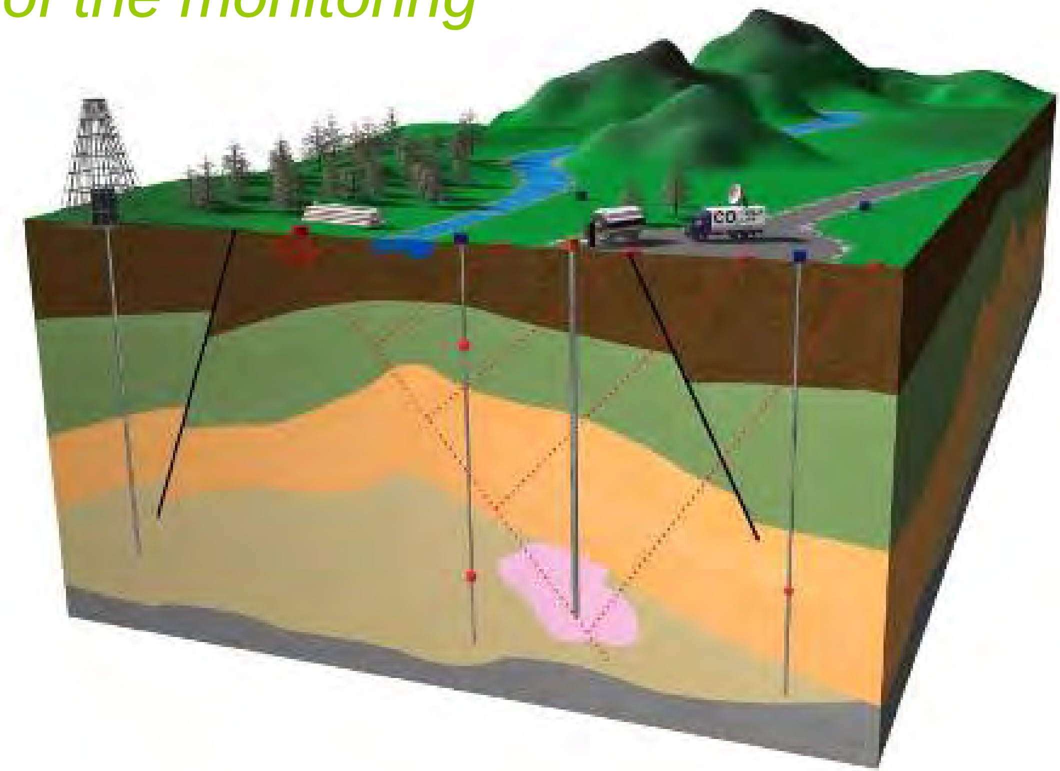
CO2 Field Lab

" It is of no use to monitor a reservoir without knowing the sensitivity of the monitoring equipment."



CO_2FieldLab

Maria Barrio, Etor Querendez, Michael Jordan

CSLF CO_2 Monitoring Interactive Workshop

18 April 2013, Rome

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The EUREKA Cluster for Low-Carbon Energy Technologies

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- DGCIS, Direction générale de la compétitivité, de l'industrie et des services (FR)

SINTEF largest independent research organisation in Scandinavia

CO$_2$ Field Lab

- Leading expertise in the natural sciences and technology, environment, health and social science
- 2100 employees from 68 countries
- Annual sales of NOK 2,8 billion – customers in 61 countries
- A non-commercial research foundation with subsidiaries

Main interests in an Operator's perspective

- Monitoring technology out of traditional O&G expertise
- Close technology gaps through research on monitoring
- Communication strategy towards local communities and general public
- Contribution to the general debate on CO2 storage safety

Objectives

CO$_2$ Field Lab

- CO_2 injection in permeable reservoir (shallow and deep)
- Sensitivity of monitoring systems
- Upscale monitoring systems and requirements
- Migration models
- Monitoring protocol & certification scheme
- Inform the public

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Location

Drammensfjord
50km SW of Oslo

Overview of time line

Sept 2009 | Jan 2011 | Dec 2013

Phase 1: Site characterization (Sept 2009 – Jan 2011)

Phase 2a: Shallow injection and deep characterization (Jan 2011 – Dec 2013)

Field tests and other injections at the site

- **Phase 0 Site selection**
- **Phase 1 (Sept. ’09 – Jan.’11)**
  - Site characterisation: geological surveys performed
  - June ’10: Drilled and logged 300 m appraisal well
  - Updated models based on logged data
- **Phase 2a (May ’11 – Dec ‘13)**
  - Sept. ’11: Shallow injection performed (20m)
  - VSP survey at 200 m & continuous sampling
  - Permeability test at 65 m (Nov.’12)
  - Consolidation of results & publication
- **Phase 2b : Original injection at 200 meters cancelled**

Shallow injection experiment

CO_2 Field Lab

- Calibration of tool measurements:
  - Detect and quantify
- Sensitivity of monitoring tools deployed
- Impact of the vadose zone on required measurements
- Rehearse and coordinate surface monitoring methods before deep injection

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Monitoring methods deployed

CO2 Field Lab

Tool	Depth	Deployment	Mode
GAS			
Gas monitor station	c. 1 m	Fixed	Continuous
Flux station	Surface	Fixed	Continuous
Eddy covariance	Surface	Fixed	Continuous
Mobile laser	Surface	Mobile	Intermittent
Flux	Surface	Point (not fixed)	Intermittent
Radon/ CO_2 monitoring probes	0.8 m	Fixed	Continuous
CO_2, O_2 and CH_4 monitoring (soil gas)	1 m	Fixed/ mobile	Intermittent
Portable GC	Surface	Fixed	Intermittent
WATER			
*Sampling for chemistry and isotopes (using peristaltic pumps)	5,10 & 15m	Fixed	Intermittent
*Idronaut probe (piezometer)	2m	Fixed	Intermittent
Water sampling with West-bay completion	Several depth levels 1-20 m	Fixed	Continuous
Borehole GEOPHYSICS			
4D cross-borehole resistivity tomography ALERT	0 – 20 m	fixed	Automatic repeat
1D resistivity observatory IMAGEAU	0 – 20 m	fixed	Automatic repeat
Time-lapse logging (resistivity, gamma-ray, sonic)	0 – 20 m	fixed	Intermittent
2D Crosswell radar (GPR) tomography	0 – 13 m	fixed	Intermittent
Pressure, conductivity monitoring in West-bay well	0 – 20 m	Fixed	Continuous

