What is the worst-case?
Understanding potential impacts from leakage: current European research

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Outline

- Introduction
- Addressing key challenges from regulators (of carbon markets and environment), politicians and NGOs
- How might leakage occur?
- What are potential impacts?
- Can we detect and measure leakage?

INTRODUCTION AND RATIONALE

Introduction

- CO2 Geological Storage will be designed to prevent leakage
- However, it is important to consider the consequences of leakage should it occur
- Much of past research has been focussed on:
  - Demonstrating feasibility of storage via opportunistic industrial projects – mainly from natural gas cleaning
  - Demonstrating detection and monitoring at depth
  - Examples include Sleipner, In Salah, Weyburn, Gorgon…

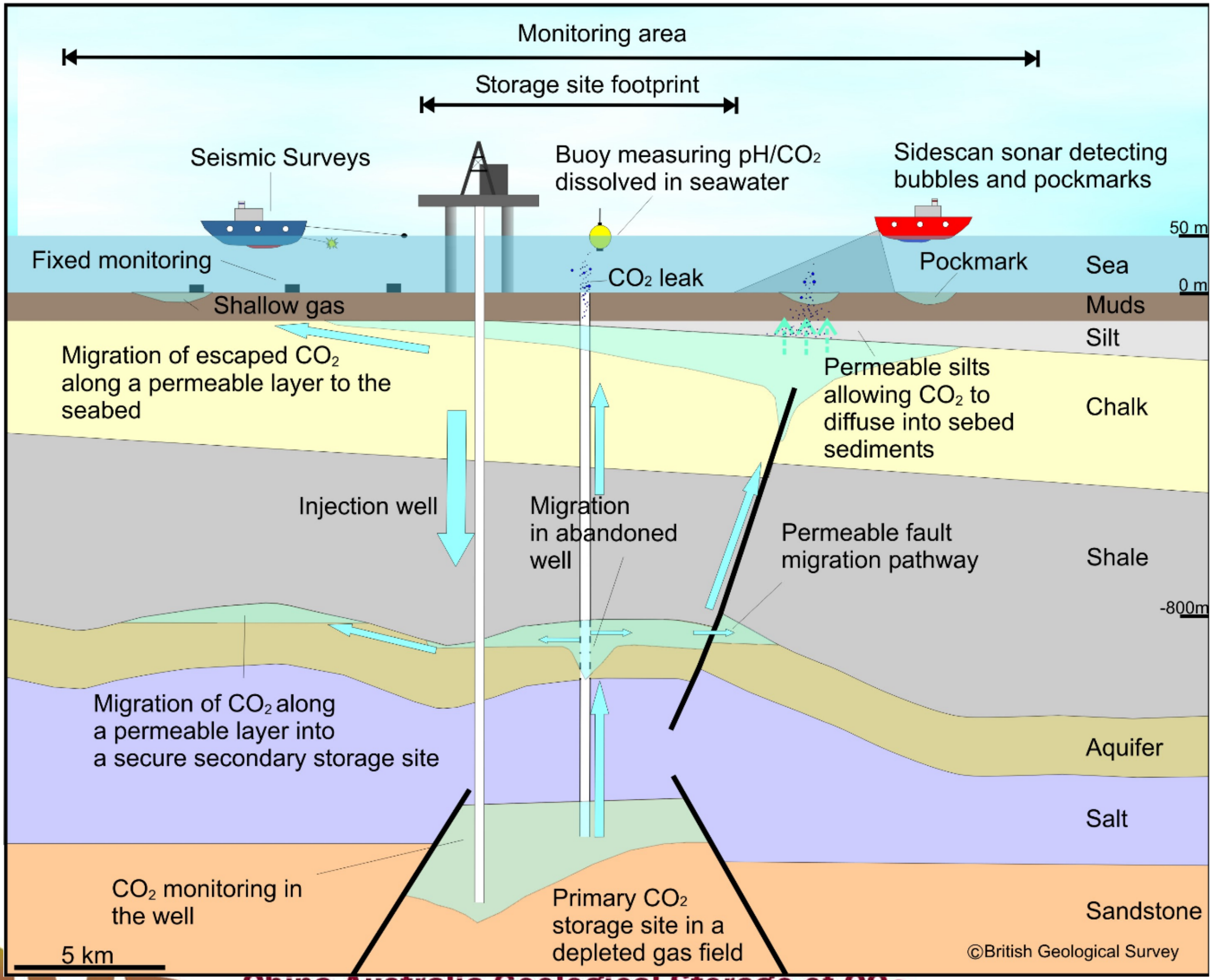
Introduction

- Critics and proponents naturally point out that some issues remain unresolved…
  - If a leak should occur:
    - What would be the impacts? (RISCS, QICS, ECO2)
    - Can we detect and measure the leak? (CO2FieldLab, CO2GeoNet, CO2ReMoVe)
  - How do we reduce the risks of leakage?
    - Site characterisation and abandonment (SiteChar, CO2Care)
    - Monitoring

Storage sites need to demonstrate:

- Appropriate capacity
  - Techno-economic assessment requiring reservoir modelling based on geological model(s) derived from site characterisation
- Suitable injectivity
  - Petroleum engineering assessment
- Long-term containment
  - Requires predictions of future performance to demonstrate reducing risk profile
    - Long-term trapping
    - Leakage mechanisms
    - Potential impacts of leakage

How might leakage occur?



