CSEM Fluid Monitoring Methodology Using Real Data Examples

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[3]- Sumatera Institute of Technology, Indonesia
[4]- Lulea Technical University, Sweden

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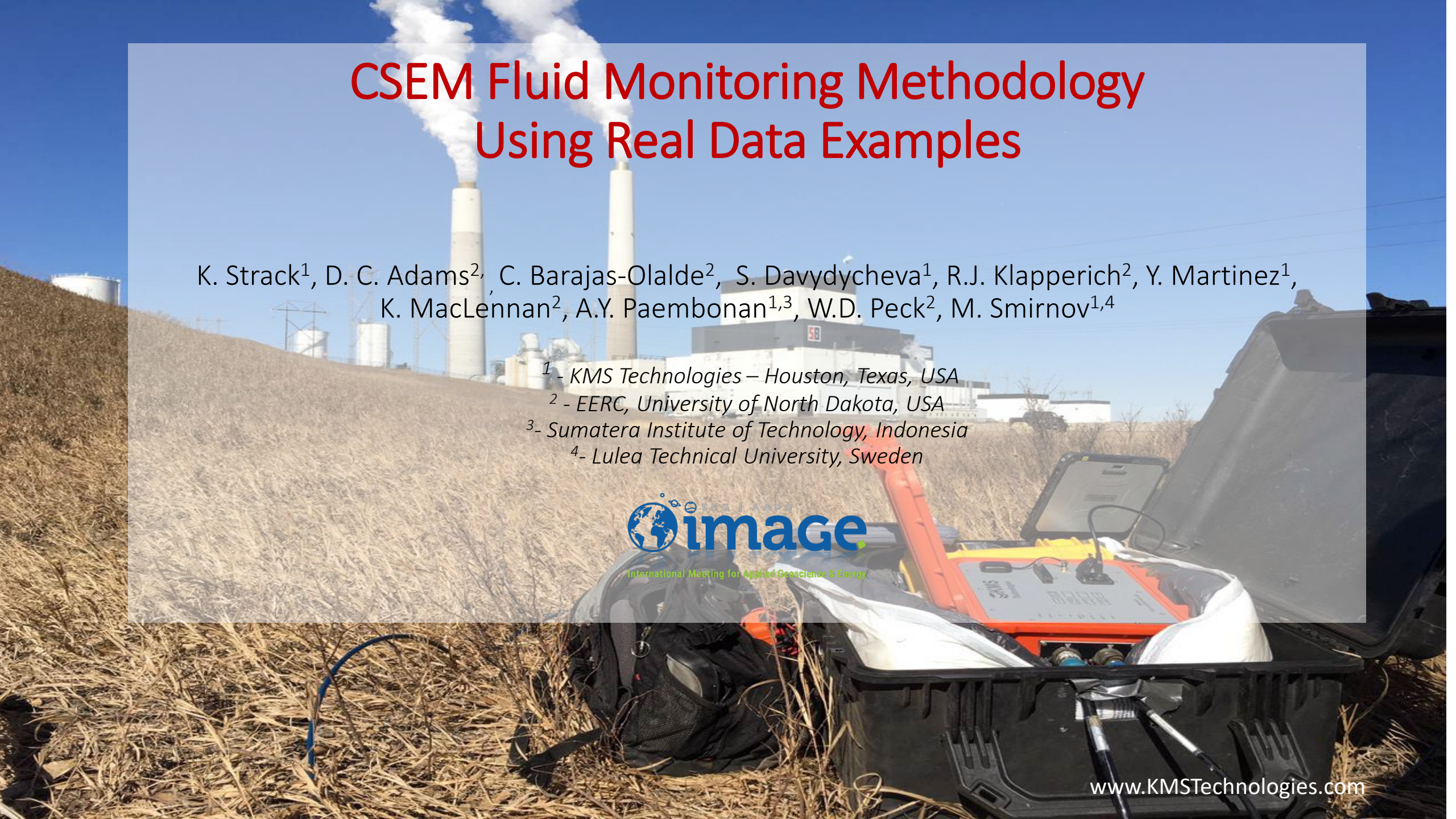

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Outline & objectives

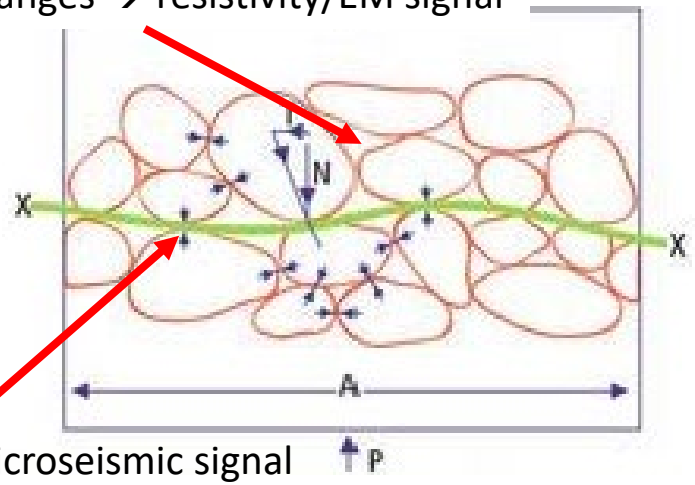
Background & physics >> methods >> examples >> issues & path forward

- We want to monitor fluid movement in a reservoir – what do we do?
- Workflow to maintain calibration to log scale!
- Two case histories from:
  - CO_2 pilot in ND, USA
  - Oil field in Asia - EOR

Key issues: Seal & plume dynamics→ microseismics and EM?

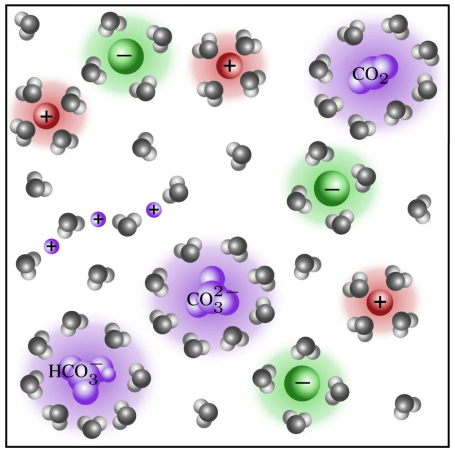
Background & physics >> methods >> examples >> issues & path forward

