Marine CSEM synthetic study to assess the detection of a CO_2 escape and saturation changes within a submarine chimney connected to a CO_2 storage site

Photo from Equinor website

Naima K. Yilo

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Carbon Capture & Storage & the Energy Transition

Texas test facility generating zero-emission electricity from natural gas with CCS

Photo from WSP website

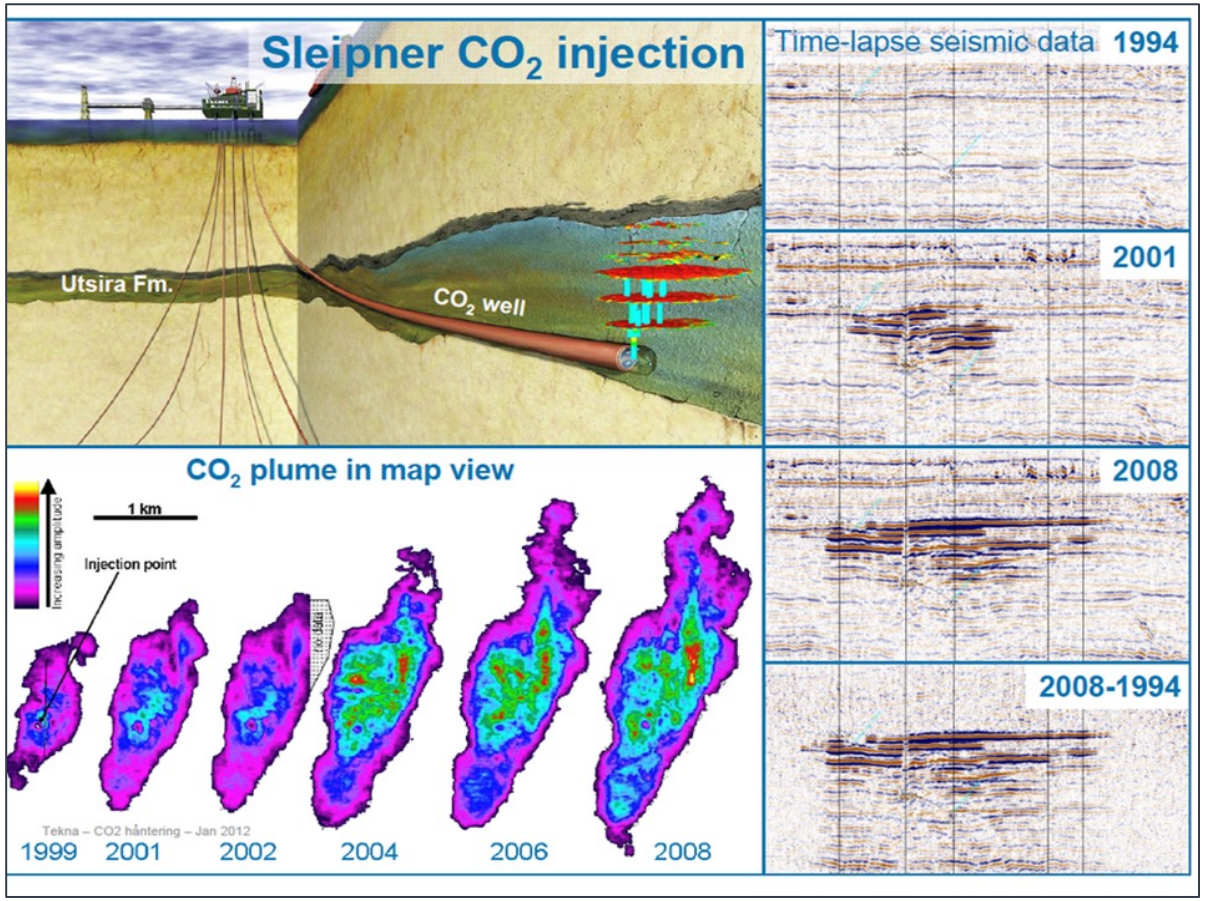
- The 2015 United Nations Paris agreement goal is to limit global warming to 1.5°C above pre-industrial levels by 2050
- Decarbonizing the energy sector is not enough (Sixth Assessment Report, IPCC 2021)
- Offshore CCS: numerous well understood depleted reservoirs and saline aquifers near existing infrastructure

Carbon Capture and Storage Subsurface Monitoring

- Monitoring, mitigation & verification (MMV) critical to ensure safe and permanent CO_2 storage

- Several monitoring techniques, most notably time-lapse seismic reflection (e.g. Sleipner)

- Here a synthetic CSEM model study demonstrates the benefit of using resistivity to monitor CCS sites



Sleipner CO_2 injection offshore Norway (Chadwick et al. 2019)

