Monitoring Requirements

Objectives, technologies and predictive modelling

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Regulatory Requirements in Europe (1)

OSPAR Treaty (June 2007) (offshore NE Atlantic)

- Performance verification
- Leakage detection
- Local environmental impacts
- To confirm effective GHG mitigation

EC Directive (April 2009)

- Comparison of predicted with actual behaviour
- Detect significant irregularities
- Detecting migration of CO_2 (e.g. out of the primary reservoir)
- Detecting leakage
- Environmental impacts (e.g. potable aquifers)
- Efficacy of any corrective measures
- Updating performance assessment
- Support case for long-term stability and permanent containment

Regulatory Requirements in Europe (2)

ETS Monitoring and Reporting guidelines

- **It is assumed that no leakage is occurring unless indicated by the Directive-based monitoring**
- **Leakage must be quantified (measured)**
- **ETS monitoring plan should include:**
  - **Quantification approaches for emissions for potential and actual releases**
  - **List of emission sources**
  - **Description of calculation- or measurement-based methods for quantifying leaks**
  - **Statements of uncertainty thresholds**

Modalities and procedures for the CDM
(synthesis of submissions to SBSTA)

Suggestions for monitoring

- **Assurance of integrity and safety**
- **Confirm permanent storage within project boundary**
- **Address identified risks and issues**
- **Detect seepage (leakage)**
- **Estimate emissions if leakage detected**
- **Verify (predictive) numerical modelling**

Summary generic monitoring requirements

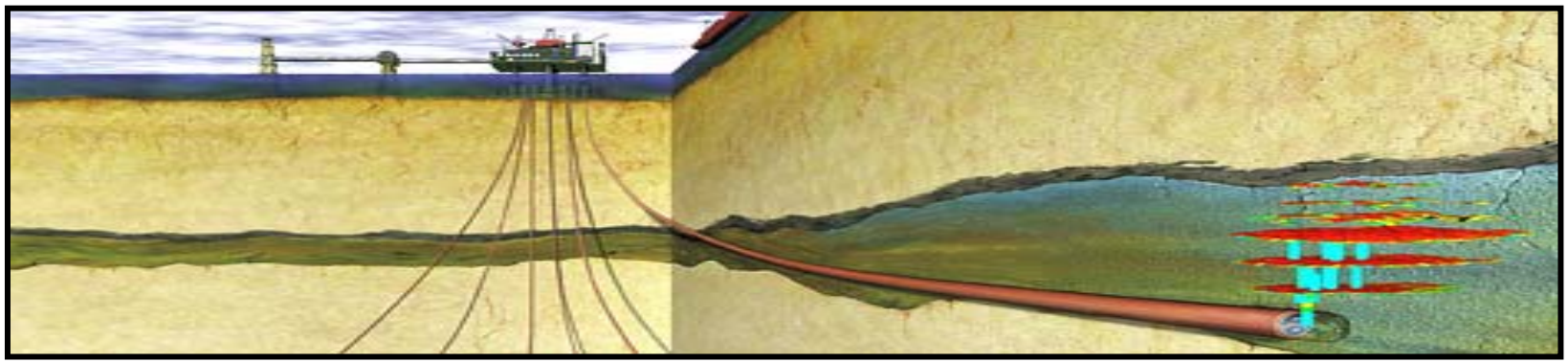
- **Performance calibration and verification**
- **Leakage detection (and measurement)**
- **Long-term stabilization and permanent containment**

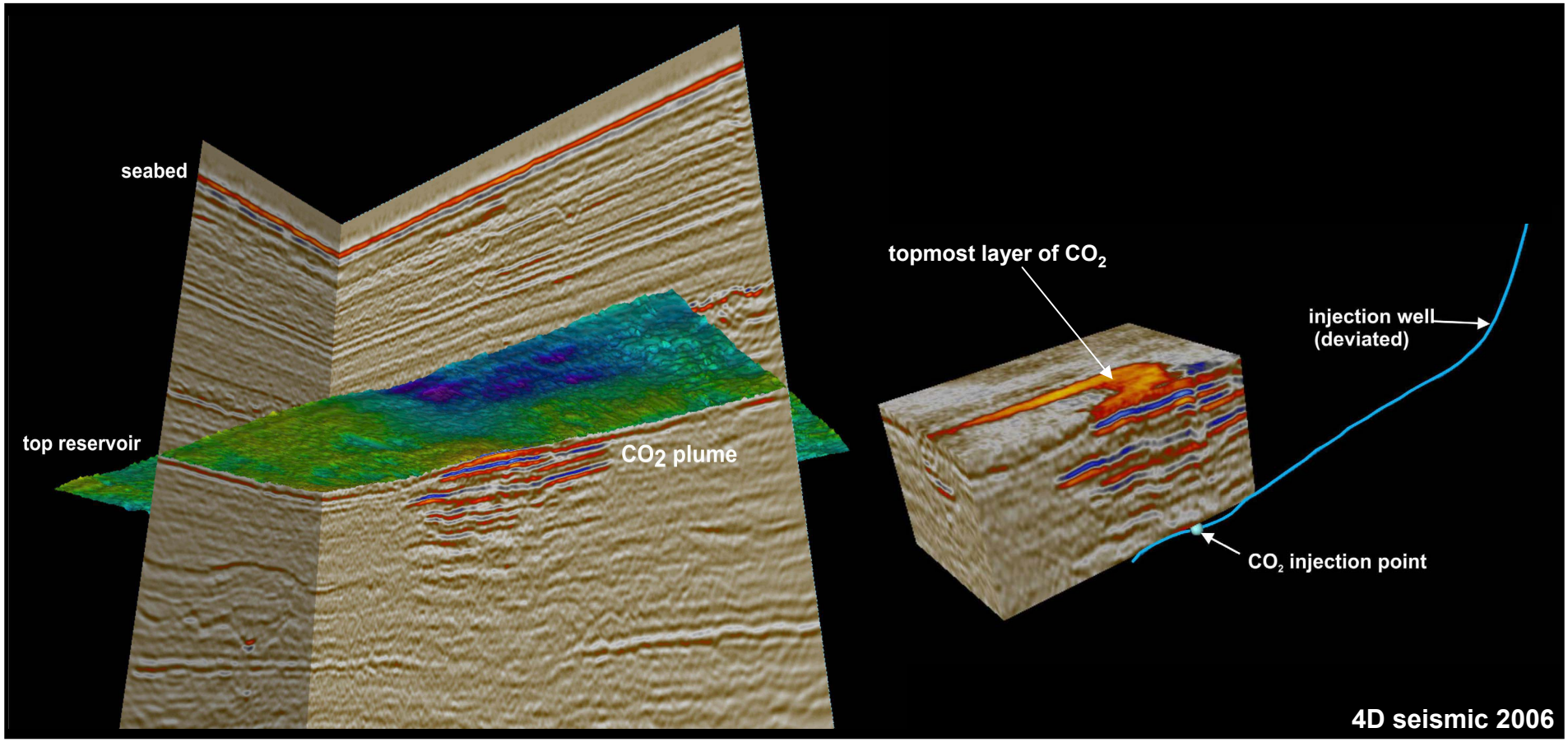
…. to what extent can monitoring meet these requirements?