WHAT COULD BE THE IMPACTS OF A LEAK?

Overview of RISCS project

- RISCS is concerned with the potential marine and terrestrial environmental impacts of leakage
- This is likely to be a requirement for Risk and Environmental Impact Assessments
- RISCS is assessing both terrestrial and marine impacts through experiments, natural observations and modelling
- Key findings in Guide to Impacts Appraisal

RISCS Project

www.riscs-co2.eu

Damaged pasture from natural CO_2 seeps in northern Greece

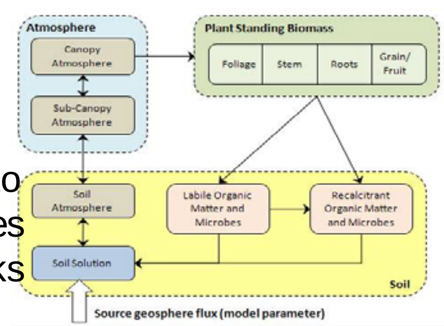
Natural CO_2 seeps near Sicilly used to investigate marine responses to CO2 leaks

Palaemon serratus, one of several marine species whose response to elevated CO_2 is being investigated

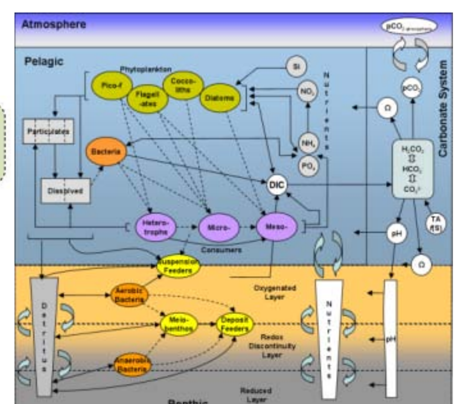
Monitoring CO_2 fluxes in experiments investigating impacts of CO_2 leaks on agricultural soils and crops

- Investigating impacts of potential leaks from storage sites to inform risk assessments

Mesocosm experiments investigating impacts of elevated CO_2 on benthic organisms. *Courtesy of Edwin Foekmar, IMARES*



Soil-plant model used to investigate plant responses to CO_2 leaks



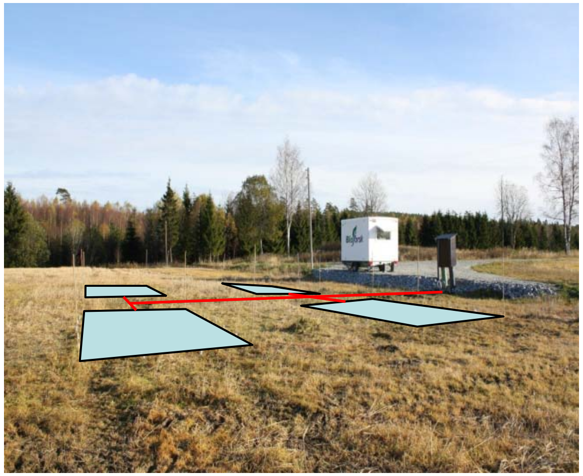
Marine biogeochemical model for investigating marine responses to CO_2 leaks

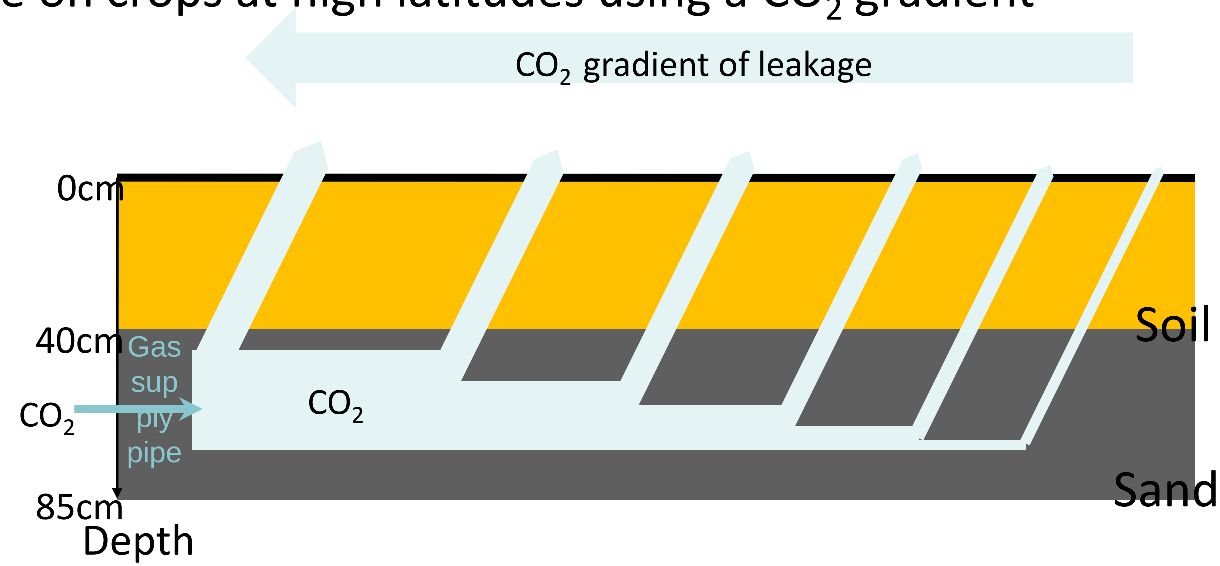
Terrestrial Impacts

- Experimental injection sites
  - Grimsrud Farm, Norway
  - ASGARD, UK
- Greenhouse experiments
  - Norway – impacts on vegetation
- Natural field observations
  - Florina, Greece – impacts on groundwater
  - Latera and San Vittorino, Italy – impacts on vegetation and groundwater
  - Montmiral, France
- Modelling of leakage scenarios using results