Multi-physics approach for monitoring CCS sites

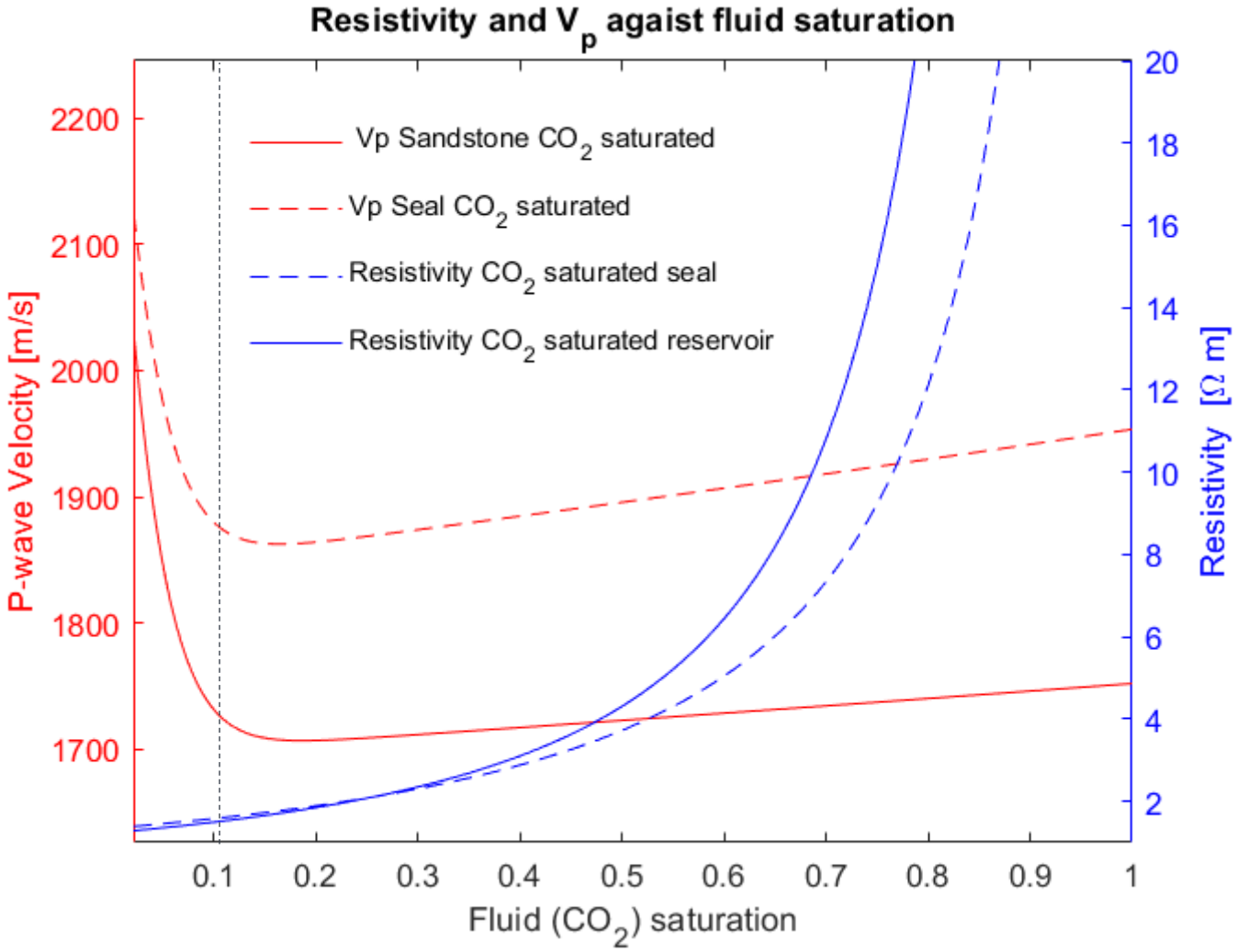
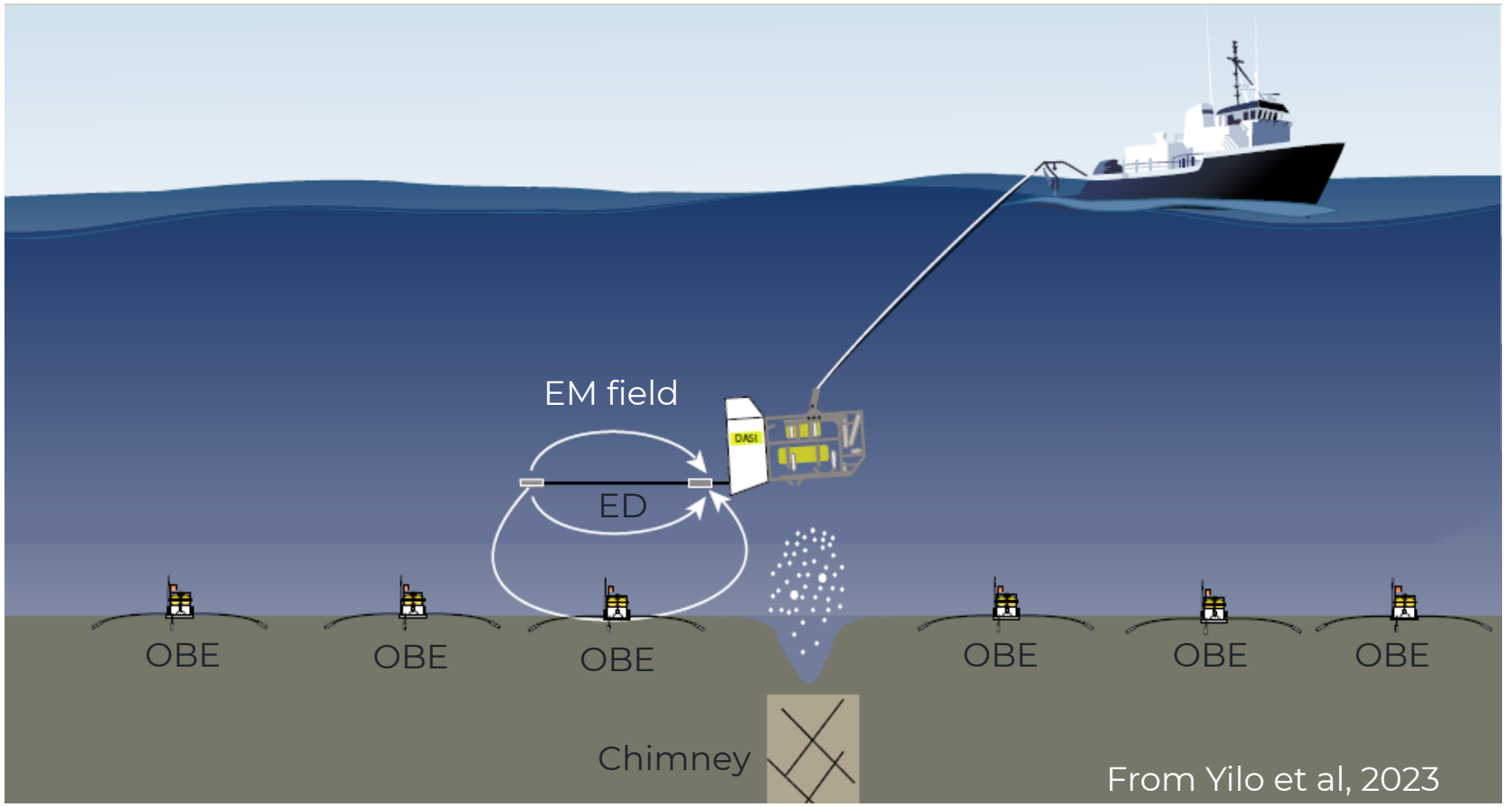