Summary generic monitoring requirements

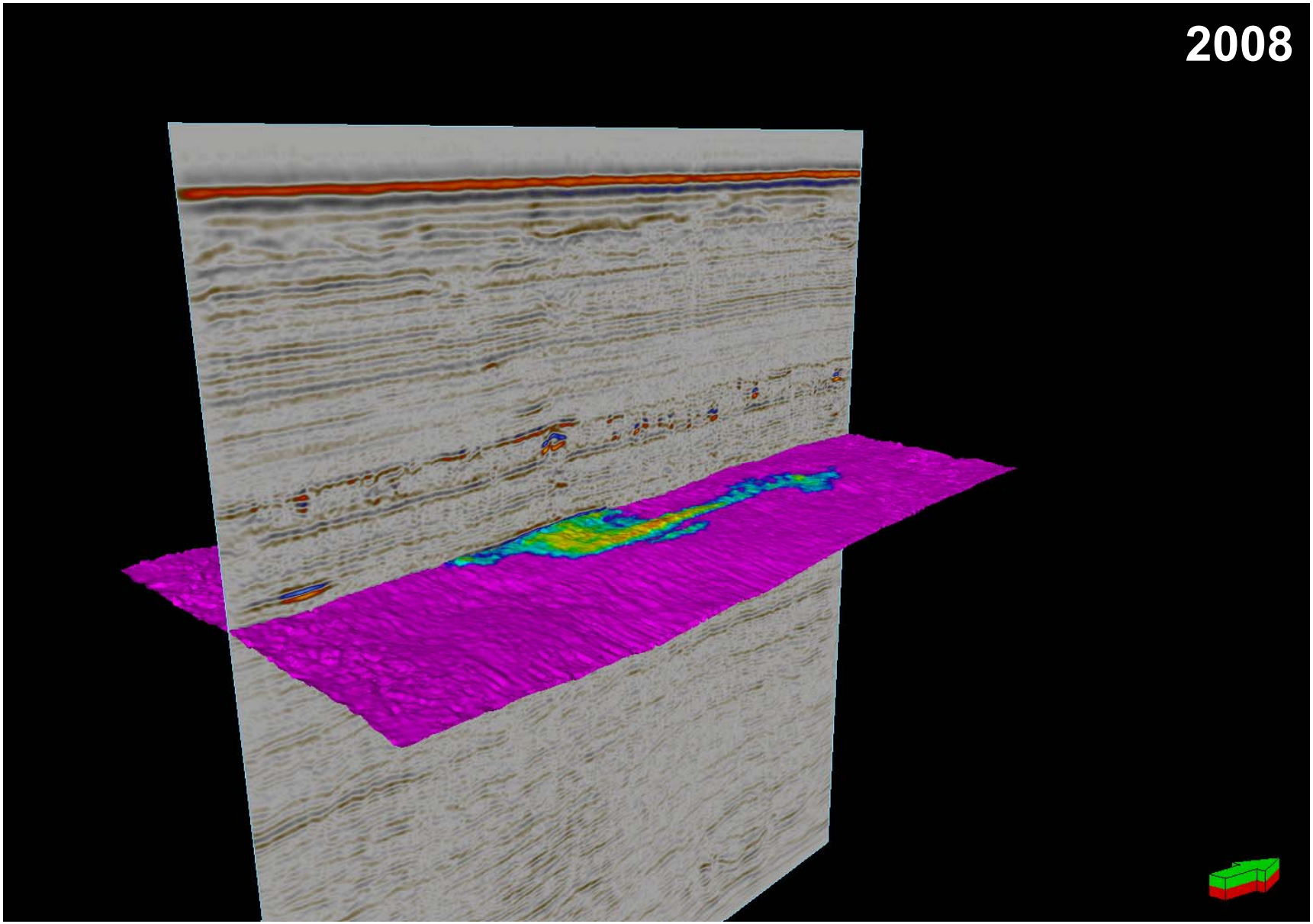
- **Performance calibration and verification**
  - **History-matching predictive models and monitoring data e.g. pressure evolution and plume migration**
- **Leakage detection (and measurement)**
- **Long-term stabilization and permanent containment**

History-matching plume migration at Sleipner (1)