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* Tubing connected to ALERT boreholes

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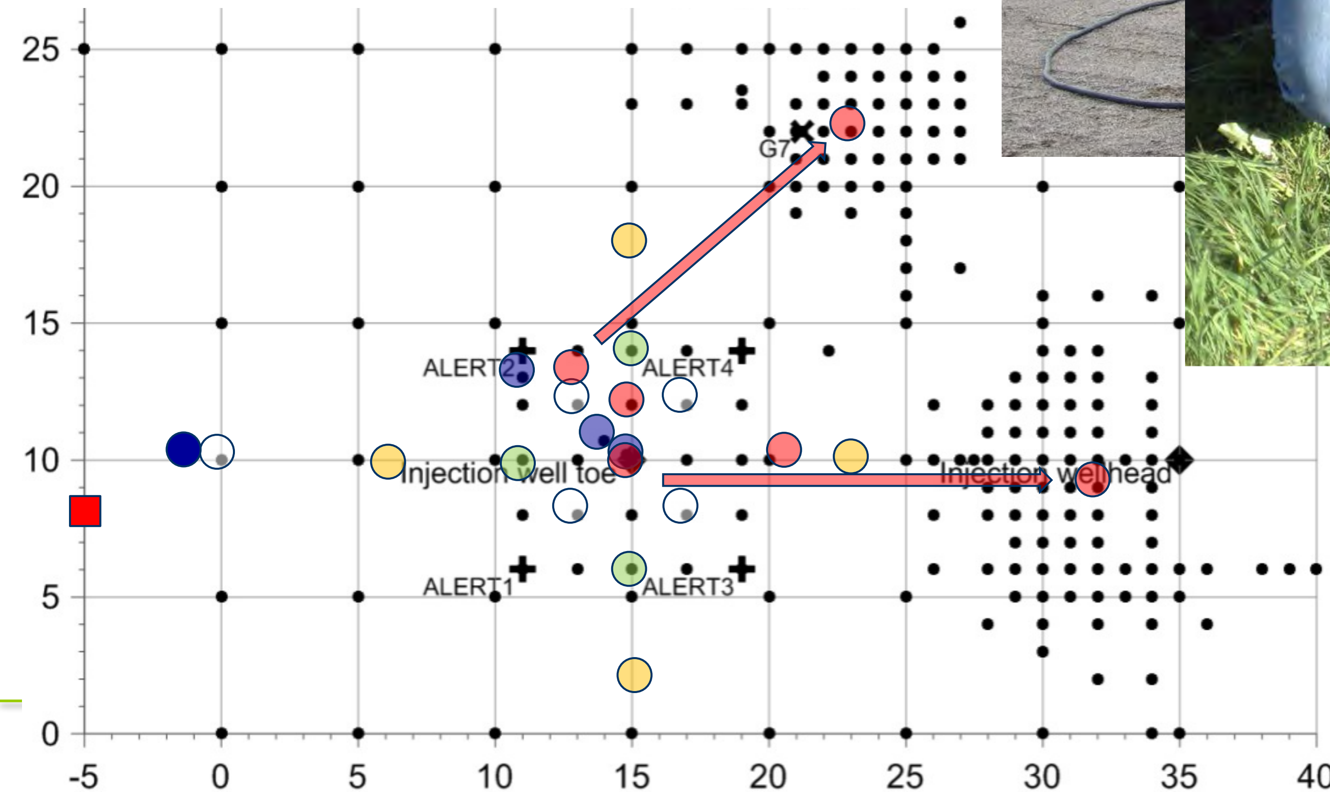
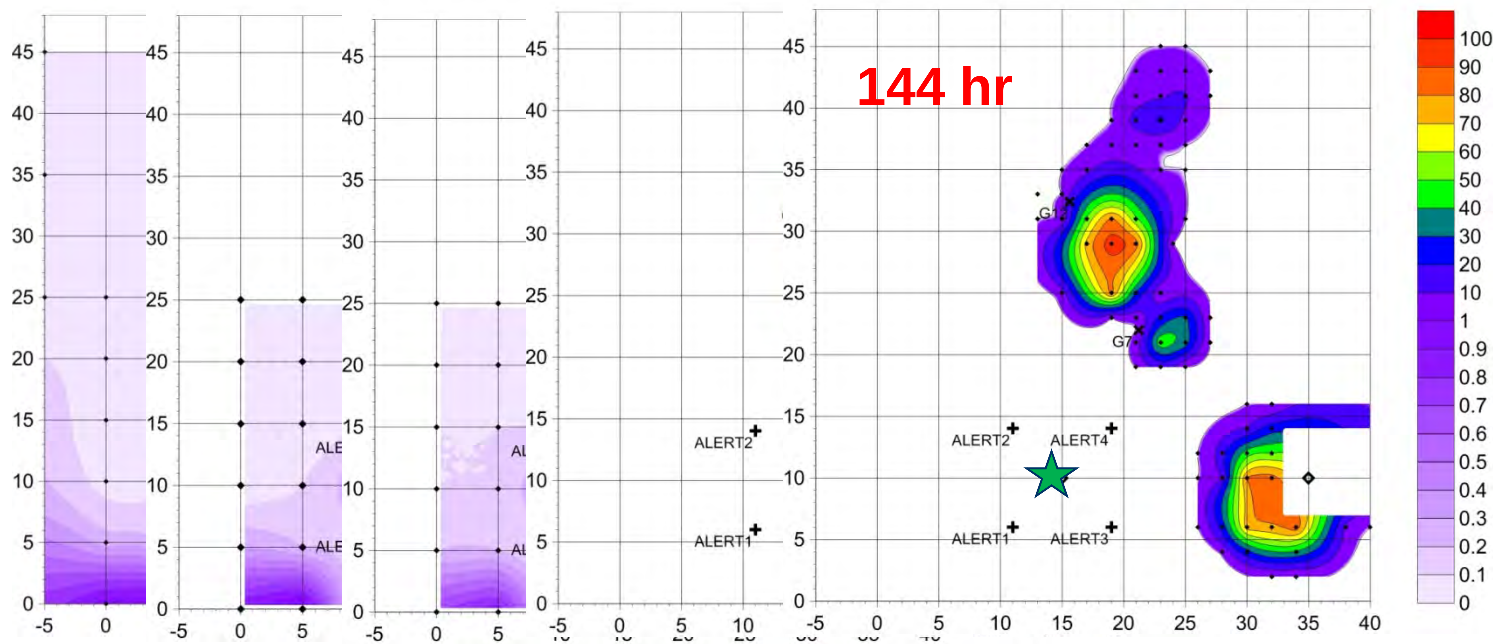
Positioning of monitoring equipment



