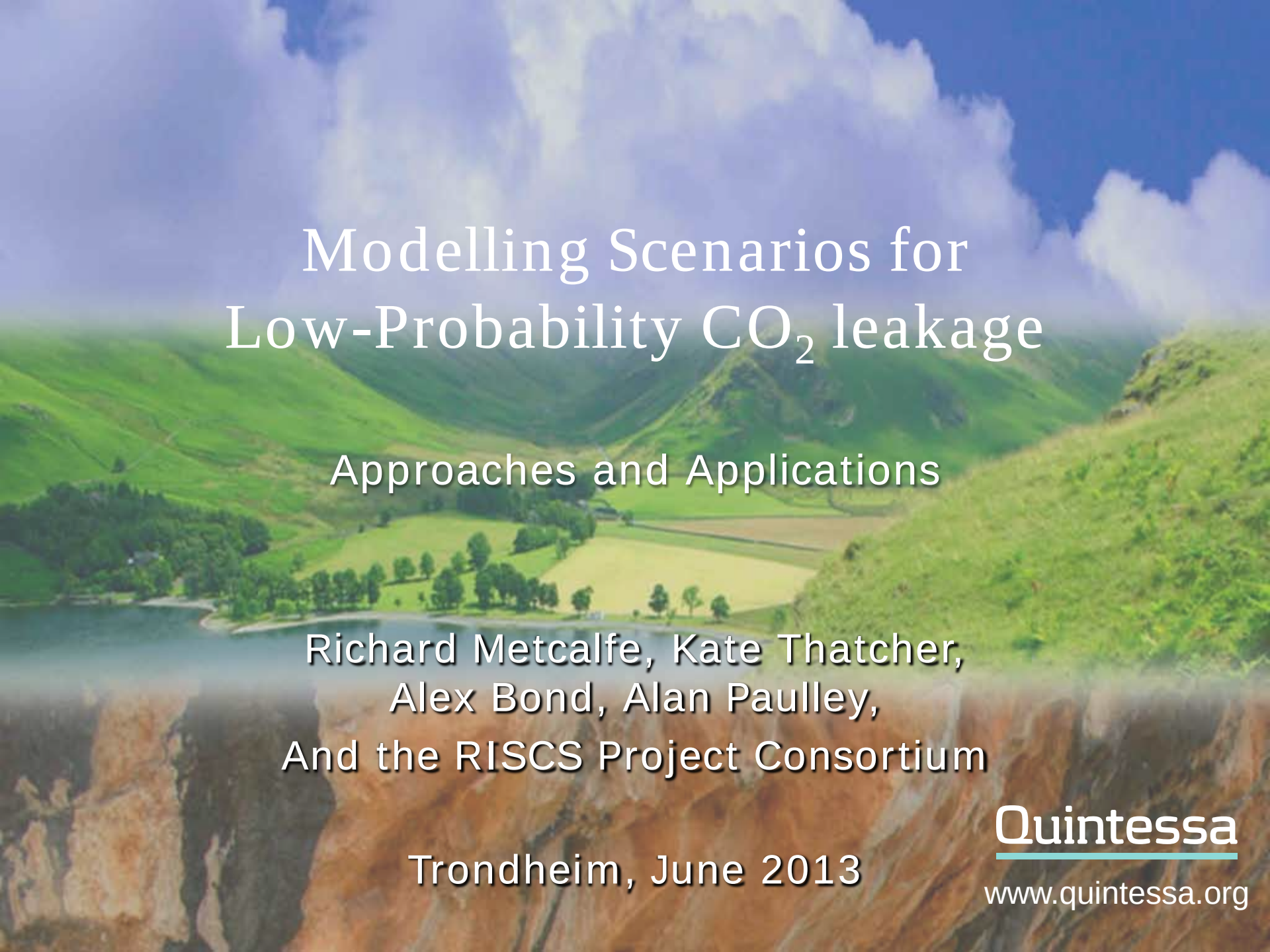

Modelling Scenarios for Low-Probability CO_2 leakage

Approaches and Applications

Richard Metcalfe, Kate Thatcher,
Alex Bond, Alan Paulley,
And the RISCS Project Consortium

Trondheim, June 2013

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Introduction

- Why investigate leakage scenarios?
- Need for “cautiously realistic”
  - Scenarios
  - Models
- Need for expert judgements
- Scenario development
- Modelling leakage scenarios
- Examples from the RISCS Project
- Conclusions

Why Investigate Leakage Scenarios?

- A well-chosen, well-operated CO_2 storage site is very unlikely to leak, but
- The EC Directive requires development of monitoring and mitigation plans
- To develop these plans consequences of unexpected leakage must be understood, also
- Such consequences need to be communicated to stakeholders (because they will ask)

Relationship to Risk Perception

Low Leakage Risk

Low Risk = Low Leak Probability x Low Consequence

Or

Low Risk = High Leak Probability x Very Low Consequence

Or

Low Risk = Very Low Leak Probability x High Consequence

- Many people most concerned about the third case, even though low risk
- Aim to ***illustrate*** the sorts of potential consequences for a range of fluxes

Need for Cautious Realism

- Stakeholders often request “worst case” scenarios
- What is “worst case”?
  - For any “bad” scenario, a worse one can be envisaged
  - The worse the scenario the lower the probability
- Why do we need “worst case” anyway, when aim to:
  - Demonstrate understanding
  - Communicate kinds of impacts (given very unlikely leaks)
  - Plan mitigation / monitoring
- “Cautiously realistic” scenarios / models can be used:
  - Clearly over-estimate negative consequences
  - Don’t violate physical / chemical principles / laws
  - Are generally agreed by workers to be conceivable

