Development of a New Facility for Testing Near Surface CO_2 Detection

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A collaborative involving Universities and DOE National Labs

- Montana State University
- Los Alamos National Laboratory
- Pacific Northwest National Laboratory
- West Virginia University
- Lawrence Berkeley National Laboratory
- National Energy Technology Laboratory
- Lawrence Livermore National Laboratory

Field Test Facility at MSU

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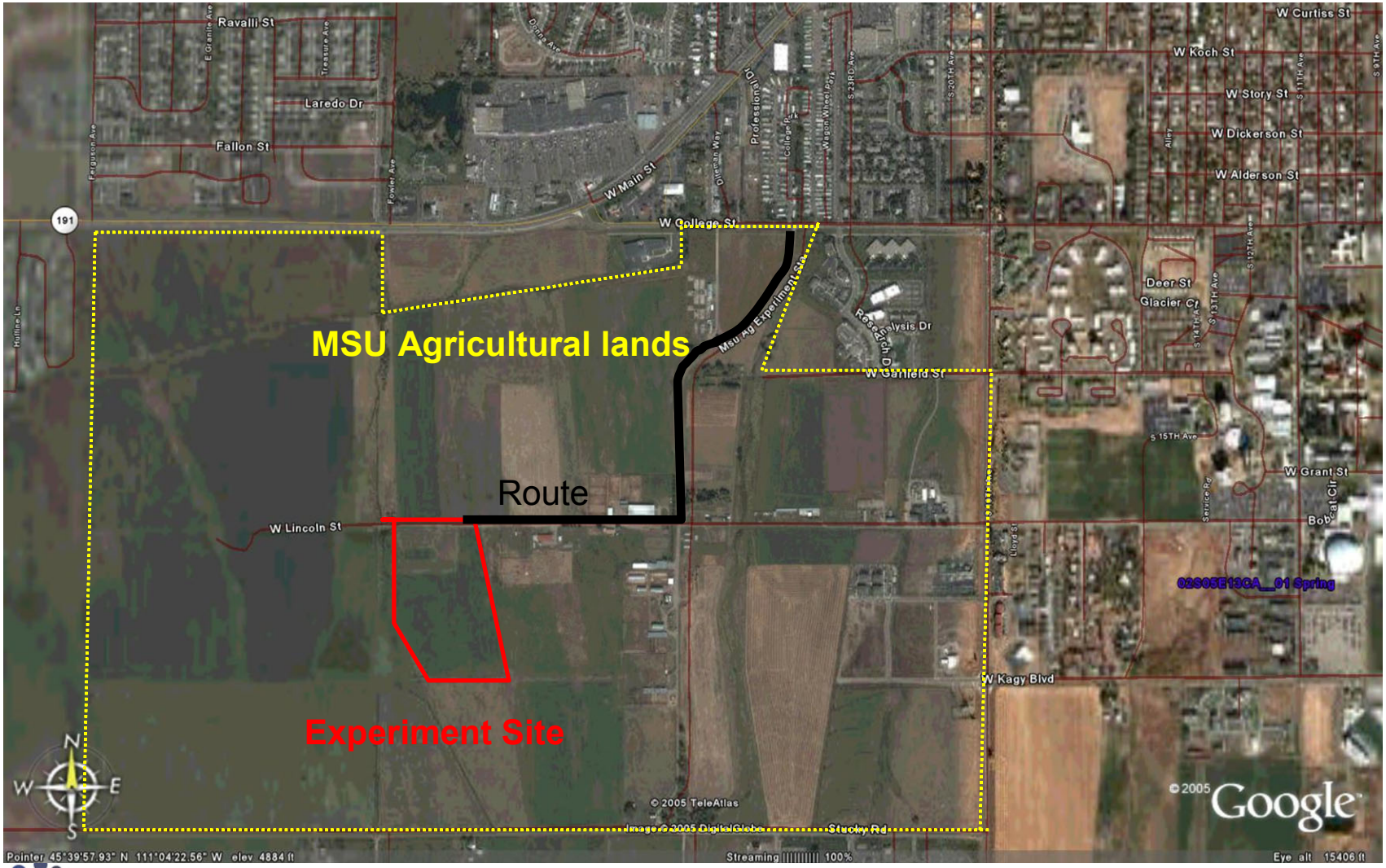

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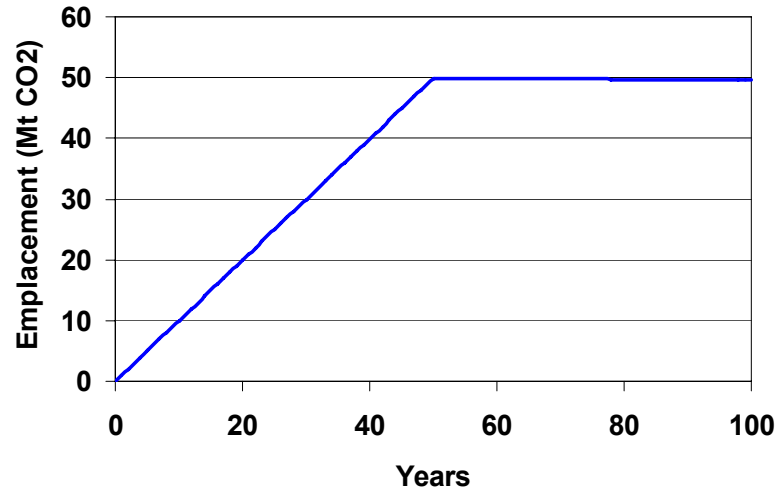
Facility Goals

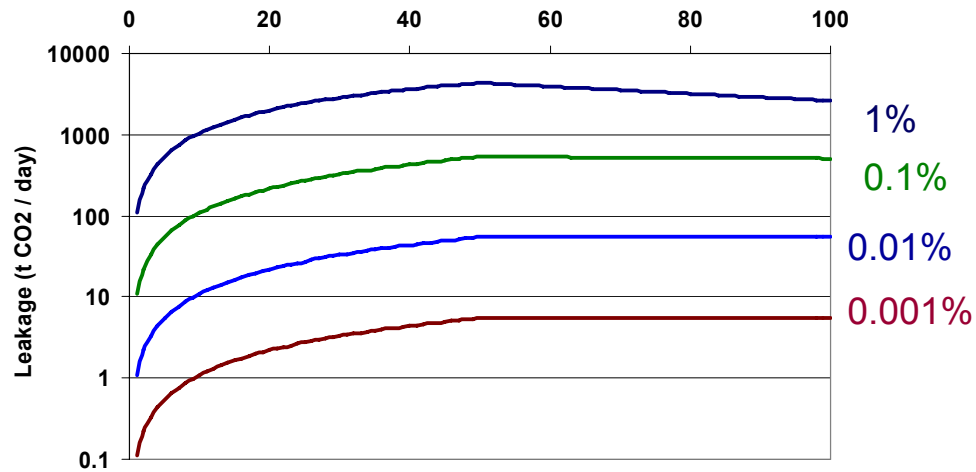
- Develop a site with known injection rates for testing near surface monitoring techniques
- Use this site to establish detection limits for monitoring technologies
- Use this site to improve models for groundwater – vadose zone – atmospheric dispersion models
- Develop a site that is accessible and available for multiple seasons / years

Scenario for Injection Rate Choice

Sally Benson

- **4 Mt/year injection ~ 500 MW power plant**
- **50 years injection**
- **3 Leakage rates**
  - 0.1%/yr. 0.01%/yr, 0.001%/year
- **2 Leakage geometries**
  - Linear fault 10*1,000 m
  - Linear fault 100*1,000 m
- **What is a meaningful rate at which to conduct the experiments?**
- **Emplacement**

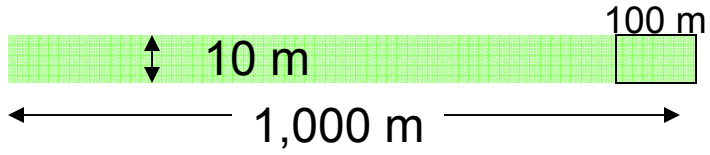


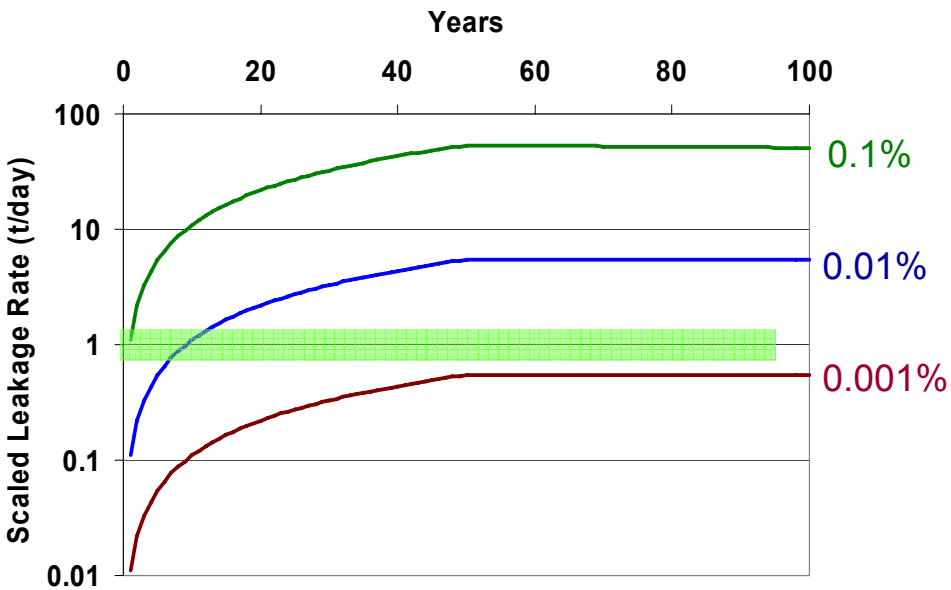


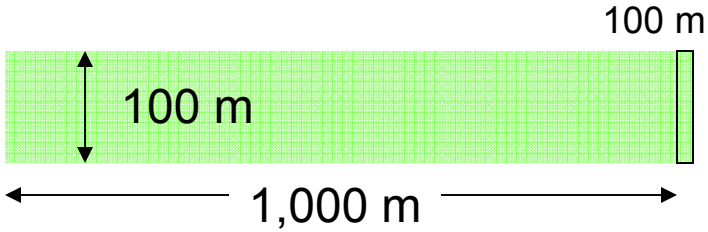
Lee Spangler

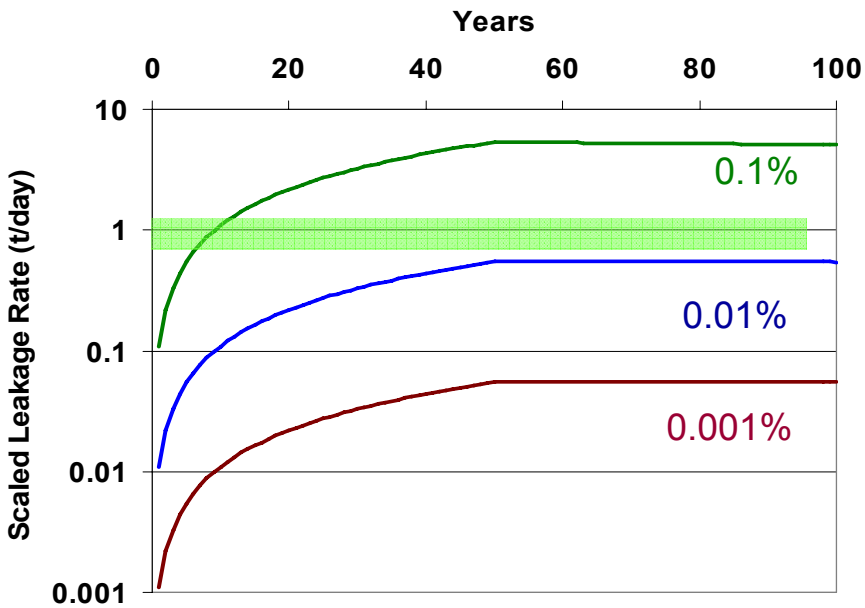
Injection Rate

Sally Benson









Scale to 1000 m leak
1,000 kg/day: 1 tonne/day

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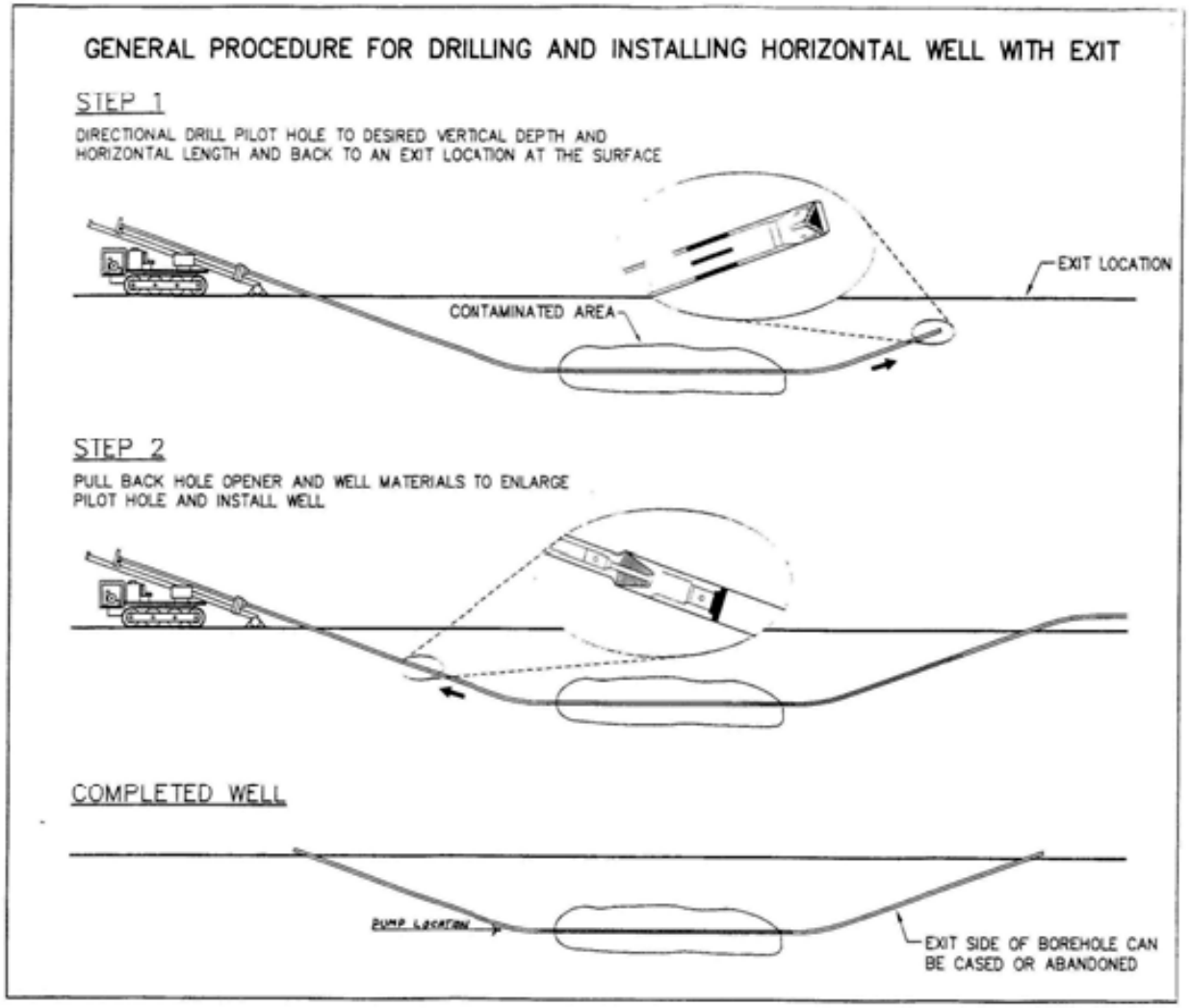
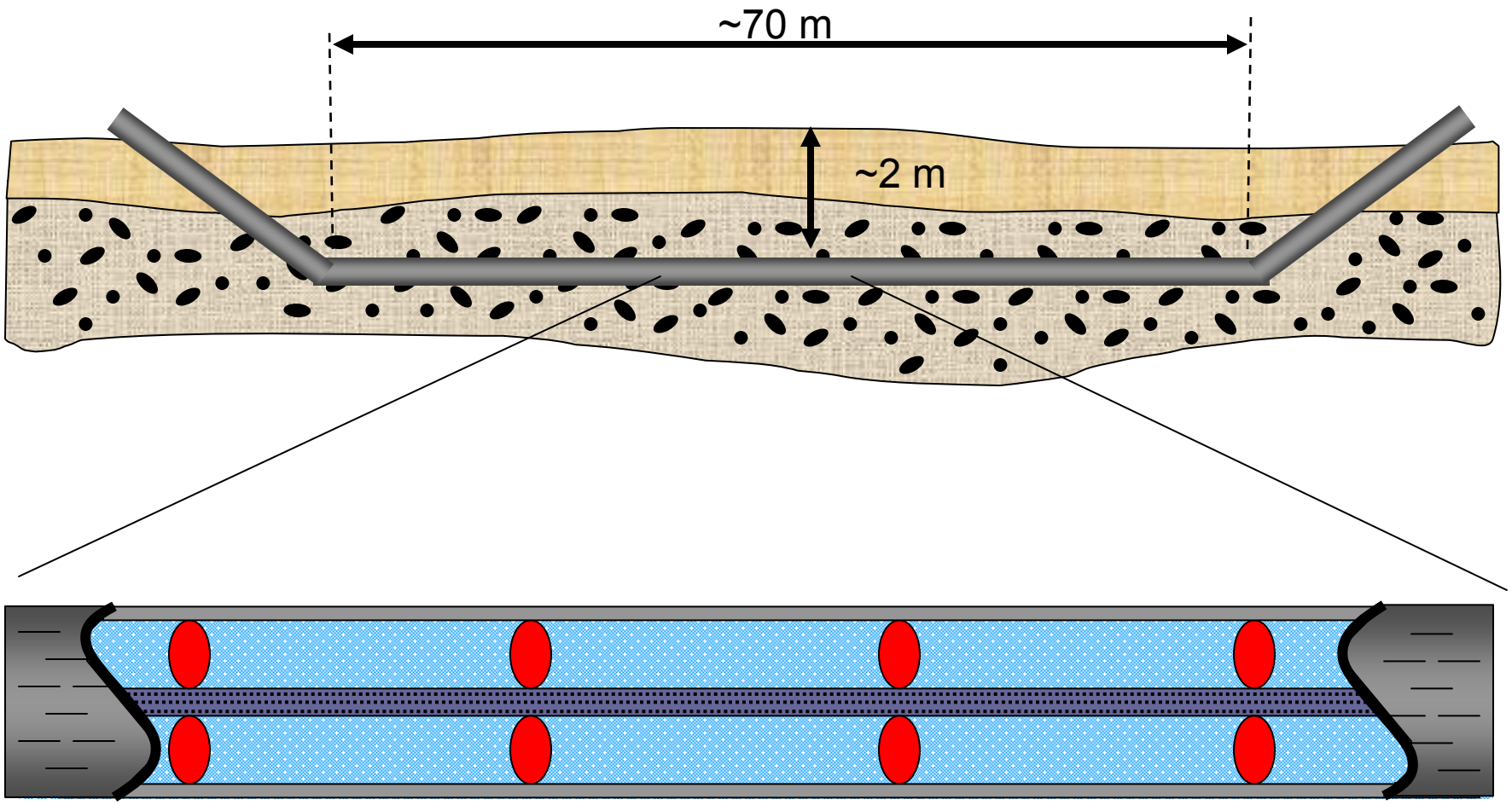
Horizontal Well

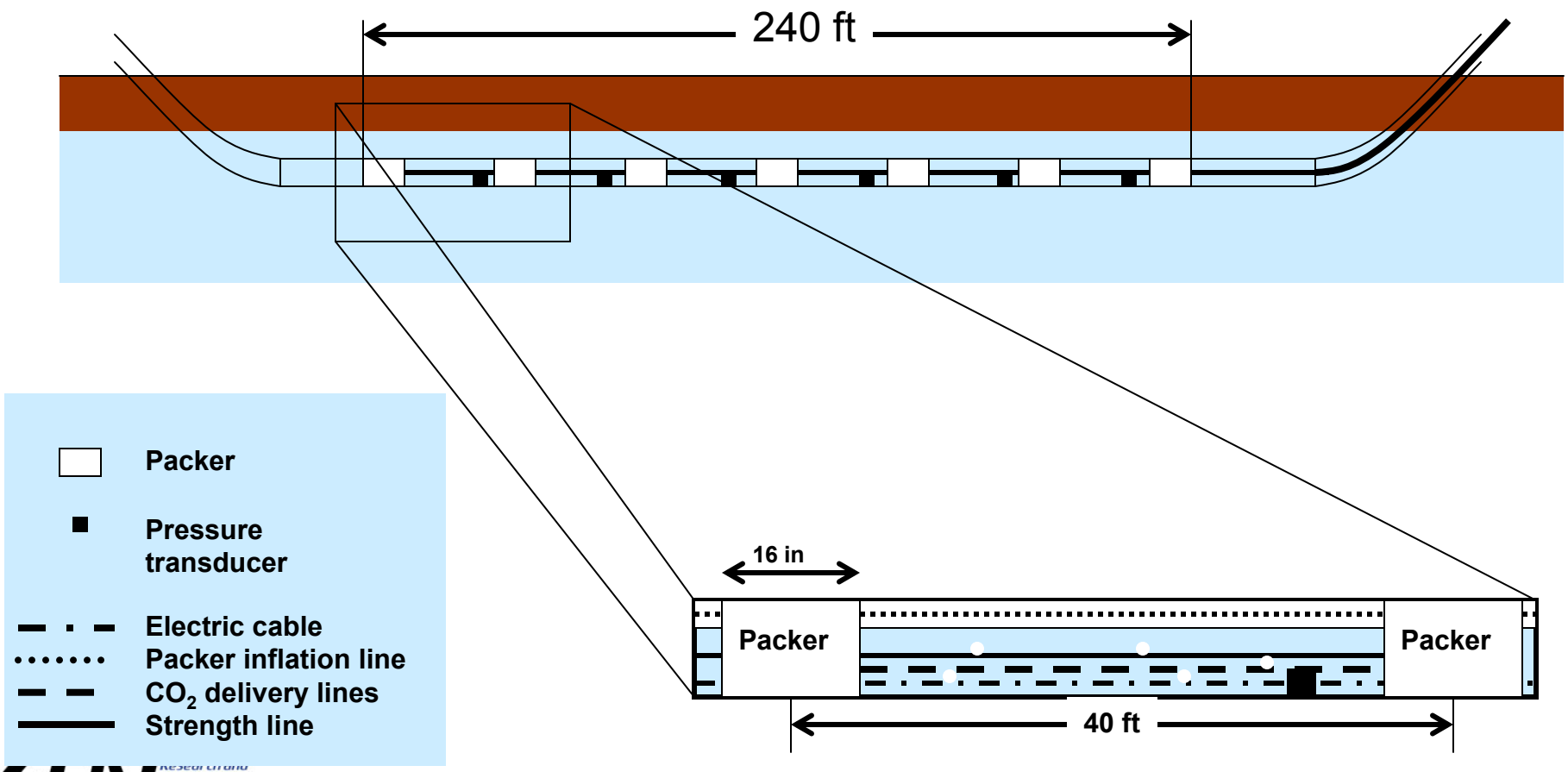


Horizontal Well

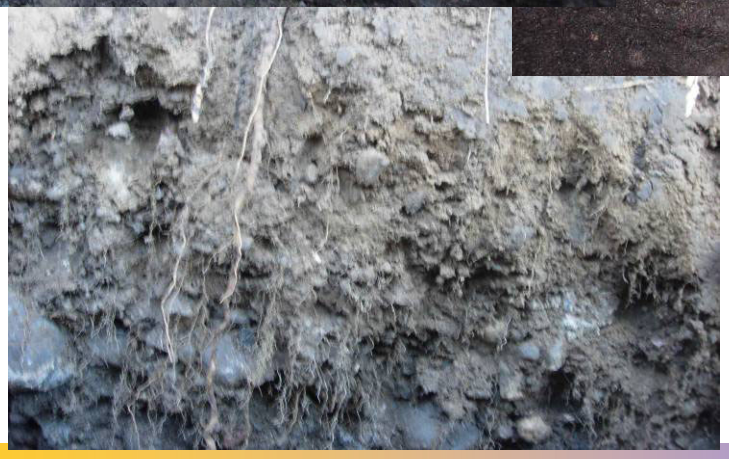


Horizontal Well Installation

Ray Solbau, Sally Benson



Site Soil Characteristics



Site Soil Characteristics

Soils

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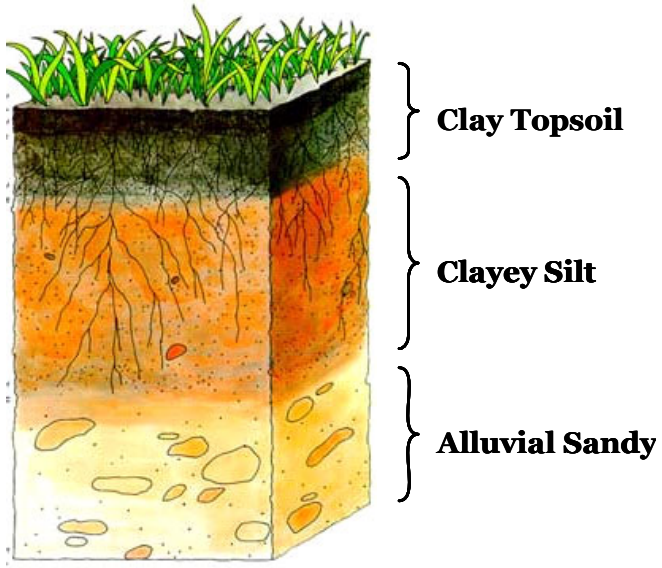
Tim Holley

Topsoil:

- USCS- CL , low plasticity clay
- AASHTO- A-6, Clay

Intermediate Layer:

- USCS- ML, Low plasticity silt
- AASHTO- A-4, Silt



- Moisture Content: 10-15%
- Grain Size (Sieve) Analysis: >60% fines (Passing No. 200 Sieve)
- Atterberg Limits (Liquid and Plastic Limit)
  Topsoil: LL 37, PI 14 Intermediate layer: LL 37, PI 10
- Organic Content by Ignition: Topsoil: 7.5%, Intermediate layer: 5.3%
- Visual In-Field Classification: Clayey silt or silty clay

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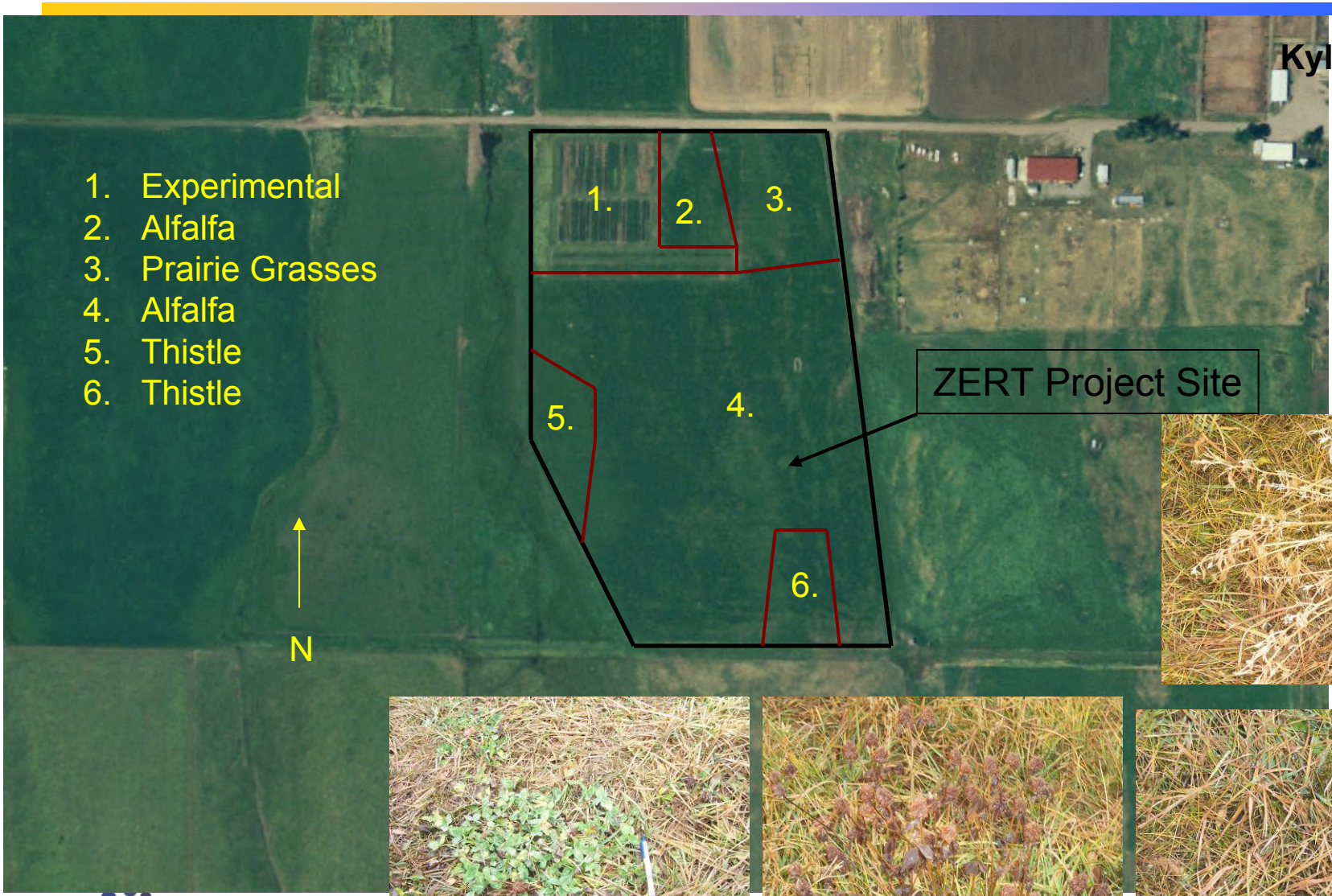
Site Heterogeneity

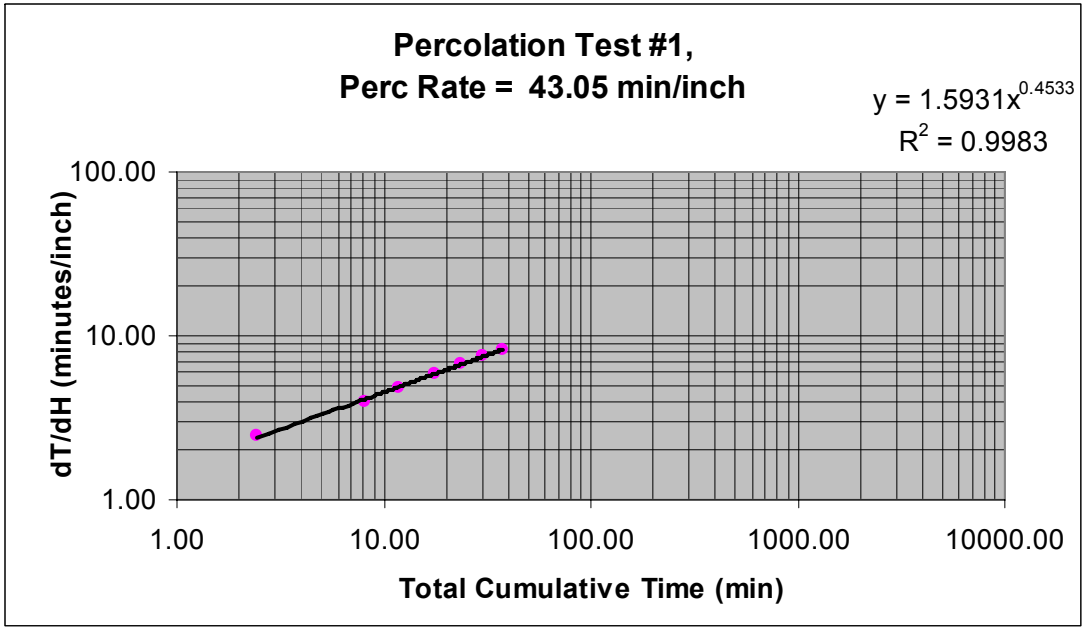
Plant Classification

Kyle Scarr



Percolation Testing: Results

Cole S. Peebles

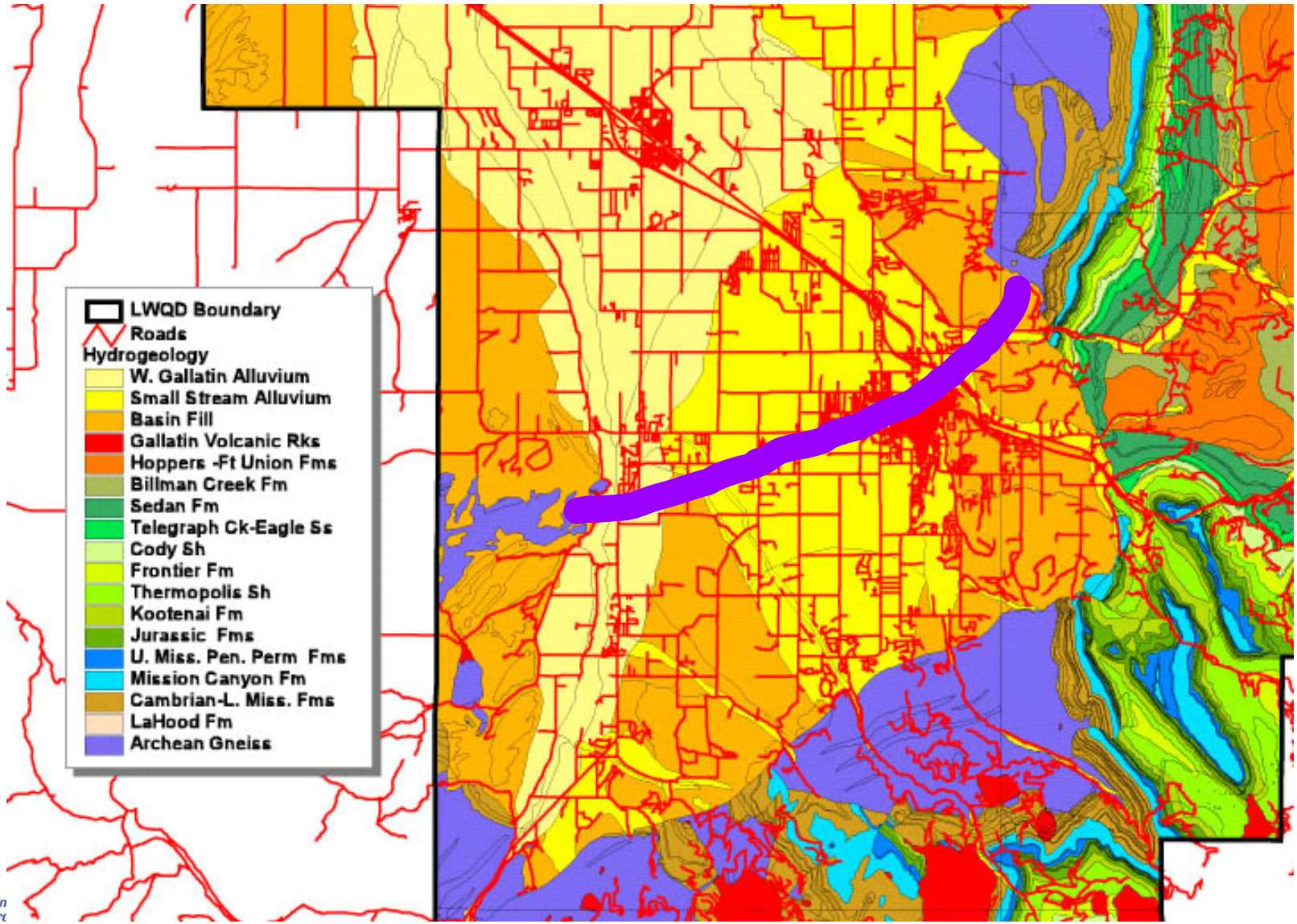


Typically only represent horizontal hydraulic conductivity.

- **Upper Silty Topsoil: k = 2.79 ft/day.**
- **Clayey Silt Zone: k = 2.18 ft/day.**
- **Silt/Sandy Gravel Interface: k = 4.70 ft/day.**
- Average Conductivity: k = 3.22 ft/day.

** This is between 2 and 3 orders of magnitude less than alluvial gravels.

Geology of the Gallatin Valley



Geology of the Gallatin Valley

- **Calculating Ground Water Gradients**
- **- Slagle's GW Map**

Calculate potentiometric drop over a known distance

EXPLANATION

Qa — PREDOMINANTLY FLUVIAL DEPOSITS (Quaternary)

QTa — PREDOMINANTLY ALLUVIAL-FAN DEPOSITS (Quaternary and Tertiary). Includes alluvial-fan deposits and old alluvium of Hackett and others, 1960

Ts — LACUSTRINE AND FLUVIAL DEPOSITS UNDIFFERENTIATED (Tertiary)

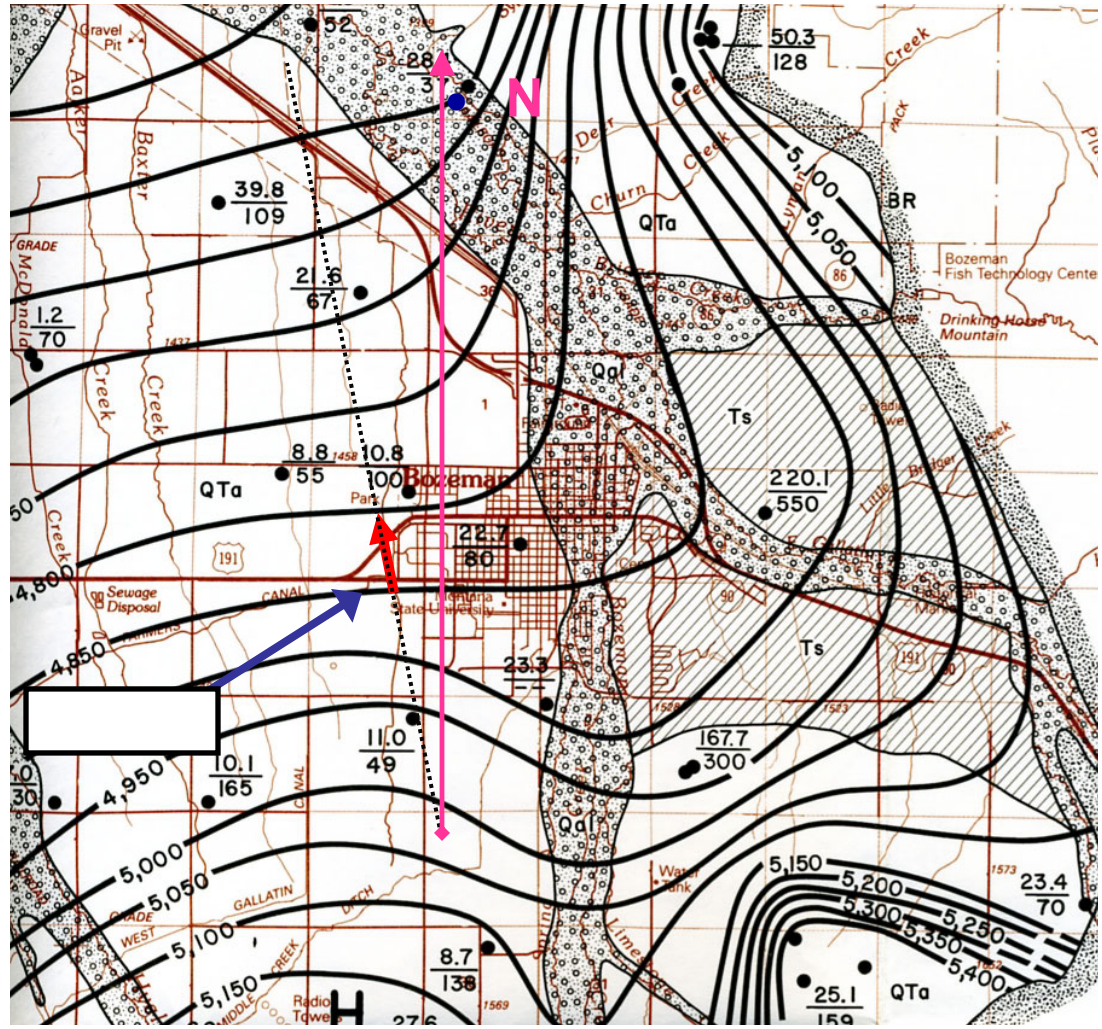
BR — BEDROCK (Cretaceous through Precambrian)

MADISON RIVER-GALLATIN RIVER DRAINAGE DIVIDE

CONTACT

4,800 — WATER-SURFACE CONTOUR--Shows approximate altitude of water surface in wells, August 2-4, 1993. Dashed where approximately located. Contour interval 50 ft. Datum is sea level

140.4E / 360 B — WELL--Top number is depth to water on August 2-4, 1993 (Slagle, 1995). E, denotes water level estimated from measurements made on other dates; bottom number is depth of well; --, no data; large letter identifies hydrograph location



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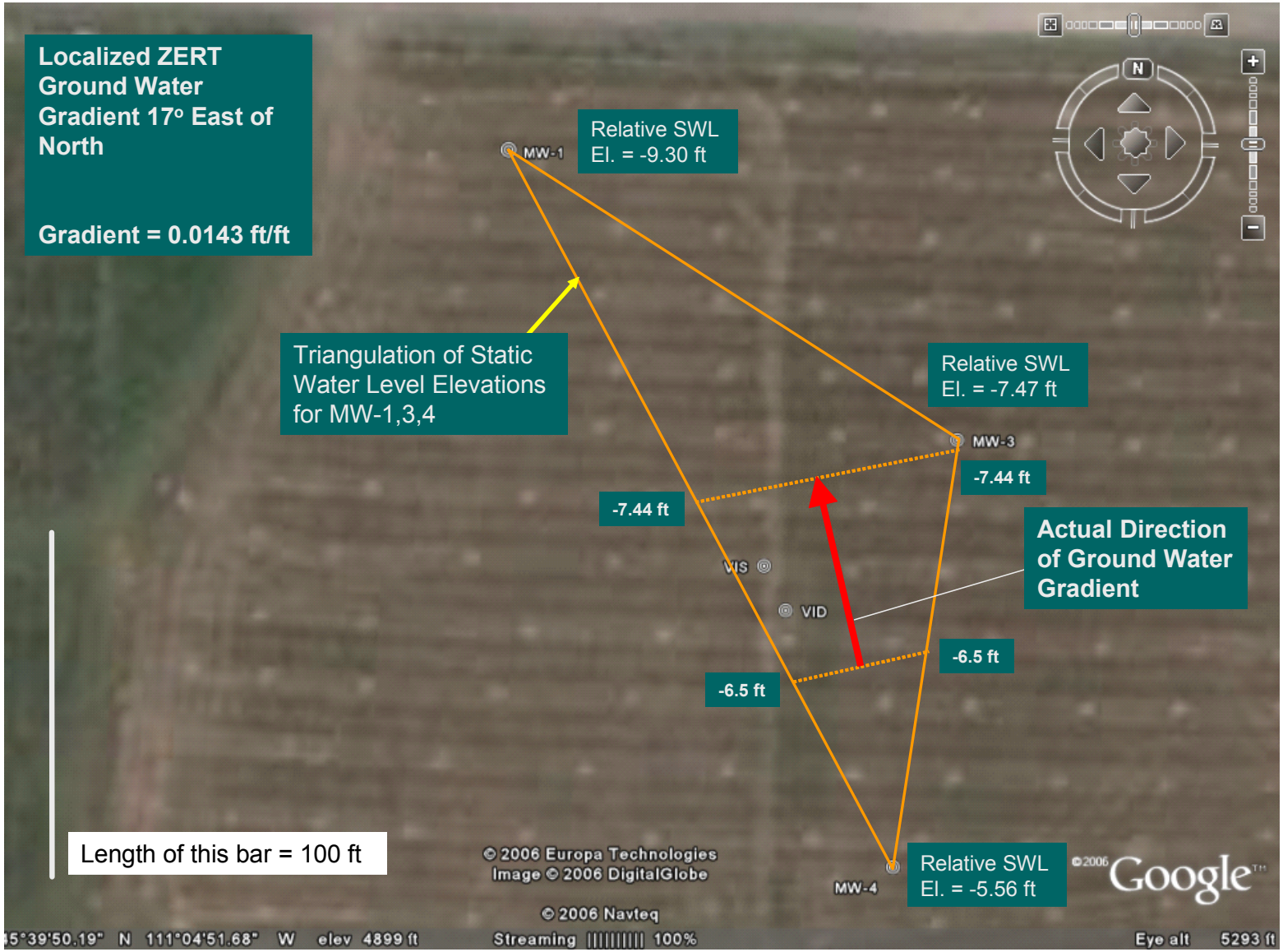
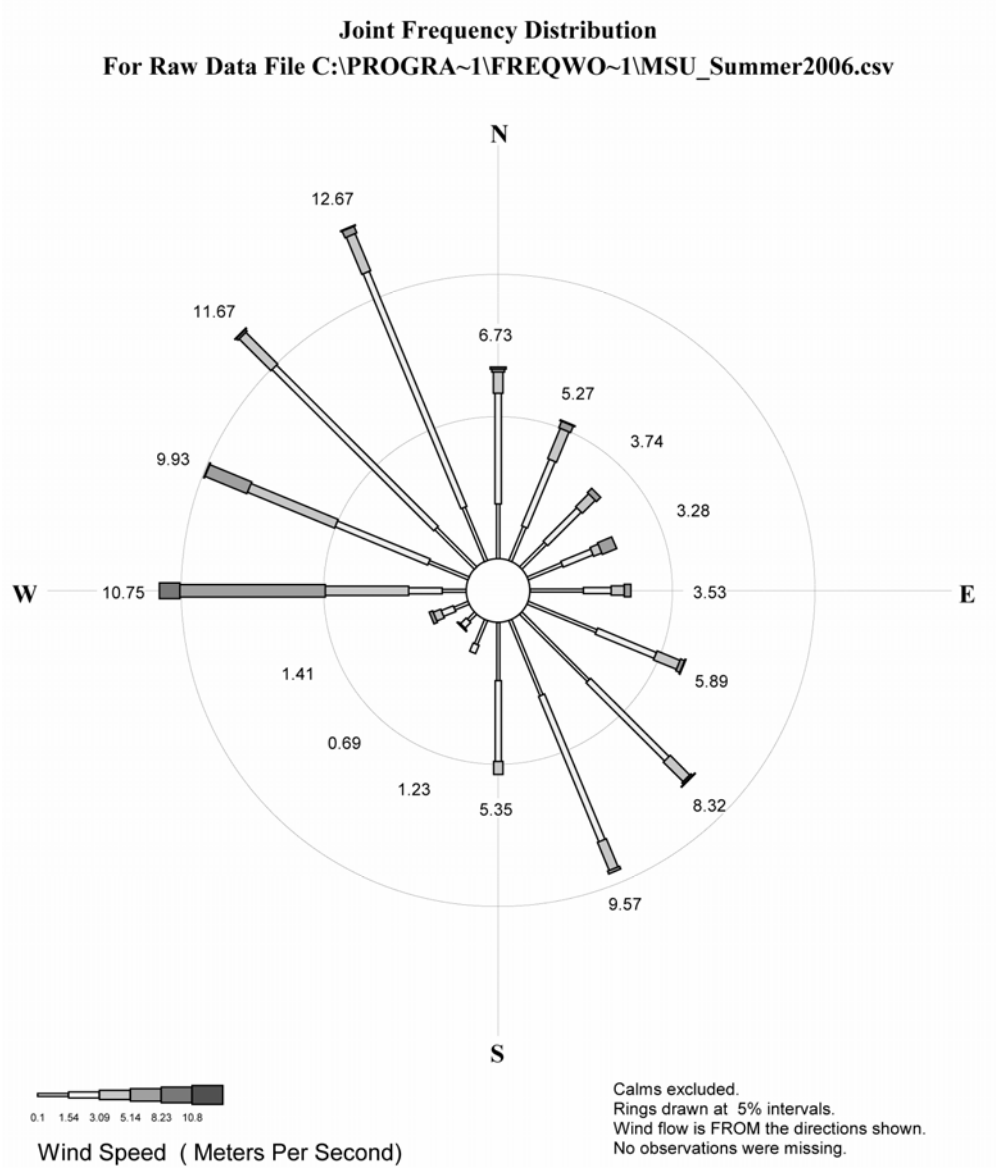
Geology of the Gallatin Valley