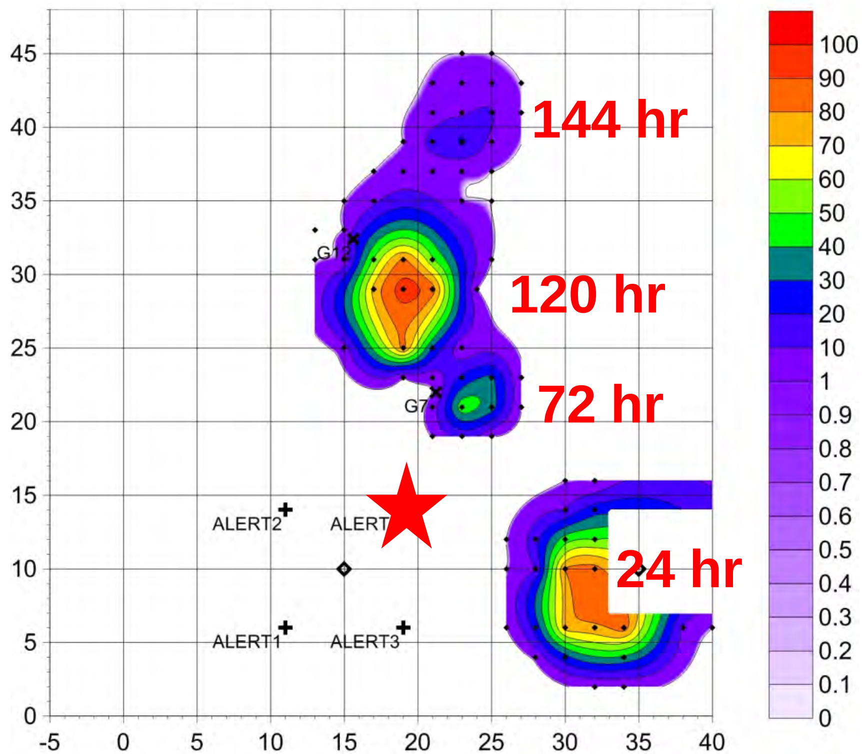
Facts

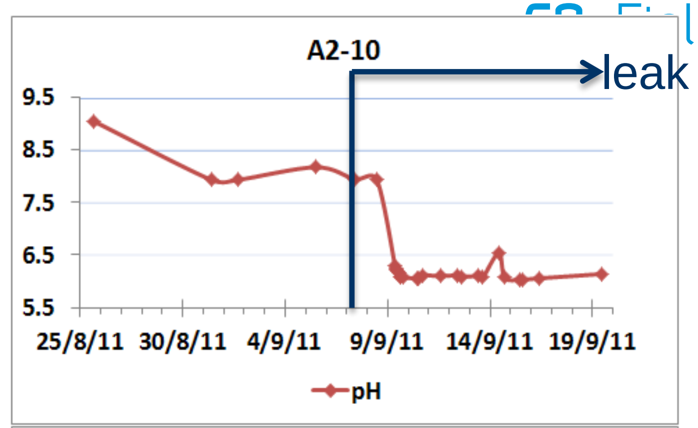
- The surface detection of CO_2 not right above injection
- CO_2 leakage along wellhead
- Breakthrough to the North at outer margin of test area.

