3D CSEM grid-modeling and time-lapse sensitivity analysis for subsurface CO_2 storage

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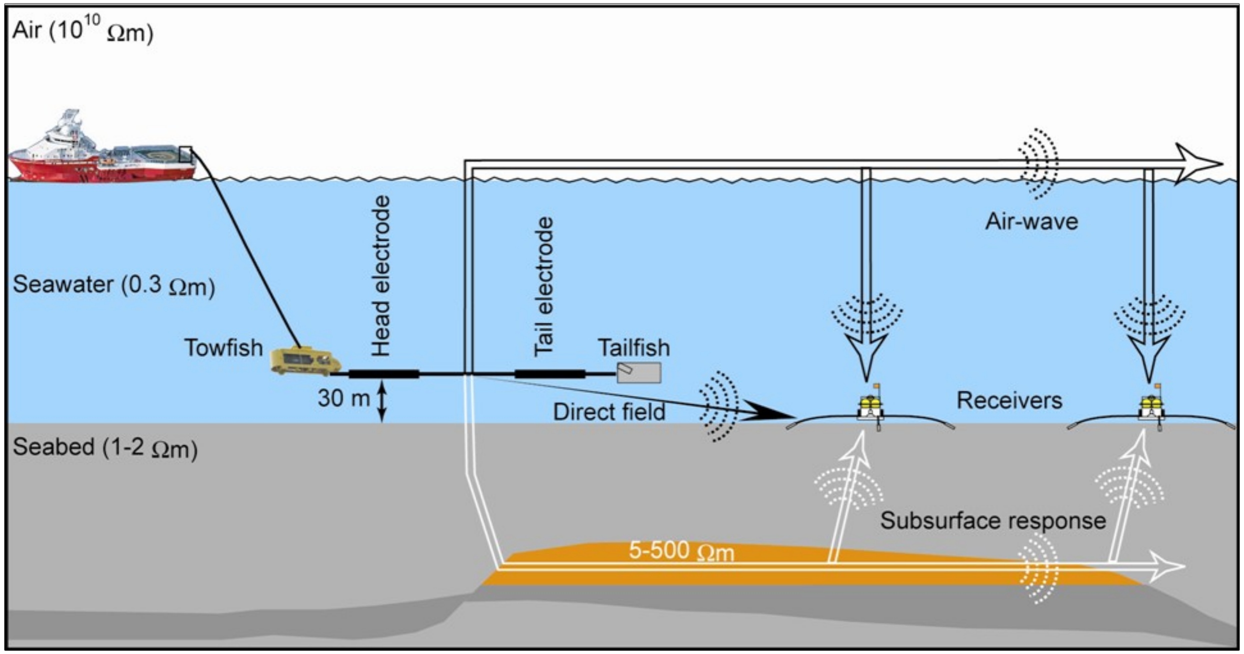
Outline

- ✓ CSEM method
- ✓ Objectives
- ✓ Time-lapse CSEM sensitivity analysis for CO_2 sequestration
- ✓ Conclusions