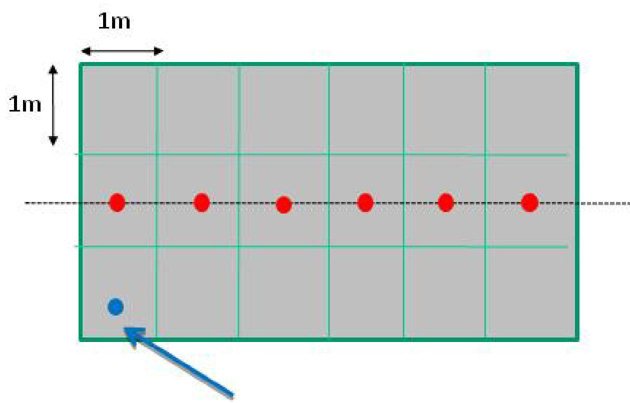
Grimsrud Farm, Experimental site

To test effects of CO_2 leakage on crops at high latitudes using a CO_2 gradient

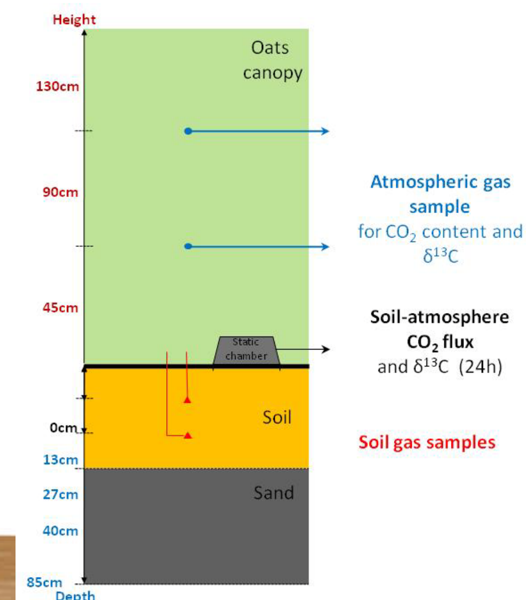




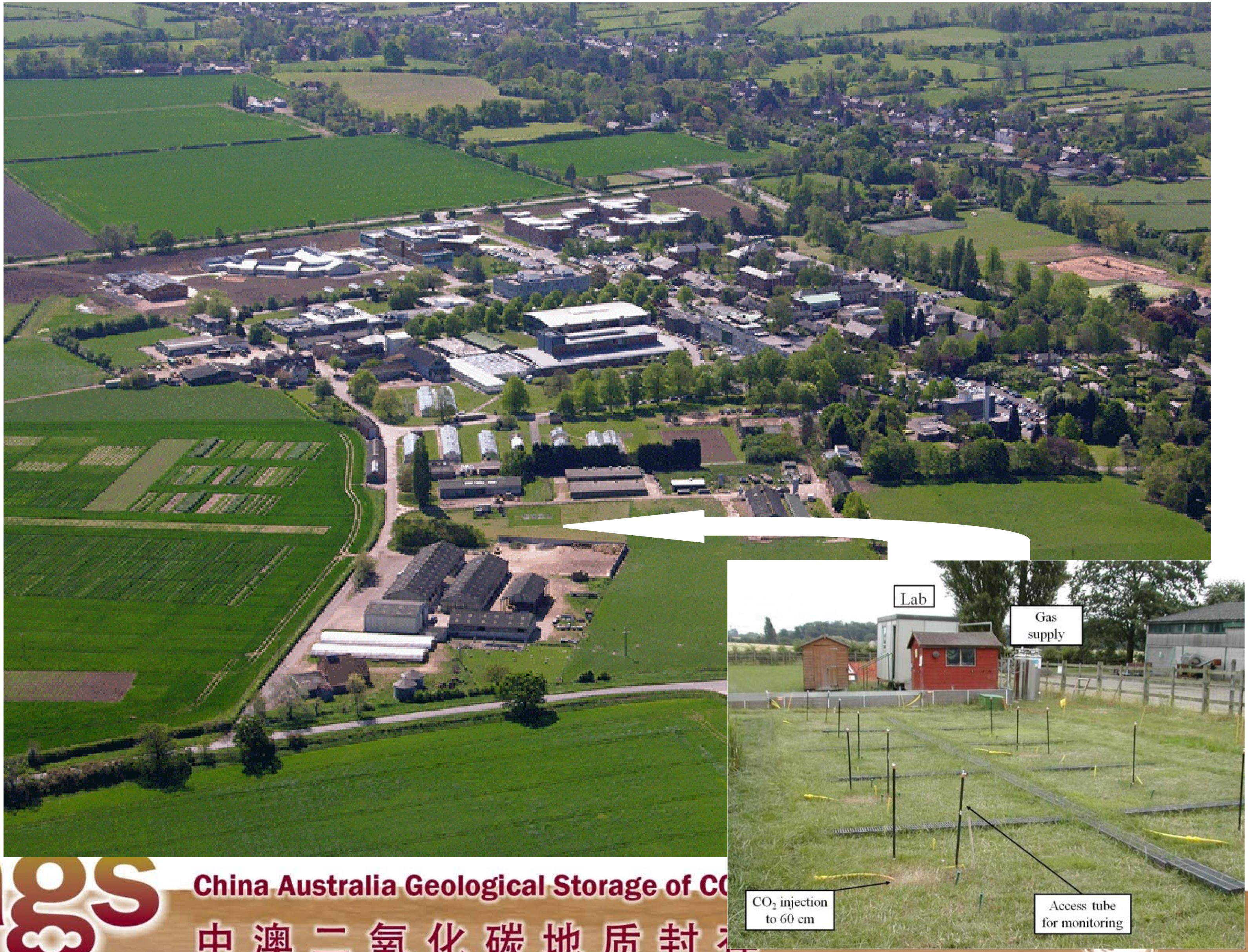
Flux measurements and gas sampling points