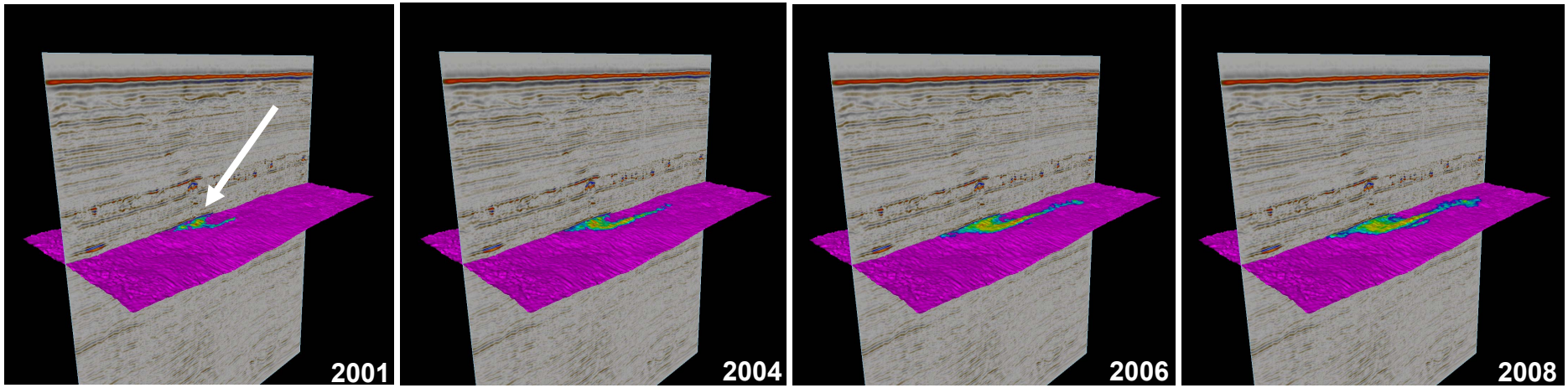


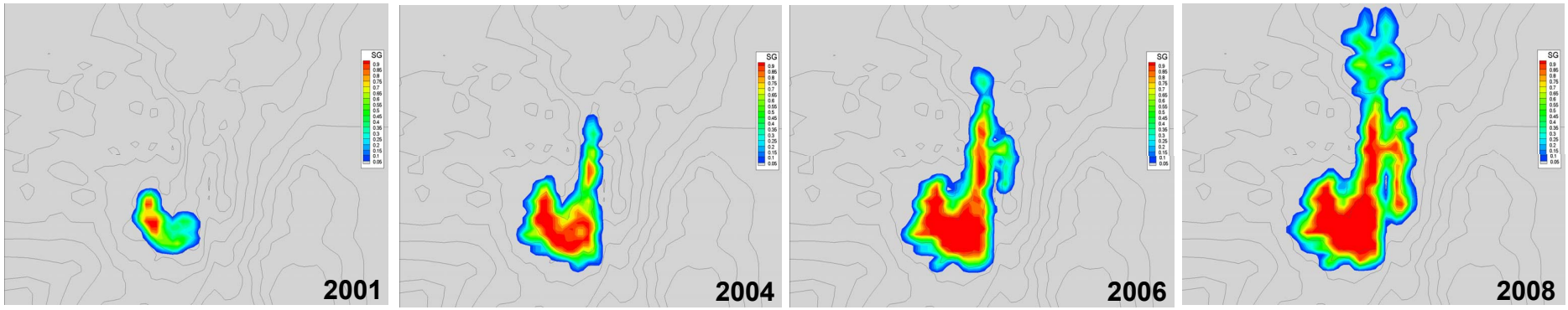
History-matching plume migration at Sleipner (2)



History-matching plume migration at Sleipner (3)

observed layer growth





numerical flow simulation of layer growth

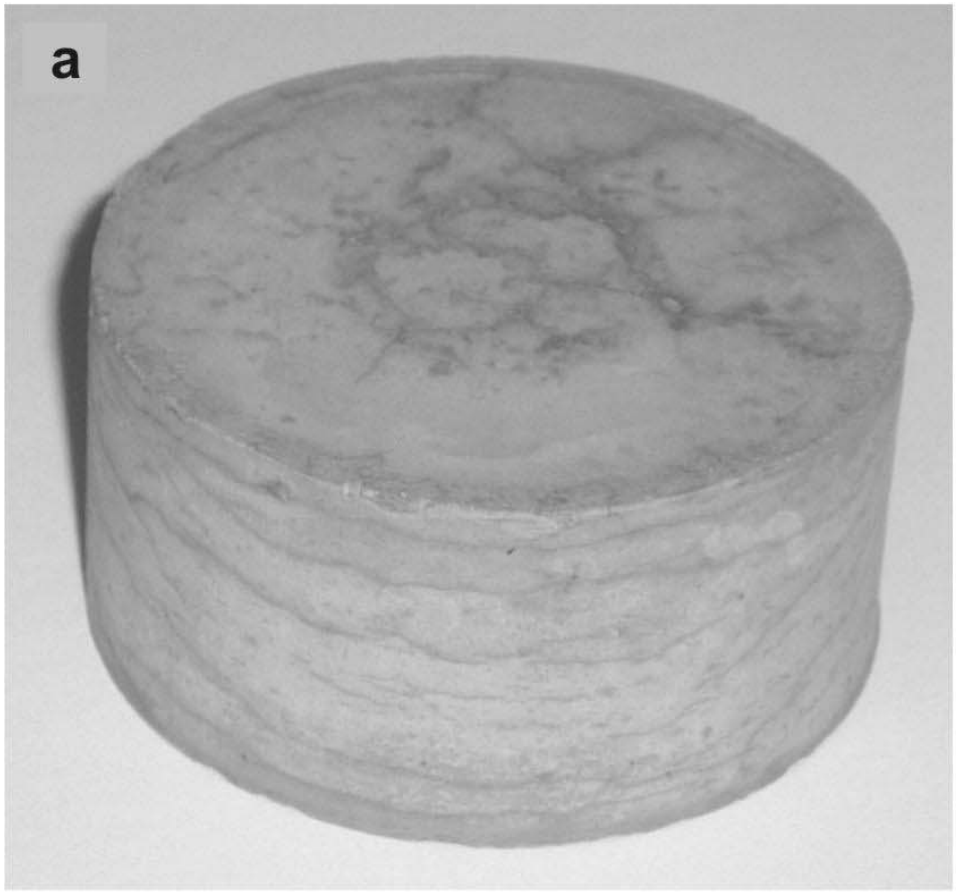
Match imperfect but sufficient to prove understanding of process

