Australian Government

Geoscience Australia

Monitoring for CO_2 storage

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cags China Australia Geological Storage of CO_2

中澳二氧化碳地质封存

Introduction

- We need to be able to safely store carbon dioxide in the subsurface and be sure we know how it is behaving
- To do this we need to be able to monitor the behaviour

Monitoring

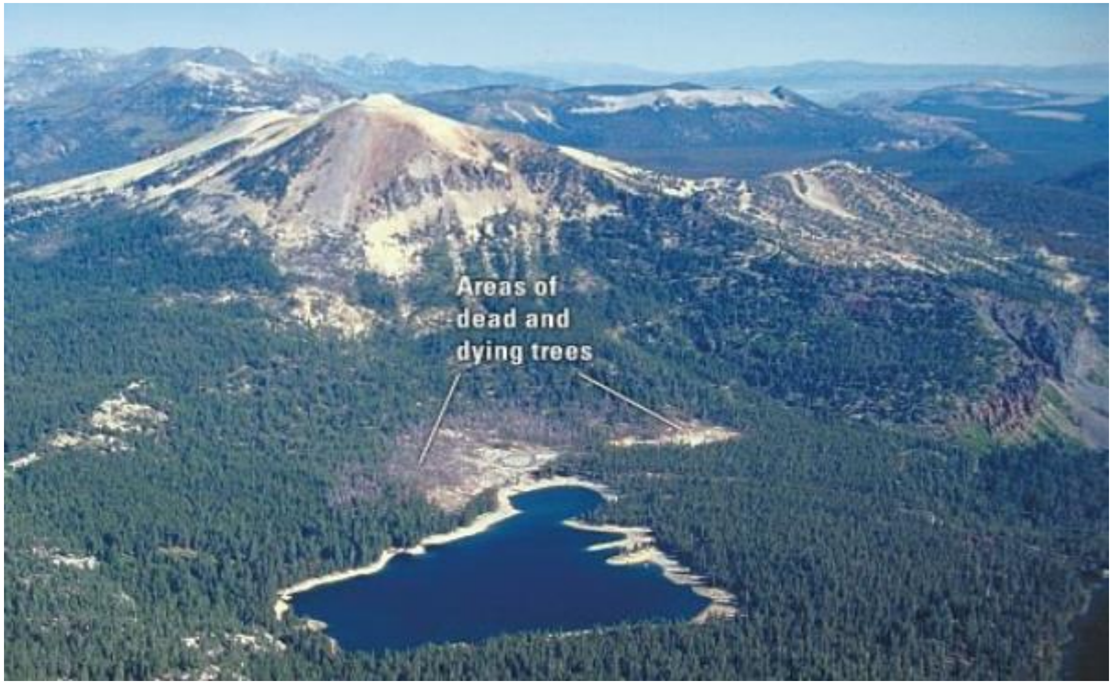
- Monitoring has a spatial dimension and a time dimension
- Spatial dimension
  - Sub-surface
  - Near surface
  - Atmosphere
- Time dimension
  - Prior to injection
  - During injection
  - Post-injection

What are we monitoring for?

- Ensure effective storage
  - Is the stored CO_2 behaving as predicted?
  - If it isn't, can we determine why?
- Understand the impact on the environment; both subsurface (aquifers) and above ground (ecosystem and atmosphere impacts)
  - Is the CO_2 leaking away from the storage formation?
  - Is the CO_2 leaking to the surface?
  - What is the rate of leakage?

Natural CO_2 leaks

- Mammoth Mountain, California
  - up to 300 tons/day CO_2
  - soil gas concentrations 20-95%