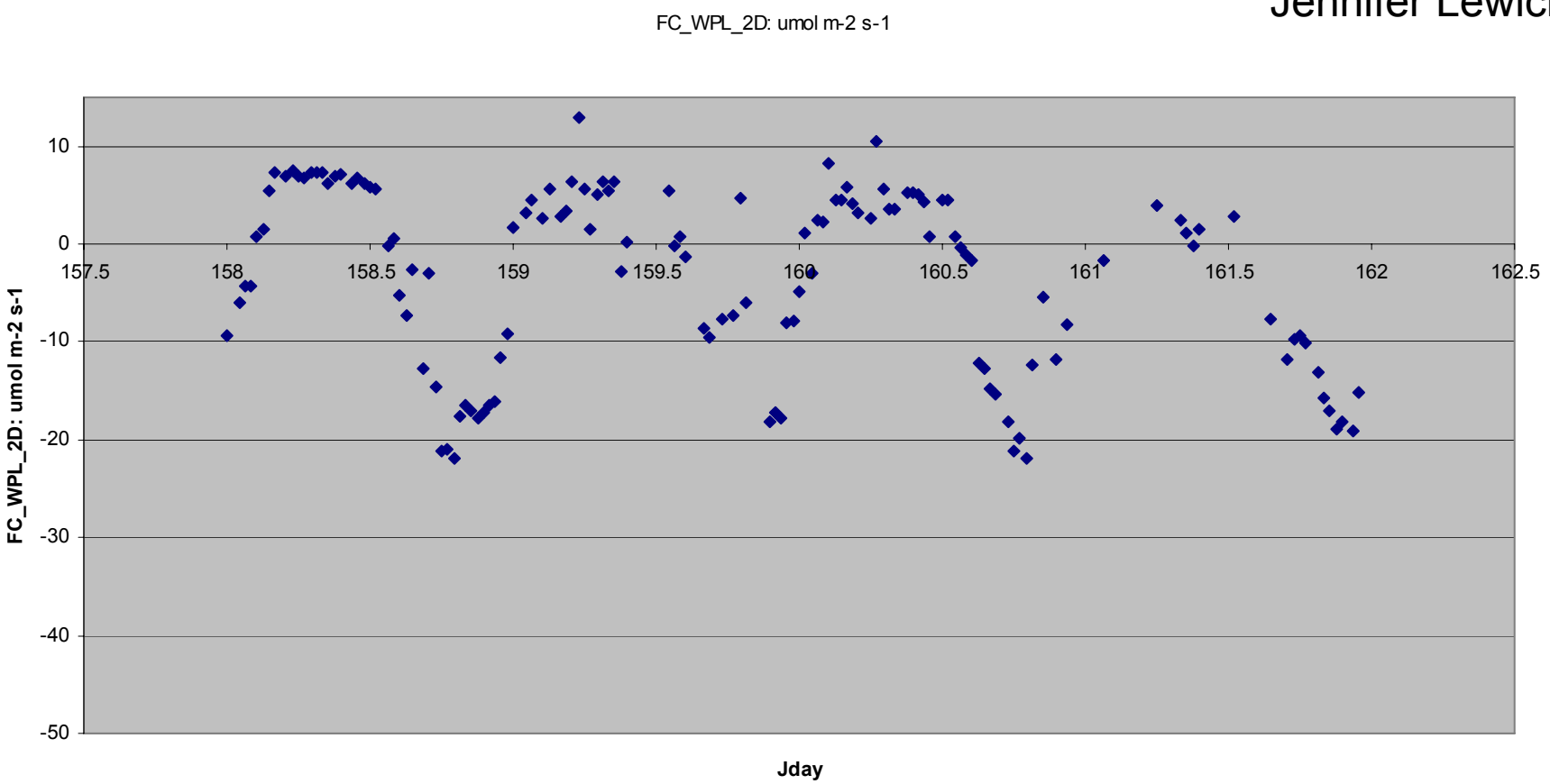
Wind Rose For Field Site Summer 2006

Jennifer Lewicki



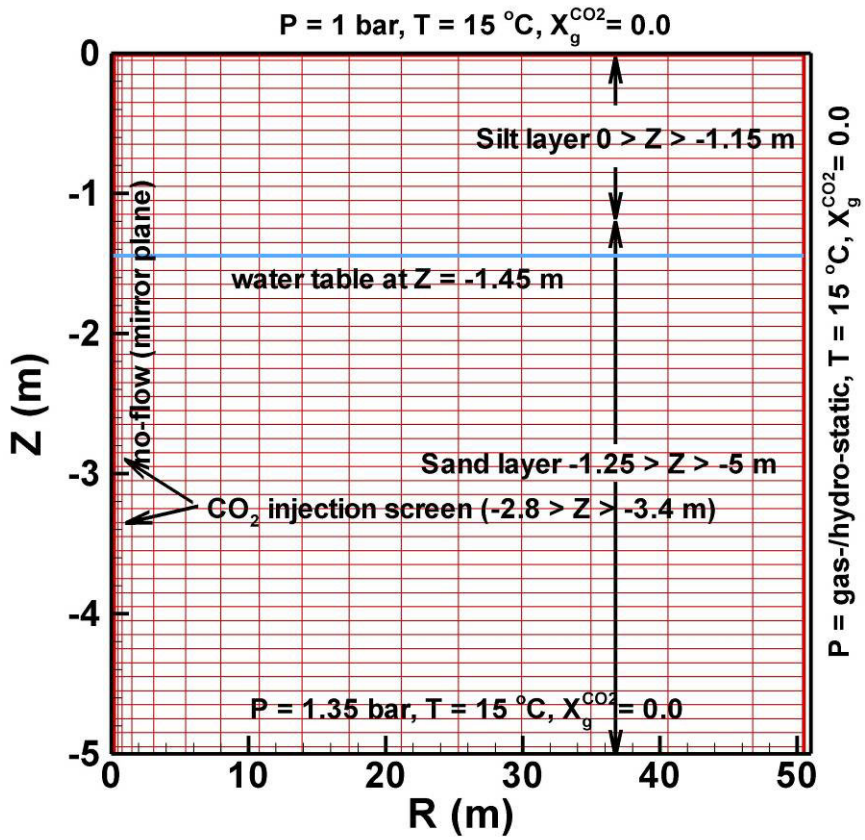
CO_2 Fluxes from Eddy Covariance

Jennifer Lewicki

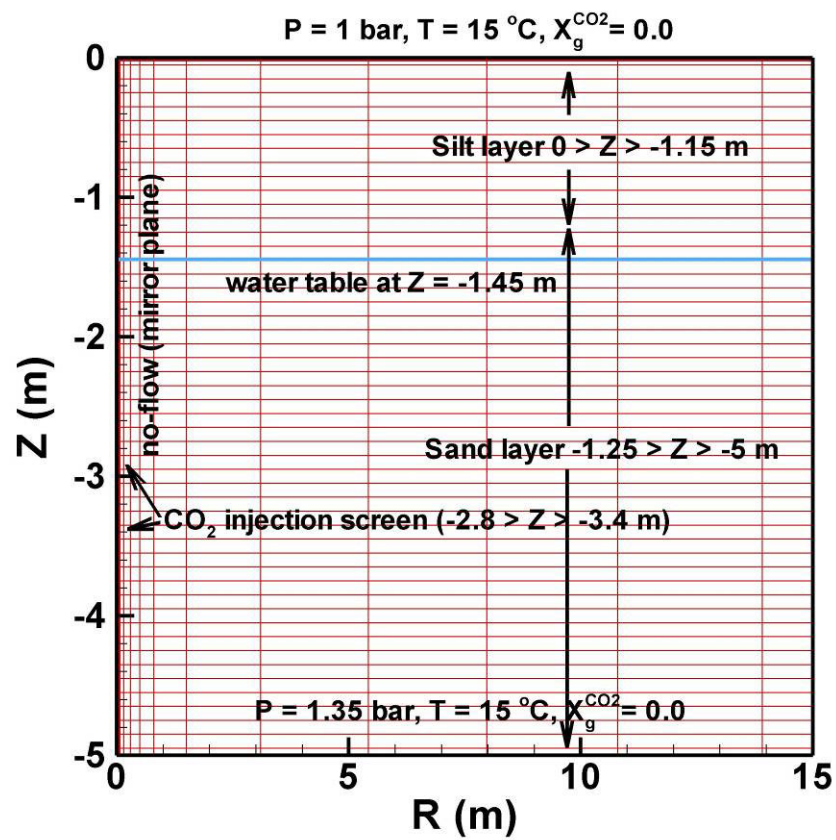


Grid and BCs of Radial Model

Curt Oldenburg



Full domain, vertical exaggeration ~ 10x.



Domain for plotting results.

Injection Rate Notes

Curt Oldenburg

For the horizontal well case, pore volume was used to derive a first-guess injection rate (this was discussed in earlier telecons).

$PV_g = LWH\ \phi\ S_g$

$L = 100$ m
$W = 3$ m
$H = 3$ m
$\phi = 0.3$
$S_g = 0.5$
$PV_g = 900\ m^3 \cdot 0.3 \cdot 0.5 = 135\ m^3$

At 1 bar, 20 °C,

$\rho_{air} = 1.2\ kg/m^3$

$\rho_{CO2} = 1.8\ kg/m^3$

$mass_{CO2} = 135\ m^3 \times 1.8\ kg/m^3 = 243\ kg\ CO_2$

If inject 10 pore volumes over 10 days,

$Q_{CO2} = 2430\ kg\ CO_2/10d * 1\ d/86400\ s$

$Q_{CO2} = 2.81 \times 10^{-3}\ kg\ CO_2/s$

In the conference call of 28 August, the suggested rate of injection for the vertical well was 1/300th that in the horizontal well.

$Q_{CO2} = 1/300\ (2430\ kg\ CO_2/10days)$

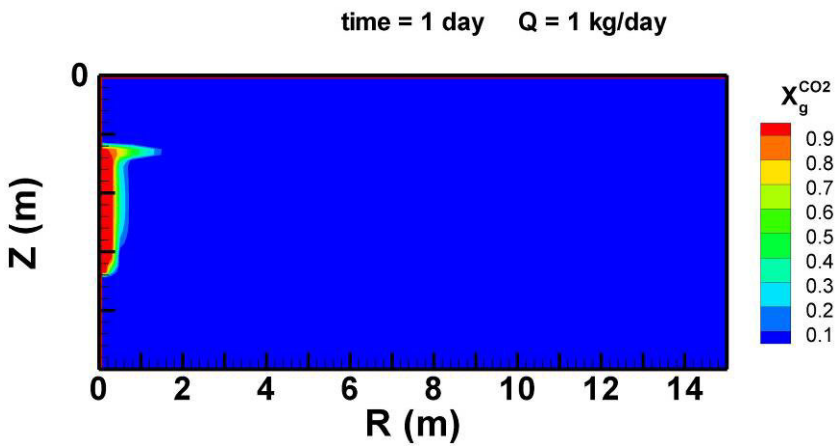
$Q_{CO2} = 0.81\ kg\ CO_2/day$

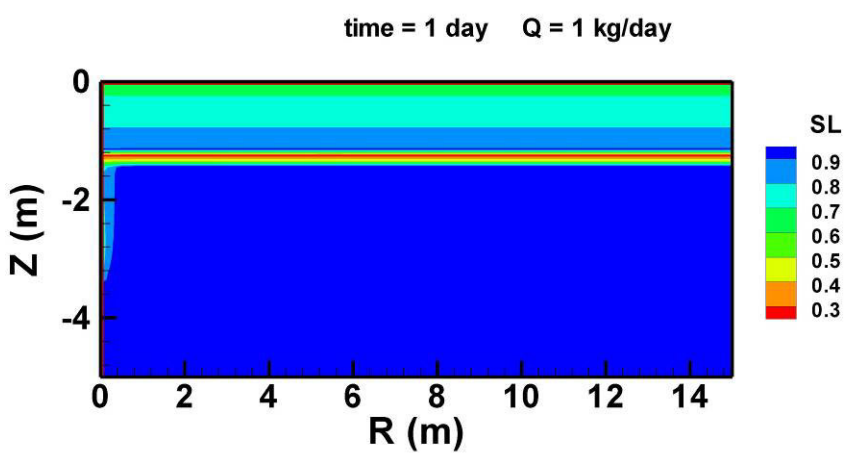
For the Cases 1 and 2 presented below, injection rates of 1 kg/day and 10 kg/day are used for comparison purposes.

Injection Calculations for Low Perm Silt

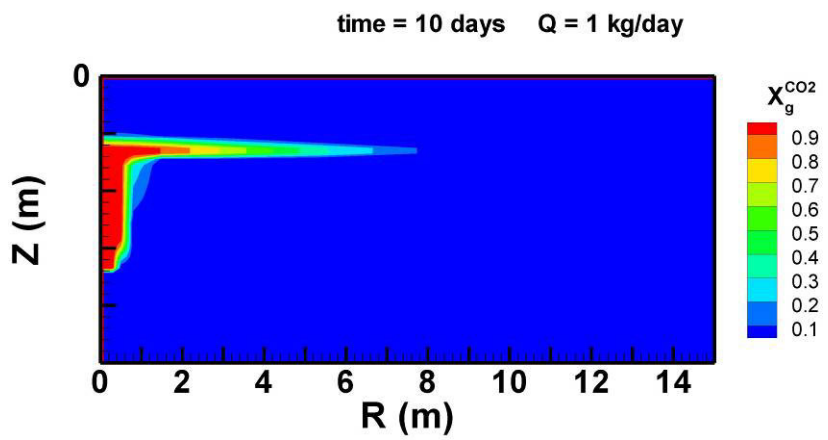
Curt Oldenburg

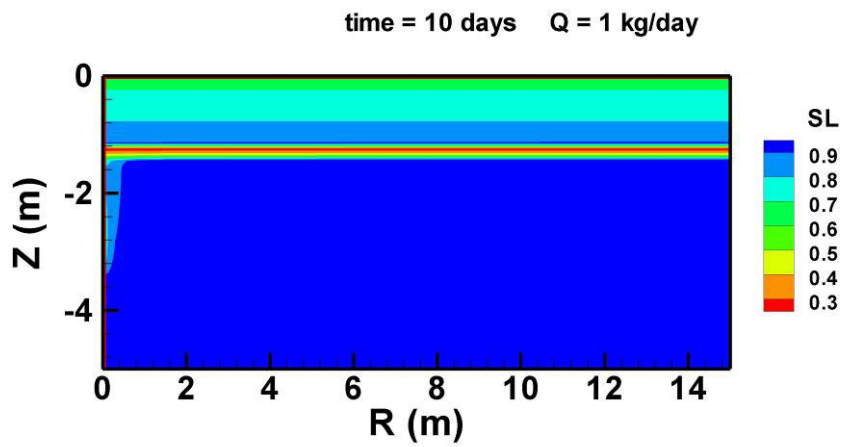
Results for 1 kg/day at 1 day





Results for 1 kg/day at 10 days



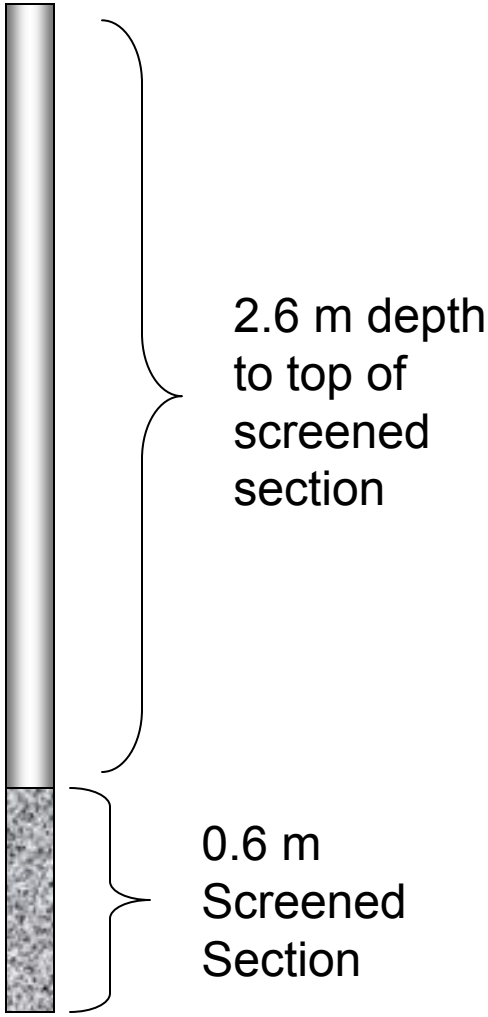


Vertical Test Injection Rate

Vertical Injection Rate = 0.8 l/min = 2.26 kg / day

Scaled up a factor of 400 (to ~ 100m)

Equivalent of 0.9 tonne / day



Vertical Injection Site

Shallow Vertical Well Installation

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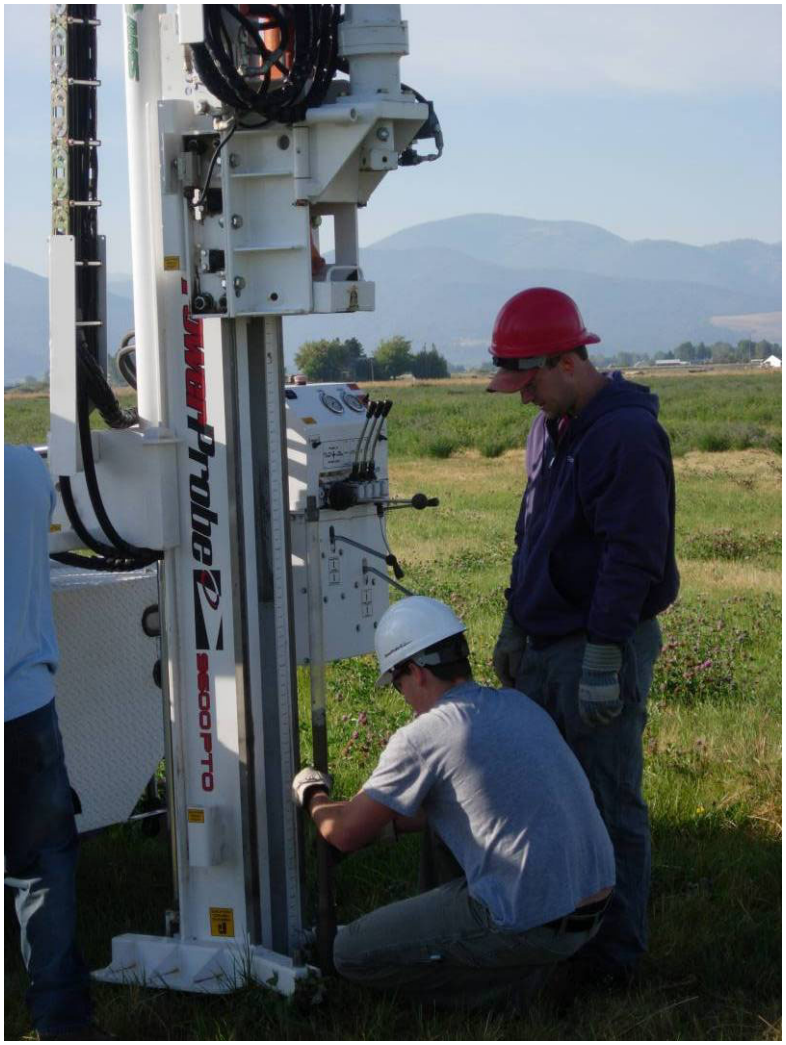
Mokwa Group, MSU



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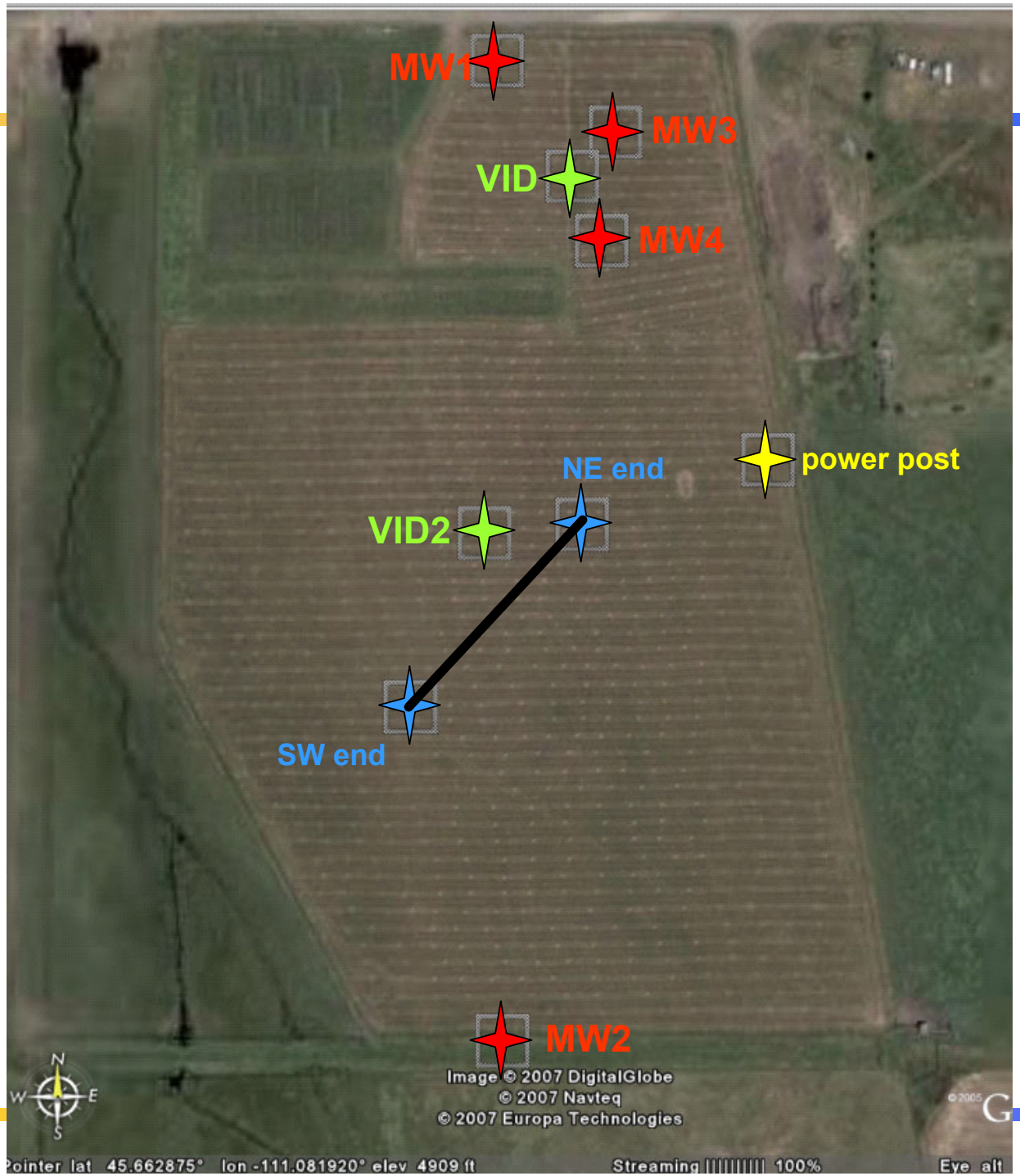

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Large Number of Participants / Methods

MSU – Geotechnical, O2, CO2 (isotope) Lidar, soil microbes.

LBNL – Eddy Covariance, Soil Gas Chamber, Modeling

LANL – EC, Stable Isotopes Gas & Water

PNNL – Soil & Hydrology, Tracers

LLNL – Gas Stable Isotope, Soil Microbes, Hyperspectral,

NETL – Background Charaterization, Tracers (sorption tubes)

WVU – Water Chemistry

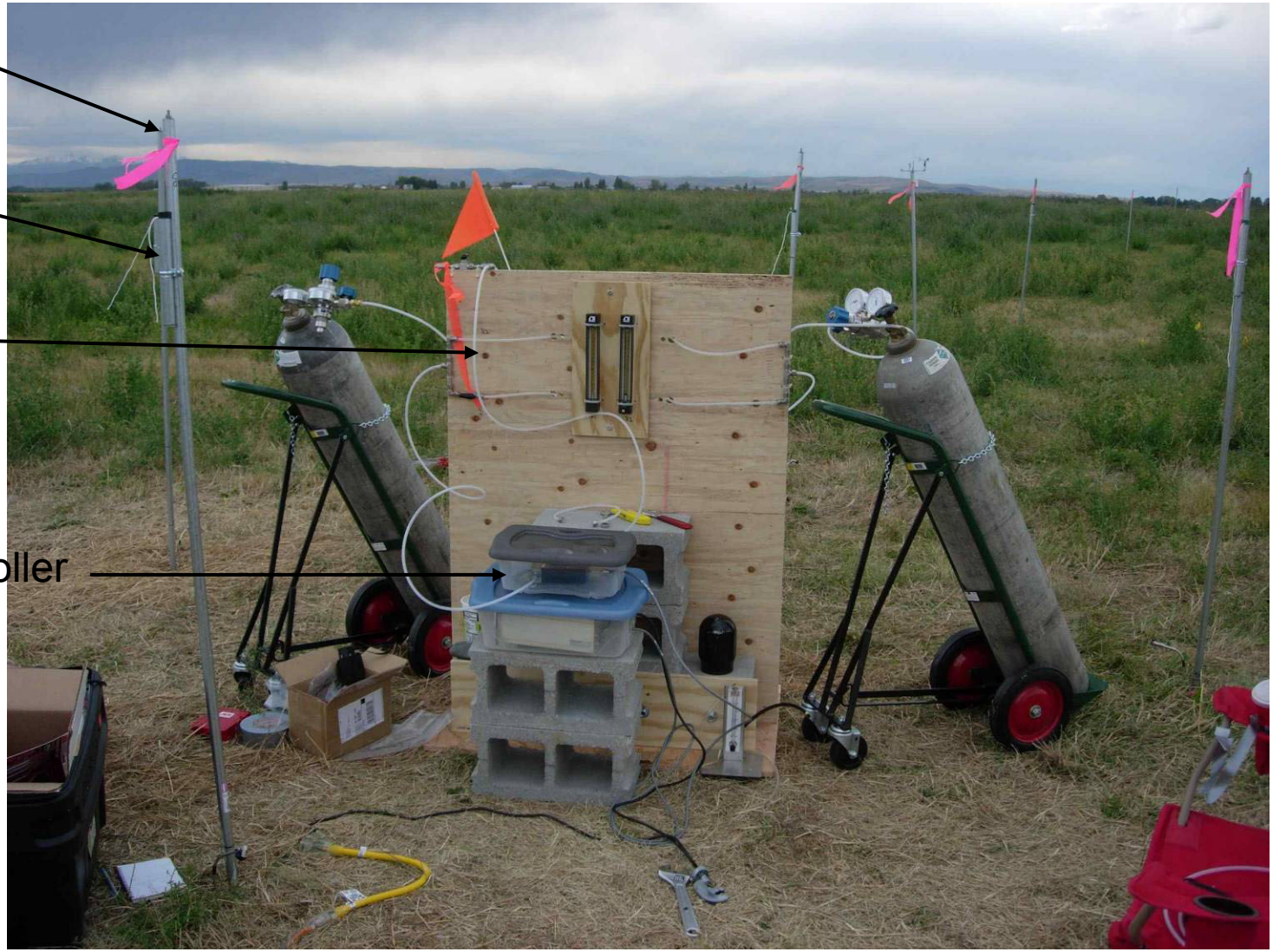
Injection System

Soil Gas Sorption Tube

Atmospheric Sorption Tube

Flow Meters

Mass Flow Controller



CO_2 Soil Gas Measurement

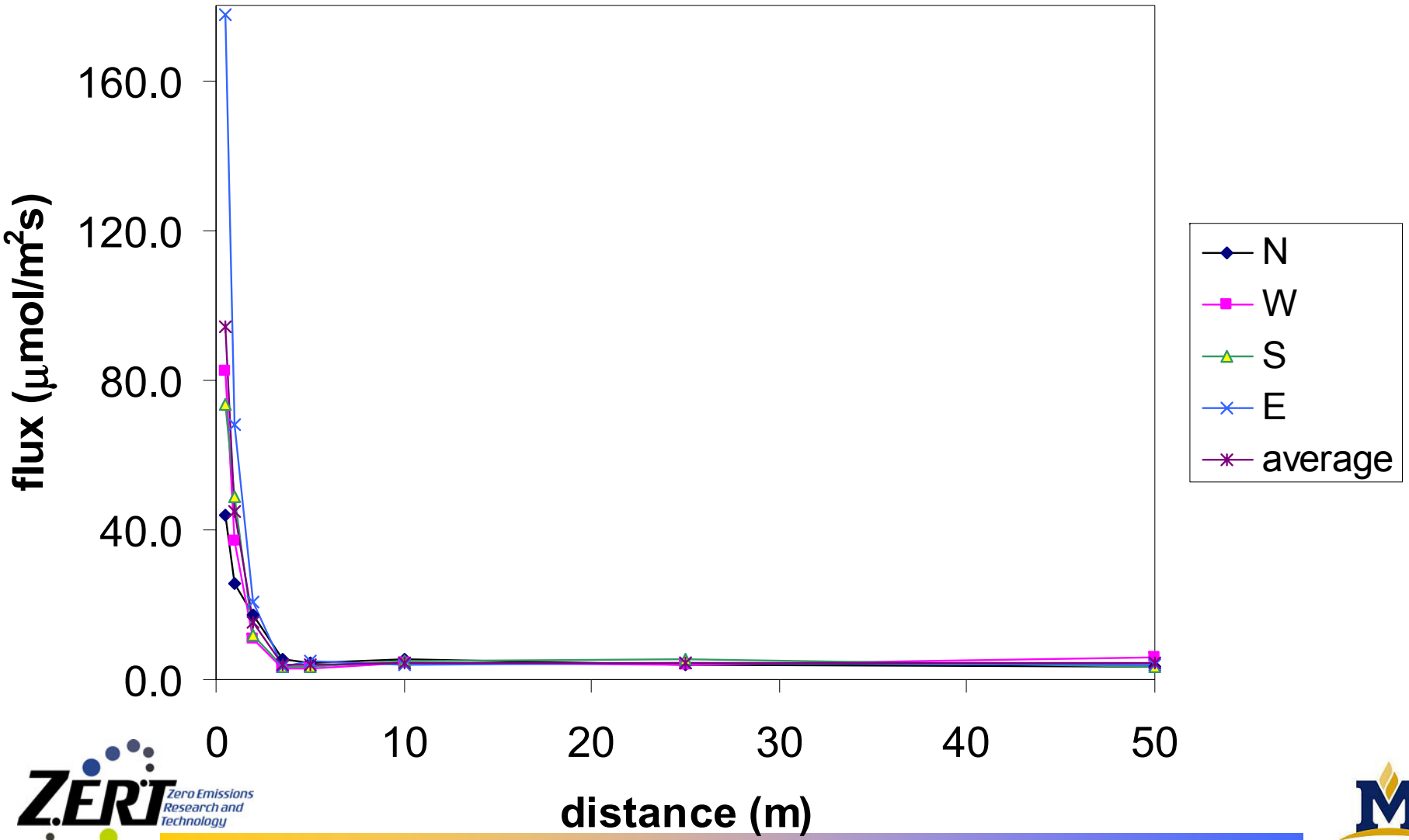
Brian Strazisar

distance (m)	fluxes ($\mu mol/m^2s$) N	W	S	E	average
0.5	44.0	82.3	73.4	177.7	94.4
1	25.8	36.9	48.7	68.0	44.8
2	17.2	10.7	12.1	20.9	15.2
3.5	5.4	3.0	3.5	3.6	3.8
5	4.4	3.1	3.5	5.1	4.0
10	5.4	4.6	4.8	3.8	4.7
25	4.1	4.1	5.4	4.3	4.5
50	3.5	6.0	3.7	4.0	4.3

