Environmental Monitoring Over CO_2 Geologic Storage Sites

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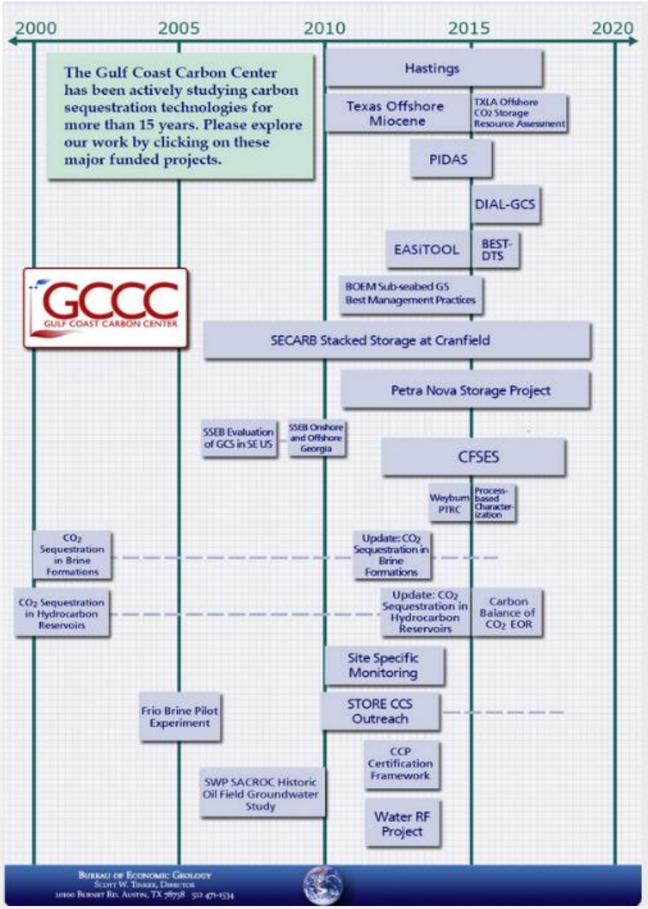
California Air Resources Board, CCS Technical Discussion Series: Monitoring, August 5, 2016

GCCC Environmental Monitoring Experience

- SWP SACROC Field
- SECARB Cranfield
- Hastings
- NRG-Petra-Nova/West Ranch
- PI of the IPAC-CO_2 Kerr Leakage Claim, Canada
- ZERT Controlled release
- Brackenridge Controlled Release Field lab
- Inform policy within UNFCCC, US Congress

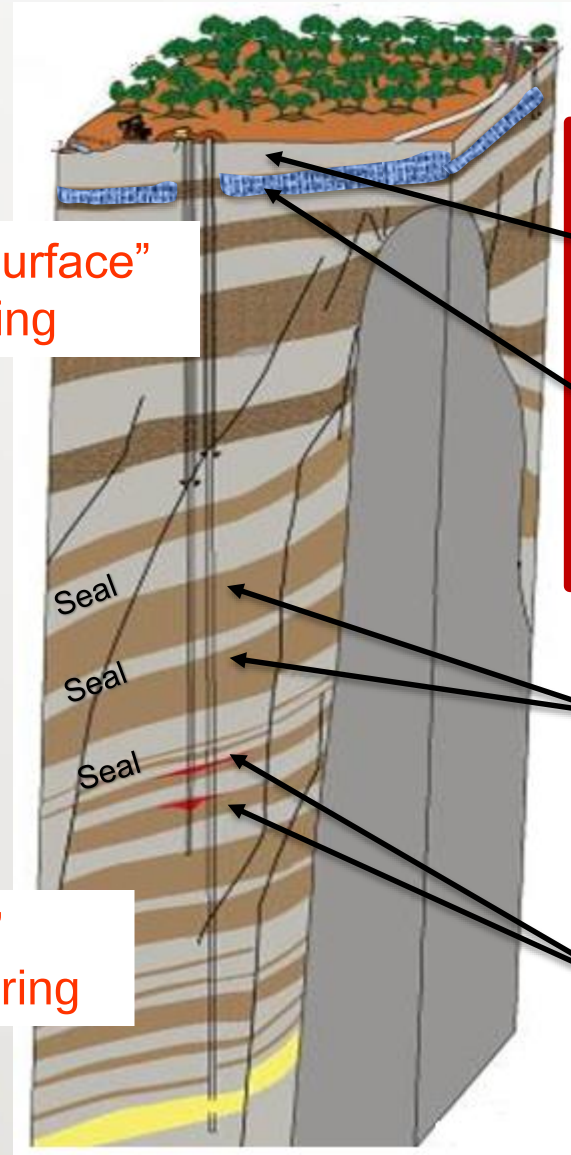


Environmental Monitoring Presentation Outline

- Overview
- Objectives and components
- Challenges/opportunities for improvement
  - Source attribution of anomalies
  - Baseline comparisons
  - Public engagement
- Example: Kerr Claim
- Transition from concentration–based to Process-based monitoring
- Summary

Overview of Monitoring Zones

“Near-Surface” Monitoring



“Deep” Monitoring

Vadose zone

Strong variability, dynamic, many challenges, release to atmosphere, biosphere impacts

Shallow groundwater

Moderate baseline variability, assurance of no damage to drinking water, easy access

Above Zone Intervals

Minimal variability, early detection, small signals

Reservoir

Static, quiet environment, variability is from CO_2 injection, CO_2/brine migration

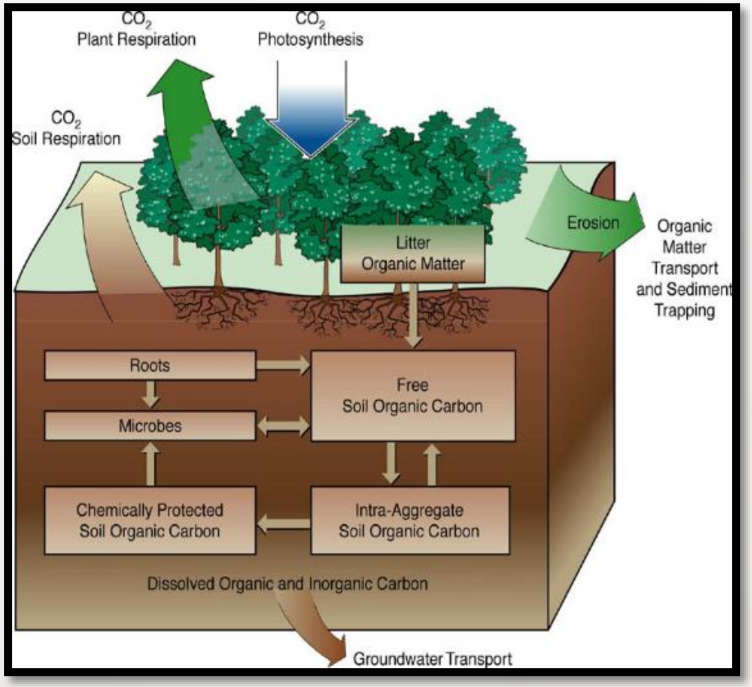
Figure courtesy of Sue Hovorka

Why Monitor in the Near-Surface?