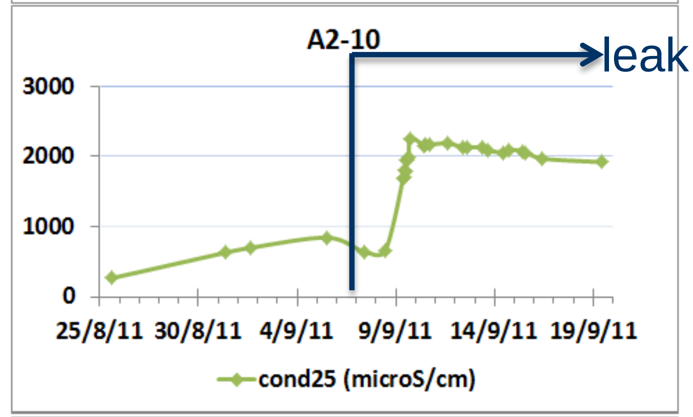


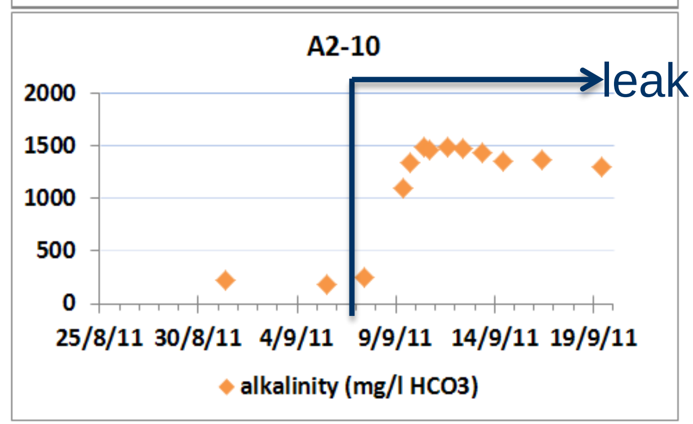
Soil gas and water sampling

Soil Gas CO_2 concentration (%) at 50cm depth





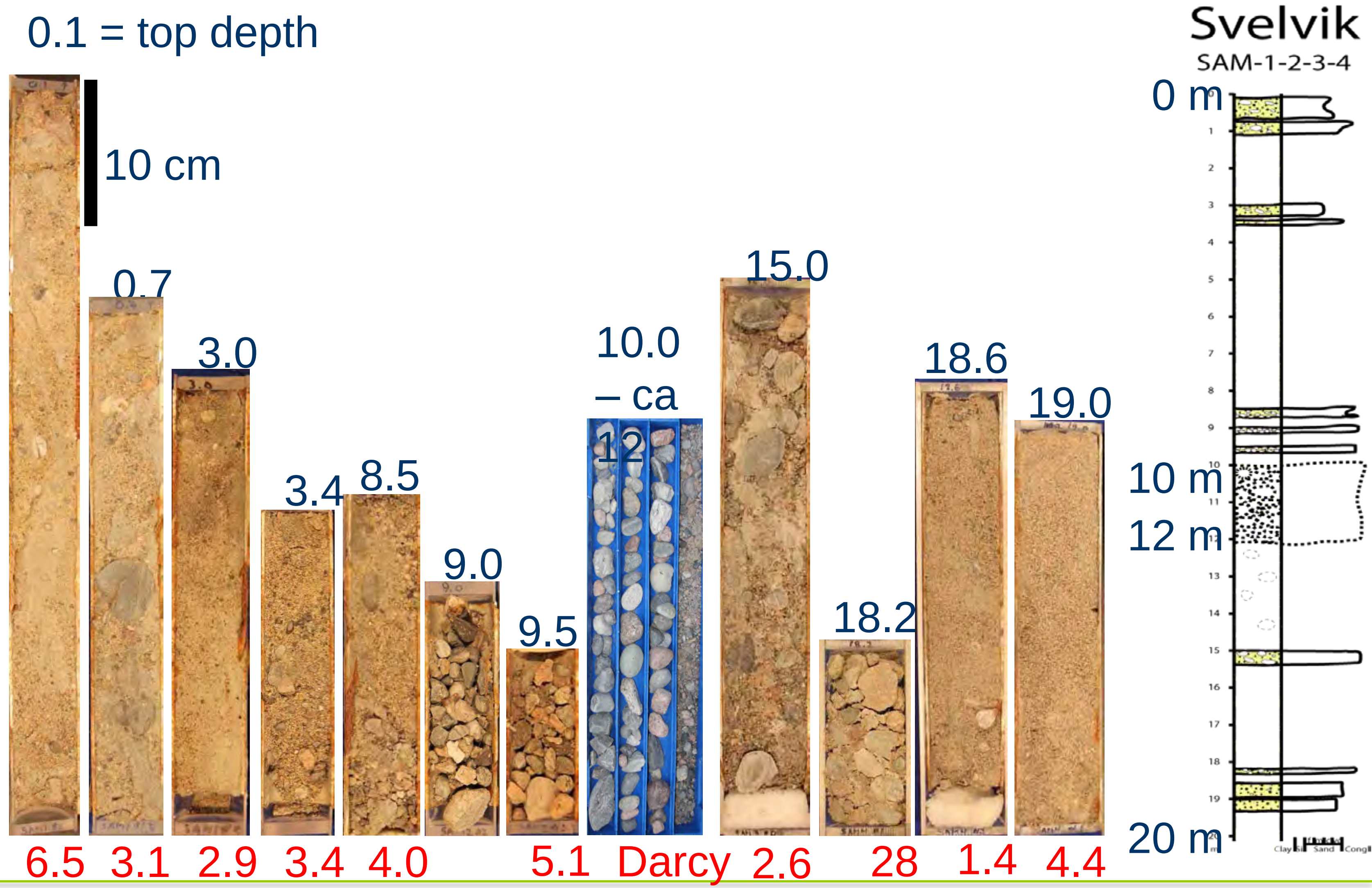




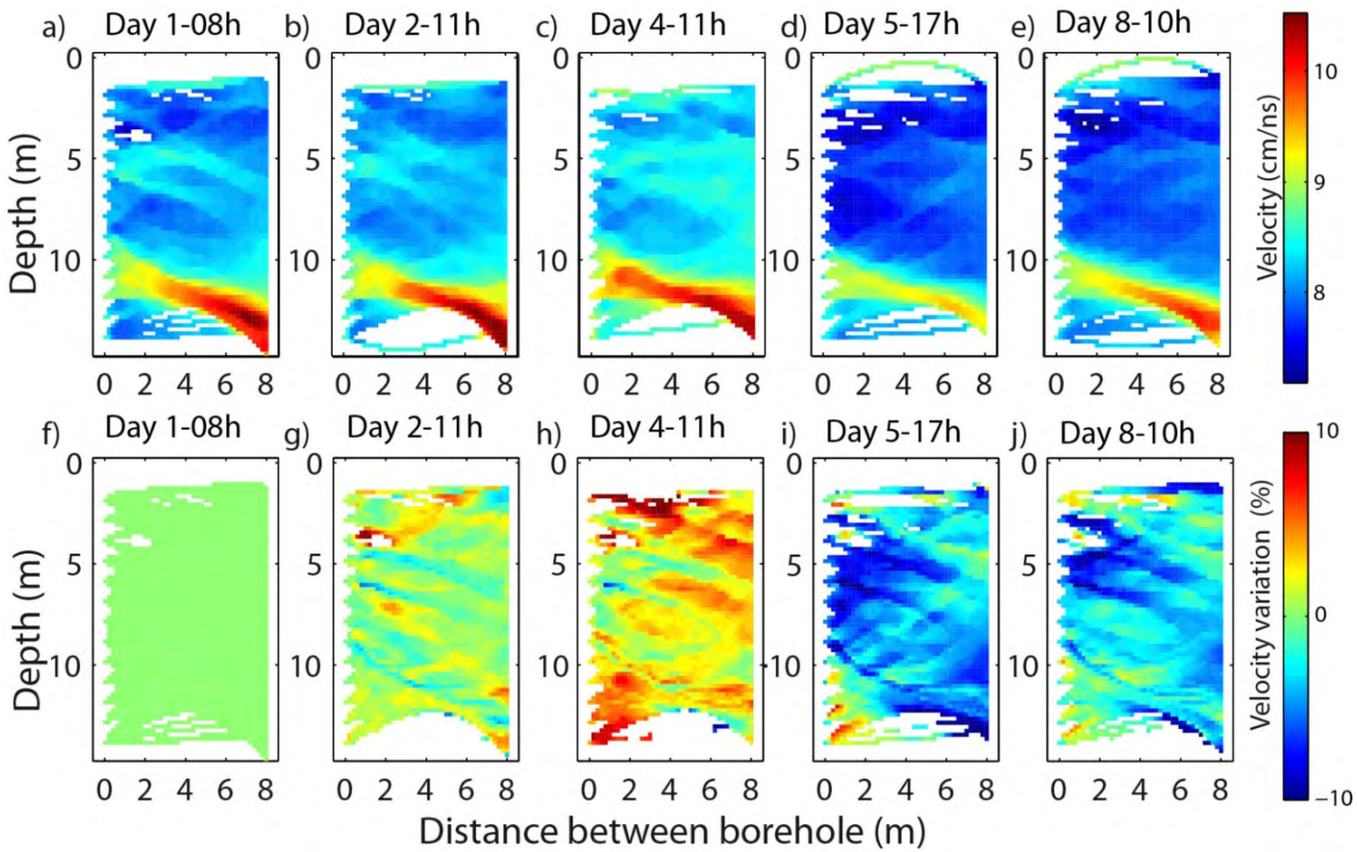
Learning from shallow injection

1. Impact of geology at short length scale
2. Complex impact of CO2 on conductivity and resistivity
    1. Saline/fresh water mixing
    2. Dissolution / gas proportion and rates
    3. Reaction rates
3. Methodology of monitoring techniques
    1. Acquired data vs interpreted data