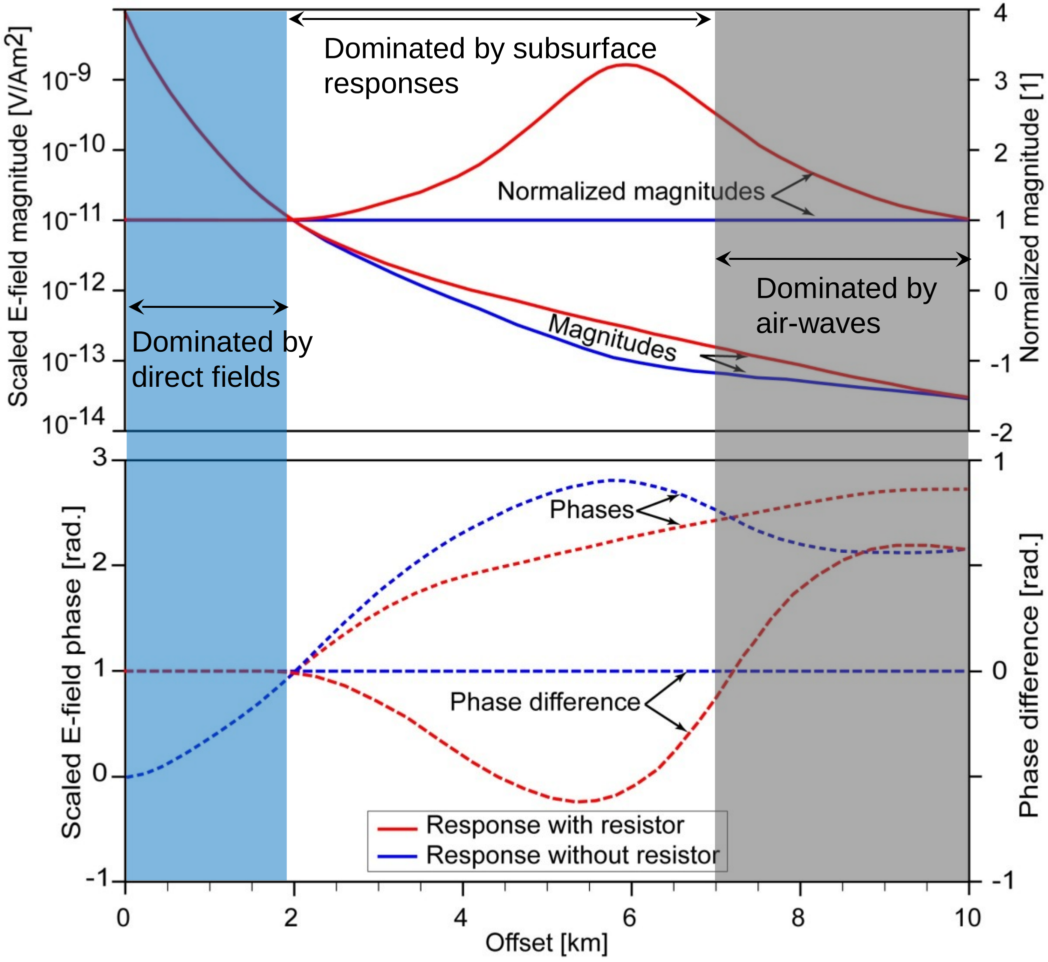
CSEM method

EM wave propagation



CSEM method

Electric field responses



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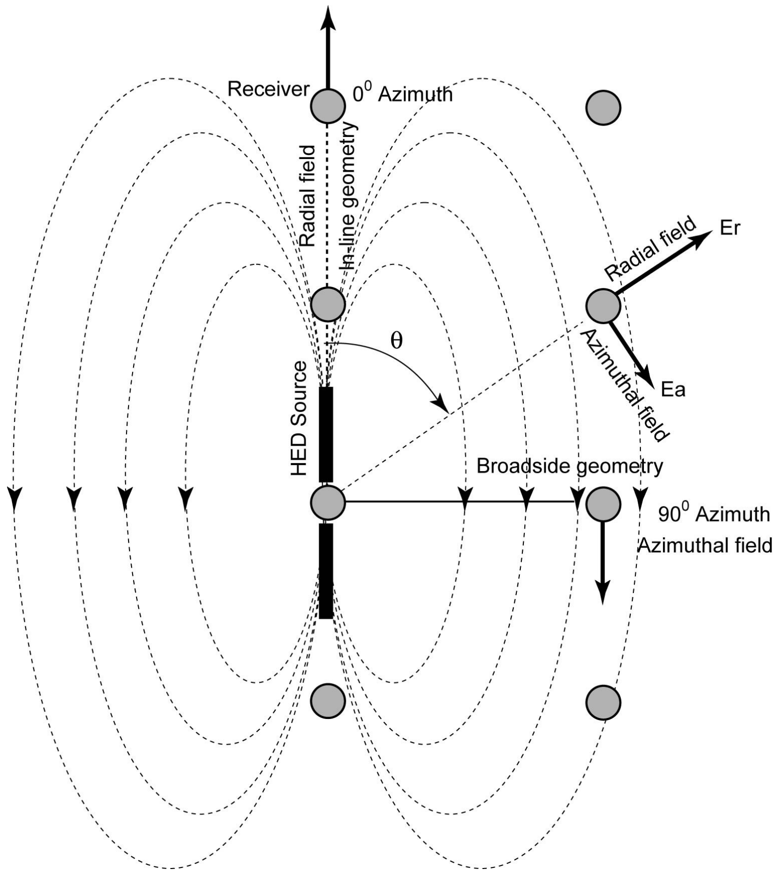
CSEM method

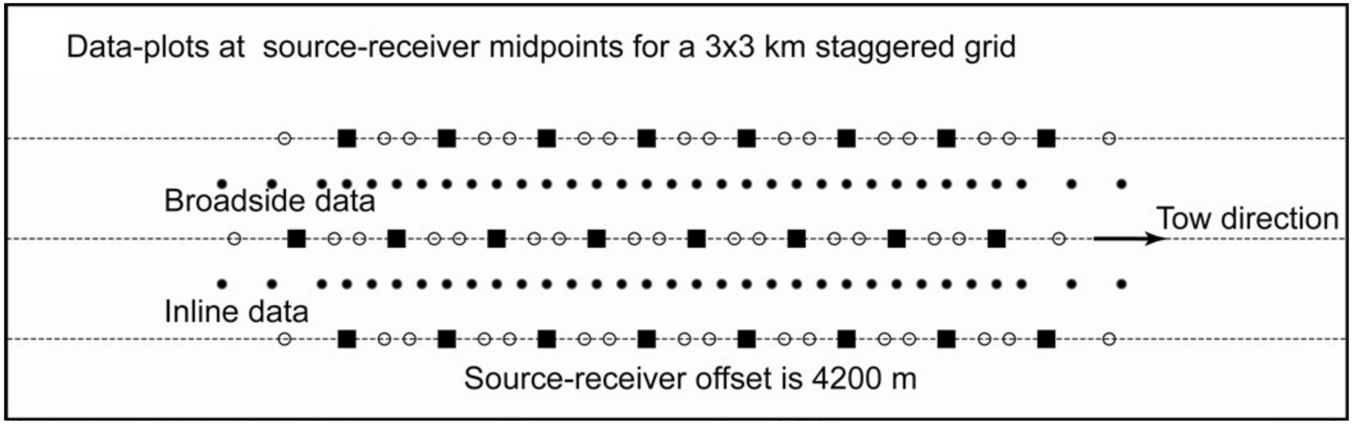
EM response is strongly influenced by **acquisition geometry,** which is expressed in terms of source-receiver azimuth

