Australian Government
Geoscience Australia

Near Surface Monitoring: Assurance versus Detection

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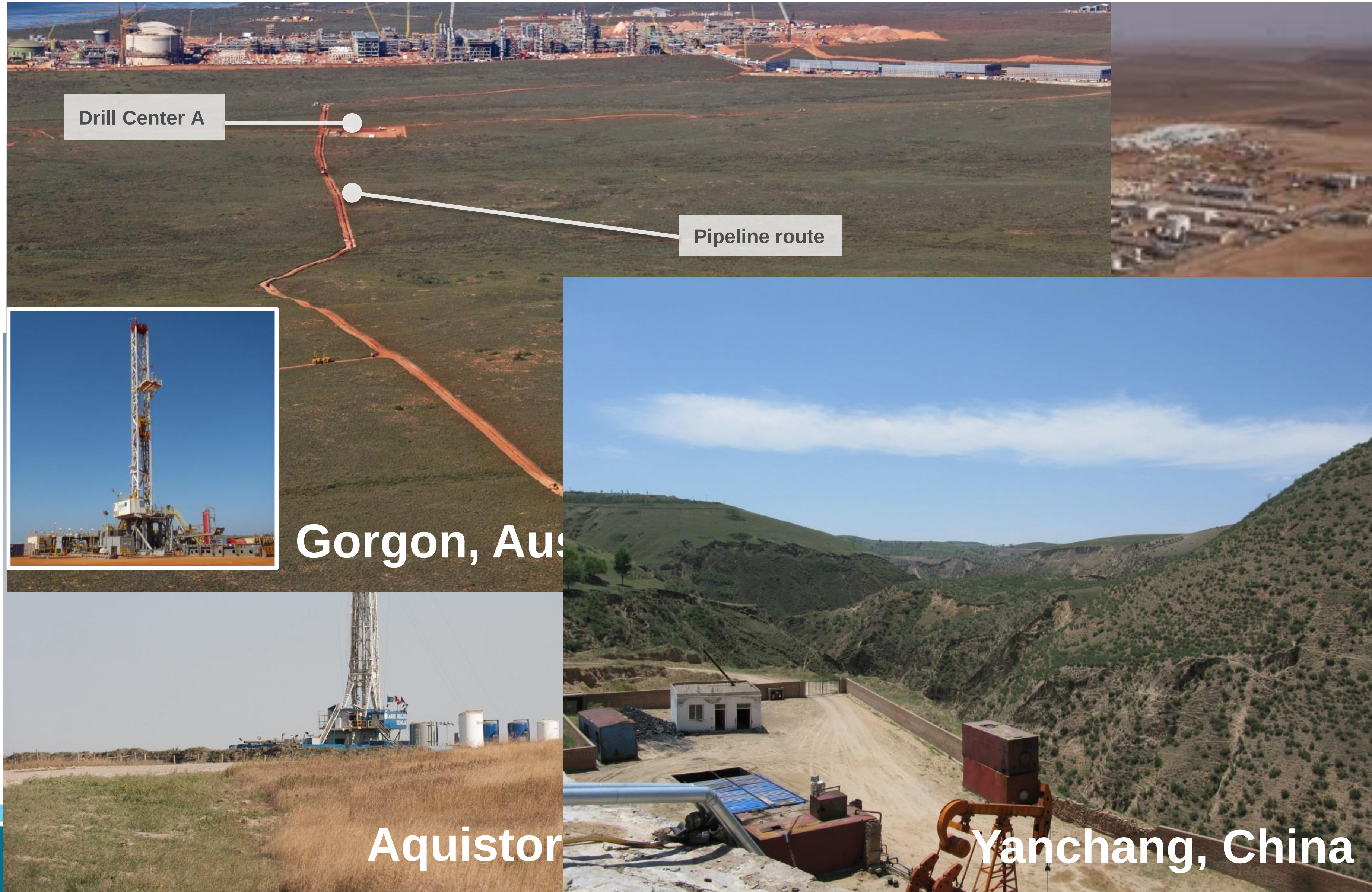
CAGS CCS School, Urumqi, 2017

What is the near surface?

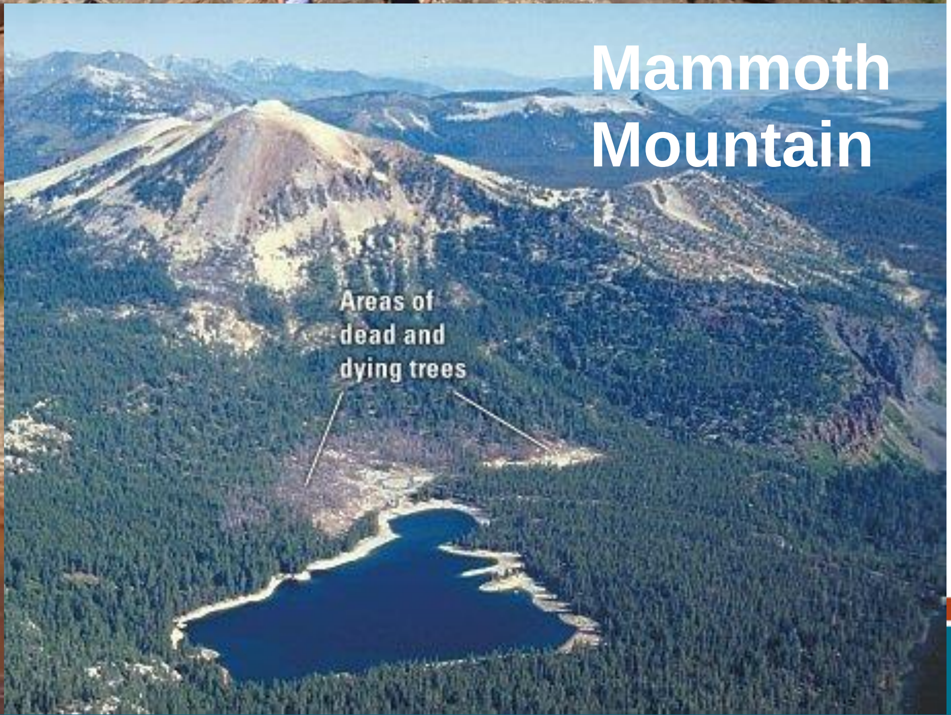
- Atmosphere
- Ground surface (incl. vegetation and fauna)
- Soil and vadose zone (soil gas)
- Groundwater

Relative importance of these depends on the local environment

Different operational environment for CCUS

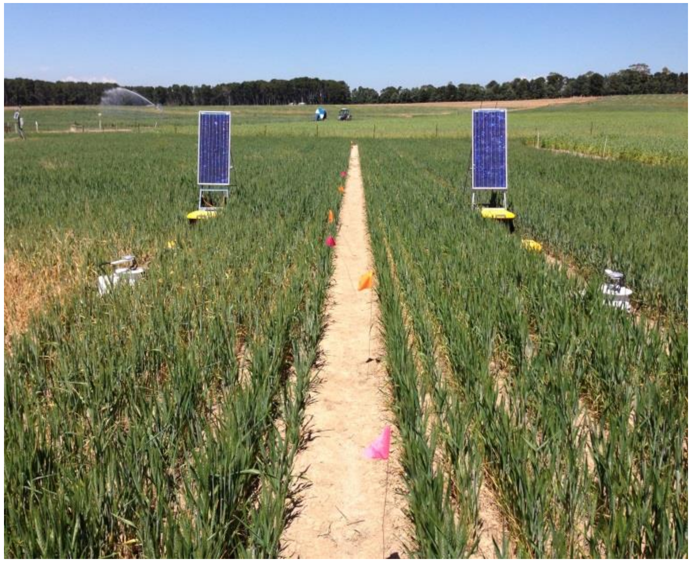


Natural CO_2 seeps



Controlled CO_2 release facilities

ZERT
(USA)