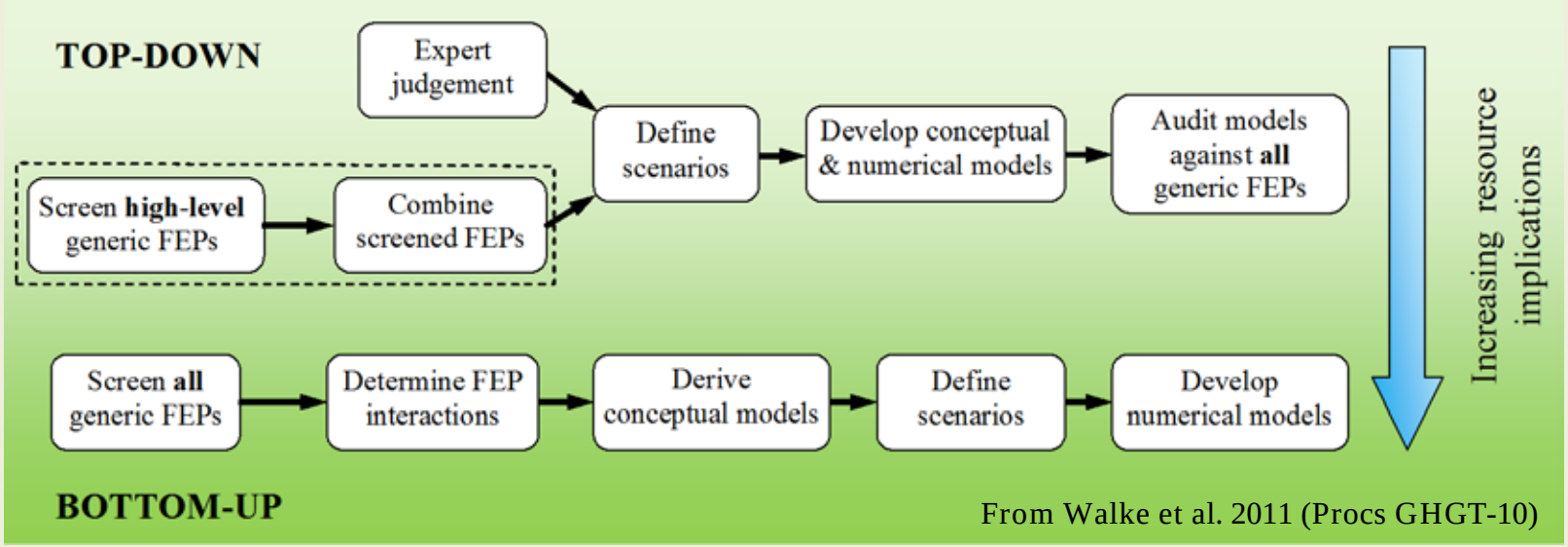
Need for Expert Judgement

- Expert judgements needed when:
  - Interpreting information / data
  - Assessing *combined* significance of quantitative & qualitative uncertainties
  - Assessing significance of lacking information
  - Identifying features, events, processes (FEPs) to be represented in "cautiously realistic" scenarios
  - Specifying conceptual models
  - Representing conceptual models numerically (including simplification)
  - Cautiously parameterizing models
  - Interpreting the significance of model results
- Expert judgements need to be made in the context of a structured conversation among experts and stakeholders

Approaches to Scenario & Model Development

- "Top-down"
  - "Big issues", then add detail
- "Bottom up"
  - Combination of features events processes