CO_2 Soil Gas Measurement

Brian Strazisar

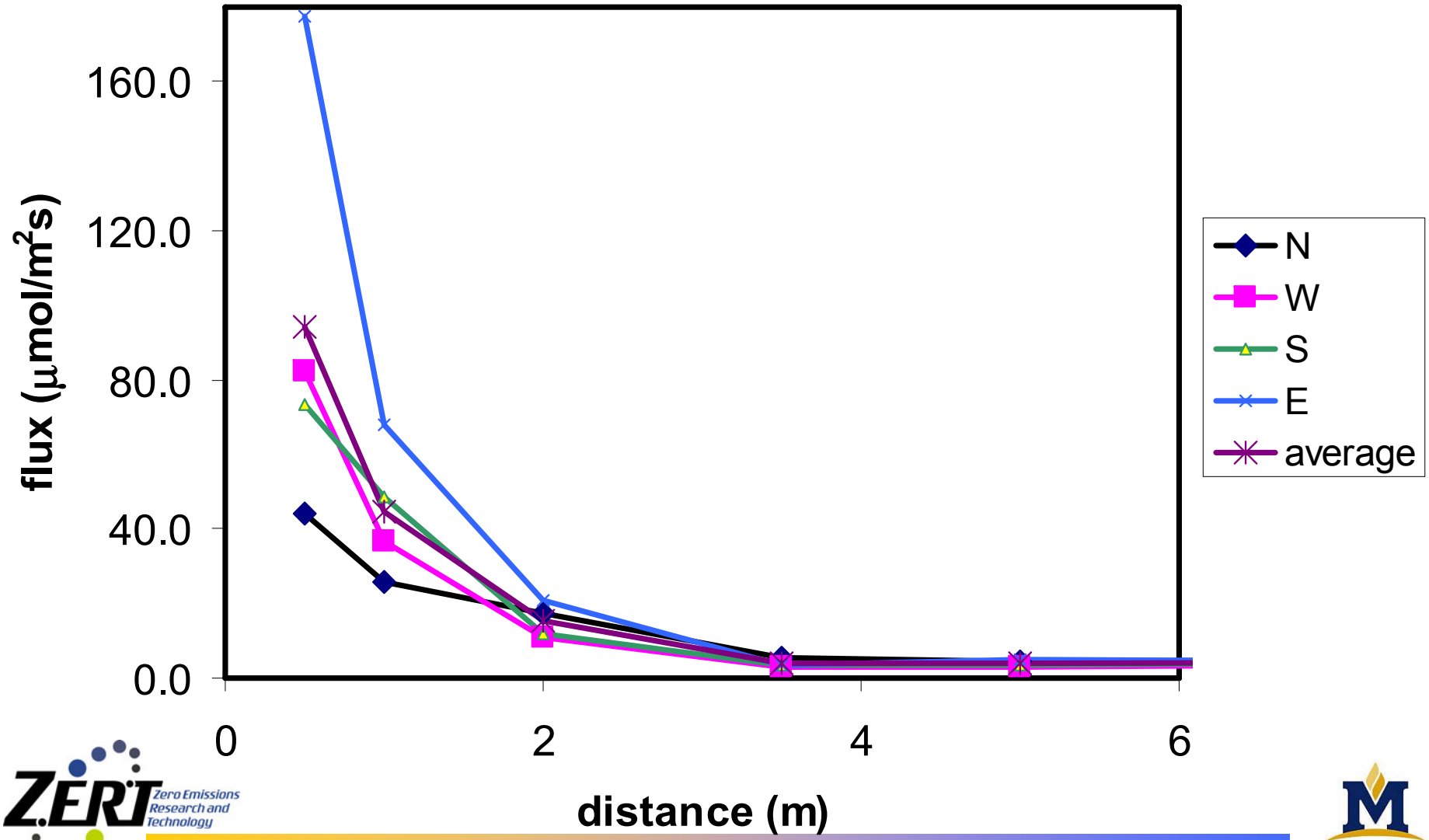
ZERT vertical injection average CO_2 fluxes



CO_2 Soil Gas Measurement

Brian Strazisar

ZERT vertical injection average CO_2 fluxes



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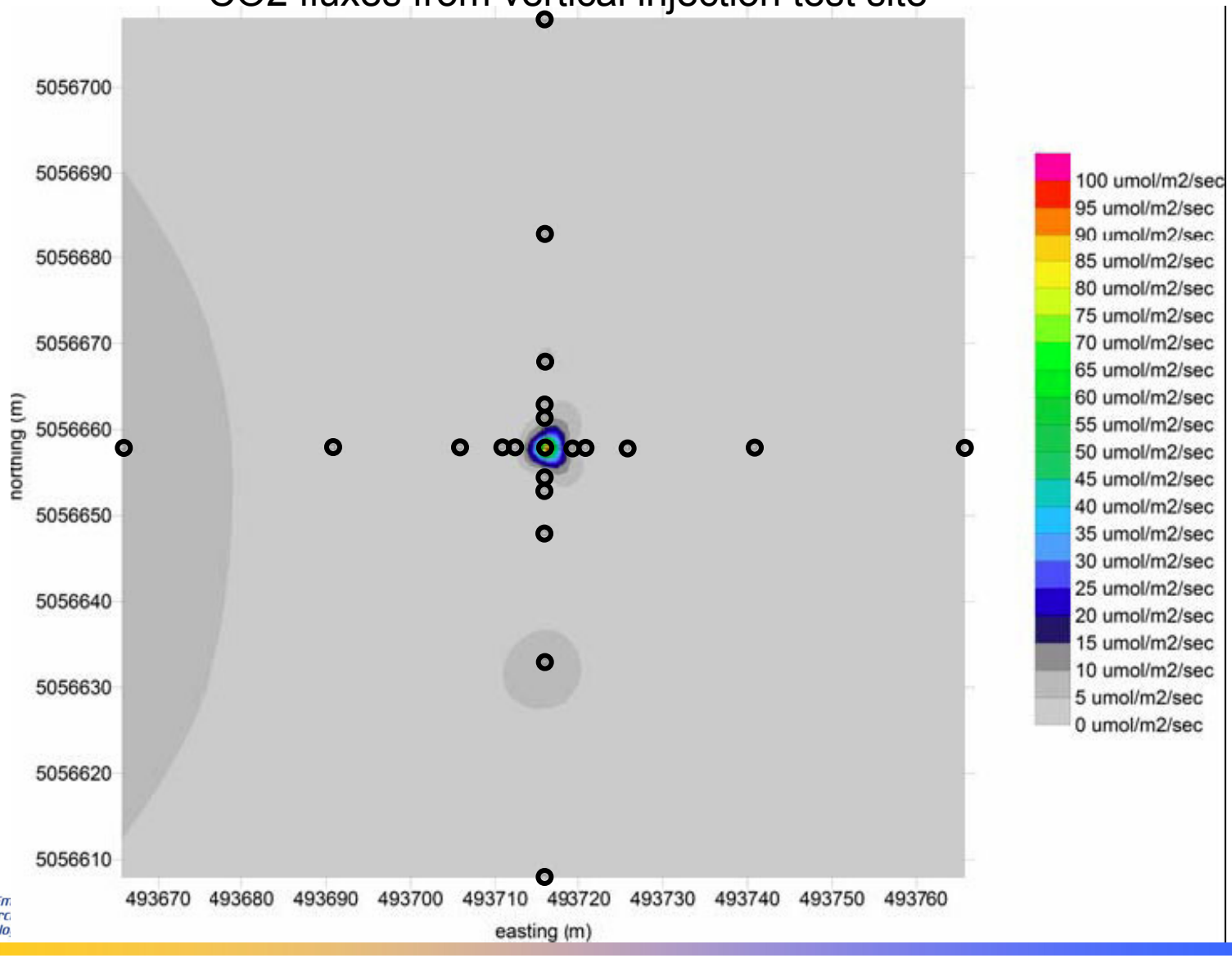
CO_2 Soil Gas Measurement

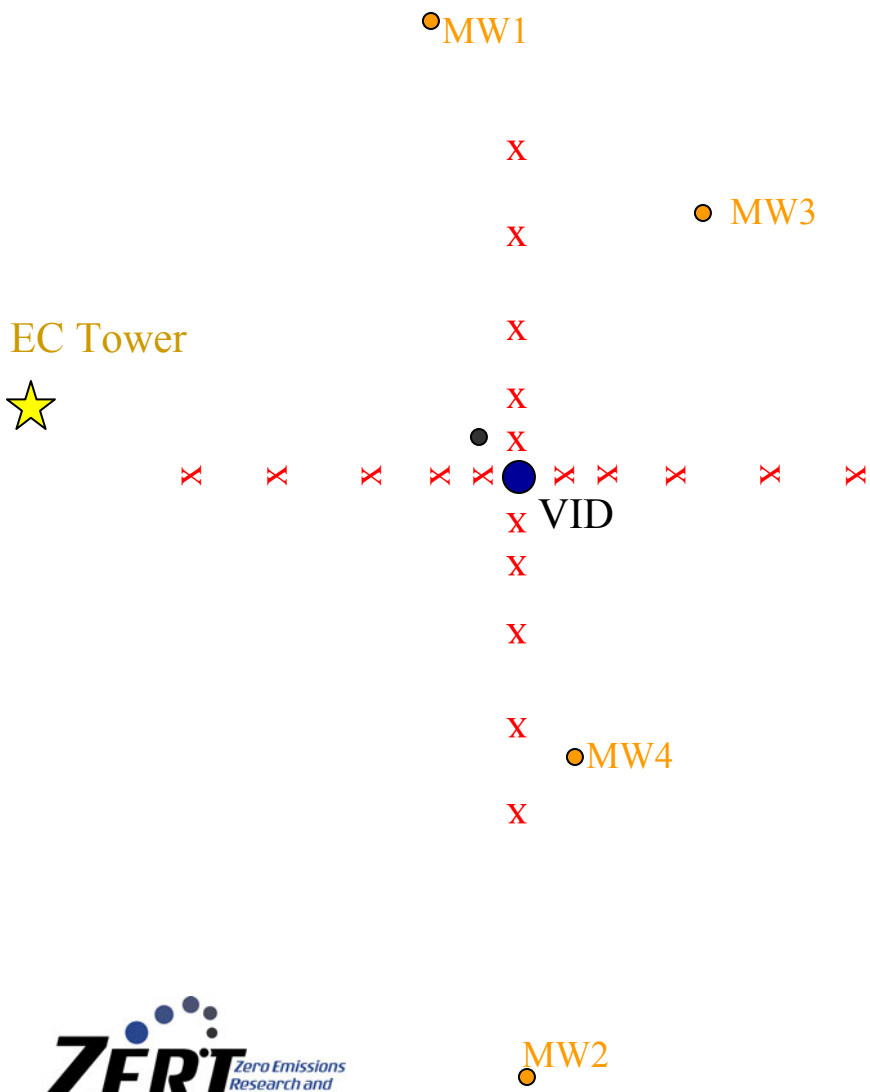
Brian Strazisar

CO2 fluxes from vertical injection test site



Tracer Studies

Art Wells *et al*



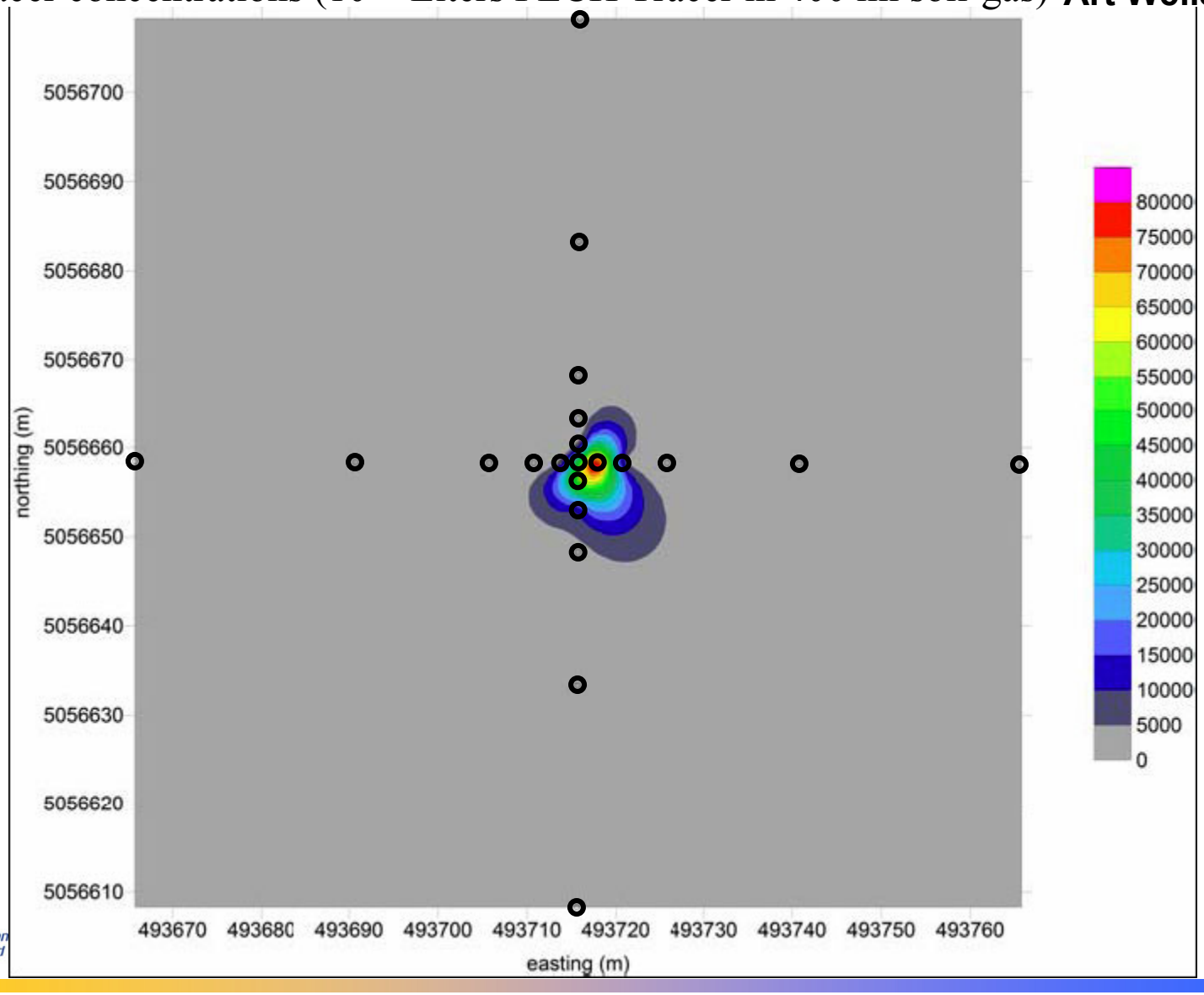
Sorption tubes placed at 2, 3.5, 5, 10, 25, and 50 m from injector

Tracer introduced for first 12 hrs of flow

Data not available yet

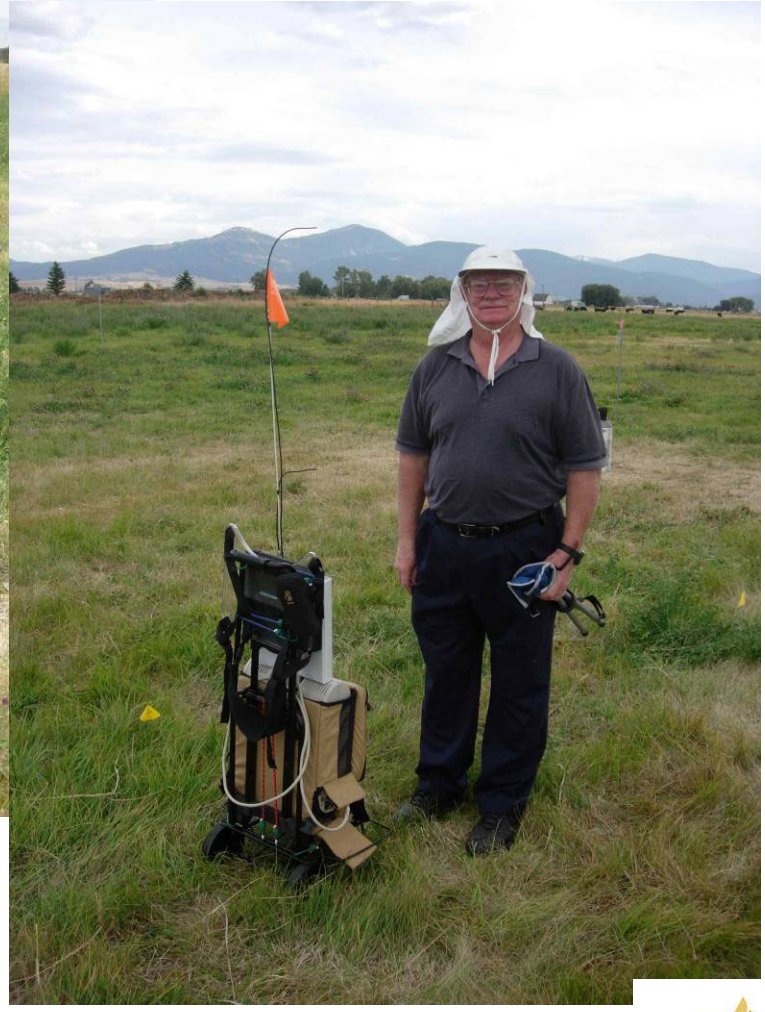
Tracer Studies

Soil-gas tracer concentrations (10^{-13} Liters PECH Tracer in 400 ml soil-gas) **Art Wells *et al***



Hyperspectral Imaging (Ground-based)

Bill Pickles



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Resistivity Measurements

Rick Hammack
Garret Veloski

Resistivity Measurements

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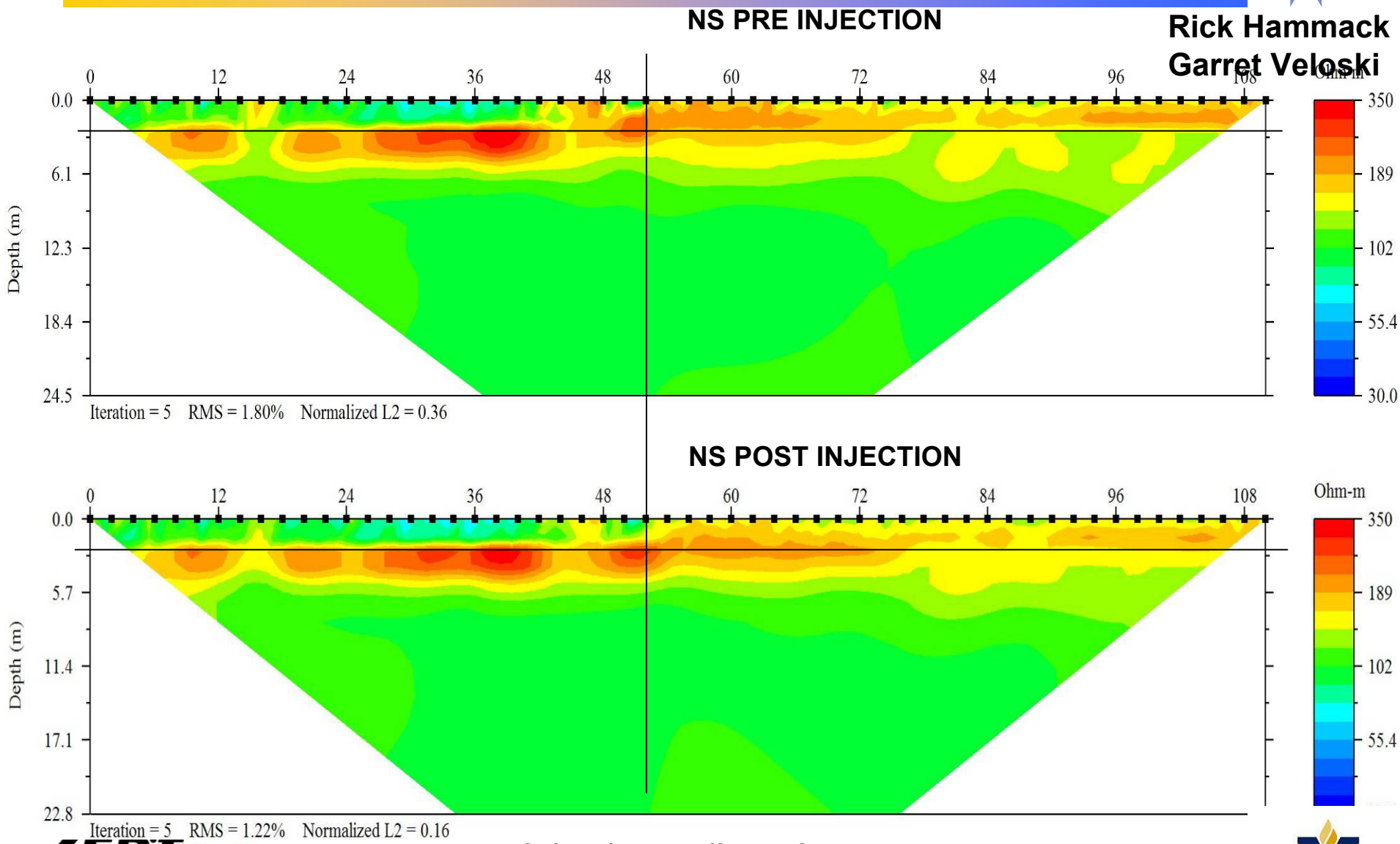
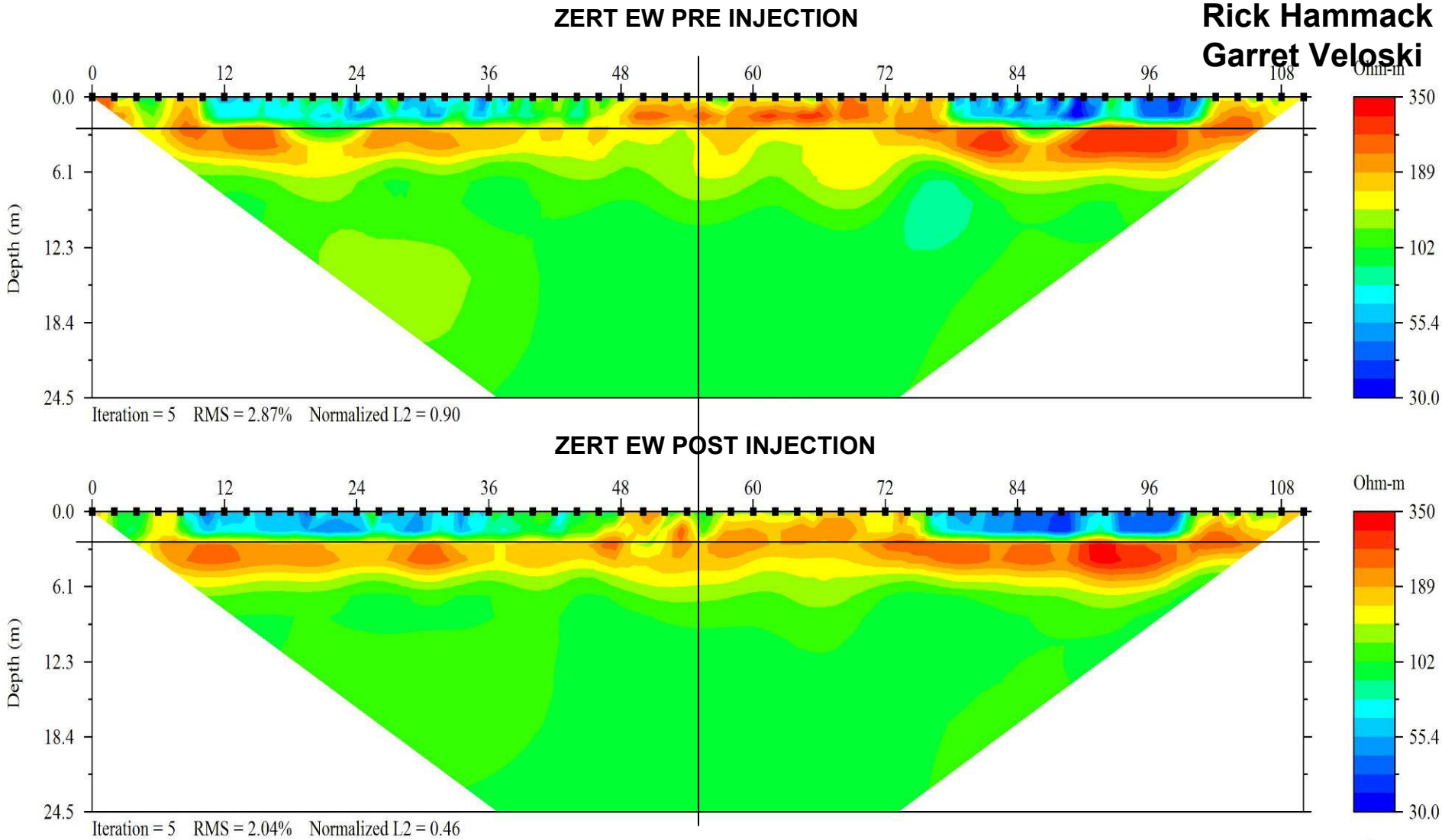
Garret Veloski