Pore fluid changes → resistivity/EM signal

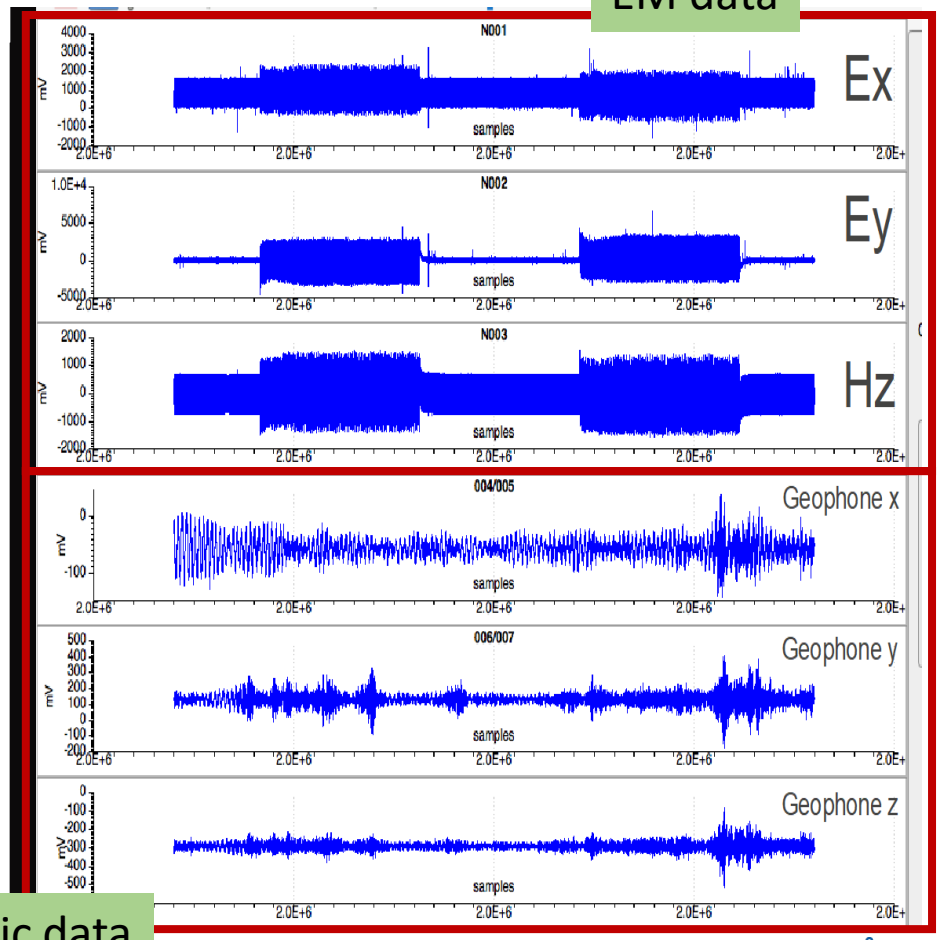


'Cracks' → microseismic signal

CO_2 dissolves → reservoir fluid RESISTIVE



EM data



Seismic data

CSEM for Carbon Capture, Utilization and Storage (CCUS)
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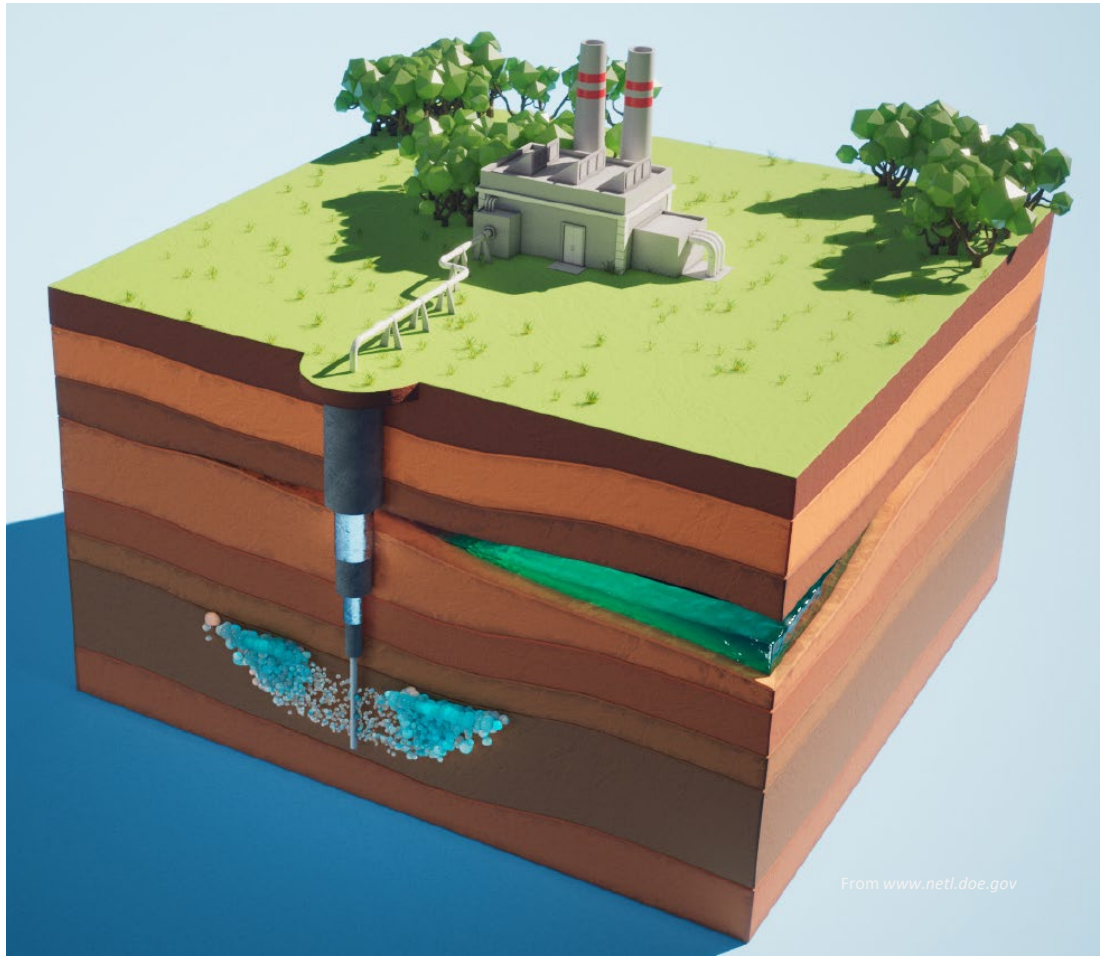

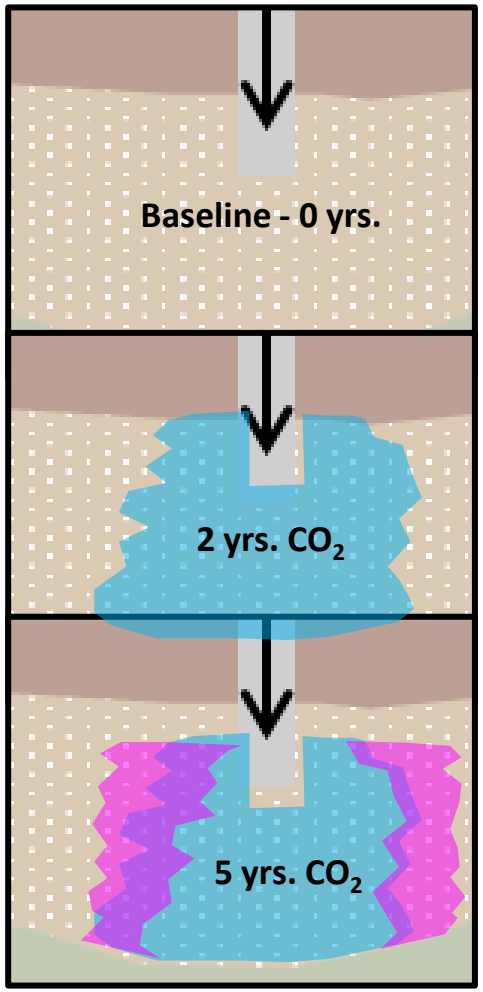

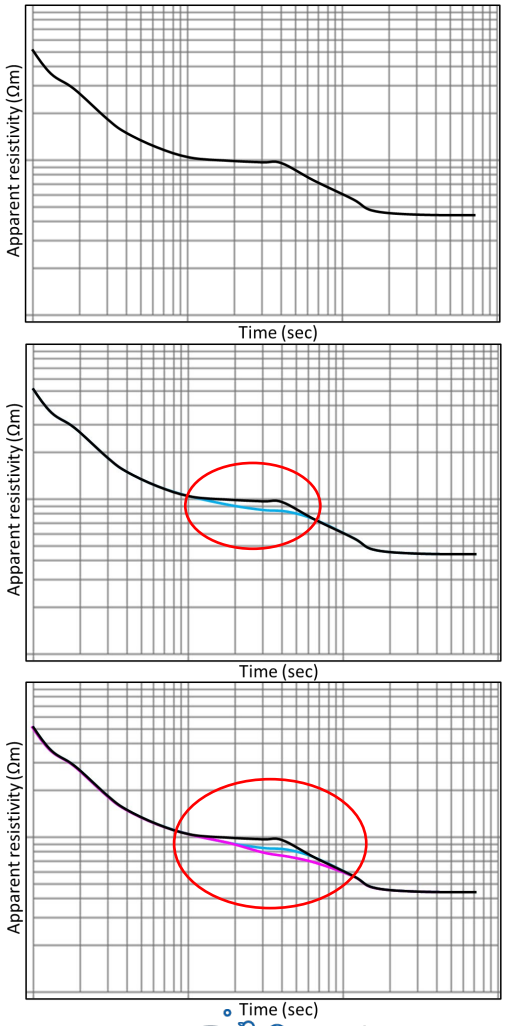

What do we know now?

- Resistive – CO_2 saturated; Conductive – brine only..
  Targets both resistive & conductive → CSEM
- Monitoring = repeat → HIGH repeatability
- DEPTH > 1.5 km

Controlled Source EM (CSEM)

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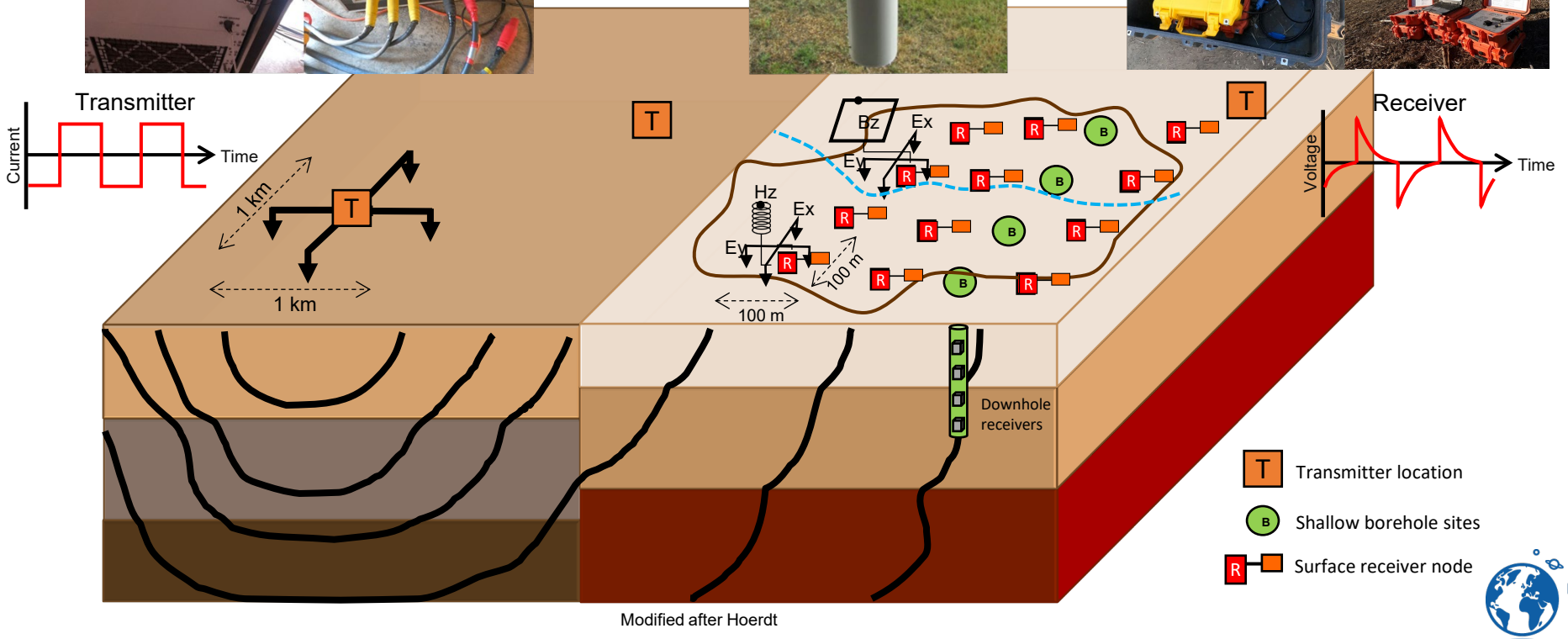