- Accessible and inexpensive
- Direct observation of environmental resources
  - Groundwater
  - Soil Biosphere
- Regulation & permitting
- Quantification and accounting
- Monitoring remediation efforts
- Fast and targeted response to public concerns

Environmental Monitoring Challenges

- CO_2 is naturally everywhere!
- Reactive
- Dynamic over space and time
  - Biologic respiration
    - Weather/Climate
  - Soil conditions
  - Land Use (industrial activity, agriculture, groundwater extraction etc..)
- Very difficult to discern leakage from natural variability.
- Critical to understand processes.



Source: DOE, 1999: *Carbon Sequestration Research and Development*

Components of Near-Surface Monitoring

✓Locate anomaly

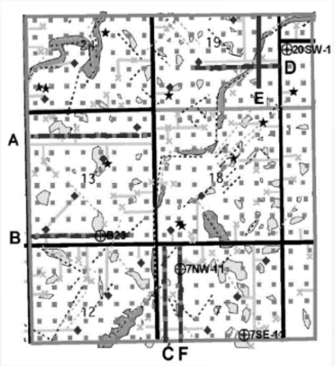
✓Attribute source

✓Quantify emissions

✓Engage stakeholders

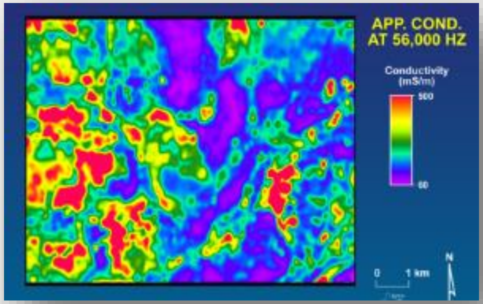
Balanced Approach to Locating Anomalies

- Sampling Grids
  - Dense grid of point measurements
  - Expensive and time consuming.
  - Doesn't cover full area

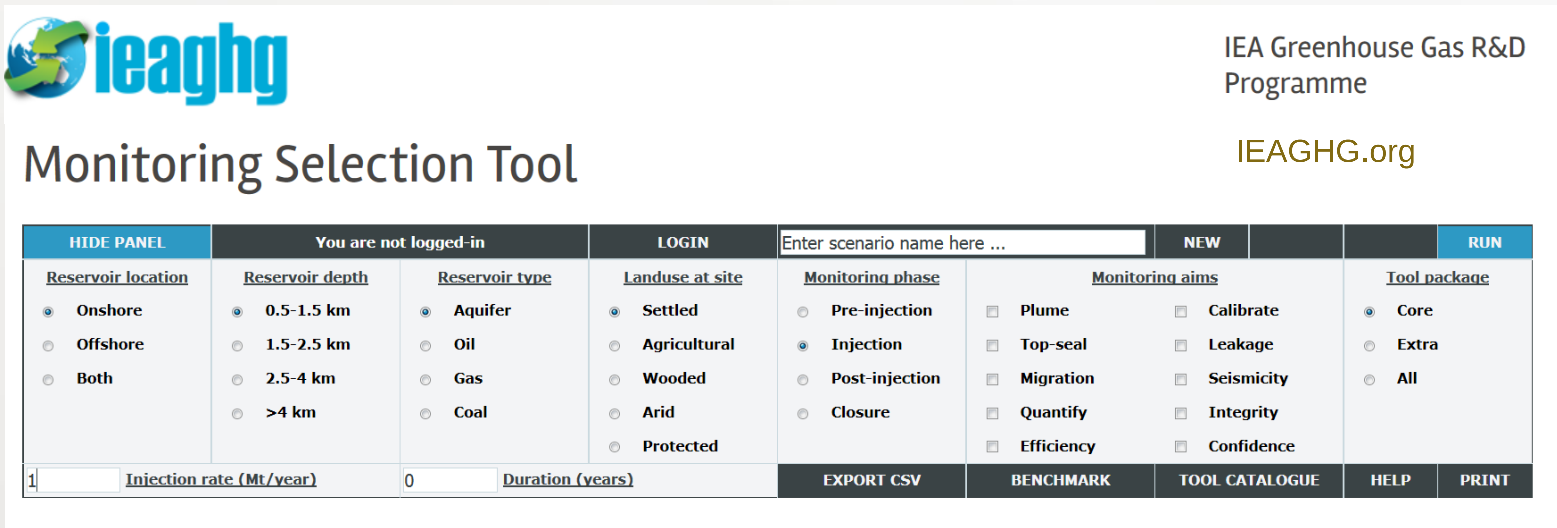


- Targeted
  - Based on risk assessment,
  - Environmental change
  - Public concern

- Remote Wide-Area Sensing
  - Excellent spatial coverage
  - Interferences/vegetation/wind



IEAGHG Interactive Monitoring Selection Tool



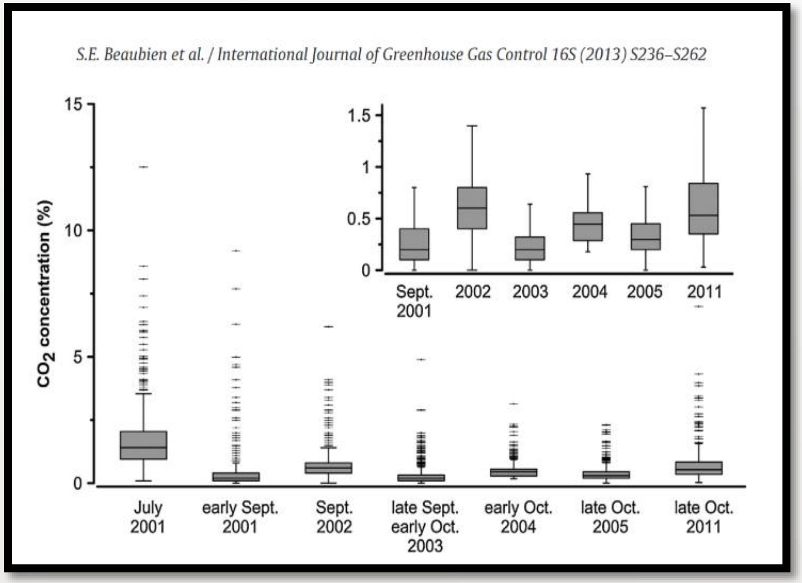
- Description of tool
- Maturity of the technique
- Cost of deployment.
- Case studies
- Bibliography

Determining What is “Anomalous”

- What constitutes an “anomaly (e.g. a potential leakage signal)?
- What parameter should be used to indicate leakage?
- When is action required (e.g. thresholds, trigger points) ?
  - “When measurements of a given parameter exceed natural variability by one standard deviation about the mean”

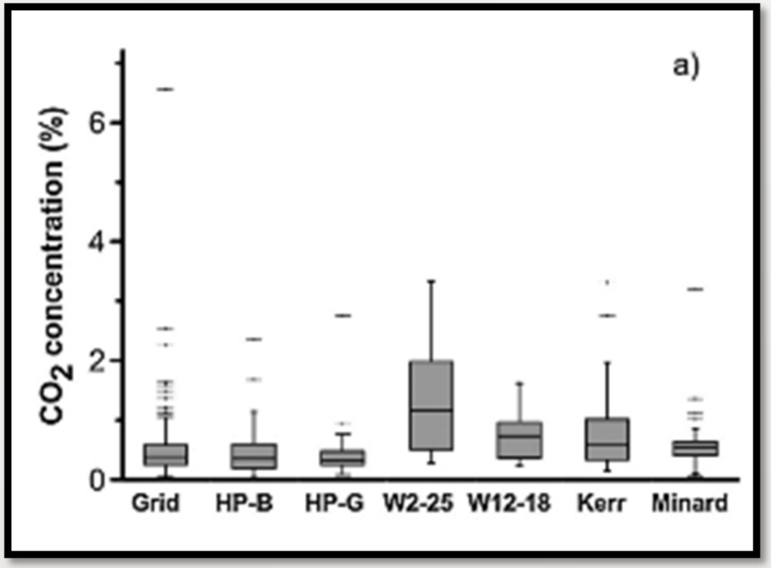
Current Thinking on "Natural Variability"

- Measure "baseline" CO_2 for 1-3 years before project starts to document seasonal variability.
- Monitor CO_2 during project and compare to baseline.
- Significant increase from baseline during a project could signal a leak



Weyburn field soil gas monitoring

What about a “Background Reference” site?