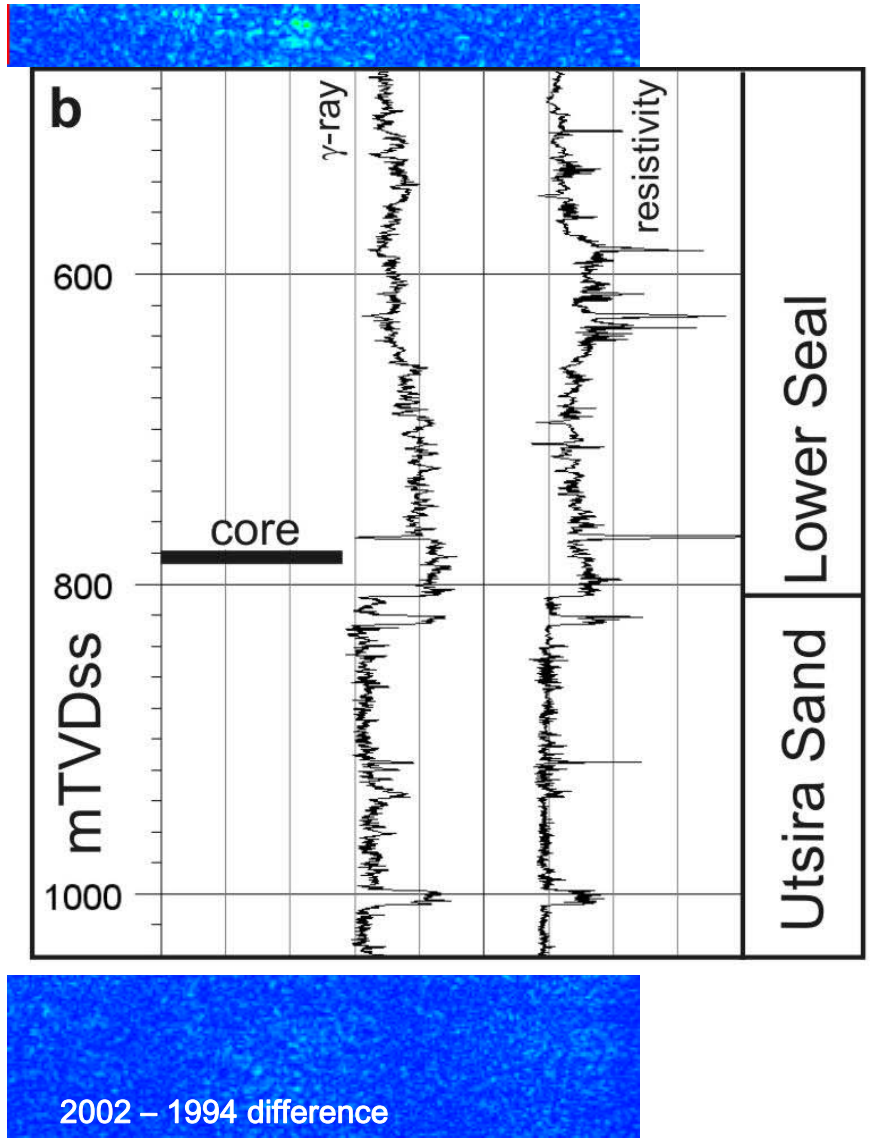
Scope for divergence in long-term predictions is limited

Summary generic monitoring requirements

- **Performance calibration and verification**
- **Leakage detection (and measurement)**
- **Long-term stabilization and permanent containment**

