RISCS

Research into Impacts and Safety in CO_2 Storage

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Project Partners

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Outline

- Project background
- Scenarios for CO_2 storage sites
- Research on Marine Impacts
- Research on Terrestrial Impacts
- Numerical solutions
- Guide to Impacts Appraisal
- Summary

Project background

- CO_2 storage sites will be thoroughly evaluated and designed to prevent the risk of leakage
- Important to consider the consequences if leakage should occur
- RISCS is concerned with the potential environmental impacts of leakage
- This is likely to 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

Purpose of Scenarios

- Communicate kinds of leakage and impacts that need to be considered
- Provide a basis for discussing impacts in a structured fashion (Guide)
- Focus experimental and modelling work

Scenarios are hypothetical situations, not predictions

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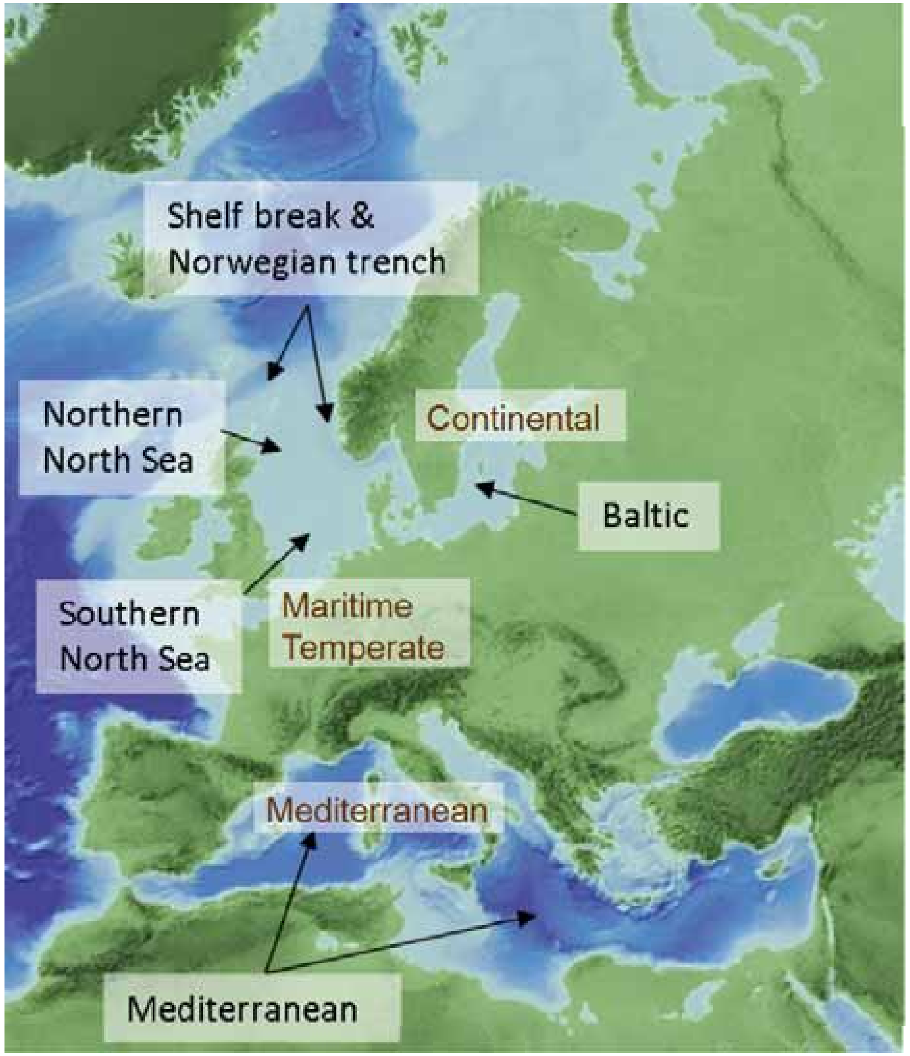
Reference Environments

- 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



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.

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.

Scenarios

Both ***marine*** and ***terrestrial*** environments:

normal evolution scenario is containment (for comparison with leakage scenarios)

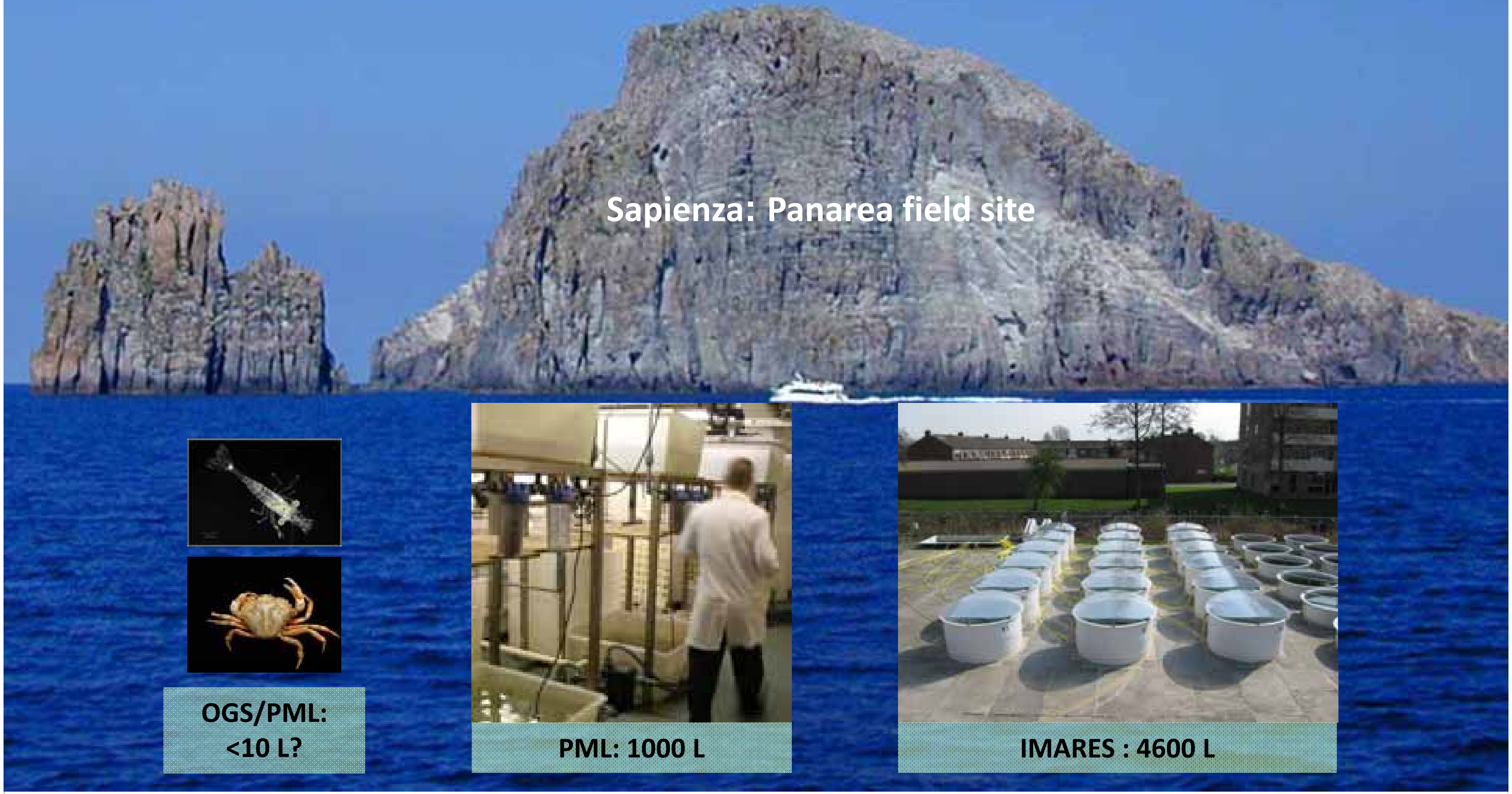
'What-if' alternative evolution scenarios for leakage consider potential impacts via:

•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)

Assessing impacts in marine environments via field experiments and observations



+ benthic chamber lander (CO_2GeoNet)

Time course of hemolymph sampling

	Short period						Long period		Recovery			
Time	*0h*	*3h*	*8h*	*24h*	*48h*	*96h*	14g	21g	*3hR*	*8hR*	*24hR*	*96hR*

Hemolymph sampling

Hemolymph parameters

Glucose: as generalizes parameters of stress
Lactate concentration and **pH**: for acid balance regulation
Total protein concentration and **density**: for their role in the osmoregulation
Total haemocyte count (THC): to assess the animal's health status and
Mortality as toxic responses

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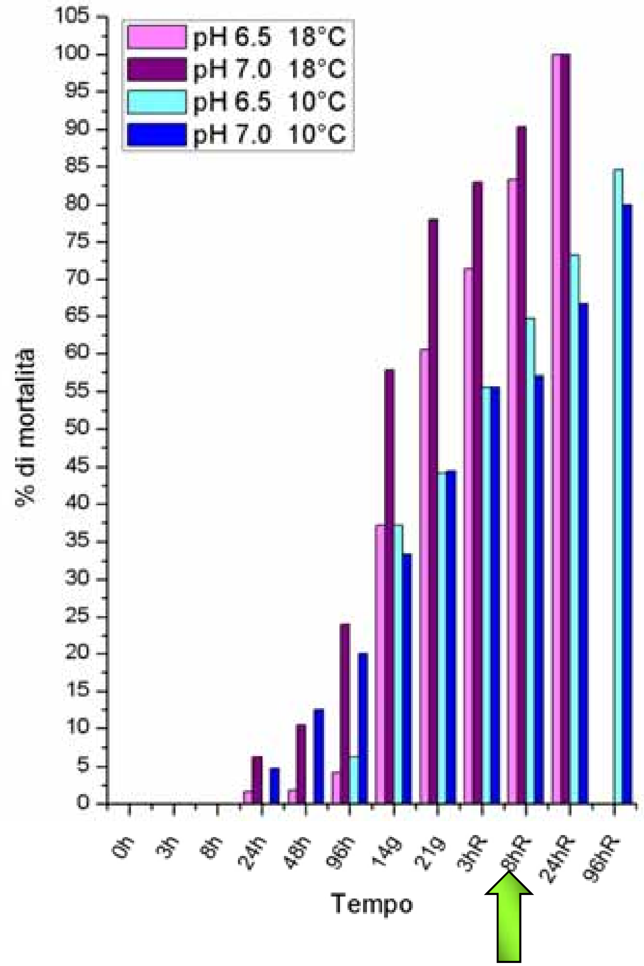
Mortality in *Carcinus aestuarii*



Short period (until 96h)

Higher mortality at pH 7.0 for both temperature

Long period (until 21 days)