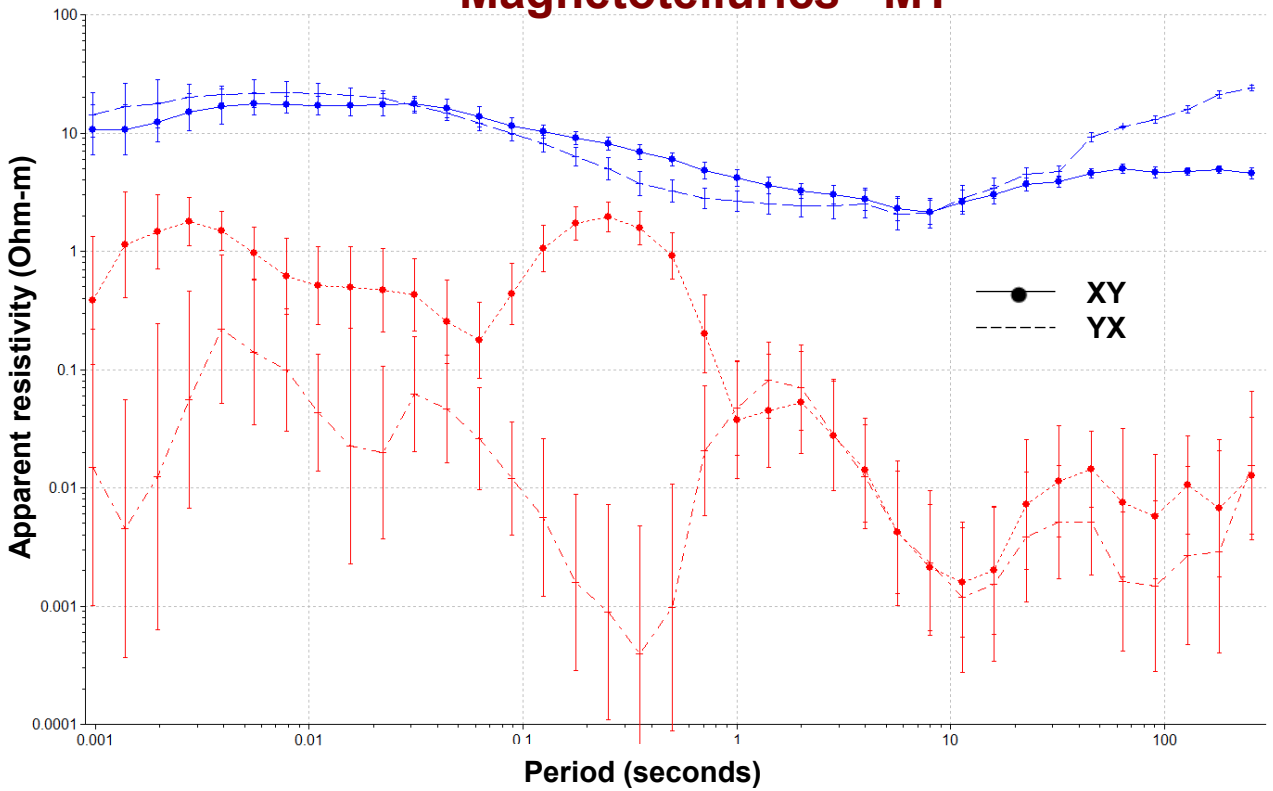
Modified after Hoerdt

High noise versus low noise data

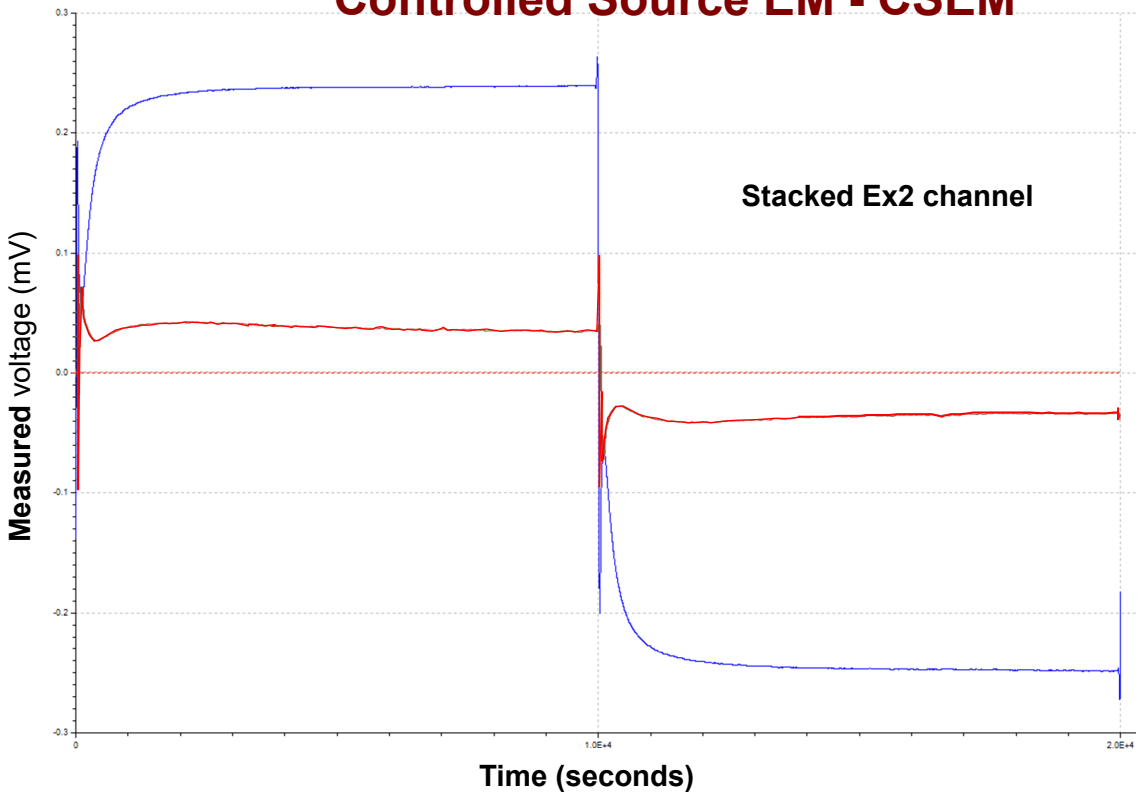
Low noise MT/CSEM site outside 1 km radius of power plant

High noise MT/CSEM site inside 1 km radius

Magnetotellurics - MT



Controlled Source EM - CSEM



BIG PICTURE strategic fluid imaging workflow

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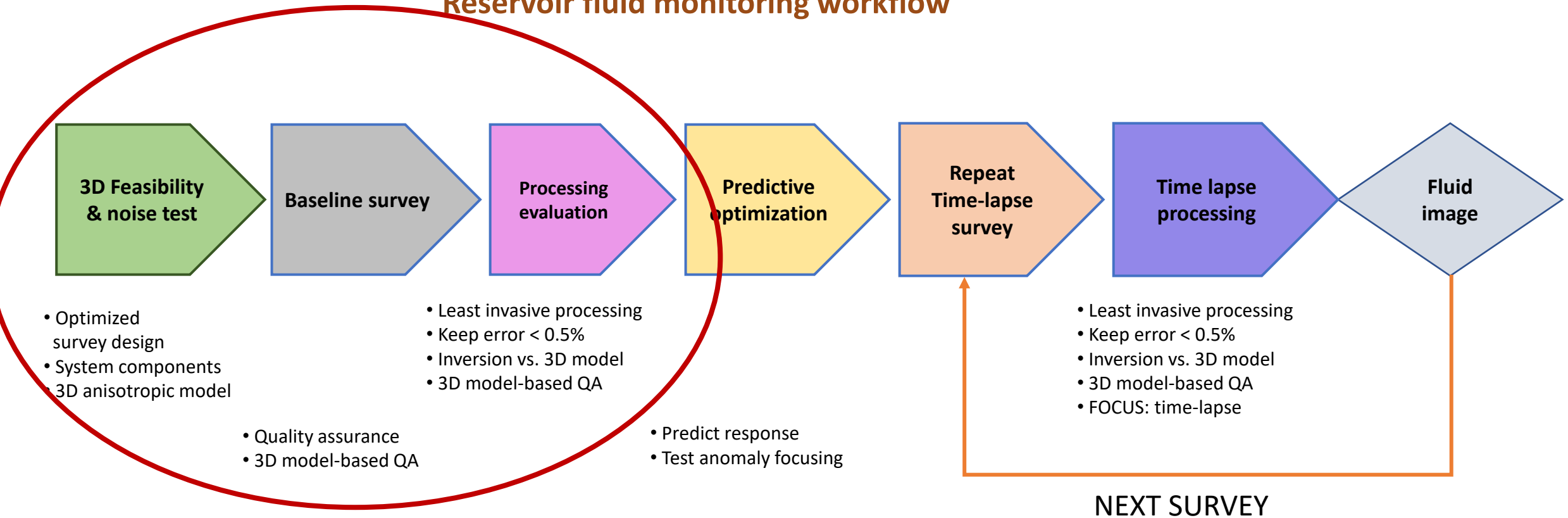
Reservoir fluid monitoring workflow



From Feasibility to baseline

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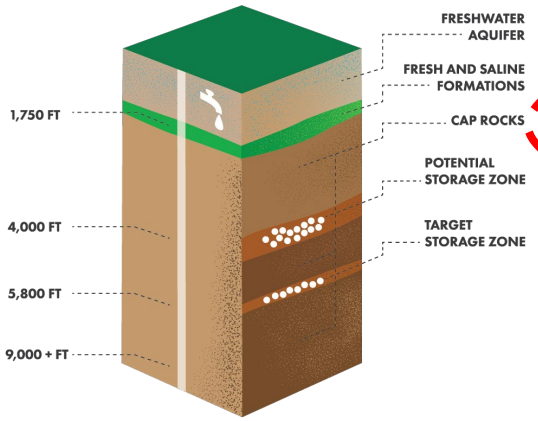

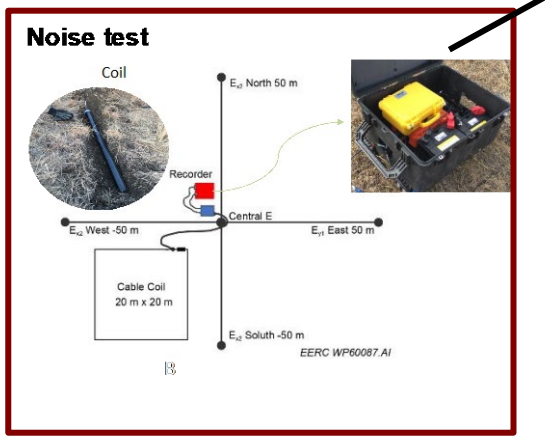

Get data: FEASIBILITY:
- Logs, geology, seismic horizons; additional surveillance