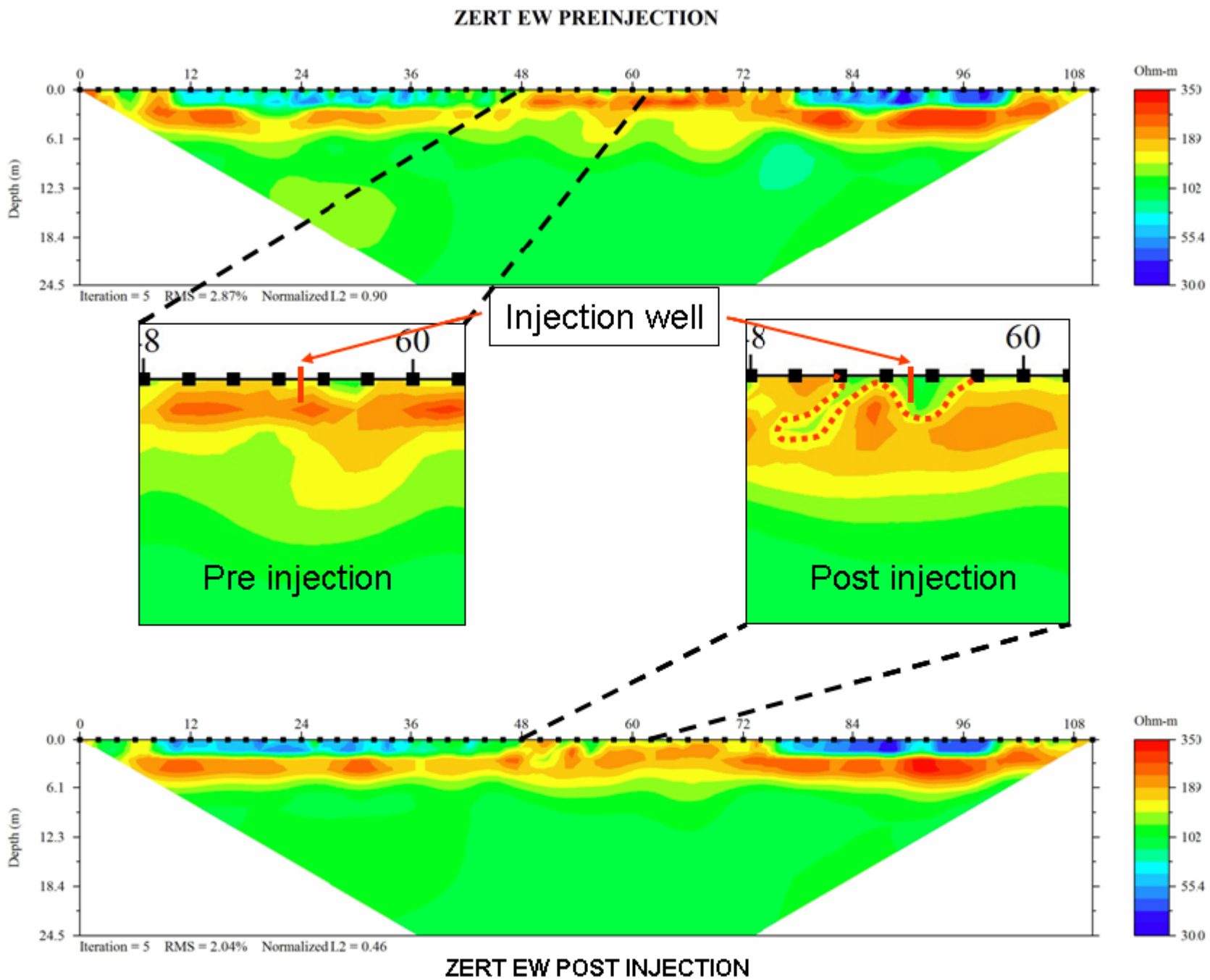
Injection well at 52 m

Resistivity Measurements

Rick Hammack
Garret Veloski



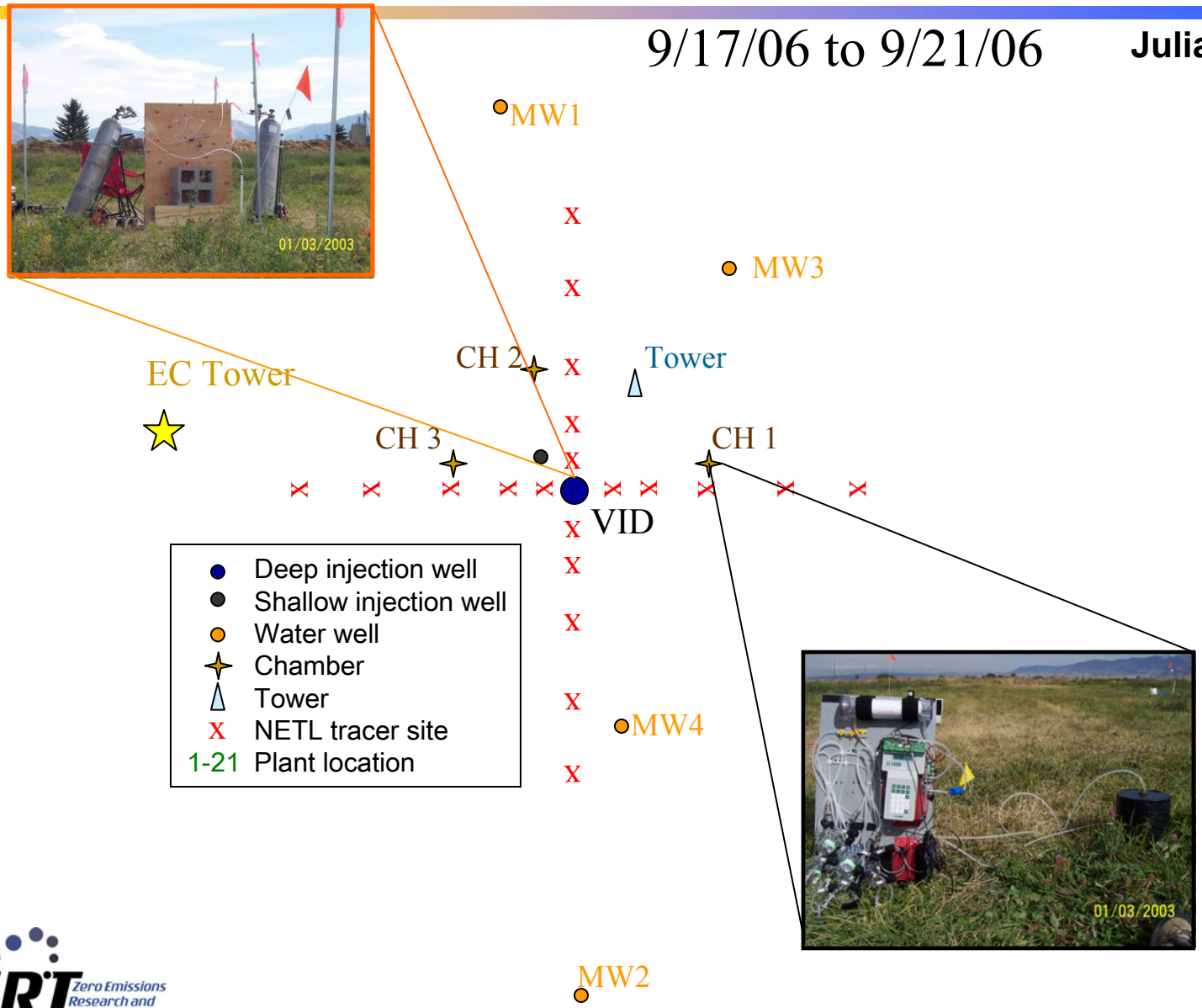
Injection well at 55 m on both profiles


ZERT EW PREINJECTION
Depth (m)
0.0
6.1
12.3
18.4
24.5
0
12
24
36
48
60
72
84
96
108
Ohm-m
350
189
102
55.4
30.0
Iteration = 5 RMS = 2.87% Normalized L2 = 0.90
Injection well
8
60
Pre injection
Post injection
Iteration = 5 RMS = 2.04% Normalized L2 = 0.46
ZERT EW POST INJECTION

Controlled Release – Experimental Design

9/17/06 to 9/21/06

Julianna Fessenden

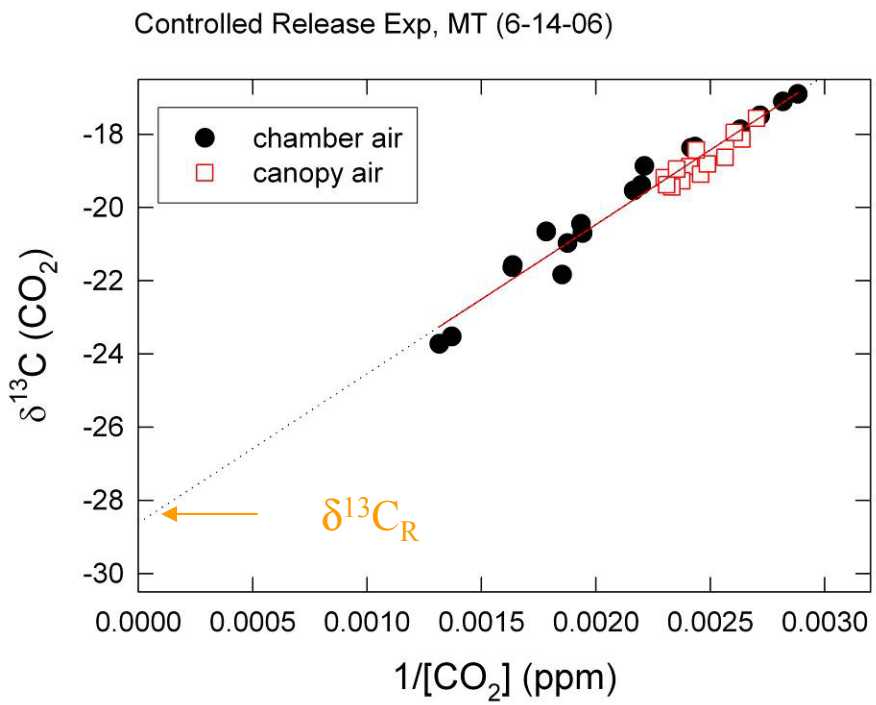


$\delta^{13}C$ of Regional CO_2 and Soil Respired CO_2

(Example from 6/12/06)

Julianna Fessenden

Mixing Model – Keeling Plot (Linear Regression): calculates $\delta^{13}C$ of CO_2 Source



Intercept value ($\delta^{13}C_R$) =

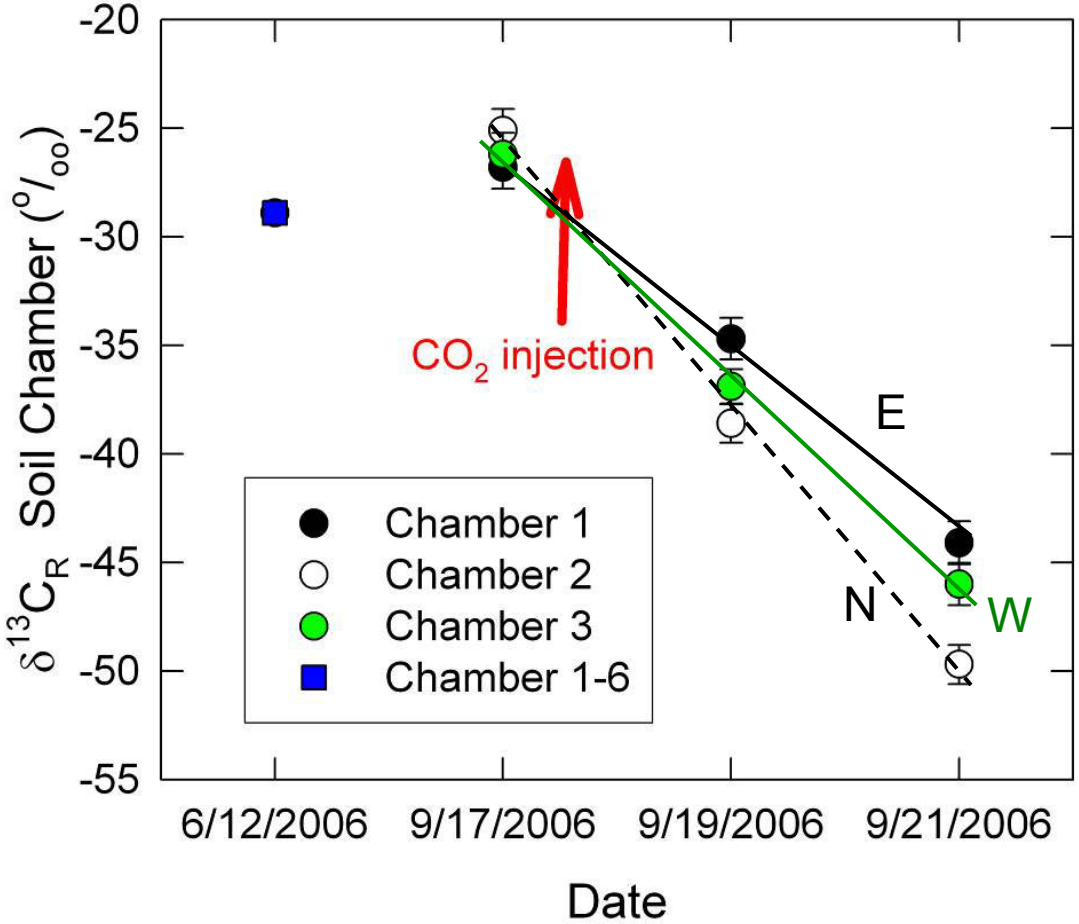
1. $\delta^{13}C$ of source of CO_2
2. Integrates multiple sources
3. Integrates over varying scales

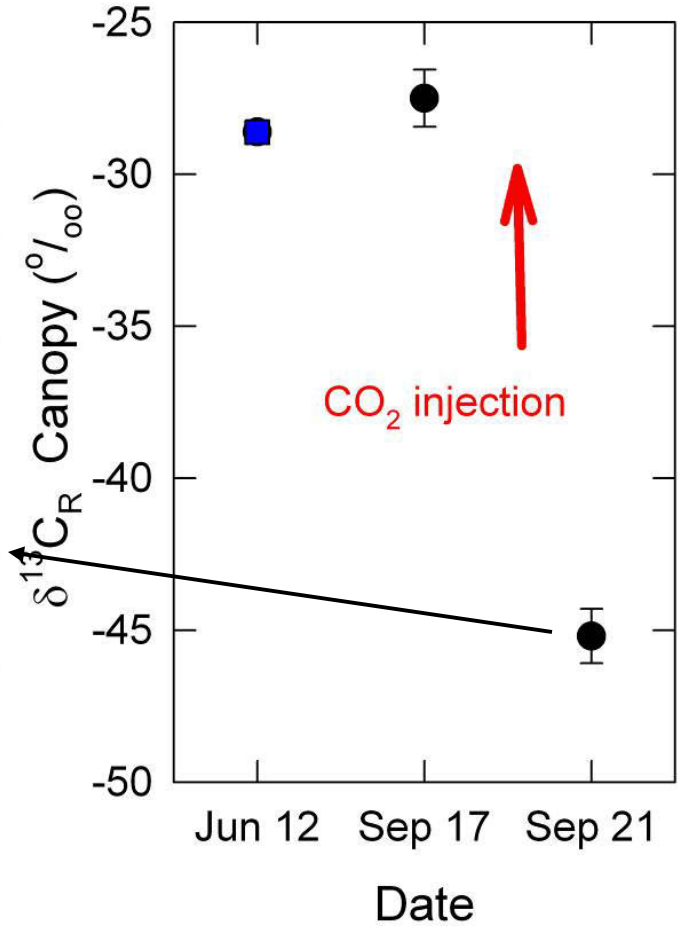
$\delta^{13}C$ Values of CO_2 (chamber and canopy air)

Los Alamos NATIONAL LABORATORY EST. 1943

Hay Field - Bozeman, MT

Julianna Fessenden





A clear isotopic shift is seen in the source of CO_2 after injection, both in the chambers and in the canopy air

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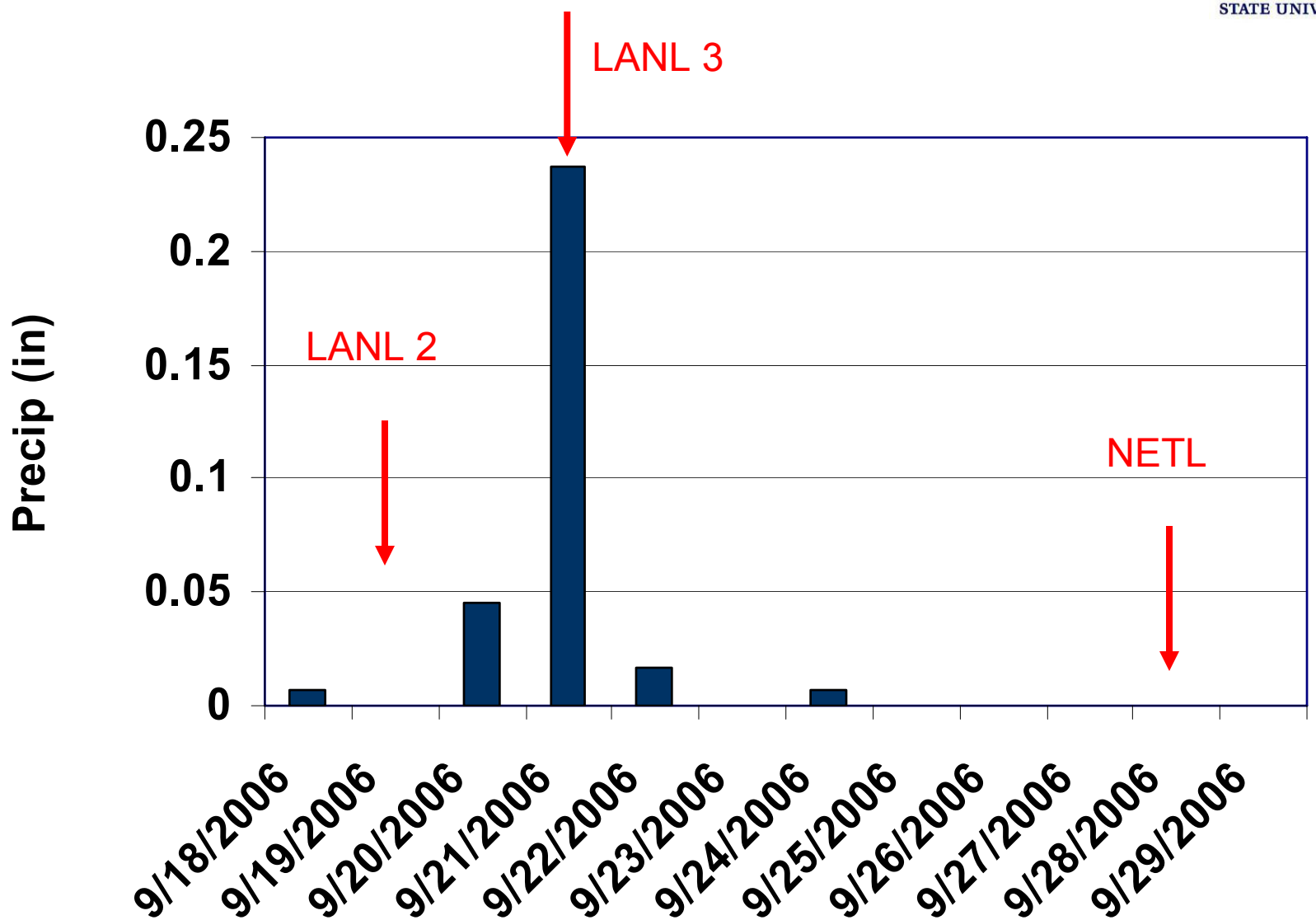
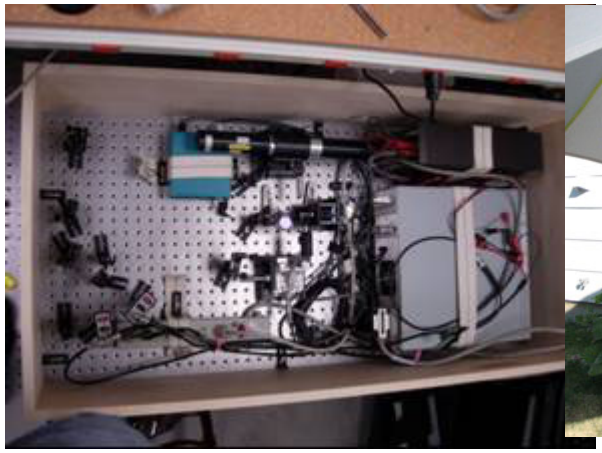
Precipitation

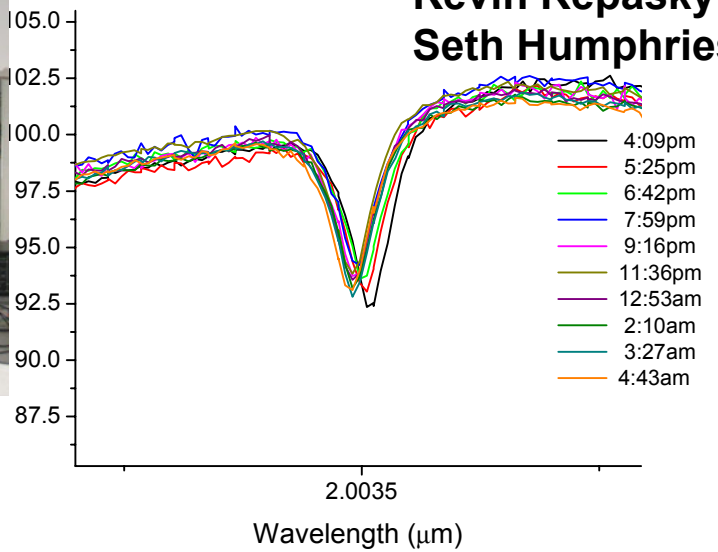


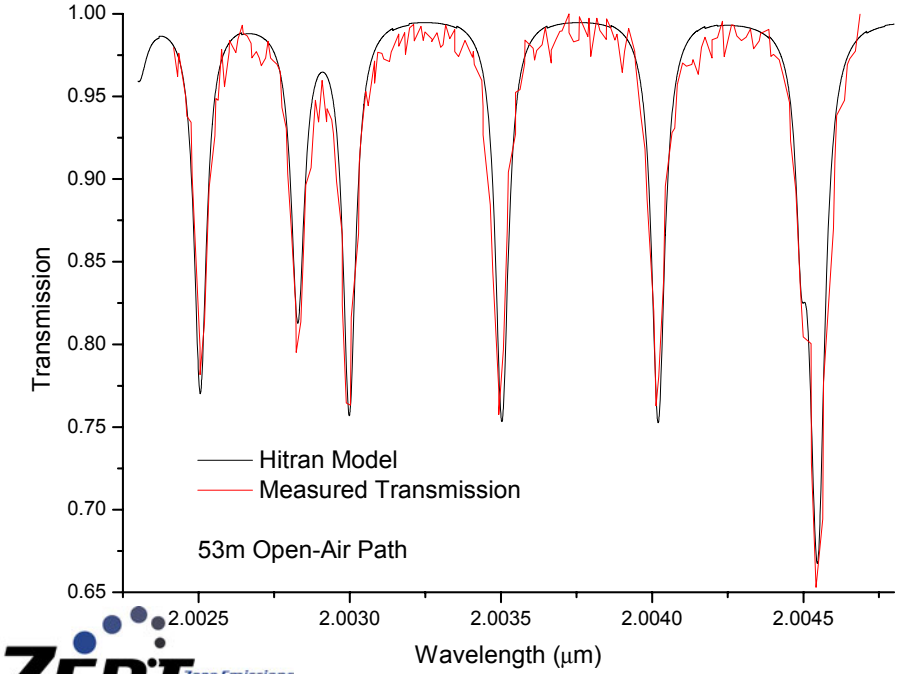
LIDAR System, Performance

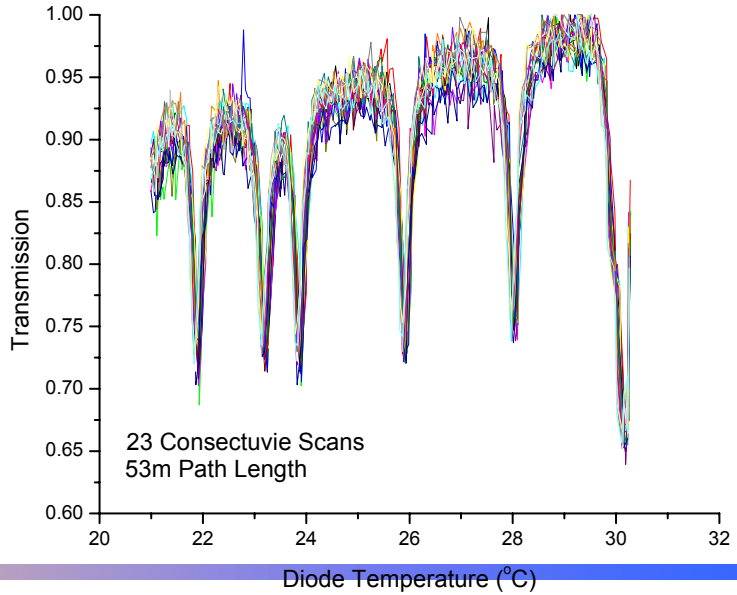
MONTANA STATE UNIVERSITY

Kevin Repasky
Seth Humphries









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LIDAR Data at Injection Well