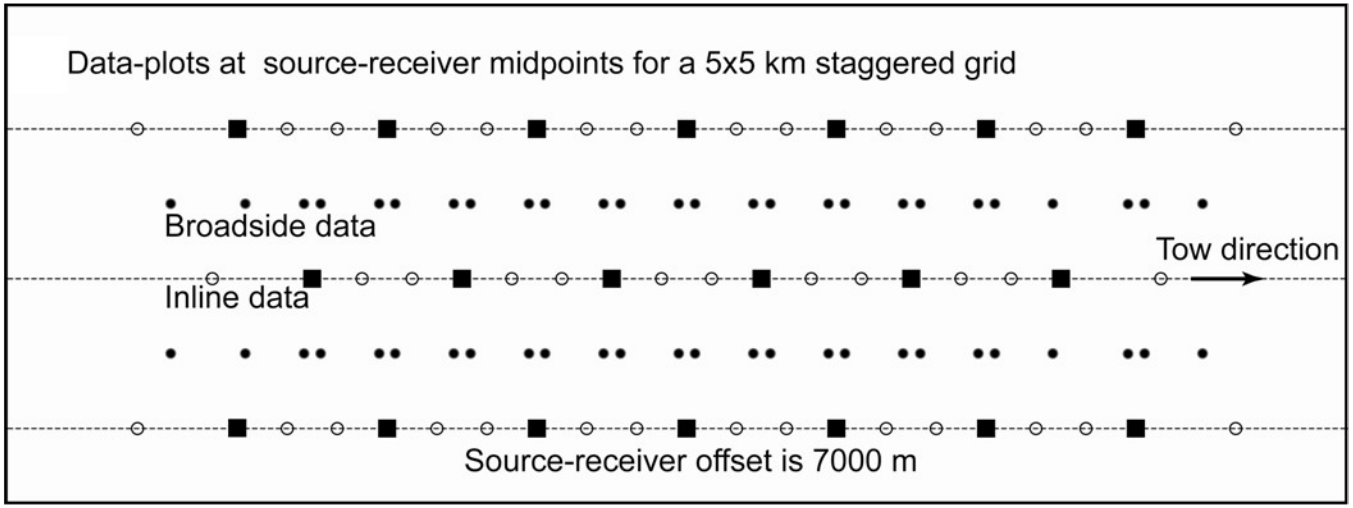
Inline geometry: fields recorded along a line parallel to the source dipole axis

Broadside geometry: fields recorded along a line perpendicular to the source dipole axis



Azimuth decomposition





TL CSEM sensitivity to CO_2 sequestration

Why CSEM?

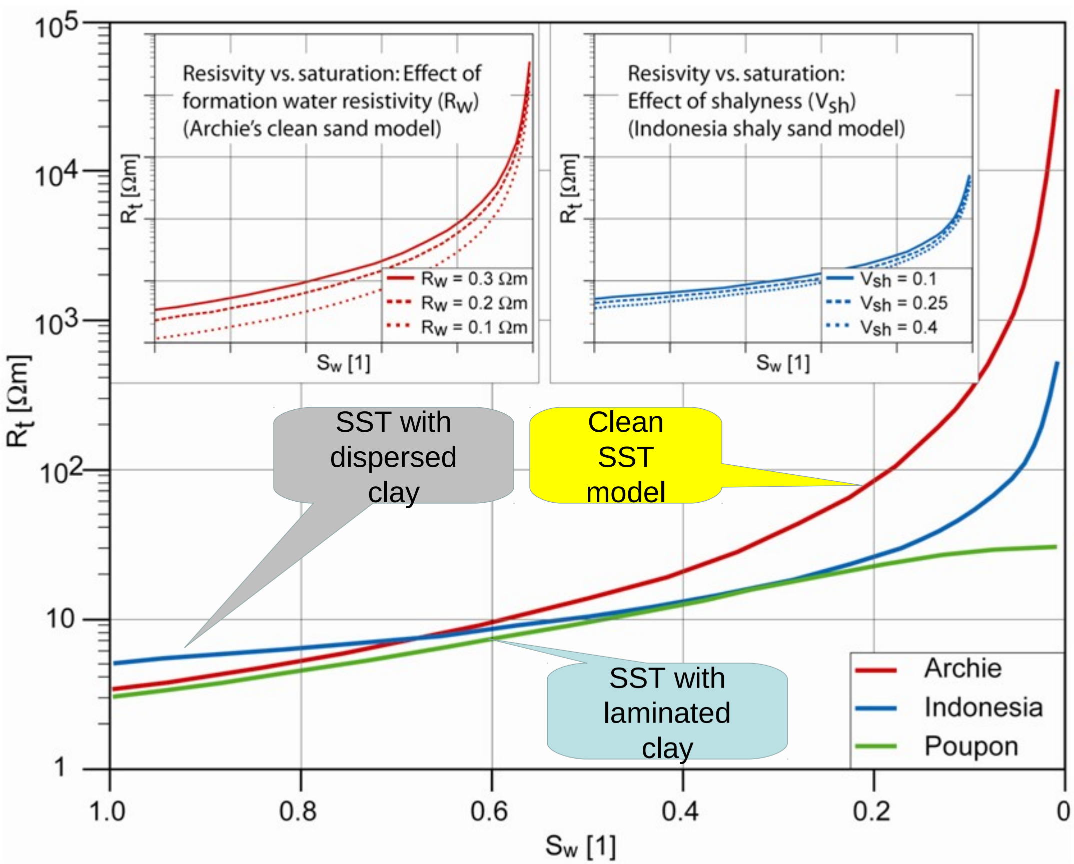
- **4D seismic monitoring is difficult beyond a certain level of fluid saturation**
- **Resistivity** is very sensitive to changes in fluid saturation. **Seismic data** have indirect sensitivity, while the **CSEM data** have strong sensitivity to resistivity
- **Therefore**, time-lapse CSEM data can be complementary in seismic reservoir monitoring

Objectives

- **Time-lapse CSEM sensitivity analysis with respect to CO_2 sequestration**
- **Detection of potential CO_2 leakage from the main storage**
- **Evaluation of the effects of shaliness on time-lapse CSEM sensitivity**