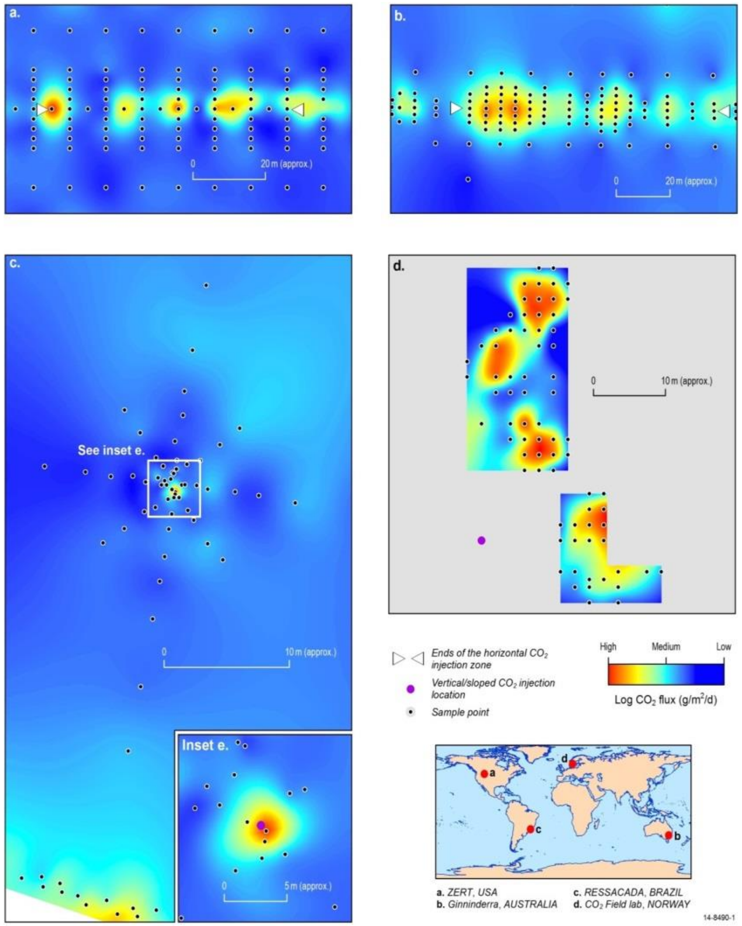
Ginninderra
(Australia)

RESSACADA
(Brazil)

CO_2 Field Lab
(Norway)

Leakage features

- Studies of natural seepage sites and controlled release experiments shows hotspots of leakage (10s of meters)
- **Not looking for small change over large area, but large change over small area**
- e.g. atmospheric CO_2, soil gas, soil flux, vegetation impacts, groundwater impact etc)



Aerial view of soil flux maps at different controlled release sites. Feitz et al. (2014)

Near surface monitoring

1) Assurance monitoring

- near surface monitoring performed to reassure stakeholders that assets with high social, economic or environmental value are unaffected by storage operations and there is no threat to health and safety.

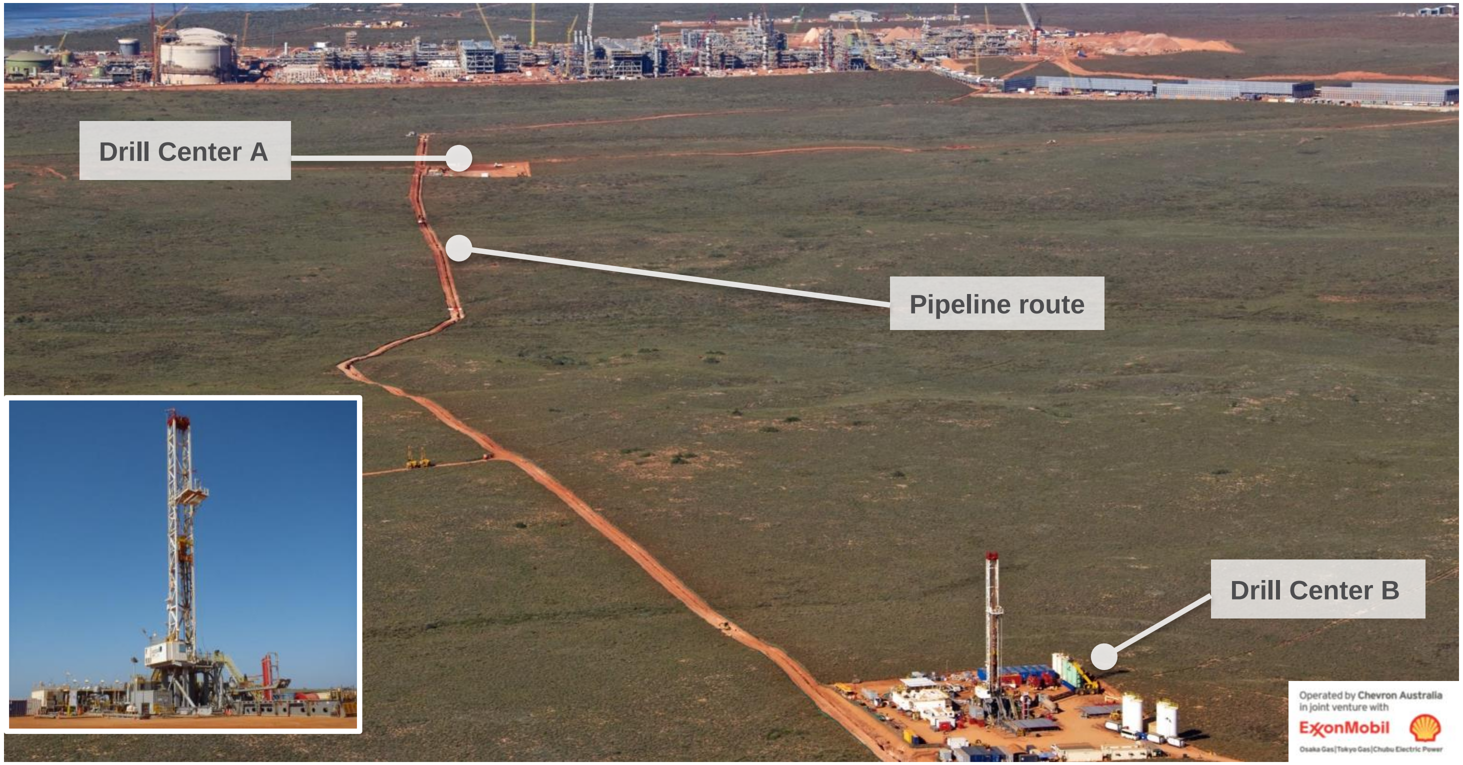
2) Locate, attribute and quantity surface leakage

- Assurance monitoring $\neq$ looking for leakage

Gorgon Carbon Dioxide Injection Project example

Chevron

- All 9 CO_2 injection wells drilled
- 7km CO_2 injection flowline completed
- Anticipated injection CO_2 volumes range between 3.4 - 4.0 million tonnes per year



Gorgon CO_2 injection project – monitoring

- **Seismic** for tracking plume migration - subsurface explosives (15m deep, approx. 1300 shot holes) and vibroseis (trucks)
- **Reservoir observation wells**
- **Pressure monitoring**
- **Soil CO_2 flux**
- **Shallow groundwater wells** (pH, salinity, CO_2, major cations, anions, metals, nutrients, trace organics)
- **Ecological monitoring** – comprehensive programme including: Mammals, Birds, Reptiles, Vegetation, Stygofauna
- **Aerial photography and LIDAR** for monitoring vegetation and changes in surface water drainage
- **InSAR** for monitoring ground deformation

Animals to be monitored at Barrow Island

Burrowing animals

- 1km zone around facilities
- Reference sites
- At risk sites
- Trapping program
- CO_2 leak detection or assurance?