Figure from Yilo et al. Calculated Velocities (Lee, 2004) and calculated resistivity for seal (Juhasz, 1981) and reservoir (Archie, 1942) from Yilo et al. 2023

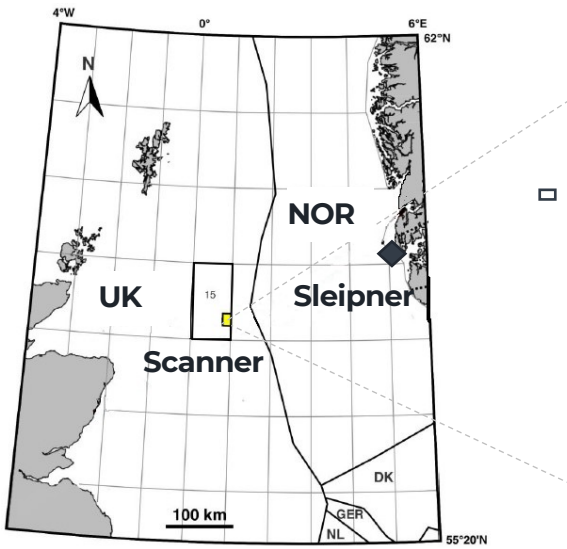
- P-wave (seismic) velocities are sensitive low CO_2 saturations (0 – 10%)
- Electrical resistivity is sensitive to moderate to high CO_2 saturations (20-80%)
- CSEM electrical resistivity and seismic velocities can be used to distinguish a significant leak