Field Noise Test

Determine which reservoir parameter varies

Link data with variations
→ FEASIBIILITY

Define PILOT
→ 2-3 monitoring cycles
→ BASELINE here

Evaluate / decide

Baseline survey

CO_2 pilot in North Dakota: survey setup & log model

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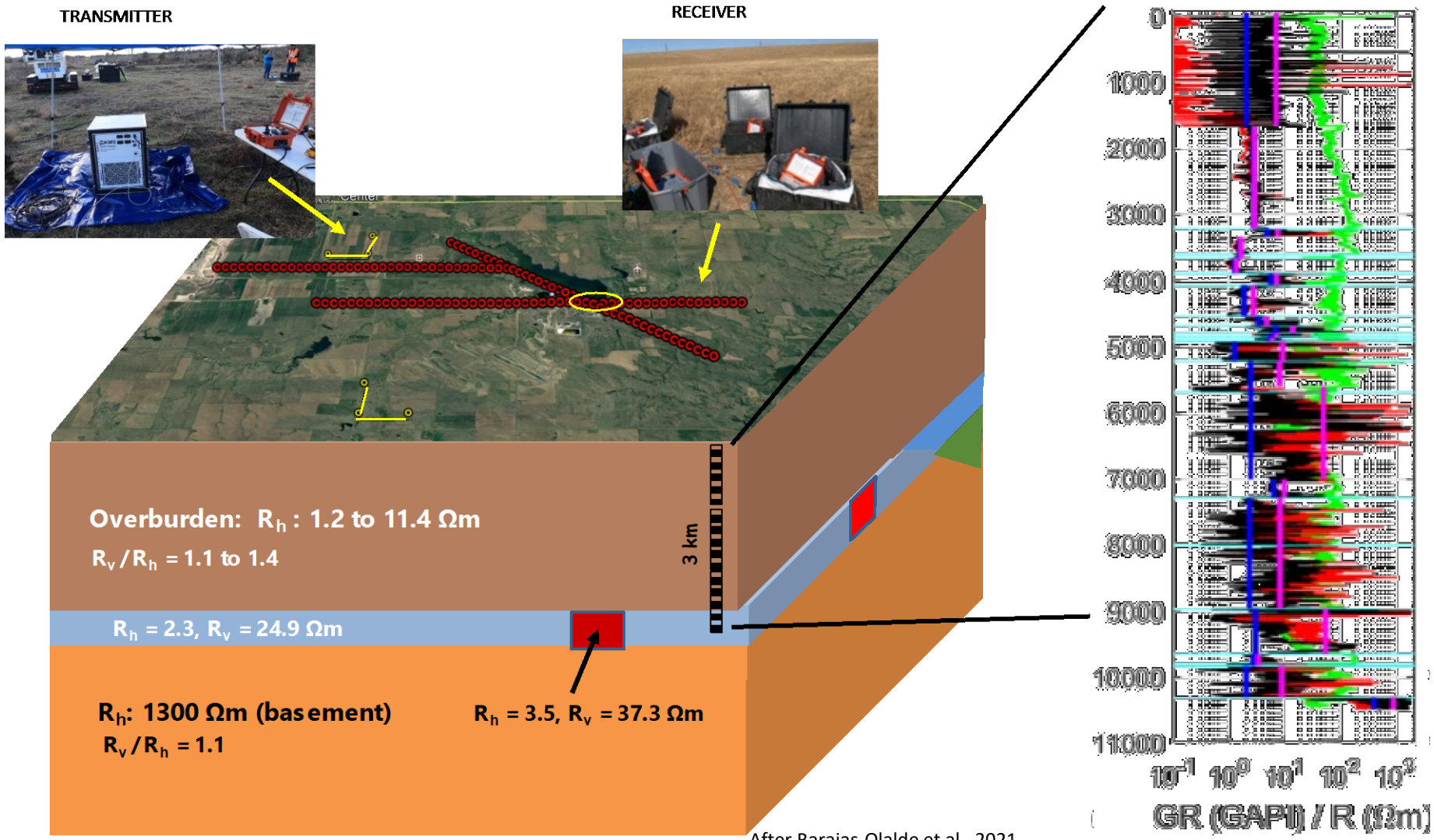

After Barajas-Olalde et al., 2021

Build anisotropic model: Fluid substitution

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- Analyze logs to provide real substituted resistivity value
- Determine substituted resistivity & scale model using anisotropy from logs (equivalencing)
- Verify scaling with forward models (1D) or 3D for anisotropy
- When modeling, check for shoulder bed influence and rescale, compare scaling (1D & 3D) versus logs
- PINFALLS: artifacts in 3D models at high contrast boundaries – compare to log
- Result: table of benchmark models

CO_2 pilot: Noise spectra & 3 models

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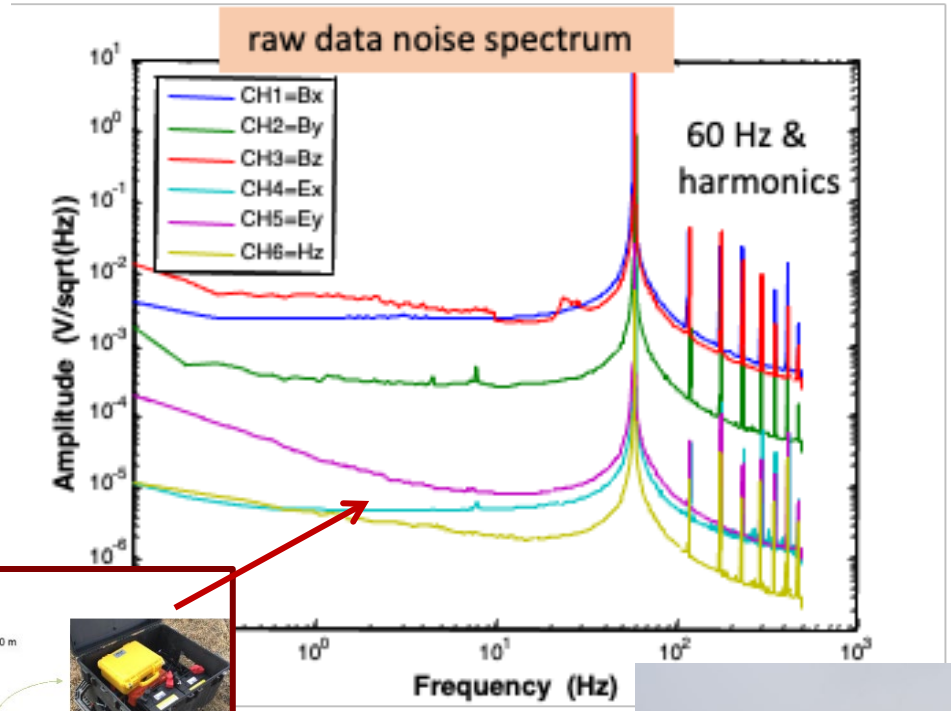
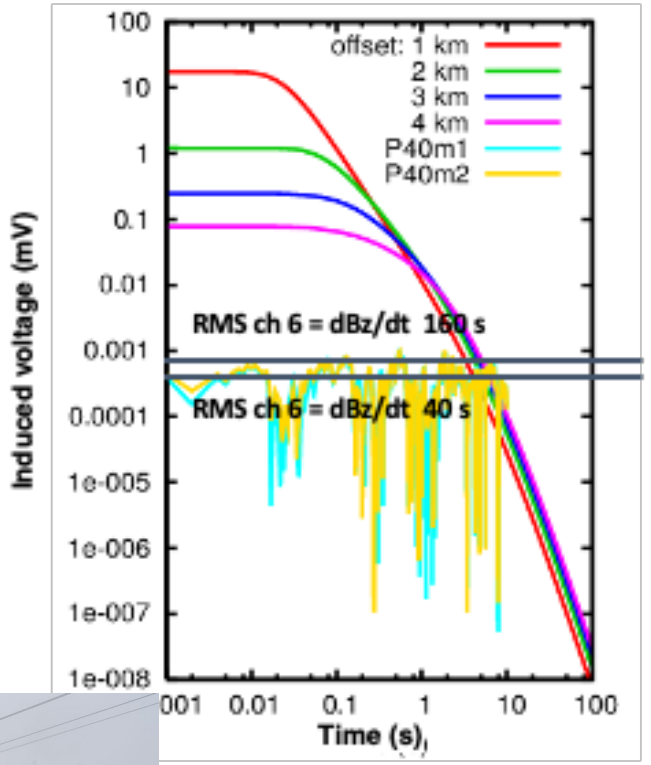
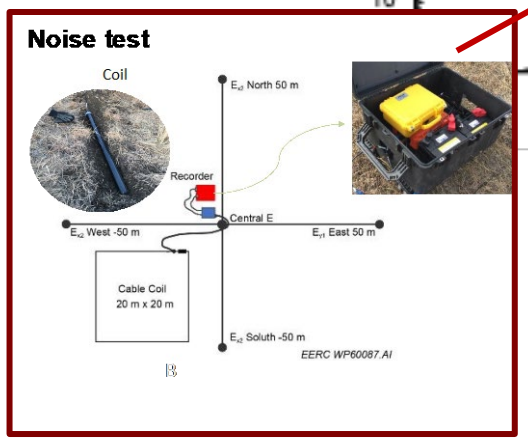
raw data noise spectrum



transient response & noise





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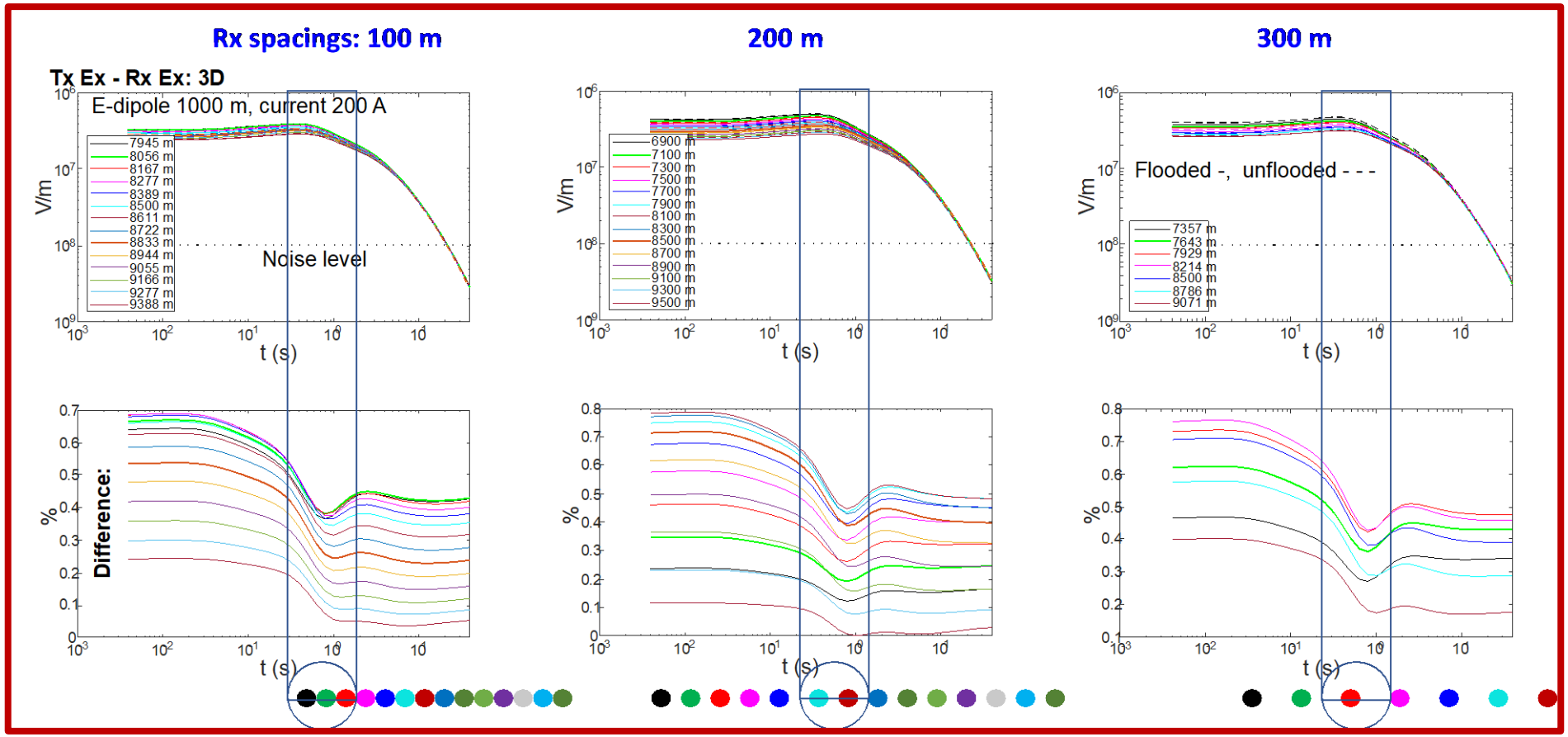
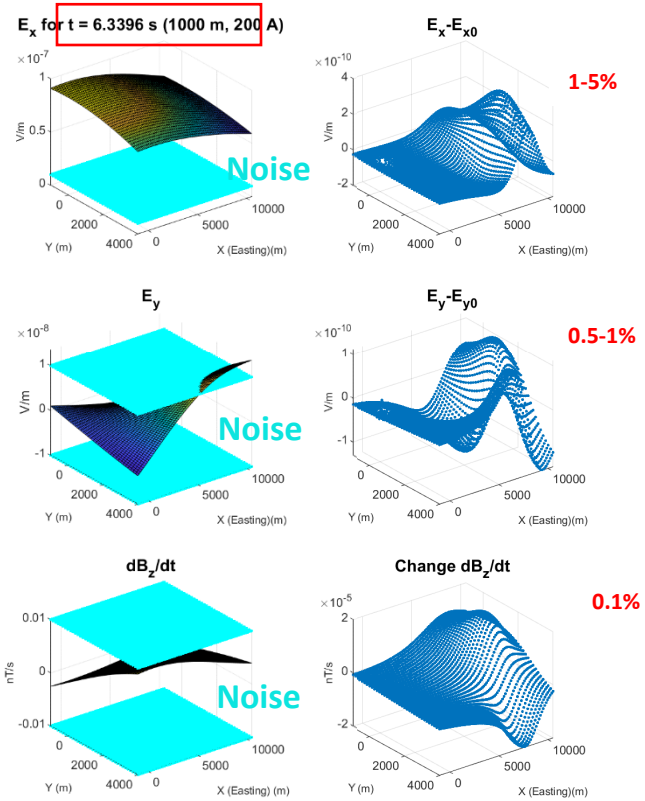
CO_2 pilot: 3D models Ex – station spacing Broom Creek