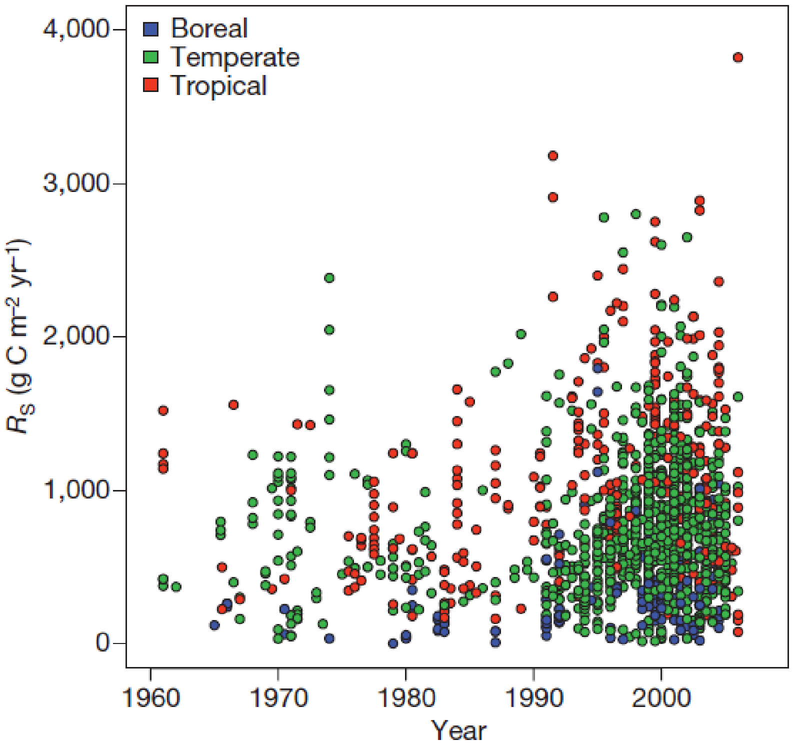
Weyburn field soil gas monitoring
Beaubien et al., 2013

Statistical distribution of soil gas CO_2 (sampled in October 2011) at sites within the WMP (Beaubien et al., 2014). The background area (Minard’s Farm) and the Kerr Farm (where leakage was alleged but disproven) are shown along with 5 other sites within the WMP.

"Baselines" are Shifting!

nature
Vol 464 | 25 March 2010 | doi:10.1038/nature08930

Temperature-associated increases in the global soil respiration record



Available online at www.sciencedirect.com
ScienceDirect
ELSEVIER
Geochimica et Cosmochimica Acta 72 (2008) 5581–5599
Geochimica et Cosmochimica Acta
www.elsevier.com/locate/gca

Increasing shallow groundwater CO_2 and limestone weathering, Konza Prairie, USA

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Received 28 January 2008; accepted in revised form 2 September 2008; available online 18 September 2008

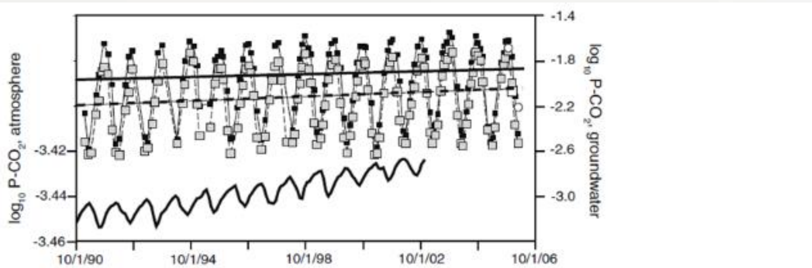
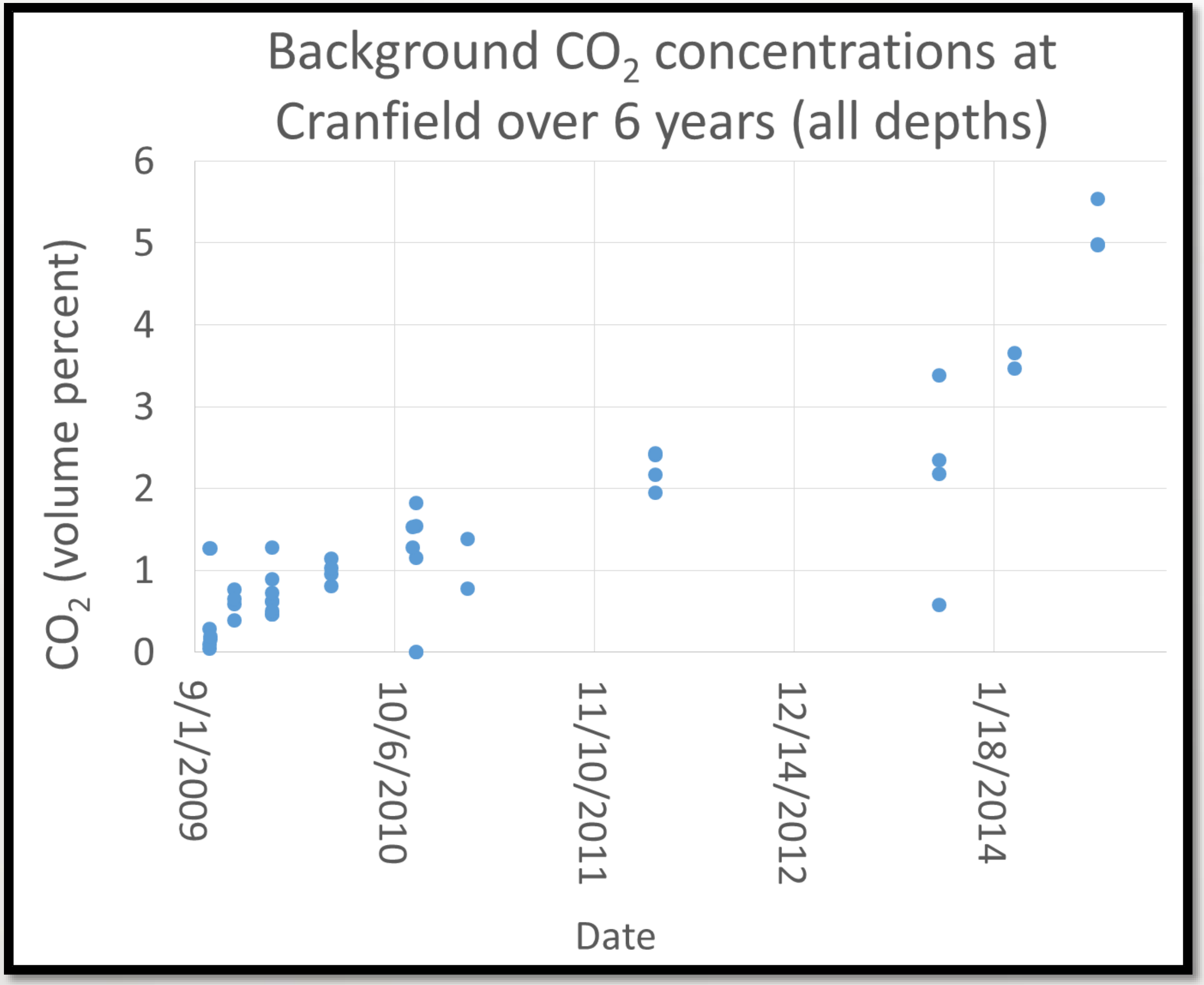


