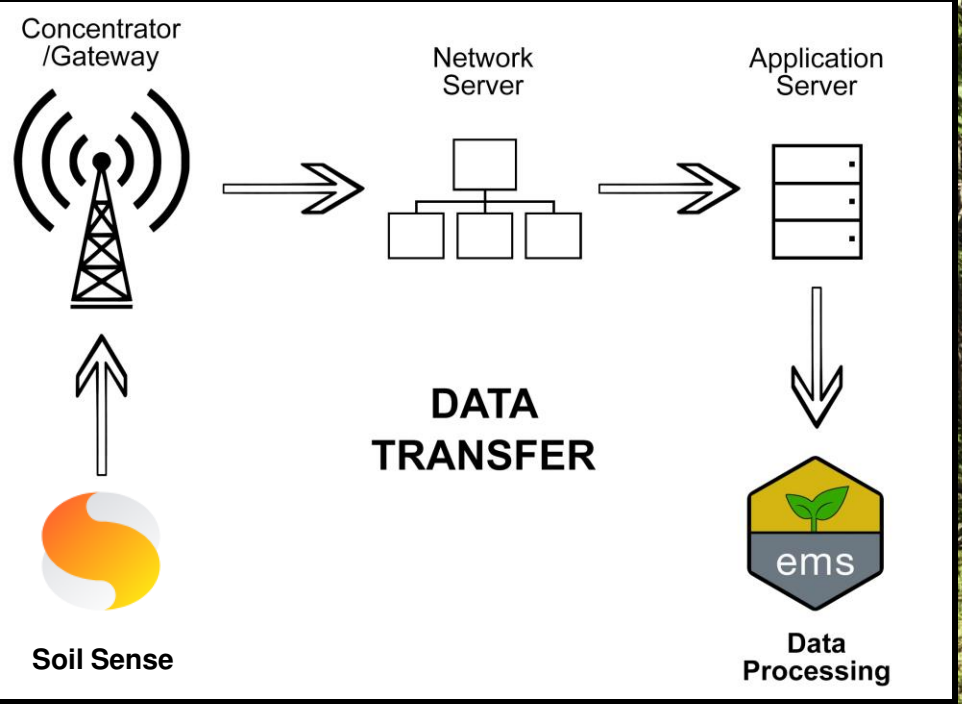
EMS Soil Sense

Every 30 Minutes
All day, every day

Direct Hydrocarbon Detection
- IR Active Hydrocarbons

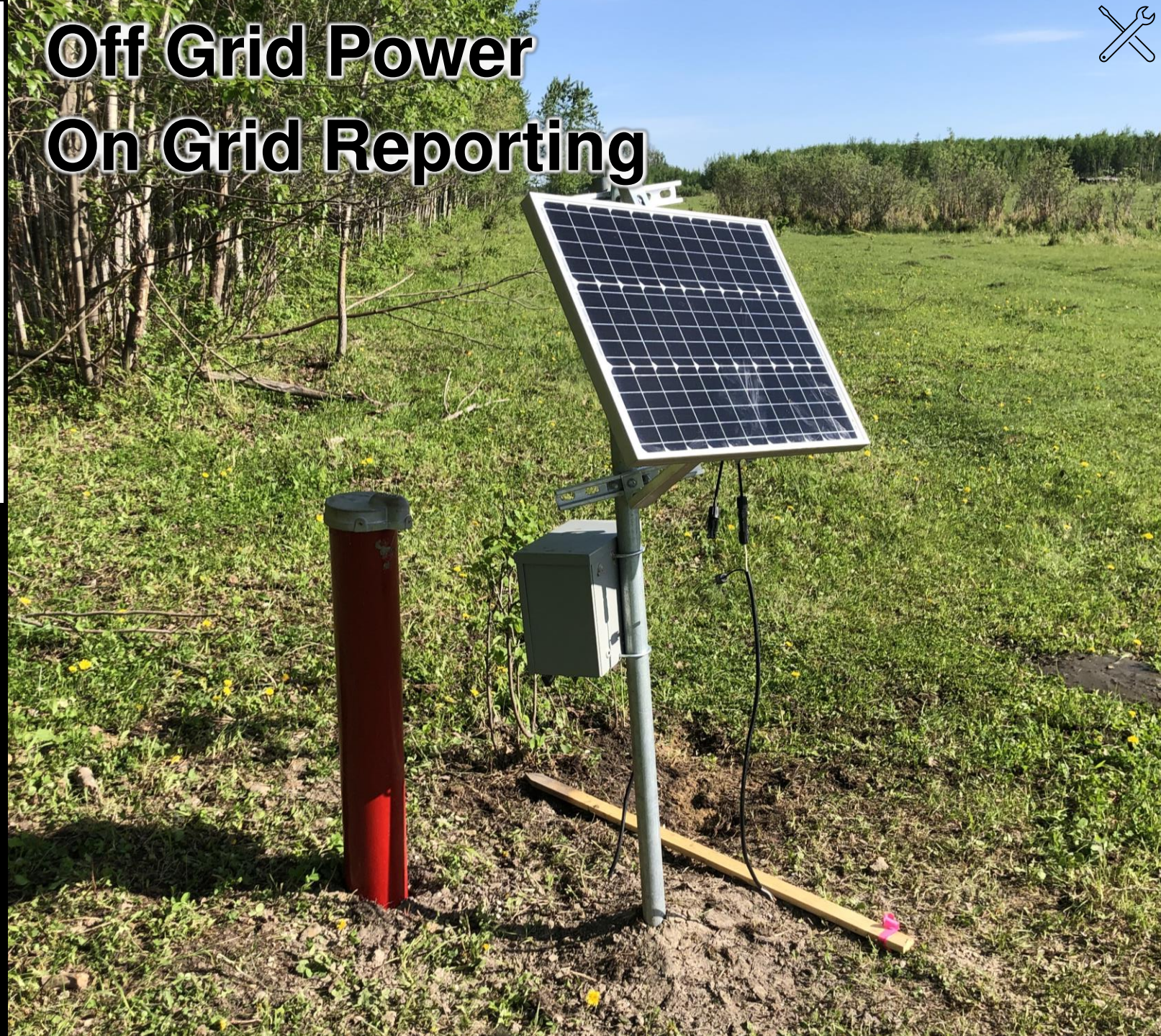
Hydrocarbon Depletion
- CO_2, CH_4, O_2

Environmental Data
- Temperature, Relative Humidity, Pressure