Formation resistivity

Resistivity estimates from petrophysical parameters

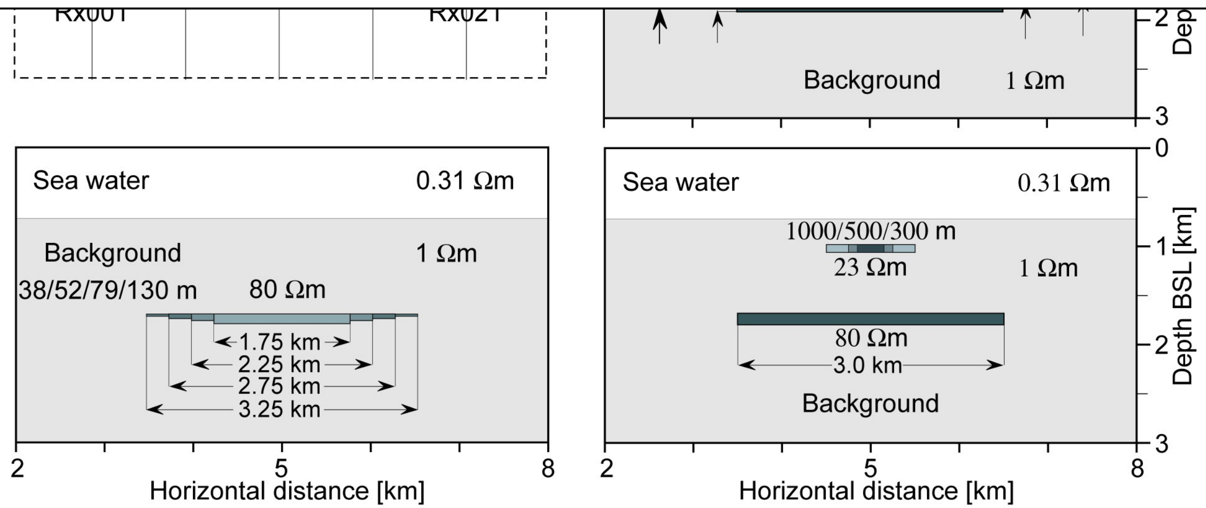


$\phi\,(\%)$	30
$\phi_{sh}\,(\%)$	5
$V_{sh}\,(\%)$	10, 25, 40
$\phi_e\,(\%)$	$(\phi - V_{Sh} * \phi_{sh})$
$\phi_s\,(\%)$	$(\phi - V_{Sh} * \phi_{sh})/(1 - \phi_{sh})$
m	2
n	2
$R_w\,(\Omega\text{m})$	0.1, 0.2, 0.3
$R_{sh}\,(\Omega\text{m})$	3

TL sensitivity to CO_2 sequestration

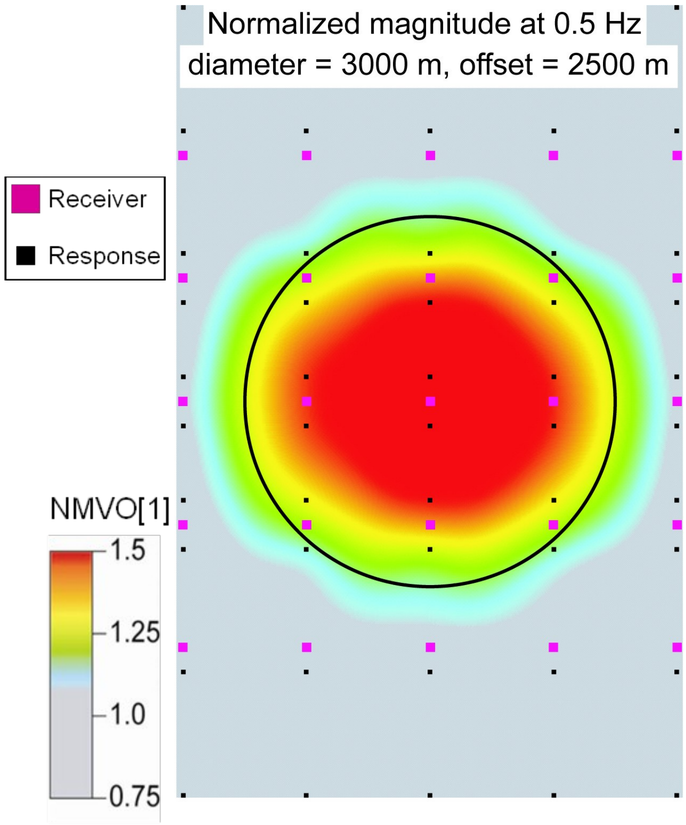
Sensitivity analyses for CO_2 sequestration include:

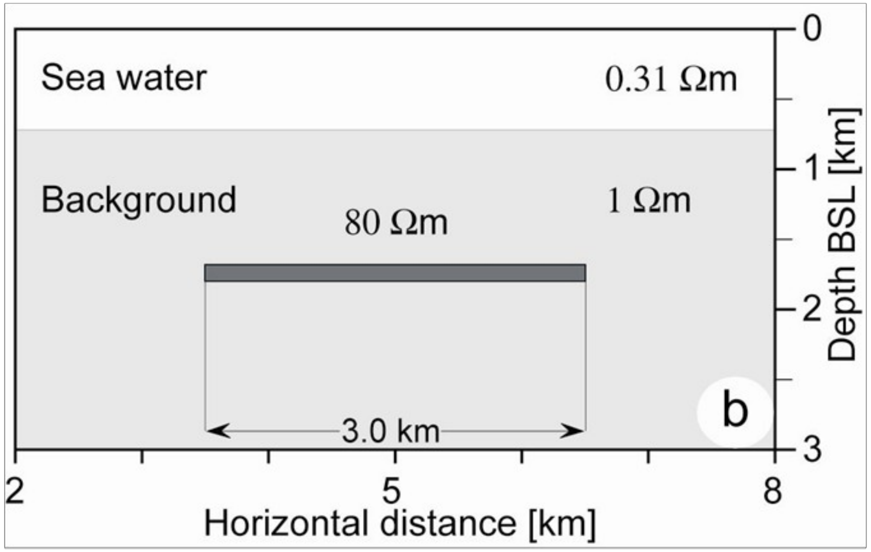
- Lateral expansion
- Vertical expansion
- Shallow accumulation of CO_2 leakage
- Effect of shaliness on time-lapse sensitivity