    2. Measuring principle for the various techniques
    3. Sufficiency of baseline data
    4. Impact of external variations (rainfall, tides)

Impact of heterogeneities



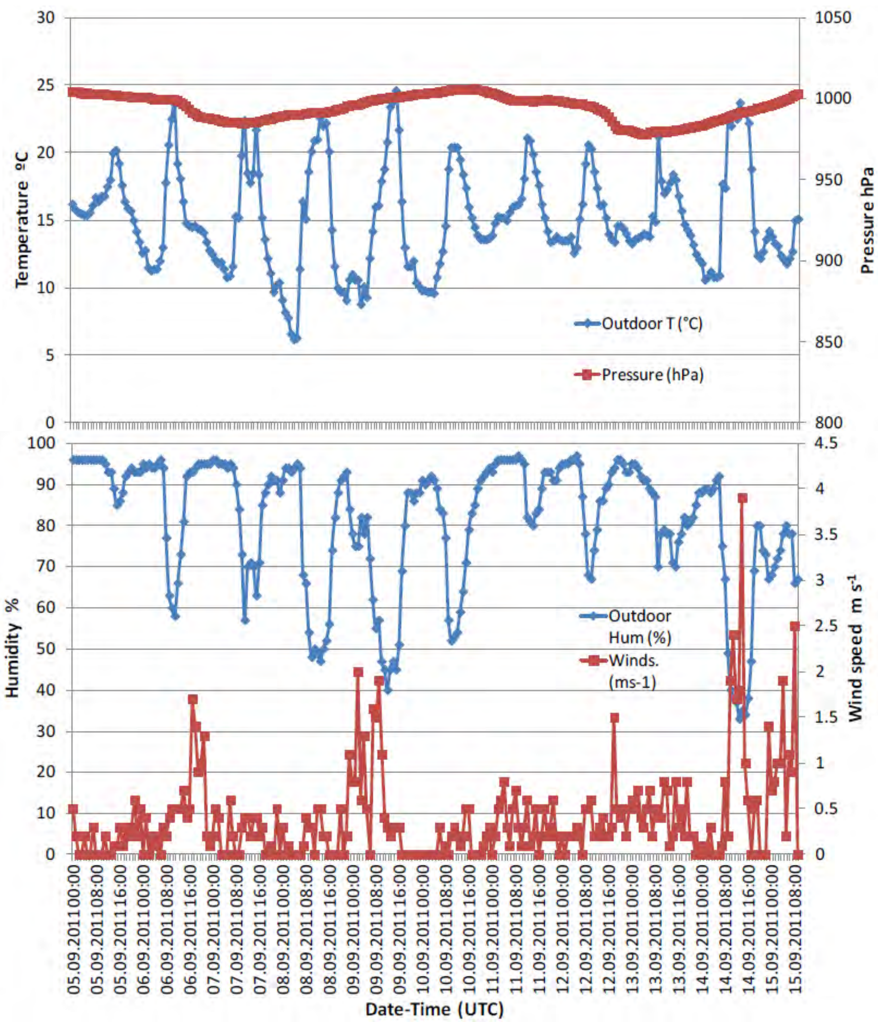
Crosswell GPR Time-lapse monitoring (BRGM)

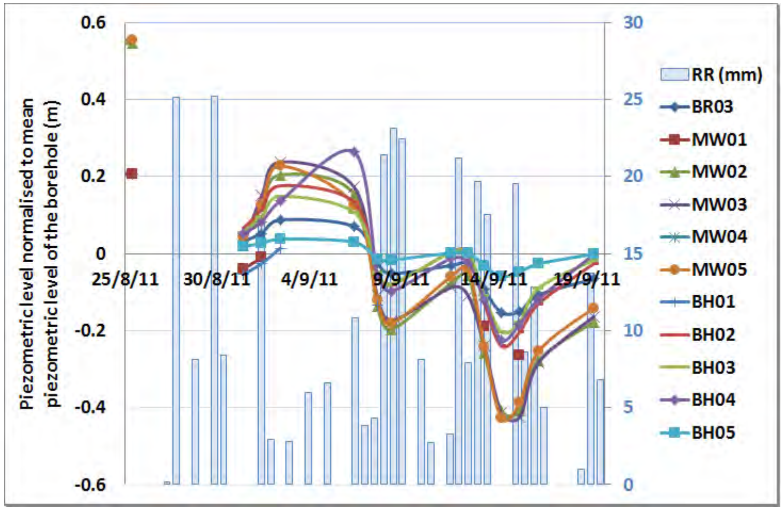


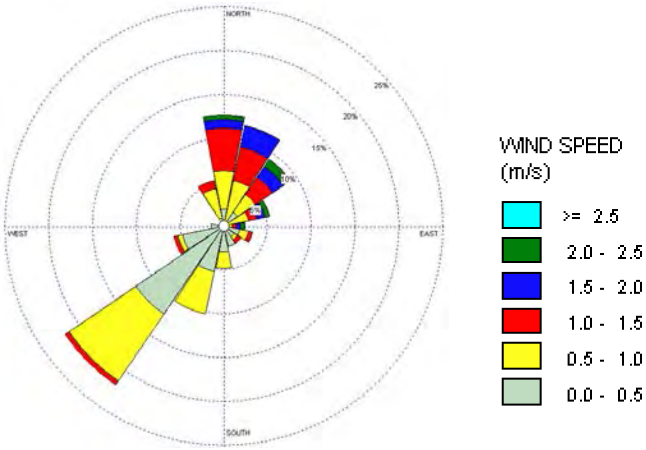
- first a 20% increase of velocity: detection of gas phase
- After 3 days of injection, abrupt return to a constant value,

~ -5% than initial conditions: detection of electrical conductivity increase.