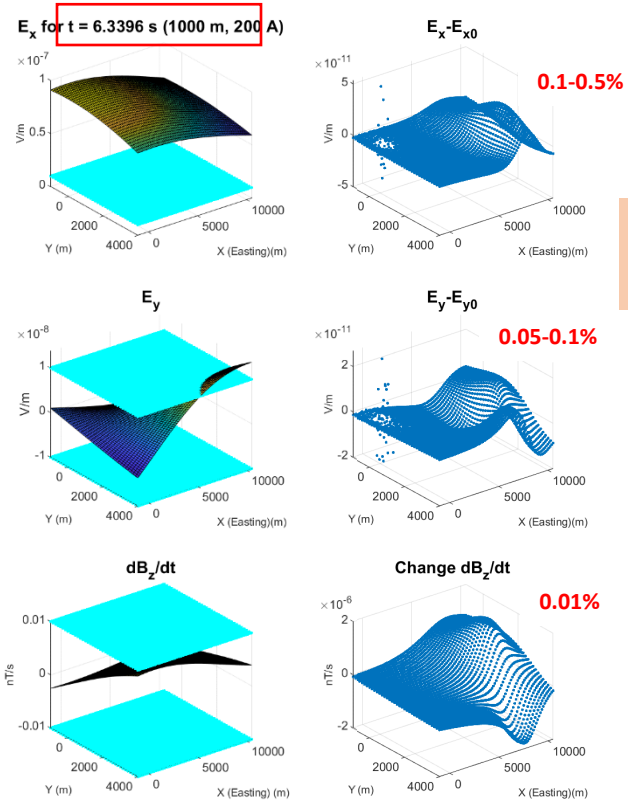


CO_2 pilot: 3D models X-directed Tx, Broom Creek, 12th bed, 3D case (60% - CO_2 sat.)

CO2 zone: r = 500 m



CO2 zone: r = 100 m



- 6.3 s after turn-off
- Absolute change

CO_2 pilot: Feasibility results – ALL confirmed by baseline survey

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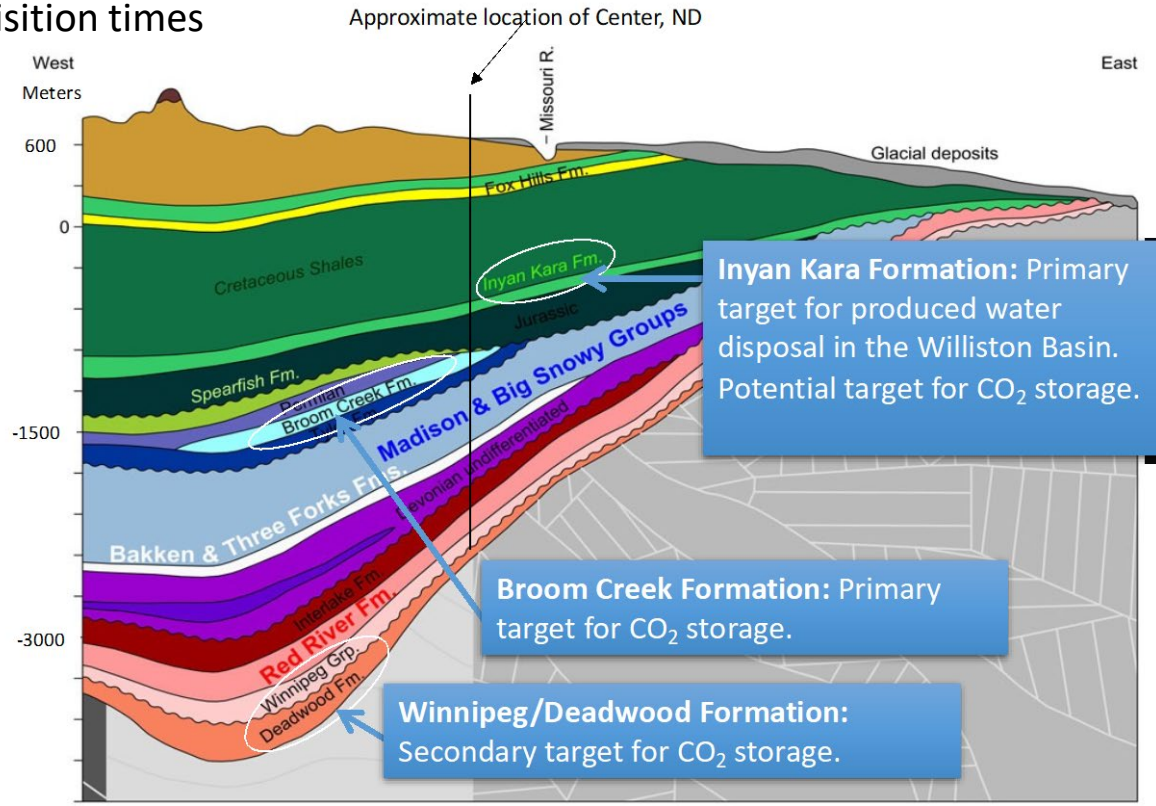
- 3D vs 1D benchmark – self consistency tests

<u>3D cases: Broom Creek, 30%, 60% saturation, 100 & 500 m flood radius; Deadwood, 30%, 60%, radius 150 m</u>

- Inyan Kara ✓ **as it is shallower**
- In Broom Creek (5000 ft - deep target zone) – detectable in 5% range
- in Deadwood (9000 ft - target zone) – around 1% → longer acquisition times
- Signal > noise level to 4-6 s.
- Time decay Receiver's Line 2
  - Broom Creek (depth 5000 ft): sensitive around to 1 - 2 s.
  - Deadwood (depth 9000 ft): sensitive around to 2 - 4 s.
- Rx spacings: **200 m choose for oversampling**



BIG PICTURE strategic fluid imaging workflow

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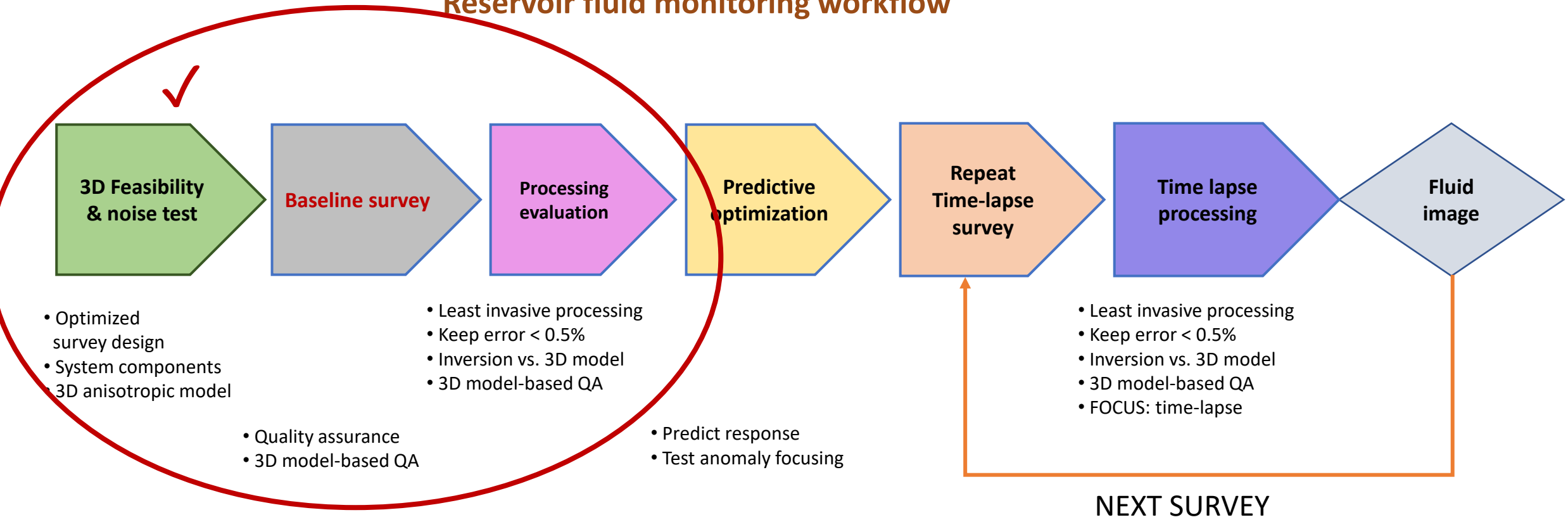
Reservoir fluid monitoring workflow