Also soil temperature and humidity (2 depths)



ASGARD experimental site



ASGARD: 2010 Spring Crop Experiments

Crops

- Oilseed rape (*Brassica nupus*)
- Barley (*Hordeum vulgare*)

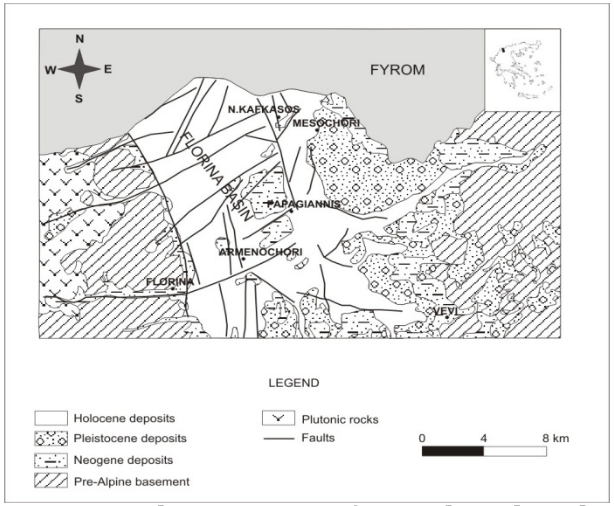
CO_2 supply

- CO_2 delivered from 6th June 201
- Injection at a depth of 60 cm
- Supply rate 1 litre min^{-1}

Visible changes

- Occurred within 7 days
- Oilseed rape leaves turned purple
- Barley leaves turned yellow