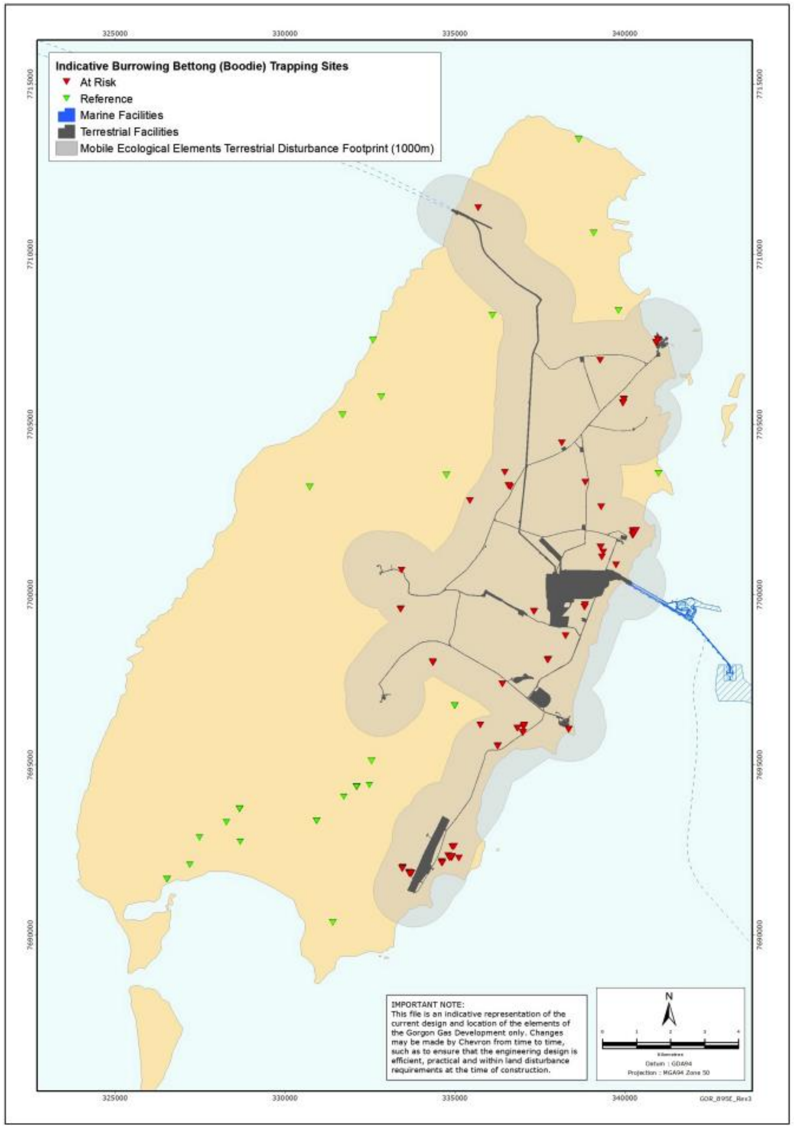


Figure 3-4: Indicative Barrow Island Burrowing Bettong (Boodie) Monitoring Sites
Chevron (2016)

Trickier one! Groundwater quality

- Looking for changes in groundwater quality due to impact of CO_2
- Leak detection or assurance?

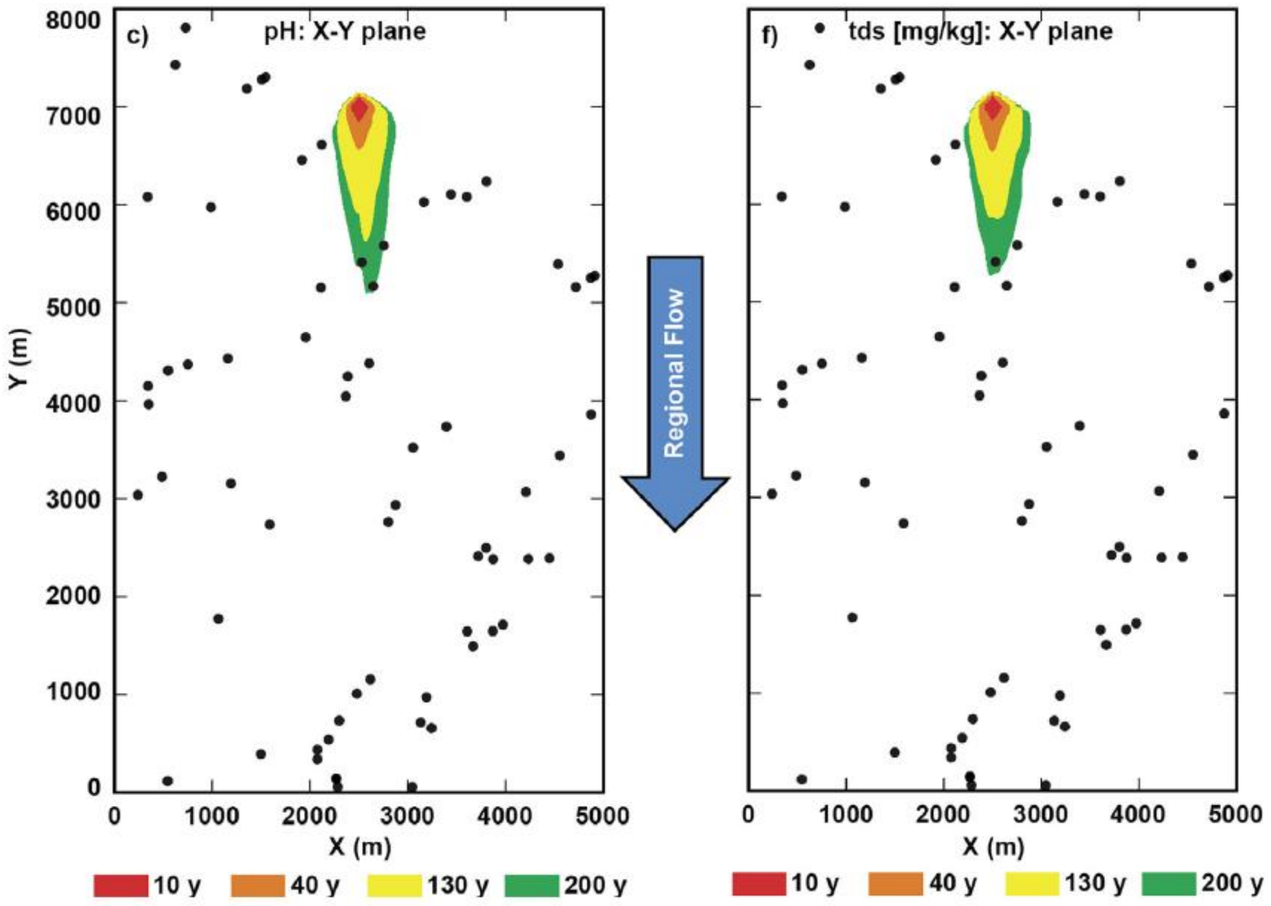
Potential impacts on groundwater chemistry from geological storage

- pH decrease (immediate)
- Weathering will lead to increased alkalinity/TDS
- Increase in major ions (Ca, Mg, Fe, K, Na, Al and Mn)
- Major concern is movement of saline water into freshwater aquifers (esp. North America)
- Other concerns
  - Mobilisation of trace metals (esp. Pb, Ni, Cr)
  - Mobilisation of trace organic contaminants
  - Mobilisation of boron (agriculture)
  - Mobilisation of Si and Br (water treatment plants)

Challenging to detect leakage in groundwater

- Zone of impact from CO_2 plume small
- Detection depends on:
  - Density of wells
  - Timeframe
  - Property measured (pH, TDS)

Detection is unlikely if the density of wells is low



Theoretical leak example based on confined alluvium aquifer in the High Plains Aquifer in Kansas, USA. Carroll et al (2014) IJGGC, 153-168

Baseline vs site characterisation

Need to characterise site environment before injection:

- Groundwater quality and levels
- Soil flux rates
- Soil gas composition
- Isotopic for soil gas and groundwater
- Vegetation and fauna

- But don’t use pre-injection data as baseline for 20 years in future
- Your baseline will change over time, especially with climate change

Baseline vs background (e.g. Ginninderra leak)

Baseline – fixed point in the past, doesn't account for future anthropogenic or climatic changes (e.g. increasing atmospheric CO_2 concentration). Reflects the small impact/large area concept of leakage.

