What's going on Underground?

GTI/ CSU CH_4 Connections, 2019

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Acknowledgements:

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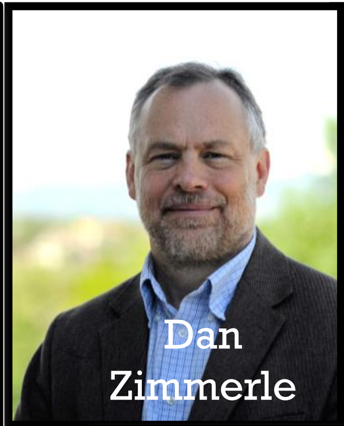
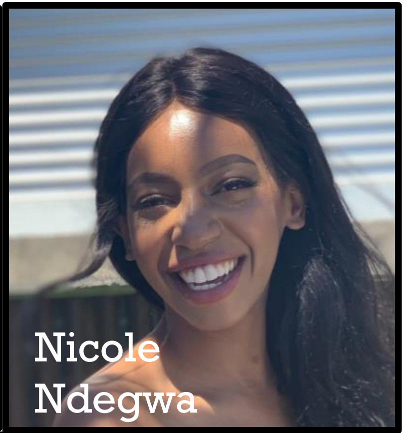
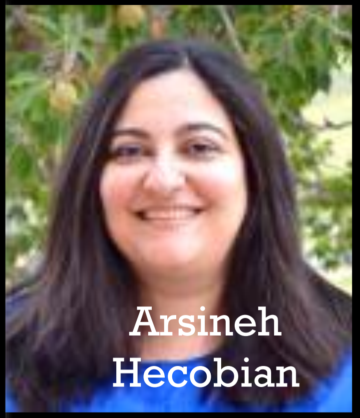
U.S. DEPARTMENT OF ENERGY

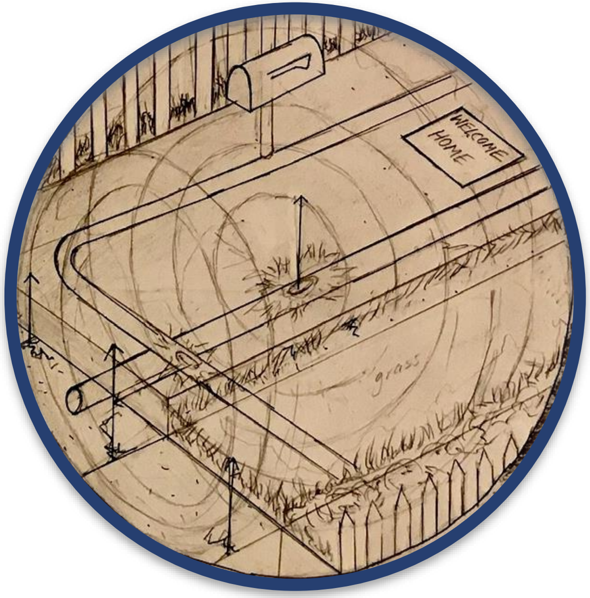


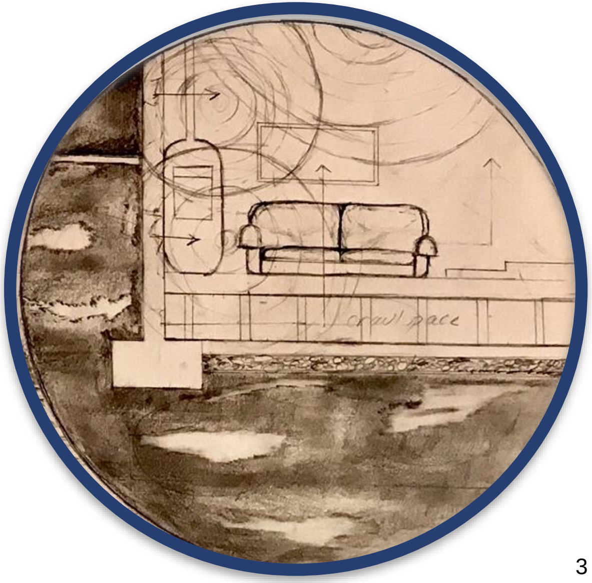




Conceptualization

Underground pipeline leakage results in gas buildup and migration though soil and ultimately its release into the air or a substructure - can be catastrophic to environment, health, safety, and public trust