Florina, northern Greece



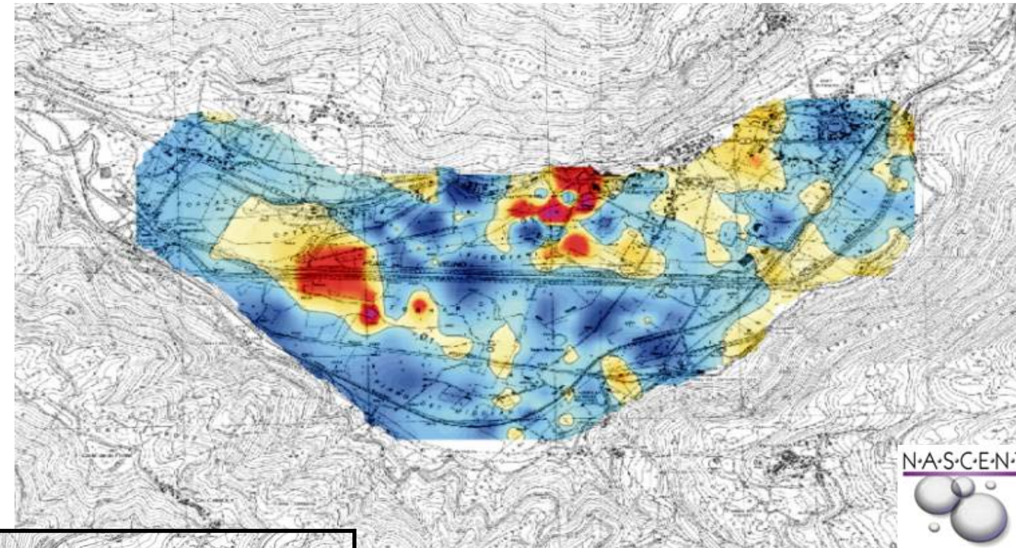
Geological map of Florina basin

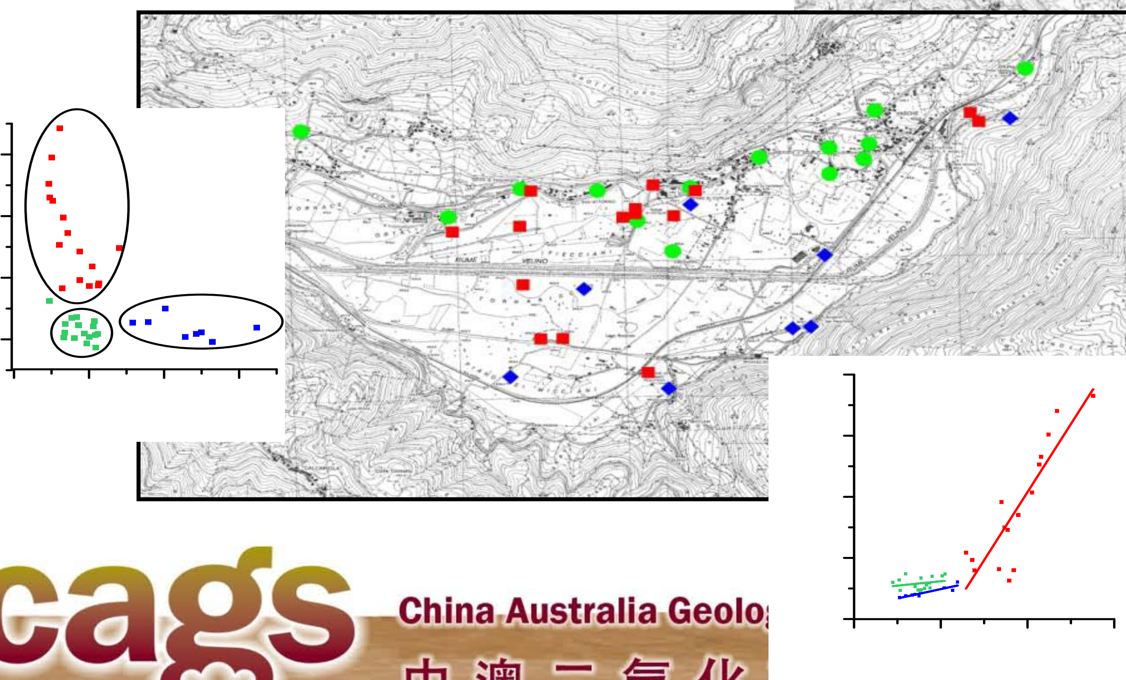
Destroyed by the CO2 irrigating well

CO_2 gas vents

- More than 50 water samples will be taken and analysed
- Soil gas concentrations will be measured at around 300 points, in the area with CO2 gas vents, at 80-90 cm depth with a grid of 15m spacing.
- Detailed and closely spaced measurements will be conducted around the specified transect.
- Sampling of plants irrigated by CO2 impacted water will have for isotope δ^{13} C_{CO2} measurements.

Groundwater impacts at San Vittorino





- Group 1 (green) are mainly along north,
- Group 3 (blue) are mainly along south
- Group 2 (red) is anomalous - associated with faults and leaking CO2

QICS summary

Scientific aims

Understanding the geological, chemical and biological impacts of a leak from a CCS system and the physics of CO_2 transfer and dispersion.

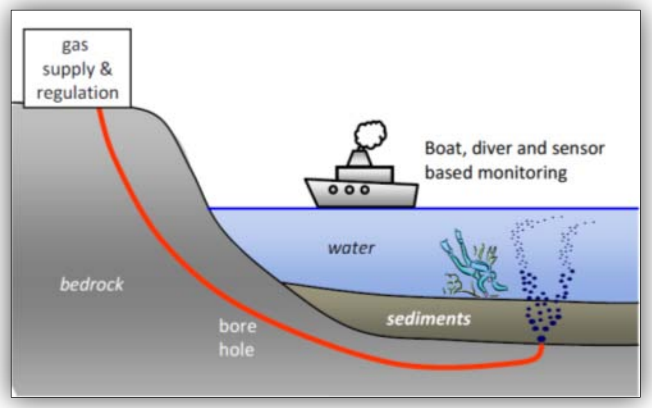
- To establish **how CO_2 behaves and moves** in different environments from the deep geological storage reservoirs, to the seabed and finally into the atmosphere.
- To evaluate the **biogeochemical and ecological impacts of a CO_2 leak** in shallow marine sediments and seawater.
- To establish **methods for the early detection and monitoring** of leaks

QICS objectives

- Determine the **manifestation of a potential CO_2 leak from the geological storage reservoir**
- **Integrate existing physical, biogeochemical and ecological models** of the shallow sediments and water column
- **Quantify the impacts of any CO_2 released** on the marine sediment and water
- Determine the **impact of CO_2 leakage on sea floor ecosystems**
- Evaluate the techniques and methods for **monitoring leaks**
- Evaluate the **impact of a wide range of leak scenarios**, and to devise a risk assessment plan and mitigation strategy

QICS activities

- Selection of a site and drilling of a borehole
- Controlled submarine release of CO_2
- Measuring and monitoring of the site prior to, during and after the release
- Knowledge exchange:
  - QICS website
  - Stakeholder Advisory Panel
  - Best Practice Manual
  - End-of-project Stakeholder Workshop
  - Conference presentations