Source: http://pubs.usgs.gov/fs/fs172-96/

Natural CO_2 leaks

- Latera Caldera, Italy
- ~10 t/d natural CO_2 leak

Source: Andrew Feitz

Natural CO_2 leaks

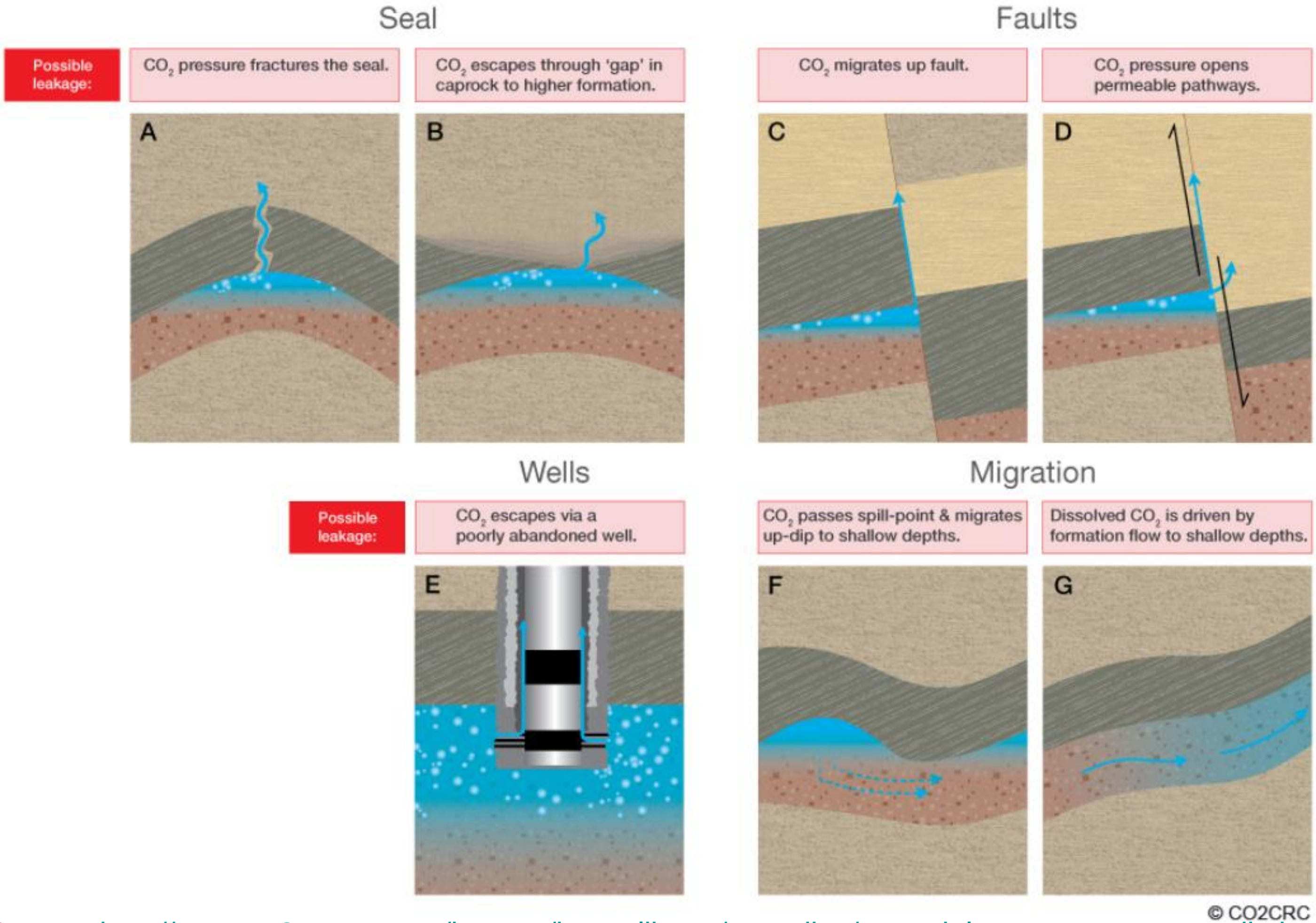
- Views of CO_2 bubbling up through stream

Source: Andrew Feitz

CO_2 toxicity

- CO_2 seeps have proved to be harmful to humans
- Material Safety Data Sheets show 47,000 ppm (4.7%) in air is considered to be toxic to humans
- "Concentrations of 8-15% cause headache, nausea and vomiting which may lead to unconsciousness if not moved to open air and given oxygen" (source:http://msds.chemalert.com/?id=21&file=0008659_001_001.pdf)
- Also harmful to the environment
  - Acidification of soils
  - Alteration of groundwater chemistry

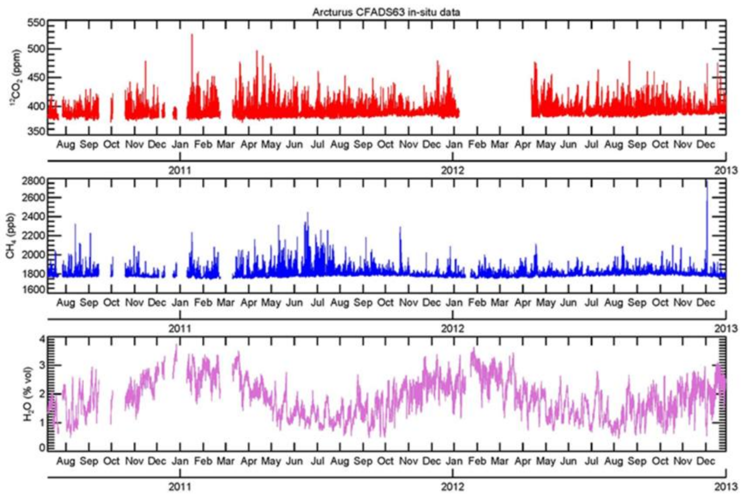
Leakage pathways



Source: http://www.co2crc.com.au/images/imagelibrary/stor_diag/potential-escape-routes_media.jpg

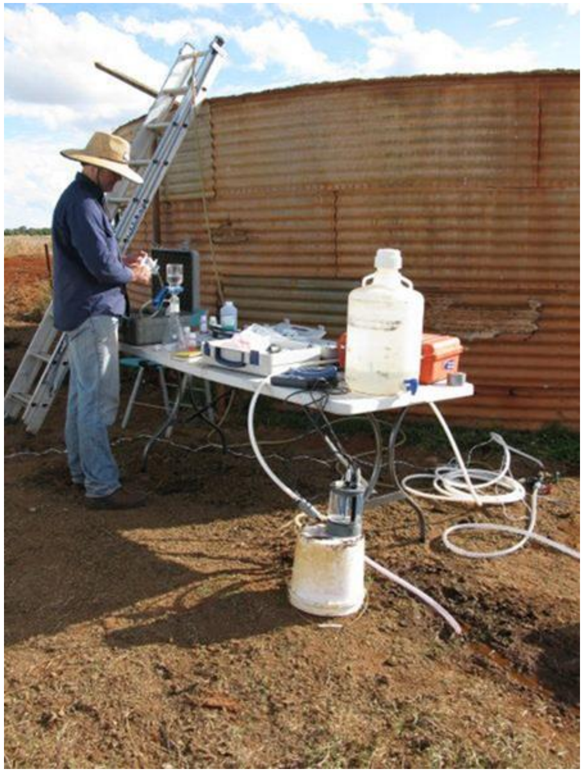
Why is baseline monitoring important?