Conceptualization

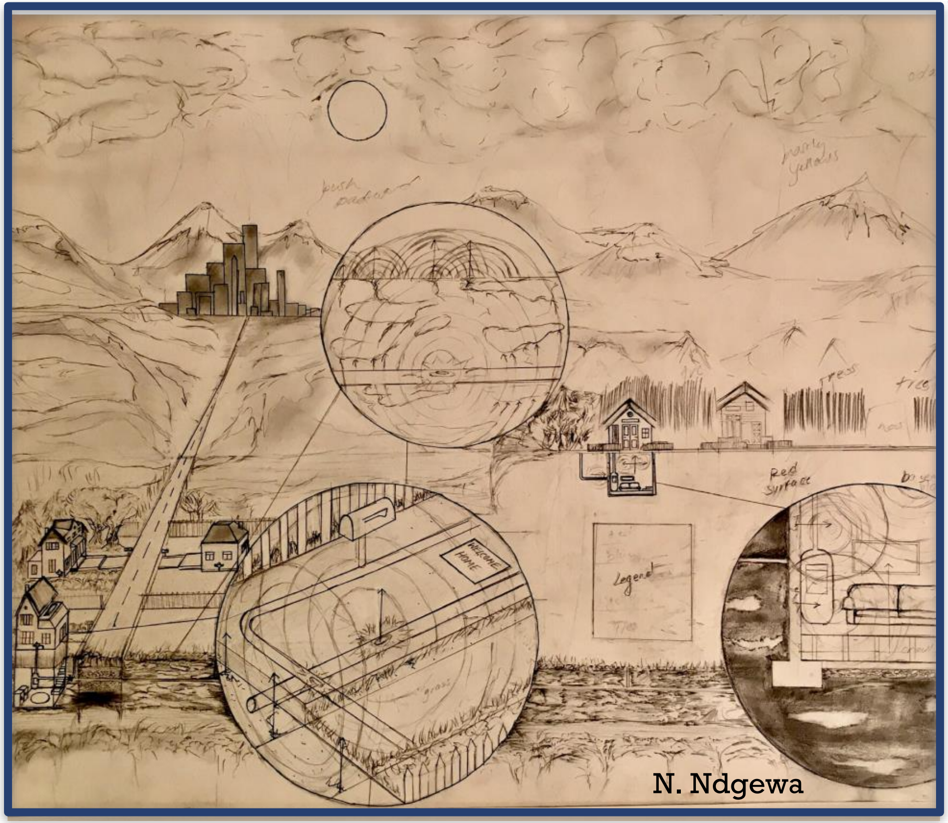
It's complex …there's 'too much' going on

Leakage behavior

Environmental conditions

- Meteorology (e.g. wind, stability, cloud cover, recirculation)
- Subsurface conditions (e.g. heterogeneity and soil moisture)

Thermodynamic, transport & chemical properties of CH_4 and other fluids



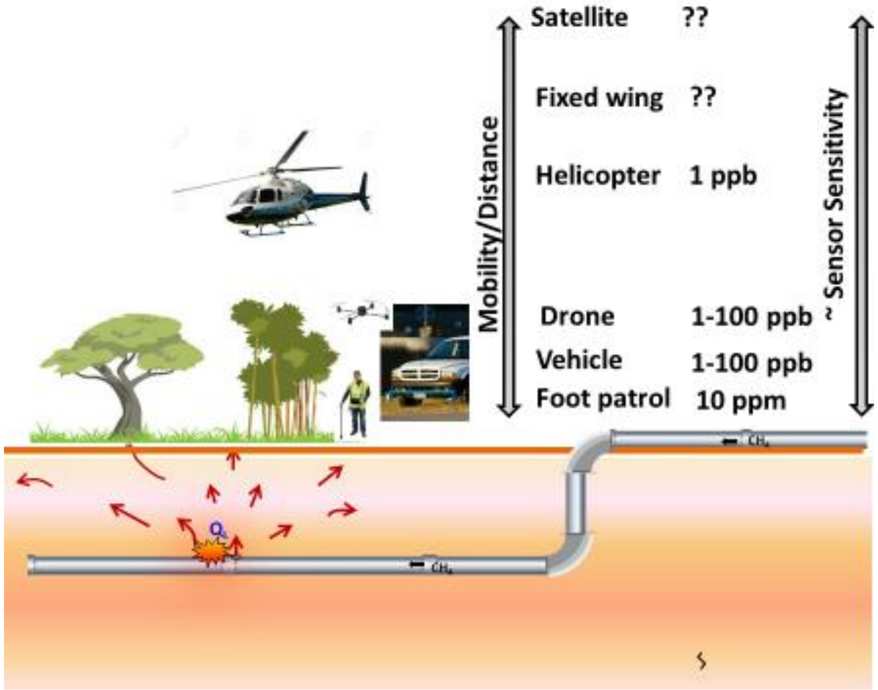
To date, there is no standardized protocol available for considering these factors and how to account for such variables in data analysis

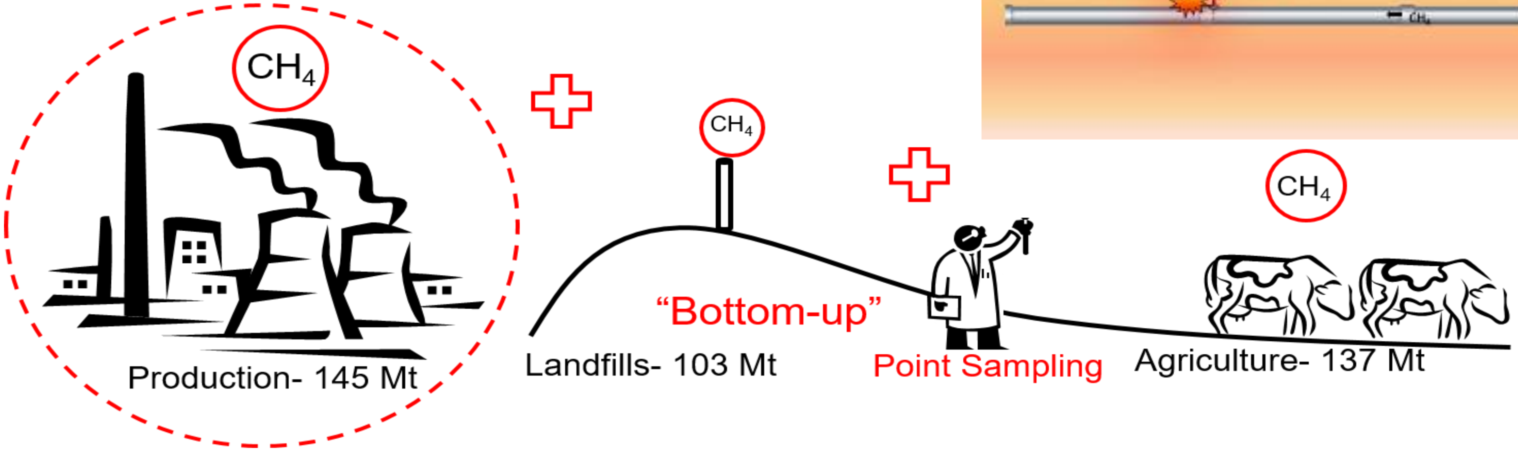
Added complexity linked to detection

Partitioning of methane emissions

Source identification (multitude of sources and colocation of multiple source types)