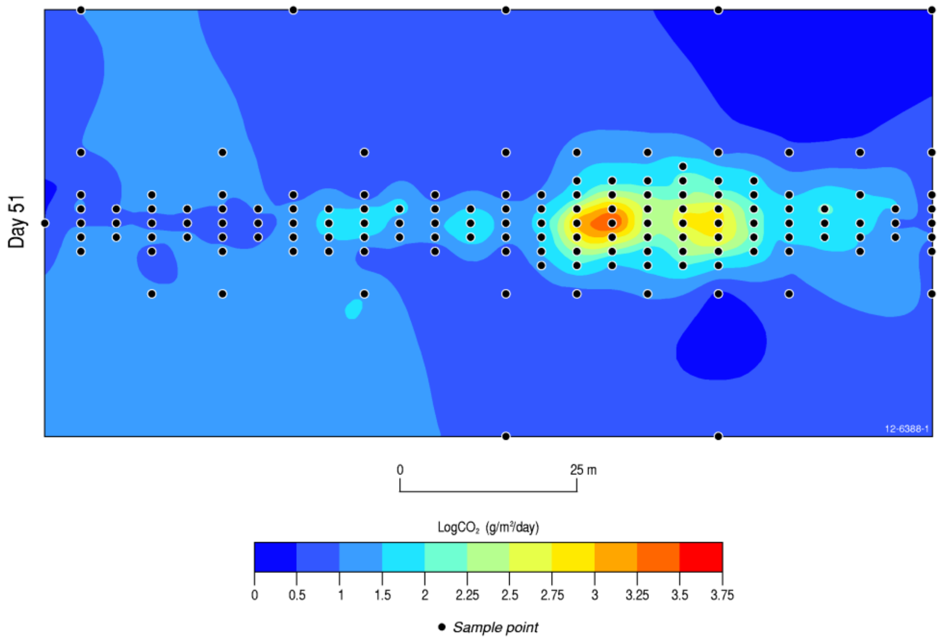
Background – reflects seasonal variation, climate variability and is directly relatable to leak feature at time of measurement.

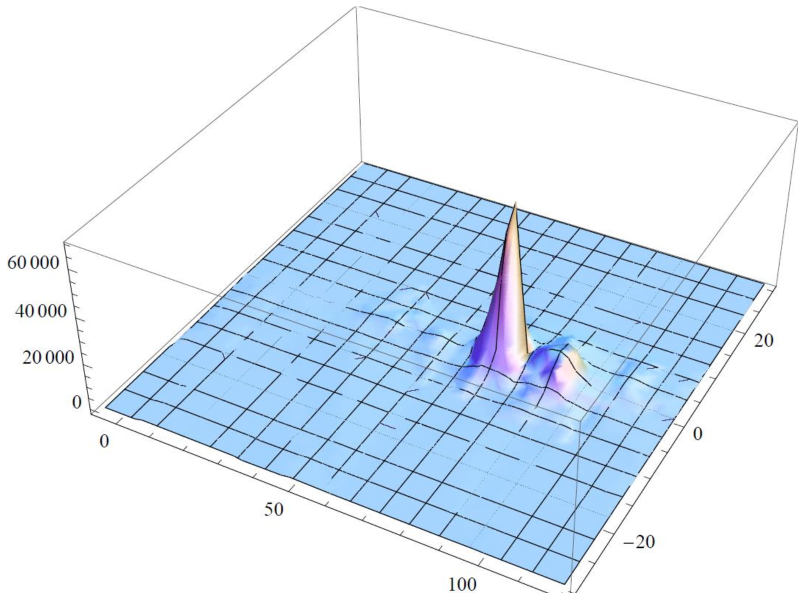
Background >30 m from leak

Leak feature

Leak vs background – e.g. CO_2 soil flux

- Soil flux data clearly shows leak above background (2 orders of magnitude)
- What if background 2x higher than baseline?

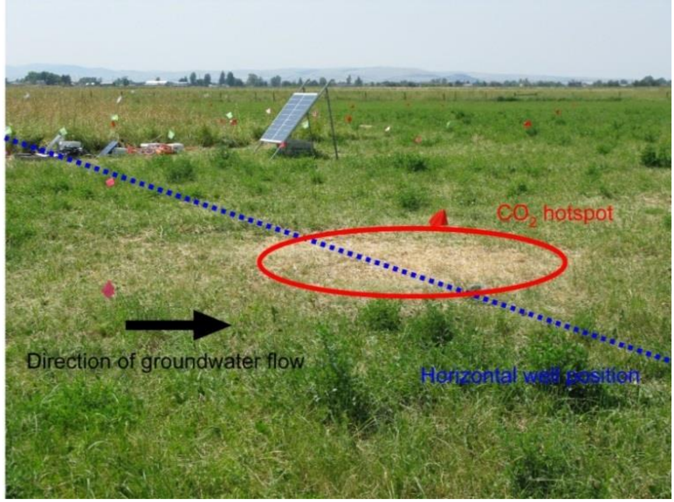




Leak detection and surface monitoring

Requirements for CO_2 leak detection:

- Find small, high concentration leakage features
- Continuous or regular measurements
- Low rate of false positives



Limitations of current surface monitoring techniques:

- sensitivity,
- spatial coverage, or;
- automated or regular sampling

The scale problem

Modelling the minimum detectable leak for an atmospheric
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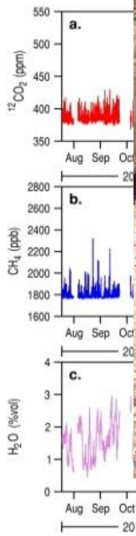
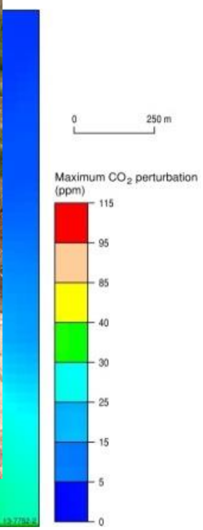
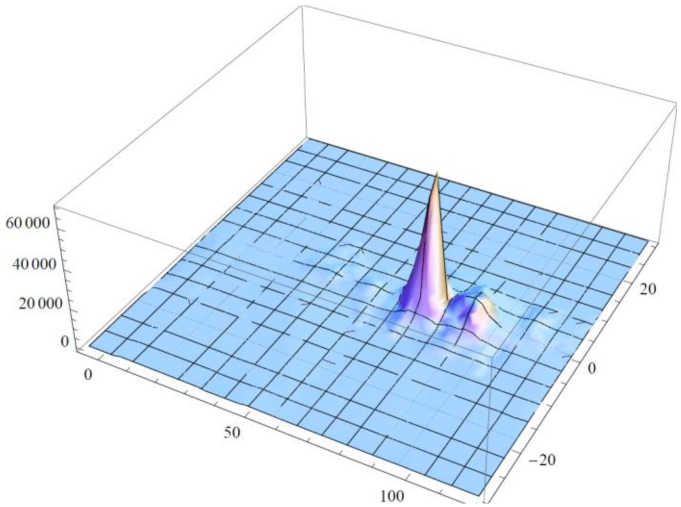
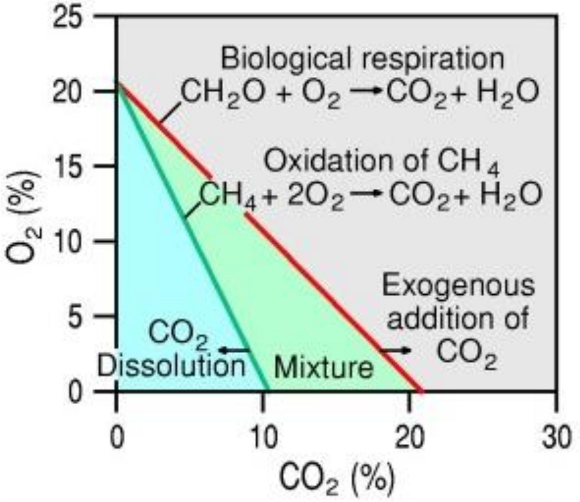




Surface monitoring applications

- Environmental monitoring of high risk (or high value) assets for public assurance
- Quantification of a known CO_2 source
- Locating a CO_2 leakage using mobile technology
- Attributing a leakage source using isotopes and gas ratios





Established techniques for quantification

- Chamber soil flux measurements
- Eddy covariance
- Atmospheric tomography

Established techniques – chamber soil flux

- Benchmark technique for characterising surface emissions
- Provides a direct measurement of CO_2 efflux
- Two different approaches:

Semi-permanent chambers

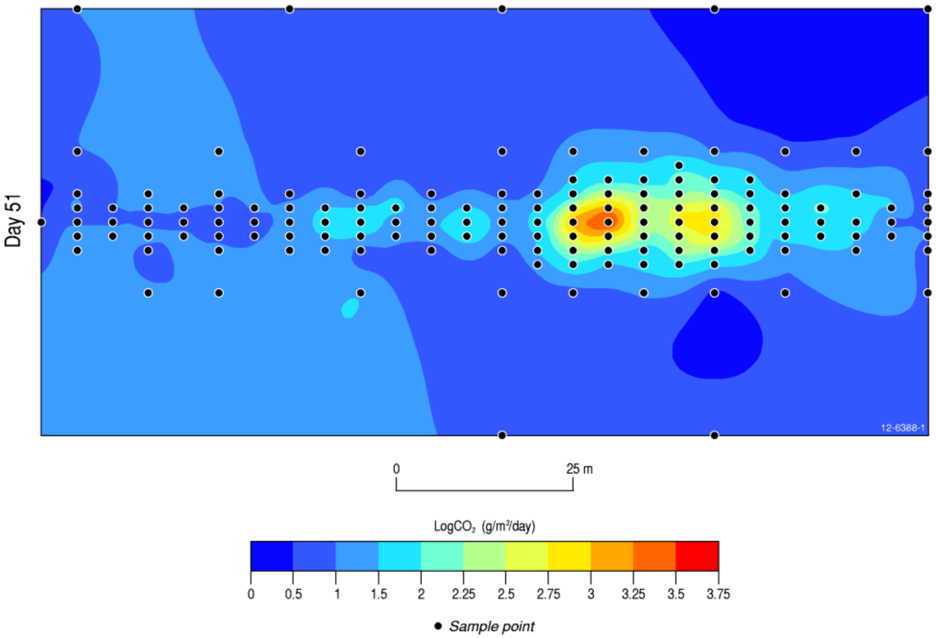
Long-term monitoring

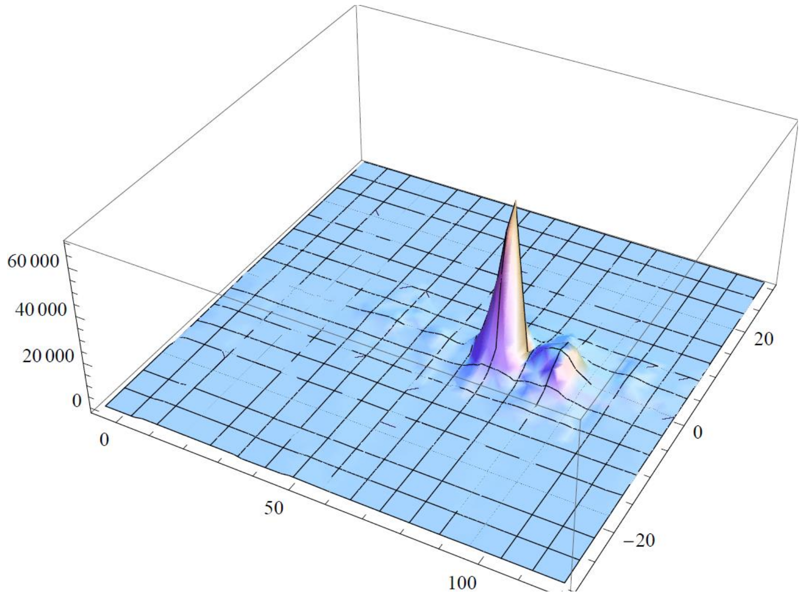
Portable chamber surveys

Spatial mapping

Established techniques – soil flux surveys

Quantification →→ Interpolation of flux surface





g/m²/d → 0.1 t/d leak

Established techniques – soil flux surveys

Benefits

- Direct physical measurement
- Can be used over land or water
- Great for benchmark emissions estimate

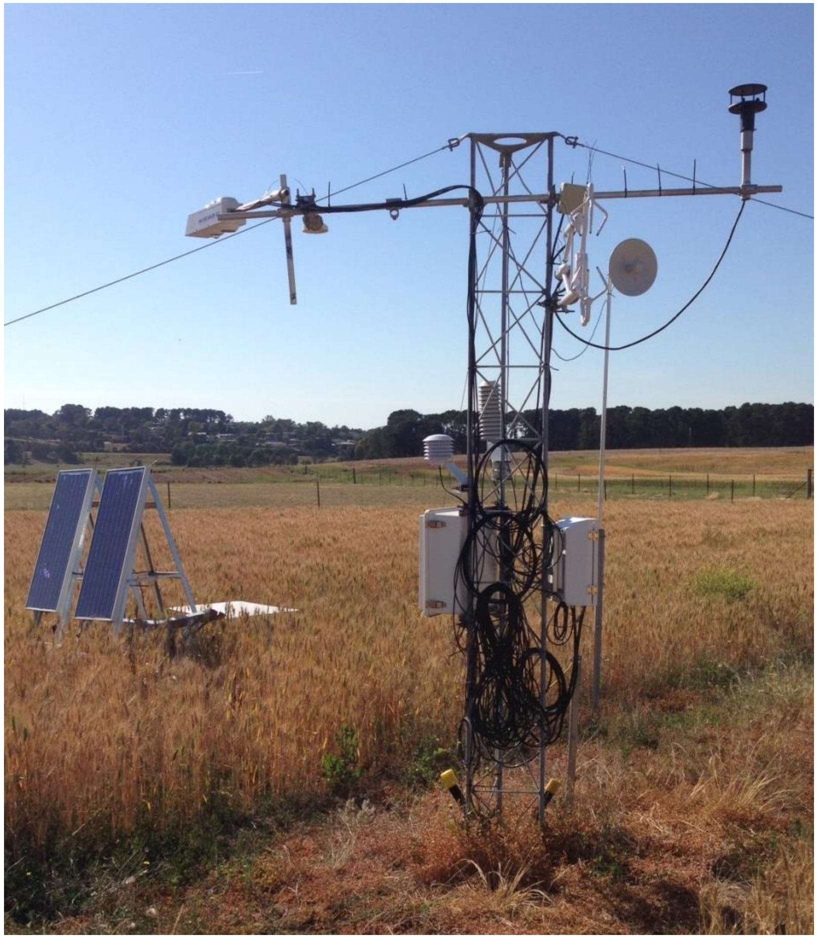
Limitations

- Leak location must be known in advance
- Trade-off between spatial coverage and sampling density
- Requires a constant leak rate over the day