- We need to establish the natural (starting) conditions in order to be able to detect changes that may be caused by leakage from our storage formation



Groundwater baseline monitoring

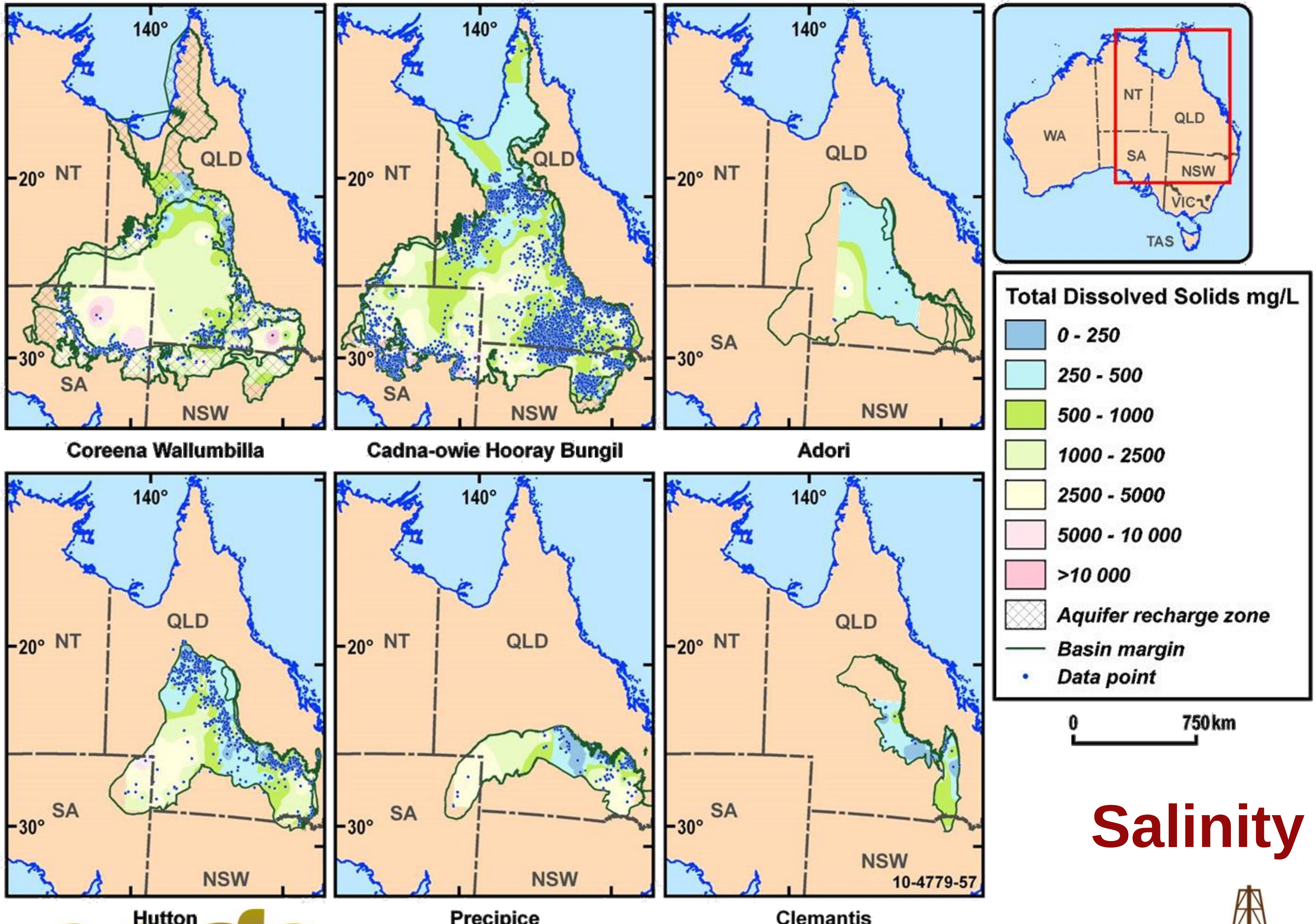
- Groundwater resources are critical as a source of water for much of Australia and China therefore we need to know if the resources are being affected by leaking/migrating CO_2
- What does the baseline look like?



Potential impacts on groundwater chemistry

- 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
- Other concerns
  - Trace metals (esp. As, Pb, Ni, Cr)
  - Trace organic contaminants
  - Boron (agriculture)
  - Si and Br (water treatment plants)
- Note metal leaching not only related to direct contact with CO_2, could occur outside assigned storage area

Salinity



Total Dissolved Solids mg/L
0 - 250
250 - 500
500 - 1000
1000 - 2500
2500 - 5000
5000 - 10 000
>10 000
Aquifer recharge zone
Basin margin
Data point
0
750 km
140°
20°
30°
NT
QLD
SA
NSW
WA
VIC
TAS
10-4779-57
Coreena Wallumbilla
Cadna-owie Hooray Bungil
Adori
Hutton
Precipice
Clemantis

What to measure?