Representativeness of measurements (sample size, temporal and spatial coverage)



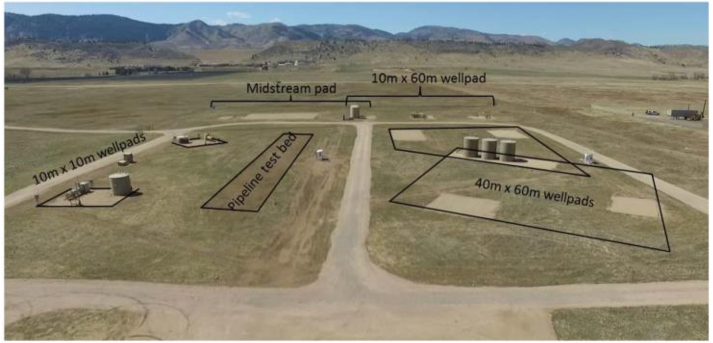


Goal:

Understand conditions and mechanisms affecting gas migration from pipeline leakage

Account for such factors in our decision making

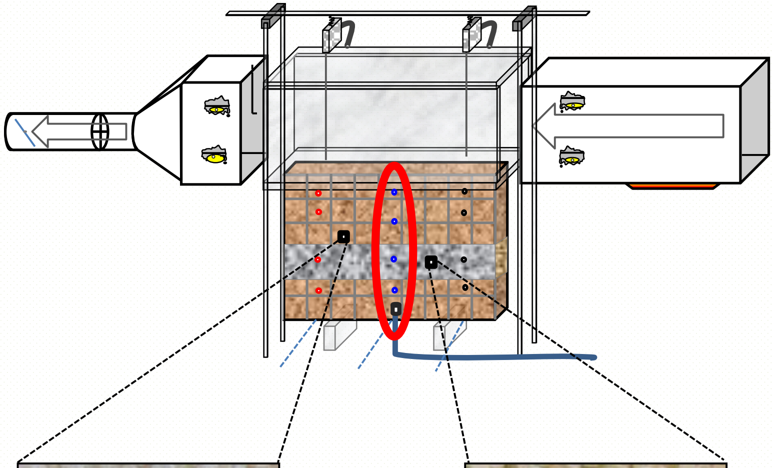
-- Better predictions of the conditions that cause gas migration will support a more efficient response to leaks



CSU Energy Institute's METEC Test Site
– Pipeline test bed used for experimentation

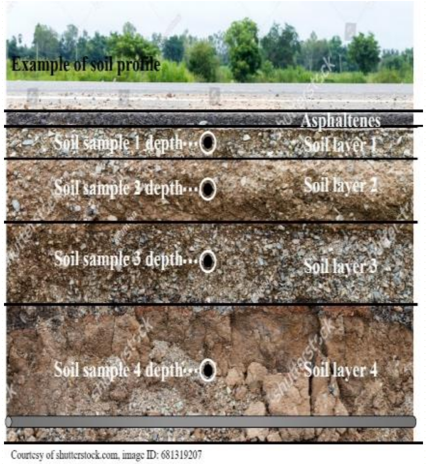
Subsurface CH_4 Transport

Subsurface methane profiles – effect of soil layering



Porosity (cm³cm⁻³) = 0.33
Permeability (m²) = 1.0×10^{-10}

Porosity (cm³cm⁻³) = 0.33
Permeability (m²) ~ 4.0×10^{-10}



Experimental Plan

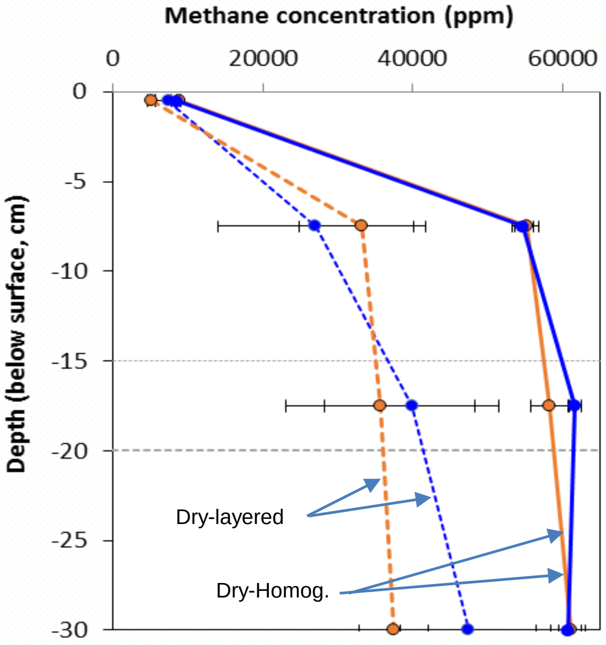
Free flow

Low temperature (20-24°C)
High temperature (35-38°C)
Wind speeds (0, 0.5, 2.0 m/s)

Porous media

Near dry (θ= ~10%)
Unsaturated (drained to -30 cm H_2O)