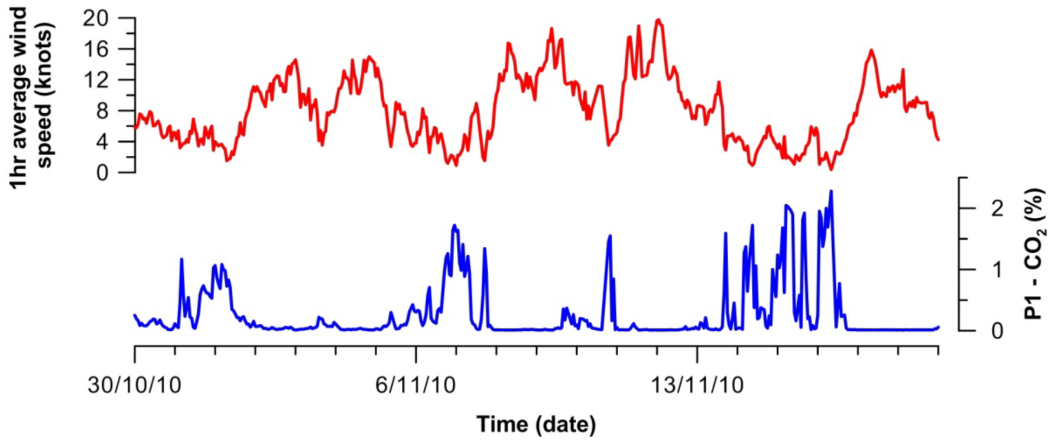


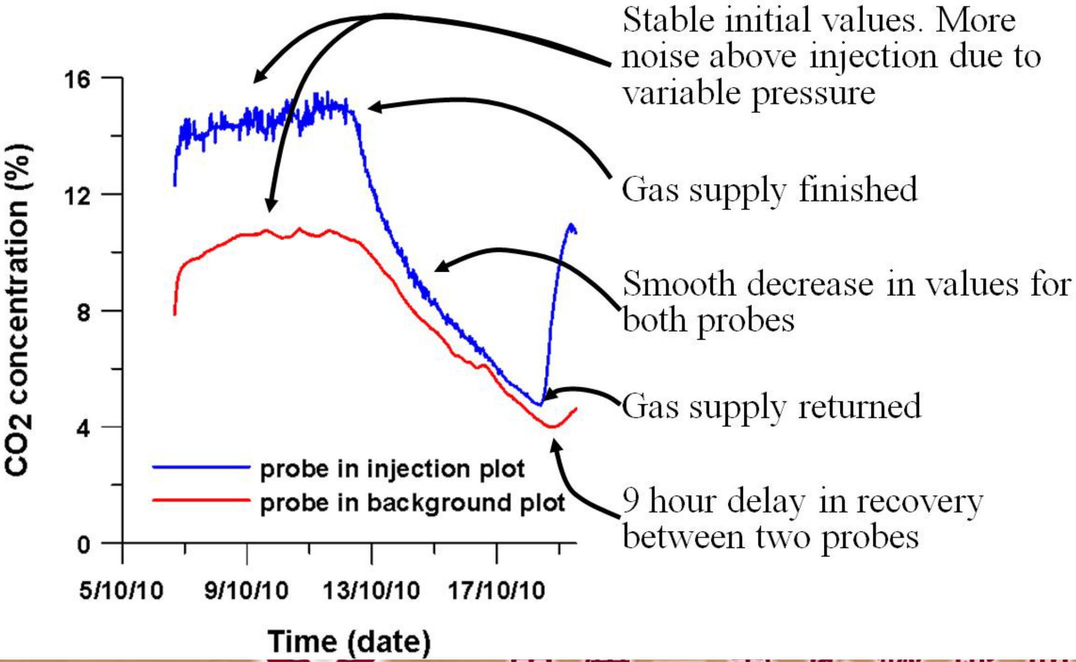
CAN WE DETECT AND MEASURE A LEAK?

Why measure?

- European Emissions Trading Scheme requires measurement of leakage to atmosphere or ocean
- Need to demonstrate remediation, if required, is effective
- Need to demonstrate no leakage to enable site transfer to the state at the end of the project.