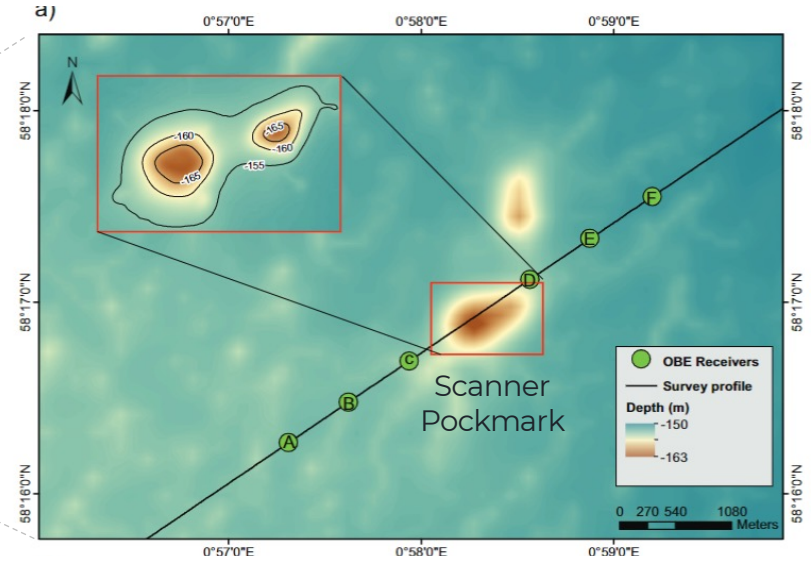
The Marine CSEM Method



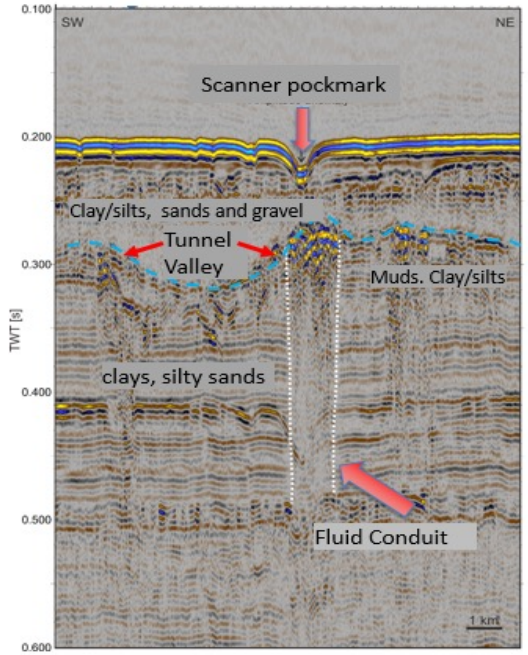
A transmitter (electric dipole/ED) generates an EM field that travels through the seafloor and is detected by EM receivers (OBE). A resistive feature, such as CO_2, elevates the electric fields measured at the receivers, providing an EM target.

The North Sea Synthetic CSEM model





Bathymetry from Berndt et al. 2017



2D Seismic Reflectivity

Cruise MSM63 (Böttner et al. 2018)

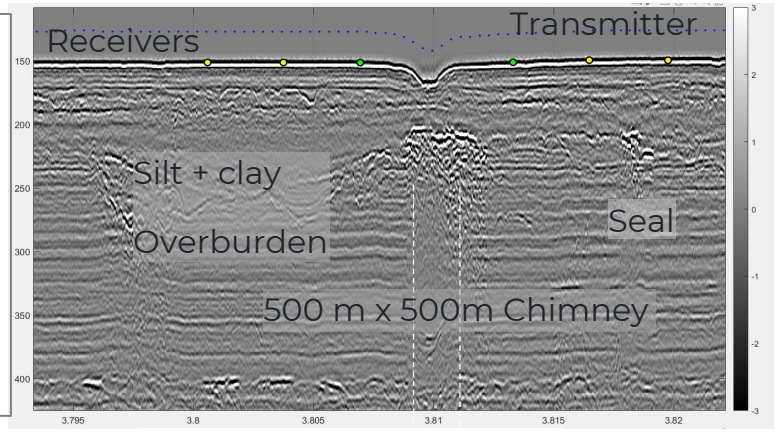
- The seal is modelled using properties from the top 400 m of sediment at the Scanner pockmark location
- Scanner is an active gas vent with a 500 m wide chimney in the UK sector of the NS at ~150 m water depth and an analogue for a breach within the seal (CO_2 leakage)
- The Sleipner CCS injection is used for the reservoir and top seal analogue

Rock physics & 2D model building

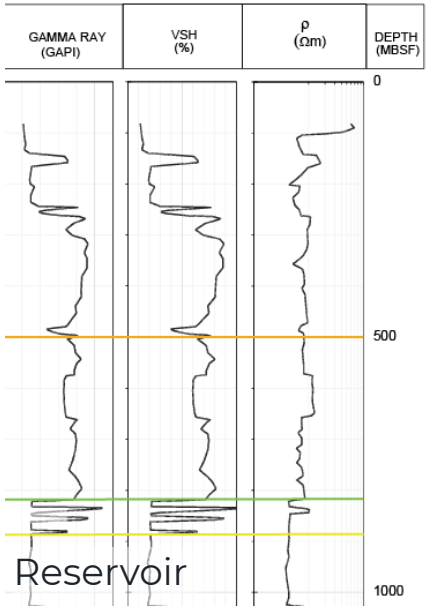
(1)

Seismic thickness and structure & literature properties, e.g. porosities (ϕ)