Subsurface methane profiles – effect of soil layering



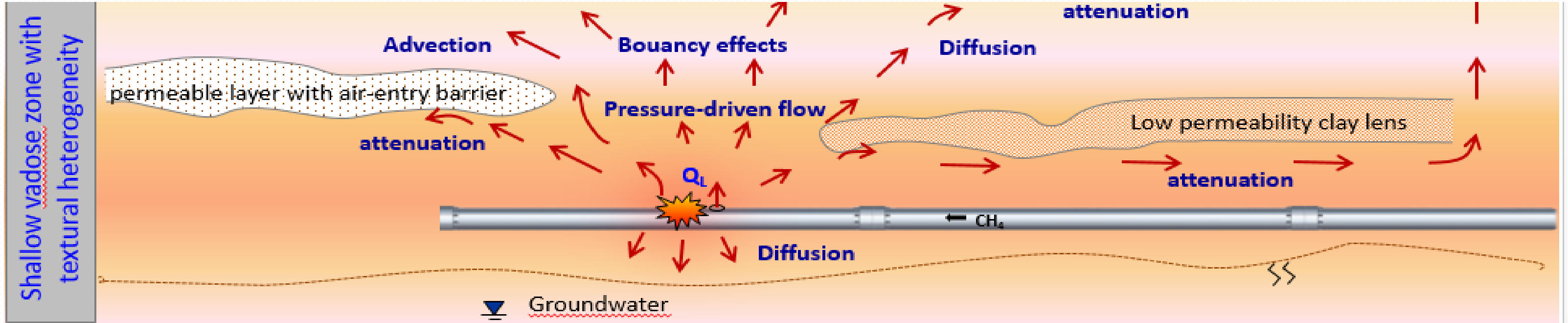
Symbol	Temp/ °C	Velocity/ms⁻¹
	22	0.5
	22	2.0

- The presence of coarse-textured layer affects subsurface methane migration
- Layered systems had lower concentrations w/ steeper gradients
- Improved advective mixing & migration w/i coarse textured layer
- Near surface concentrations for both systems comparable

Deepagoda *et al.*, 2016, J. Greenhouse Gas Con.
Deepagoda *et al.*, 2016, Vadose Zone J.

Subsurface methane profiles – effect of soil layering

- Gas will move upward through soil when
  - there is vertical permeability available or
  - the capillary entry pressure of the overlying layer is exceeded
- Gas can migrate into high permeability zones and pool under low permeability inclusions due to capillary barrier effects (very high entry pressures)
  - Note: in the presence of microbes, this could increase the pressure . . . microbially mediated pressure increases



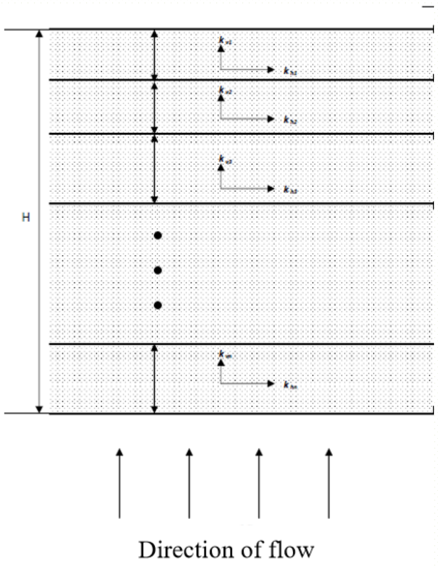
Permeability

Decreases with the square of the pore radius
-- small reduction in pore size (e.g. due to swelling) has a large effect
Direction dependent
Fluid dependent (viscosity)
Presence of mucilage cyanobacteria (Belnap, 2013)