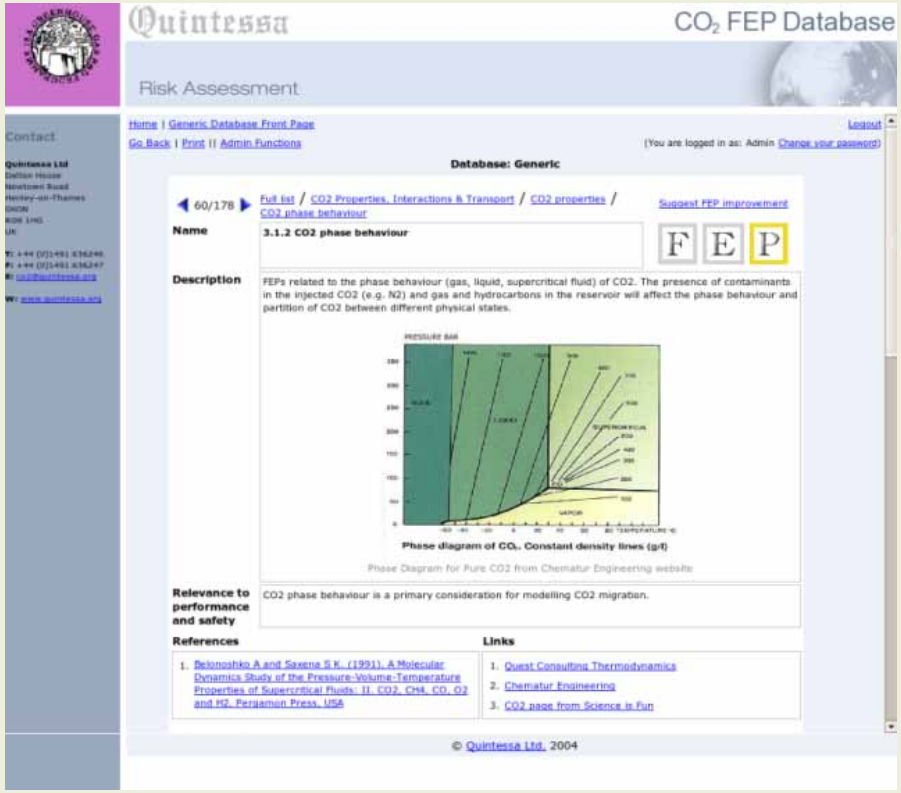
} Consider further here

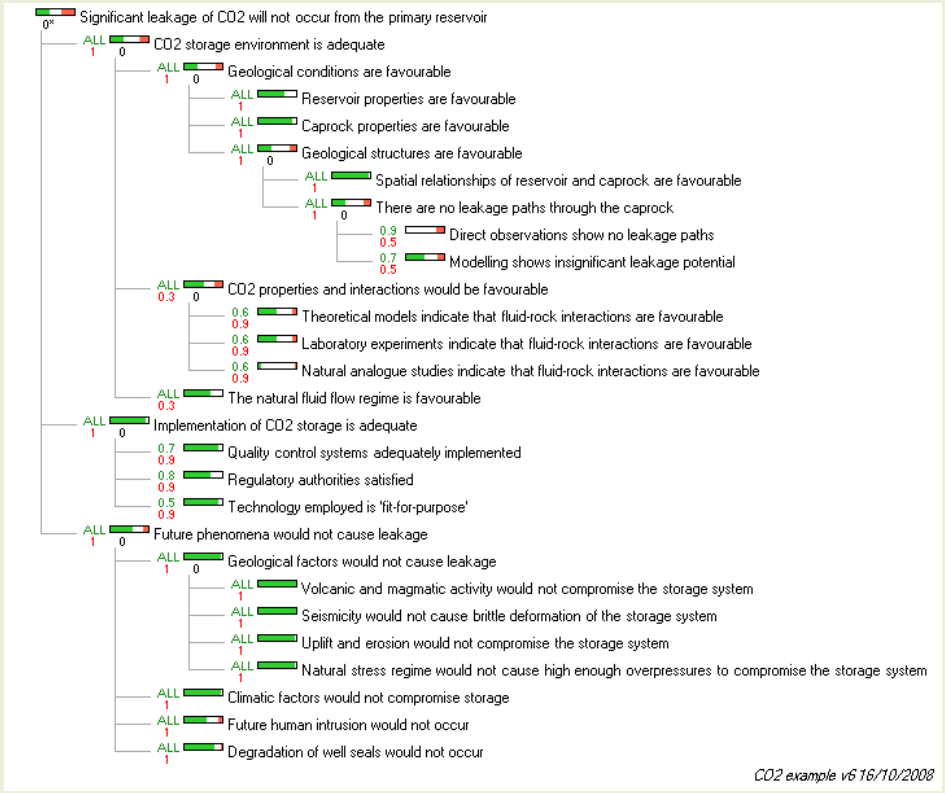


From Walke et al. 2011 (Procs GHGT-10)

Tools for Structuring Judgements

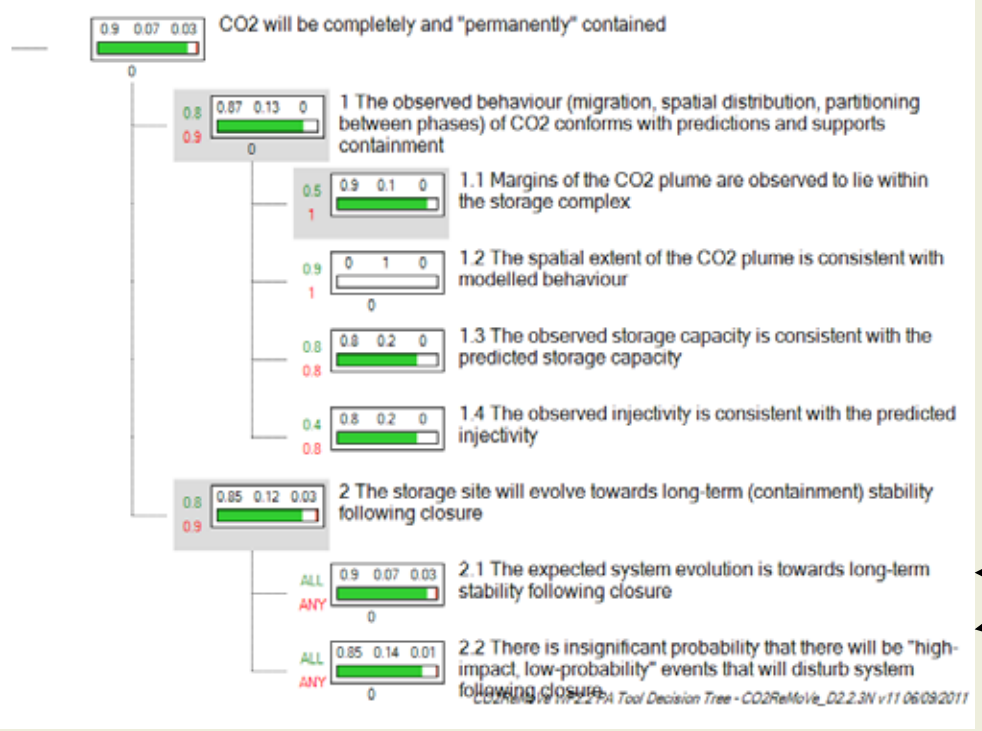
- Databases of important issues (Features, Events, Processes)
  - audit tool
  - support discussion
- Decision-support / integration tools
  - provide audit trail
  - Identify important issues
  - demonstrate relevant issues have been judged





Balancing Confidence Based on Evidence

- Confidence-building is key
- Need to understand uncertainties – identify / address those that are significant
- Need structured framework for conversation among experts / stakeholders
- Balancing multiple kinds of evidence for and against multiple hypotheses
- Here illustrate approach using decision trees