Higher mortality recorded at 18 ° C

Recovery period

Both experimental groups at **18 °C** reach 100% mortality within 24hr

Experimental groups at **10°C** show higher mortality rates at **pH 6.5**

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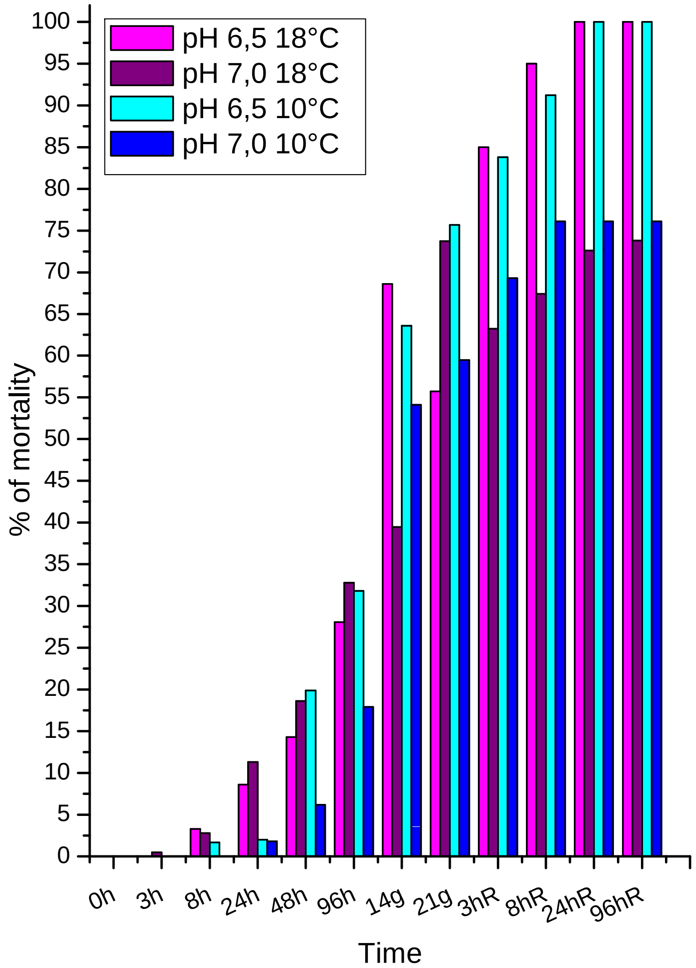
Mortality in *Palaemon elegans*



Short period (until 96h)

Lower mortality at **pH 7.0 10°C**

Long period (until 21 days)

Higher mortality recorded at 18 ° C

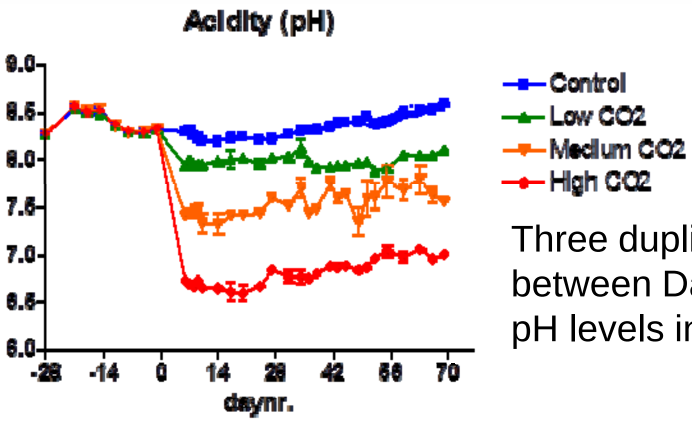
Recovery period

Both experimental groups at **pH 6.5** reach 100% mortality within 24hrR

- This species shows a greater sensitivity to reduced pH independent of temperature

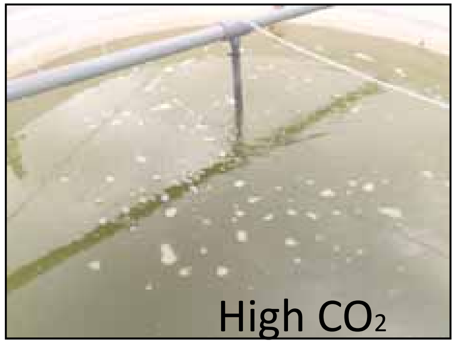
- Exposure to elevated CO_2 can cause mortality even after exposure ends
- Exposure can cause physiological changes, some of which can persist for a long period after exposure
- Evidence that some species can alter their physiology to cope with short periods of exposure.
- Interactions with other factors can effect organism vulnerability

RISCS Mesocosms (IMARES)



Three duplicated levels of CO_2 addition, between Day 0 and 70, resulted in reduced pH levels in the mesocosm water columns

Control



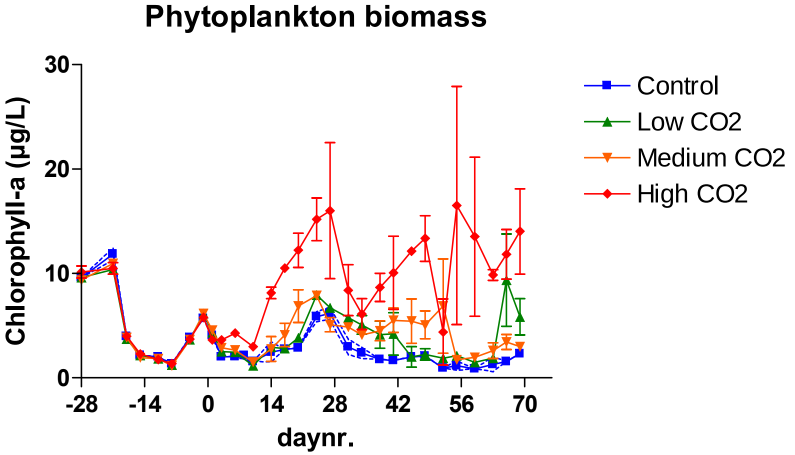
High CO_2

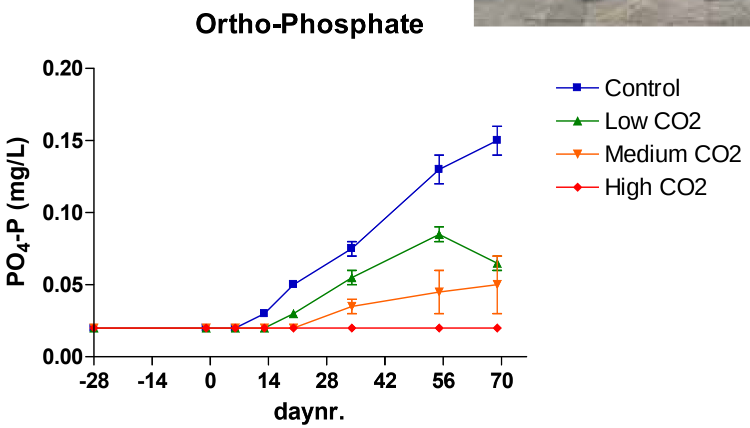
High CO_2

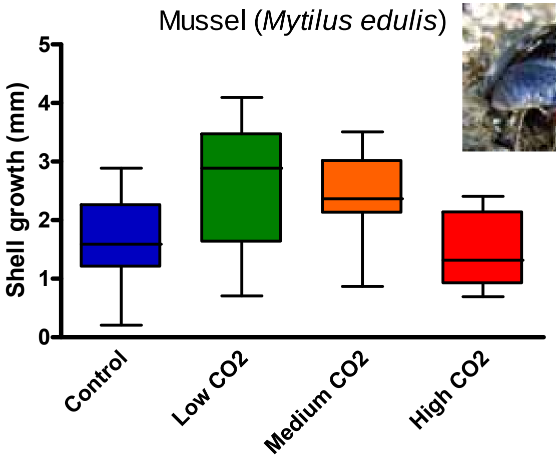
High CO_2 addition resulted in enhanced algal densities

..and affected the shell of some individuals

RISCS Mesocosms (IMARES)







The addition of CO_2, stimulated algal production making ortho-phosphate the limiting factor at high CO_2 level. Mussels in the low and medium dosed mesocosms took advantage of the increased food (algae) availability. At high CO_2 levels this advantage was probably undone by negative effects of the elevated CO_2.

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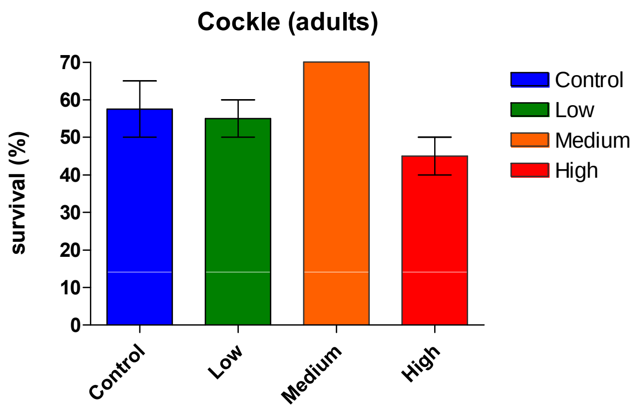
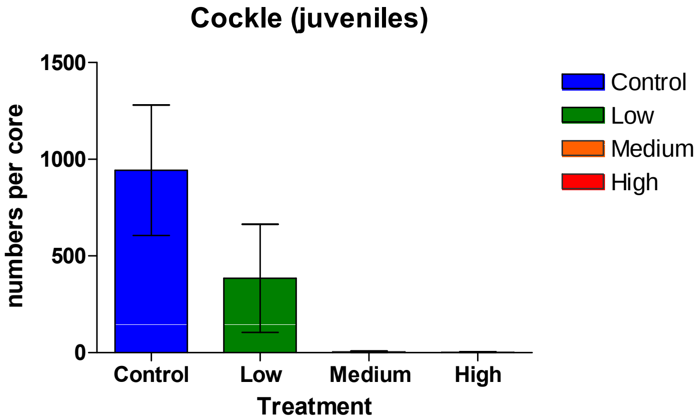
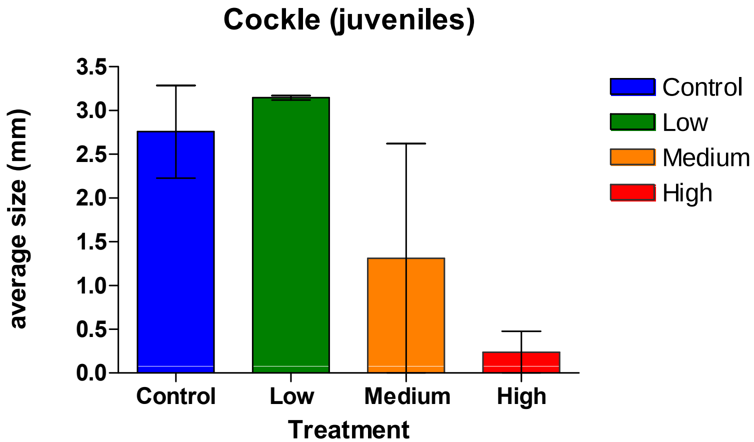
RISCS Mesocosms (IMARES)



The survival of the Cockle (another filter feeding bivalve) was not substantially affected by elevated CO_2 levels. However reproductive success was, as indicated by reduced densities and smaller size off spring at higher CO_2 levels.





Field observations

- To address issues related to system complexity and space-time variability at a marine site where natural CO_2 is leaking to the water column
- To extrapolate the laboratory and mesocosm experiments into real-world situations
- An integrated study including measurements of the physical, chemical, and biological systems

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Research Tasks

4 field campaigns (one per season). 2 have been completed:

- 21-23 October 2010 (fall campaign)
- 26-31 July 2011 (summer campaign)

Chemical monitoring

- CTD, pH, nutrients, gases, etc. in water column
- Enlargement of pCO2 monitoring station

Biological monitoring

- Biological analyses of water column samples
- Benthic chamber measurements

Physical monitoring

- ADCP current characterisation
- GOTM modelling

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Task 2.2.1 – Chemical monitoring

<u>CTD casts</u> and water samples along a transect crossing venting area to investigate influence of vent system on the surrounding water masses.