Detecting ‘out of reservoir’ migration

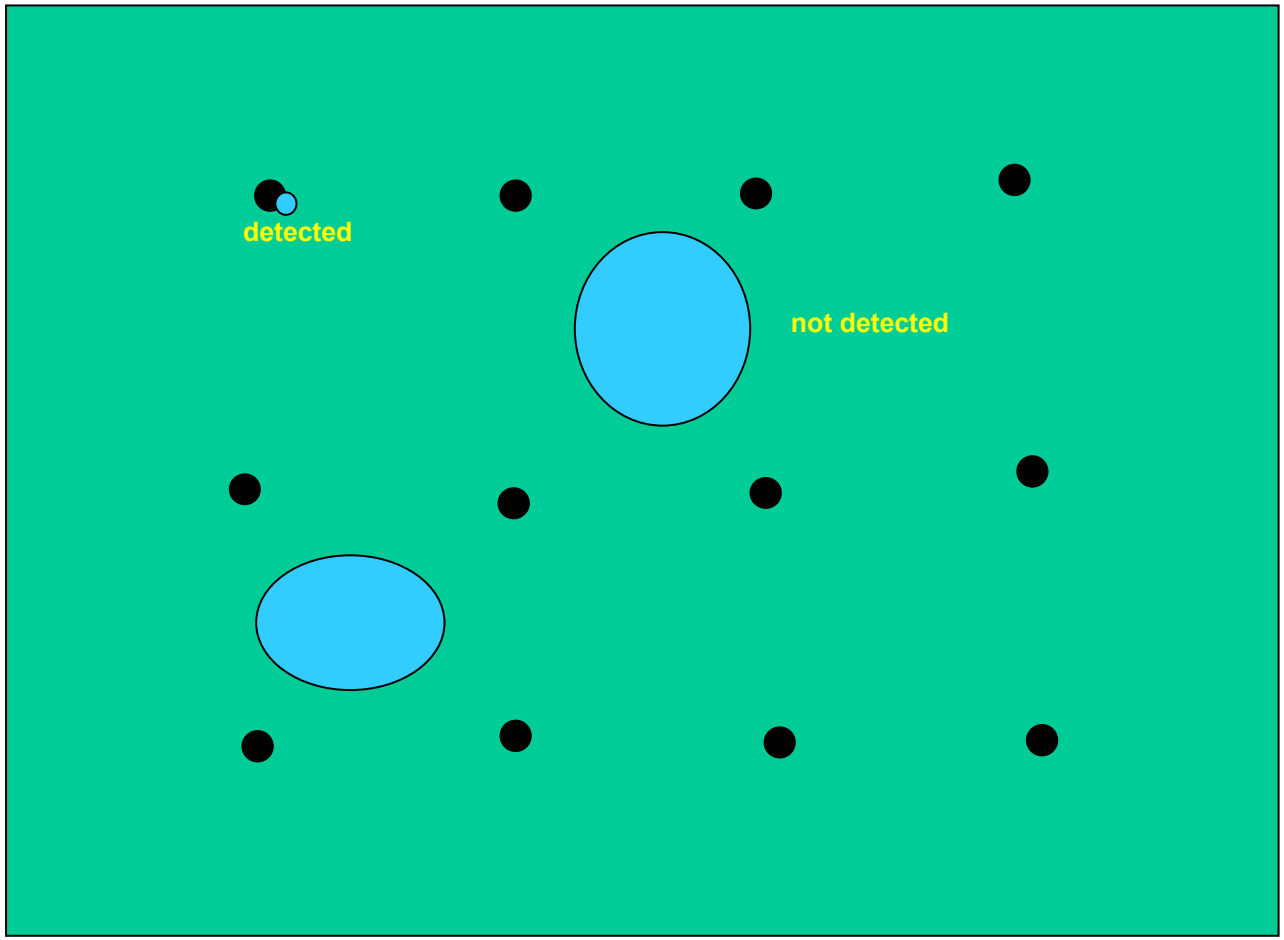




Detection limit for Sleipner data:

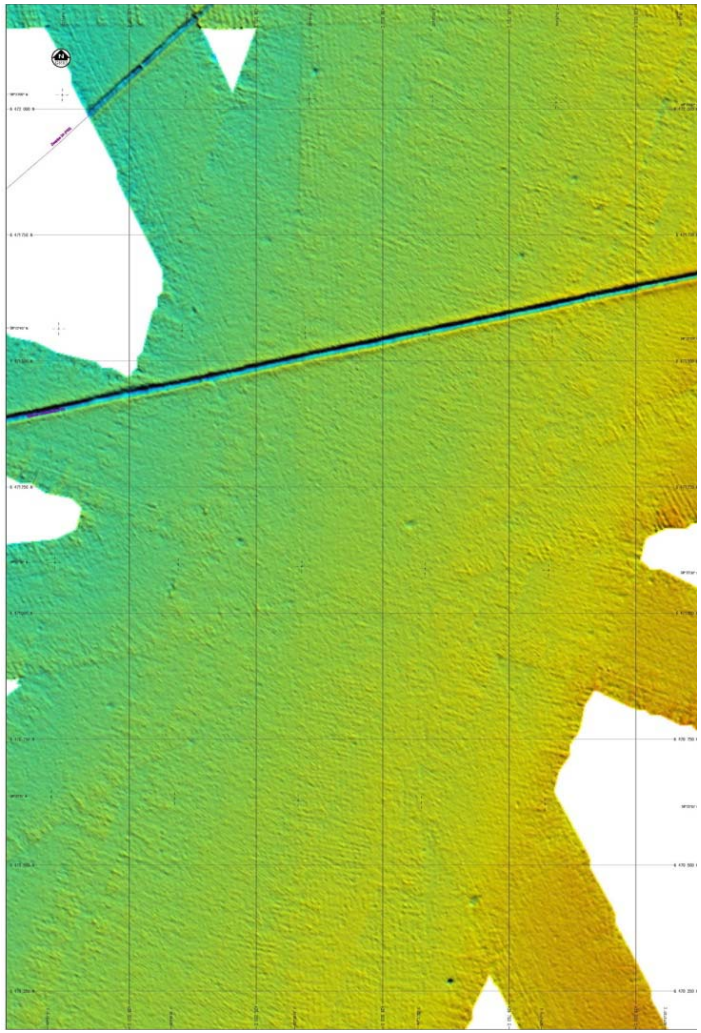
~ 4000 m^3
~ 2500 tonnes at top reservoir
< 1000 tonnes in overburden (<0.01% after 10 years)

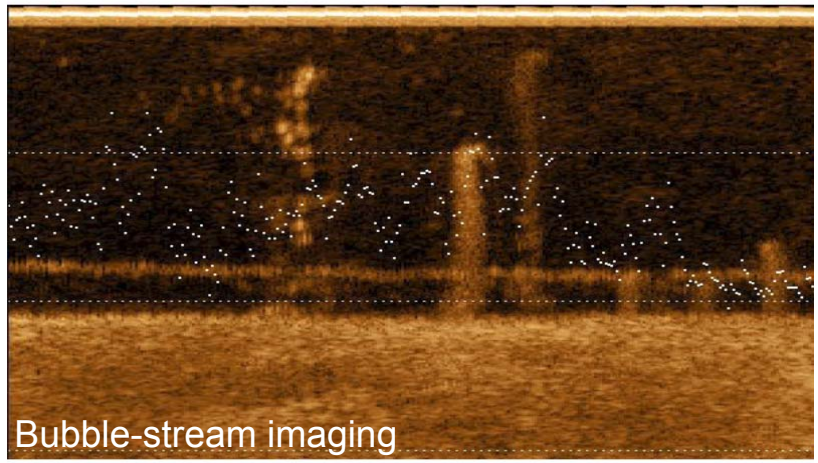
Emissions measurement (1)