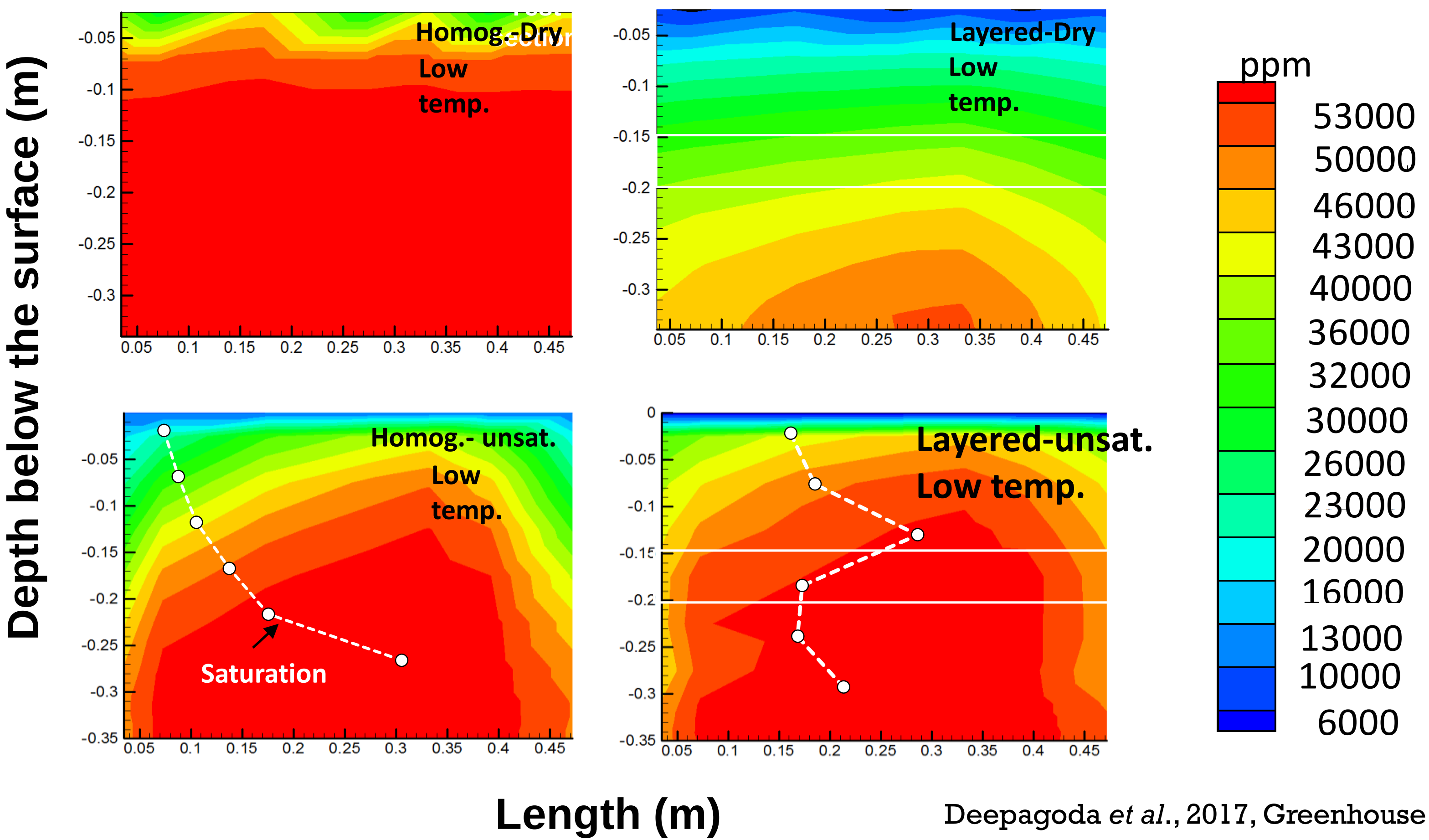
Porosity and Permeability Ranges for Sediments

	Porosity	Permeability
Well-sorted sand or gravel	25-50%	High
Sand and gravel, mixed, poor sort	20-35%	Medium
Glacial till	10-20%	Medium
Silt	35-50%	Low
Clay	33-60%	Low

From C.W. Fetter, 1994. Applied Hydrogeology, 3rd edition.



Subsurface methane contours – effect of soil moisture



Deepagoda *et al.*, 2017, Greenhouse Gases S&T

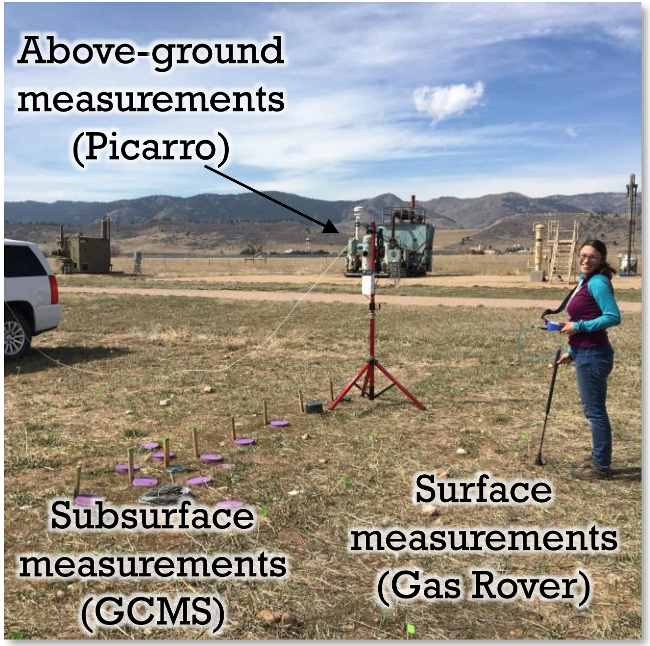
Controlled Field Experiments (METEC)

Experimental Objectives

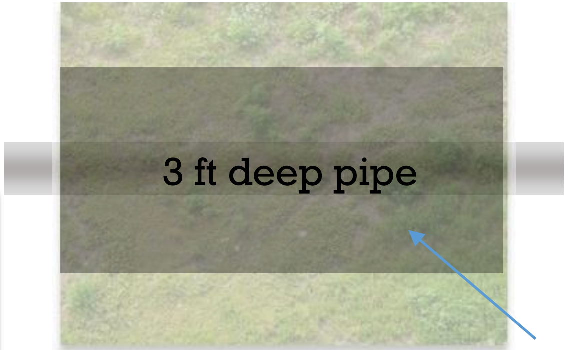
Study Objective:	Detection Phase Informed:
1. "**Above-ground detection study**" - Understand the above ground concentrations associated with a range of leak rates	Initial detection
2. "**Migration extent study**" – Understand how leak rate and subsurface conditions affect migration extent (subsurface and surface plume size) that would be measured during Additional Detection	Additional detection/ Final repair
3. "**Surface cover study**" – Understand how surface cover conditions (impermeable cover, moist soil layers) affect migration extent	Additional detection/ Final repair

Experimental Approach

Simulate underground leak → **Evaluate above-ground, surface, and subsurface methane concentrations**