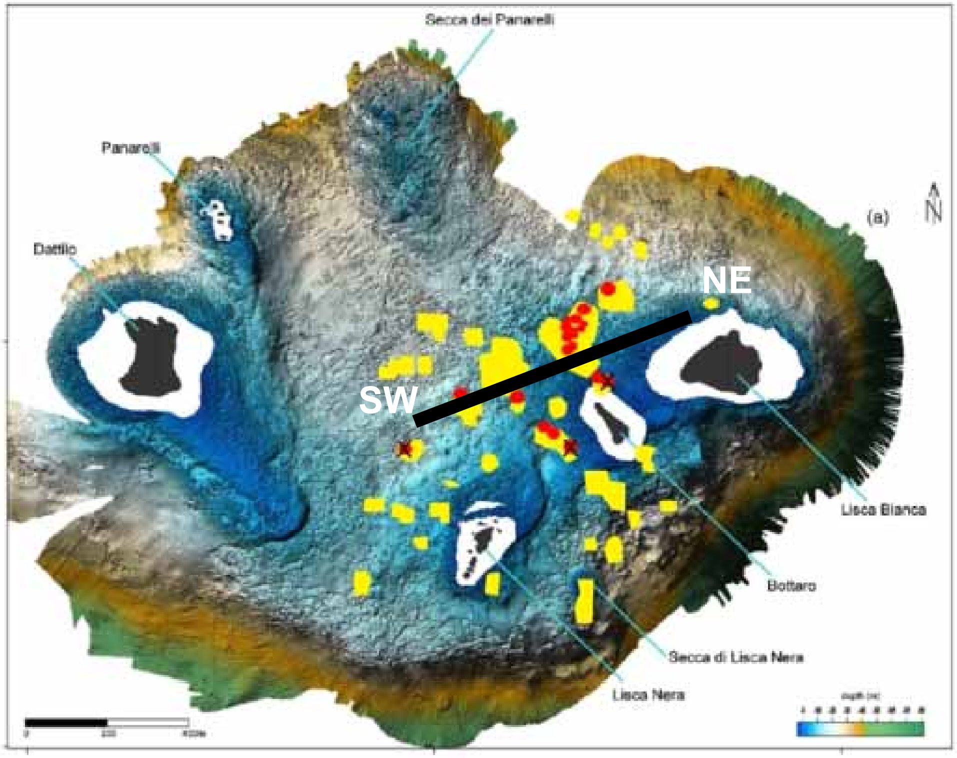
7 sampling points, at three depths

- bottom, intermediate, and surface water

Total length of profile about 500 m

Difficulties encountered:

- Irregular bathymetry
- Irregular gas vent distribution
- Small craft, strong currents complicated point location



Parameters along the transect

- CTD casts (P, T, S, DO, Chl*a*, pH)
- Dissolved inorganic nutrients
  - NH_4^+, NO_3^-, NO_2^-, $Si(OH)_4^-$, PO_4^{3-}
- DOC, DIC, Alkalinity, DO, pH
- Dissolved gases
  - CO_2, N_2, O_2, C1-C5 alkanes
- Major and trace elements

Look for potential input of ions (from deep water or acid-rock interaction) and gases, mixing and possible impact on water column chemistry.

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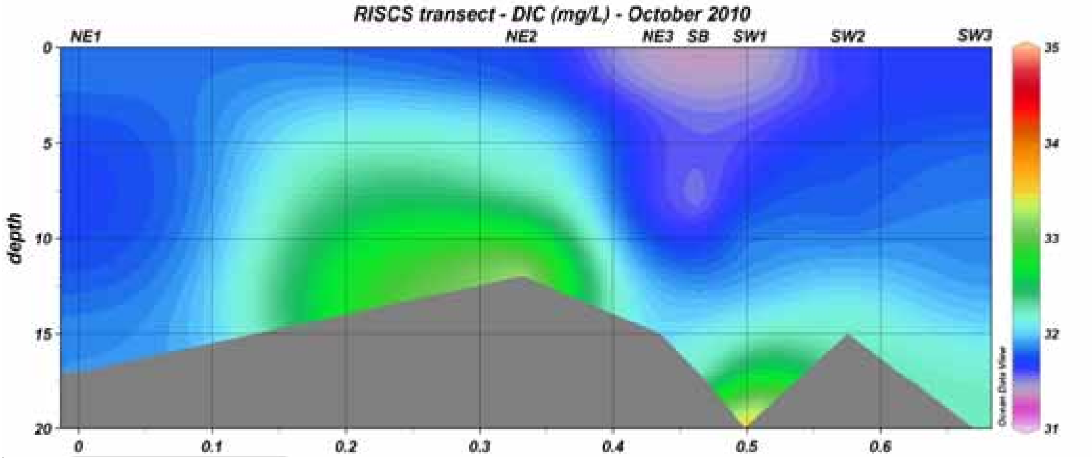
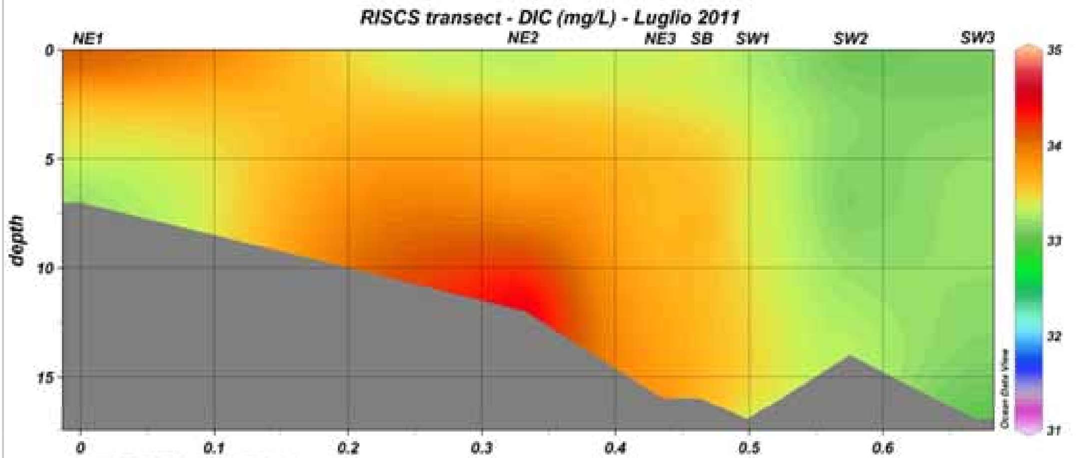
Chemical monitoring