Impact of natural temporal variations





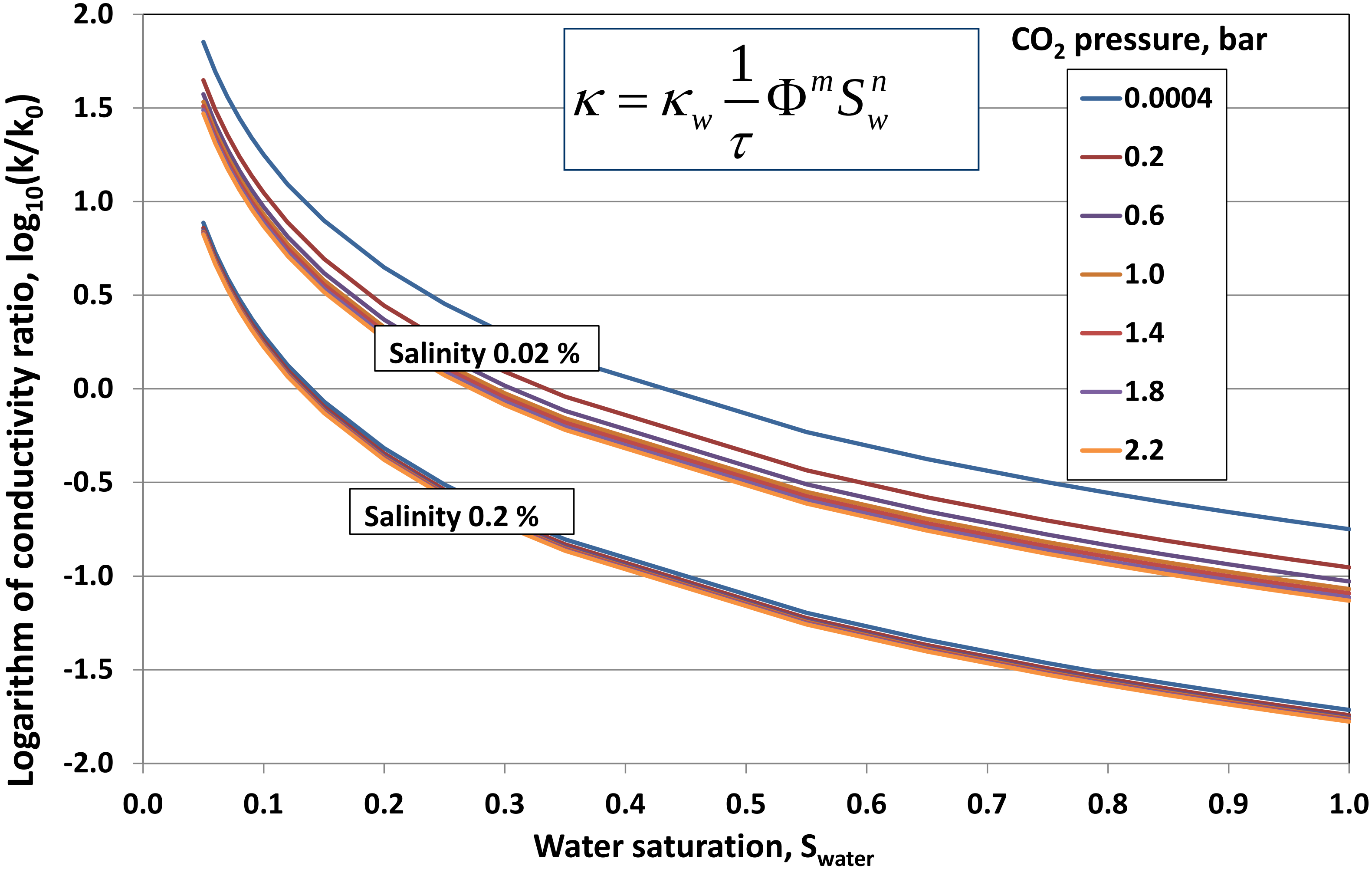


Complex setting

- Several phenomena co-exist and interact
  - convection currents causing mixing of water from layers with different salinity
  - dissolution of CO_2 into water inducing new rock-water interactions
  - migration of the CO_2 gas phase.

Conductivity
Salinity
Dissolution

Change in conduction due to change in water saturation



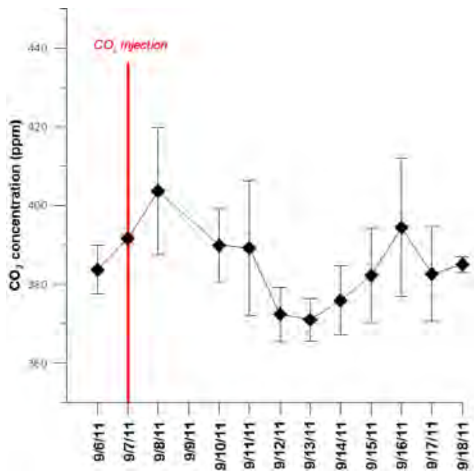
The resistivity of ground water will always decrease upon exposure to CO_2

Why? Chemistry:

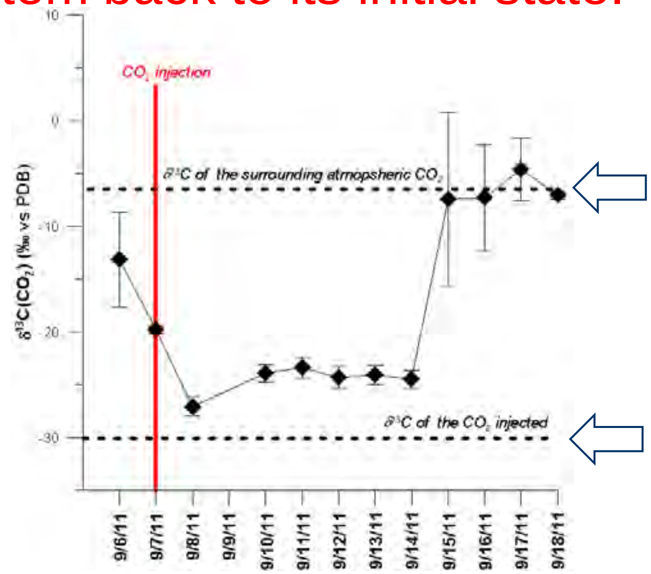
Process	Reaction	Effect on pH	Effect conductivity	Rate
Dissolution of CO_2 in water	CO_2^g -> CO_2^{aq}	None	None	Slow
Formation of carbonic acid	$CO_2^{aq} + H_2O$ -> H_2CO_3	None	None	Instant
Dissociation of carbonic acid	H_2CO_3 -> $H^+ + HCO_3^-$	Decreases	Increases	Instant
Dissociation of carbonic acid	HCO_3^- -> $H^+ + CO_3^{--}$	Decreases	Increases negligible at pH < 9	Instant
Dissolution of carbonates*	$MeCO_3 + H^+$ -> $Me^{++} + HCO_3^-$	Compensates some of the decrease, buffering	Increases	Slow

Soil Gas isotopic monitoring

CO_2 concentration :
No significant variations observed



The carbon isotope compositions (BRGM)
Both the CO_2 leak and the return of the system back to its initial state.



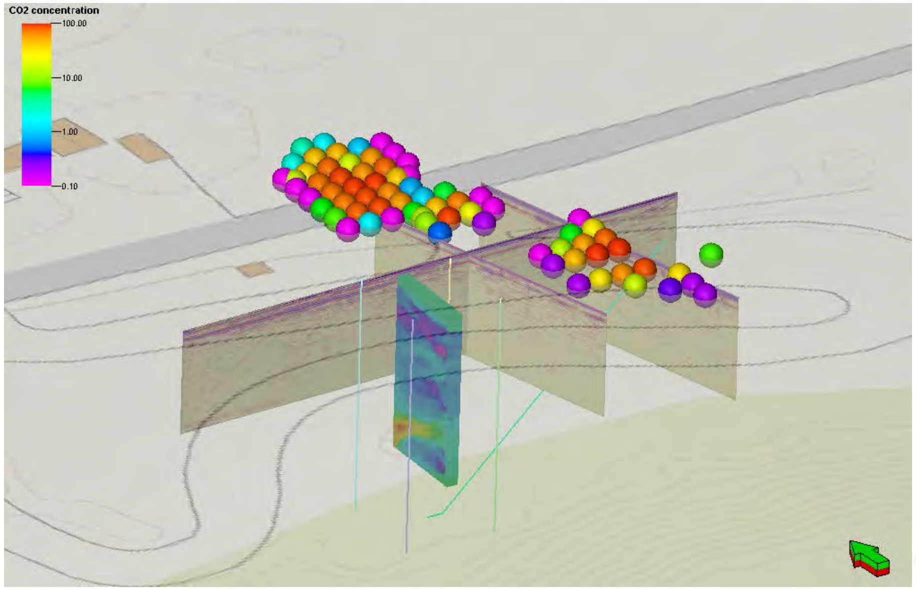
$\delta^{13}C$ of atmospheric CO_2

$\delta^{13}C$ of injected CO_2

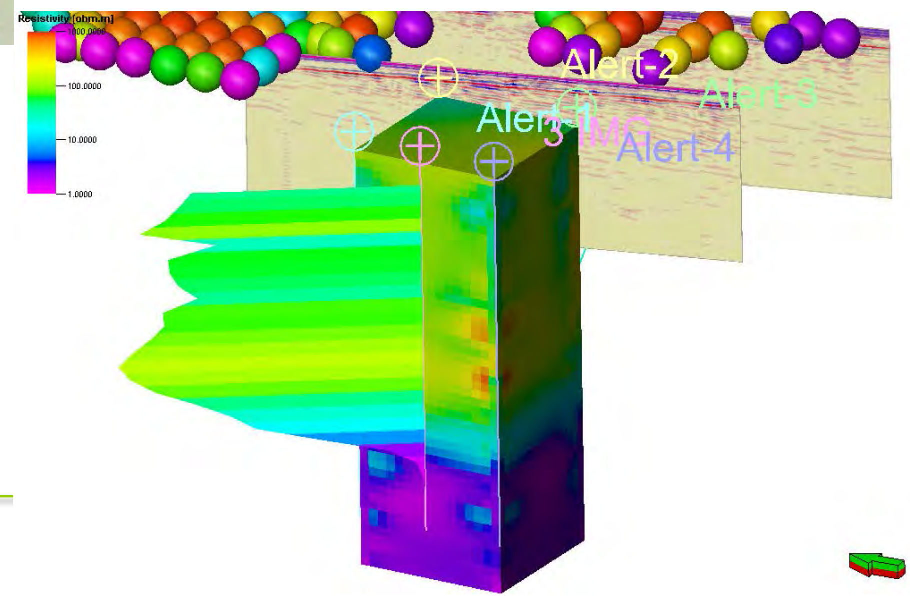
$\delta^{13}C$ is explained by a binary mixing between the surrounding atmospheric CO_2 and the injected CO_2.

Daily averages and standard deviations reported.