Soil gas monitoring station – e.g. ASGARD

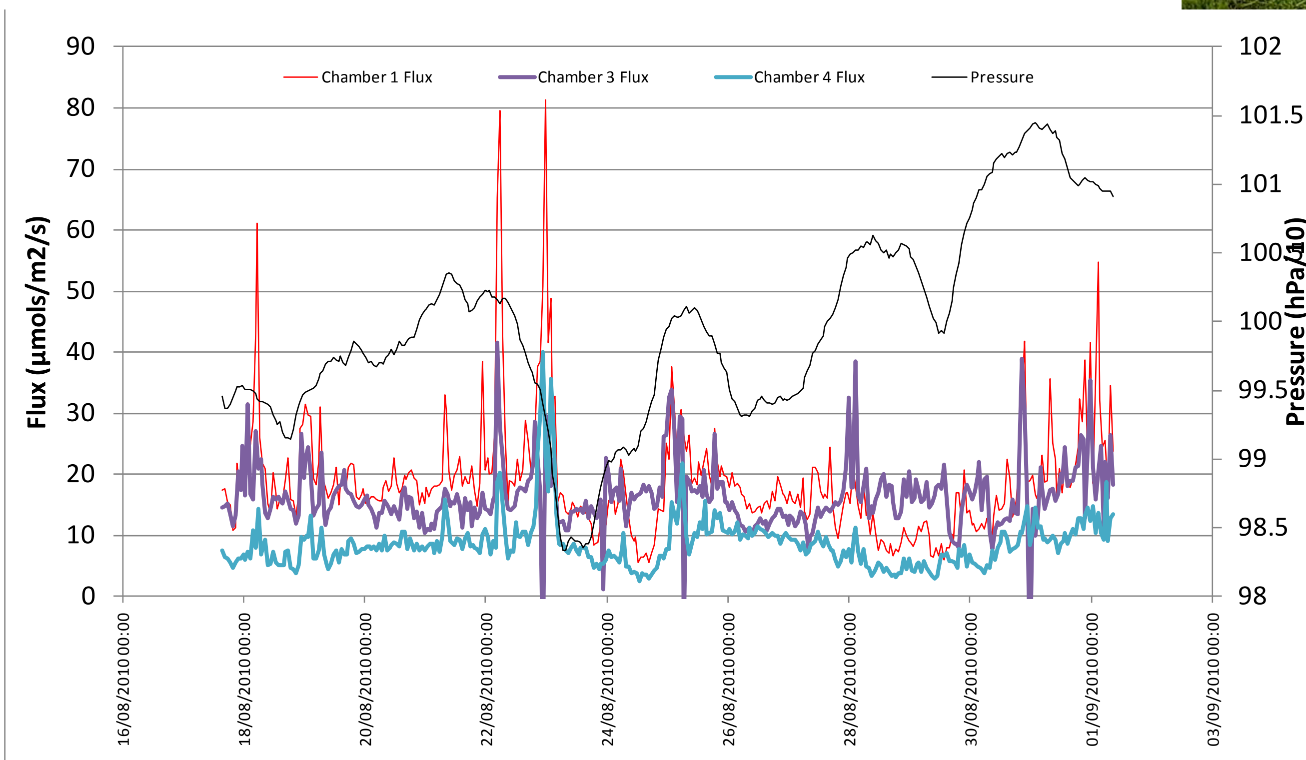




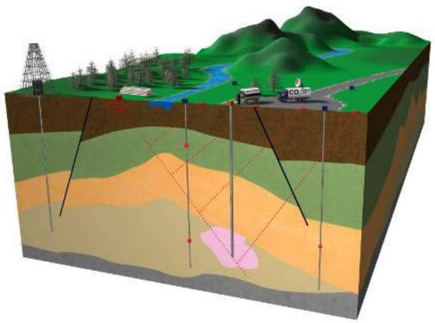
- 3 probes – 2 in soil, one on ground surface
- Monitor CO_2 and CH_4 concentration, T, P every 30 minutes
- Data transfer in real time, access via the internet
- Strong inverse correlation between CO_2 and wind speed
    - High CO_2 values (up to 2%) observed in the vegetation canopy only when wind values are lower than 4 knots, whereas higher winds result in concentrations near normal atmospheric values

Flux monitoring station

- I measurement/Ch/h
- 15 days data
- Measure in sequence
- Remote control/data

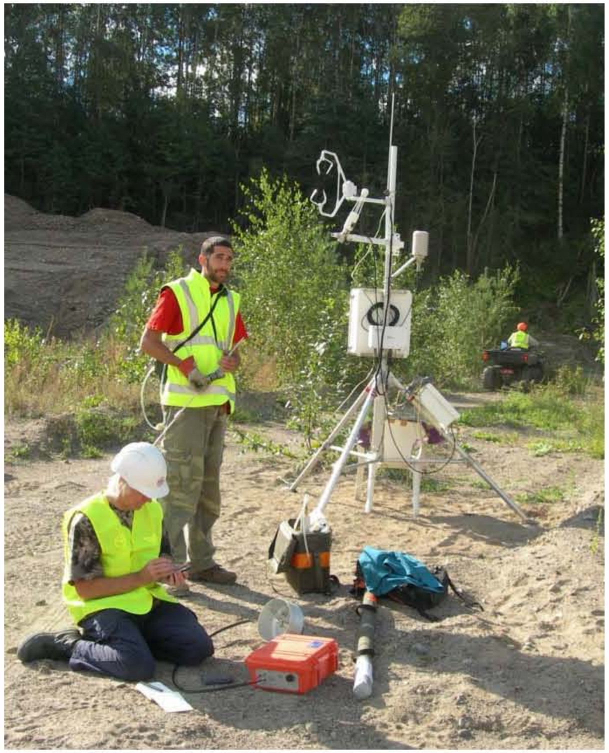


CO2Fieldlab



- A field Laboratory, where CO_2 can be injected in permeable rocks in a well-controlled and well-characterised geological environment. CO_2 will be injected to obtain underground CO_2 distributions that resemble leakages.

Objectives



- CO_2 injection in permeable reservoir
  - Shallow
  - Deep
- Sensitivity of monitoring systems
  - subsurface migration
  - surface leakage
- Assess monitoring systems and requirements
- Migration models
- Inform the public
- Protocol / certification scheme

Drilling – June 10

Monitoring of CO_2 displacement

Geophysical surface measurements	Monitoring well measurements	Soil / surface / atmospheric m.
• 4D ERT, SPT • EM, NMR • Passive seismics • Active seismics • Time-lapse ERT	**MW1: WestBay** • CO_2, isotopes, induction logging, pressure, temp. **MW2:** • Permanent electrode array, logging	• Soil gas • Surface gas: Laser gas analyser, accumulation chambers, atmospheric tower • Shallow wells: water sampling

Modeling: History matching

Monitoring of CO_2 impact

Geophysical surface measurement	Well measurements	Soil / surface / atmospheric m.
	MW1: WestBay • Water sampling • Analysis of bacteria activity	• Water sampling • Analysis of bacteria activity

