British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Assessing technical risks in the geological storage of CO_2

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With many thanks to: Richard Metcalfe (Quintessa),
Jerry Blackford (Plymouth Marine Laboratory) and the RISCS team.

Outline

- Introduction
- Key risks in storage operations
- Risk quantification
- Examples of quantifying consequences/impacts
- Quantifying probability
- Conclusions

Why do we need to assess storage risks?

- Storage remains the ‘riskiest’ part of CCS, being the least proven and least predictable
  - Operators are reluctant to currently undertake demonstrations without government acceptance of storage risks

- The long timescales associated with CO_2 storage require operators to demonstrate storage will be safe both during injection and importantly following site closure.
  - This requires a detailed assessment of risks and uncertainties.
  - Assessment will continue throughout the project life.

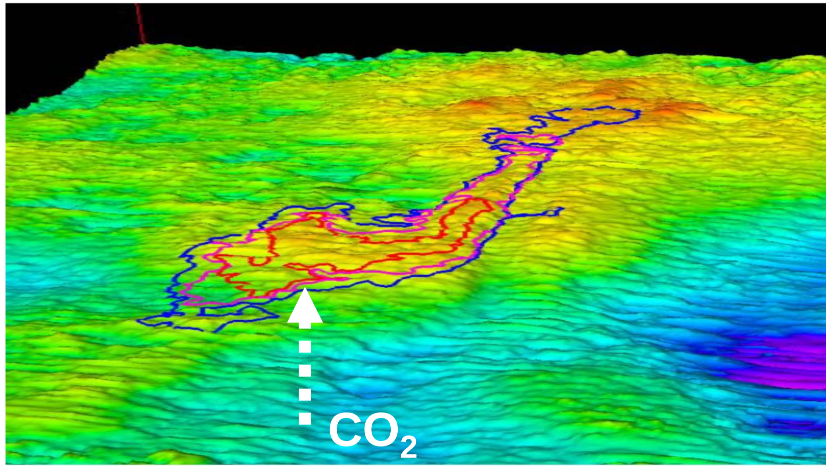
What are the principle forms of storage risk?

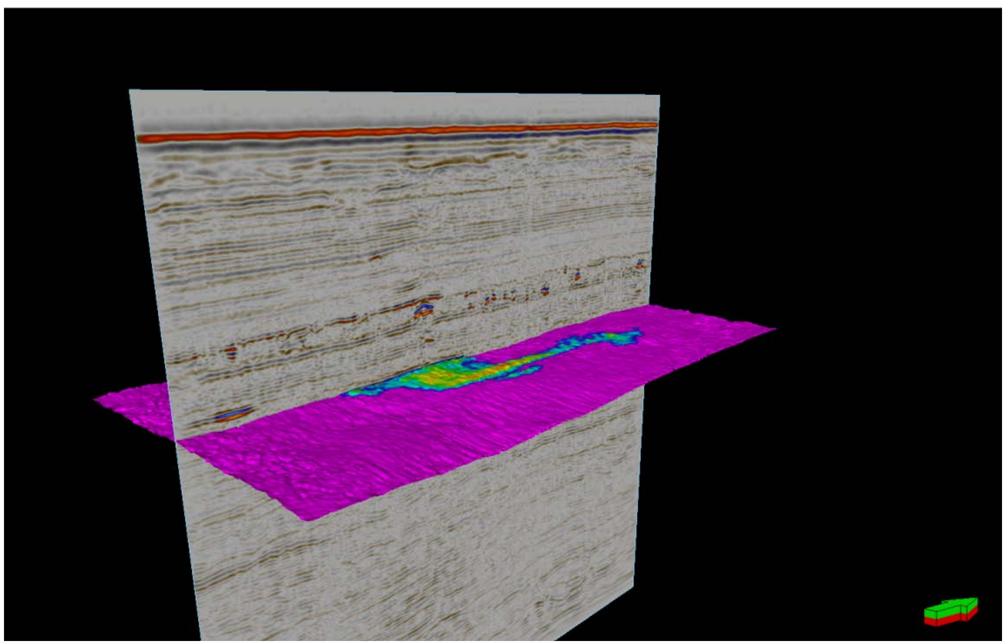
- Inherent geological uncertainty
  - Site characterisation, driven by risk assessment, will reduce this uncertainty as much as possible.
    - How much certainty is enough?