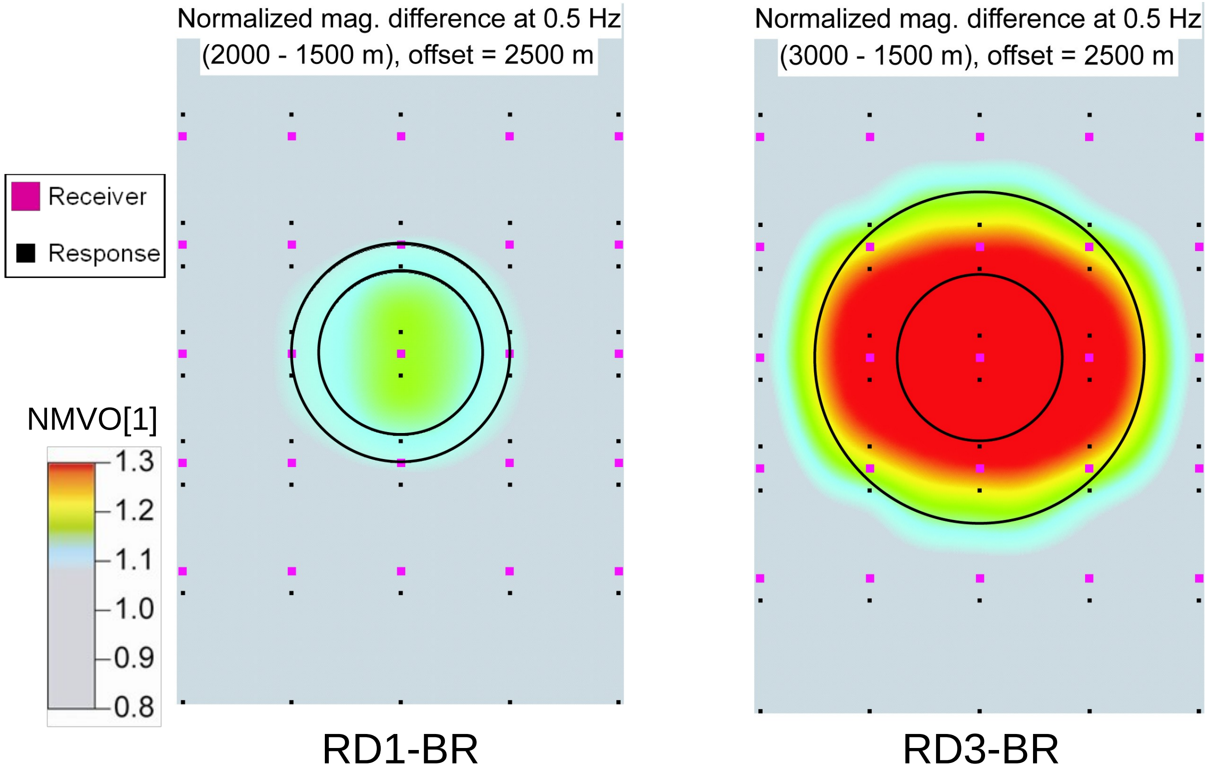
Changes in CO_2 plume diameter

Area response





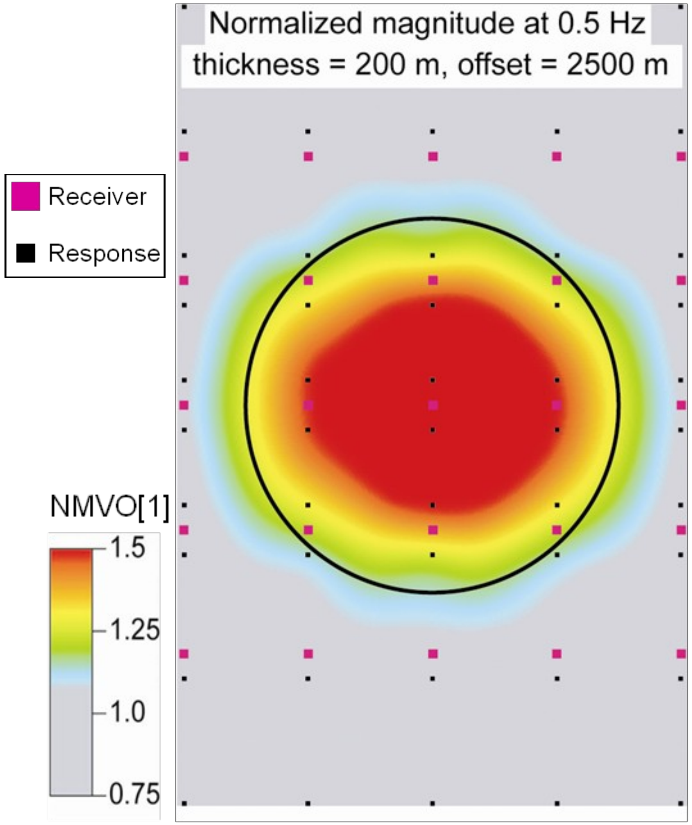
TL anomaly for changes in plume diameter

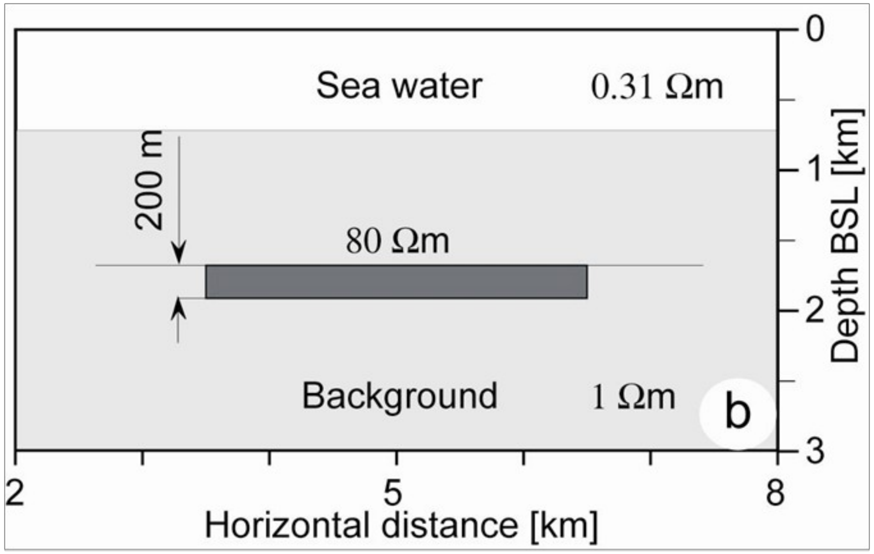


Lateral expansion of CO_2 plume by 200% gives 40% time-lapse anomaly at 2500 m offset for 0.5 Hz.