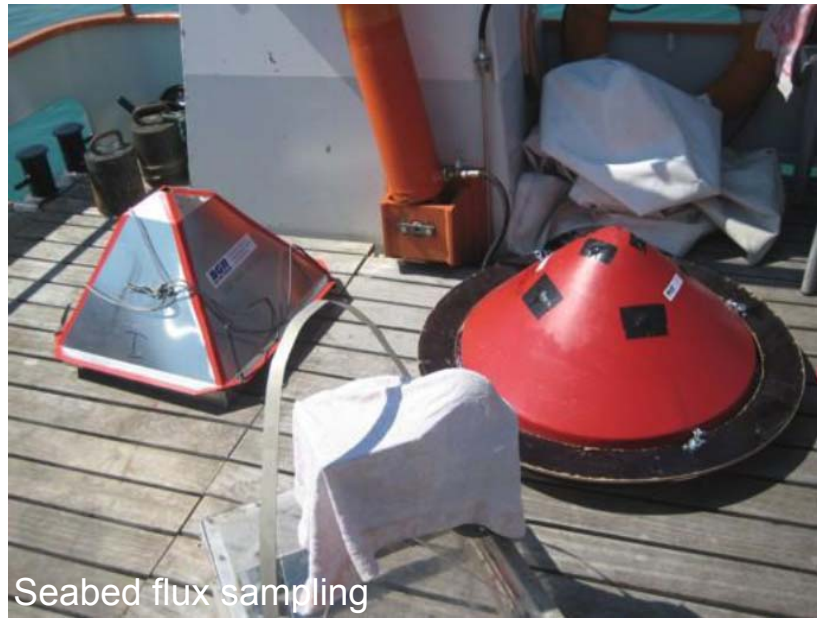


Spatial sampling issues

Emissions measurement (2)



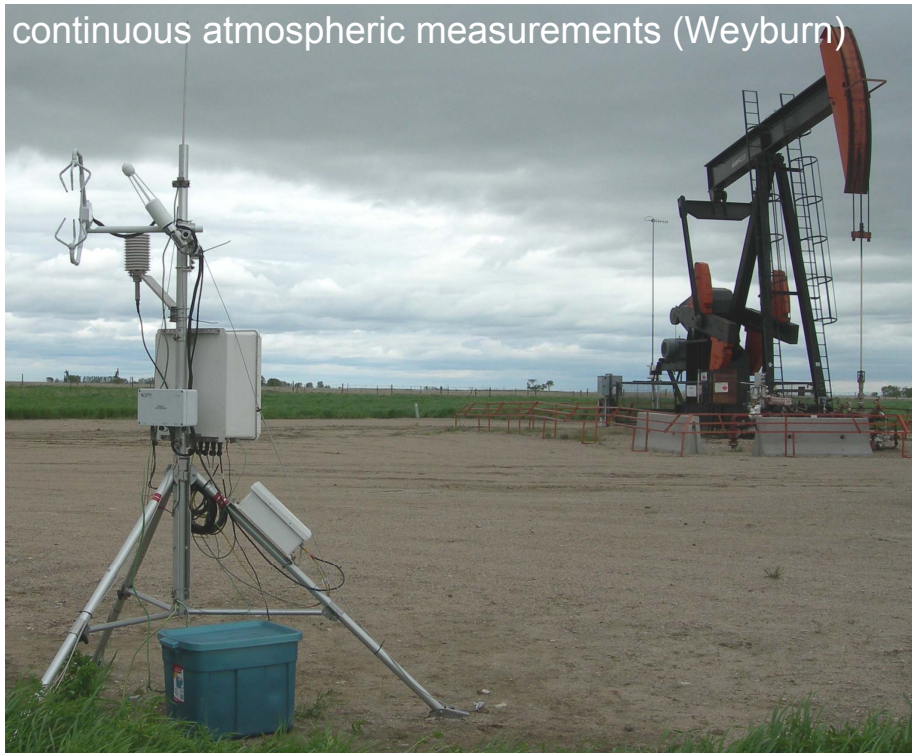




[Courtesy CO2ReMoVe]

Integrated areal and point surveys - offshore

Emissions measurement (3)



Integrated areal and point surveys - onshore

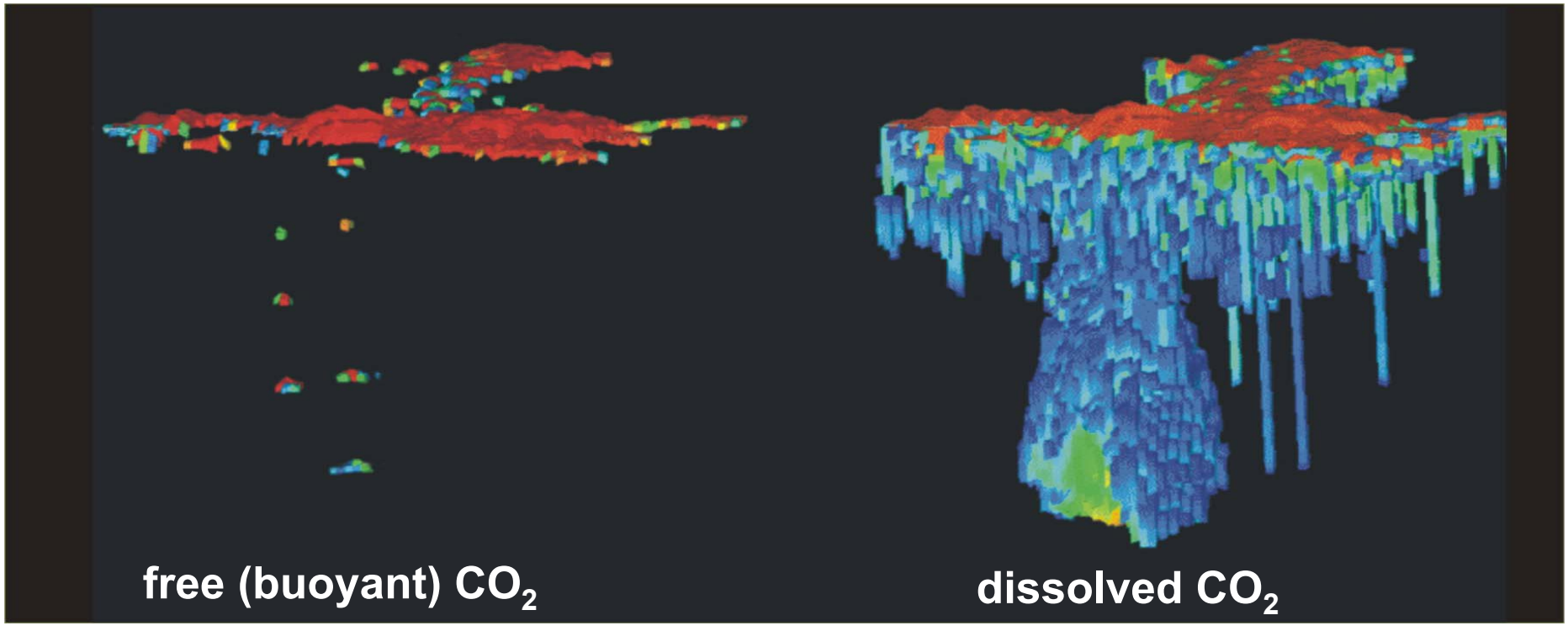
[Courtesy CO2ReMoVe]