- Impacts on other resources
  - For example, pressure responses and brine displacement

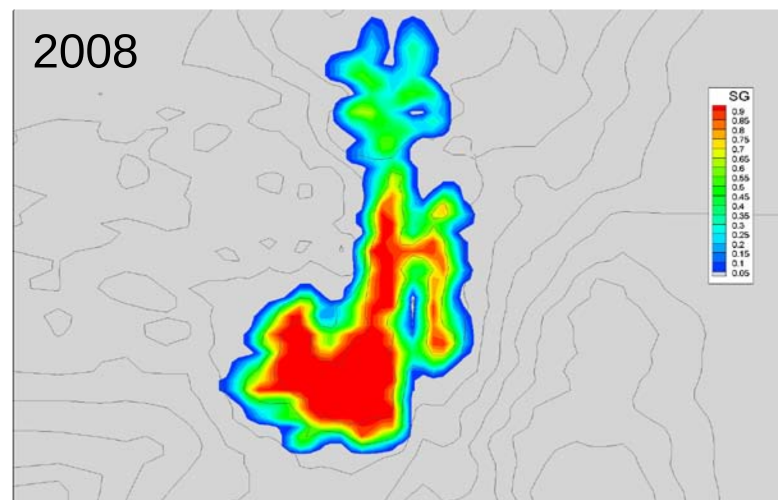
- Risk of leakage
  - Loss of revenue
  - Potential environmental impacts

Inherent uncertainty:
Monitoring & prediction at Sleipner





observed layer growth

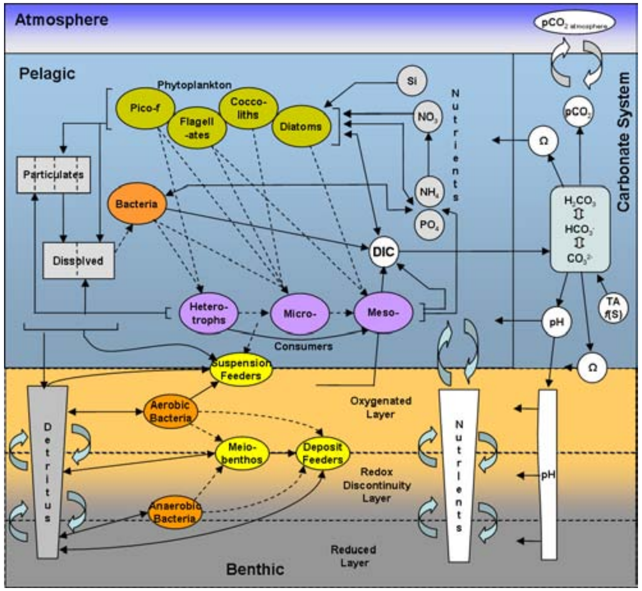


simulated layer growth

Quantifying consequences

- Quantifying processes and consequences is more easily achievable – though still some gaps
  - Processes include:
    - geochemical reactions (dissolution, reactions with minerals, hydrocarbons)
    - Movement of CO_2 and other fluids underground and at the surface
- Requires detailed site characterisation to constrain rates and likely scenarios of site evolution
- Consider impacts of leaks from CO_2 storage sites as an example.

CO_2 dispersion in sea



Physical dispersion.

Adopting a prognostic, unstructured-grid, finite-volume, circulation model (FVCOM).