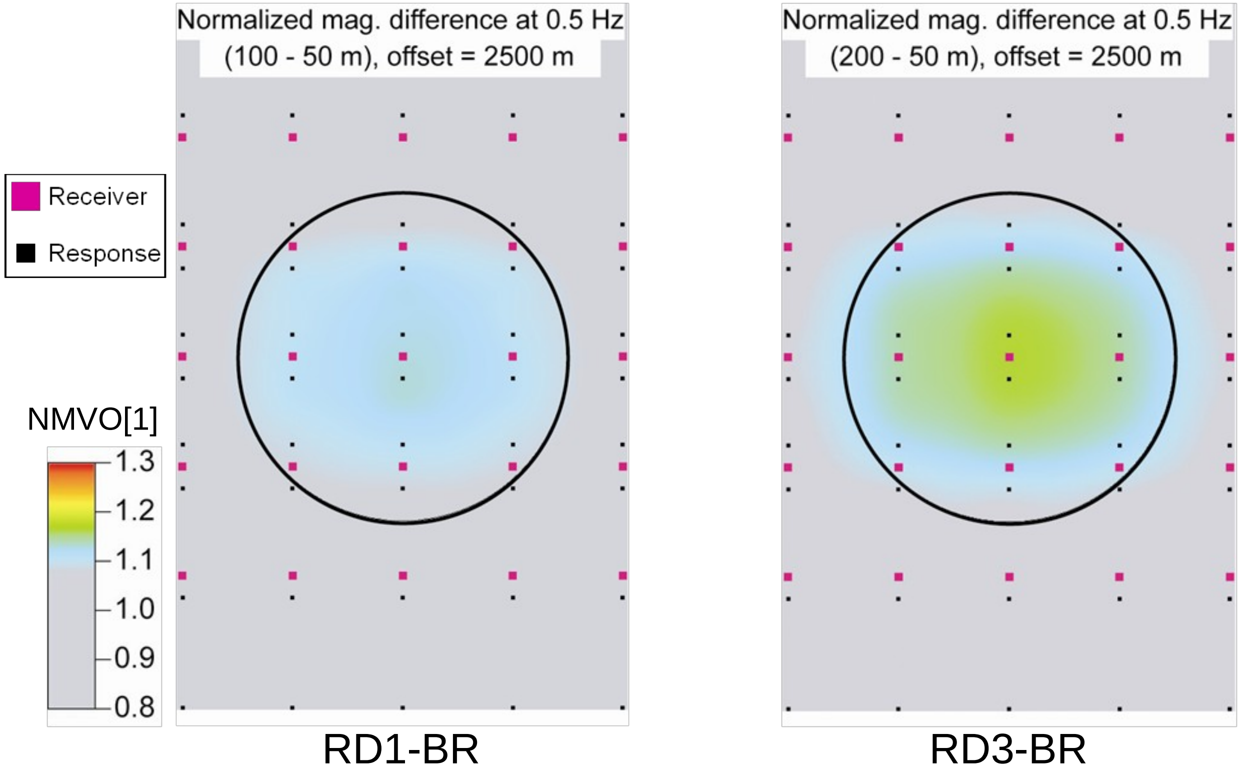
Changes in CO_2 plume thickness

Area response





TL anomaly for changes in plume thickness

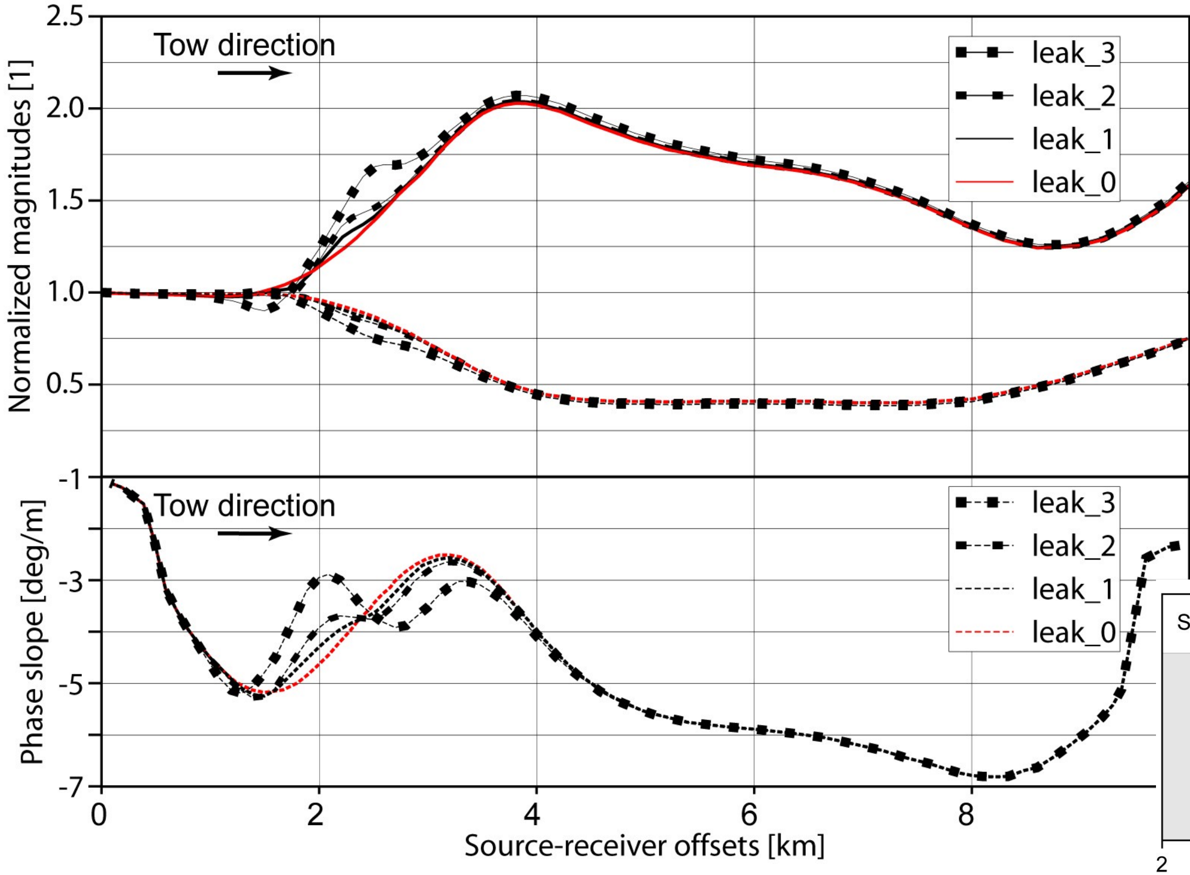


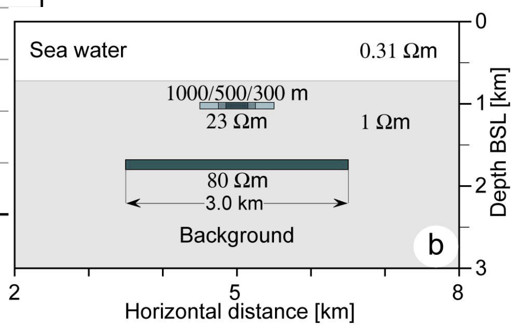
Vertical expansion of CO_2 plume by 300% gives only 9% time-lapse anomaly at 2500 m offset for 0.5 Hz.