Scanner pockmark



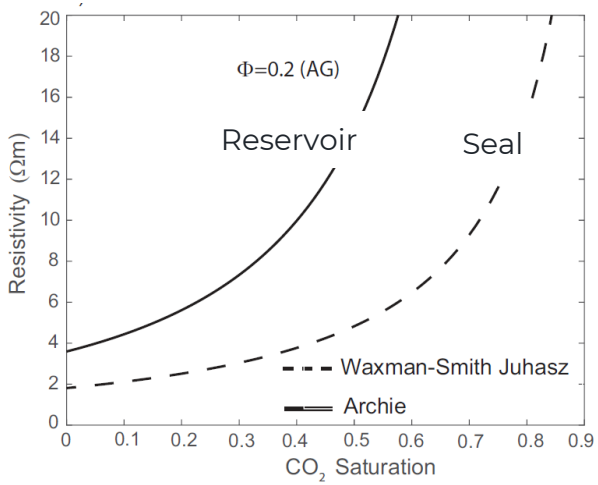
Sleipner

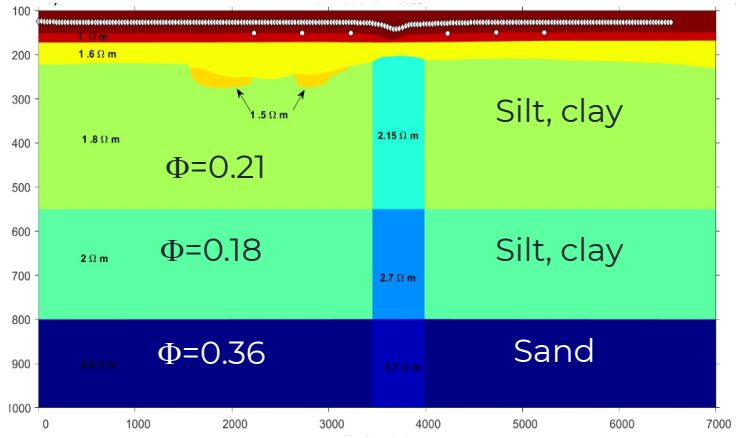


(2)

CO_2 saturation scenarios into electric resistivity two models

Archie's & Waxman-Smith model





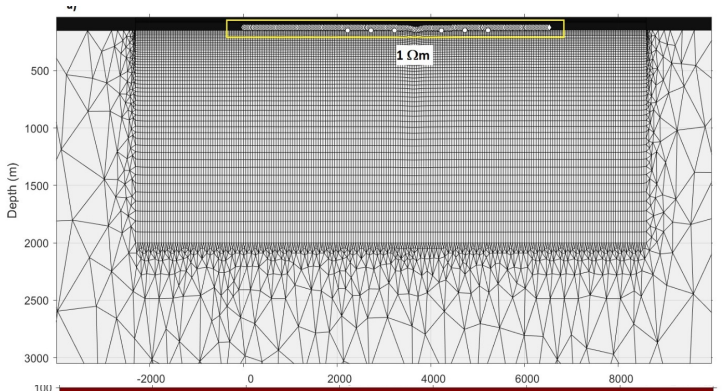
From Yilo et al, 2023

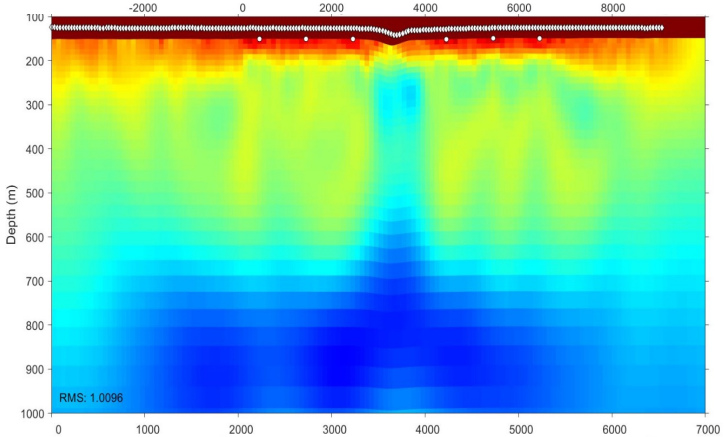
(3)

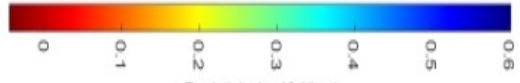
CSEM navigation->Synthetic CSEM Ey, Ez data + 4% Gaussian noise

(4)