- **Essential: Field pH and total dissolved solids (salinity)/ Electrical conductivity**
- Lab pH can be quite different to actual (field) pH due to rapid equilibrium with atmosphere
- Field analysis (pH, redox, temperature, EC; also helpful is Fe^{2+})
- Cations (Na, Mg, Ca, K) and anions (Cl, SO_4, HCO_3, F)
- Trace metals and metalloids (e.g. Pb, As, Al, B, Ni, Mn, Hg, Sr, Rb)
- Isotopes useful for aquifer characterisation (e.g. d^2H, $d^{18}O$, $d^{13}C$, ^{14}C, ^{36}Cl, $^{87}Sr/^{86}Sr$) but analysis is expensive
- Trace organics if mobilisation of oil/condensate a concern (e.g. BTEX, napththalene and total recoverable hydrocarbons)
- Analysis of exsolved gases including composition and isotopic d^2H and $d^{13}C$ analysis (methane and CO_2)

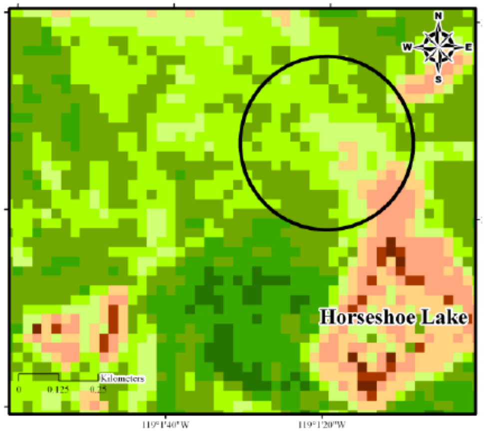
How can we monitor the CO_2 plume?

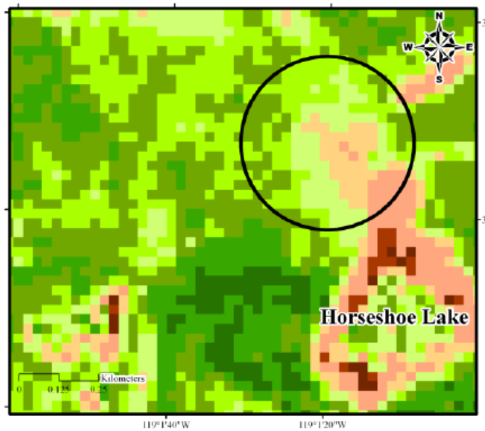
Remote	Hyperspectral imaging INSAR
Surface	Conventional seismic surveys Vertical seismic profiles (VSP) Gravity surveys Some electromagnetic techniques
Subsurface - downhole	Saturation logging Cross-well electromagnetic Borehole gravity Pressure Thermal effects Cross-well seismic Fluid sampling (tracers)

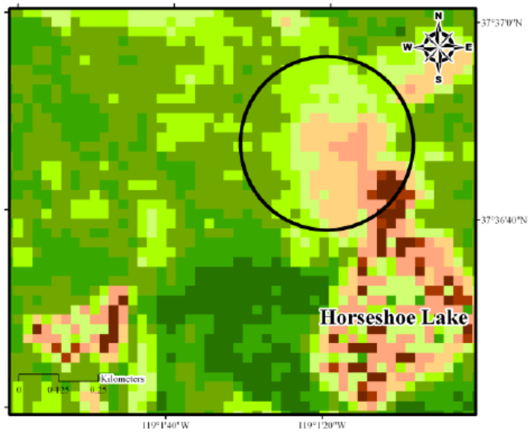
What should an injection monitoring program look like?

- Clearly no “one size fits all”
- Program needs to be customised to the particular storage area
- Will be a combination of any or all of the techniques on the previous slide plus any we have yet to think of