Summary generic monitoring requirements

- Performance calibration and verification
- Leakage detection (and measurement)
- Long-term stabilization and permanent containment
  - Post-injection monitoring

Sleipner predicted stabilization

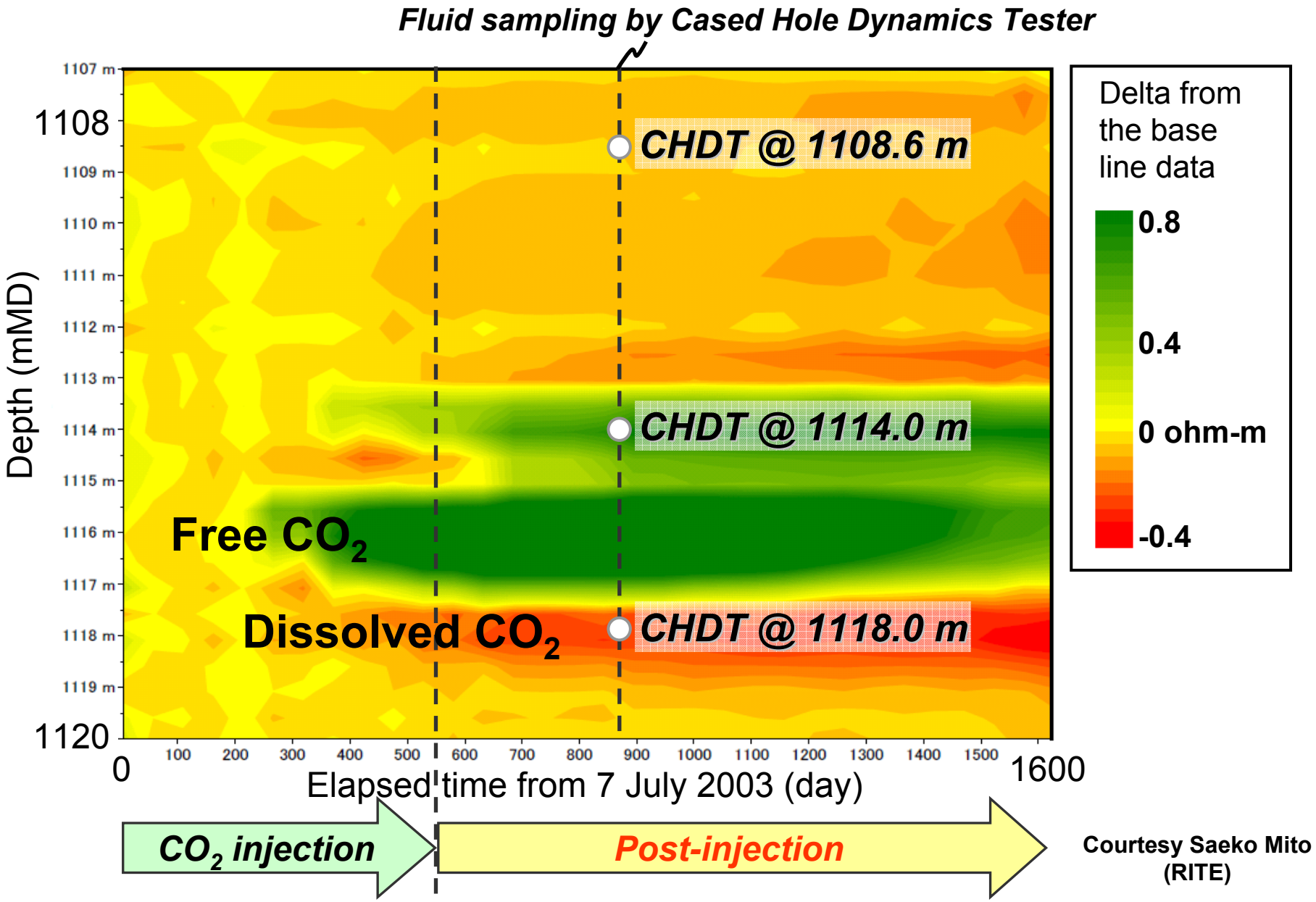
(250 years after injection)



[Courtesy Erik Lindeberg]

Onset of dissolution: gravitational stabilization

Post-injection monitoring at Nagaoka (Japan)



Courtesy Saeko Mito (RITE)