Transect preliminary results



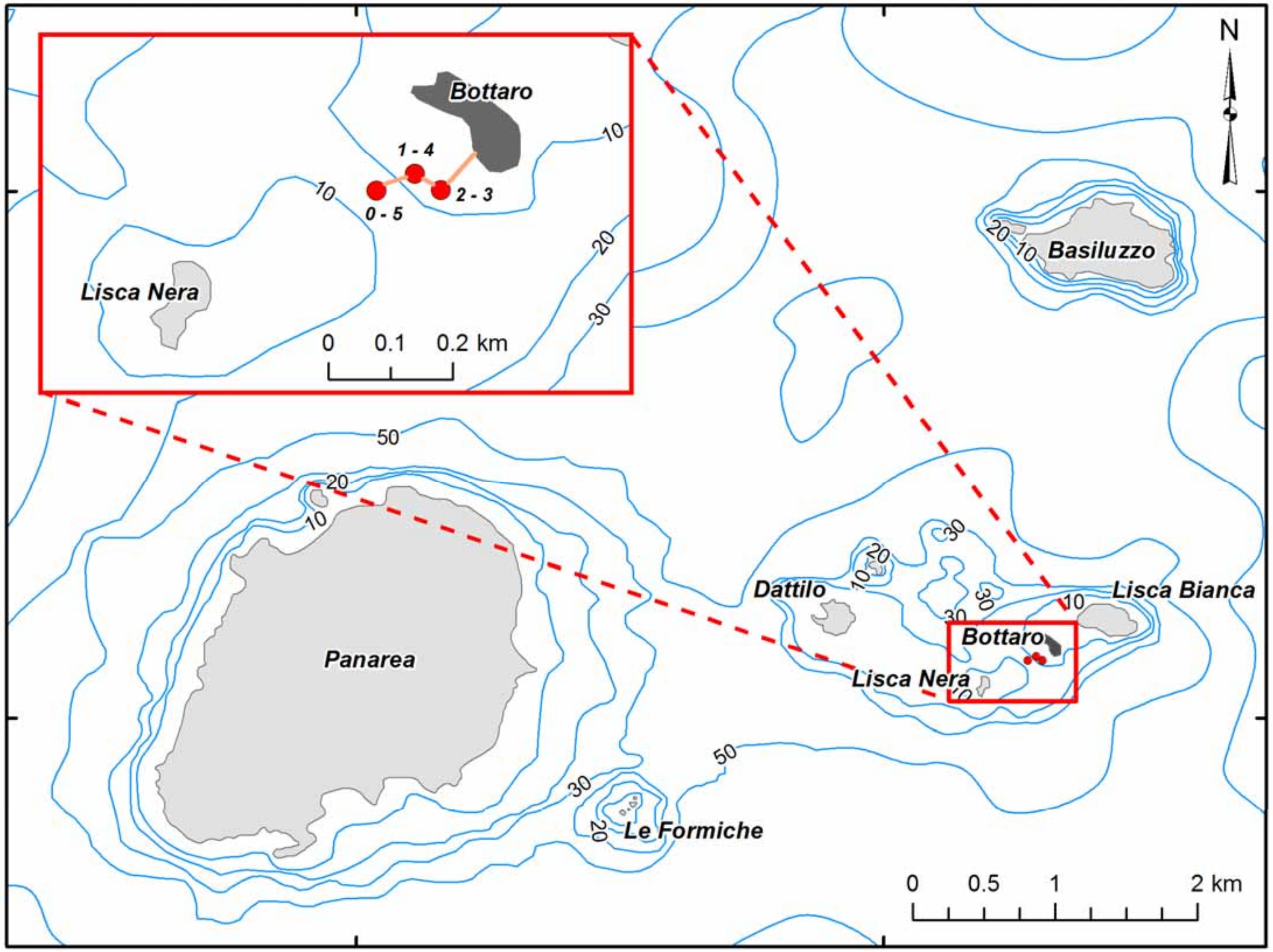


Dissolved inorganic carbon

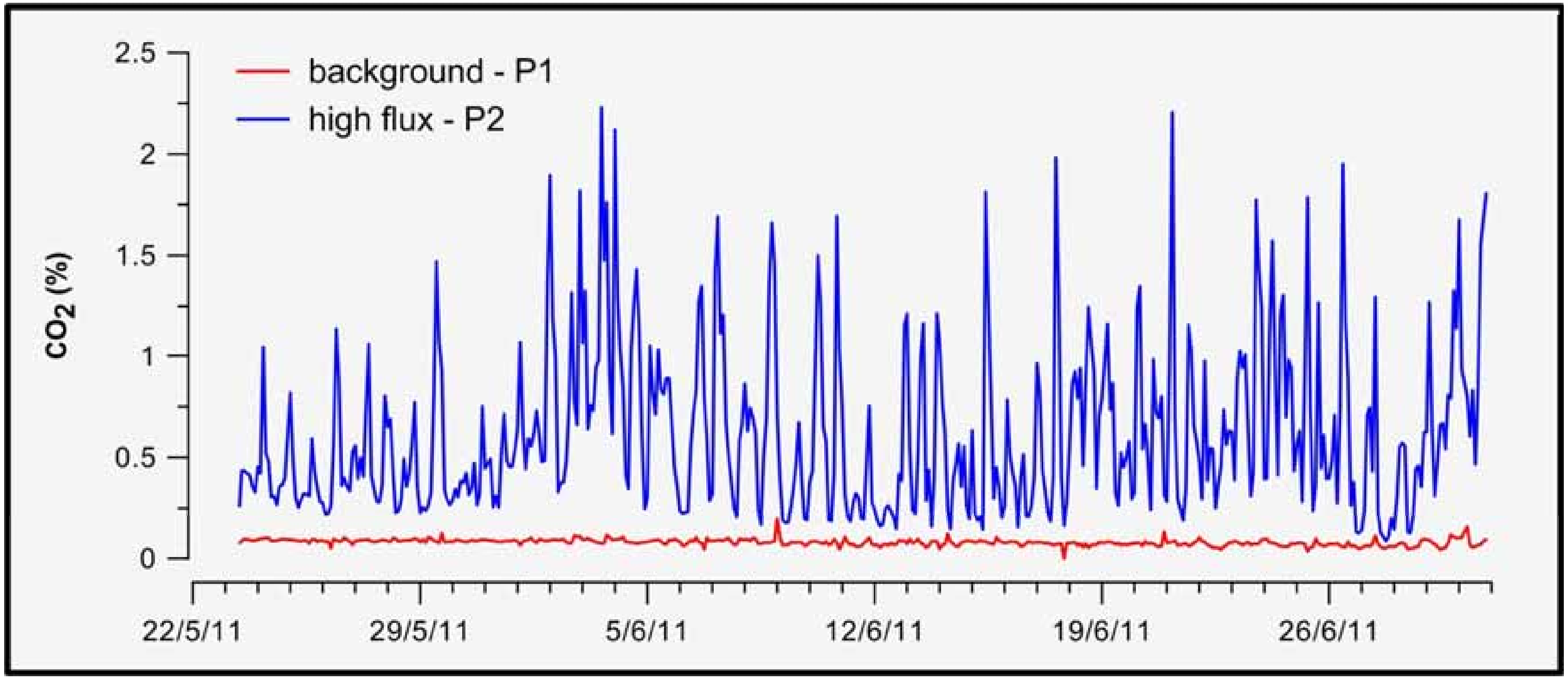
- both campaigns show elevated values near the sediment-water boundary
- values are generally much higher during the summer campaign than the fall one

Chemical monitoring

pCO2 monitoring station deployed within CO2ReMoVe, with addition of 3 sensors and continued monitoring / maintenance within RISCS.



Monitoring station preliminary results



- Background probe vs high flux probe
- High flux point shows elevated values, but also much variability

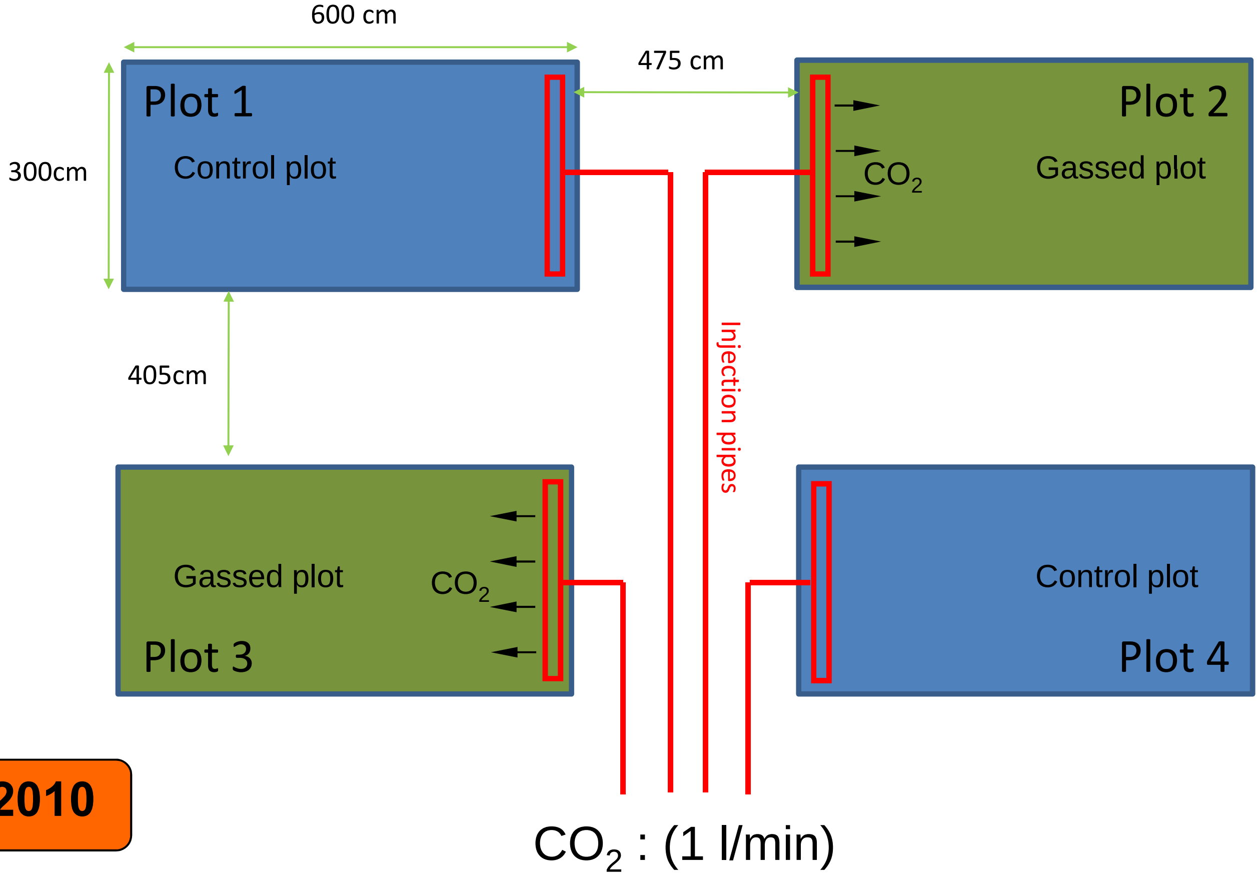
Assessing impacts in terrestrial environments

- Northern Europe
  - Norwegian experiments (Grimsrud Farm)
  - UK (ASGARD) experiments
- Southern Europe
  - Observations (Italy, Greece, France)
    - Vegetation and groundwater impacts

Experimental plot preparation

Four experimental plots (6m X 3m) were opened in a clayey soil that has developed on moraine deposit.

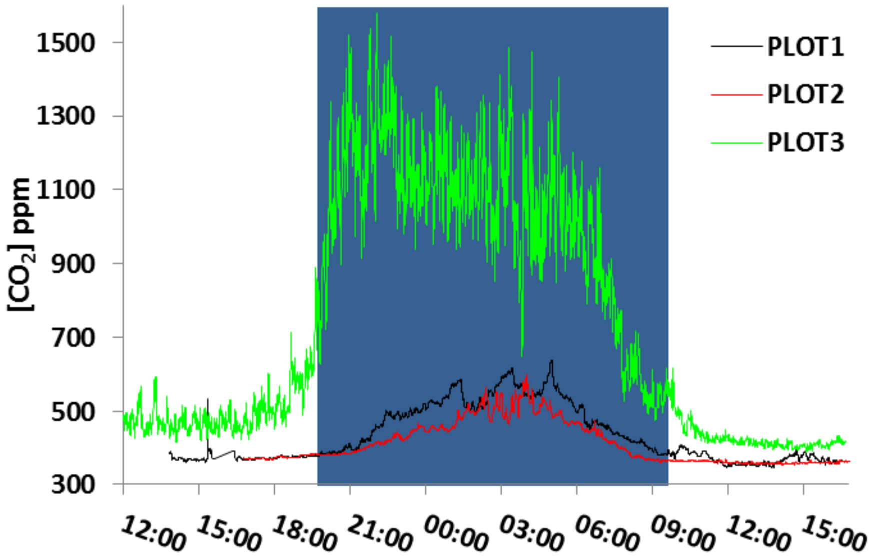
Two of this plot were gassed to simulate a leakage and two others were used as control.