Shallow accumulation of CO_2 leakage

Single receiver response

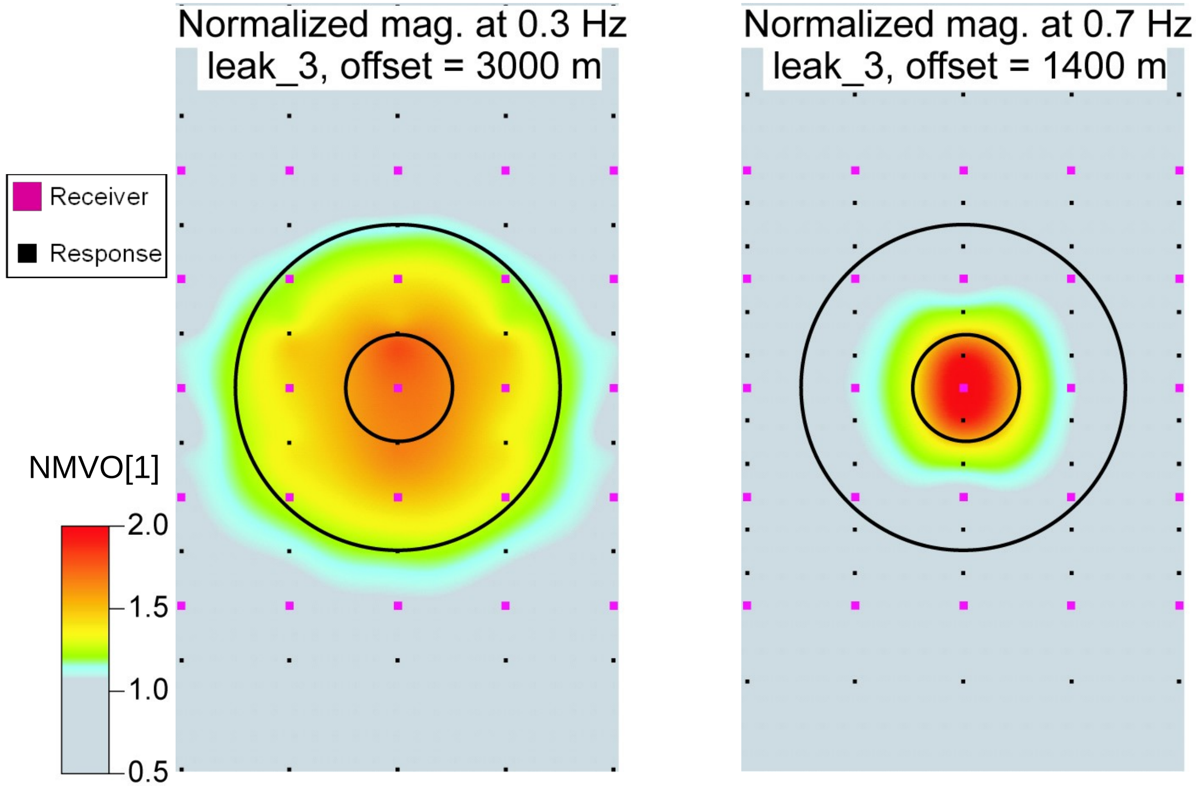
No leak
Leak_1 300 m
Leak_2 500 m
Leak_3 1000 m





Shallow accumulation of CO_2 leakage

Area response



Inverse variation of frequency and offset combination helps to differentiate shallow and deep anomalies