Fig. 7. P-CO_2 cycles annually and has been rising in Konza Prairie groundwater. Speciation modeling of groundwater from two wells, 3–5 Mor, 6.3 m deep (shaded squares) and 4–6 Mor, 12.6 m deep (filled squares), shows that log P-CO_2 cycles annually; points are connected with lines, without smoothing. Kendal Theil lines (see text) are shown for time series for both wells (dashed line, well 3–5 Mor; solid line, well 4–6 Mor). The increase is highly probable ($p \ll 0.1$) and tau values are positive for both trends (see Table 2). In any year, highest P-CO_2 occurs in September to November and lowest P-CO_2 occurs in February to April. Large white symbols in 2005 are measured dissolved CO_2 in the two wells (circles, 3–5 Mor; squares, 4–6 Mor); the measured values correspond well with model-predicted results. Atmospheric P-CO_2 (mixing ratio) from Niwot Ridge is shown as a heavy line.

RS = the flux of microbially and plant-respired CO_2 from the soil surface to the atmosphere,

Increased dissolution of CO_2 in groundwater and associated mineral dissolution

…and at our Monitoring Sites



THE UNIVERSITY OF TEXAS AT AUSTIN

WHAT STARTS HERE CHANGES THE WORLD

Source Attribution is Critical

- BEG’s experience in attribution: 2 blind anomalies: Cranfield anomaly and Kerr Claim
  - Very difficult
  - The risk of false positives is much greater than the risk of leakage.
  - Fast accurate attribution is CRITICAL for public acceptance

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Improving monitoring protocols for CO_2 geological storage with technical advances in CO_2 attribution monitoring

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Leakage

ABSTRACT

Existing monitoring protocols for the storage of carbon dioxide (CO_2) in geologic formations are provided by carbon dioxide capture and geological storage (CCS)-specific regulations and bodies including the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories, the European Union (EU) CCS and Emission Trading Scheme (ETS) Directives, United States Environmental Protection Agency (US EPA) Final Rules, and the United Nations Framework Convention on Climate Change (UNFCCC) Clean Development Mechanism (CDM) Modalities and Procedures (for developing countries). These protocols have varying levels of detail but similar principles and requirements for monitoring, and all include the need to quantify emissions and measure environmental impacts in the event of leakage to the surface. What they do not all include is the clarification that quantification monitoring should only be undertaken in cases where CO_2 has been attributed to leakage and not when leakage is only suspected. Quantifying suspected emissions is a significant monitoring challenge and undertaking, and may rely on acquiring large data sets over long time periods. This level of effort in monitoring would be unnecessary if the source of CO_2 detected at the surface is attributed to natural sources rather than from leakage, but a step to attribute CO_2 source is either missing from these protocols or is outdated in technical scope. Regulatory bodies call for protocols to be updated based on technical advances, and ongoing technical advances into leakage monitoring have now benefited from a first-ever public claim of leakage over a geologic CO_2 storage site in Saskatchewan, Canada, bringing more emphasis on the role of attribution monitoring. We present a brief update of some of the newest technical advances in attribution and suggest that CO_2 ‘attribution monitoring’ could now be included in monitoring protocols to avoid unnecessary and costly quantification monitoring unless it is fully warranted. In this context, this paper describes an option to improve the existing protocols for monitoring CO_2 at geological storage sites made possible because of recent developments in near-surface attribution monitoring techniques.

Dixon and Romanak, 2015, Improving monitoring protocols for CO_2 geological storage with technical advances in CO_2 attribution monitoring, IJGGC vol 41

Attribute, THEN Quantify

Table 1
Summary of the six main monitoring activities for the CCS regulations discussed in the text.

Regulatory Body / Monitoring Objectives:	IPCC GHG Guidelines	EU		London Convention and Protocol	OSPAR	UNFCCC Clean Development Mechanism	US EPA	
		CCS Directive	ETS Directive				UIC Class VI well regulation	GHG reporting Subpart RR
Overall Objectives	GHG accounting	Protection of the environment	GHG accounting	Protection of the marine environment	Protection of the marine environment	GHG accounting and protection of the environment	Protection of the environment (underground sources of drinking water)	GHG accounting
Baseline/ Background Measurements	✓	✓				✓	✓	✓
Storage Performance	✓	✓		Only in terms of retention	Only in terms of retention	✓	Only in terms of pressure and plume extent	
Detection of Leaks or Anomalies	✓	✓		✓	✓	✓	✓	✓
Attribution of Leaks and/or Anomalies	Mentions in the context of baseline isotopic ratios. Not included as a step					Not included as a step but accommodates a range of monitoring techniques		Mentions in the context of baseline CO_2 concentrations. Not included as a step
Environmental Impacts		✓		✓	✓	✓	✓	
Quantification of GHG	✓		✓			✓		✓

Dixon and Romanak, 2015, Improving monitoring protocols for CO_2 geological storage with technical advances in CO_2 attribution monitoring, IJGGC vol 41