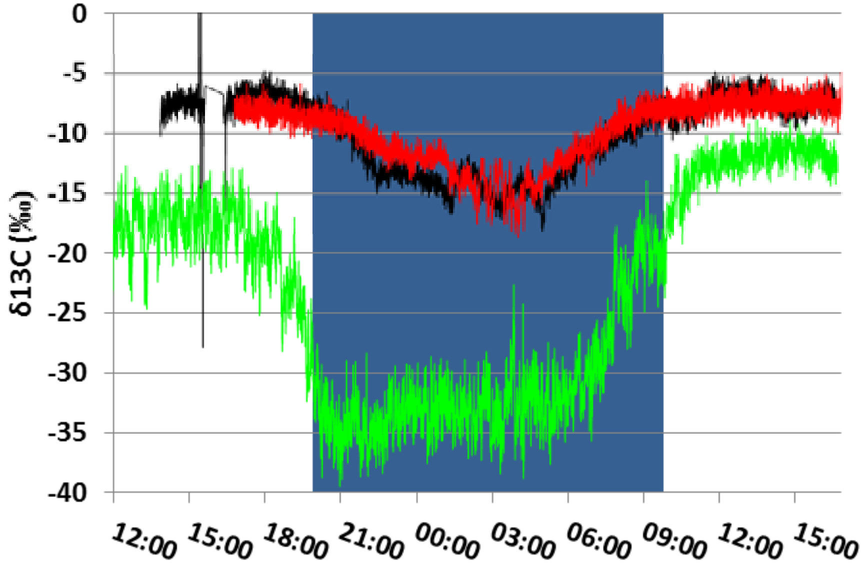


August 2010

Results: Atmospheric CO_2 continuous measurements

Beginning of July 2011

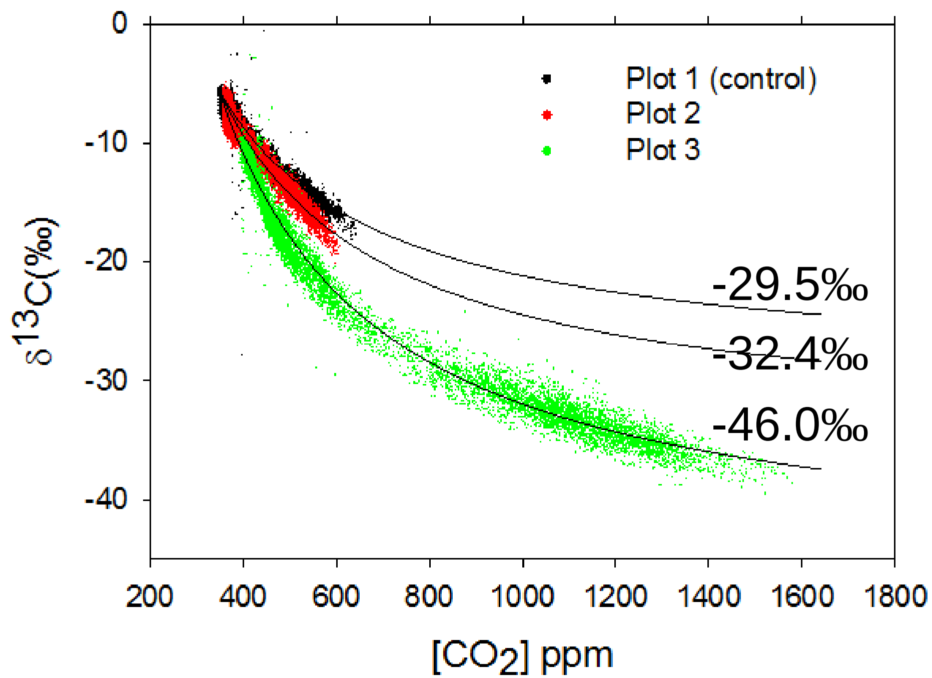




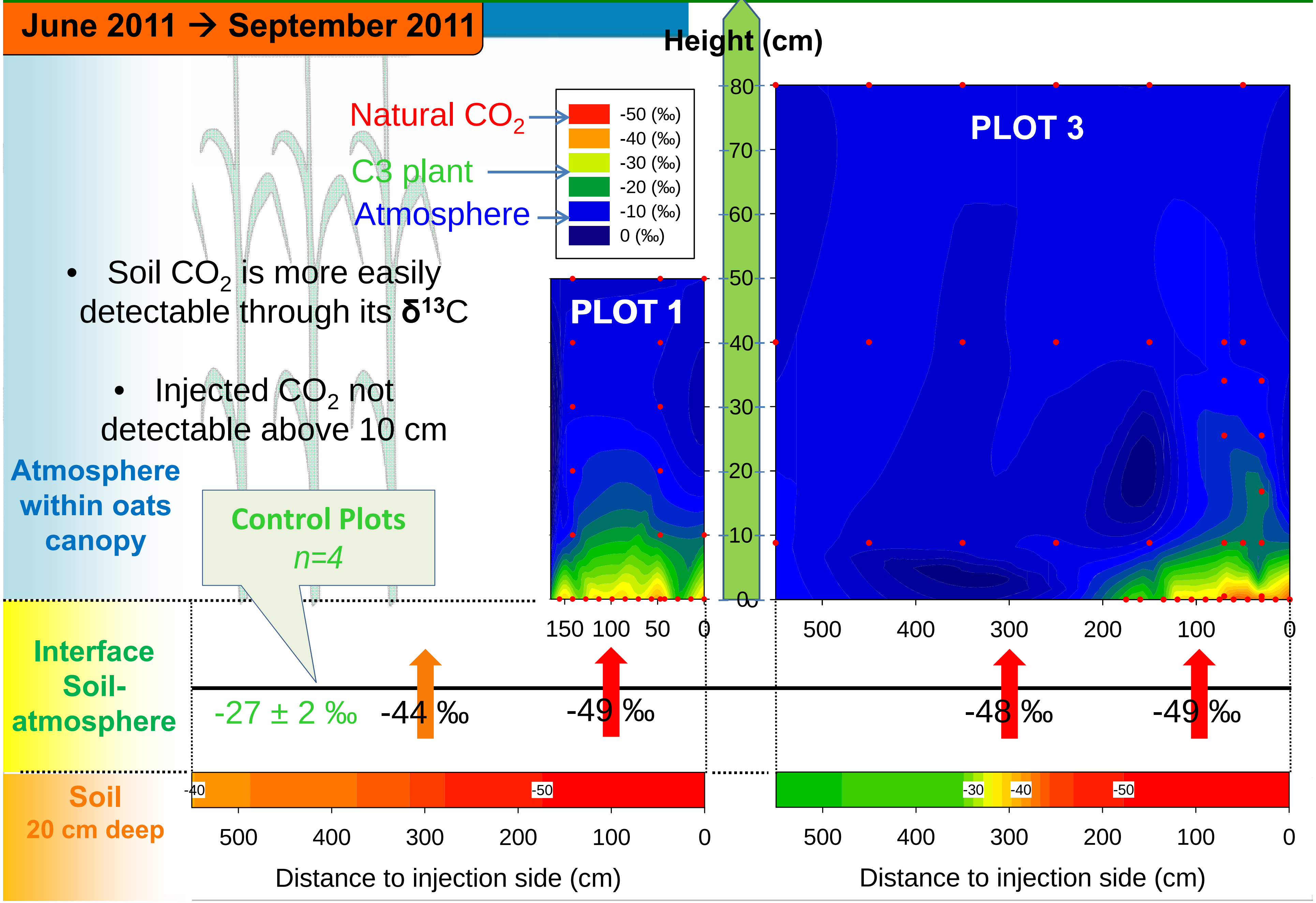
- Diurnal CO_2 variations
- CO_2 more visible at night due to reduced:
  - *Photosynthesis*
  - *Turbulence mass transport*

- Injected CO_2 detected only on Plot3
- Injected CO_2 detected on Plot2 when data fited with a mixing model

Mixing model



CO_2 - $\delta^{13}C$ within the soil-atmosphere continuum



Results: Influence of leaking CO_2 on the cover crop

September 2011 ***(end of growing season)***

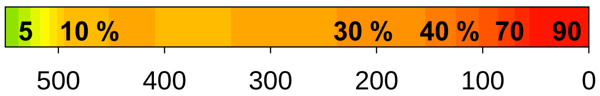
Height (cm)

Plot 1

110	110	110	105	110	115	110	110	100	100	100	110
110	100	110	110	110	110	100	90	100	100	90	90
100	100	110	110	110	110	100	100	95	100	90	90
105	110	110	105	100	110	110	105	90	100	90	80
100	110	120	100	100	110	105	90	95	95	100	100
100	110	110	100	100	100	100	105	100	95	95	110

← CO_2 From dai=28

Soil [CO_2] in (%)

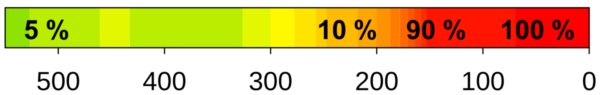


Plot 3

90	90	85	85	85	90	85	90	80	75	65	65
90	90	95	90	85	85	85	80	80	70	65	75
90	100	95	95	90	85	85	80	65	65	65	55
90	85	85	85	80	90	80	80	55	50	45	45
90	90	85	90	95	90	95	85	70	55	50	50
90	95	95	100	90	90	95	80	75	75	65	60

← CO_2 From dai=0

Soil [CO_2] in (%)



Distance to injection side (cm)

- Crop seems to be affected by the gassing treatment
- Consequences are more important when the gassing start early
- Soil CO_2 contents superior to ~50% seems to influence the developement of the cover crop

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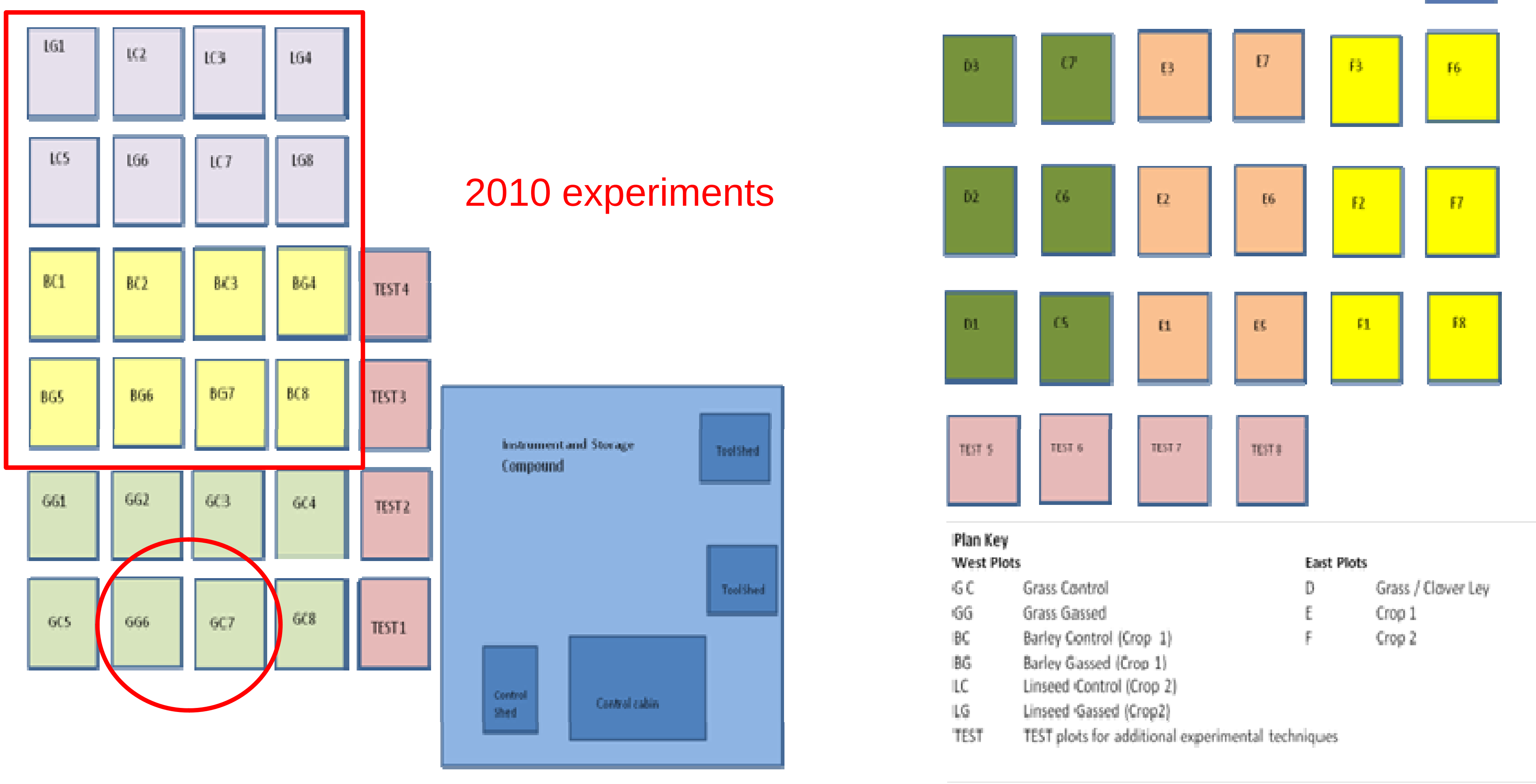
ASGARD experimental site

New RISCS plots

Existing plots



ASGARD: 2010 Spring Crop Experiments

Crops

Oilseed rape (*Brassica nupus*)

Barley (*Hordeum vulgare*)

CO_2 supply

CO_2 delivered from 6th June 2010

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

ASGARD: 2010 Root Measurements

Root photographs of oilseed rape

Control roots

Number of primary and secondary roots increase with time and depth.