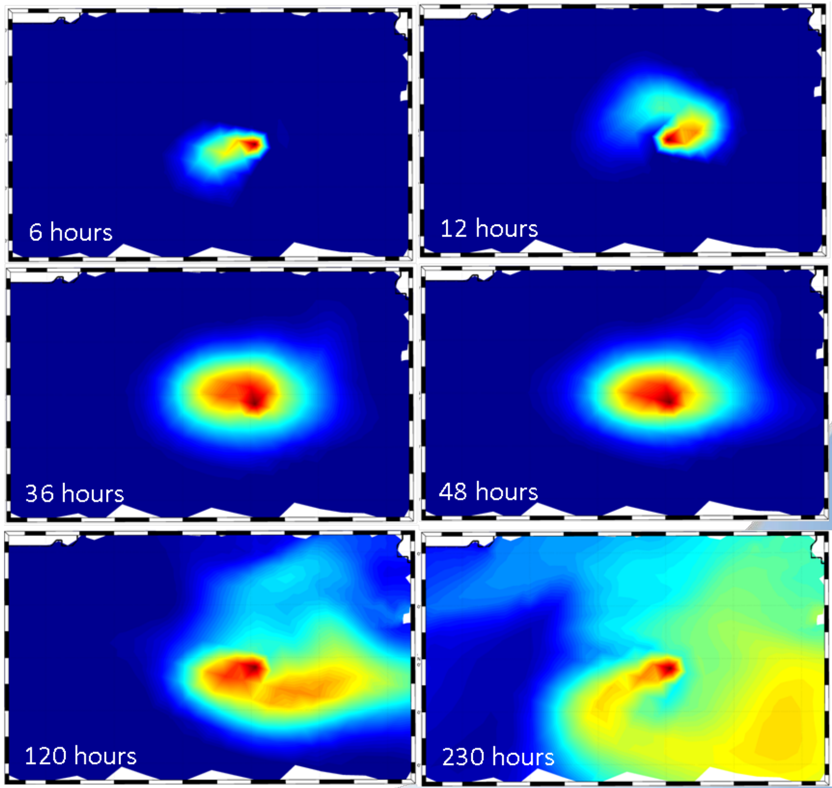
Developed model to include high CO_2 density effects and a full Carbonate (CO_2 chemistry) System.

Key findings to date:

Strong tidal mixing in NW European seas implies that the dispersion of a leak will be complex making monitoring a challenge. However rapid dispersion will generally mitigate against extreme impacts due to dilution.

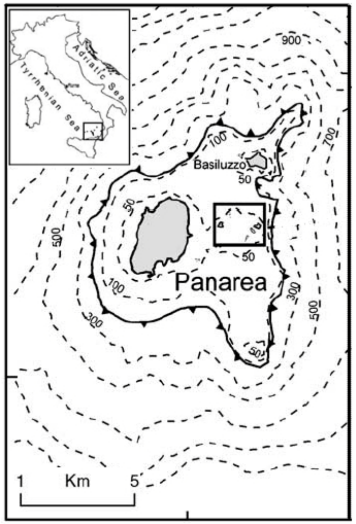
Due to density effects the sea floor is likely to see greater exposure to CO_2 plumes than the water column or surface waters.

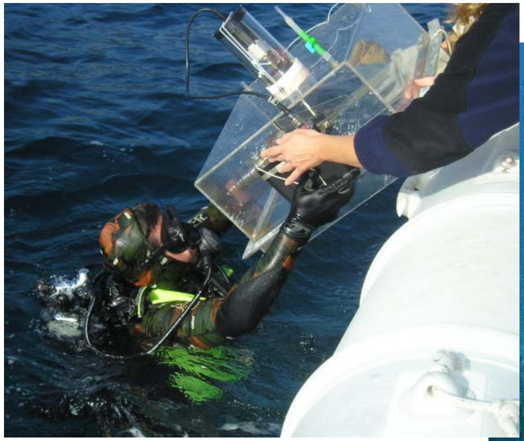
Any leak event will be unique, depending on the state of the tide, wind driven mixing, geographical location and leak amount and duration.