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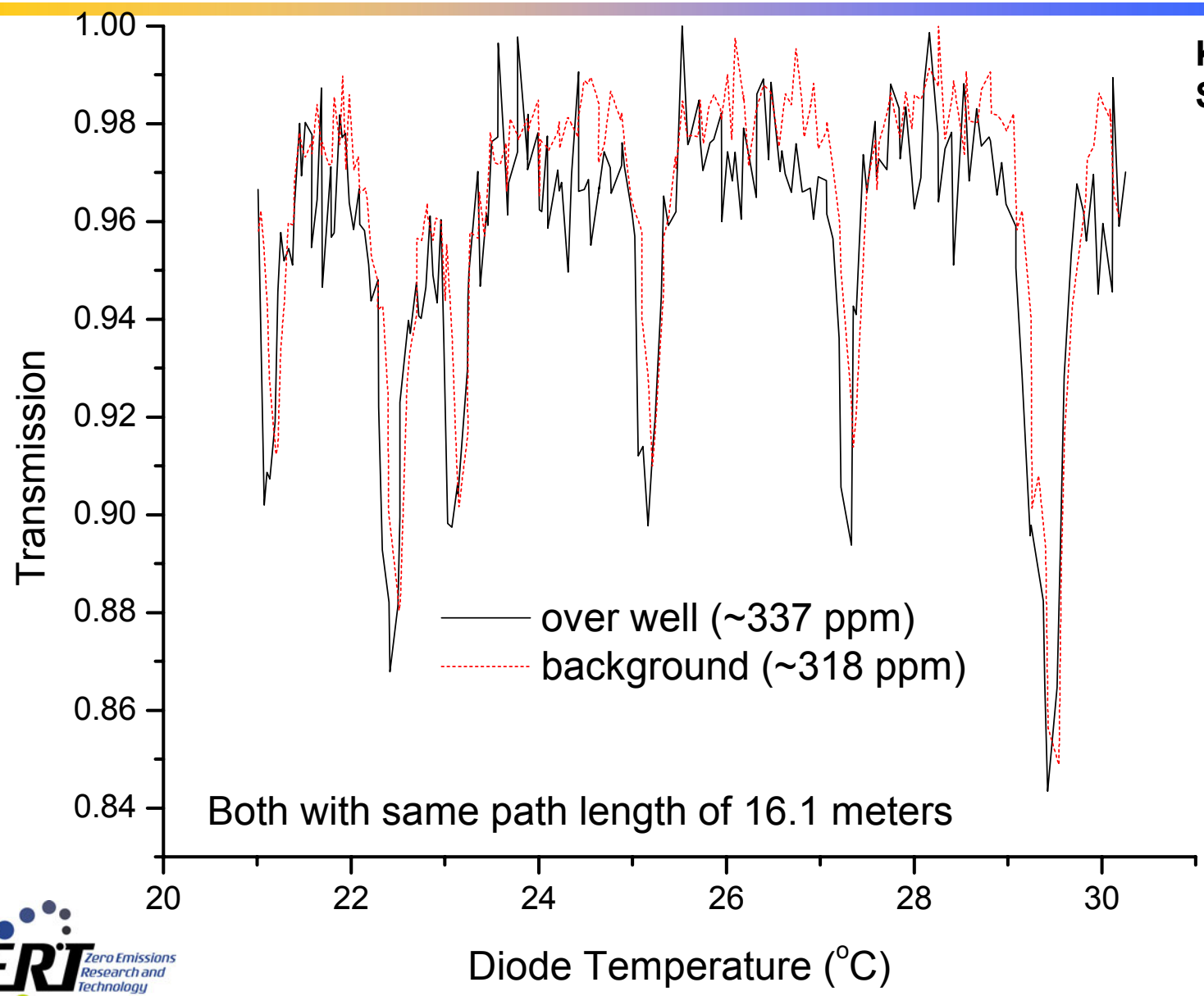
Kevin Repasky
Seth Humphries



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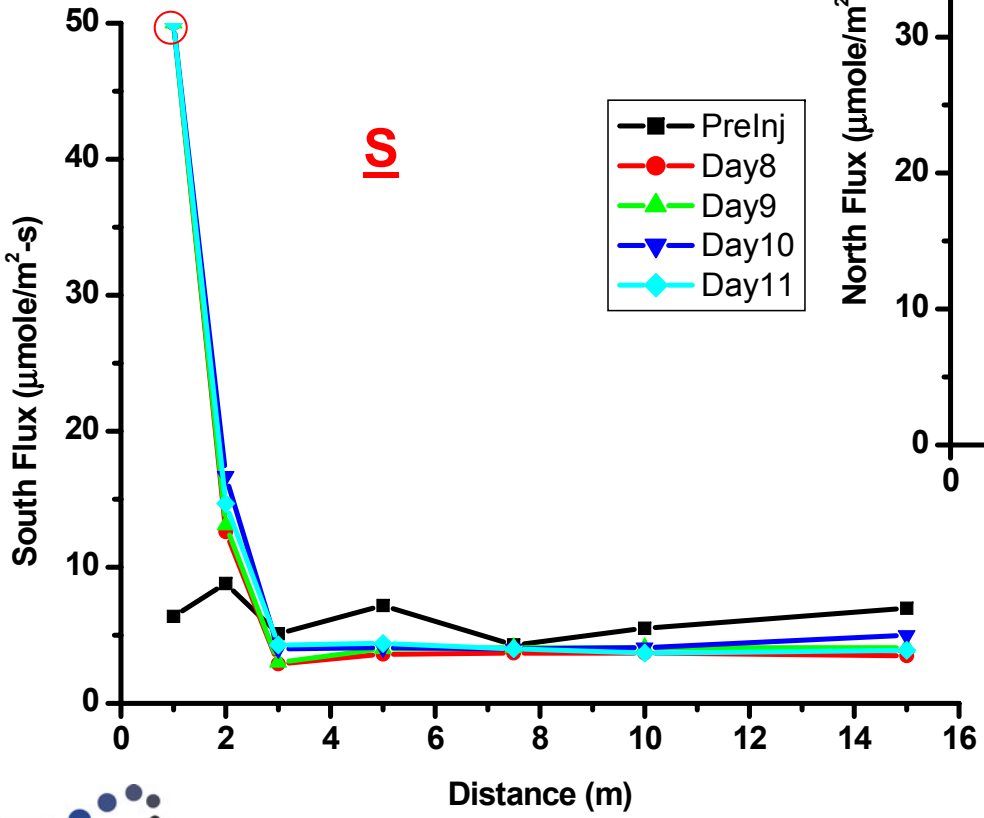
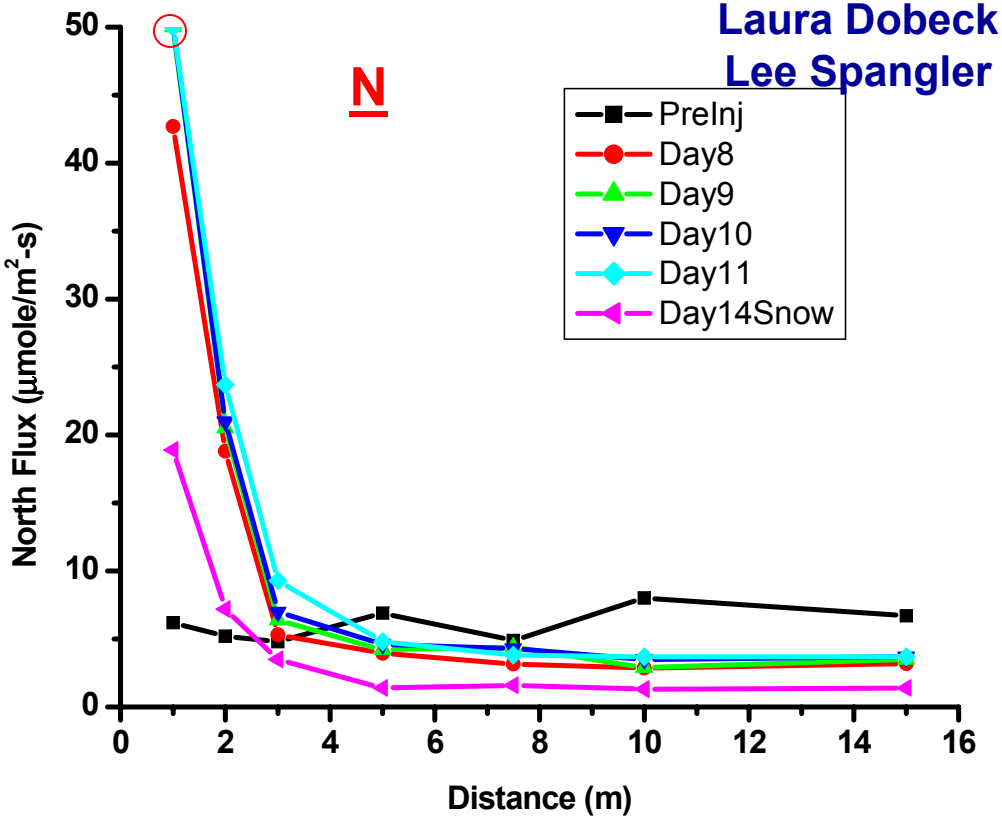
Soil Flux Radial Distribution, New Injector

Laura Dobeck
Lee Spangler

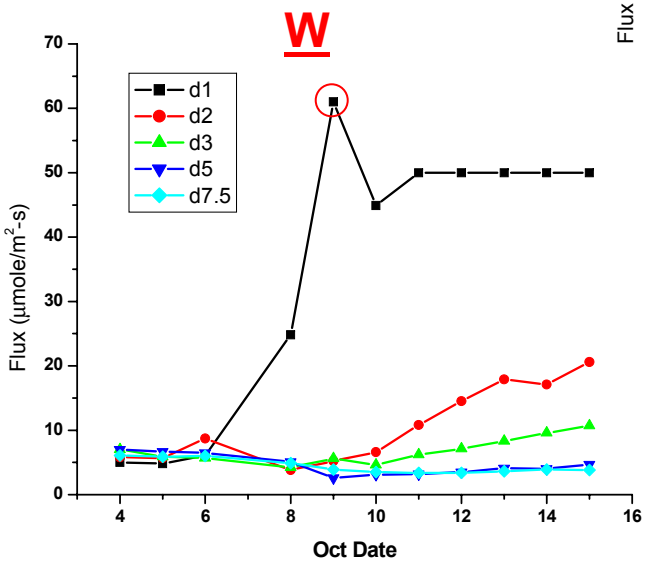


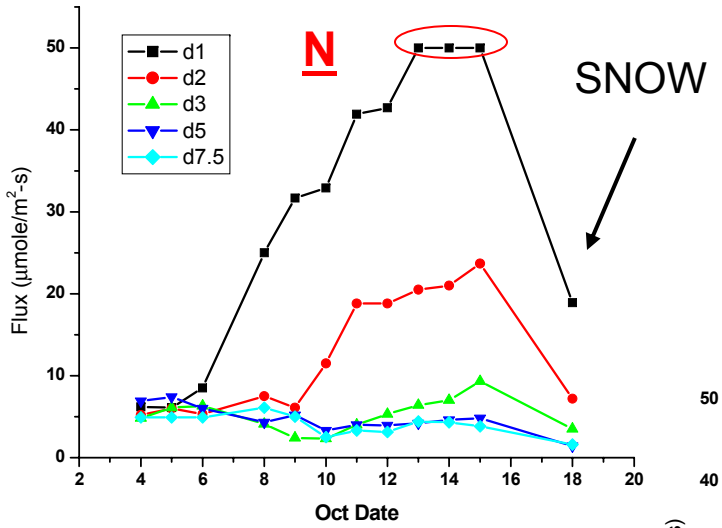


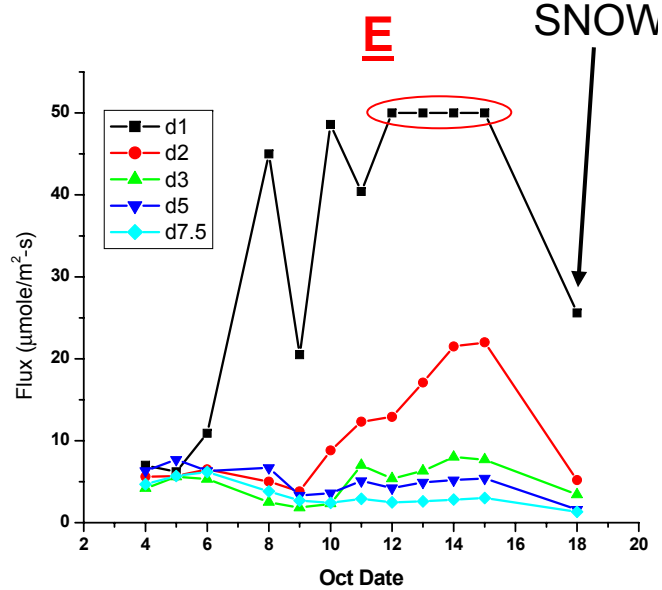
Soil Flux Time Series, New Injector

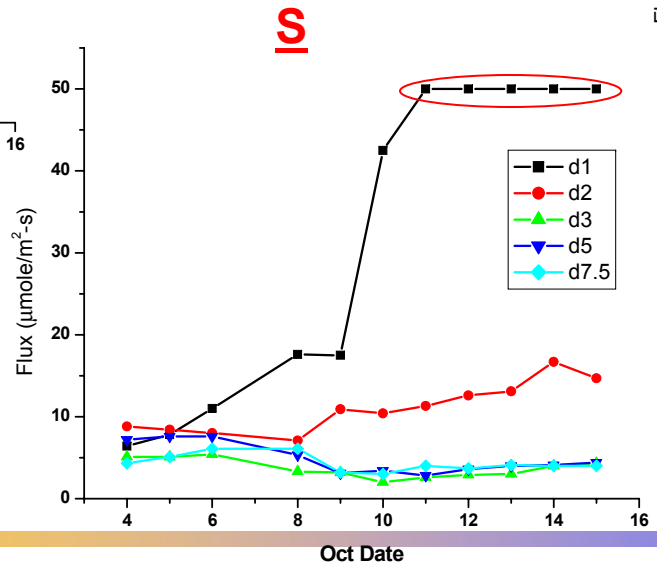
MONTANA STATE UNIVERSITY
Laura Dobeck
Lee Spangler

Note: No flux increase at 0 m in first 6 hours









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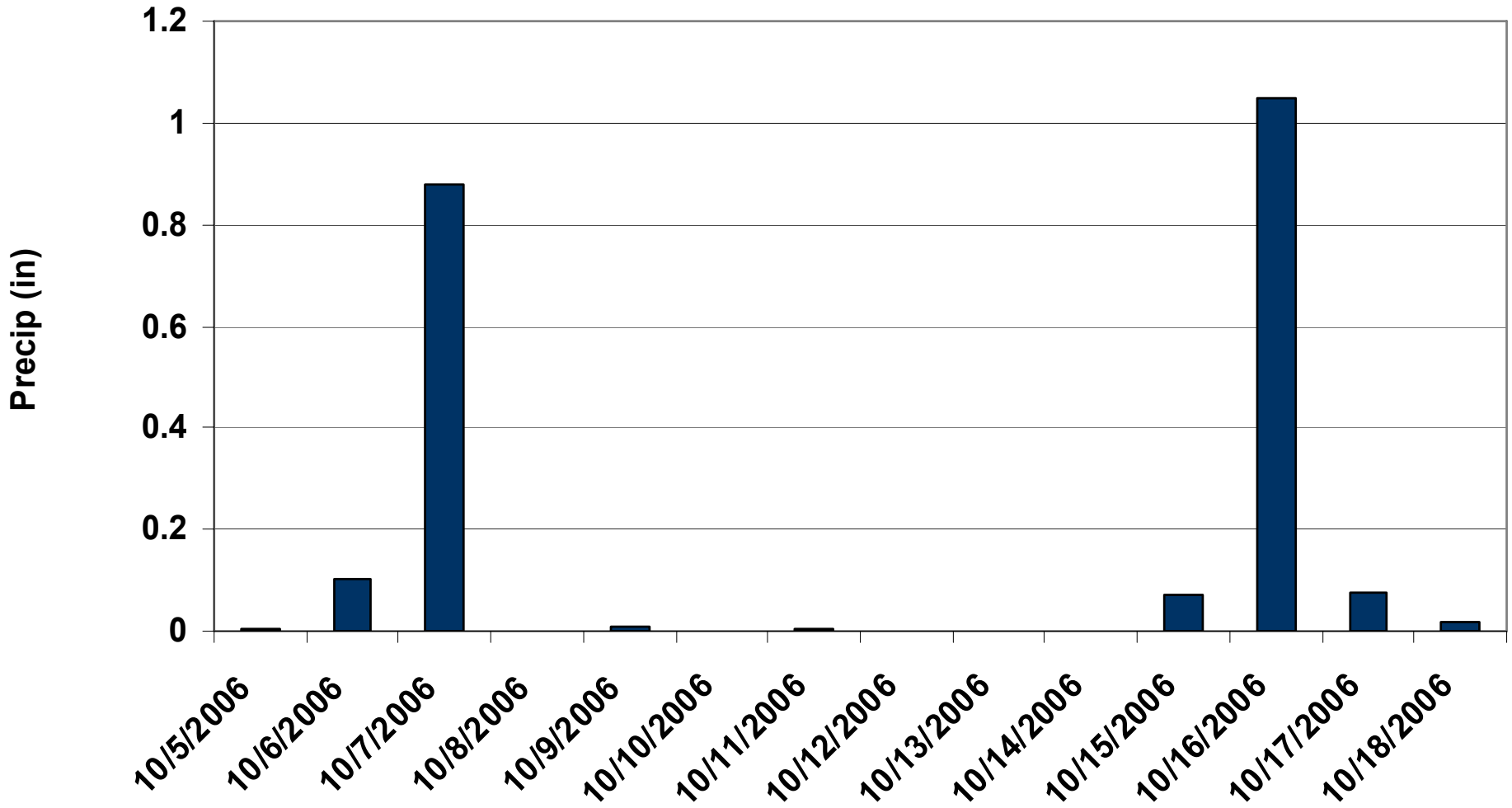
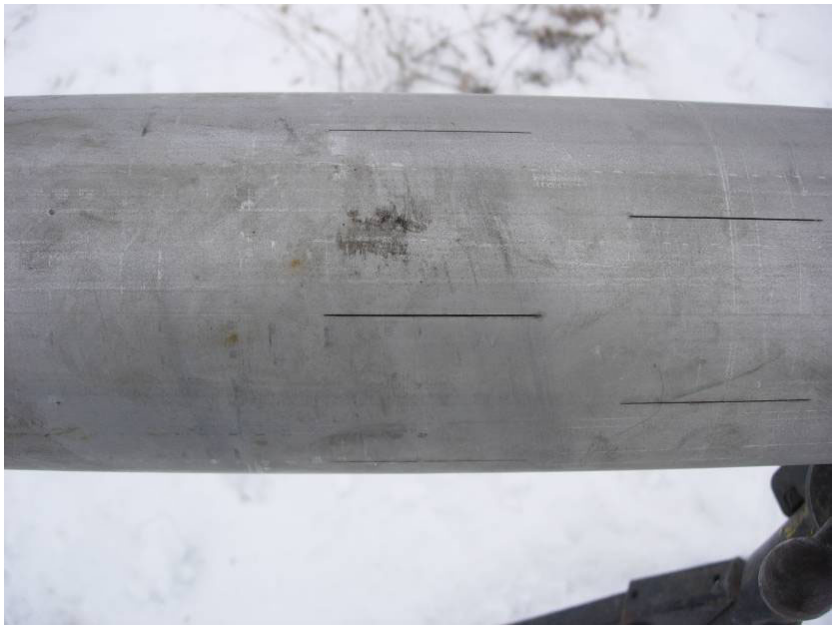
Precipitation for 2nd Vertical Injection



~~Conclusions~~ Preliminary Thoughts

- Concentration and flux measurements are less sensitive than ^{13}C
- Soil moisture content and temperature can have a large impact on soil flux measurements
- CO_2 flow may desiccate soil, increase gas permeability, and generate a faster flow pathway. I.e. flow may effect plume diameter over time.
- Depending on geometry of underground source, relevant surface fluxes may be measurable