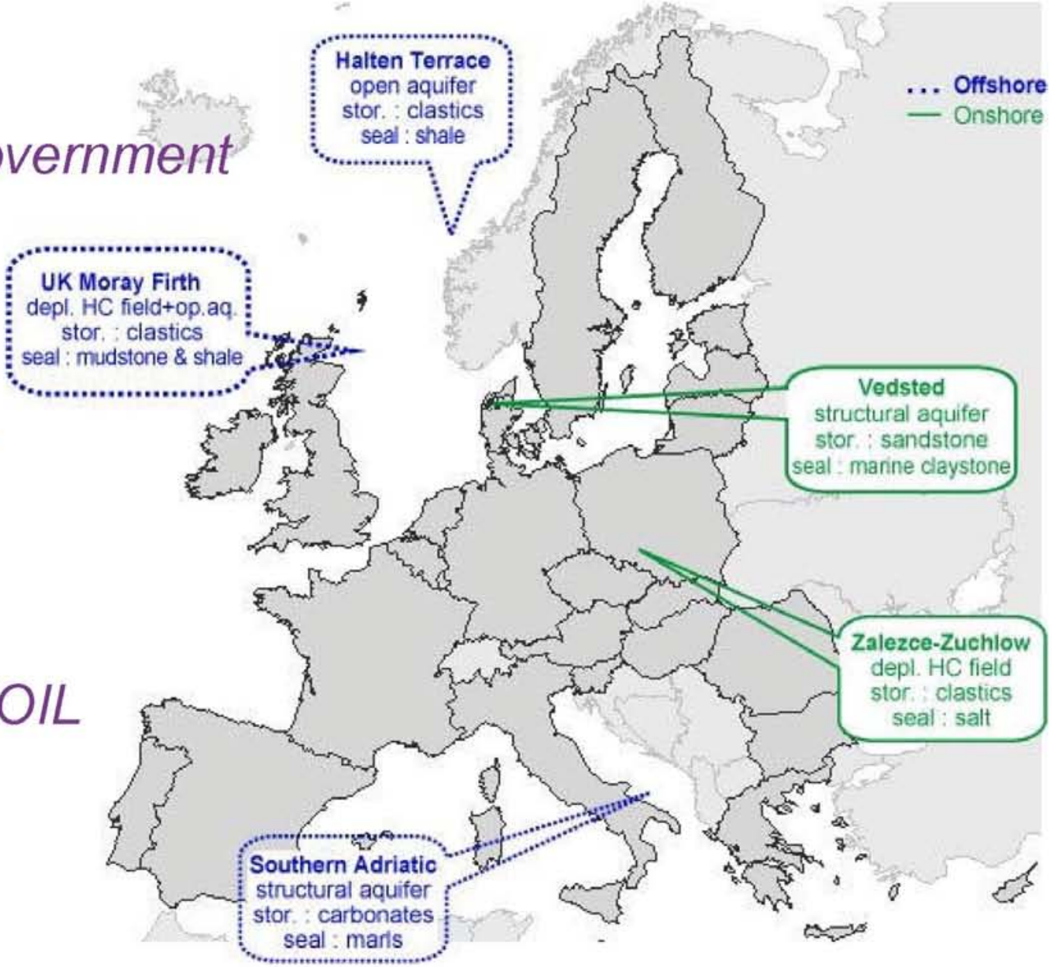
SITE CHARACTERISATION

Site Characterisation: The SiteChar project

- Provide the key steps required to achieve readiness for large-scale implementation of CO2 storage in Europe:
  - Demonstrate the level of geological characterisation and assessment of long-term storage complex behaviour rigorously tested in accordance with the regulatory requirements
  - Refine the complete generic storage site characterisation workflow up to the final stage of licensing
  - Assess dry-run licence applications by a group of geological experts and regulators
- Focus on representative sites where CCS is most likely to develop in the near term

The portfolio of sites

- **UK North Sea**
  NERC */ Scottish Government*
- **Vedsted**
  GEUS */ Vattenfall*
- **Zalecze & Zuchlow**
  PGNiG */ AGH*
- **Halten Terrace**
  SINTEF-PR */ STATOIL*
- **Southern Adriatic**
  OGS */ Enel*



SiteChar issues

- **Development of a generic CO_2 storage site characterisation workflow**
- **Impartial reviews of licence applications**
- **Comparative economic assessment of the sites**
- **Social site characterization and public engagement activities**
  - **Raising public awareness and enable informed opinion formation**
  - **Making available site-specific information**

SiteChar outcomes

➔ **Technical recommendations for storage site characterisation and best practice guidance for storage licensing from the perspective of both applicant and regulator**

www.sitechar-co2.eu **or** ***www.sitechar.eu***

Conclusions

- Appropriately selected, designed and operated sites are not expected to leak
- Regulators, policy makers and the public are now challenging industry and scientists to:
  - Demonstrate an understanding of potential for leakage
  - The impacts of leakage
  - Capabilities to detect and measure leakage
- A range of projects (some discussed here) are addressing this issue through:
  - Laboratory experiments
  - Small-scale field tests
  - Examination of natural 'analogues'

Conclusions

- However prevention is better than cure:
- If leakage did occur, operators may be faced with the burden of very long monitoring
- Hence the focus will be on deep monitoring of the reservoir for early detection