Confidence for

Confidence against

Uncertainty represented, recorded

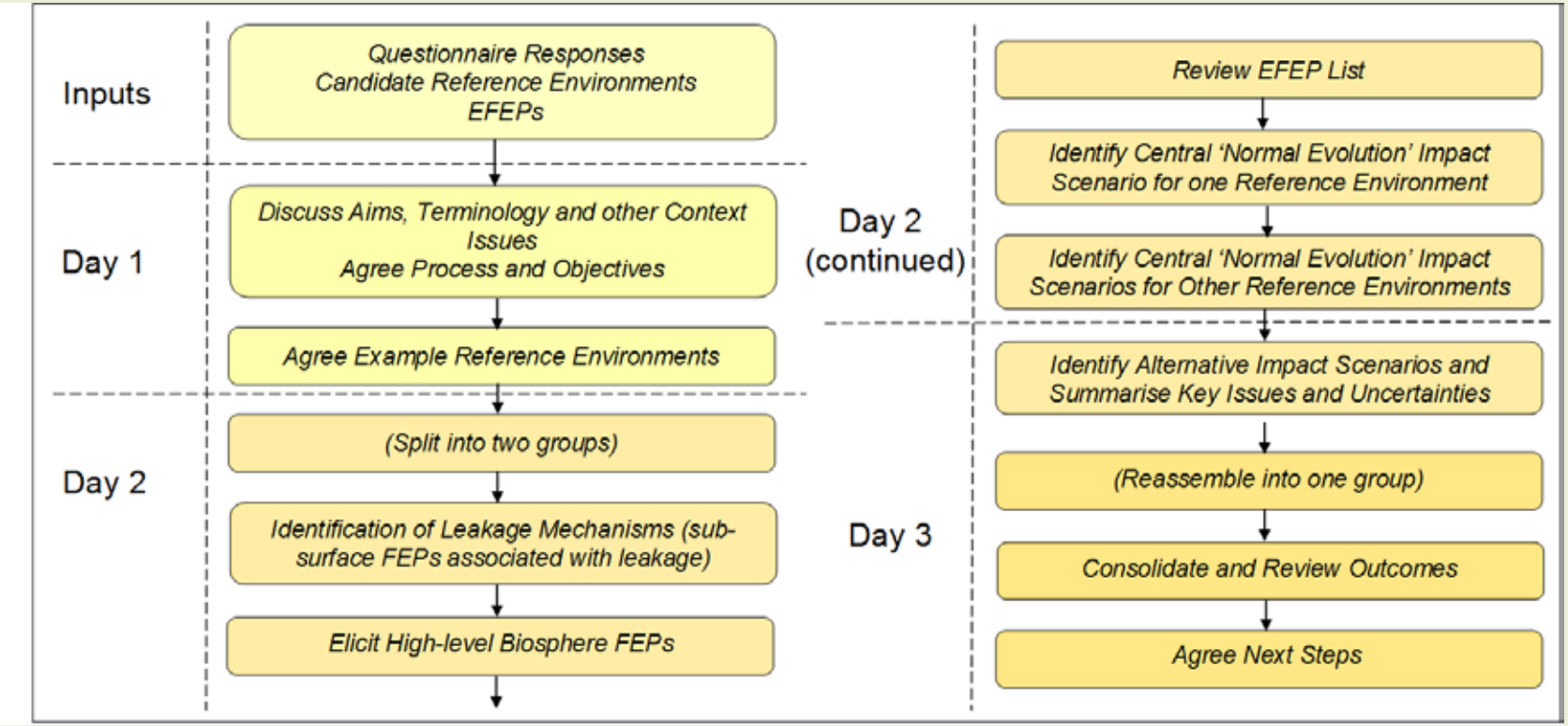
Inputs confidence values to lowest level

Example from the RISCS Project

- RISCS, a 4-year European (FP7) project, currently in its final year
- 24 organisations participate in RISCS:
  - research institutions
  - industry environmental associations
  - International Energy Agency Greenhouse Gas R & D Programme
- The project is studying a wide range of potential impacts
  - provides tools for developing appropriate legislation
  - helps to ensure safe management of CO_2 storage sites
  - aims to improve understanding of those impacts that could plausibly occur in the hypothetical case that unexpected leakage occurs, however unlikely
- Unintended displacement of natural formation fluid such as brine may have impacts, but not a RISCS priority
- Pipeline failures during operations not considered separately by RISCS (impacts likely similar to those of some forms of CO_2 leakage)

Development of Leakage Scenarios

- Structured Expert workshops
- Iterative reporting and review by partners



Environments

Terrestrial Environments

Maritime Temperate

Representative of a northern European, cool climate (e.g. UK, Netherlands etc.)

Continental

Climate associated with northern (not Arctic) European continent

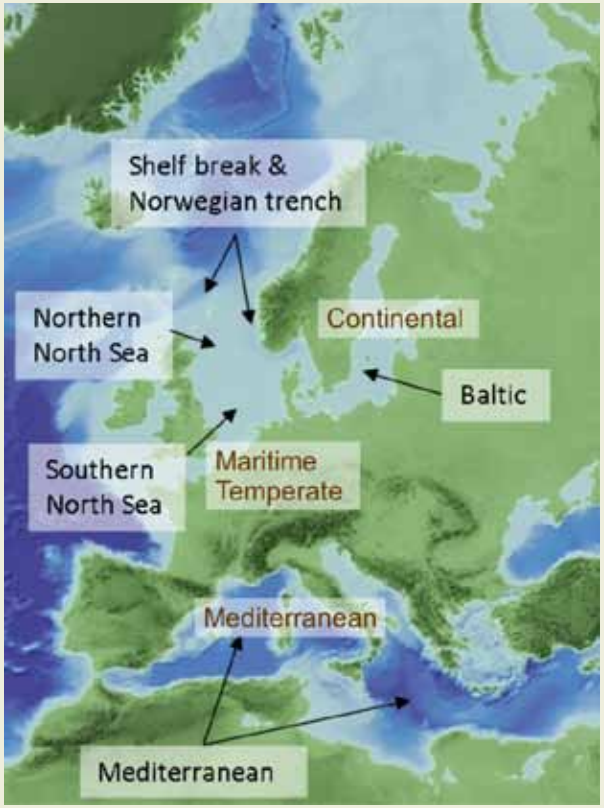
Mediterranean

Represents warmer, more arid, southern European climates

Generic Urban

Explores potential impacts to humans of near-urban storage

Focus here



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Marine Environments

Cool, temperate, deep

c. 60 m to 100's m deep, continental shelf far from shore (e.g. N North Sea)

Cool, temperate, shallow

Few 10's m deep, fairly close to land (e.g. S North Sea)

Warm shallow

Relatively warm, few 10's m deep, fairly near land (e.g. Adriatic)

Low salinity

Saline but << mean ocean, few 10's m deep, fairly near land (e.g. Baltic)

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:

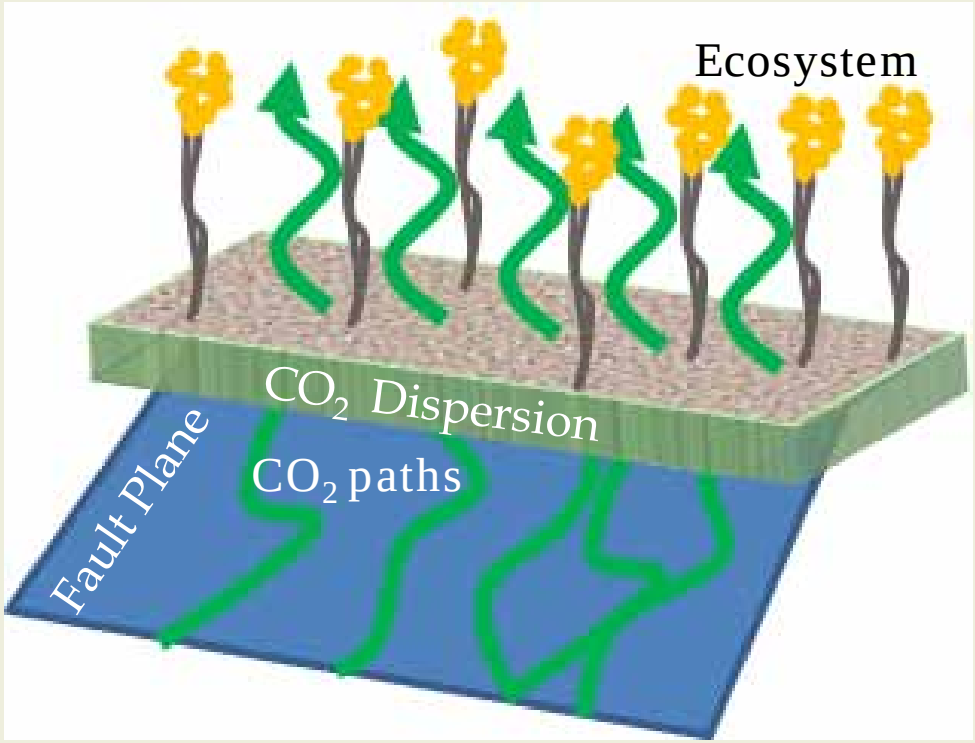
- Direct release of CO_2 to the atmosphere (***terrestrial*** environments)
- Localised (point-source) short- or longer- term emissions to near-surface soils or to aquifers (***terrestrial***); to sediments and the water column (***marine***)
- Diffuse (linear or over a wide area) emissions to the same systems
- Release to a ***terrestrial*** urban environment

Scenarios noted but **not** considered in detail include:

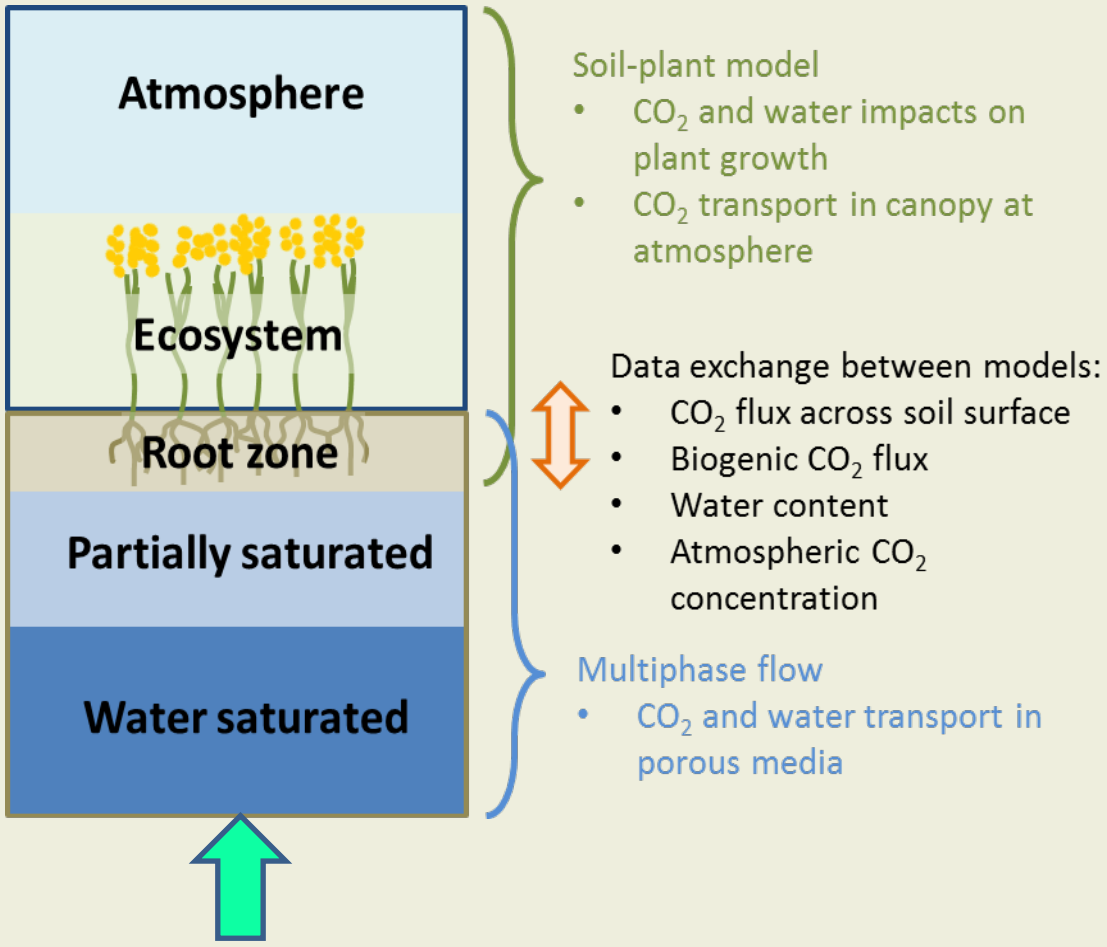
- *Displacement of saline formation water due to storage activities* (outside scope)
- *Impacts through inadvertent human intrusion into the facility* (a lower priority);
- *scenarios related to leakage as a result of seismic activity* (considered sufficiently encompassed by primary 'what-if' scenarios)

Illustrative Scenario

- Localized release to soil as a result of wells / faults / fractures, leading to high concentrations of CO_2 in the near surface