South tube (Low surface gas/high deep gas areas)

↓ Roots with depth and time

↓ No. of secondary roots

East tube (High gas areas)

↑ Roots at 10-30 cm depth

↓ Roots at 30-60 cm depth

↓ No. of secondary roots

Nu … y
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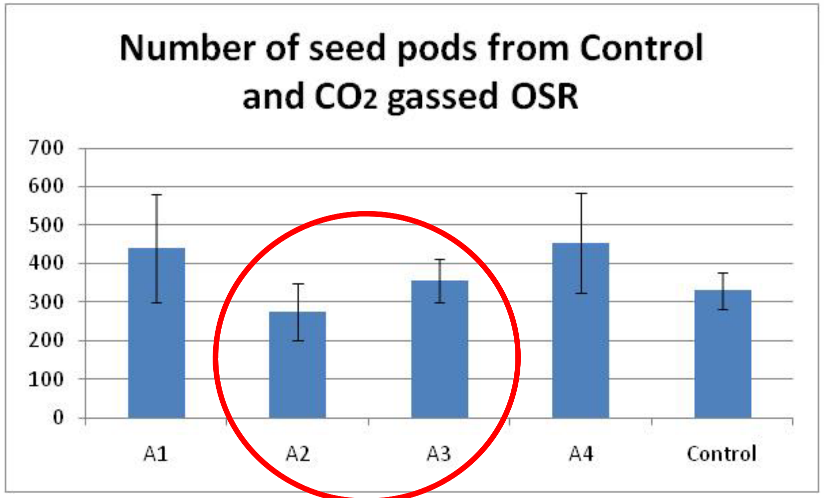
ASGARD:2010 Spring Crop Experiments: Biomass

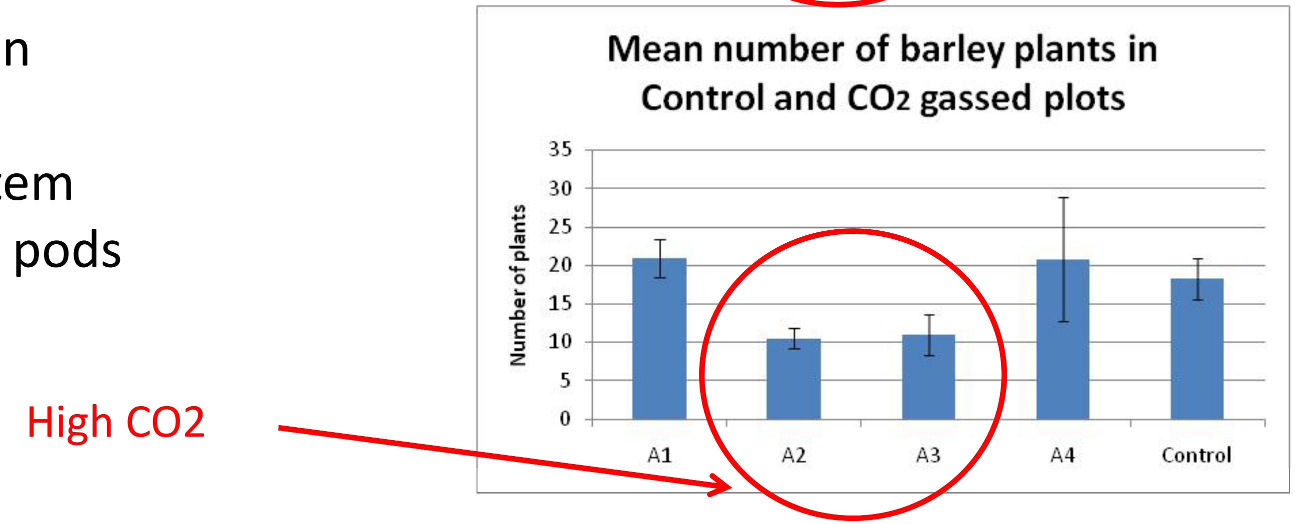
Barley

- ↓ number of plants and tillers
- ↓ weight of stem and ears
- ↓ no. of grain

Oilseed rape

- ↓ length of stem
- ↓ no. of seed pods





Naturally leaking sites in southern Europe

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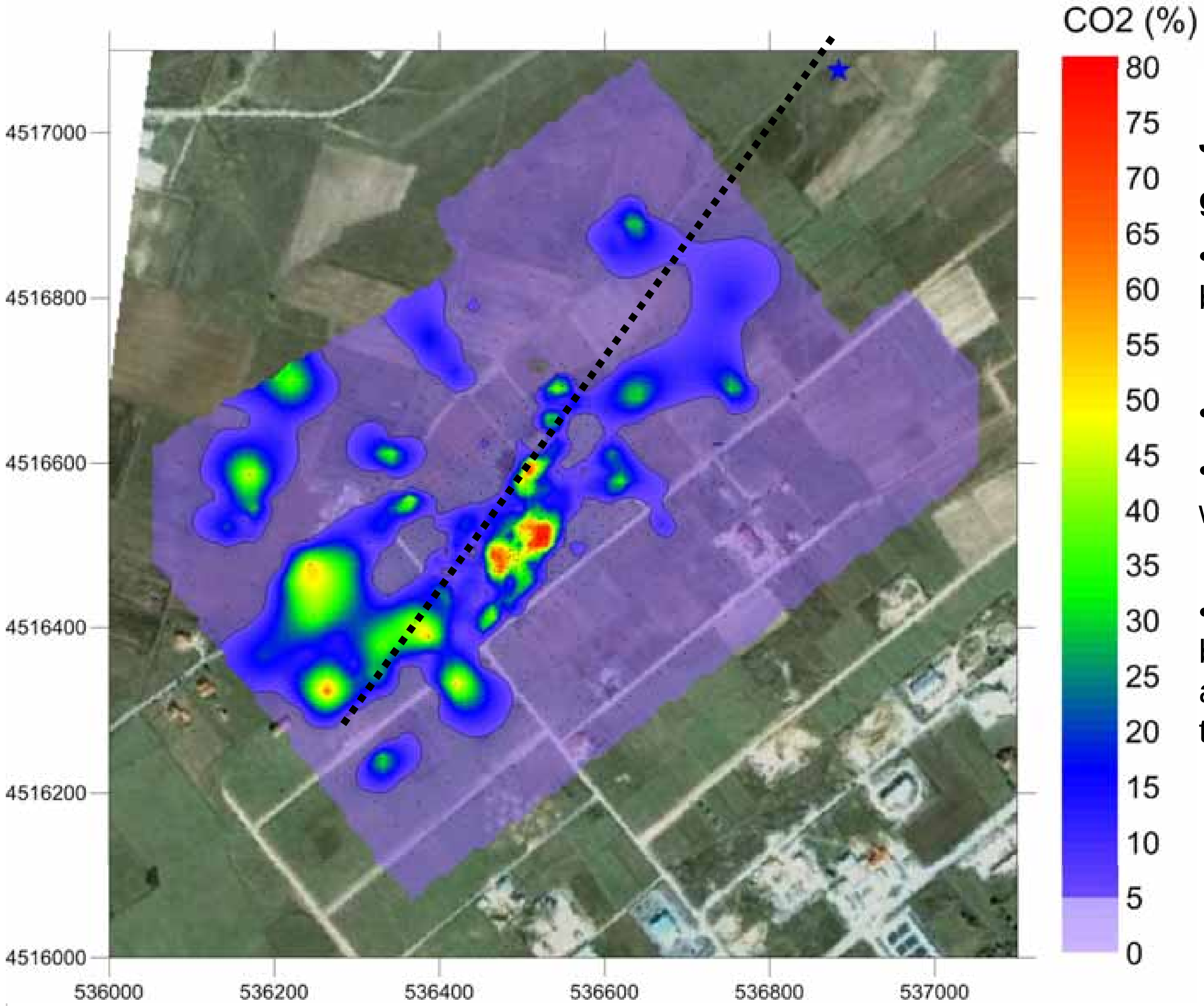
Impact of CO2 leaks on vegetation – Activities (1)



July and September soil gas surveys

- regional sampling conducted to better delineate structural control
- CO2 IR analyses in the field
- Values above 5% delineated with a contour line
- main structural trend appears to be more NE-SW, although anomalies to the W complicate the interpretation