EMS SOIL SENSE

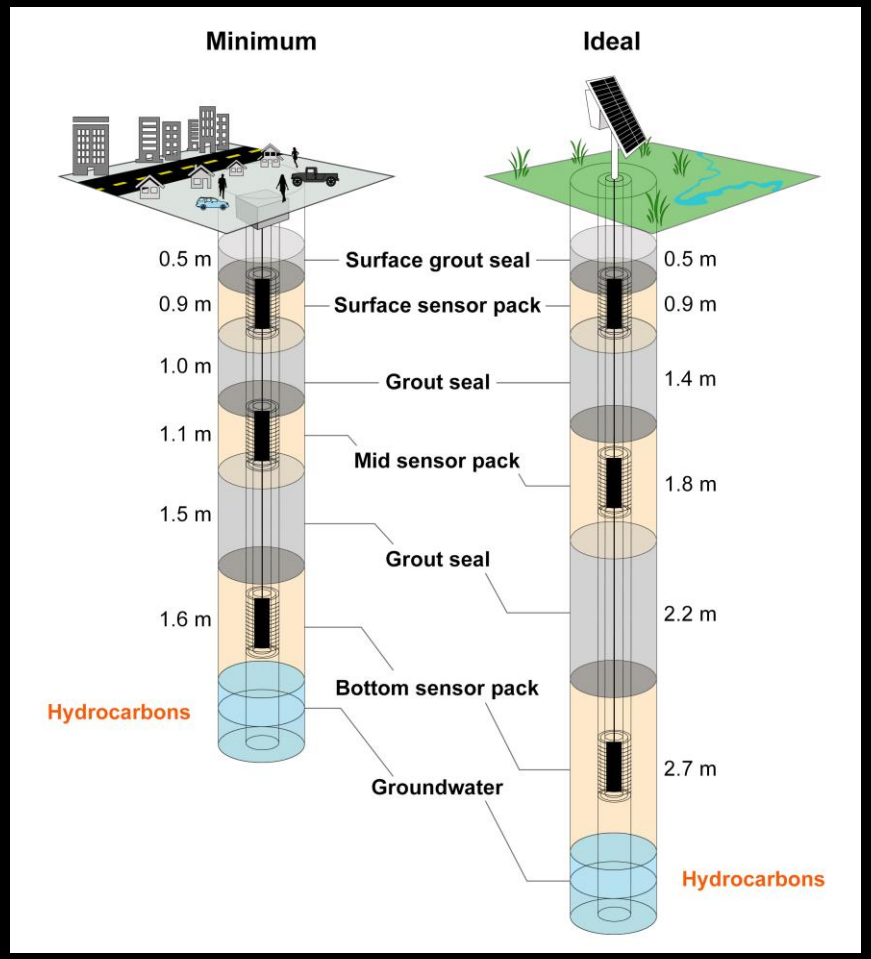
- **Trenched Power**
  - Ideal for active sites with existing infrastructure
- **Battery Power**
  - Well suited for sites with wildlife or malfeasance concerns.
- **Solar Power**
  - Perfect for remote sites, hard to access.