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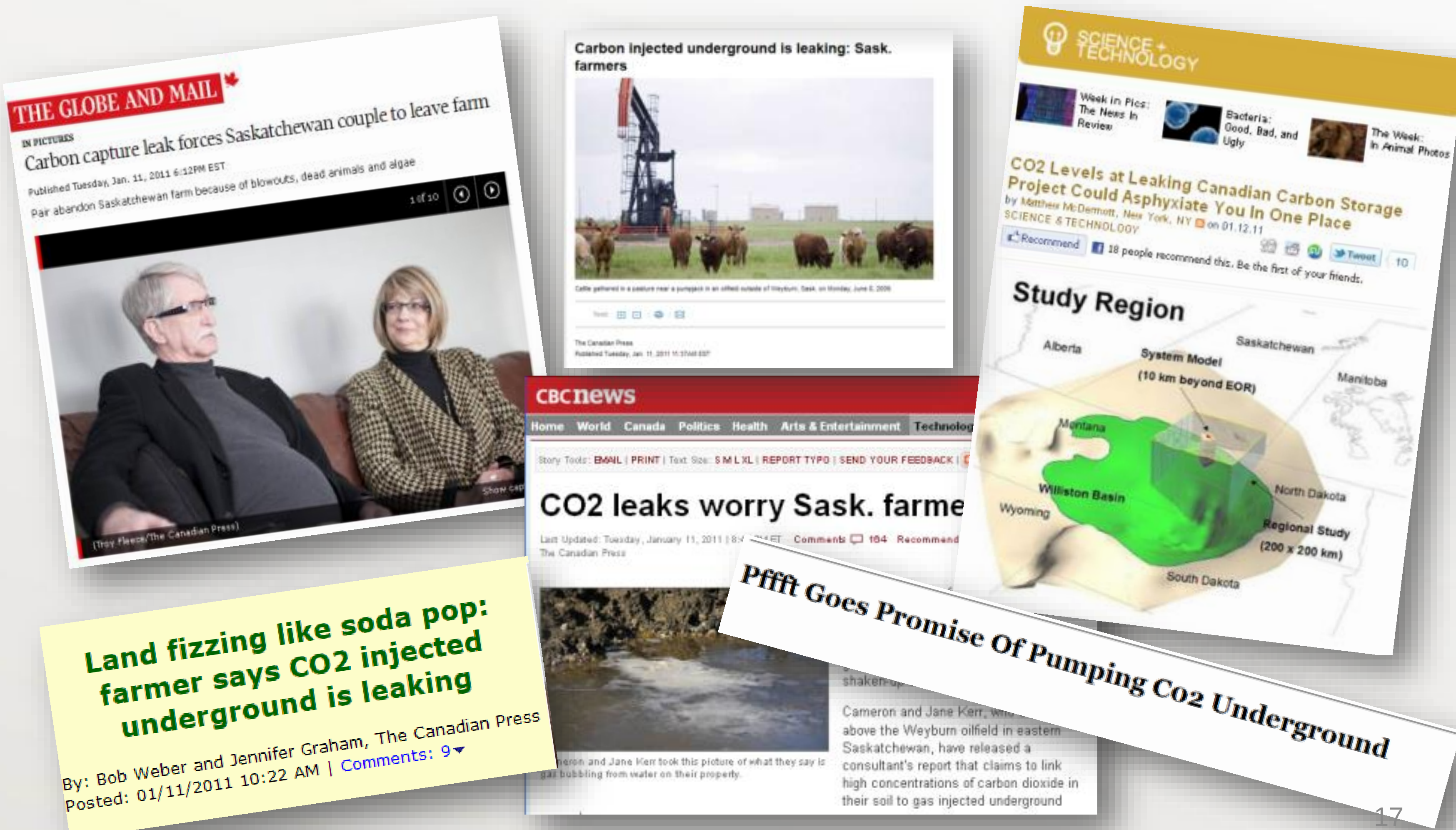
News of a “Leak” at the Kerr Farm Weyburn Field: January 2011


THE GLOBE AND MAIL
IN PICTURES
Carbon capture leak forces Saskatchewan couple to leave farm
Published Tuesday, Jan. 11, 2011 6:12PM EST
Pair abandon Saskatchewan farm because of blowouts, dead animals and algae
(Troy Fleece/The Canadian Press)

Carbon injected underground is leaking: Sask. farmers
The Canadian Press

CBC news
Home World Canada Politics Health Arts & Entertainment Technology
CO2 leaks worry Sask. farme
Last Updated: Tuesday, January 11, 2011
The Canadian Press
Cameron and Jane Kerr took this picture of what they say is gas bubbling from water on their property.
Cameron and Jane Kerr, who ... above the Weyburn oilfield in eastern Saskatchewan, have released a consultant's report that claims to link high concentrations of carbon dioxide in their soil to gas injected underground

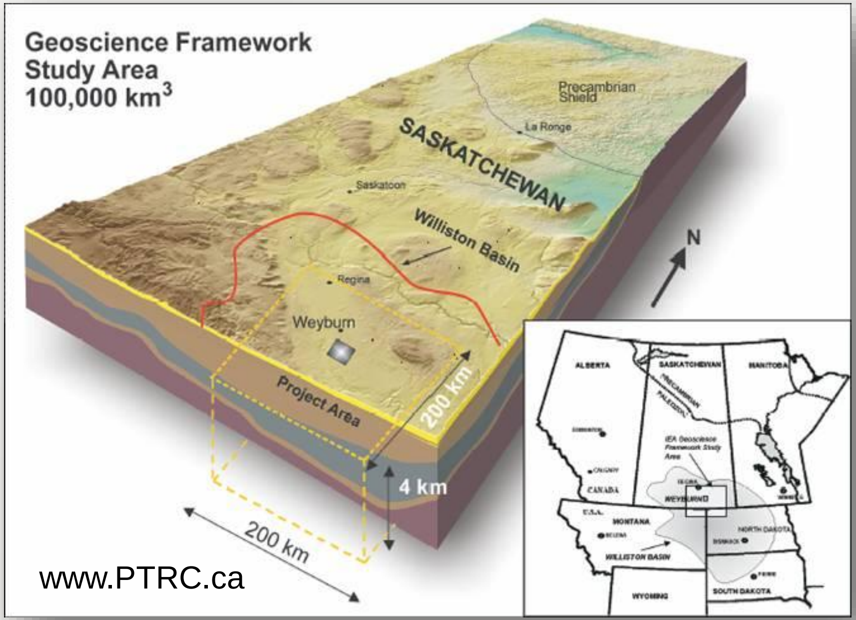
SCIENCE + TECHNOLOGY
Week in Pics: The News In Review
Bacteria: Good, Bad, and Ugly
The Week: In Animal Photos
CO2 Levels at Leaking Canadian Carbon Storage Project Could Asphyxiate You In One Place
by Matthew McDermott, New York, NY on 01.12.11
SCIENCE & TECHNOLOGY

Land fizzing like soda pop: farmer says CO2 injected underground is leaking
By: Bob Weber and Jennifer Graham, The Canadian Press
Posted: 01/11/2011 10:22 AM | Comments: 9

Pffft Goes Promise Of Pumping Co2 Underground

Alleged Land Disturbances

IEAGHG Weyburn-Midale CO_2 Monitoring and Storage Project



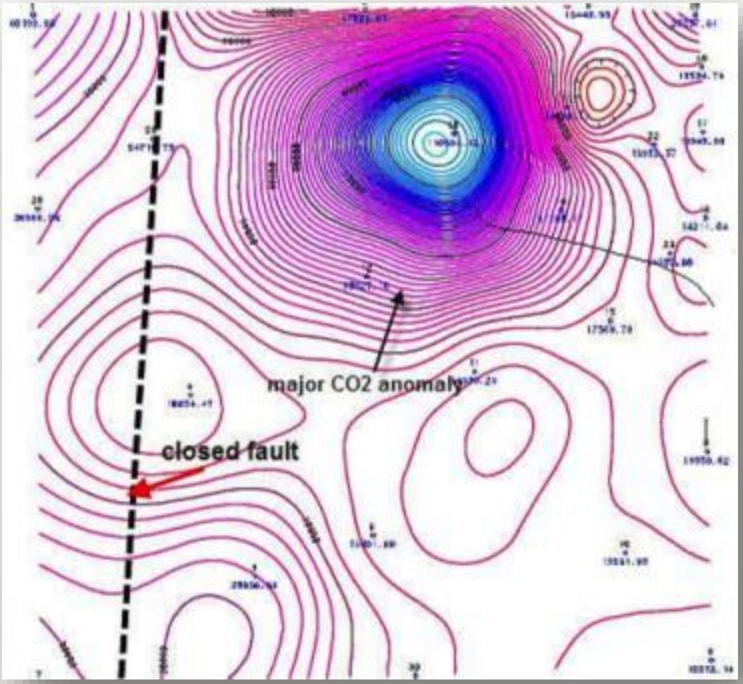
Rostron and Whittaker, Energy Procedia 4 (2011) 3636–3643