Horizontal Well Installation



Horizontal Well Installation

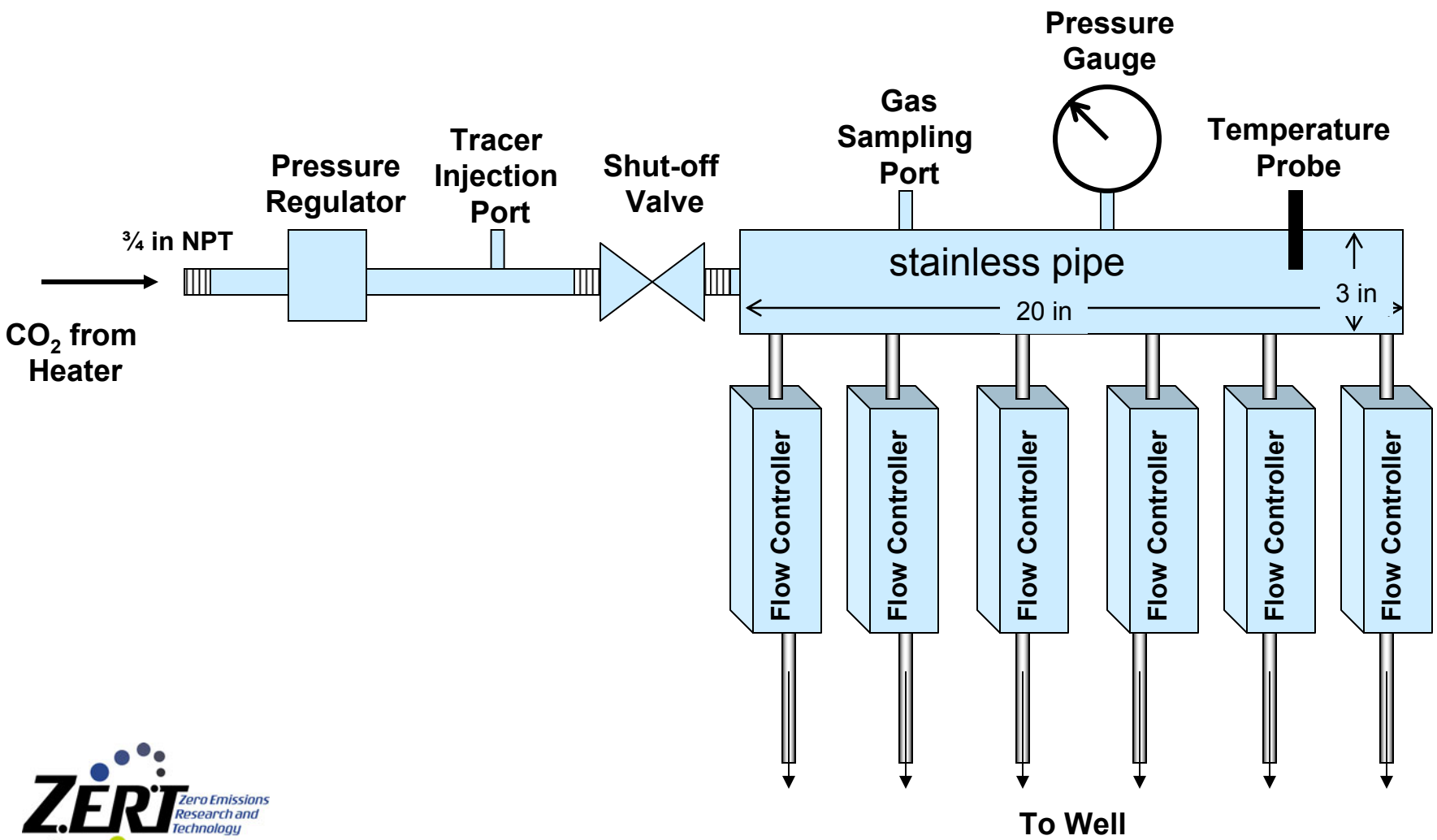
LC-2600
SYRINGE
PUMP

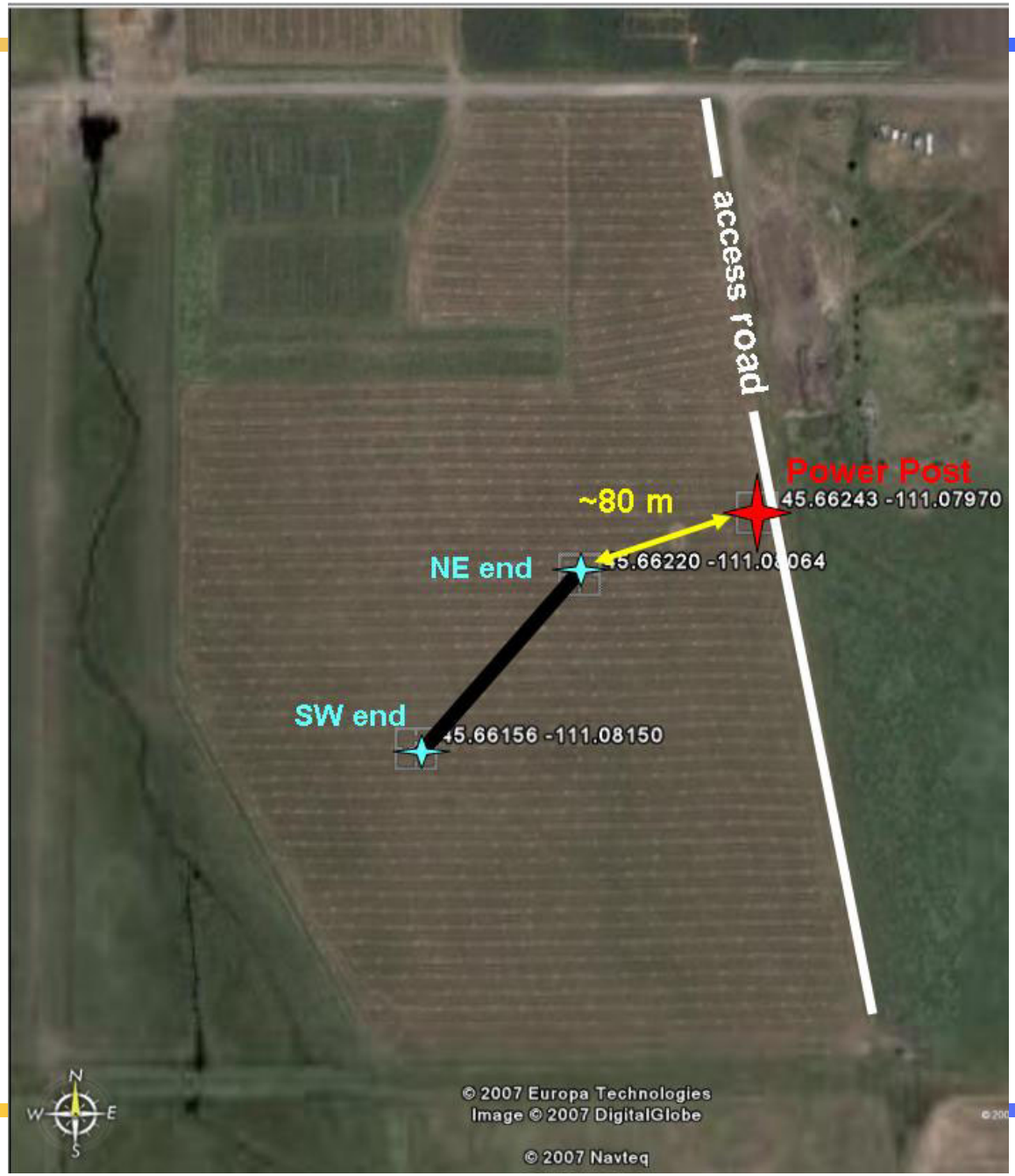
Test Set-Up

Ray Solbau, Sally Benson

Surface Manifold for Injection

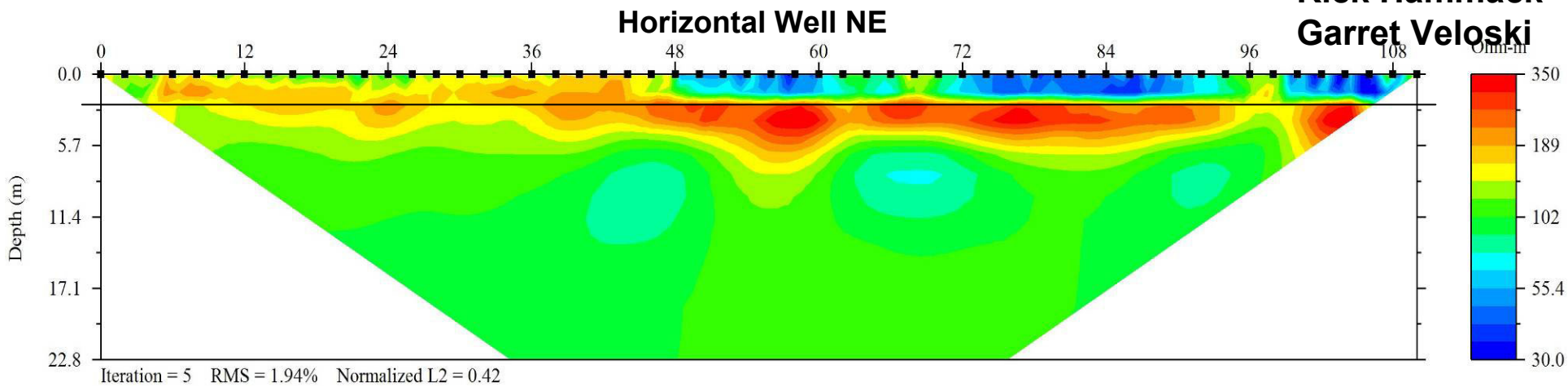
Ray Solbau, Sally Benson



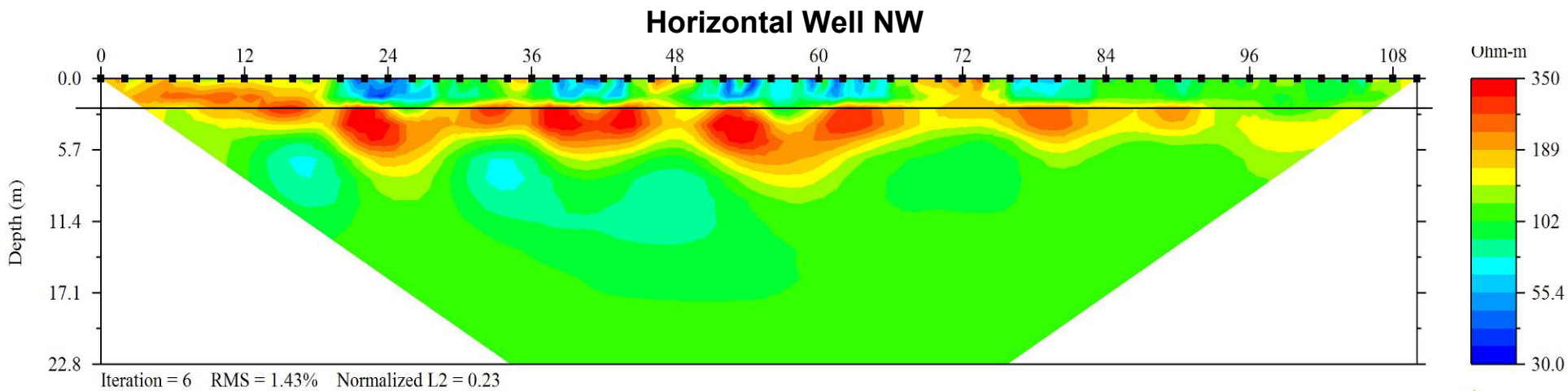

access road
Power Post
45.66243 -111.07970
~80 m
NE end
45.66220 -111.08064
SW end
45.66156 -111.08150
© 2007 Europa Technologies
Image © 2007 DigitalGlobe
© 2007 Navteq

Planned orientation for horizontal well

Rick Hammack
Garret Veloski



Normal to planned orientation; intersecting at midpoint (55 m)



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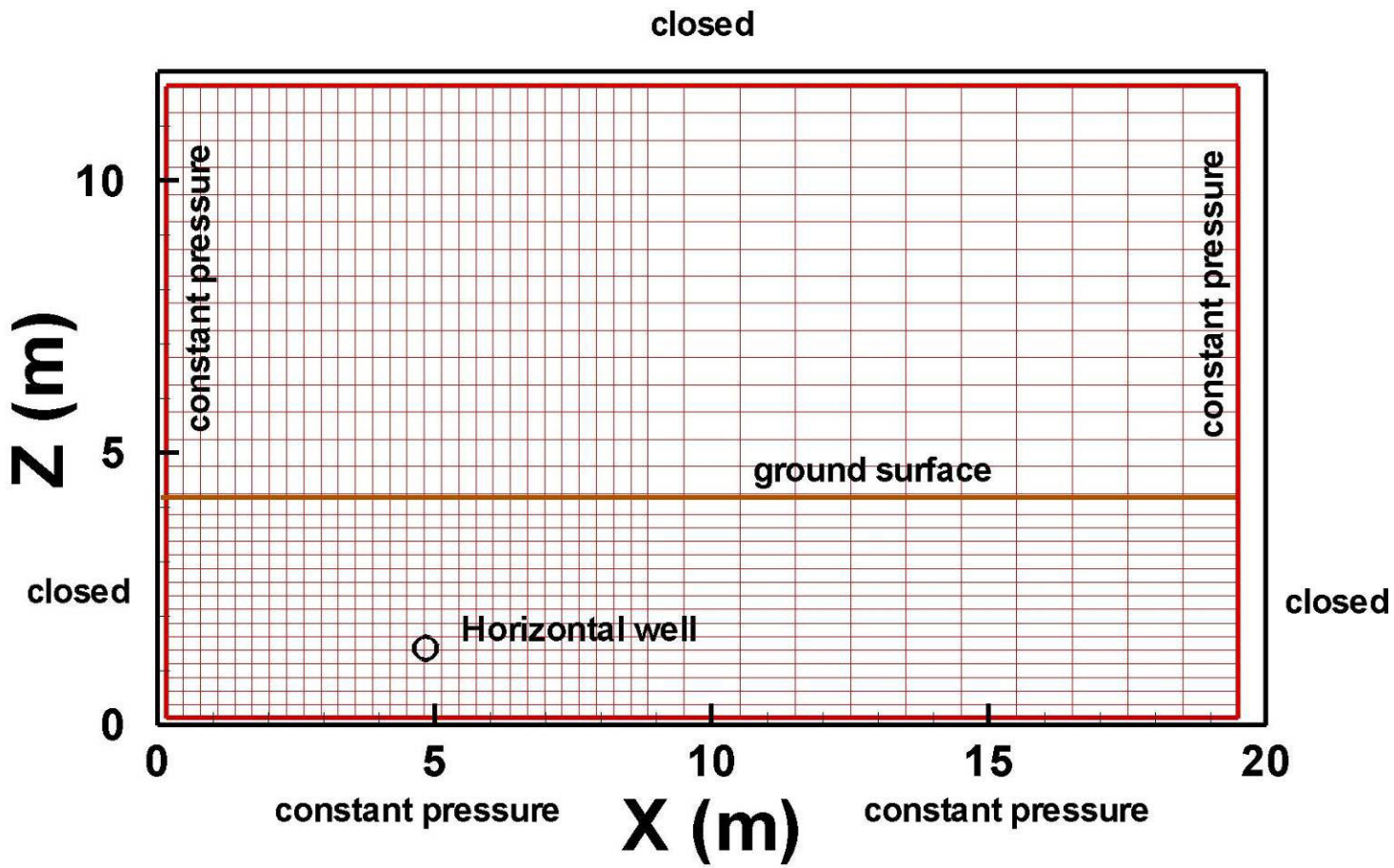
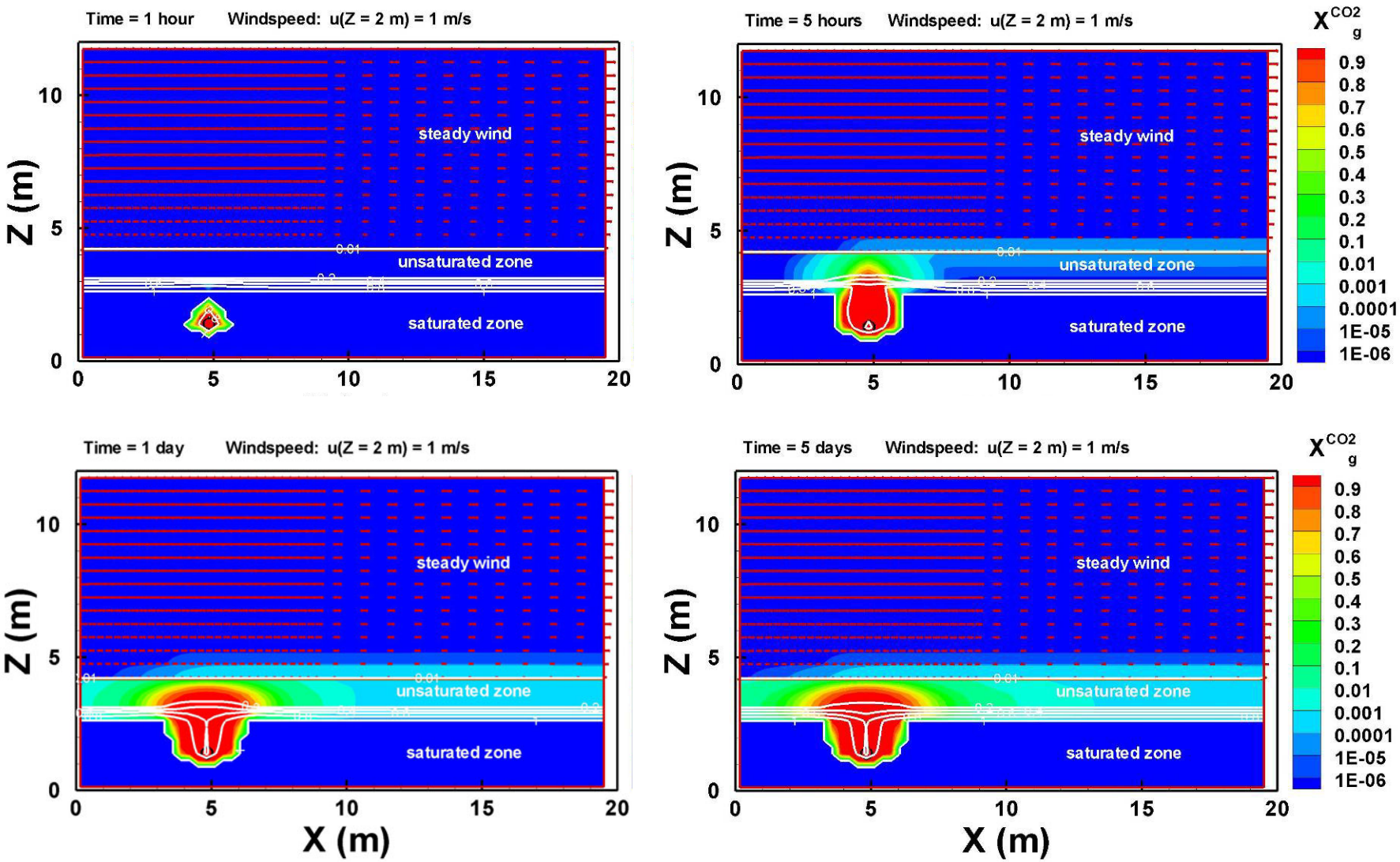
2-D Cross-Section of Horizontal Release

Curt Oldenburg



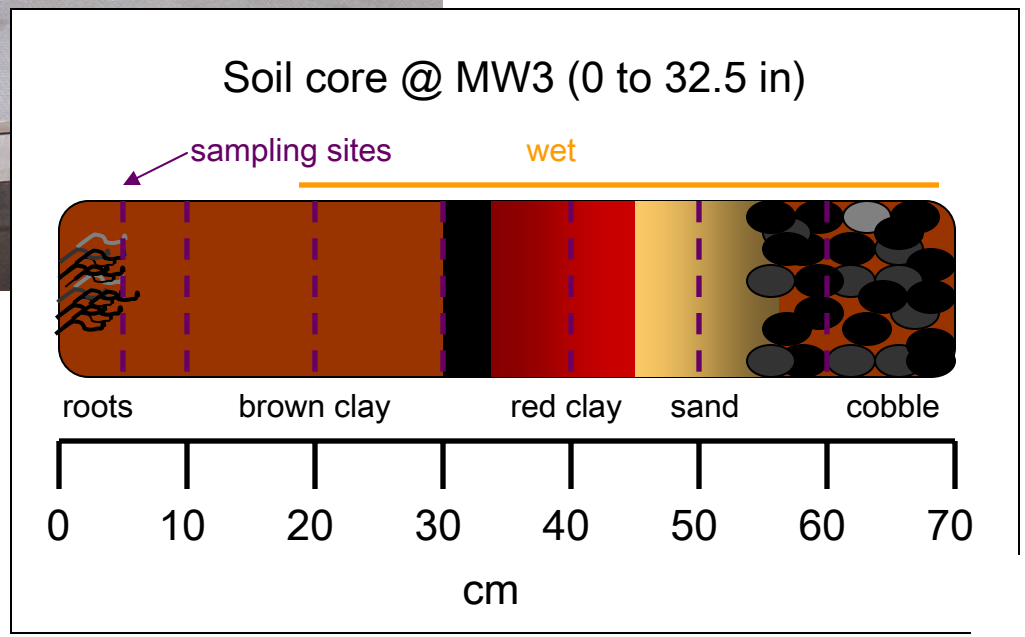
CO_2 Migration at Four Times

Curt Oldenburg



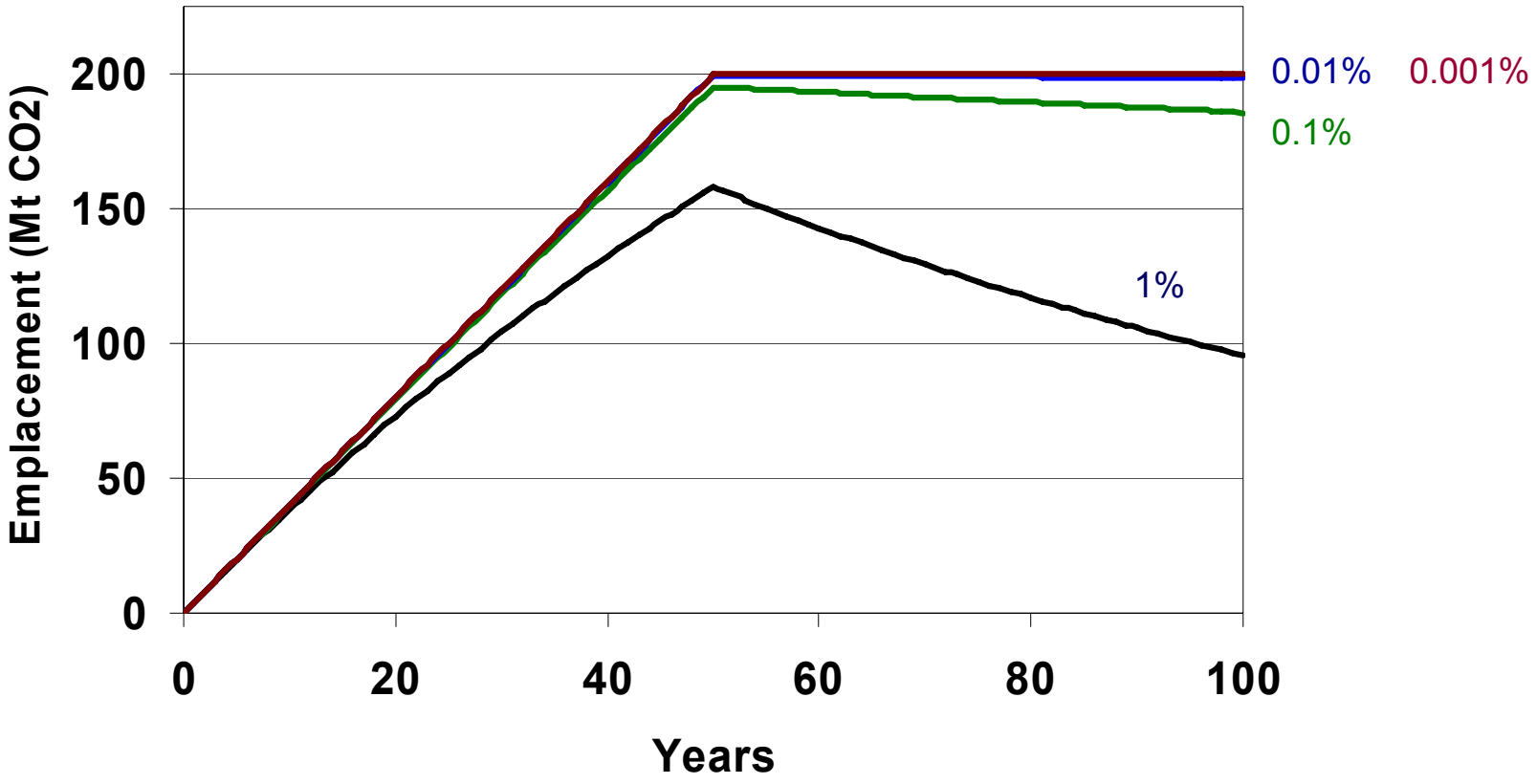
Soil Core taken from MW3 (upper 32 “)

Julianna Fessenden



Scenario

Sally Benson



Lee Spangler

Well Locations

"Deep" (8 ft) Vertical Injection Well

VID	**45.66344˚ -111.08069˚**	**12T 0493715**	**5056656**

Shallow (2 ft) Vertical Injection Well

VIS	**45.66348˚ -111.08072˚**	**12T 0493713**	**5056662**

Monitoring Wells

	lat long	**UTM**	
MW1	**45.66385˚ -111.08107˚**	**12T 0493683**	**5056703**
MW2	**45.66039˚ -111.081040˚**	**12T 0493687**	**5056317**
MW3	**45.66360˚ -111.08047˚**	**12T 0493731**	**5056677**
MW4	**45.66321˚ -111.08054˚**	**12T 0493725**	**5056631**

Map Datum=NAD83
Typical resolution of hand held GPS = +/- 4 m

CO_2 Soil Gas Measurement

Brian Strazisar

60 cm soil gas samples

	North		East		South		West		average	
distance	CO_2	$\delta^{13}CO_2$	CO_2	$\delta^{13}CO_2$	CO_2	$\delta^{13}CO_2$	CO_2	$\delta^{13}CO_2$	CO_2	$\delta^{13}CO_2$
m	%	‰	%	‰	%	‰	%	‰	%	‰
0	80.53	-56.1	80.53	-56.1	80.53	-56.1	80.53	-56.1	80.53	-56.09
3.5	0.84	-22.1	0.61	-21.1	0.57	-22.0	1.32	-22.9	0.835	-22.0225
10	1.26	-21.7	1.05	-23.9	0.46	-21.7	0.83	-22.1	0.9	-22.35
25	0.83	-24.4	1.17	-22.5	0.69	-21.9	1.07	-22.6	0.94	-22.845
50	0.65	-21.9	1.17	-21.9	0.45	-20.5	0.76	-21.2	0.7575	-21.3875

CO_2 Soil Gas Measurement

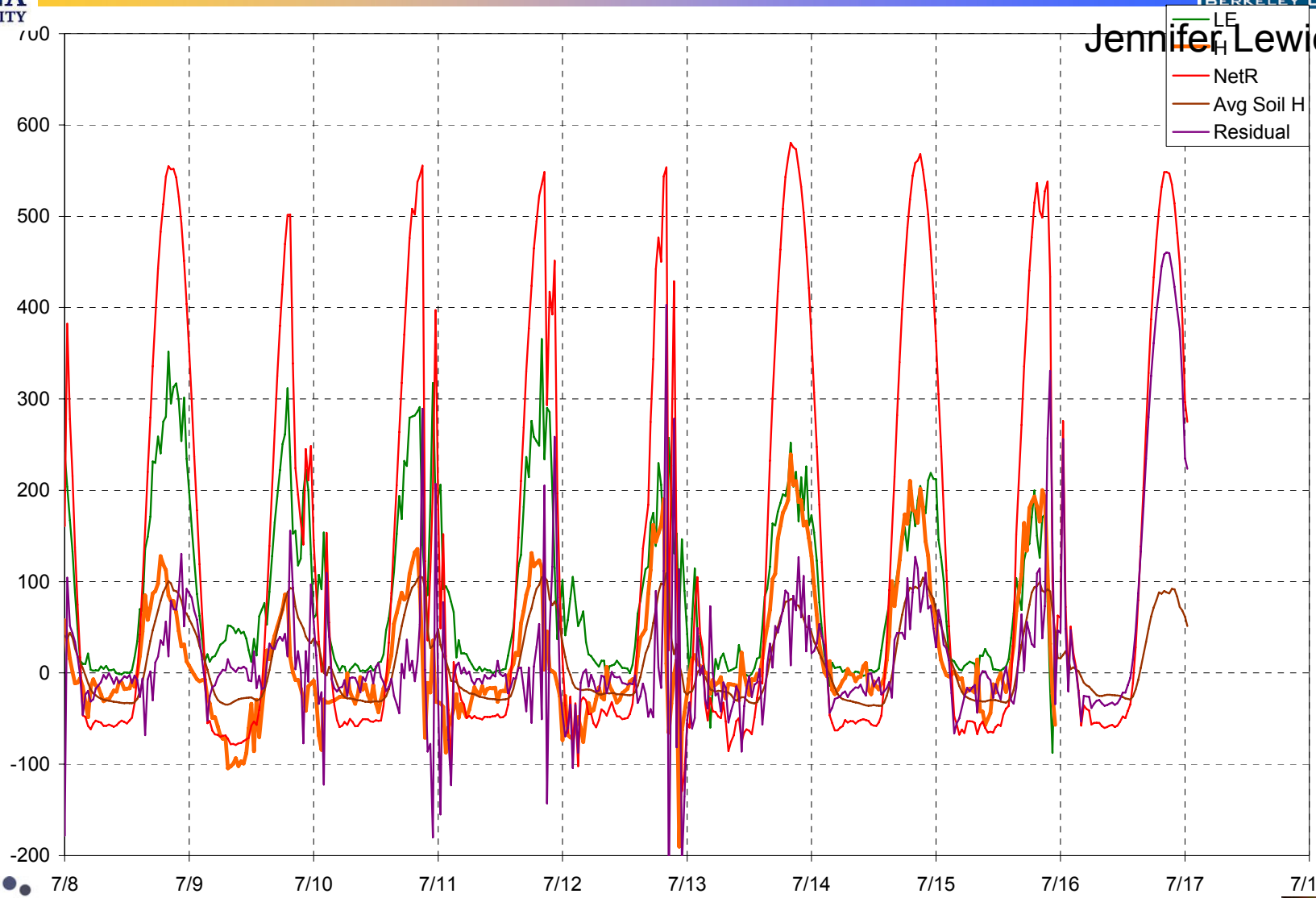
Brian Strazisar

30 cm soil gas samples

	North		East		South		West		Avg.	
distance	CO_2	$\delta^{13}CO_2$	CO_2	$\delta^{13}CO_2$	CO_2	$\delta^{13}CO_2$	CO_2	$\delta^{13}CO_2$	CO_2	$\delta^{13}CO_2$
m	%	‰	%	‰	%	‰	%	‰	%	‰
0	30.99	-55.0	30.99	-55.0	30.99	-55.0	30.99	-55.0	30.99	-55.03
3.5	0.57	-22.6	0.32	-22.3	0.28	-22.9	0.7	-22.6	0.4675	-22.5825
10	0.46	-22.8	1	-22.4	0.21	-20.2	0.41	-22.2	0.52	-21.91
25	0.46	-23.4	0.66	-23.5	0.32	-22.9	0.71	-23.0	0.5375	-23.2075
50	0.37	-22.6	0.31	-21.2	0.24	-21.9	0.33	-21.6	0.3125	-21.8175