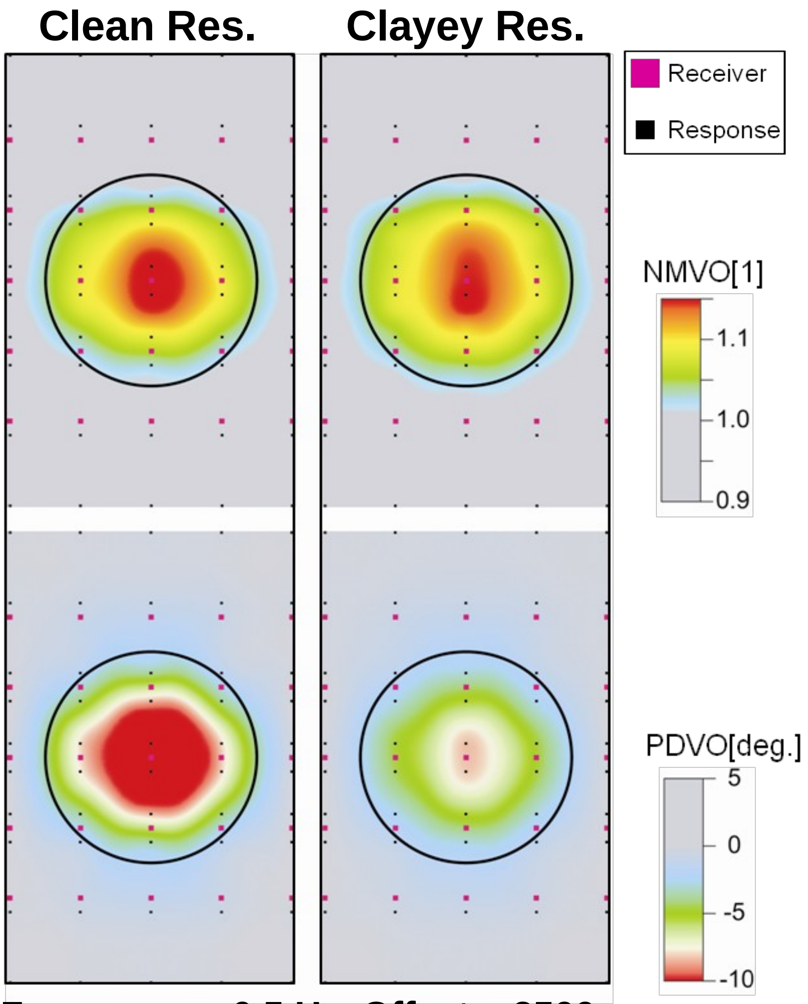
Effect of shaliness on TL CSEM anomaly

A clean sandstone reservoir with 60% CO_2 saturation gives 23 Ωm resistivity

CO_2 saturation increase upto 80%, which gives resistivity estimates of 50 Ωm

A clayey reservoir (10% dispersed clay) with 60% CO_2 saturation gives 10.6 Ωm resistivity

80% CO_2 saturation gives resistivity estimates of 23 Ωm for clayey reservoir



Frequency = 0.5 Hz, Offset = 2500 m

Volumetric resistance vs. TL anomaly

Assume that CSEM sensitivity of a 3D earth model is the function of volumetric resistance (*S*=*ρV*). Time-lapse anomalies with respect to variation in volumetric resistance is evaluated as:

$$\delta S = V(\delta\rho) + \rho(\delta V)$$

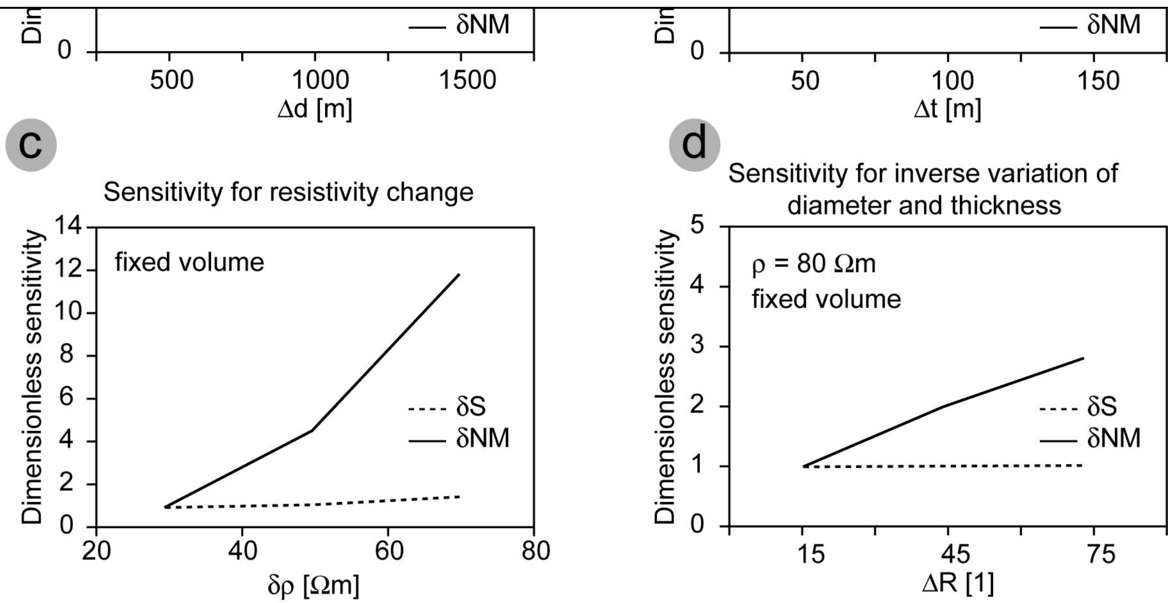
Time-lapse responses considered for

- ✓ **Changes in diameter, while thickness and saturation remain fixed**
- ✓ **Changes in thickness, while diameter and saturation remain fixed**
- ✓ **Inverse variation of thickness and diameter, while volume & saturation remain fixed**
- ✓ **Only saturation change**

Volumetric resistance vs. TL anomaly

The empirical relationship between time-lapse anomaly, δ(*NM*) and volumetric resistance can be given as:

$$\delta(MN) = \chi D + \gamma H + \psi e^{\tau\rho}$$



Conclusions: TL CSEM sensitivity analysis

- Time-lapse CSEM anomaly is the combined effect of diameter, thickness & resistivity of the resistive pore-fluids and lateral changes has higher sensitivity than the vertical ones
- Gradual inverse variation of frequency and offset allows for detecting shallow accumulation of CO_2 leakage
- Small percentage of dispersed clay (e.g. 10%) within a reservoir has weak significance on the magnitudes of time-lapse anomaly

Thanks for your attention