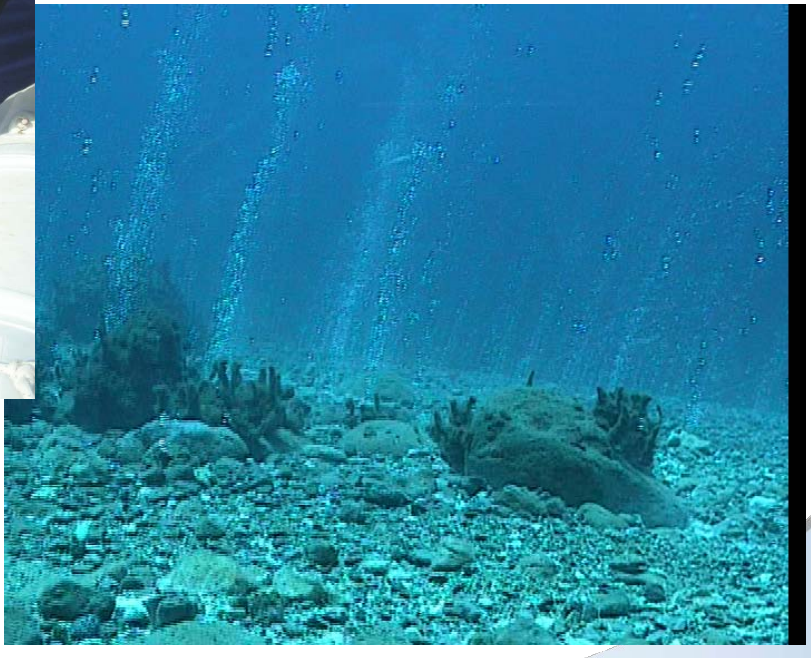


Models of CO_2 interactions in marine ecosystems

- Constraints on rates, scales and responses from specific species can be determined from experimental studies and characterisation of natural analogues







Quantifying likelihood or probability

- Site characterisation, project design and subsequent operation are designed to minimise likelihood of hazard ocurring.
- Quantifying likelihood or probability is more difficult
  - Lack of a mature industry prevents the use of statistical enquiry on the number of incidents, failures etc
  - Estimates of probability sometimes based on expert opinions which might differ widely
  - Any quantitative probability might have large range of uncertainty
- Do we need to quantify likelihood?
  - Is there an alternative approach?

Alternative approach

- Operators should demonstrate:
  - Relevant risks have been identified and qulaitatively ranked (consequence/severity and likelihood/probability)
  - Where possible, risks have been mitigated through:
    - Site selection
    - Site characterisation
    - Project design
  - Any remaining risks are acceptable
    - Consequences will be small
    - (Qualitative) Likelihood will be low
    - Monitoring and remediation plans are comprehensive, flexible and meet requirements