Optical satellite remote sensing



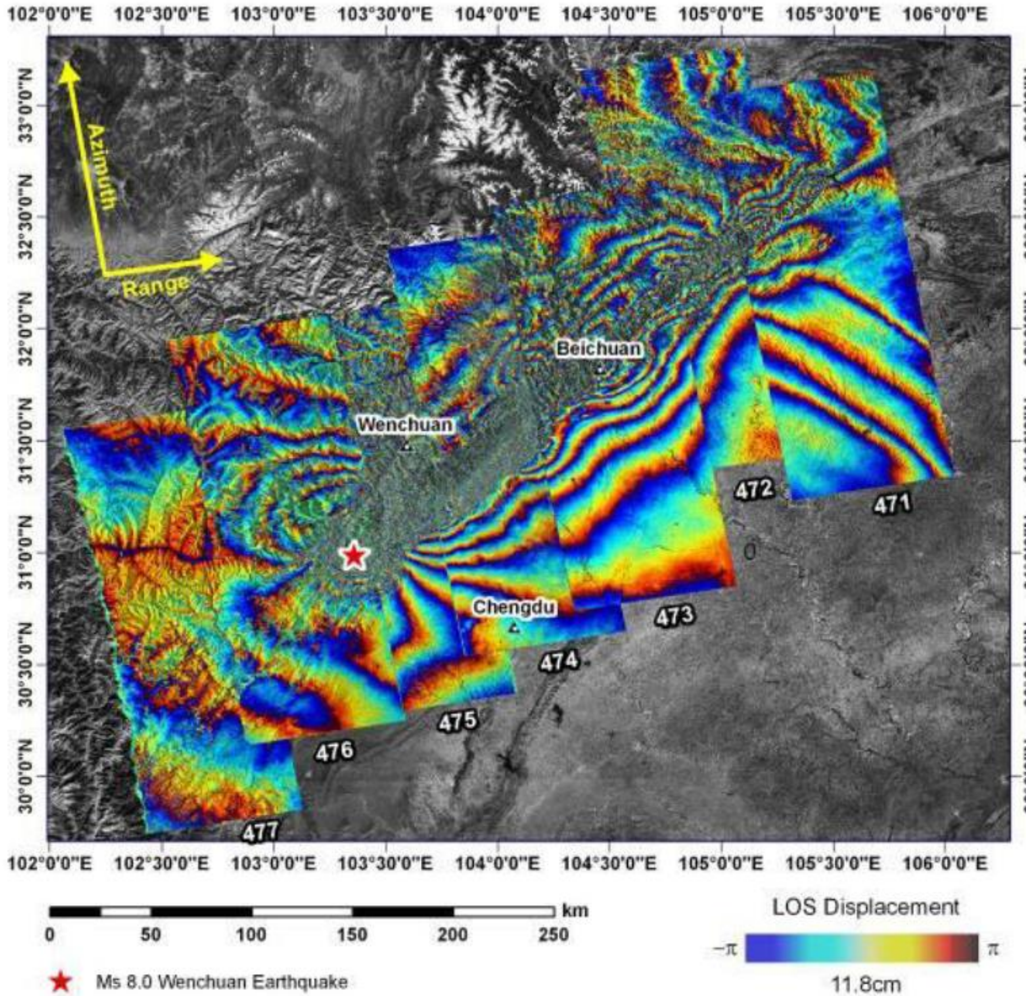




- 4th September 1988 5th September 1994 1st April 2010

Source: http://www.cagsinfo.net/pdfs/cags2-workshop1/5-1LinlinGe1.pdf

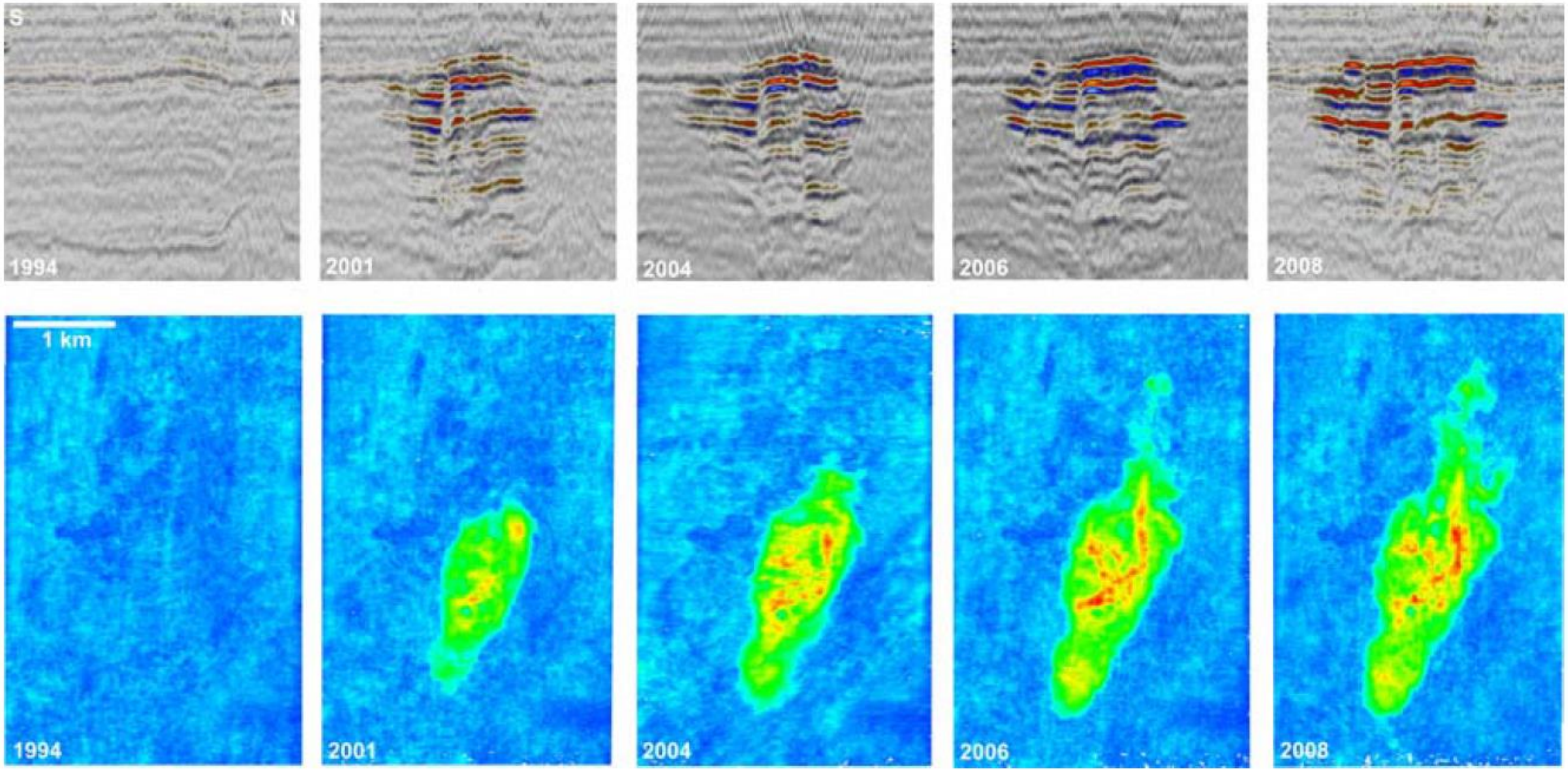
Radar satellite remote sensing



Source: http://www.cagsinfo.net/pdfs/cags2-workshop1/5-2LinlinGe2.pdf

4D seismic - Sleipner

Time-lapse seismic images of the Sleipner CO_2 plume – North-South inline through the plume (top), plan view of total reflection amplitude in the plume (bottom)