Shallow and Deep Geomodels



- Surface GPR
- Cross-well GPR
- Shallow gas CO2 concentration
- ALERT resistivity cube
- Resistivity log



- Used for data integration and interpretation
- Used for modelling

Key results

- All deployed instruments measured changes over the course of the CO_2 injection
  - Some inside noise level
  - Some can be misleading (no CO_2 concentration variations even though isotopic signature of injected CO_2 visible)
- All methods agreed about the CO_2 plume migrating outside of the monitoring region
- Indirect measurements above 5m depth might not reliable due to environmental noise
- Direct geochemical measurements (pH, Alkalinity, Isotopic analysis…) have the highest sensitivity to CO_2 presence

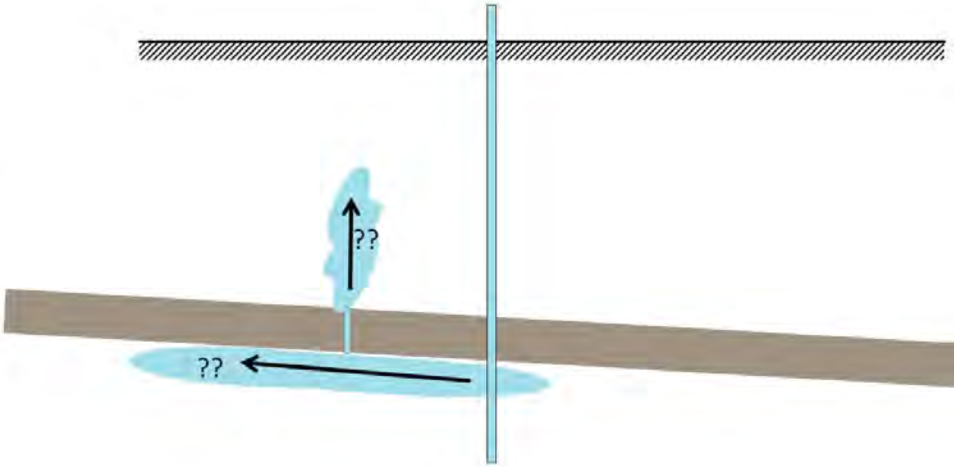
WHAT NEXT?

New injection at 65 meter deep

Feasibility of monitoring strategy

- Develop and test comprehensive workflow for determining optimum, site specific monitoring strategy of CO2 injection/storage

  "How can we detect and quantify the CO2 at any given site?"
- Scalable
- Quantification of CO2



Feasibility study for monitoring strategy

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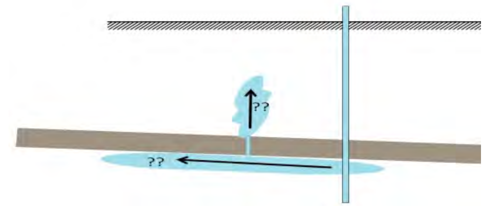
Derive different geomodels for the possible injection scenarios

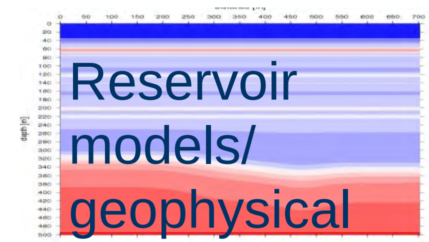
Geophysical modelling of various data sets at several time steps during the injection

- Multiple monitoring scenarios
- Take into account realistic conditions: E.g., attenuation, anisotropy, topography,…

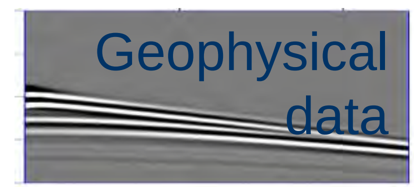
Determine optimum methods, acquisition, and resolution for monitoring

- 4D FWI (2D / 3D), CSEM, Resistivity, Gravity
- Joint/constrained inversion





Reservoir models/ geophysical models



Geophysical data

Suitable Monitoring methods / quantification

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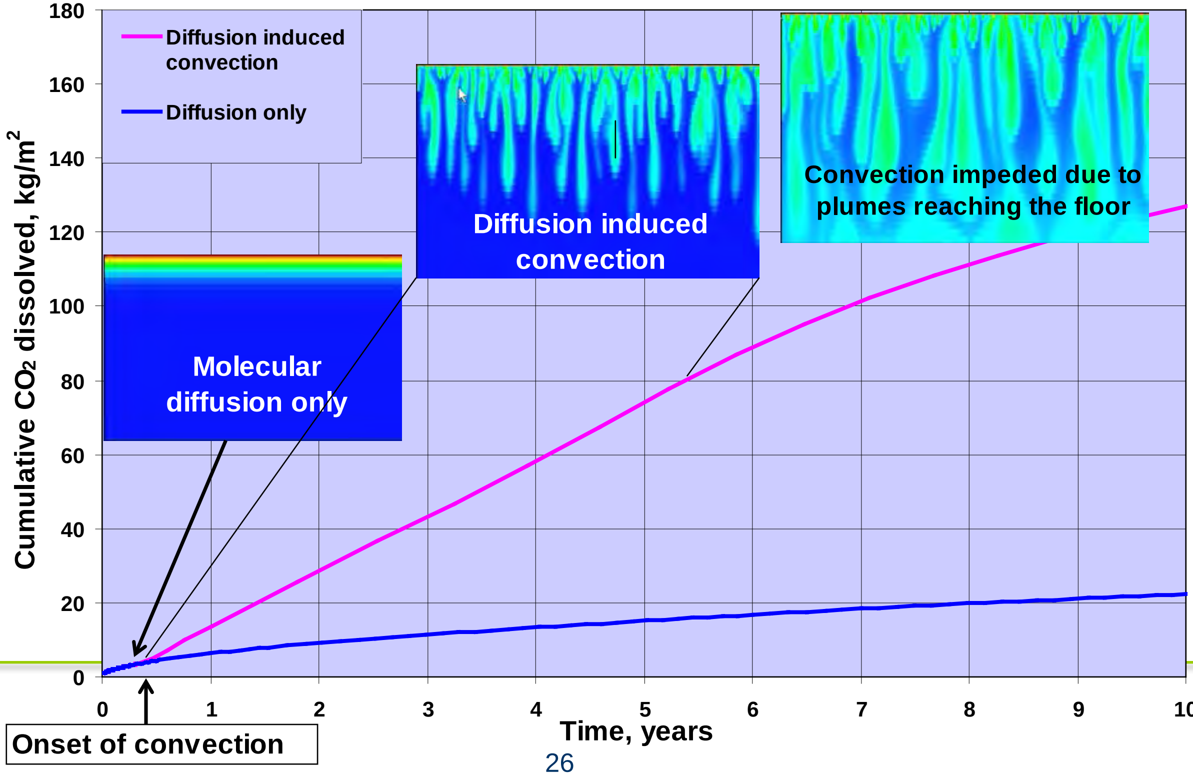
Field scale test of diffusion induced convection

- Test predictions for onset time at a scale larger than laboratory
- Determine the onset time and dissolution rate CO2 in a geological environment



Field scale test of diffusion induced convection