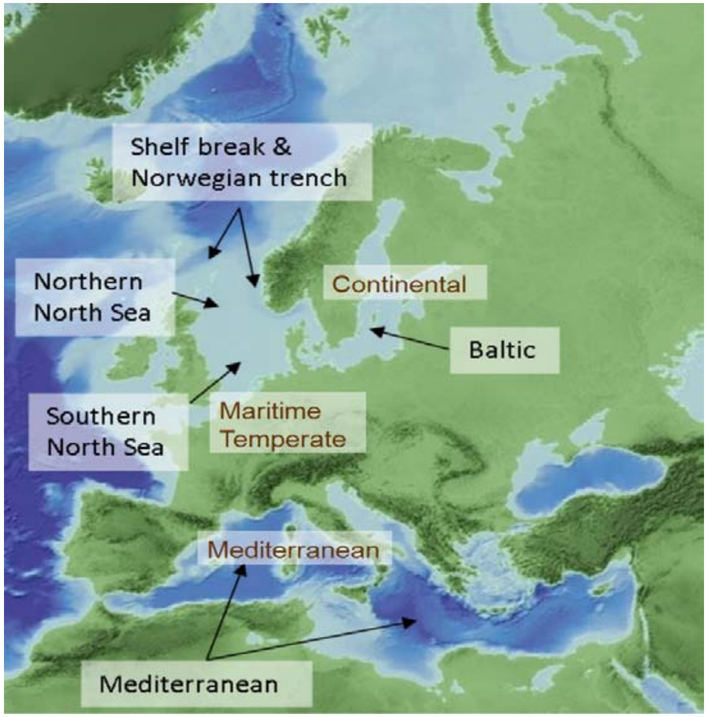
Taking a whole-system view

- Need to define plausible scenarios for storage site behaviour:
  - The RISCS research consortium defines scenarios as:

    "A plausible description of the potential evolution of a system according to the nature of the features, events and processes that might act within and upon it."
  - Scenarios are hypothetical situations, not predictions
- *Plausible:*
  – Consistent with fundamental physical / chemical / biological principles and laws
  – Probability not agreed to be so low as to be of no concern to anyone

Reference Environments

- Identify a range of European ***environment types (not specific sites)***
- CO_2 could feasibly be stored in the kinds of environment
- Aim to ensure that all relevant processes influencing potential impacts / safety are represented to some degree across one or more of the environments



*Recognize impossibility of investigating **explicitly** all environments that occur and processes that might affect them*

Scenarios

- Both ***marine*** and ***terrestrial*** environments:
- ***normal evolution*** scenario is containment (for comparison with leakage scenarios)
- ***'What-if' alternative evolution*** scenarios for leakage consider potential impacts via:
  - Direct release of CO_2 to the atmosphere (***terrestrial*** environments)
  - Localised (point-source) short- or longer- term emissions to near-surface soils or to aquifers (***terrestrial***); to sediments and the water column (***marine***)
  - Diffuse (linear or over a wide area) emissions to the same systems
  - Release to a ***terrestrial*** urban environment

Marine Reference Environments

Cool, temperate, deep	**Continental shelf remote from shoreline, water depth > 60 m, typically > 100 m. Not Arctic but bottom water ~5˚C. E.g. northern North Sea, or to the west of Norway.**
Cool, temperate, shallow	**Land is relatively close and the water depth ~ 10s of m. Temperature varies: ~ 4˚C - ~15˚C. e.g. southern North Sea.**
Warm, shallow	**Land is relatively close and the water depth ~ 10s of m. Temperature is a minimum of 5˚C at the seabed and varies from ~ 6˚C to ~ 25 ˚C, at the sea surface. e.g. Adriatic Sea.**
Low salinity	**Land is relatively close and the water depth ~ 10s of m. Water salinity lower than that of open ocean water. e.g. the Baltic Sea.**