CO_2 pilot: Field operations – field test Hockley salt dome

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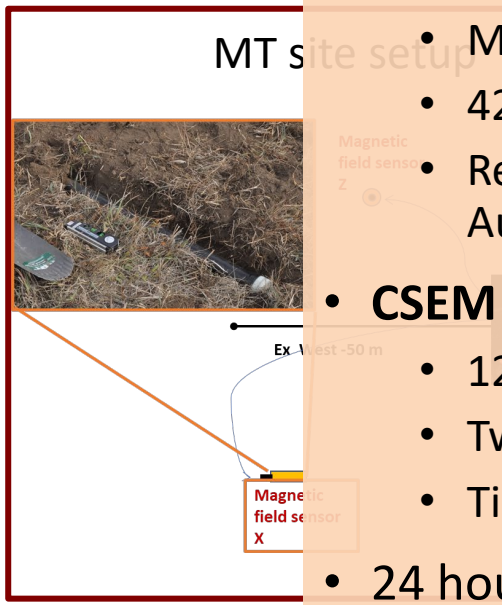
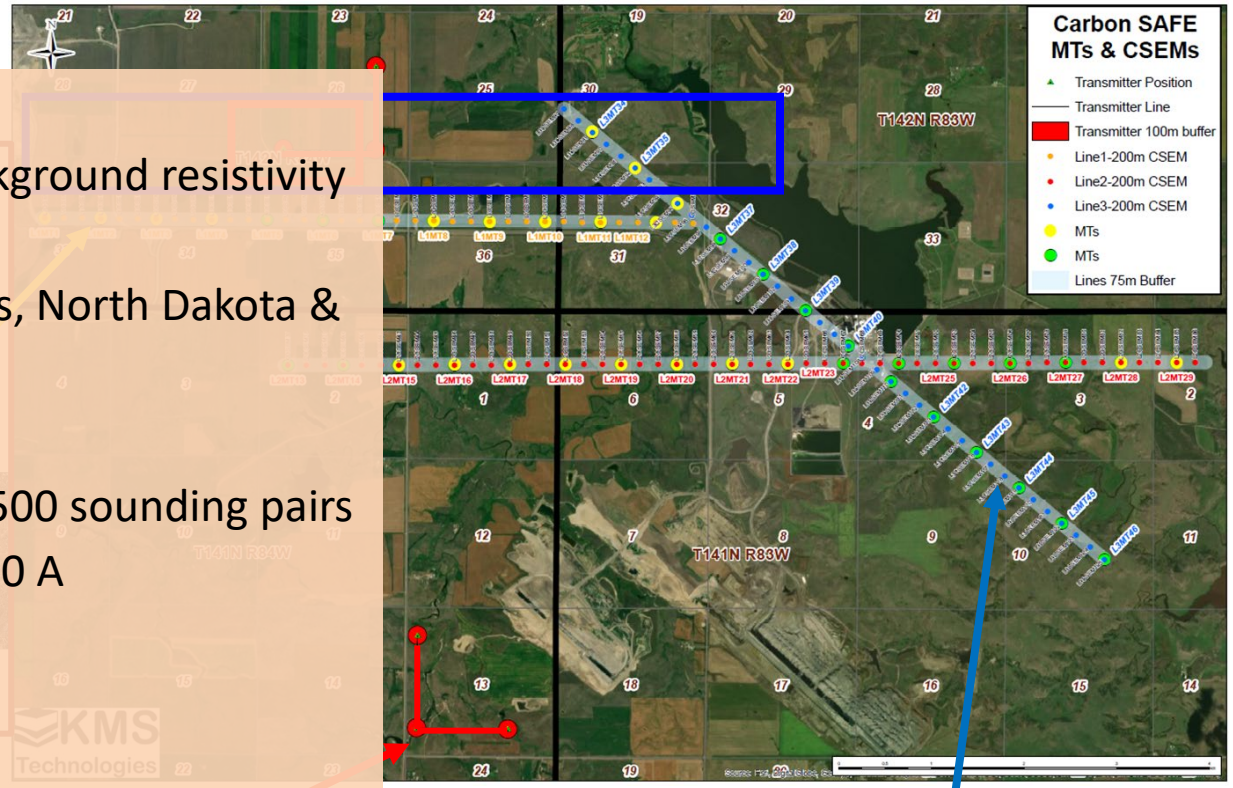
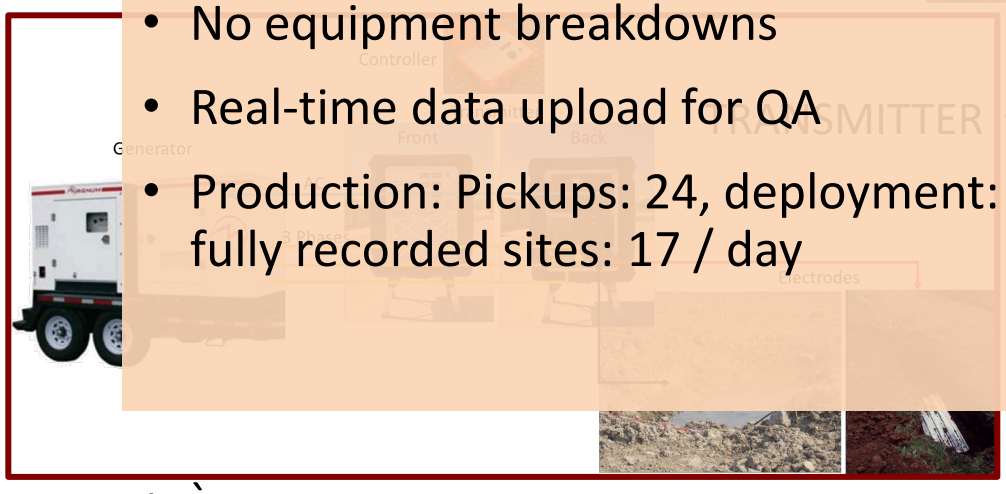
1. Build systems
2. Calibrate in lab (magnetic chamber)
3. Field test (components)
4. System integration field test in Houston (Hockley salt dome)

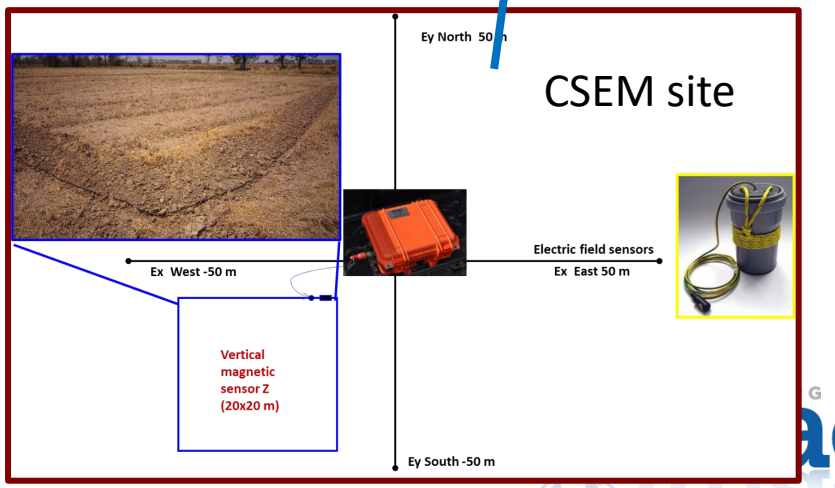
CO_2 pilot: MT/CSEM survey

- **MT**
  - Measures model's baseline background resistivity
    - 42 Stations, 600 m spacing
    - Remote station near Grand Forks, North Dakota & Austin, Tx
- **CSEM**
  - 124 Stations, 200 m spacing,~ 3500 sounding pairs
  - Two transmitter sites (A & B), 400 A
  - Time domain
- 24 hours operation
- No equipment breakdowns
- Real-time data upload for QA
- Production: Pickups: 24, deployment: 16, fully recorded sites: 17 / day
-









CO_2 pilot: Cloud based acquisition workflow

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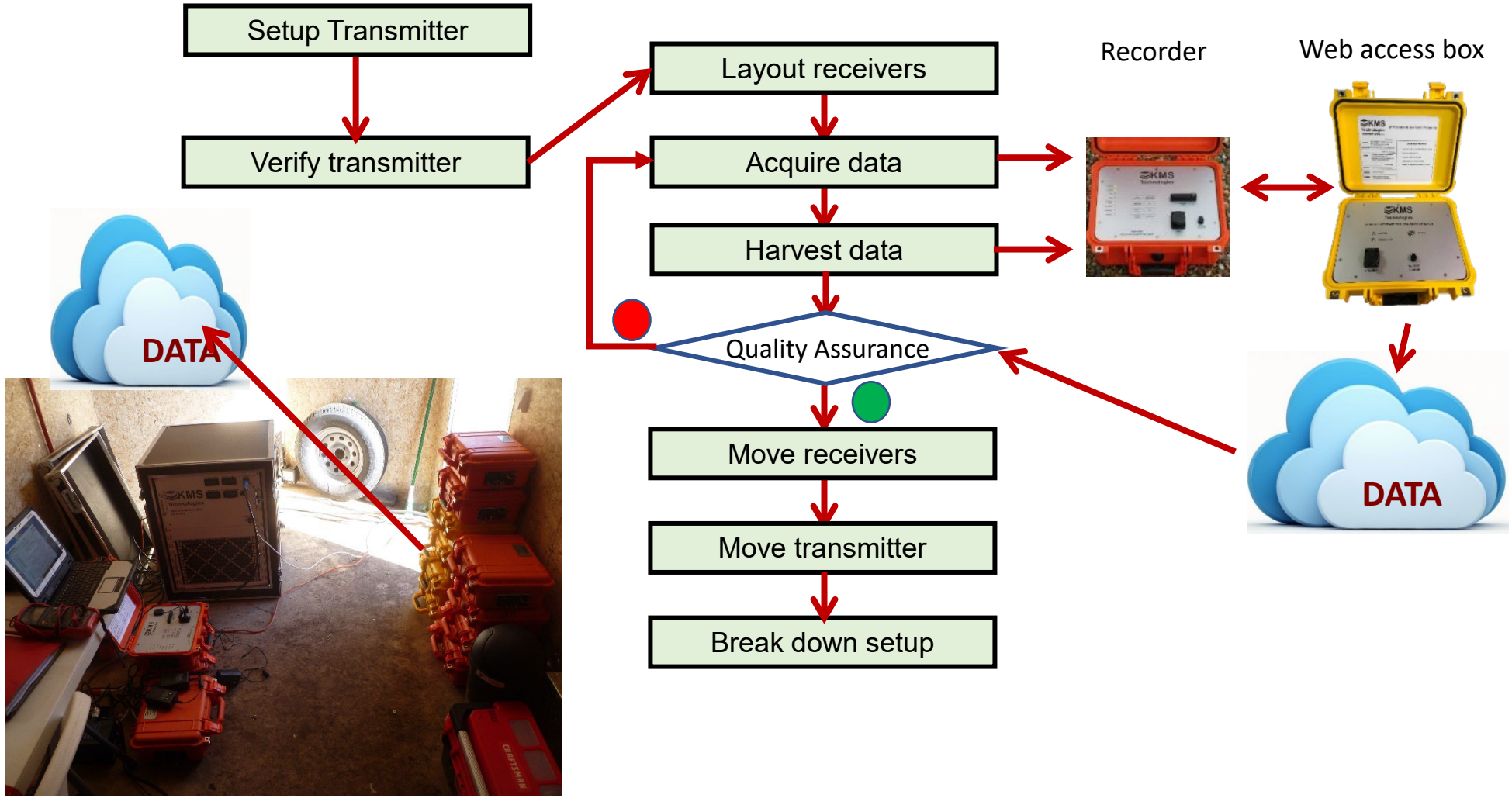