Source: http://nora.nerc.ac.uk/9418/1/Sleipner_TLE_v7_revised.pdf

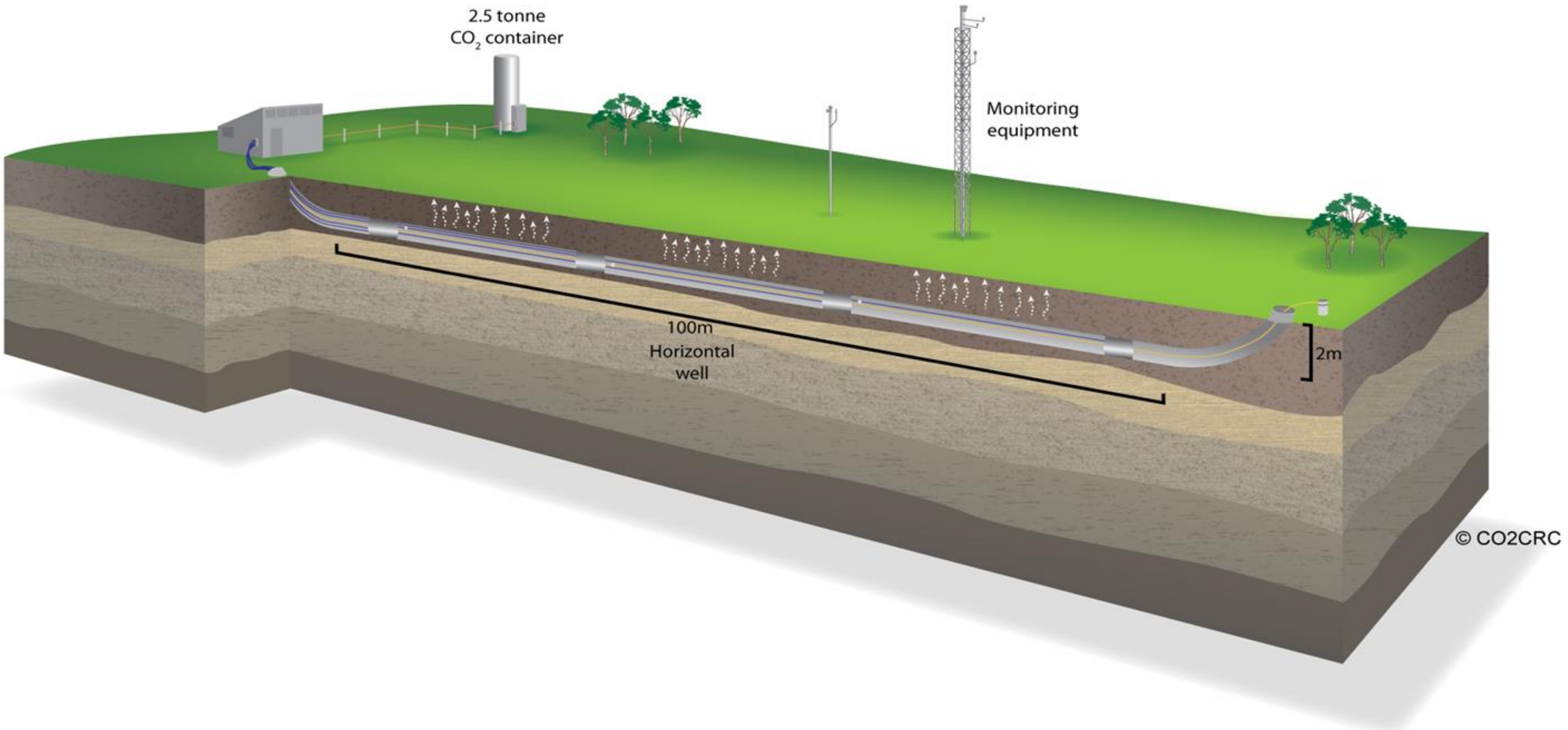
Gas isotopes in groundwater

Field collection of exsolved gases from groundwater for isotopic analysis useful for detecting small leaks in overlying aquifers

What would a leak look like?