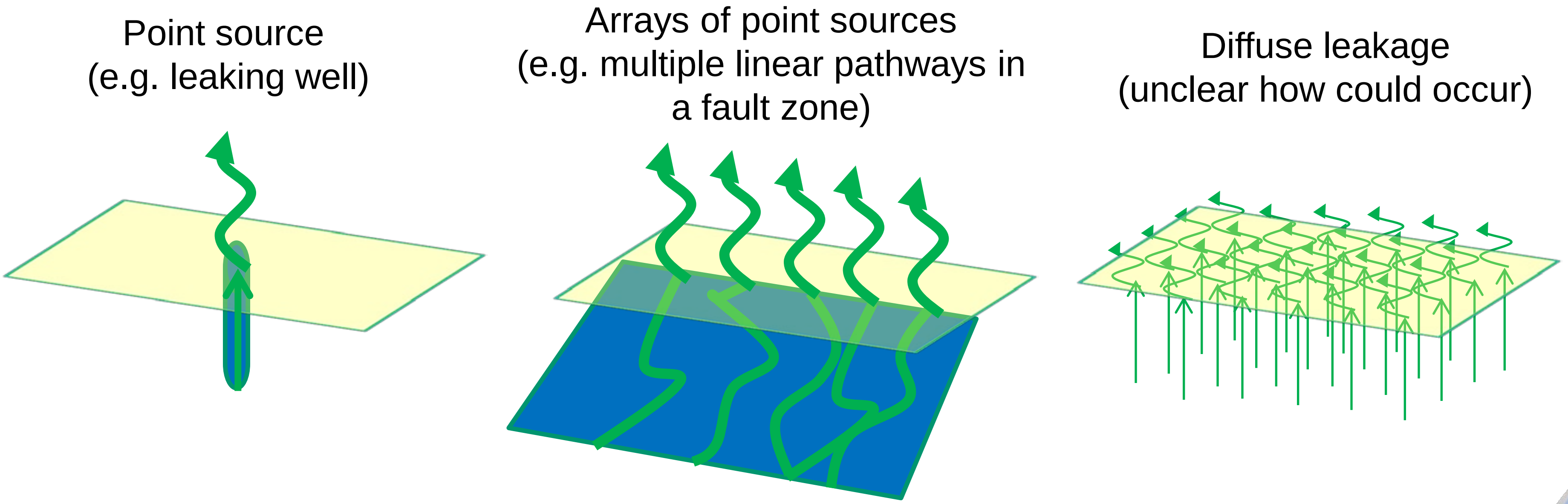
Terrestrial Reference Environments

Maritime Temperate	Representative of a northern central European, cool climate (e.g. UK and the Netherlands).
Continental	Climate associated with northern (but not Arctic) European continental land mass countries.
Mediterranean	Representative of warmer, more arid, southern European climates.
Generic Urban	Specifically designed to explore potential impacts on humans should a storage system be located close to a large urban centre.

Plausible Fluxes and Areas

Fluxes = Quantity of CO_2 per unit area per unit time

Various leakage patterns can be envisaged, e.g.



- Given CO_2 storage would not be permitted if significant probability of leakage fluxes and areas inherently unlikely
- "Plausible" means does not violate fundamental physical / chemical principles / laws and all parties agree to be conceivable

The RISCS project Guide to Impacts Appraisal

- Inform key stakeholder groups on specific issues:
  - What to consider when appraising potential impacts in the event of leakage from a storage site;
  - How to evaluate the potential impacts at the various stages of a storage project development: design stage, construction, operation, post-injection and to enable transfer of site liability to the competent authority;
  - Options for directly assessing the potential scales (temporal and areal, realistic leakage ranges (fluxes, masses)) and ecosystem responses.;
  - Options for identifying, predicting and verifying the nature of impacts.

Conclusions 1

- Storage risks arise from:
  - inherent geological uncertainty - some sites will be inherently more 'uncertain' than others – especially larger saline aquifers
  - Long-term nature of storage and properties of CO_2
- Processes that influence risk can be measured quantitatively, and predicted semi-quantitativley, with increasing certainty
  - Gaps in knowledge are gradually being addressed
- The likelihood or probability of a hazard occurring is more difficult to quantify
  - But do we need to do this?

Conclusions 2

- Operators need confidence that if site performance meets conditions of a storage permit, they will be allowed to close the site and transfer liability back to state.
- Regulators need confidence that site performance will be demonstrated and that future predictions are robust, defensible and indicate risk levels are low and will remain low following abandonment.
- Therefore, defining and measuring site performance is crucial and relies on detailed and continuous assessment of risks
- What is an acceptable degree of uncertainty?
  - Prior to permitting, during operation, after closure and delicensing

Thank you.

For more information:

- RISCS project website www.riscs-CO2.eu
- Contact Jonathan Pearce: jmpe@bgs.ac.uk