Established techniques – eddy covariance

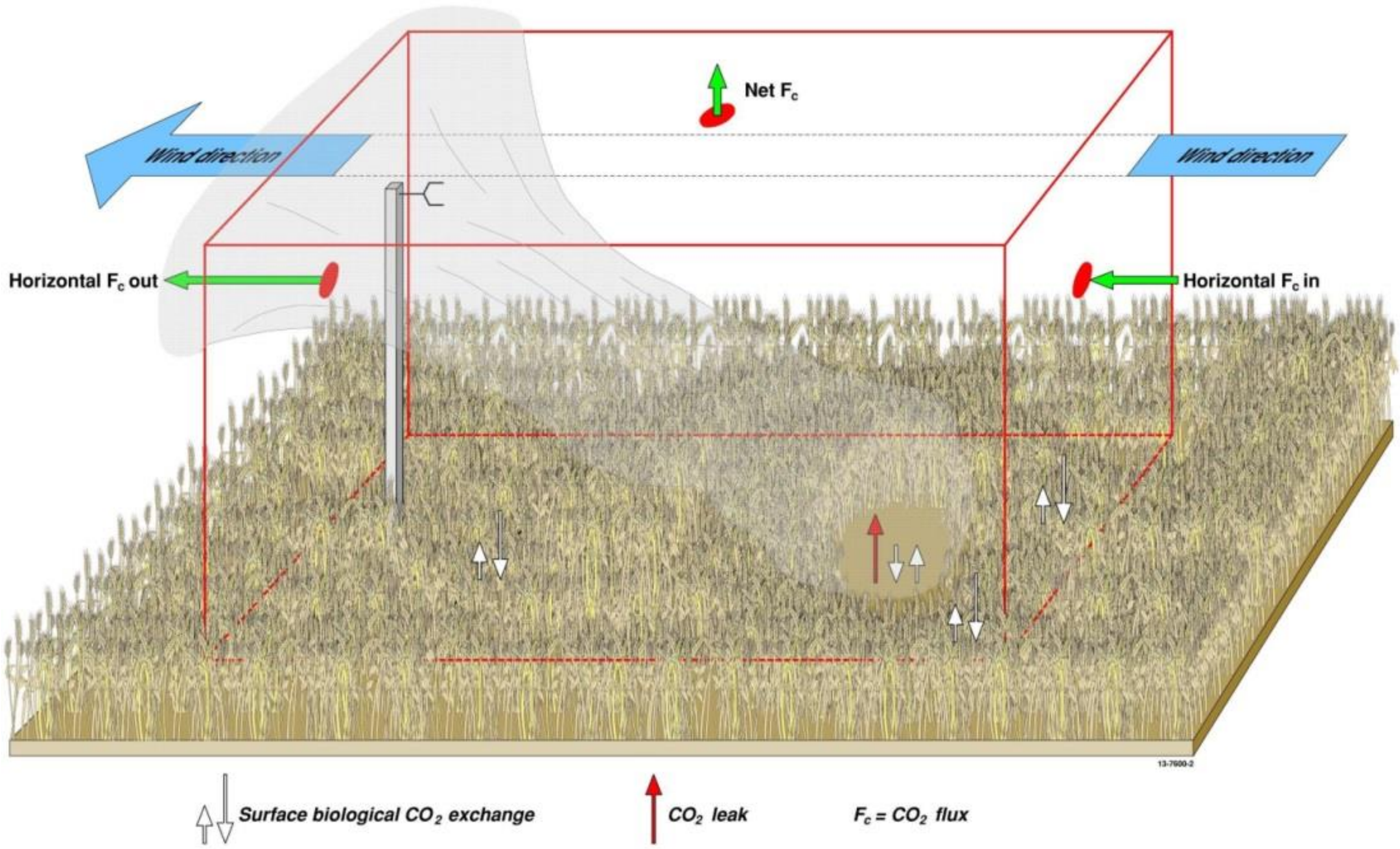
- Measures vertical exchange of CO_2 at high frequencies.
- Complete meteorological package for characterisation of ecosystem
- Significant amount of data processing required

Photo from http://joewheatley.net/wp-content/uploads/2009/09/eddycovariance.jpg



Established techniques – eddy covariance

- Quantification →→ Couple with Lagrangian Stochastic models or footprint models



Established techniques – eddy covariance

Benefits

- Continuous automated monitoring
- Great for characterising the ecosystem
- Large spatial scale (m^2 - km^2)

Limitations

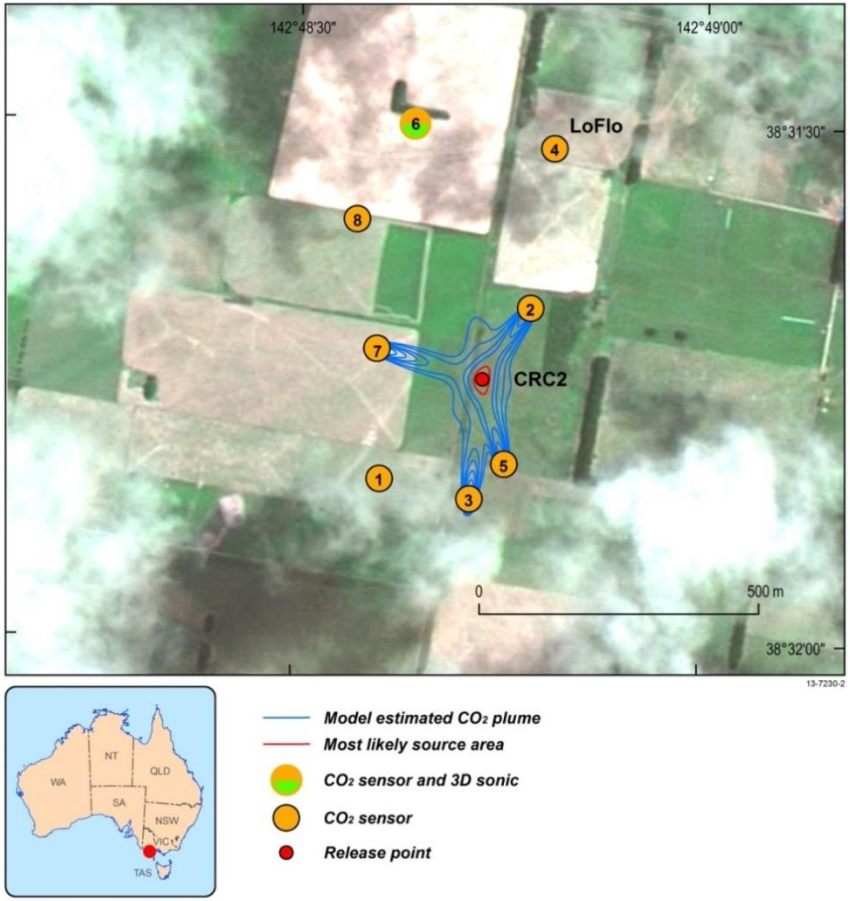
- Many assumptions required – some don't hold true for CO_2 leakage scenarios
- Dependent on user defined model parameters
- Requires collection of a long baseline
- Requires a constant leak rate over many days

Established techniques – atmospheric tomography

- Array of CO_2 concentration measurements around leak
- Requires a lot of measurements and data processing
- Can be applied to both location and quantification of a leak

Established techniques – atmospheric tomography

- Quantification →→ Dispersion plume model + Bayesian inversion
- Triangulates source location



Jenkins et al (2016) IJGGC, 158-174

Established techniques – atmospheric tomography

Benefits

- Can provide very accurate location and quantification estimates
- Removes background variability

Limitations

- Know leak location prior, to ensure the leak is within the array
- Several weeks of measurements are needed

Developing techniques for quantification

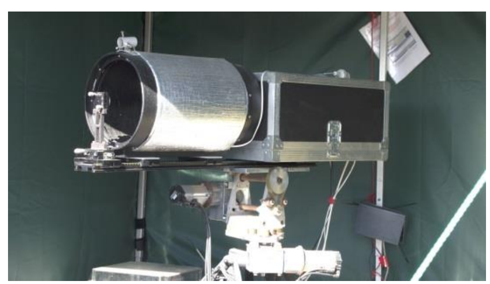
Highlights of the:

2015 Ginninderra Controlled CH_4 and CO_2 Release Experiment







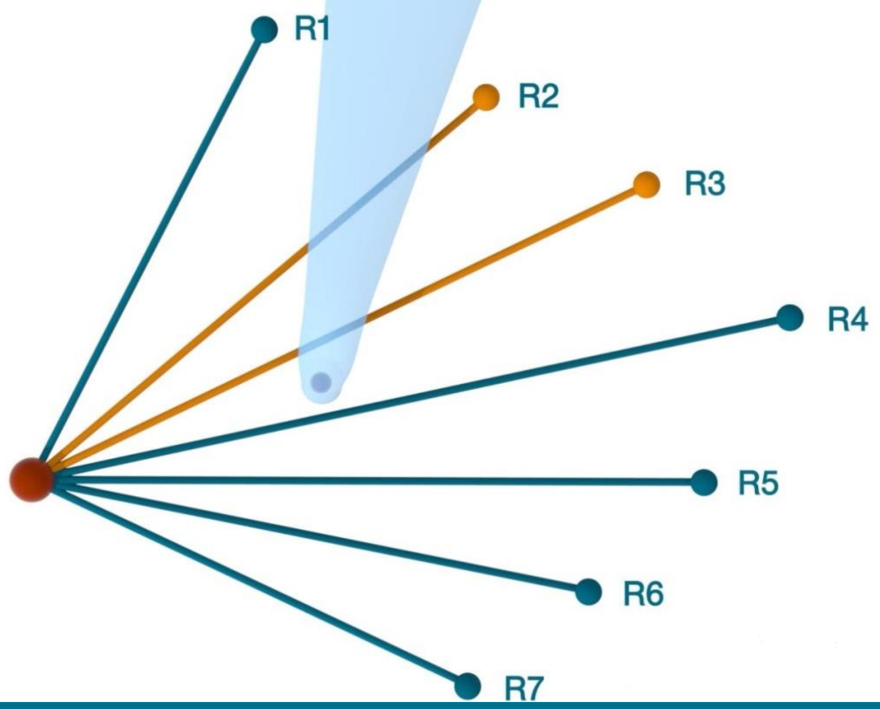




Developing techniques – line tomography: laser

- Equivalent to atmospheric tomography
    - Line concentration measurements
- Functional at scales of 50-1000+ m