Measuring soil gas and flux along the 25m long profile

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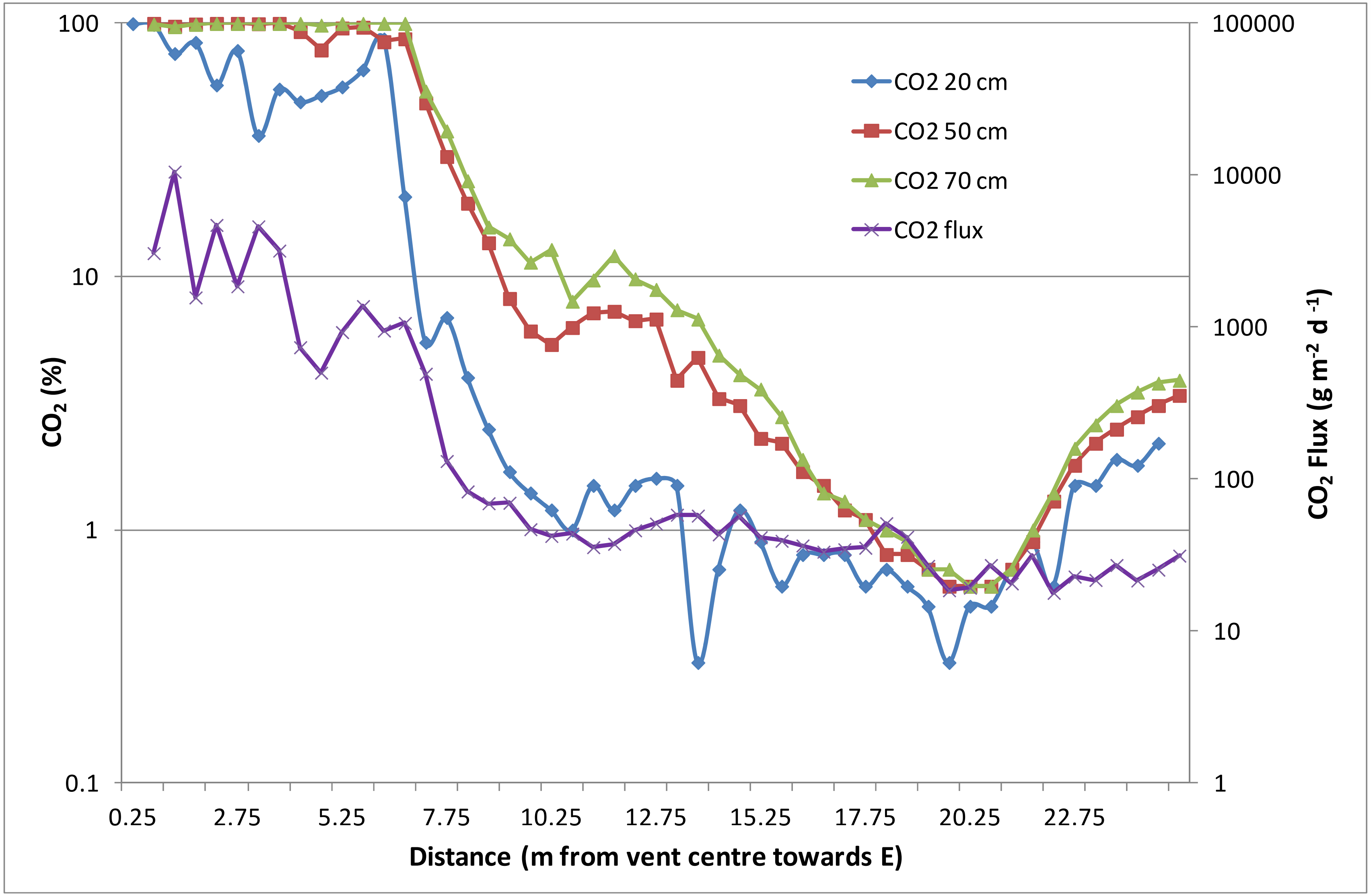
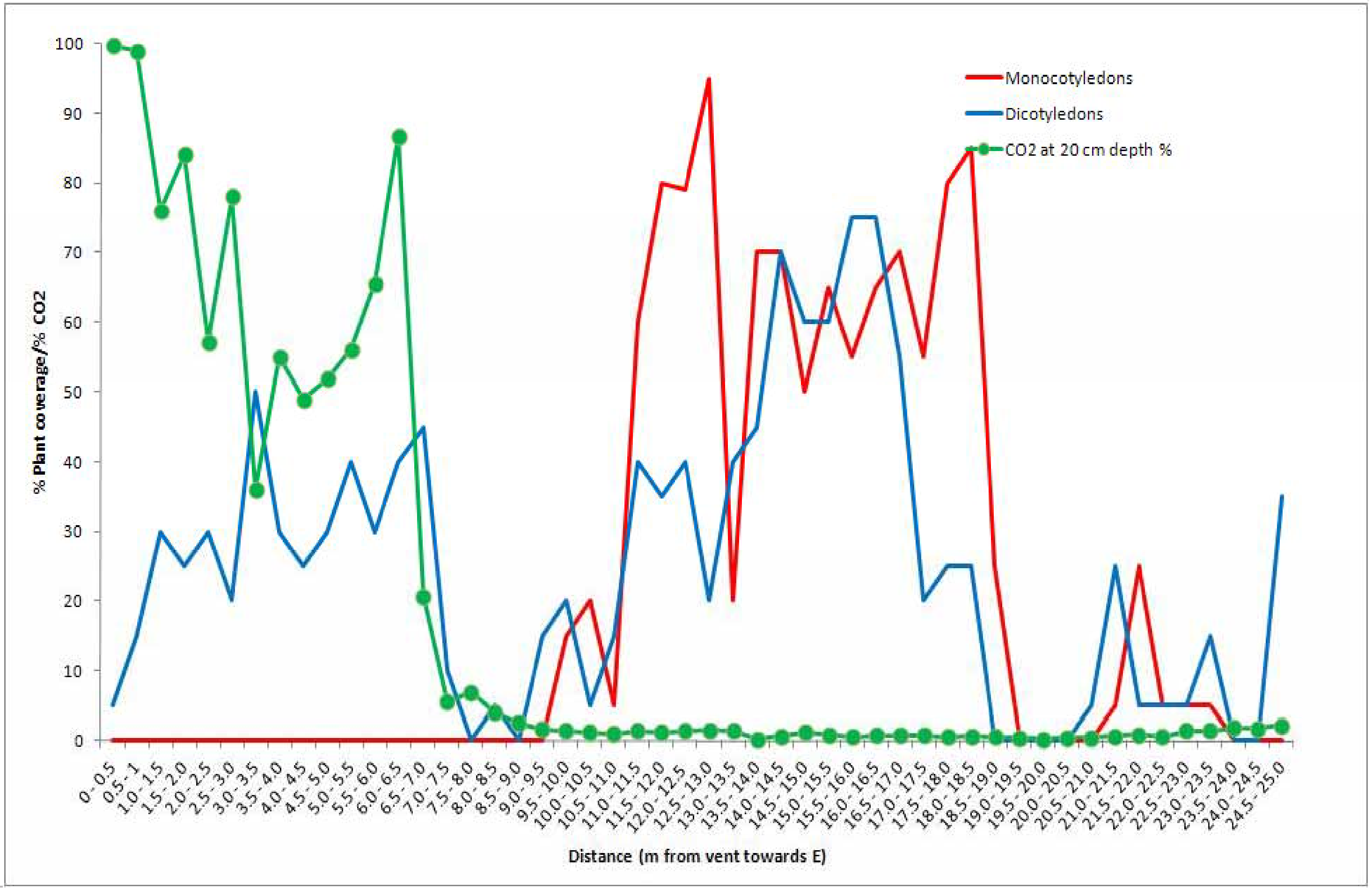


NB: log scales

Impact of CO_2 leaks on vegetation – Activities (2)

- At CO_2 concentrations of 20 – 99,7 % at 20 cm depth only the dicotyledonous plant (*Minuartia glomerata*) was observed and could be used as bio-indicator of high CO_2soil gas (similar dicot species identified in Laacher See)
- Where concentrations of CO2 are below 20% at 20 cm depth, monocot plants predominate and *Minuartia glomerata* is not observed (8-25 m) although other dicotyledonous plants are present



Assessing Impacts – numerical solutions

- Synthesize information from the scenarios, and Marine and Terrestrial experiments/observations
- Develop marine system model describing the key biogeochemical and ecological components relevant to CO_2 and its impacts in shallow sediment layer and overlying water column
- Develop terrestrial systems model representing the important processes in the transport of CO_2 to and in the near-surface terrestrial environment

Modelling Terrestrial Impacts

Work has focussed on 3 main areas:

- Improvement of the soil-plant impacts model
- Understanding CO_2 mass balances at field experimental sites
- Development of the QPAC Player impacts tool

Soil-Plant Model

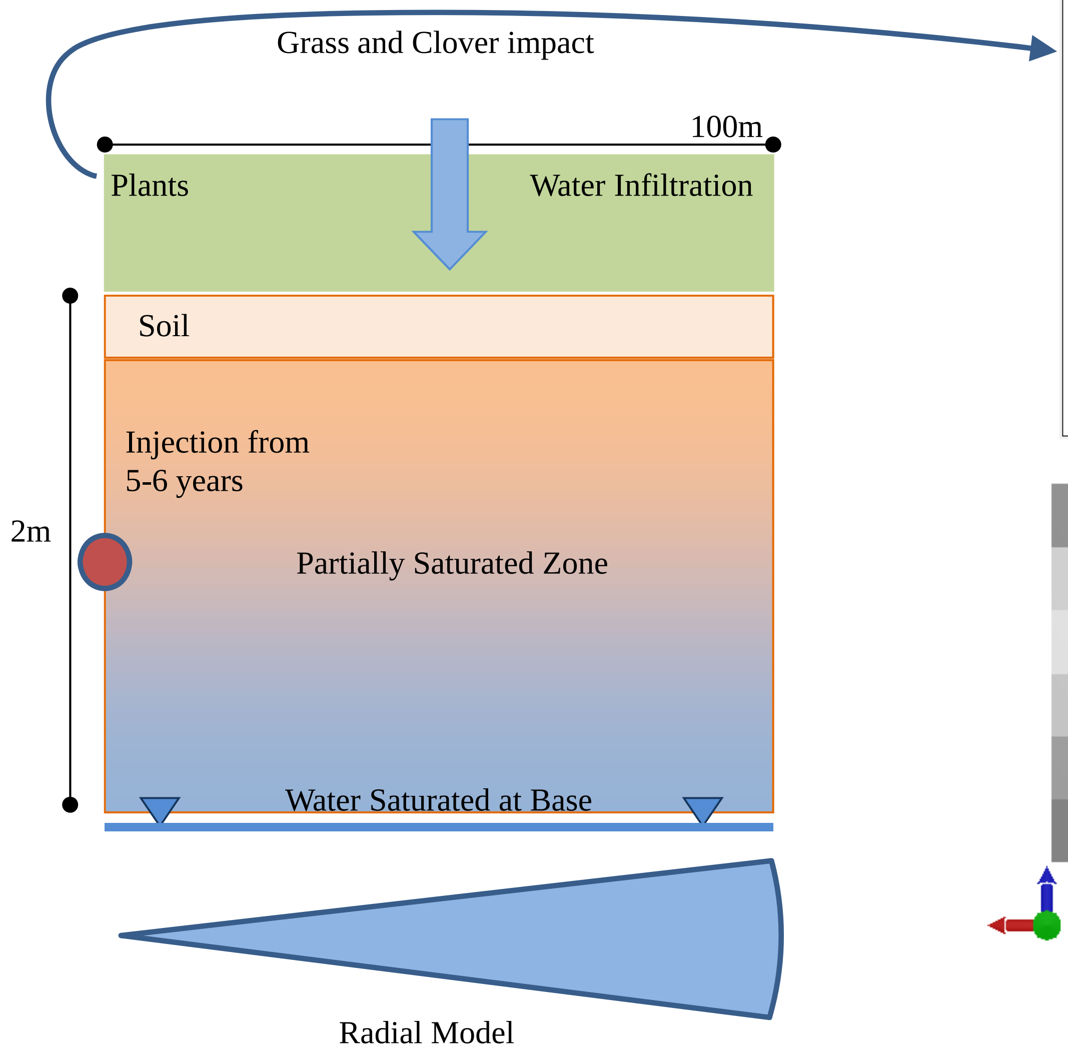
Major improvements:

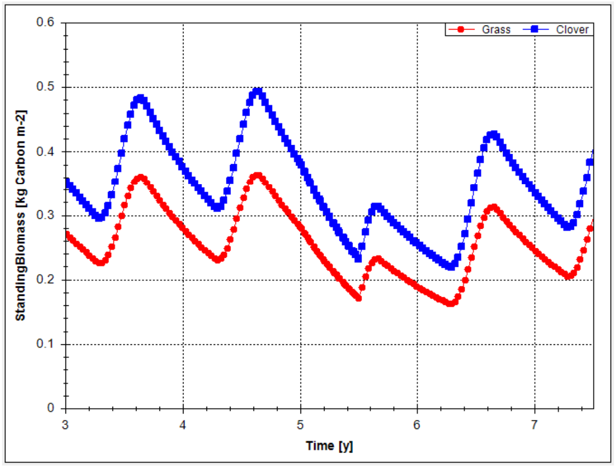
- Modelling of plant species competition
- Better impact model allowing canopy and soil zone concentrations to contribute to toxicity on a by-species basis
- Full coupling with multi-phase flow (MPF) porous media models including CO_2 and water (recharge, infiltration, transpiration) couplings; as needed.

Mass Balance Modelling (i)

- Have been applying the new model (MPF + SPM) to ASGARD type geometries.
- Initial results encouraging:
  - Able to replicate *general* patterns of loss of CO_2 radially and vertically through the soil zone.
  - Observe rapid transients of CO_2 decrease in soil zone when injection stops, and slow increases as injection starts.
  - Work ongoing, illustrative results.