Conceptual Model



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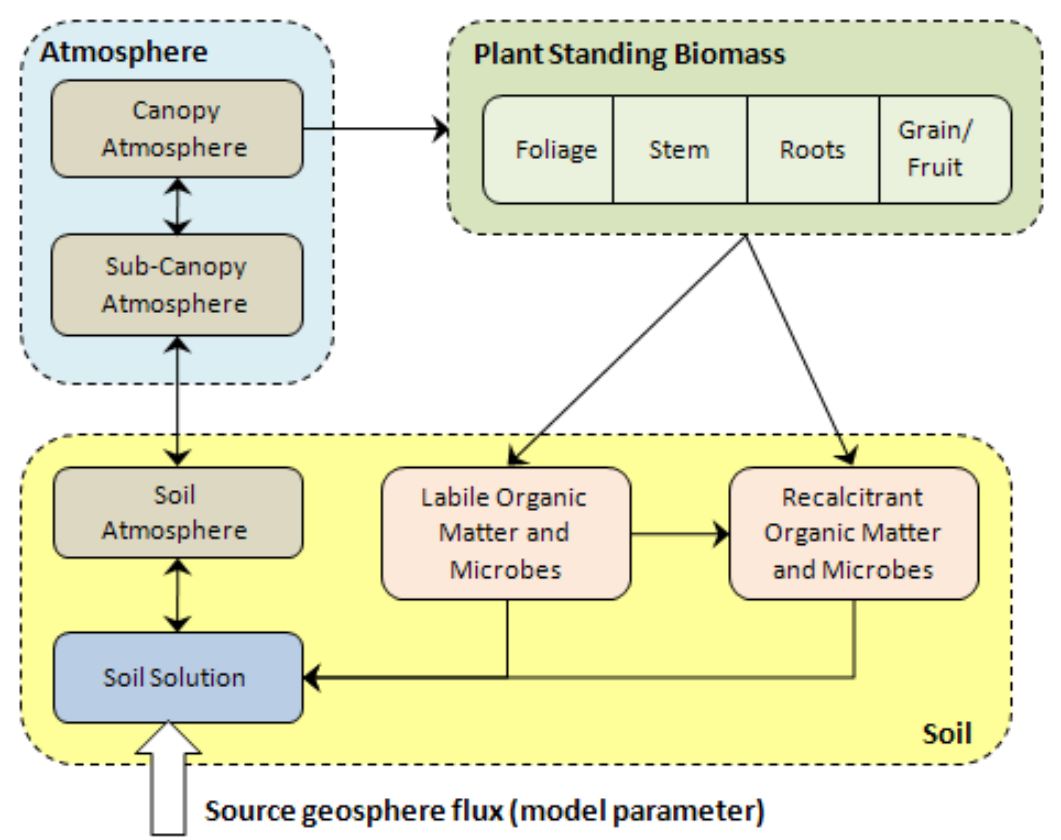
Numerical Model



Potential to link to reservoir / overburden models also implemented in QPAC

- Implemented in Quintessa's QPAC software & specialist modules
- QPAC - multi-physics software for simulating coupled systems
- Used for systems modelling in CO2GeoNet (Latera), CO2ReMoVe (In Salah) & other projects
- 'Model as Input' approach allows rapid prototyping of process representations, analysis of conceptual model uncertainty
- Can "wrap" applications as Player versions - users can modify key parameter values via GUI

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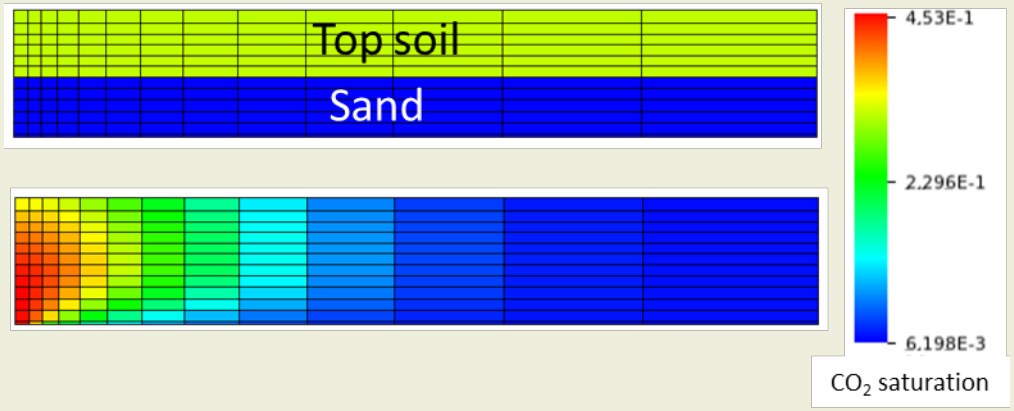
Model Calibration (1)

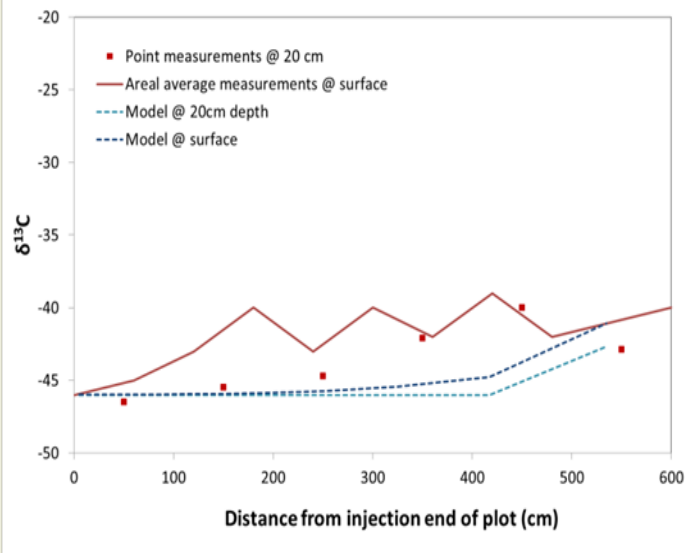
- Use data from Grimsrud Test Site, Norway
- Experiment carried out by Bioforsk (Daniel Rasse, Christophe Moni)
- Create CO_2 gradient in soil & near-surface
- Test various CO_2 exposures in cropped field