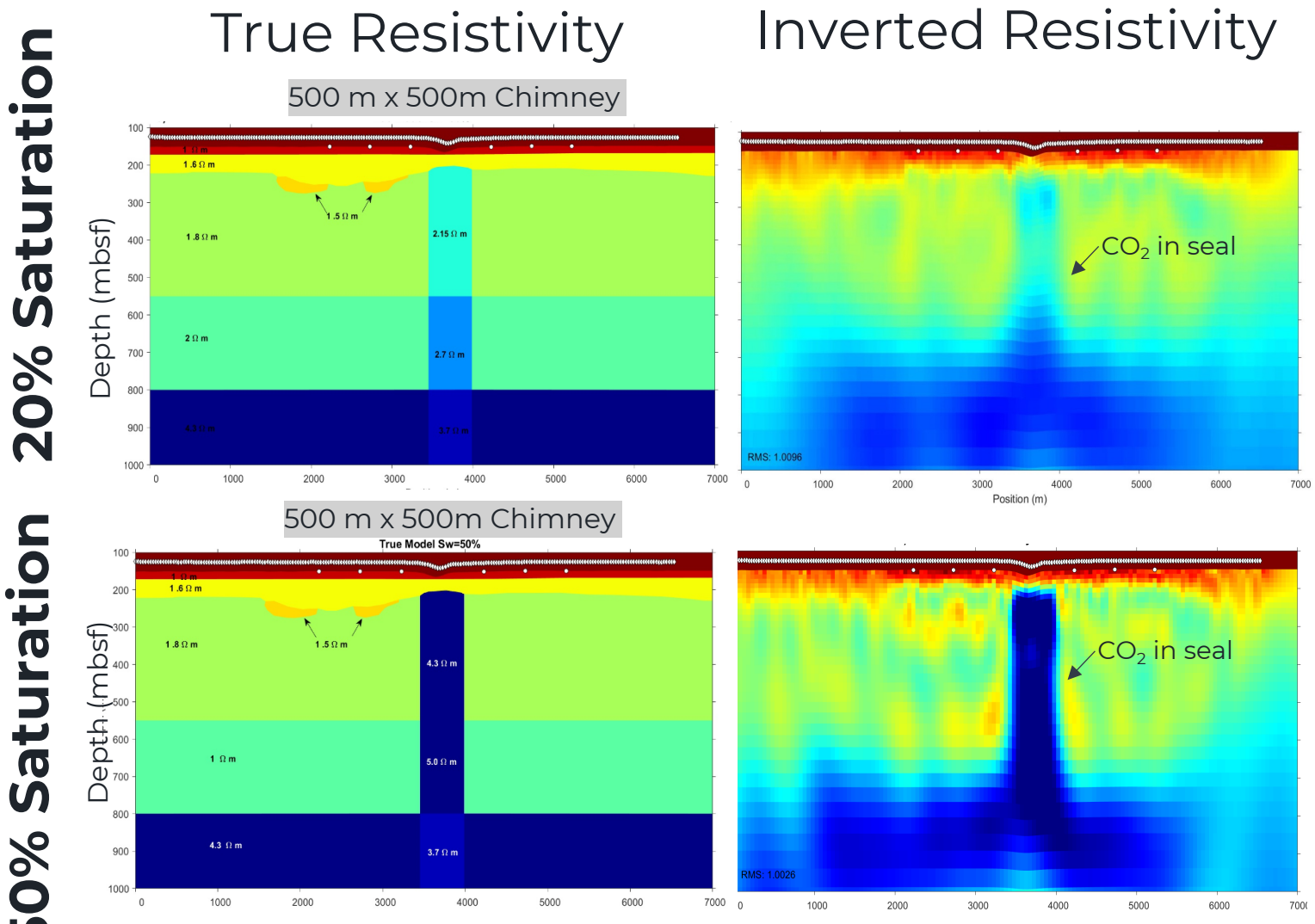
2.5D Inversion with 1 Ωm half space Initial model and quadrilateral mesh