- Largest geologic CO_2 monitoring and storage project
- Since 2000 > 24 M tonnes of CO_2 injected
- CO_2-EOR operated by Cenovus Energy
- Studied by an international team of CO_2 storage experts
- Managed by Petroleum Technology Research Centre (PTRC)

Industry and Government Response

- **1998**: (Operator) Weyburn Pump and Water Conditioning, groundwater test report
- **2002 – 2005**: (Operator) Farm well Inventory Project, regional groundwater analysis
- **2004**: (Operator) KBL Land Use Consulting Ltd., gravel pit water and soil samples
- **2005**: (Operator) Enviro-Test Analytical soil sample
- **2005**: (Government) Saskatchewan Health Provincial Laboratory, gravel pit and domestic well water
- **2006**: (Operator) Aqua Terre Solutions Inc., well and gravel pit water test
- **2006:** (Landowner) MR2 McDonald & Associates, water quality investigation
- **2007**: (Landowner) Consultation with Dr. Malcolm Wilson, Office of Energy & Environment, University of Regina
- **2008**: (Government) Ministry of Environment – Review of studies
- **2008:** (Government) SRC Analytical Laboratories, soil, water and air quality monitoring
- **2008:** (Government) Droycon Bioconcepts Inc., Bacteriological content of water
- **2010-2011** (Landowner) Petro-Find Geochem Ltd. Soil gas surveys.

Petro-Find Conclusion



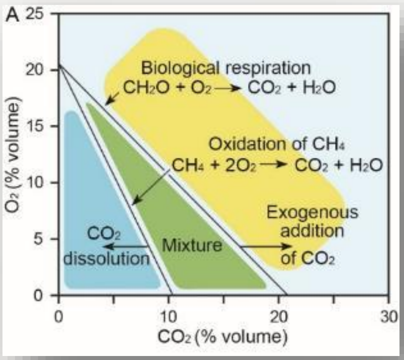
Source: Lafleur, P. 2010. *Geochemical Soil Gas Survey: A Site Investigation of SW30-5-13-W2M Weyburn Field, Saskatchewan. Saskatoon, SK: Petro-Find Geochem Ltd.)*

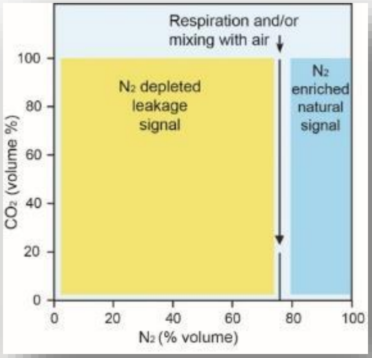
"The...source of the high concentrations of CO_2 in soils of the Kerr property is clearly the anthropogenic CO_2 injected into the Weyburn reservoir."

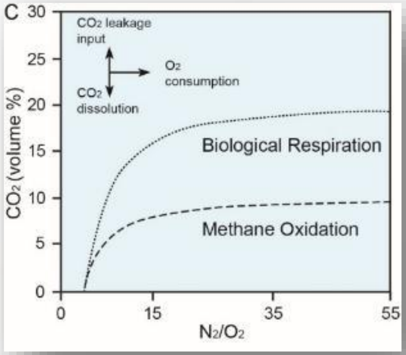
How To Avoid This?

- High risk of false positives from inaccurate attribution.
- Need protocols and techniques in place before a project begins.
  - Methods,
  - Parameters
  - Trigger points
- Need quick response tools and protocols that do not rely on "background" measurements.

Process-Based Soil Gas Ratios







- Uses simple gas relationships to identify **processes.**
  - Biologic respiration
  - Methane oxidation
  - Dissolution
  - Leakage
- No need for years of background.
- Method can be applied in any environment regardless of variability

Romanak et al., 2014, International Journal of Greenhouse Gas Control, 30, 42-57
Romanak et al., 2012, Geophysical Research Letters, *39* (15).

Leakage Allegation Discounted

“In a media release, Ecojustice lawyer Barry Robinson, who represented the Kerrs, accepted the IPAC-CO2 study’s findings while emphasizing its necessity, saying that “without a full scale investigation, it has been impossible until now to rule out CO_2 contamination.”

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FOR IMMEDIATE RELEASE

Long-awaited investigation into CO2 impacts a ‘win for all Canadians’

DEC 12, 2011 09:37 AM

ACCN Canadian Chemical News
L’Actualité chimique canadienne

Weyburn CO_2 leak a false alarm

By Tyler Irving
Posted February 2012

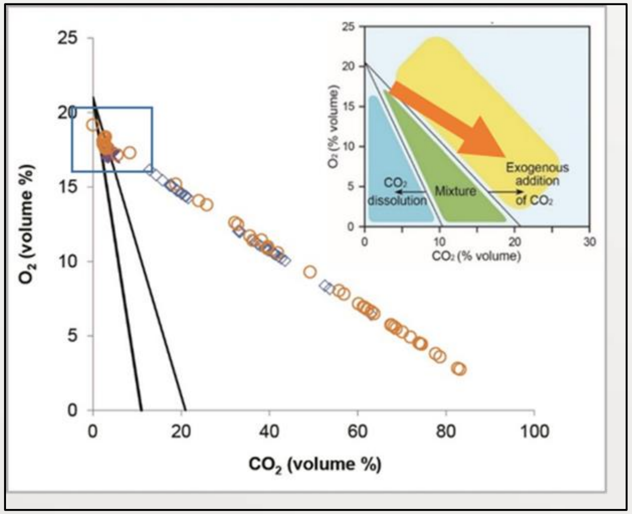
In January 2011, Cameron and Jane Kerr alleged that CO_2 from a nearby experimental carbon storage project was leaking onto their farm near Weyburn, Sask. A year later, two independent investigations have concluded that this is not the case.

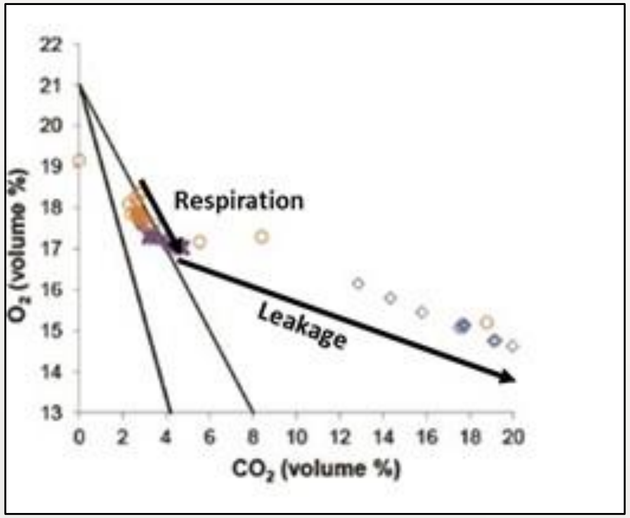
The project consists of piping CO_2 from a coal gasification plant in North Dakota into an oil field operated by Canadian oil company Cenovus. Last summer, Cenovus contracted TRIUM Environmental to undertake extensive soil and surface water sampling operations on the property. The results, delivered last November, show CO2 concentrations consistent with what is commonly found in prairie soil gas in summer. Moreover, carbon levels were inversely correlated with oxygen levels, a sign that the CO_2 was produced by biological respiration. Finally, the presence of unstable ^{14}C indicated a young carbon source. Since ^{14}C has a half-life of about 5,730 years, it would have been absent in CO_2 from the several million-year-old coal deposits.