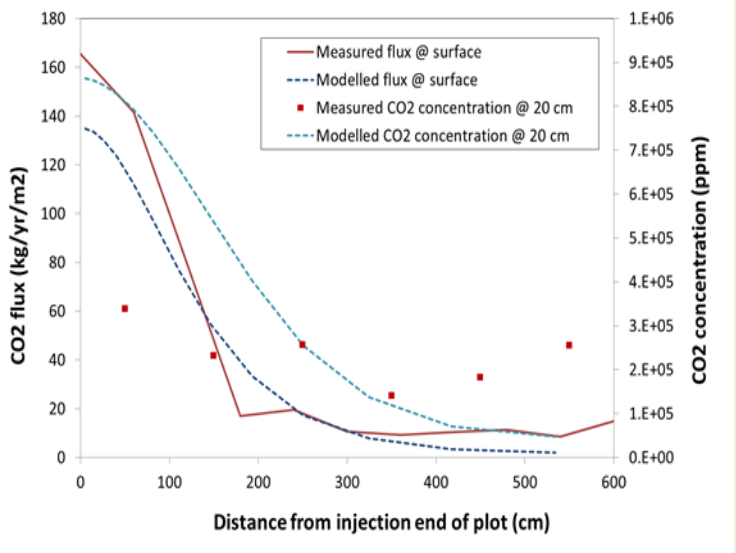


Christophe Moni, Daniel Rasse, and RISCS Project Team 2012, Procs GHGT-11

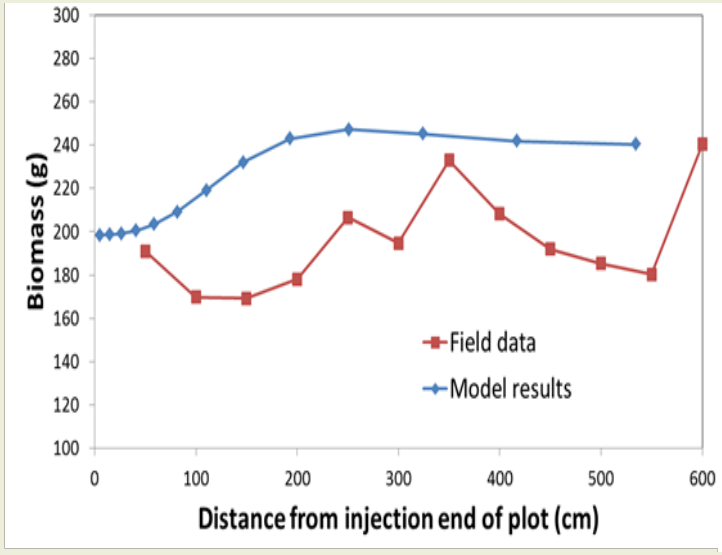
Model Calibration (2)

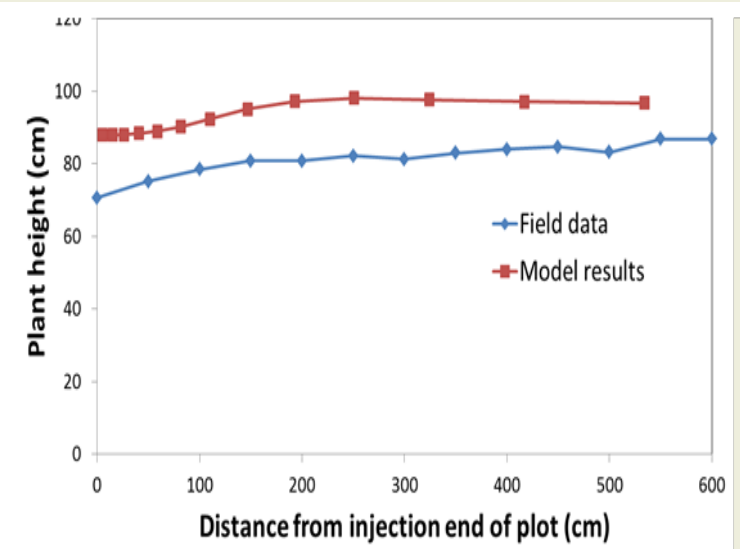
Plot 1





Plot 1





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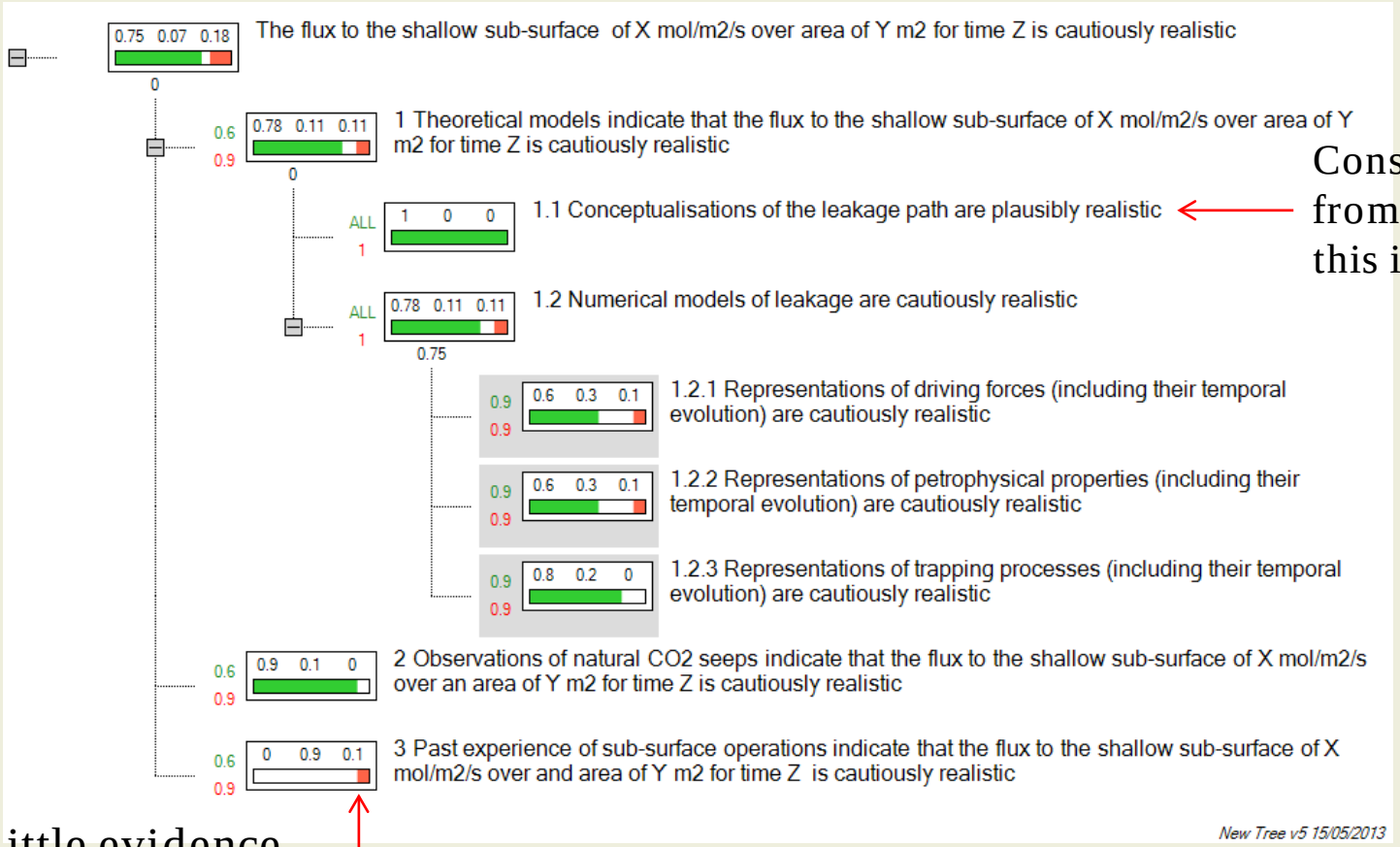
Model Parameterisation for Scenario Analysis