BIG PICTURE strategic fluid imaging workflow

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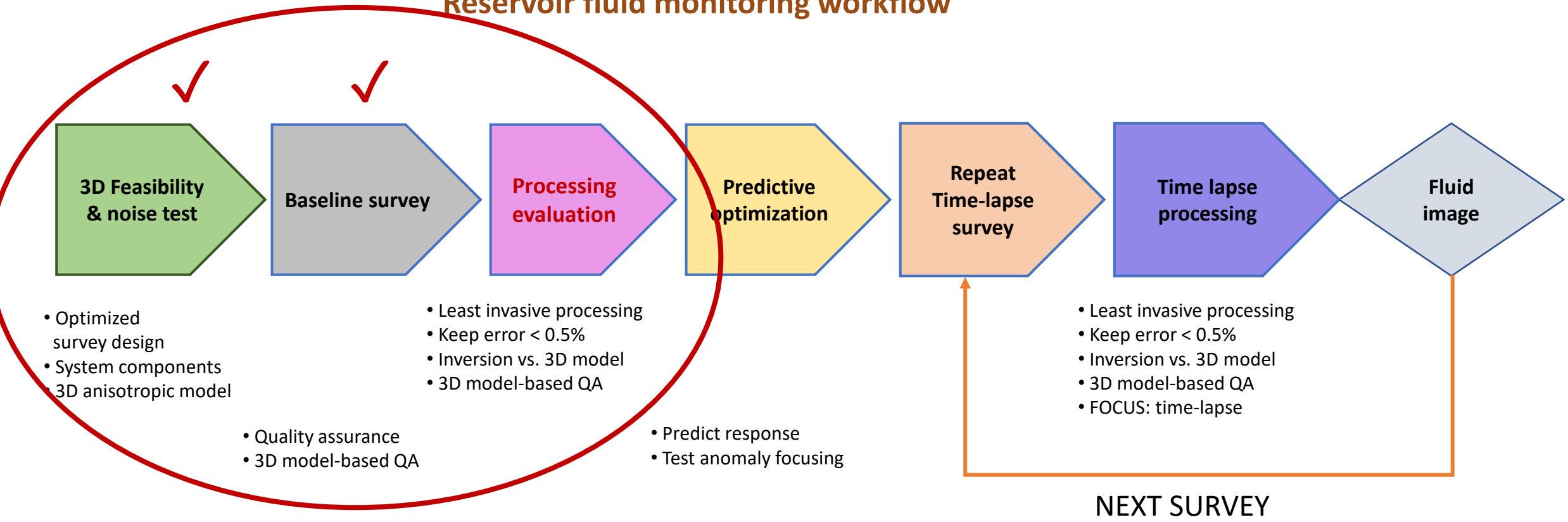
Reservoir fluid monitoring workflow



CO_2 pilot: MT results. Initial RR & 3D model

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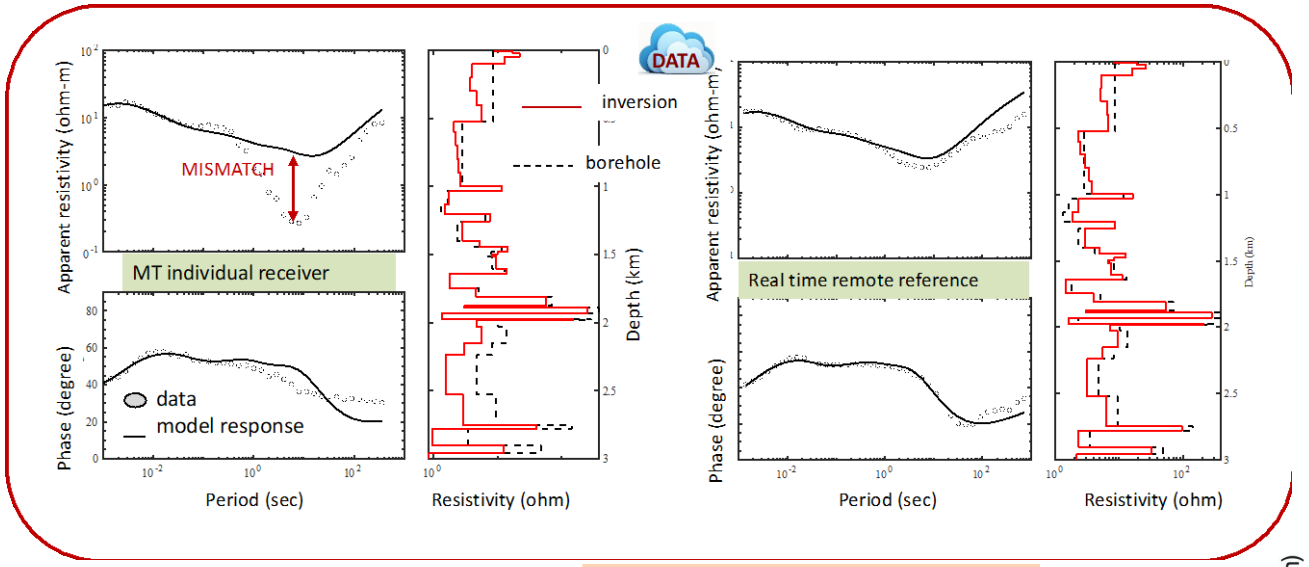