Energy Terms

Jennifer Lewicki



Jim Ammonette

Ambient after rain ~400 ppm

Within 2 m of injection after 1 week ~800 ppm

Soil Flux Radial Distribution, New Injector

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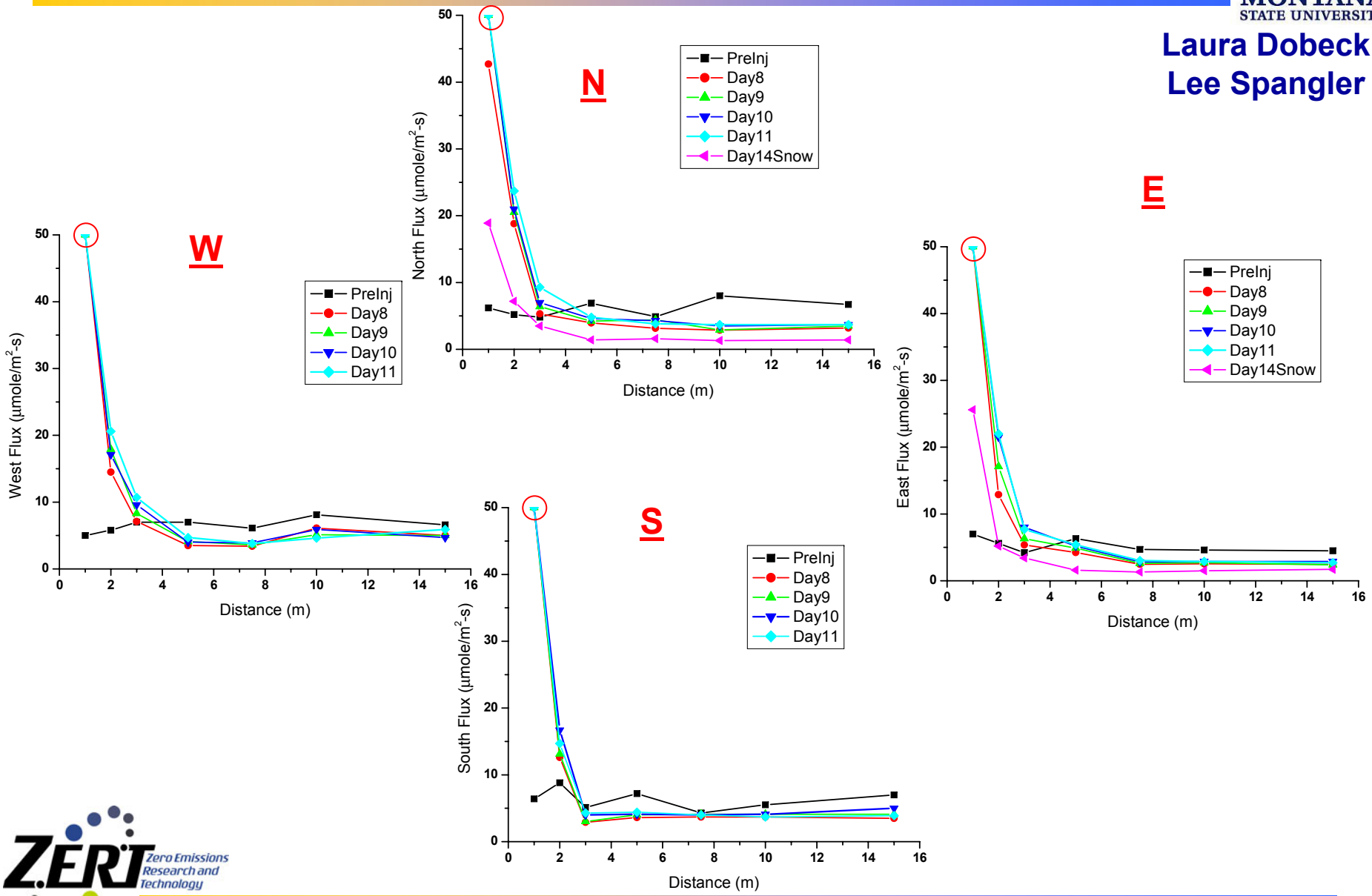
Laura Dobeck
Lee Spangler



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Soil Flux Radial Distribution, New Injector

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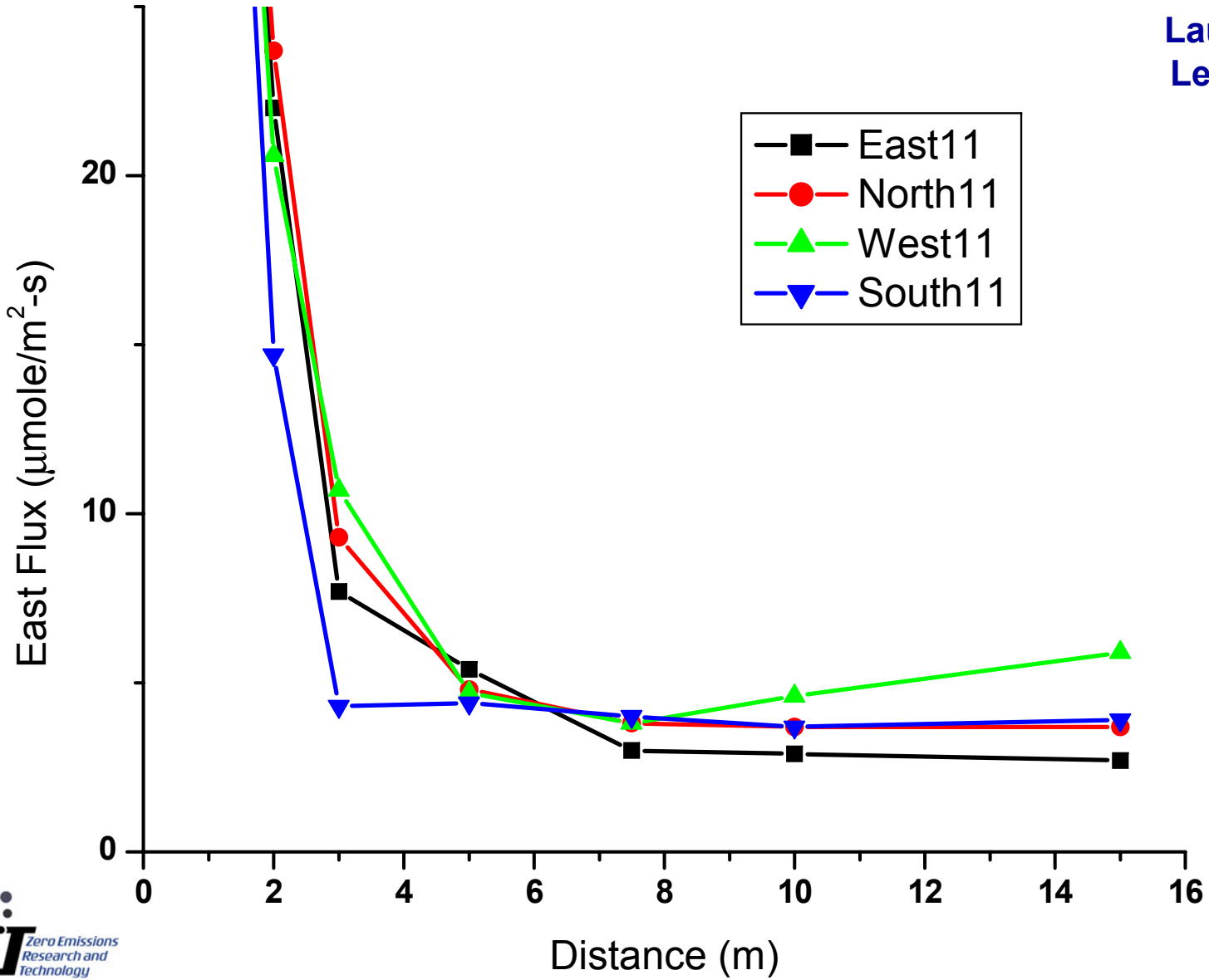
Lee Spangler



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Soil Flux Time Series, New Injector

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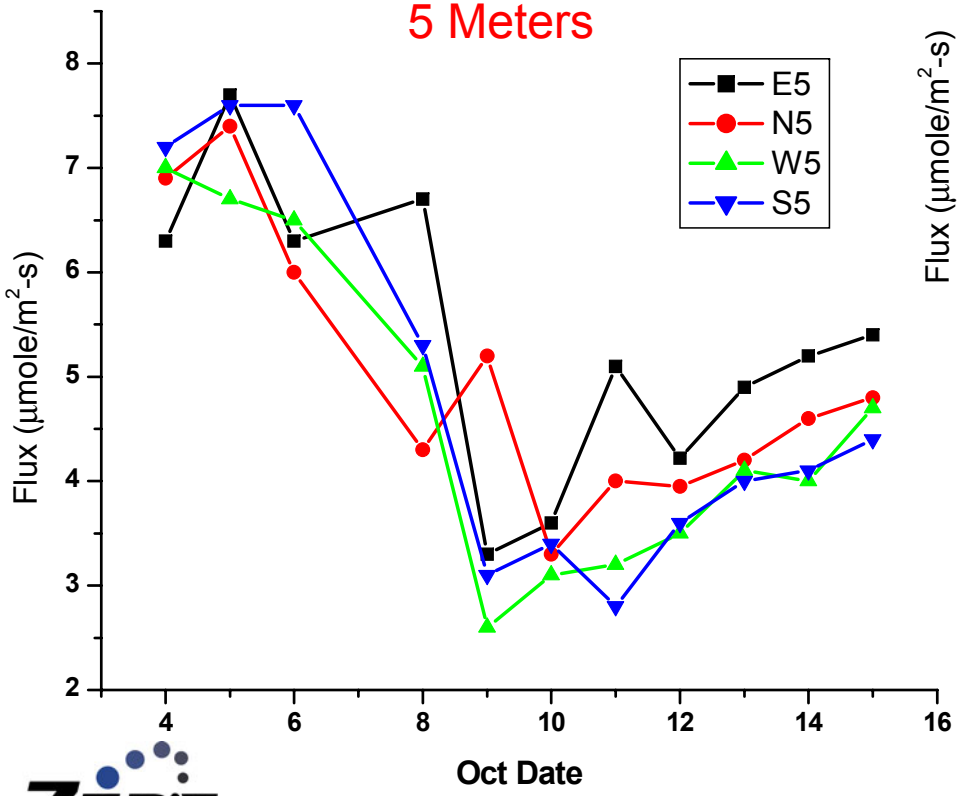
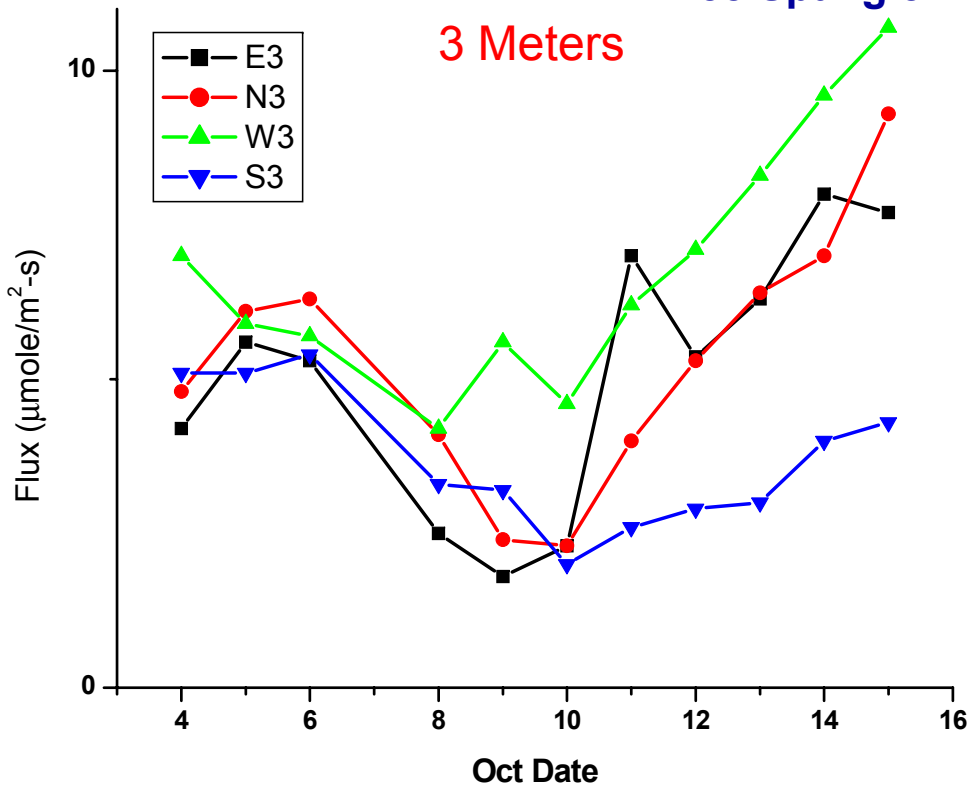
Laura Dobeck
Lee Spangler





ZERT Zero Emissions Research and Technology

Zero-Emission Research & Technology Center

Major Areas of Effort:

- **Basic Sequestration Science**
  - Geophysics and geochemistry of CO_2
  - Interaction with formation minerals and waters
- **Modeling**
  - Understanding two-phase flow
  - Reactive transport
  - Validation with experiments
  - Cross validation of models
- **MMV**
  - Development of new technologies for monitoring and mitigation
  - Assessment of technologies
  - Effective deployment of suites of technologies

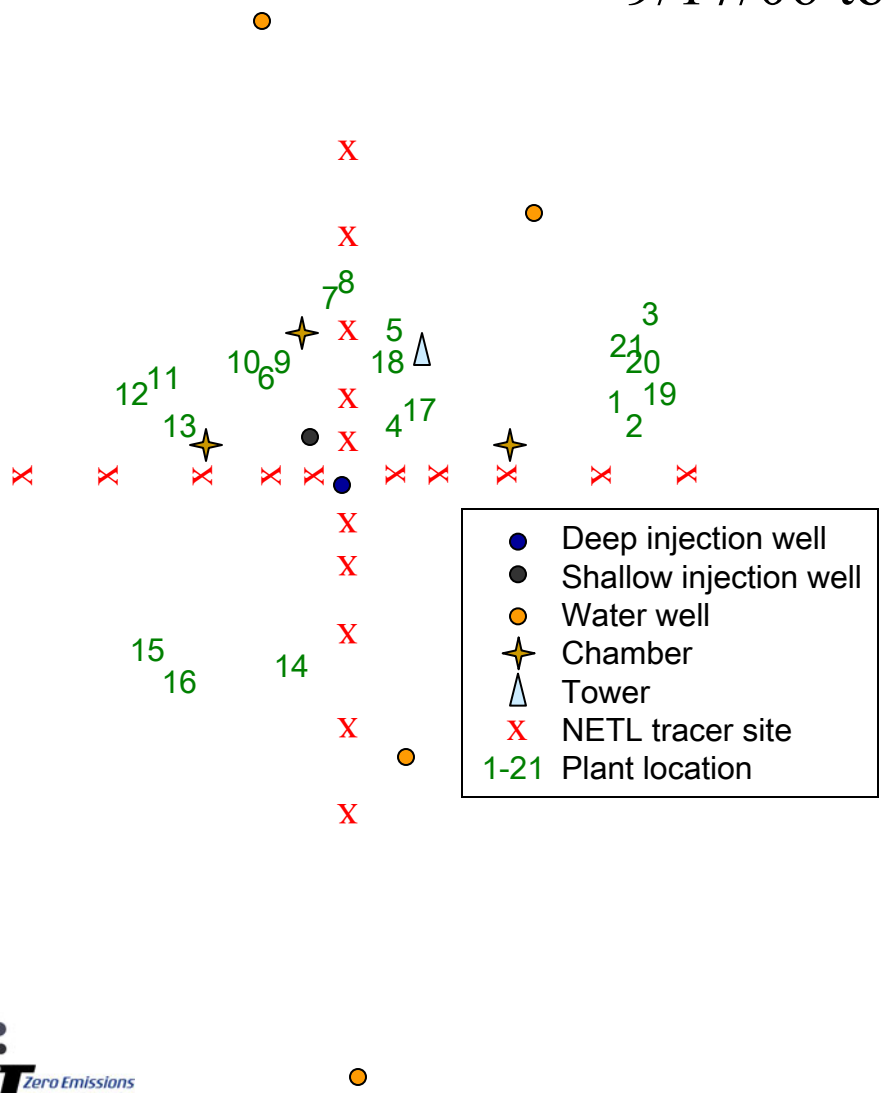
NSF- Partnership for International Research and Education

- **PIRE to be submitted by Feb 28**
- **Partnership with**
  - Princeton hydrology
  - U of Stuttgart Institute of Hydraulic Eng.
  - U of Bergen Math Dept & Petroleum Institute
  - Interest from EWHA University, Korea, Singapore National University, Netherlands
- **European institutions have asked for some involvement from us regardless of proposal success**

Controlled Release – Plant Stations

Julianna Fessenden

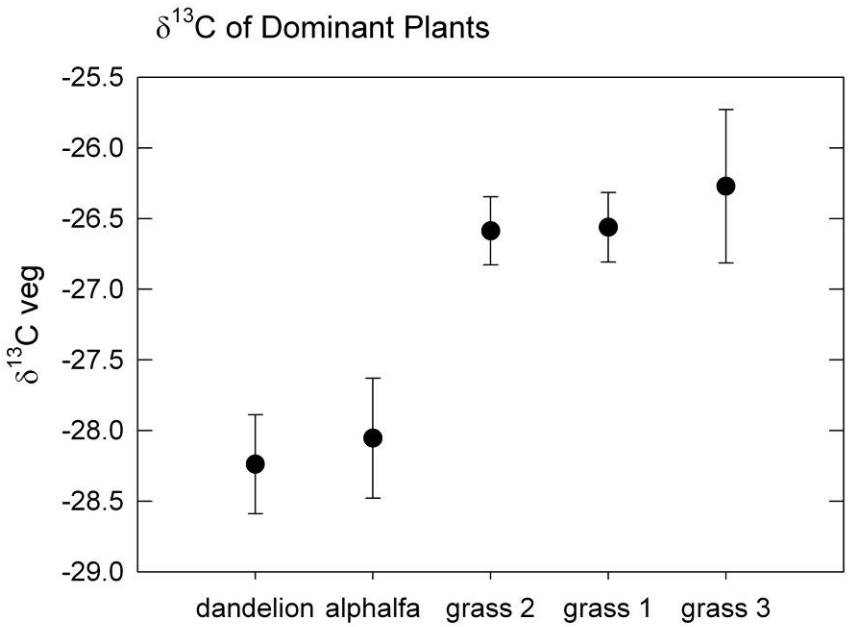
9/17/06 to 9/21/06

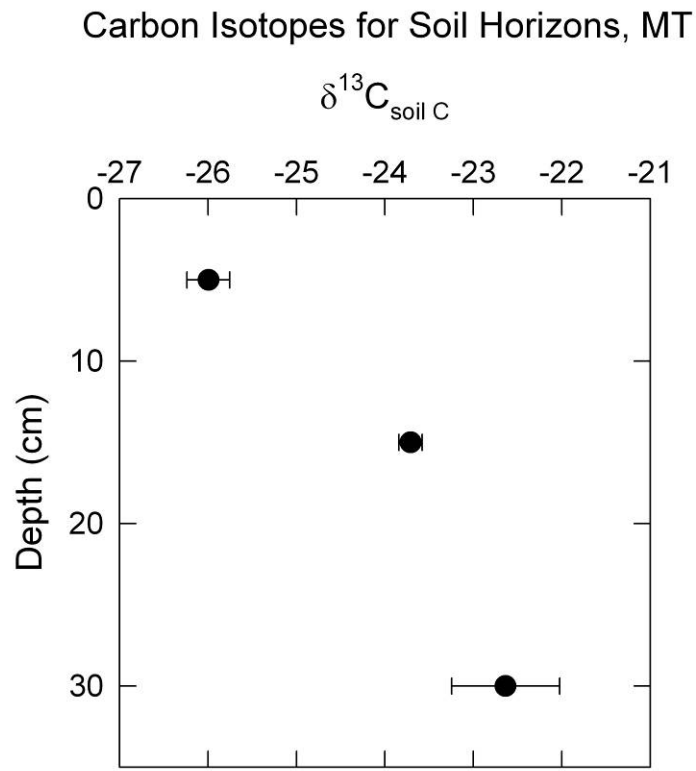


$\delta^{13}C$ of the Dominant Carbon Pools (Plants and Soils)

From 6/12/06

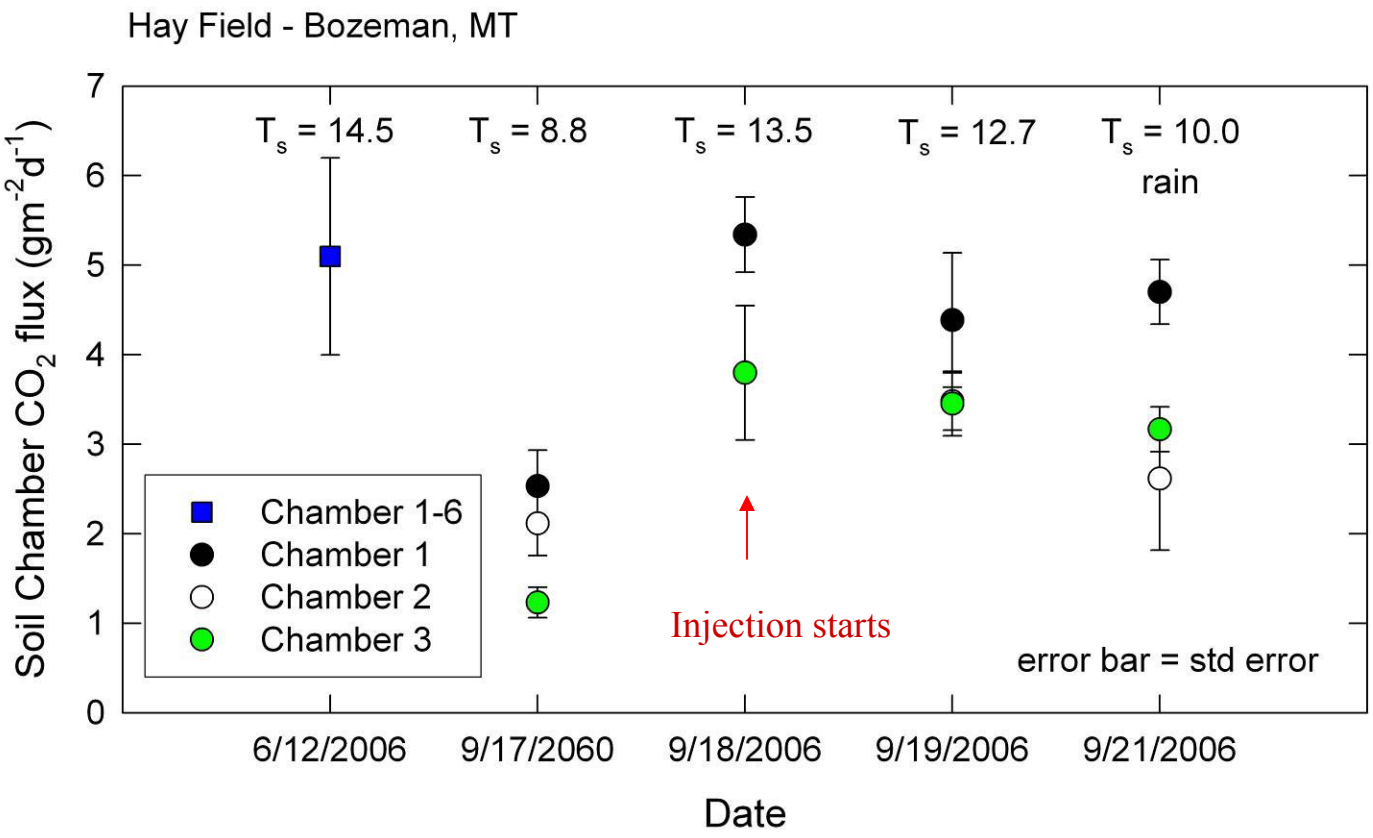
Julianna Fessenden

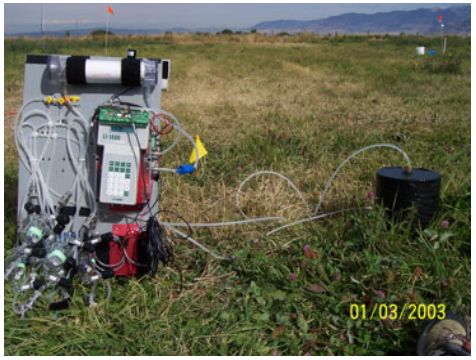




Soil CO_2 flux (Chamber Measurements)

Julianna Fessenden





Interest Generated By Field Work

- **Within 2 weeks we received an invitation to speak at the GHGT Monitoring Network meeting in Melbourne**
- **That talk generated multiple contacts requesting collaboration / informationa sharing from:**
  - University of Knottingham
  - Sintef, Gassnova (+8 others) partnership in Norway
  - Govt of BC