Modalities and procedures for the CDM

Monitoring Plan

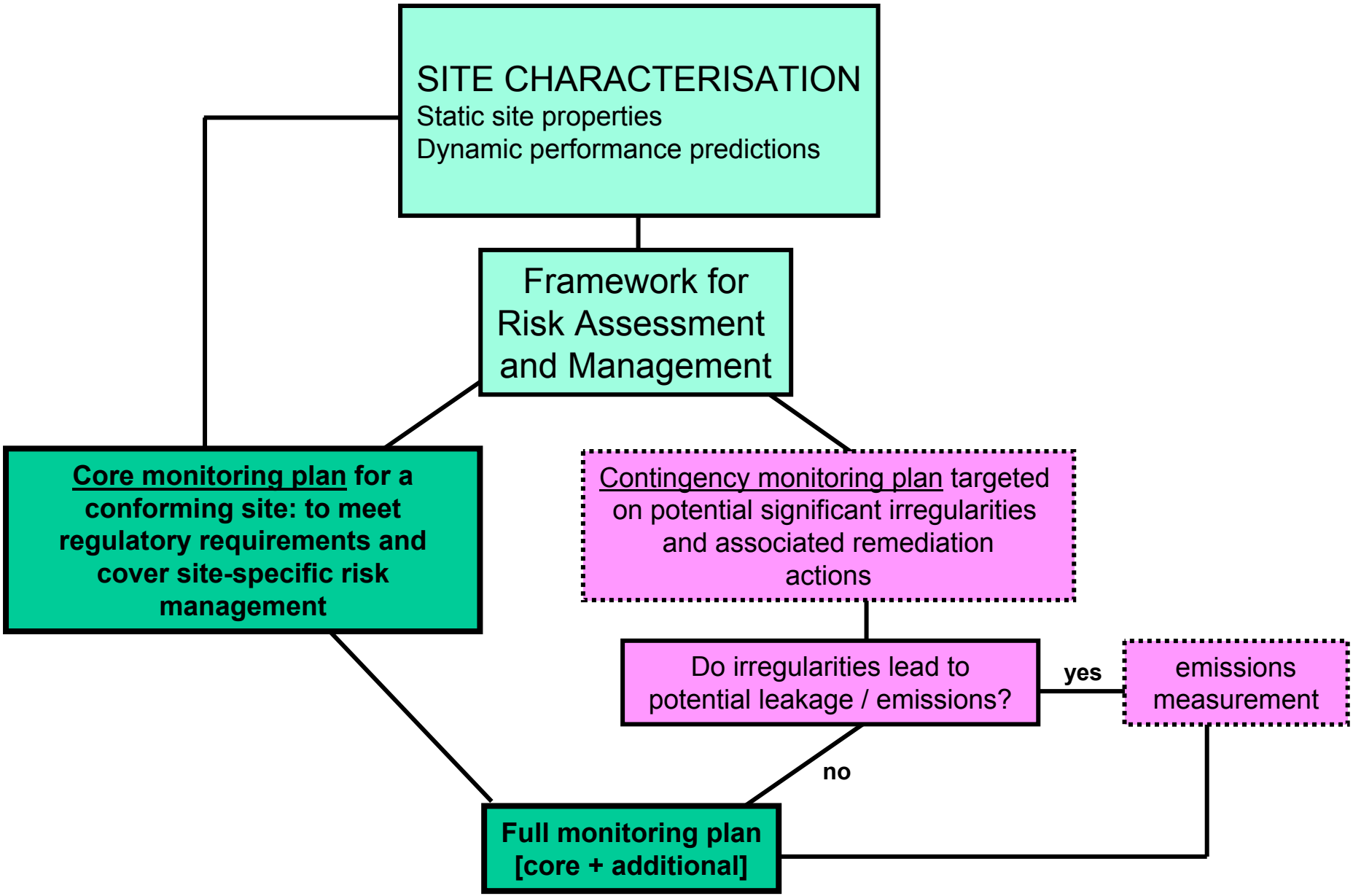
- Site - specific
- Non - prescriptive
- Updated during operations
- Linked to predictive models

Monitoring Plan

	Sleipner	Snovit	In Salah	Weyburn	Ketzin	K12-B	Nagaoka	Otway	Frio	Cranfield
	offshore (~900m)	offshore (~2700m)	onshore (~1900m)	onshore (~1400m)	onshore (~600m)	offshore (~3800 m)	onshore (~1100m)	onshore (~2100 m)	onshore (~1500m)	onshore (~3100 m)
Deep-focussed										
3D/4D surface seismic	■	■	■	■	■		■	■		
2D surface seismic	■	■								
Gravity surface	■									
Seabed CSEM	■									
Wellhead P,T	■			■	■	■	■			
Wellhead/annulus sampling			■							
Downhole P,T		■	■	■	■	■	■	■		■
Continuous temperature (DTS)		■			■	■				
Geophysical logs			■	■	■	■	■			
Crosshole seismics				■			■		■	■
Downhole fluid chemistry				■	■	■	■	■	■	■
Micro (passive) seismics			■	■	■			■		■
Electromagnetic wellbore					■				■	
Electromagnetic surface					■					
Spontaneous potential										
Tracers			■		■	■		■	■	■
Monitoring shallow aquifers			■					■		
Downhole well integrity						■		■		
VSP / MSP				■	■			■		
Electrical Resistivity Tomography					■					■
InSAR			■							
Shallow-focussed										
Multibeam echosounding	■									
Sidescan sonar	■									
Tiltmeters			■							
Bubble-stream detection										
Bubble-stream chemistry										
Soil gas/surface flux			■	■				■		■
Flux towers (eddy covariance)				■				■		
Passive detectors			■	■				■		
Ecosystem (including biomarkers)	■		■							
Microbiology			■		■					
Seabottom ROV video	■									

Multiple technologies tested worldwide

Monitoring Strategy flowchart



[Courtesy Energy Technologies Institute]

Conclusions

Performance Verification

- Different tools separately or in combination can provide required assurance
- Some sites can offer very high monitorability
- ‘Perfect’ matches difficult to achieve
- Fit-for-purpose

Leakage detection/measurement

- Sampling issues need to be overcome

Long-term Assurance

- Post-injection monitoring datasets

Monitoring Plans

- Site-specific
- Limited number of technologies
- Core and Contingency elements

Acknowledgements

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