Romanak et al,. 2014, Process-based soil gas leakage assessment at the Kerr Farm: Comparison of results to leakage proxies at ZERT and Mt. Etna, IJGGC vol 30

Ramifications for Monitoring

ZERT Controlled Release Experiment, Montana USA

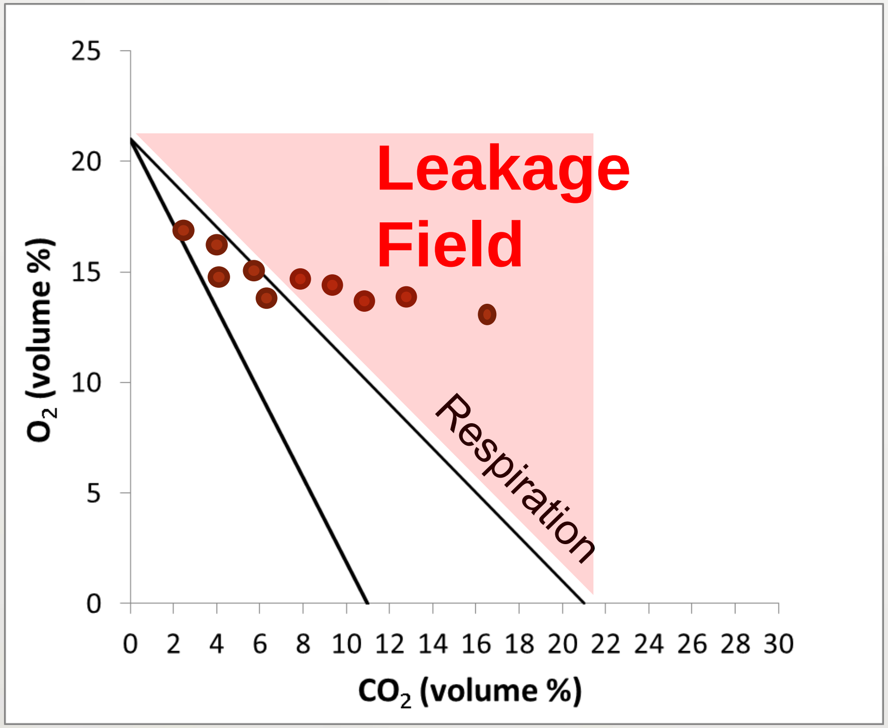


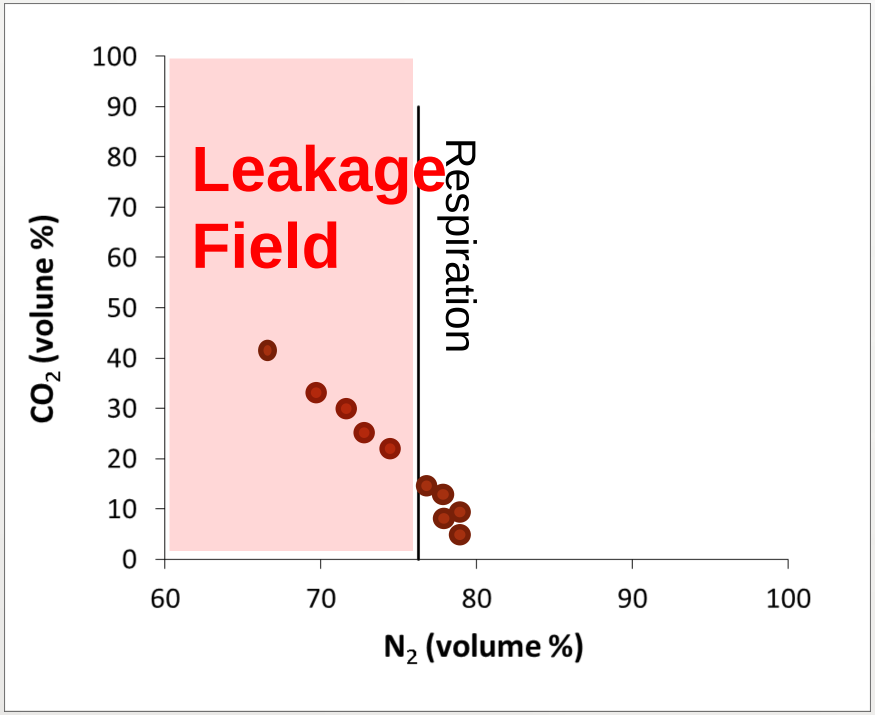


Respiration relationship = “Baseline” or “threshold”

"User-Friendly" for Public Engagement

- Instant data reduction
- Reduces risk of false positives.
- Graphical analysis
- Continuous monitoring capability will give instant real-time leakage detection information.

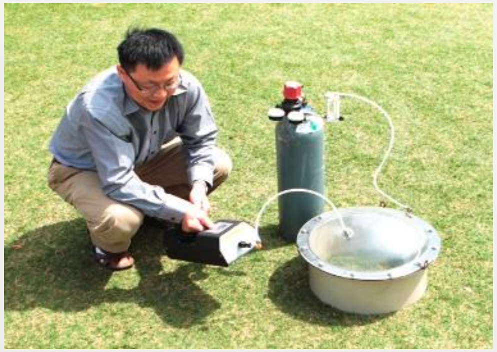




Katherine Romanak BEG

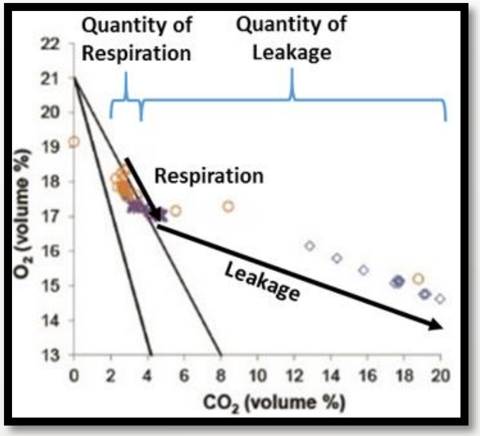
Quantification and Remediation Monitoring

Translating Ratios into Surface Flux



http://odour.unsw.edu.au/content/facilities

https://www.youtube.com/watch?v=i5sTnGPesKE



$$EF_i = \frac{(C_i)(Q)}{A}$$

EF_i = emission rate of species i in ug/m^{2}min

C_i = measured concertation of species i in vol% converted to ug/m^3

Q = sweep air flow rate in m^3/min

A = exposed surface area in m^2

Summary and Recommendations

- Environmental variability is a significant challenge for environmental monitoring.
- Most protocols call for the use of baseline values to determine if variability is from leakage or natural variation.
- Baselines are shifting due to climate change and will not provide accurate “attribution” of anomalies.
- Recognizing the importance of “attribution” is critical to environmental monitoring but most protocols and regulations do not include attribution as a monitoring step.
- Attribution should precede quantification.
- The Kerr claim shows a great need for accurate methods and protocols for attribution to be in place before a project begins.
- The risk of a false leakage claim due to inaccurate attribution is likely higher than the risk of actual leakage.
- A process-based type of approach may give more accurate, immediate, and stakeholder-friendly monitoring results and may be useful for quantification and remediation monitoring.