Vertical placement parameters

EMS SOIL SENSE

Design flexibility



Waterproof

- Sensor packs can survive being submerged in areas with a fluctuating water table.

Ideal Design

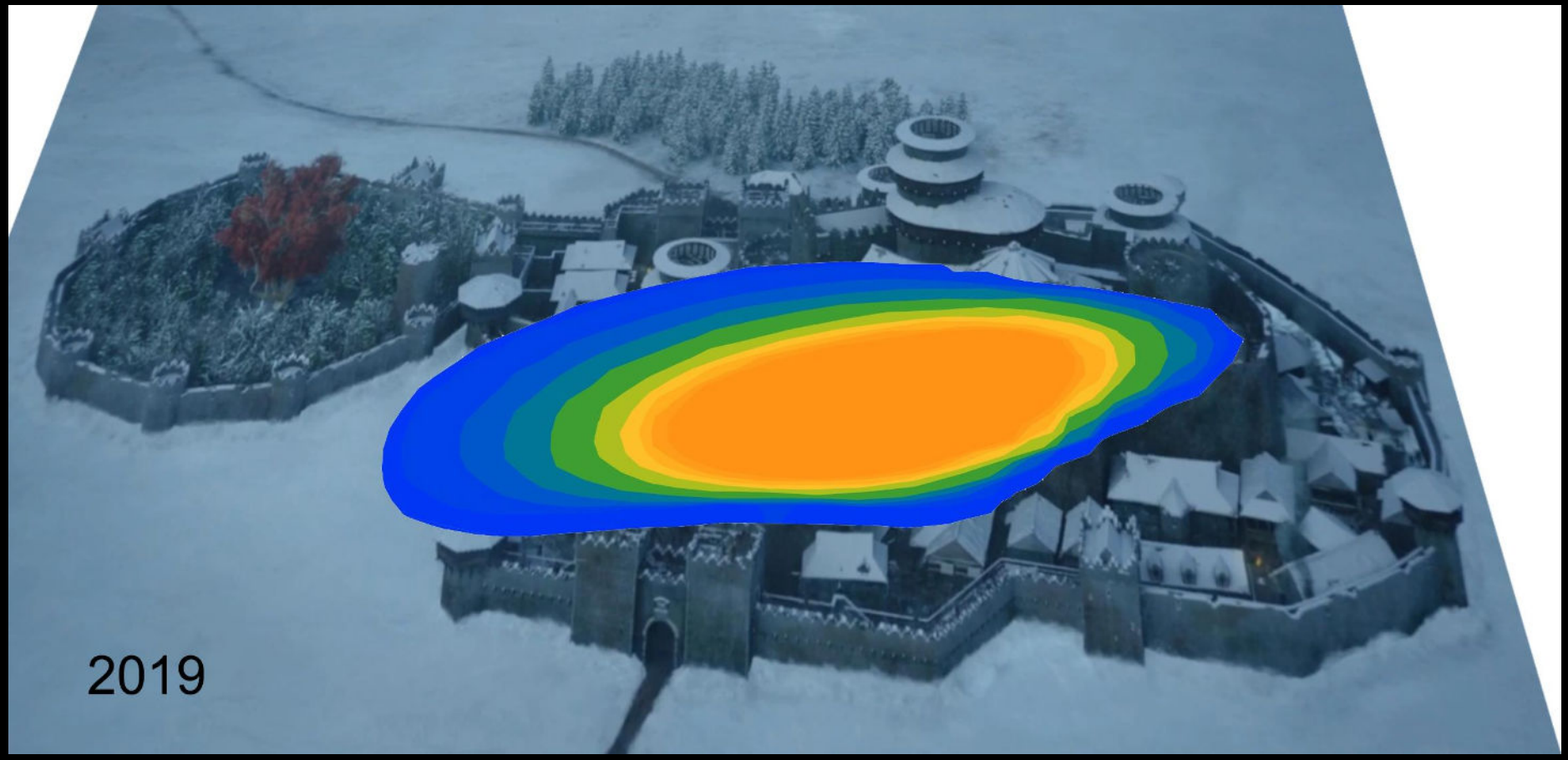
- Sensor Pack 1 near surface
- Sensor Pack 3 above LNAPL
- Sensor Pack 2 mid way between 1 & 3

Site Variability

- Borehole permeability
- 1 and 2 D modelling of gas fluxes

Old dragon rendering Facility

Old dragon rendering Facility



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