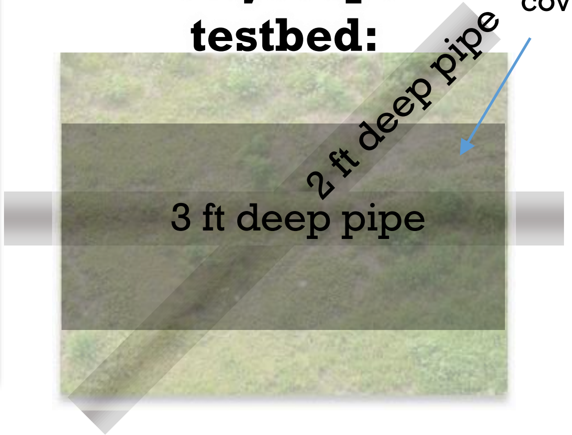


Rural testbed:

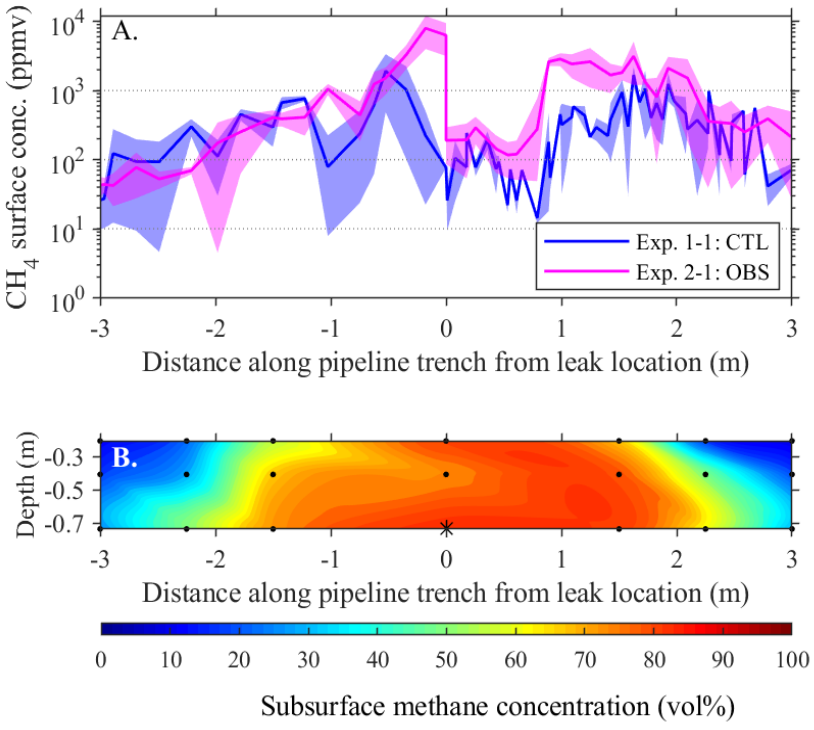


Impermeable surface coverage

Cityscape testbed:



Surface and Subsurface Concentration Distributions



*Black dots indicate subsurface sampling locations, and the asterisk indicates the location just above the leak.

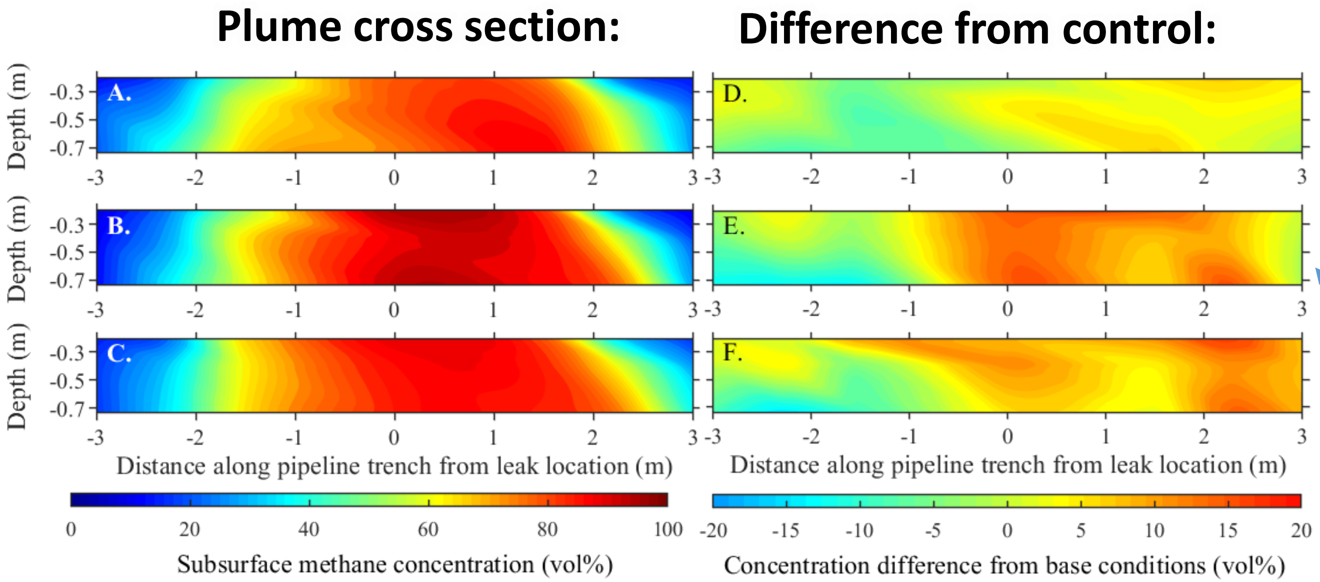
Surface (exp 1) : Mean surface concentrations dropped from 2000 ppmv to < 100 ppmv b/t plume's center and 3 m along the trench