Mass Balance Modelling (ii)





CO_2 saturation 0.4 years after injection, note **log scale** in the radial direction

Modelling Marine impacts - Key challenges

- Develop 3D simulations of leak dispersion, using fine scale models and incorporating CO_2 buoyancy effects
- Develop representations of sediment carbonate system dynamics (pH and alkalinity)
- Develop representations of bioturbation and response of bioturbation to changes in pH

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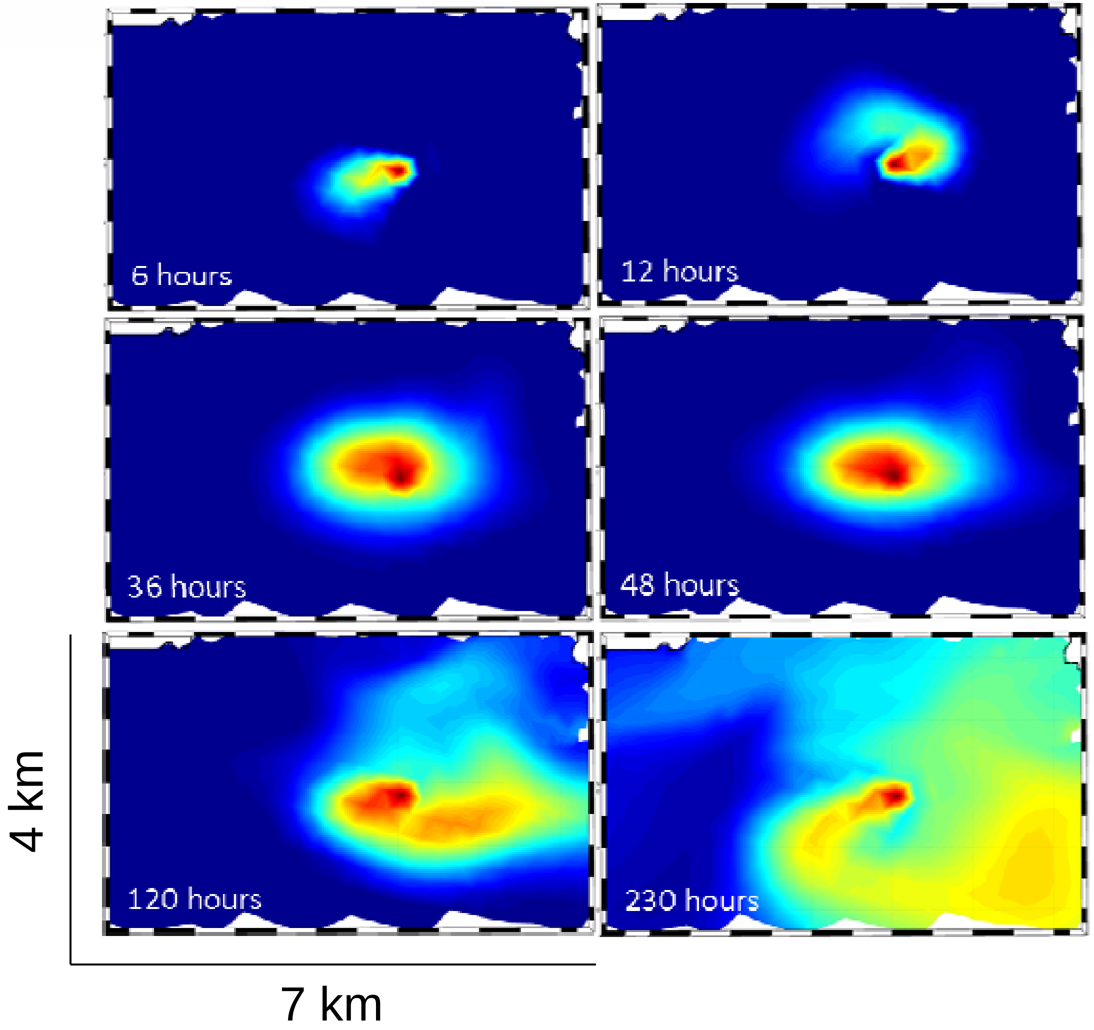
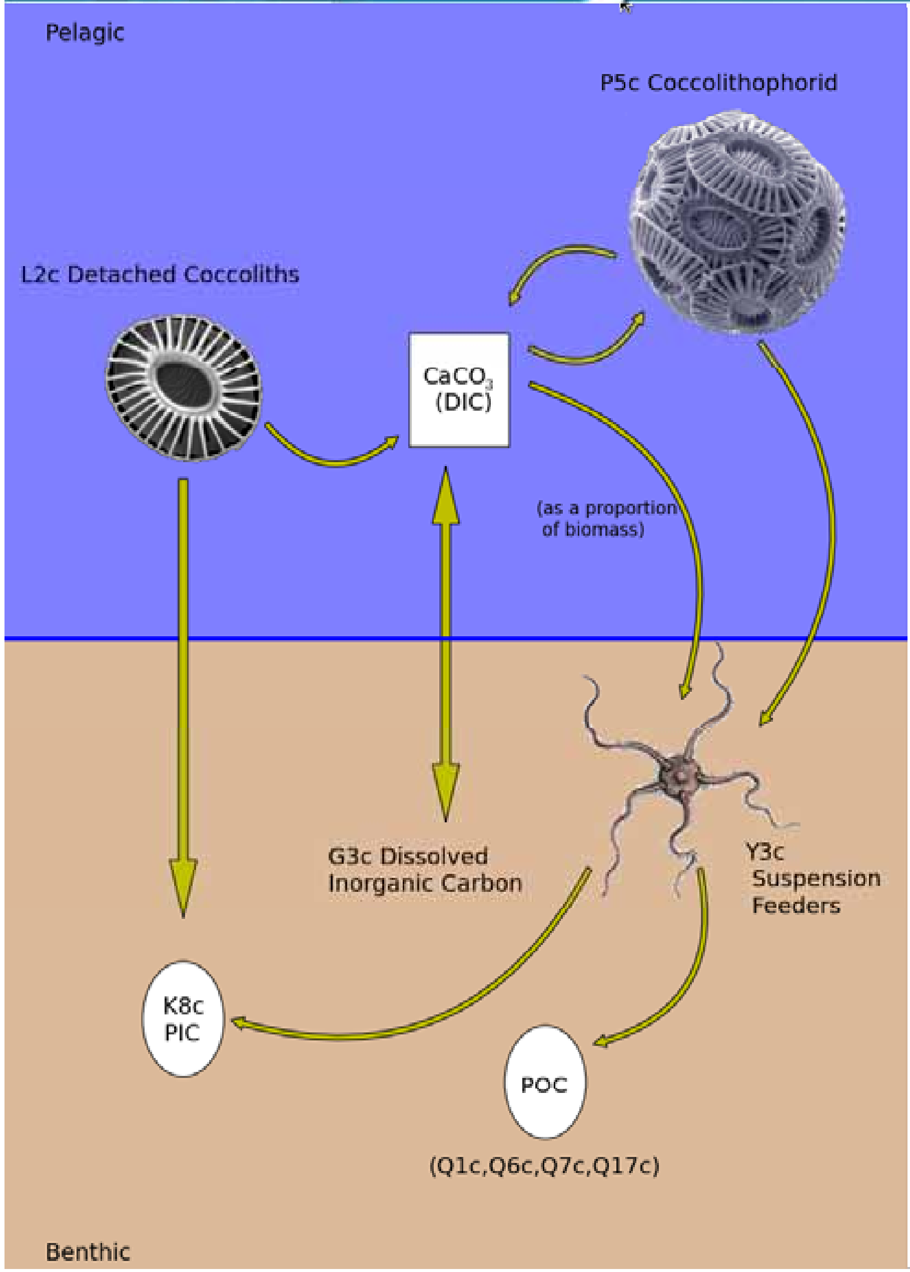
Dispersion modelling Initial simulations using FVCOM model system.



Complex tidal ellipse influence can be clearly seen.



Biological model developments

Reworking of existing ERSEM model

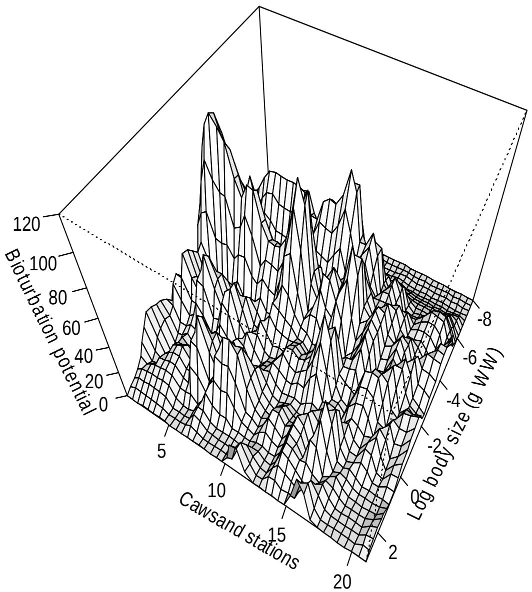
Accounting for Sediment type and grain size, eventually relating community type to sediment type

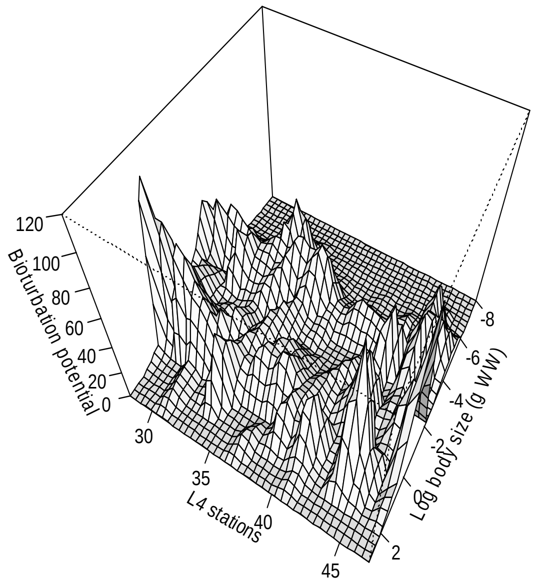
The key sensitive process is likely to be bioturbation and bio-advection/irrigation, caused by mobile sediment infauna.

Bioturbation

The effect of bioturbation in the model will also be investigated. Primarily by refining the description for Community Bioturbation Potential (BPc) and a bioturbation mixing intensity coefficient (D_b) to account for sub-divisions of the benthic community contributions that range from small meso-scale organisms through polychaetes and bivalves to the gallery forming species of crabs and lobsters.

Manila and palourde clams (Queiros *et al. in prep)*





Smoothed distribution of BPc across the (typical) body mass size spectrum at each site (Queiros *et al.*, unpublished)

The approach will allow a more quantitative and pragmatic representation of the bioturbation process in a way that aids model implementation

Guide to Impacts Appraisal

An integration of key results from RISCS and elsewhere to 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 of storage project development: design stage, construction, operation and post-injection, transfer
- Options for directly assessing the potential scales of leaks and ecosystem responses
- Options for identifying, predicting and verifying the nature of impacts

Guide Output

- A high-quality, well-illustrated report will be produced in 3 versions and then a final version
- Each version will supersede and extend the previous version
- The Guide will be developed through close consultation with key stakeholder groups at a series of workshops
- Scope of impact appraisals will be set within relevant regulations
- The final version is due for release in October 2013
- We will be seeking further comments and input at future workshops.

GIA – What should it do?

- The GIA is therefore a key mechanism for delivering RISCS outputs
  - To inform and influence stakeholder groups
  - To move storage impacts assessment from theoretical to (more) practical considerations
  - To provide focus for discussions both internally and externally on how the results from RISCS can be applied to storage projects

Summary

- Scenarios developed
- Experiments and observations for almost 2 years
- The data generated will help quantify the relative vulnerability and sensitivity of different functional groups - increasing our ability to predict the likely impact of CO_2 leakage
- Data from recovery experiments will be used to generate model predictions of recovery under different scenarios of CO_2 leakage.
- Results from field observation will be used to provide basic input and control data for modelling work
- Key findings in Guide to Impacts Appraisal

Project Partners

CERTH

RWE

www.riscs-co2.eu