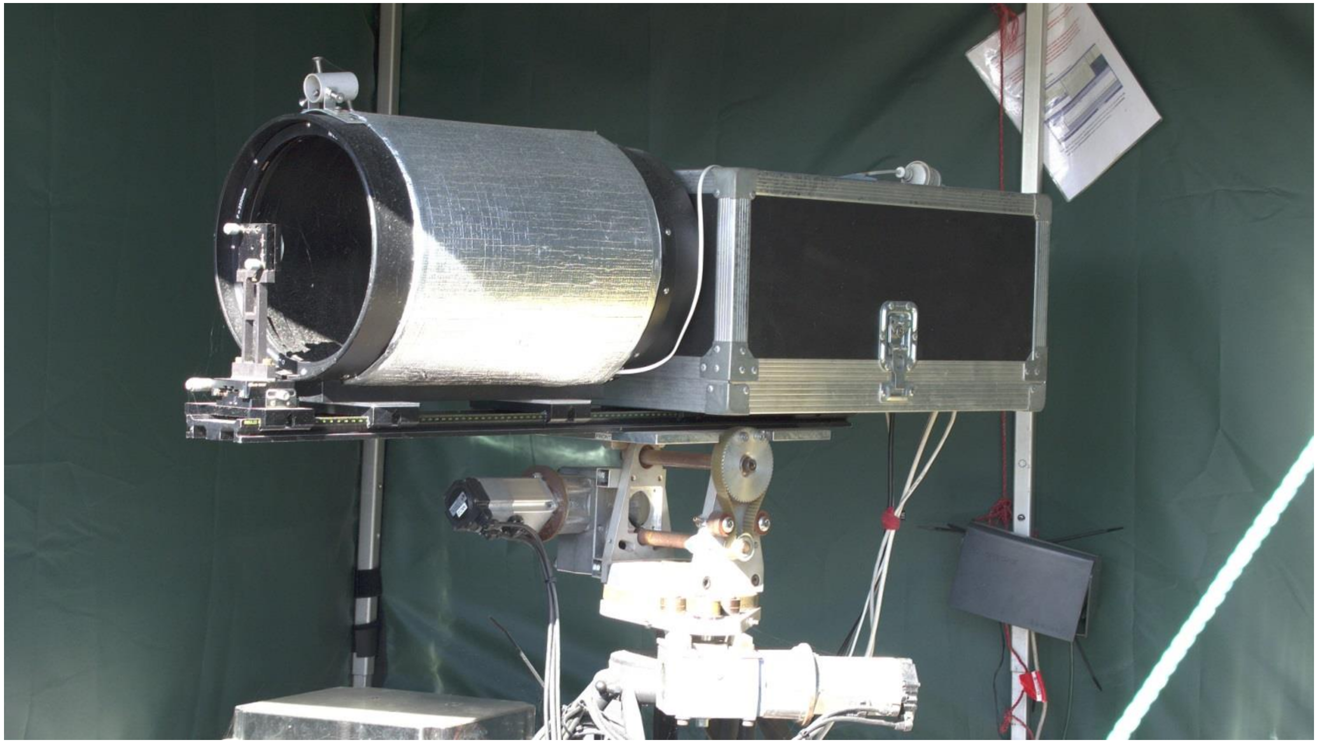
Future work:

- A consistent approach for performing inversion
- Scaling up to large releases or active CO_2 seeps



Developing techniques – line tomography: FTIR

- Simultaneously measure multiple gas species
- Quantification →→ Backward Lagrangian Stochastic model
    - Corrections applied from tracer performance

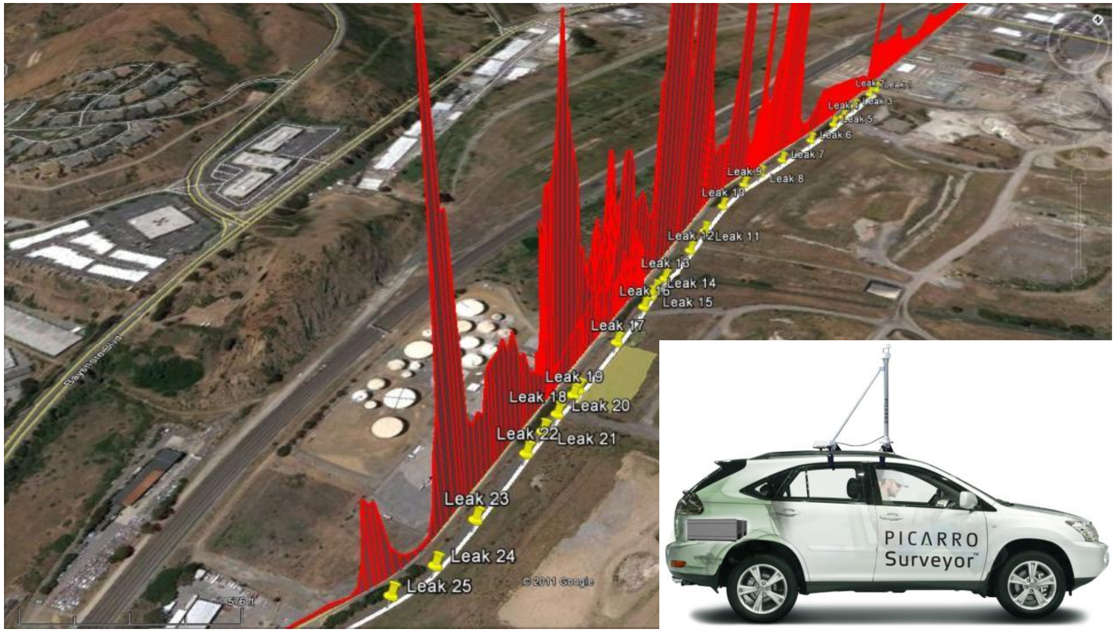


Developing techniques – tracer method

- Co-release a tracer (i.e C_2H_2) at leak source
- Measure transects downwind of source
- Quantification →→ $F_{CH4} = F_{Tracer} \times \frac{(C_{CH4} - B_{CH4})}{(C_{Tracer} - B_{Tracer})}$
- Performs in light and variable winds, up to 200 m down-wind
- Need to know the leak location
- Upscaling to non-point sources?