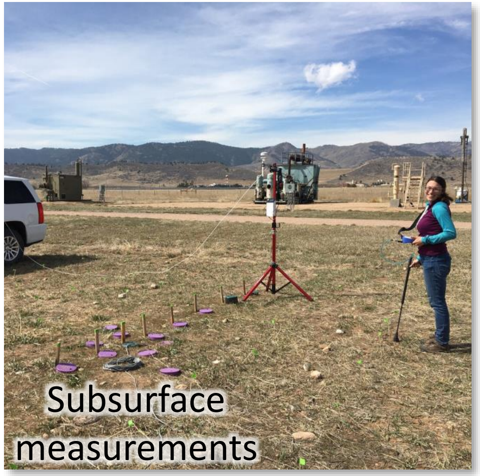
Subsurface (exp 1 & 2) : Extent of plume mimicked surface extent

Little to no effect of wind on subsurface concentrations <u>for this specific soil</u>

Ulrich et al., 2019, ESTL

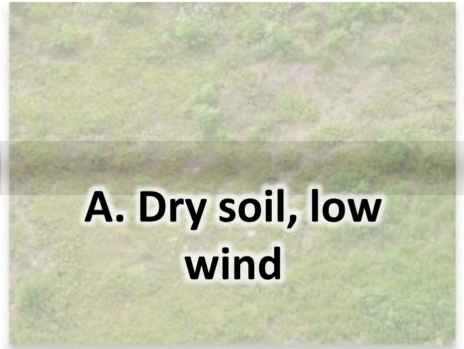
Subsurface Methane Plumes



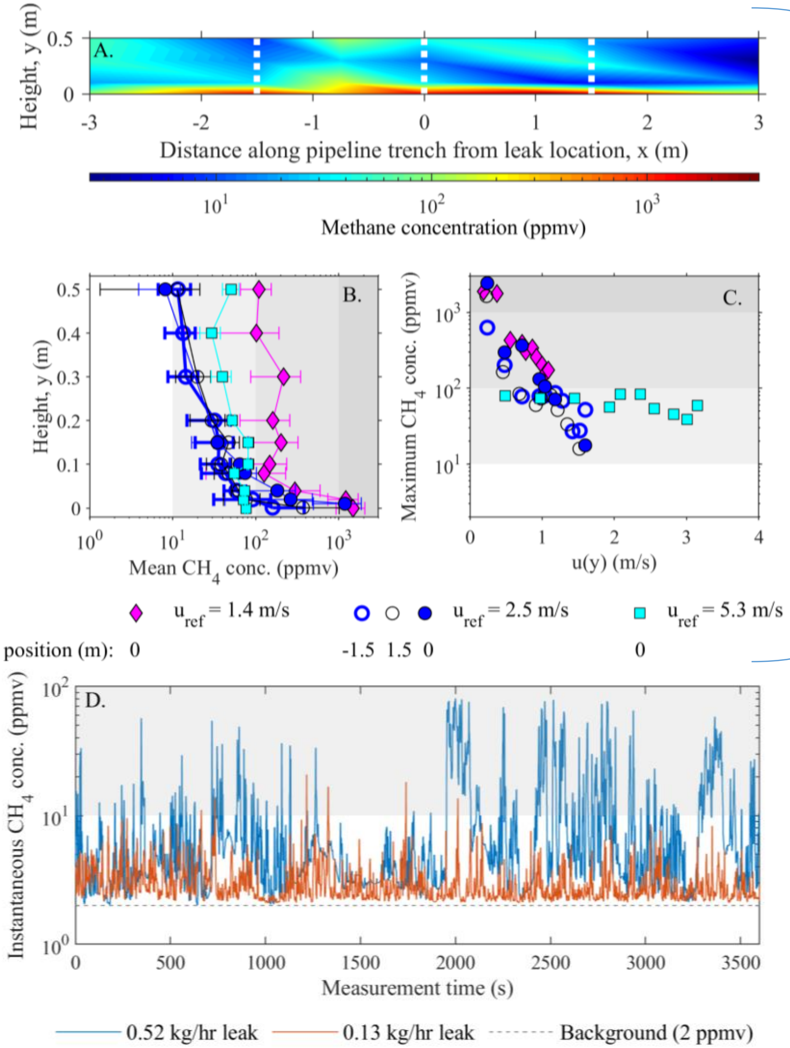


Elevated subsurface concentrations

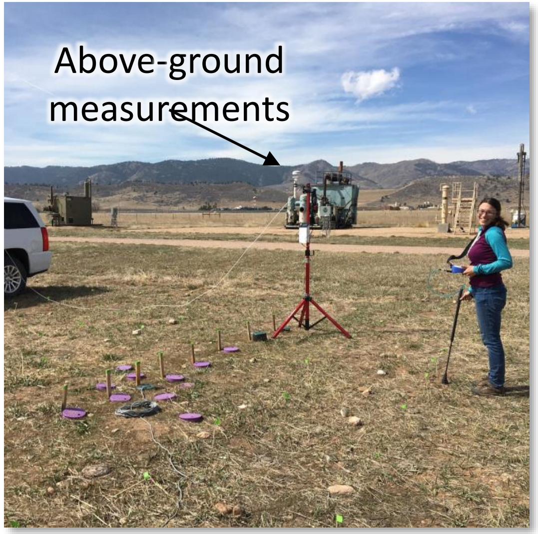
Rural test-bed:



Above-ground concentrations



Substantial dissipation in first 10 cm above ground at low wind conditions (<2 m/s)