Thank You

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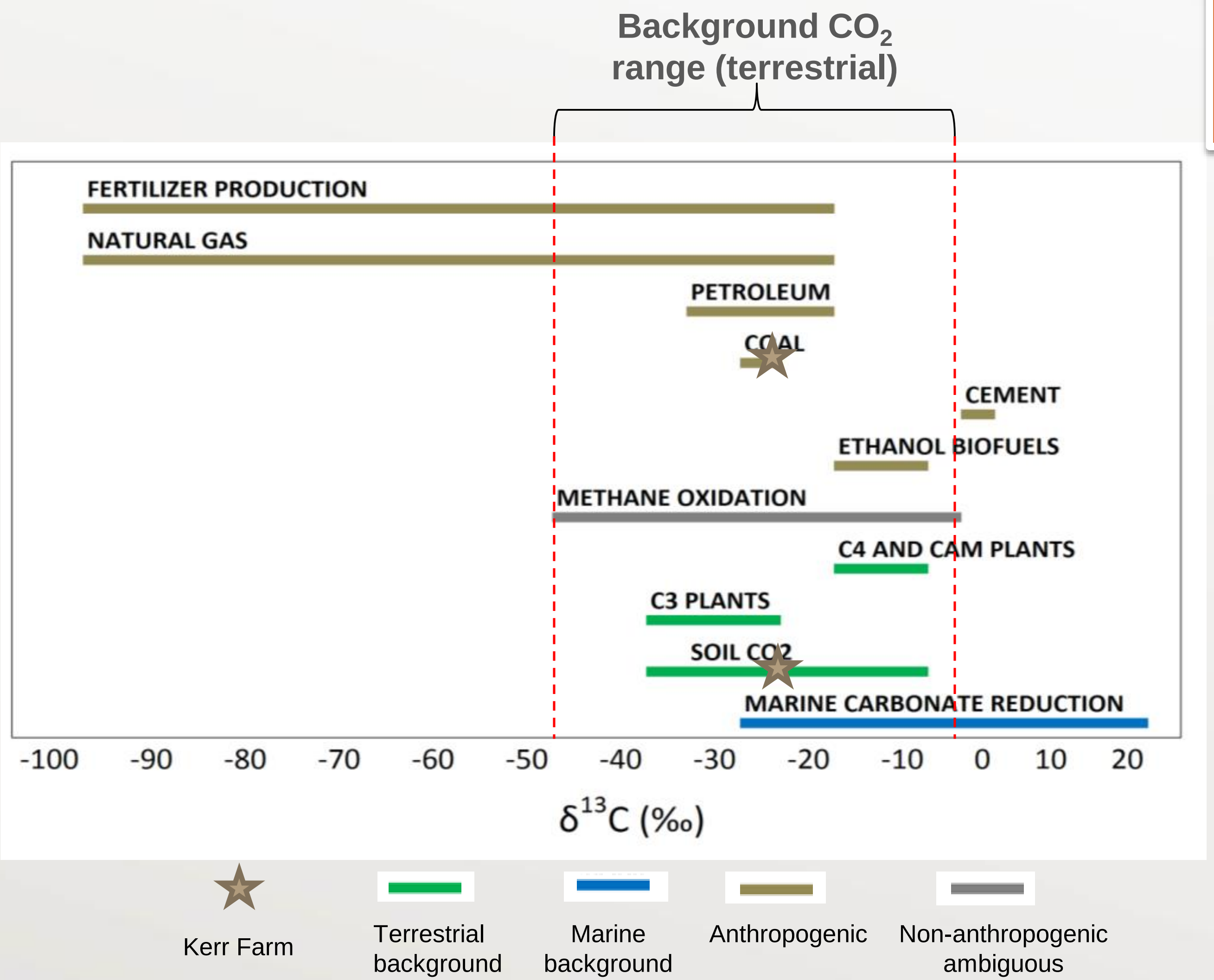
http://www.beg.utexas.edu/gccc/

BUREAU OF ECONOMIC GEOLOGY

GCCC GULF COAST CARBON CENTER

Isotopic Signature

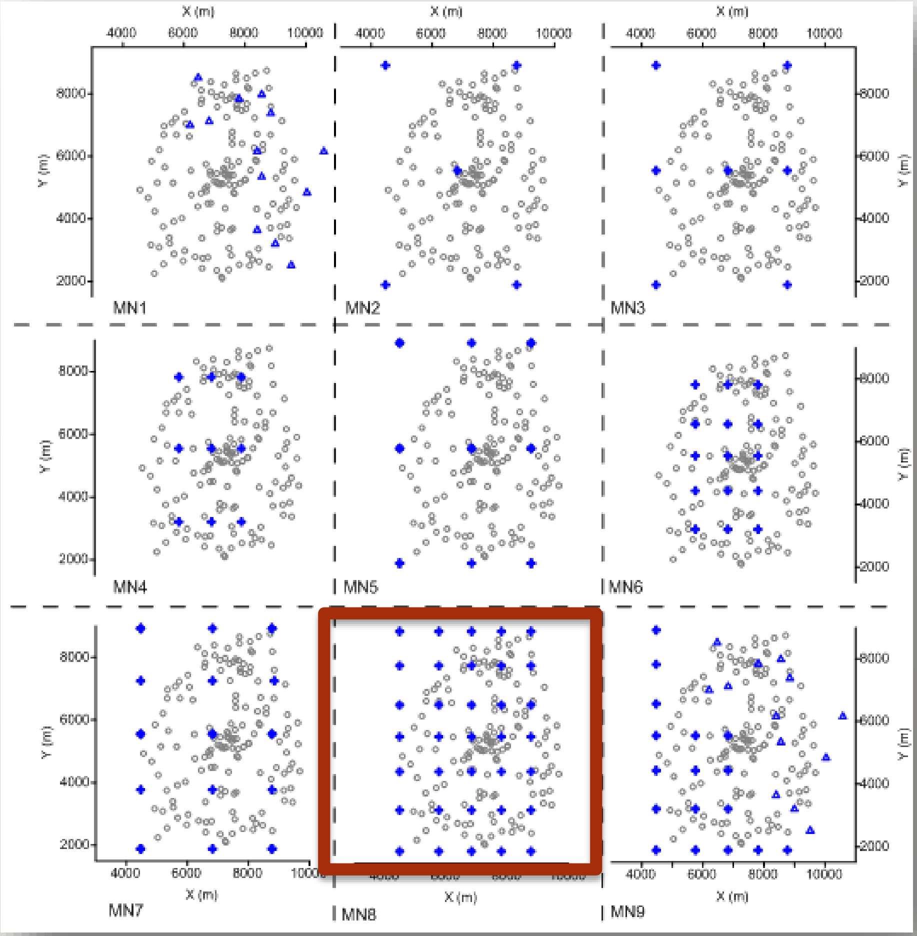
Data Sources
Andres et al,. 1994
Redondo and Yelamos, 2005
Whiticar, 1999



$\delta^{13}C$ not always definitive

Groundwater Monitoring Network Efficiency

- For Cranfield case: 1 well/km needed to detect a leak within >20 years of release.
- Monitoring network efficiency depends on regional hydraulic gradient, leakage rate, flow direction, and aquifer heterogeneity.



Yang et al., 2015, *Environmental Science & Technology* 49, 14

Unit: wells/km^2

MN1: 0.322
MN2: 0.124
MN3: 0.173
MN4: 0.223
MN5: 0.223
MN6: 0.371
MN7: 0.371
MN8: 0.866
MN9: 0.742

Process-Based Example

- Uses geochemical relationships to identify key processes rather than concentration comparisons