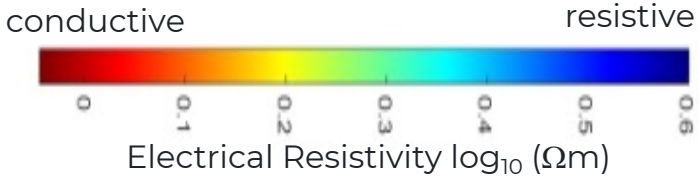
conductive  resistive

CSEM and Seismic Monitoring

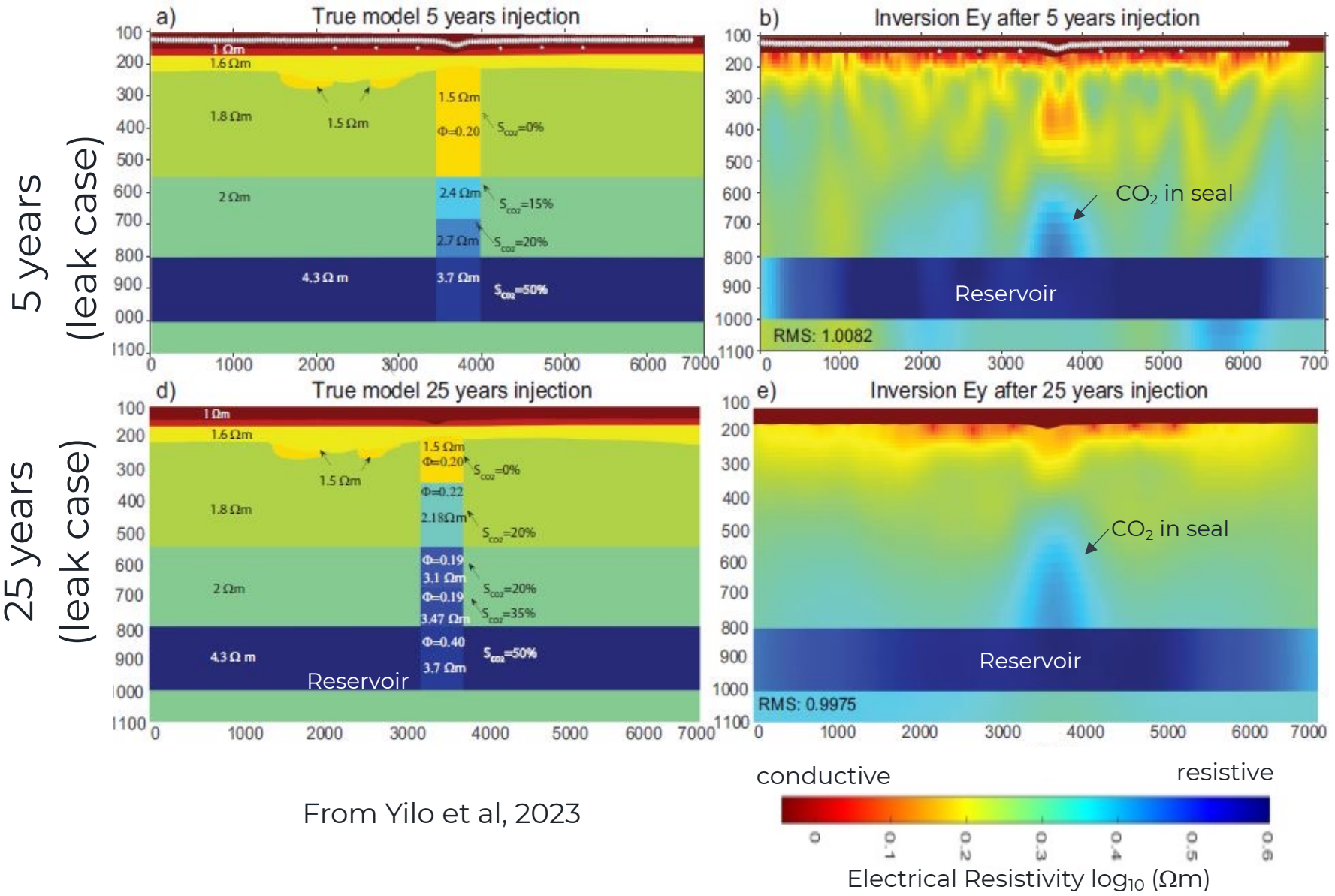


From Yilo et al, 2023

- Two CO_2 leak scenarios within the chimney
- Whole chimney saturated
- CSEM distinguishes changes in saturation as the leak evolves (S_{CO2}=20-50%)



Time Lapse CO_2 Injection Monitoring with CSEM

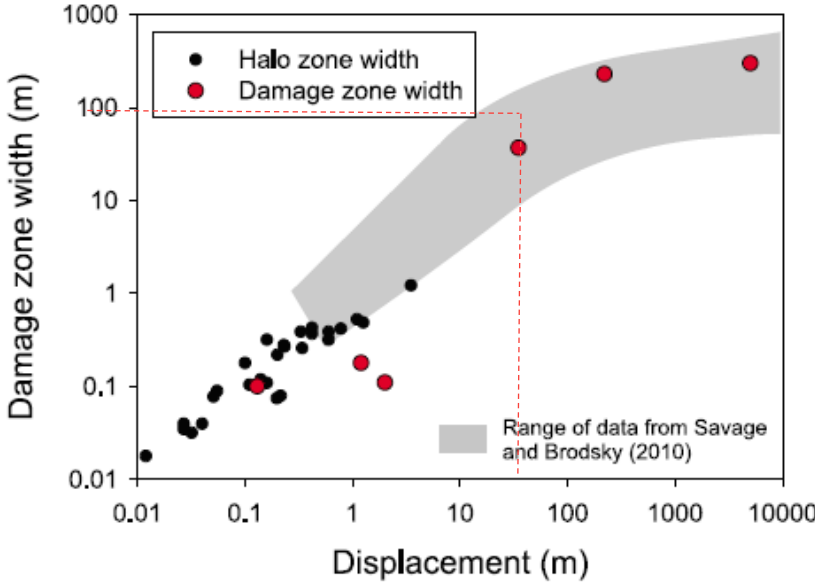


From Yilo et al, 2023

- Saturation distribution from Marin-Moreno, 2019 dynamic model
- CO_2 propagation velocities from flow model
- 5 and 25 years scenarios show distinct resistivity response

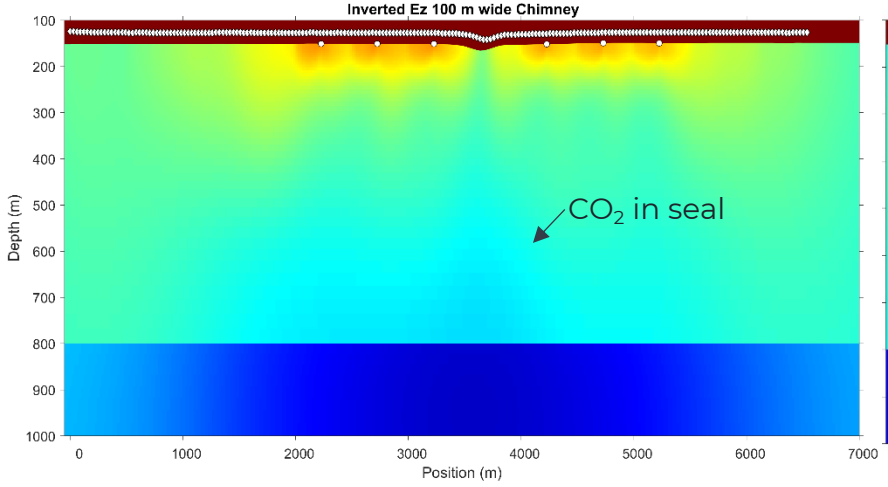
CSEM Limitations, narrower (100 m) chimney