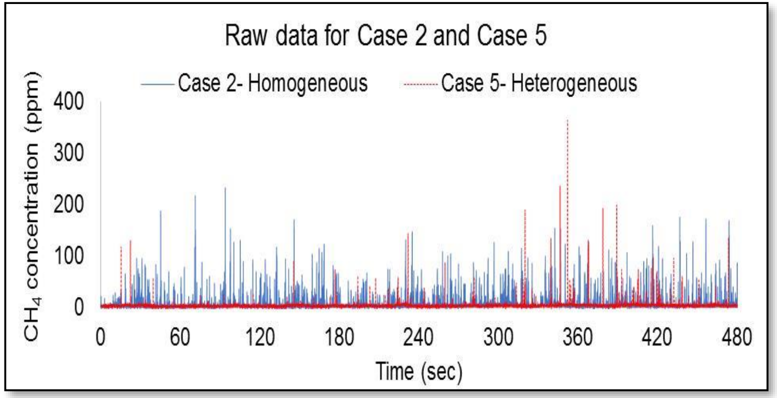
Above-ground concentration fluctuations:

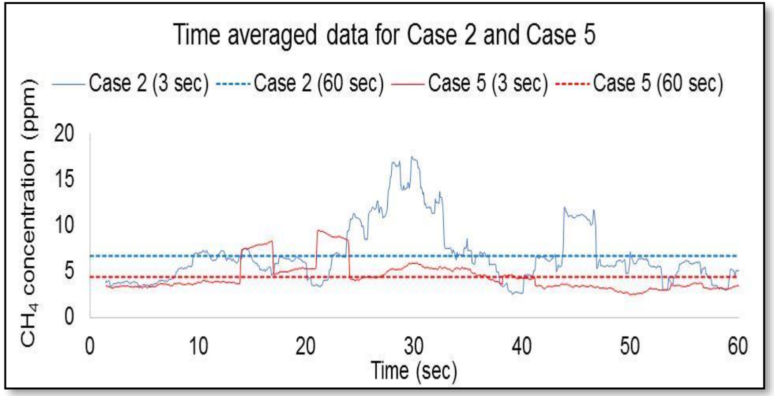
- Up to 100 ppm for 0.5 kg/hr leak
- Up to 10 ppm for 0.13 kg/hr leak

***~80% urban leaks < 0.1 kg/hr**

Ulrich et al., 2019, ESTL

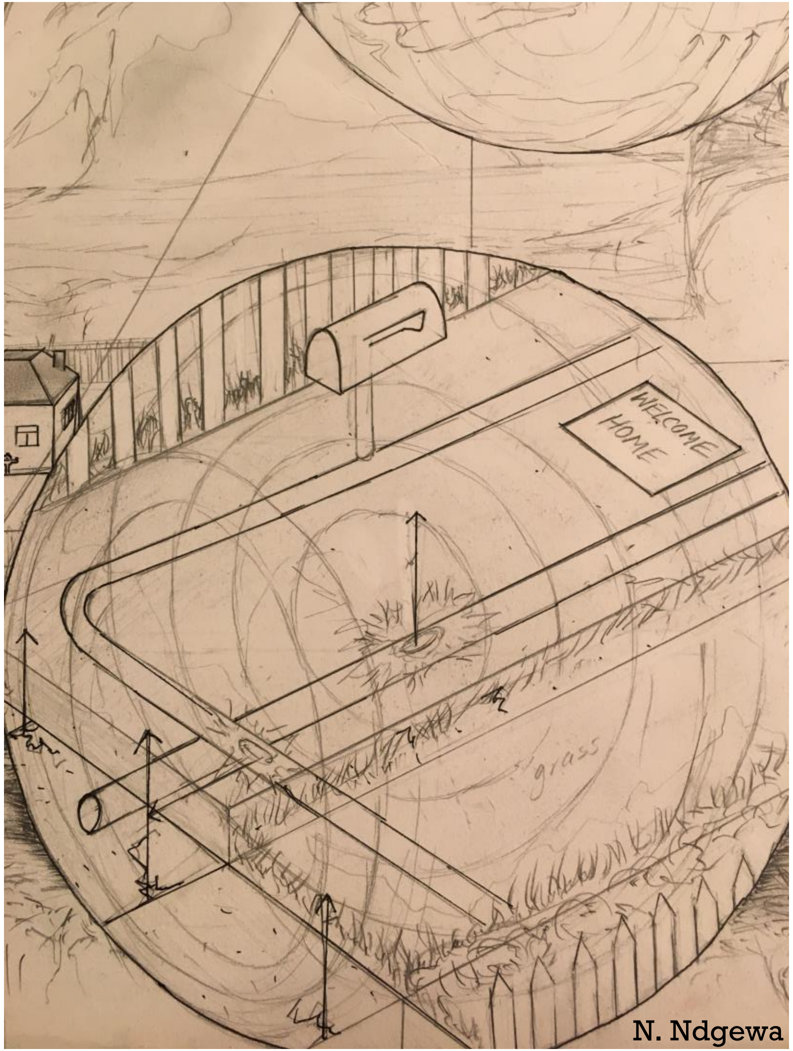
Implications of detection duration & data averaging techniques on concentration estimates





- Detection duration and data averaging techniques have an impact on concentration estimates
- Variable temporal nature of gas and the potential for confusion when sampling gas at a single point in time and space
- Measurements are highly variable at a single sampling location, such that instruments with response times of the order of 1-2 s have an advantage when detecting low concentrations that appear in narrow bursts

Conclusions & Future Work



N. Ndgewa

- Numerical models linked with controlled experiments assist in understanding behavior
- Many open questions about gas migration and accurate quantification of leaks