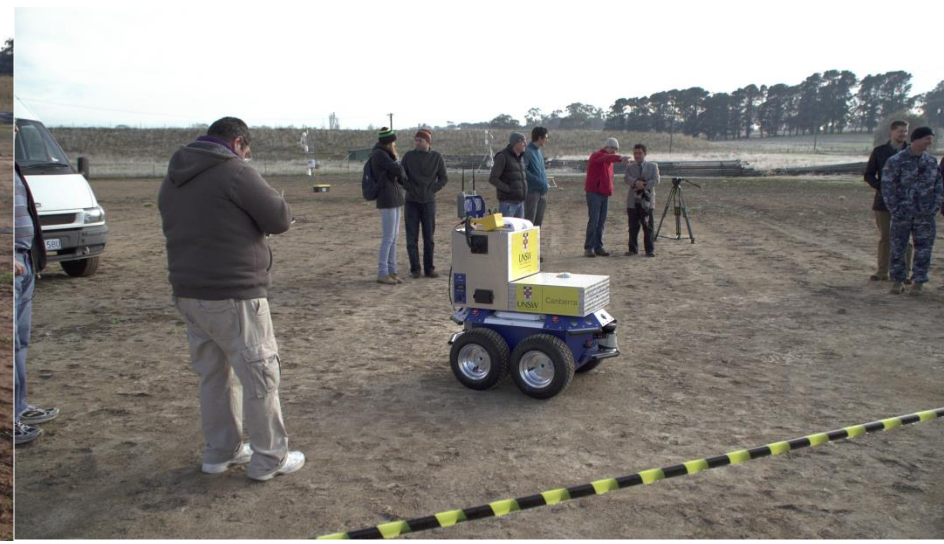
Developing techniques – vehicle surveying

- High performance gas analyser, GPS and wind sensor mounted in/on vehicle
- Carbon isotopes can be used for identifying source
- Quantification →→ Vertical concentration profile + dispersion model



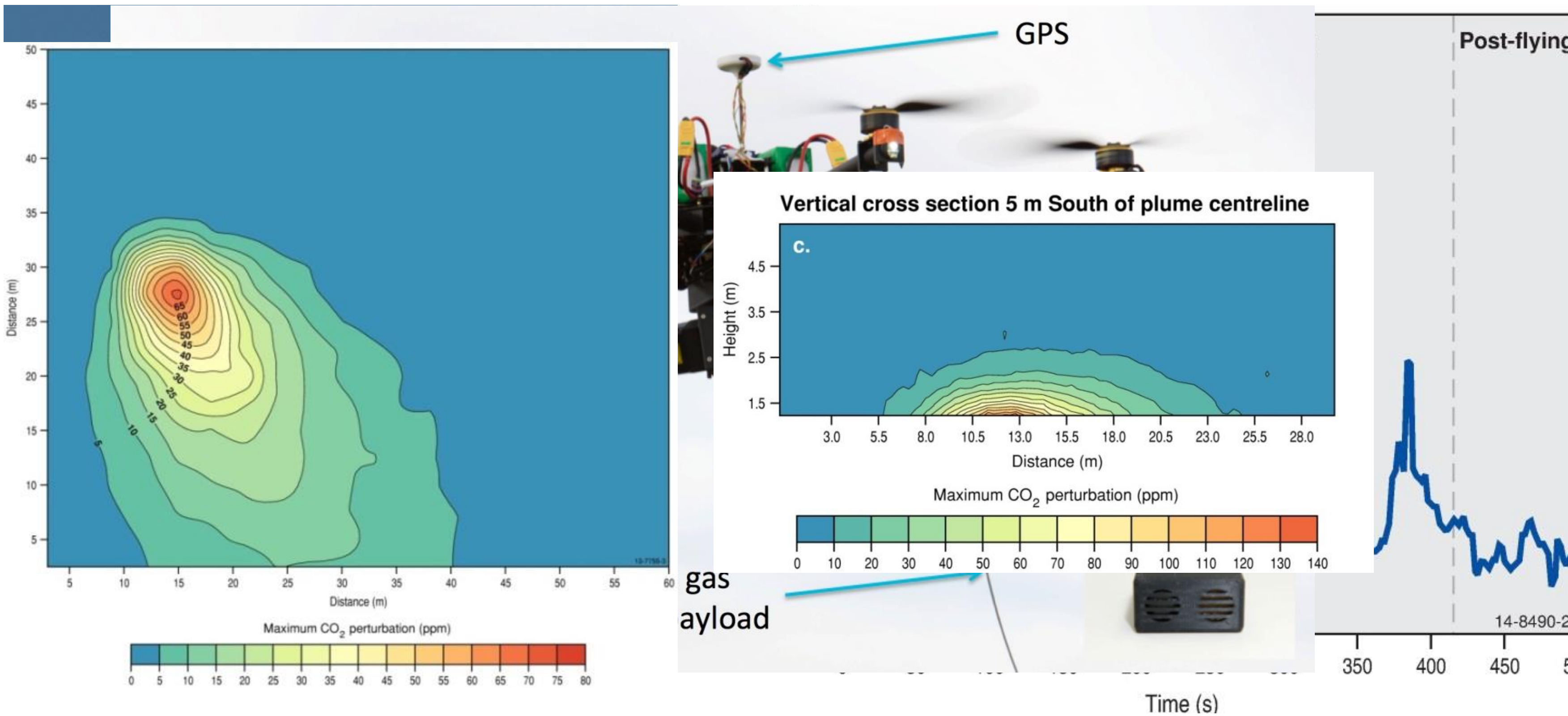
Developing techniques – Robotic surveying

- Automated or remotely controlled 'sniffer' vehicles
- Quantification →→ Spatial concentration map + dispersion model



Developing techniques – locating a leak

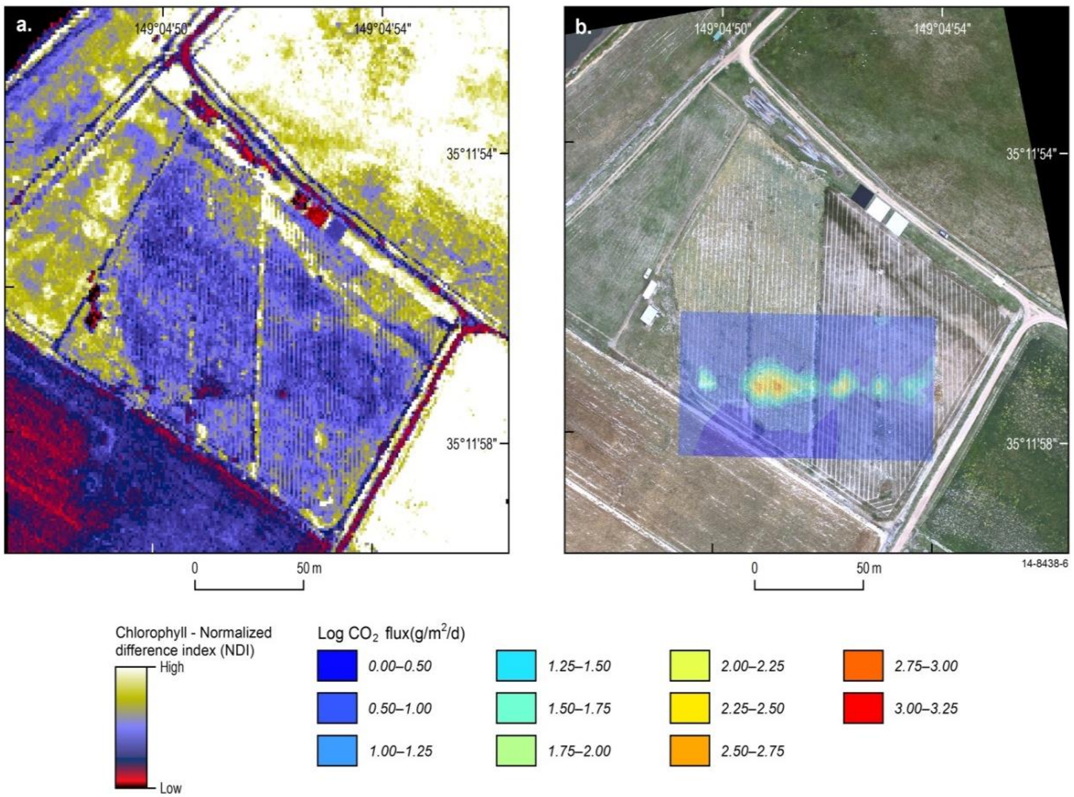
- Automated or remotely controlled 'sniffer' drones
- Sensor needs to be close to the ground and leak due to atmospheric dispersion



Developing techniques – locating a leak

Airborne hyperspectral

CO_2 impacts on vegetation clearly visible at ground level, but current airborne technique suffer from many false positives



Feitz et al., 2014

Summary

- Applications for surface monitoring:
  - Verifying no leakage ✗ no observable impact on monitored asset
  - Leak detection ✗ not yet
  - Quantifying a leak; locating a leak; attributing source ✓
- Established quantification techniques are powerful
  - Need to understand their limitations
- New pipeline of technology and methods for **locating** and **quantifying** leaks
- Controlled release facilities provide the opportunity for improving techniques and testing new ideas

Thank-you