Modified from Faukner et al. 2011

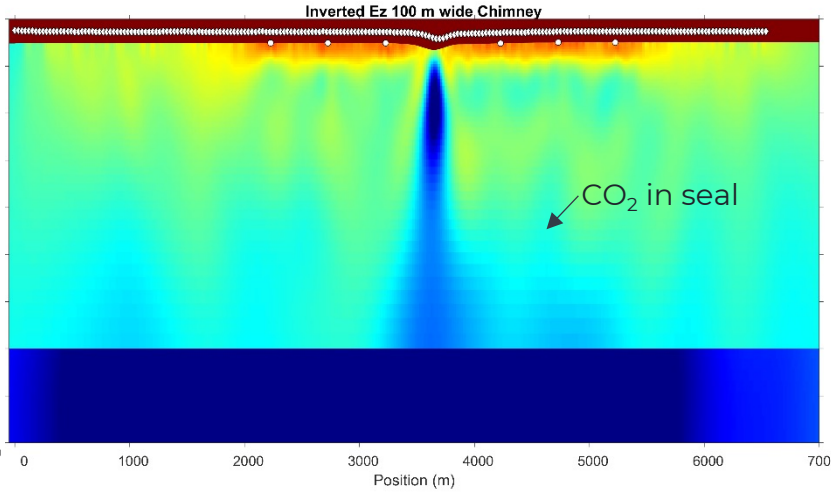


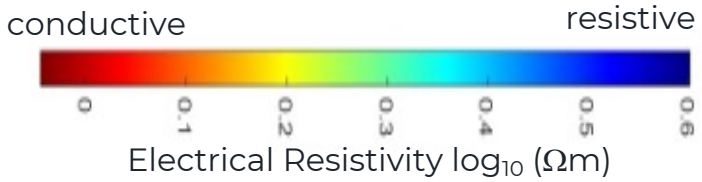
- CO_2 plume size limits detectability
- Fault damaged zones width directly proportional to fault displacement (Scholz et al. ,1993)
- Fault displacements of 100's m can result in a 100's damage sone width (Faukner et al. 2011)

20% Saturation

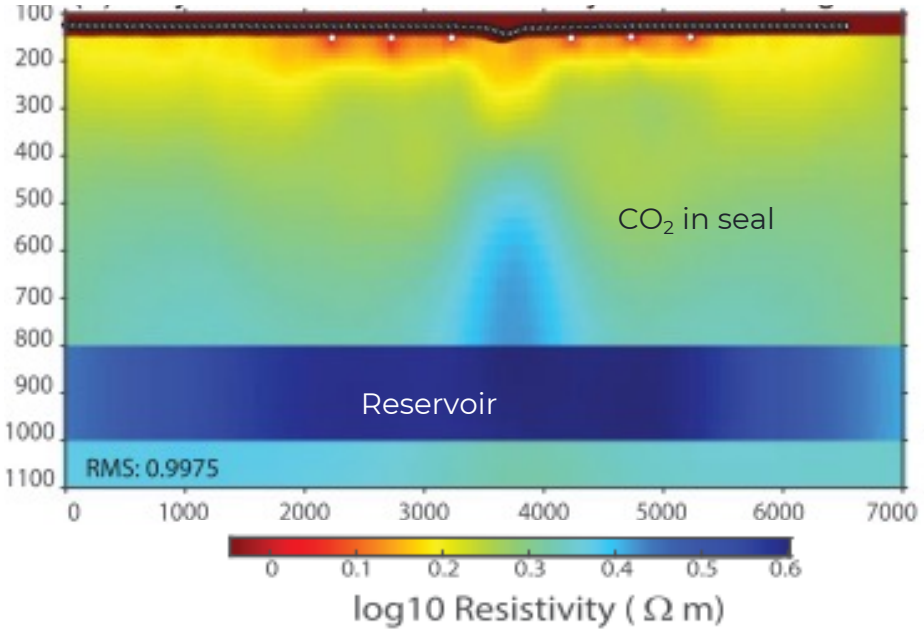


50% Saturation





Conclusions and recommendations



From Yilo et al, 2023

- CSEM method detects modelled CO_2 leakage from a storage reservoir into a chimney /faulted zone of 100's m wide.
- CSEM distinguishes changes in saturation as the leak evolves
- Seismic velocities detect fluid presence at low saturation ranges but cannot quantify saturations >10%. Utilization of both CSEM and seismic is needed
- Repeat CSEM surveys to be considered CCS measurement, monitoring and validation (MMV) strategies.

Thank you

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