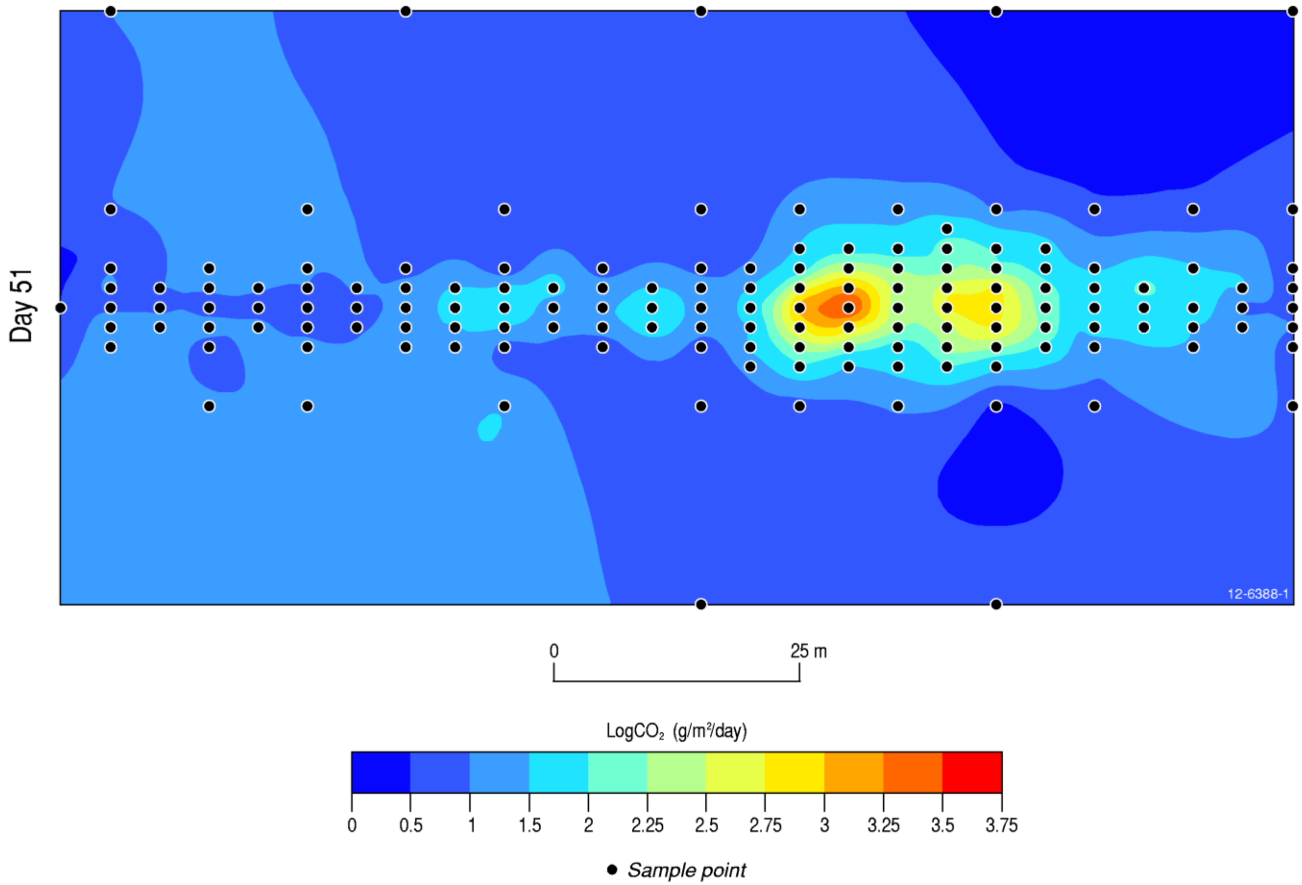
- No reported CO_2 leaks from CO_2 storage sites
- Investigating possible leakage scenarios using:
  - known leaky wells
  - natural CO_2 leaks
  - simulated leaks from controlled release facilities

Ginninderra controlled release facility, Canberra



Ginninderra - 0.1 t/d simulated CO_2 leak

Ginninderra CO_2 hot spots



Leaks are ‘patchy’

- Patchiness is a common theme from controlled release experiments (ZERT, Ginninderra, CO2 Lab (Norway)) and natural CO_2 seeps
- CO_2 finds highest permeability pathways to the surface
- High fluxes over a small area, not low fluxes over large areas
- Patches of dead vegetation a good indicator
- What appears homogenous is not when it comes to leakage

How do we quantify a leak?

- Primary technique is soil flux measurements
- Atmospheric measurements
  - Eddy covariance
  - Single sensor
  - Sensor array
  - Integrated line measurements

Soil flux

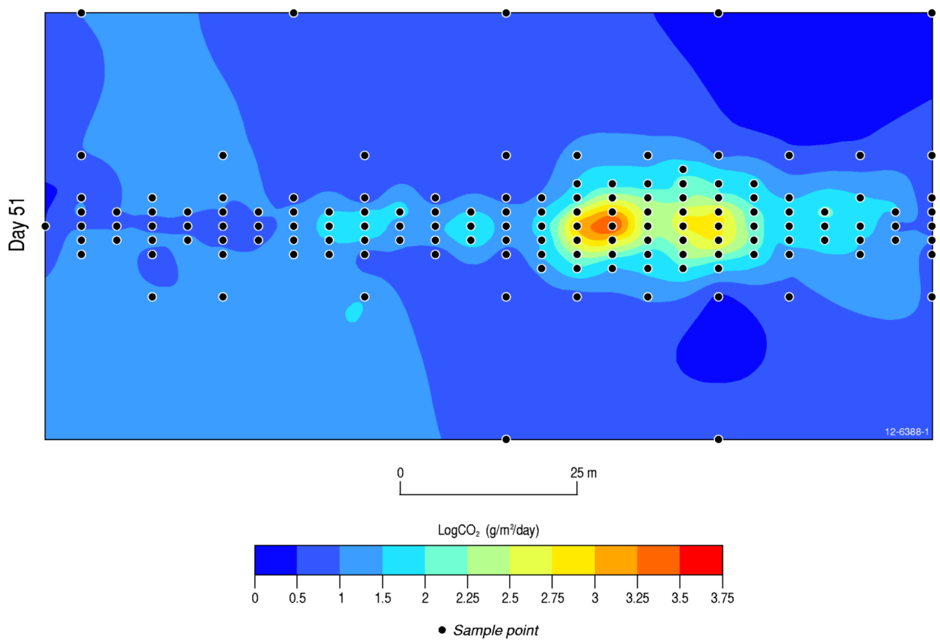
- Quick and easy but laborious
- ~150 measurements per day
- Accuracy is ~ 15%
- Two different approaches:

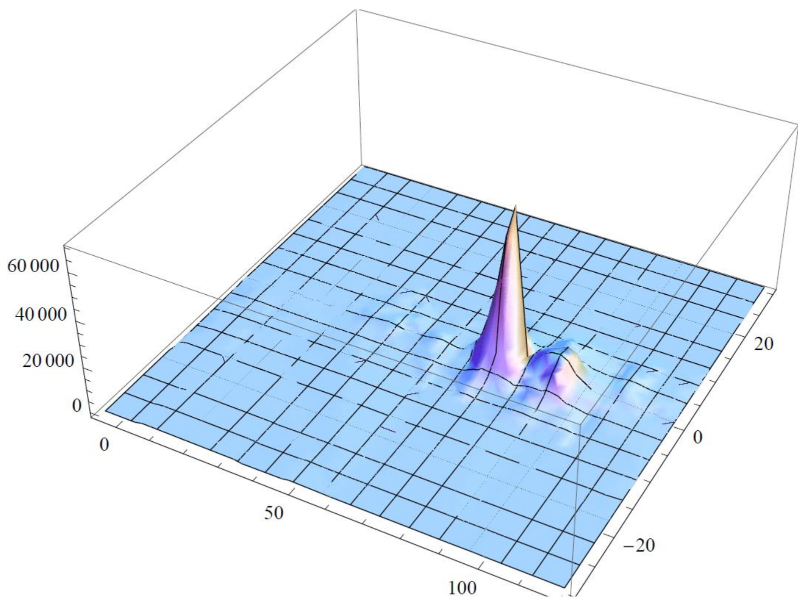
semi-permanent collars

portable chamber

Source: Westsystems, 2012

Soil flux – integrate flux measurements for total emission





g/m^2/d → 0.1 t/d leak

Atmospheric techniques – Eddy Covariance

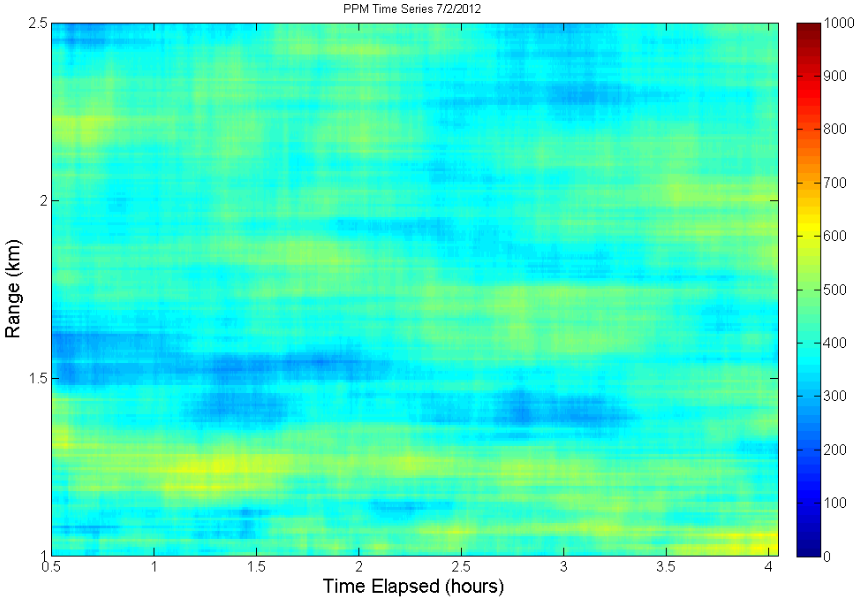
- Measures the vertical flux over relatively small areas (e.g. ~100 x 100m)
- Quantifying leaks requires lot of data processing
- Footprint not well defined
- Application to small leaks could violate EC assumptions

Atmospheric techniques - single sensor

- Quantifying leaks requires lot of data processing
- Need meteorological data
- Need to be downwind of leak
- Couple with modelling software
  - Backward Lagrangian Stochastic “bLS” model for short distances (e.g. Windtrax)
  - atmospheric transport models for greater distances (e.g. TAPM)
- Total flux quantification can be moderately accurate (e.g. typically 10-50%)

Atmospheric – integrated line measurements

- Line measurements (e.g. DIAL or TDL) could resolve emissions quicker and accurately when coupled to inverse models
- Tuneable Diode Laser (TDL) systems presently too insensitive for small CO_2 leaks



CO_2 DIAL system (Figures courtesy of Kevin Repasky, Montana State University)

Conclusions

- CO_2 leaks likely to be small and patchy
- Soil flux measurements easiest method for quantifying leaks
- Atmospheric tomography is very accurate but difficult and slow
- Integrated line measurements coupled to inverse modelling show promise for rapid quantification (e.g. within a day)
- But … need to find the leak in the first place

  soil flux and atmospheric techniques are primarily for quantification, not detection

Questions?

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