- Hypothesis: Sustained flux of 1 x 10^{-4} mol / m^2 / s through 6 6m diameter points in a zone 1000 m long and 50 m is cautiously realistic



Considerable evidence from natural seeps that this is correct

Little evidence
Actual experience suggests no leak

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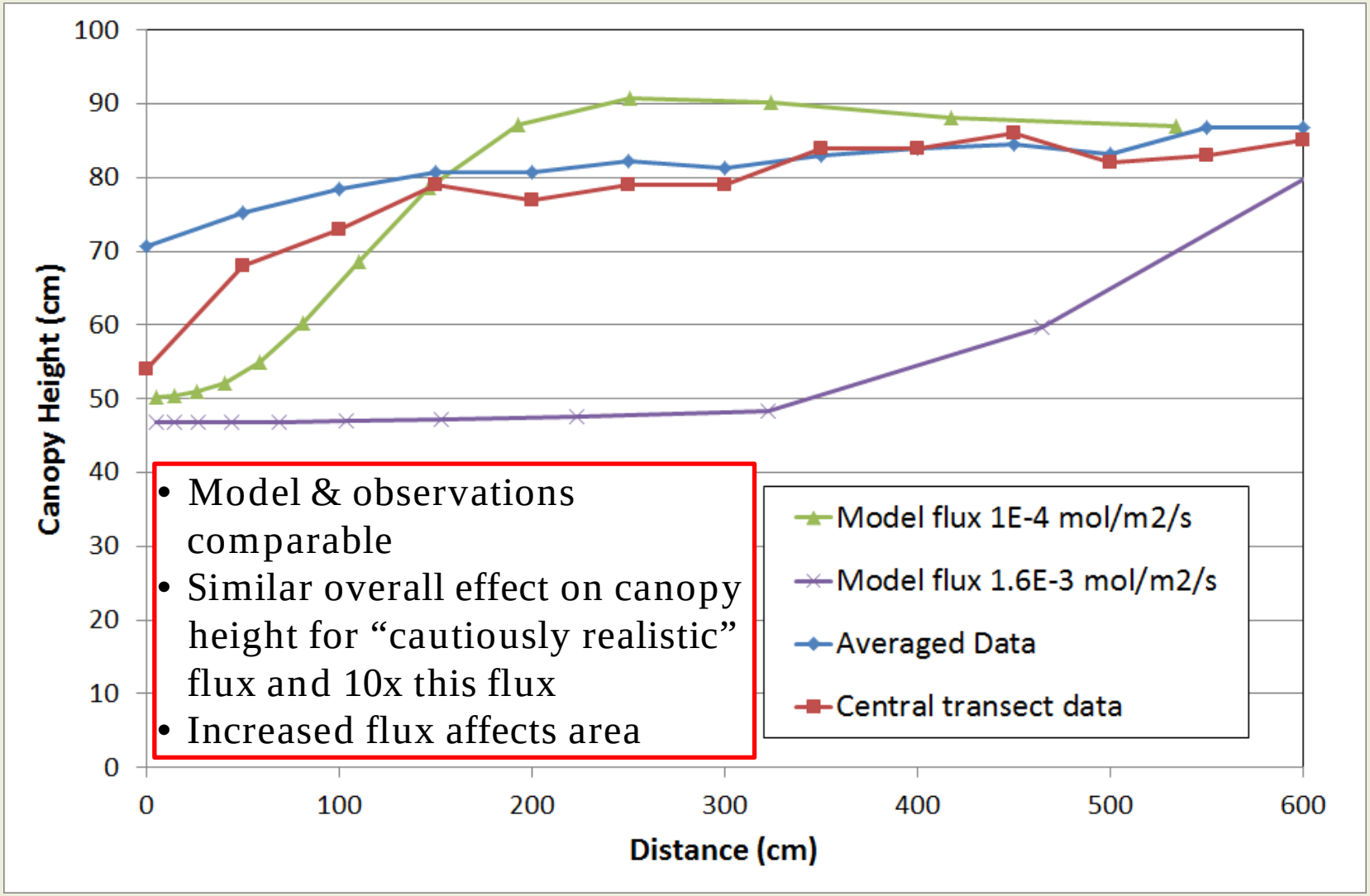
Outputs from Leakage Models



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Conclusions

- A well-chosen & operated CO_2 storage site very unlikely to leak
- "Worst-case" scenarios & models not readily specified and unnecessary
  - Need to show only sufficient understanding of processes to support monitoring and mitigation plans
  - Need to demonstrate uncertainties don't call into question these plans
- "Cautiously realistic" scenarios & models needed to communicate risks
  - Must be based to a large extent on expert judgements
  - Transparent / structured approaches to development are needed
- For the given example of leakage from a fault:
  - There is considerable confidence that a flux of 5×10^{-4} mol / m^2 / s is cautiously realistic
  - The actual impacts of such a flux on vegetation growth predicted to be small and similar to the natural variations
  - The impacts are qualitatively similar for fluxes ranging over several orders of magnitude
  - For the purposes of communication to stakeholders, we should not worry excessively about debating whether a flux X or a flux 10 x X is adequately cautious.

Acknowledgements

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Four R&D institutes outside Europe participate in RISCS:

CO2CRC from Australia, University of Regina from Canada and Montana State and Stanford Universities from the USA

For more information please go to the website:

www.riscs-co2.eu

All partners contributed to the scenario development.