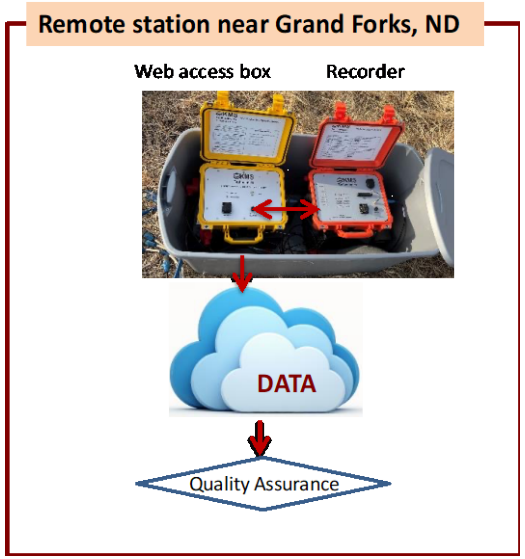

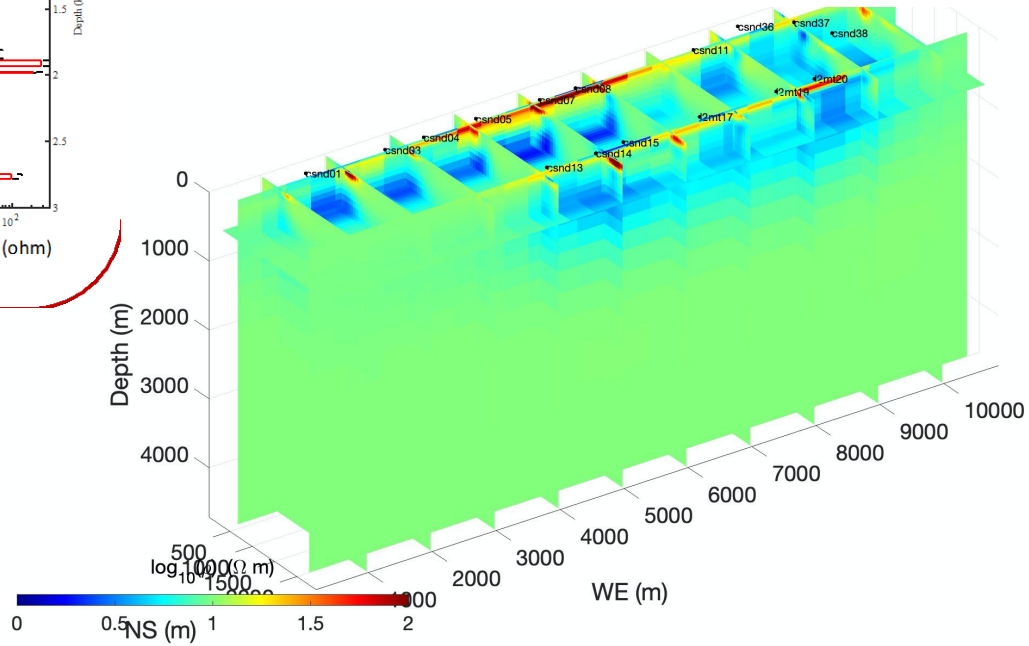

CO_2 pilot: CSEM Data processing

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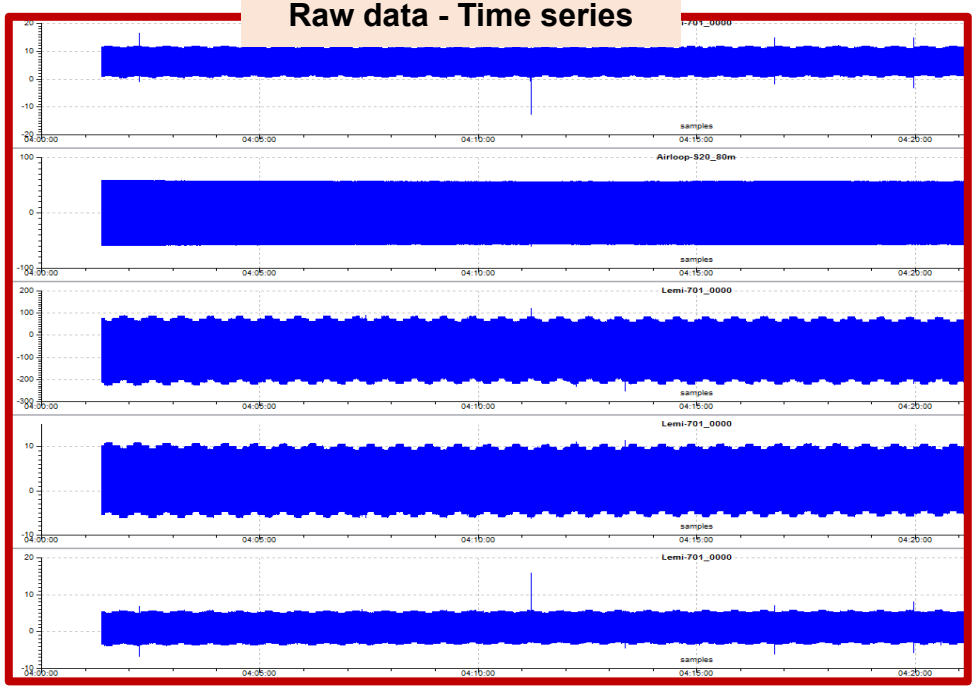
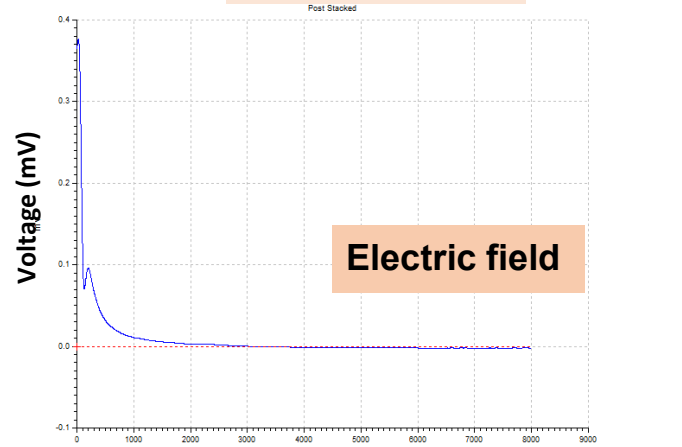
Raw data - Time series

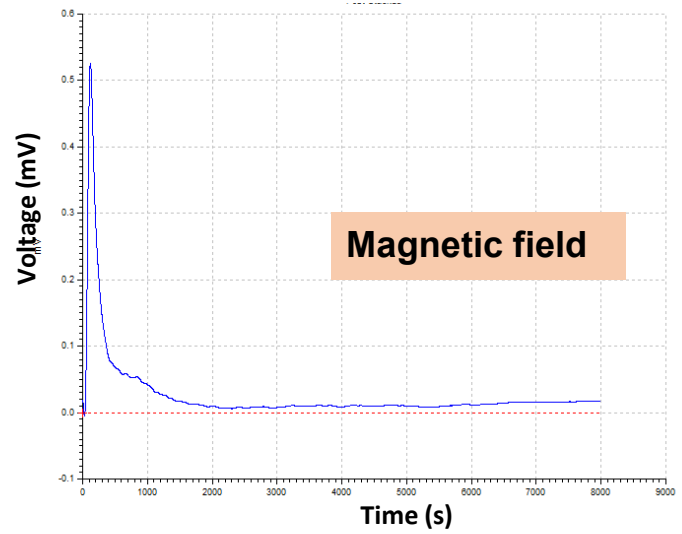


Station: L1CSEM002

Processed data



Ex1



dB/dt

How do we quality control the data?

- We know the average 3D anisotropic model in the area.
- Variations are gentle (except SE).
- Check via inversion- SIMILARITY to log
- Verify sensitivity via Eigenvalues (from inversion)
- NEXT: Time-lapse measurements

CO_2 pilot: MT/CSEM results

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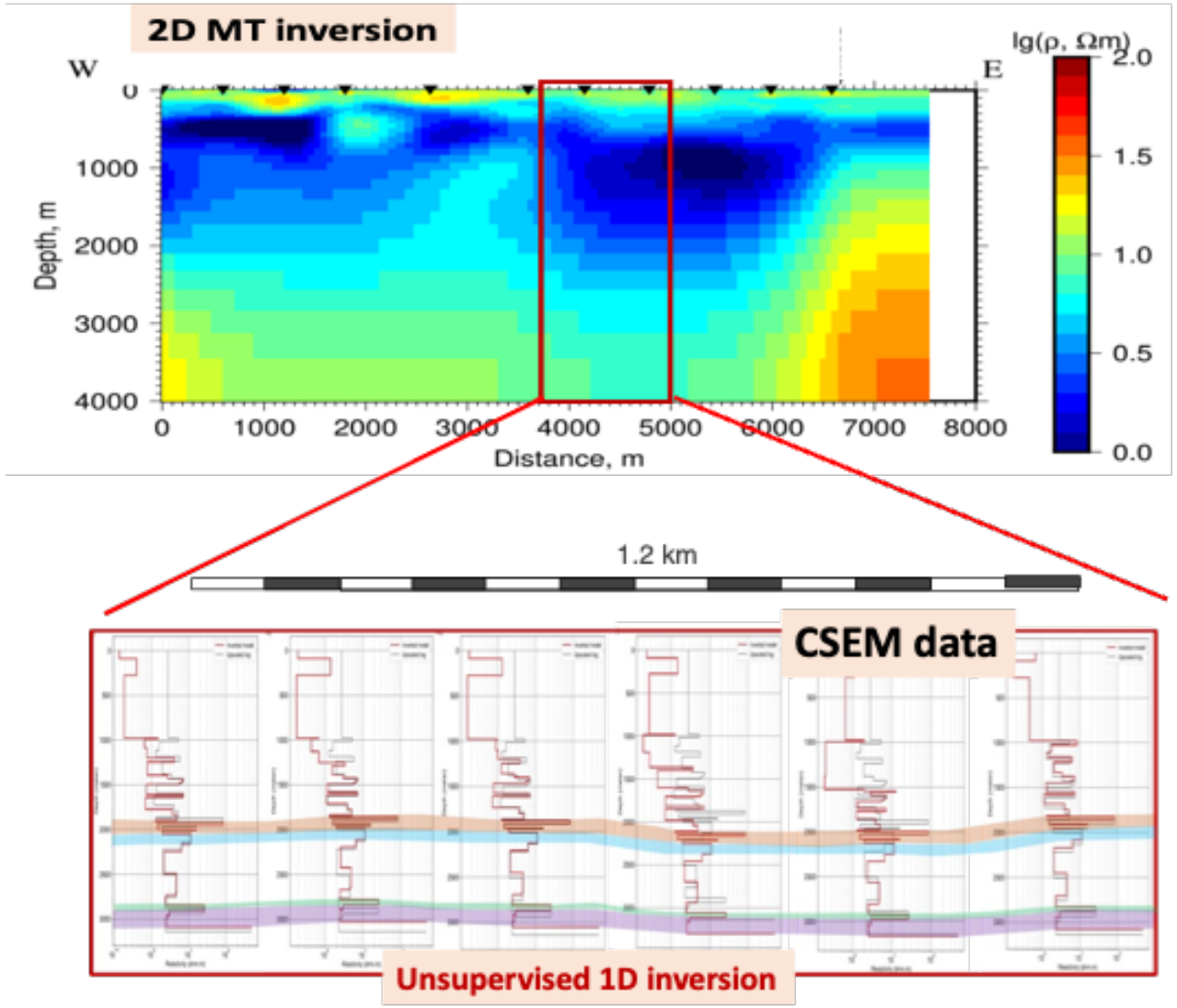

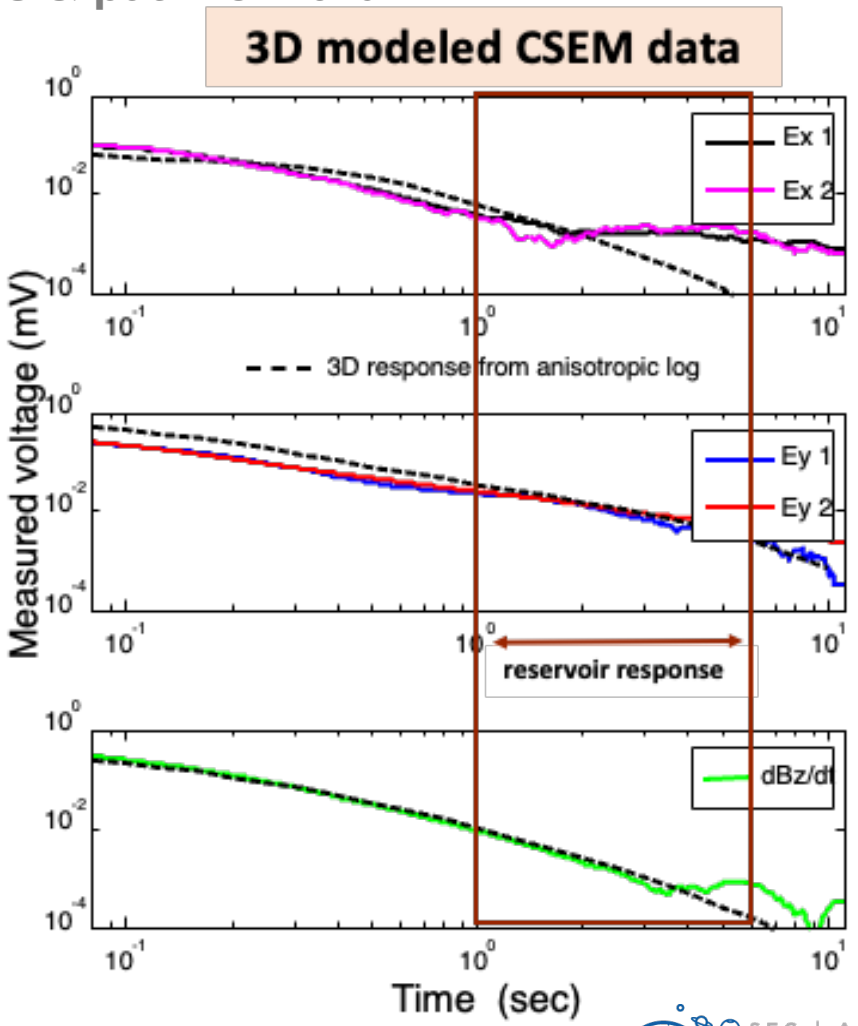

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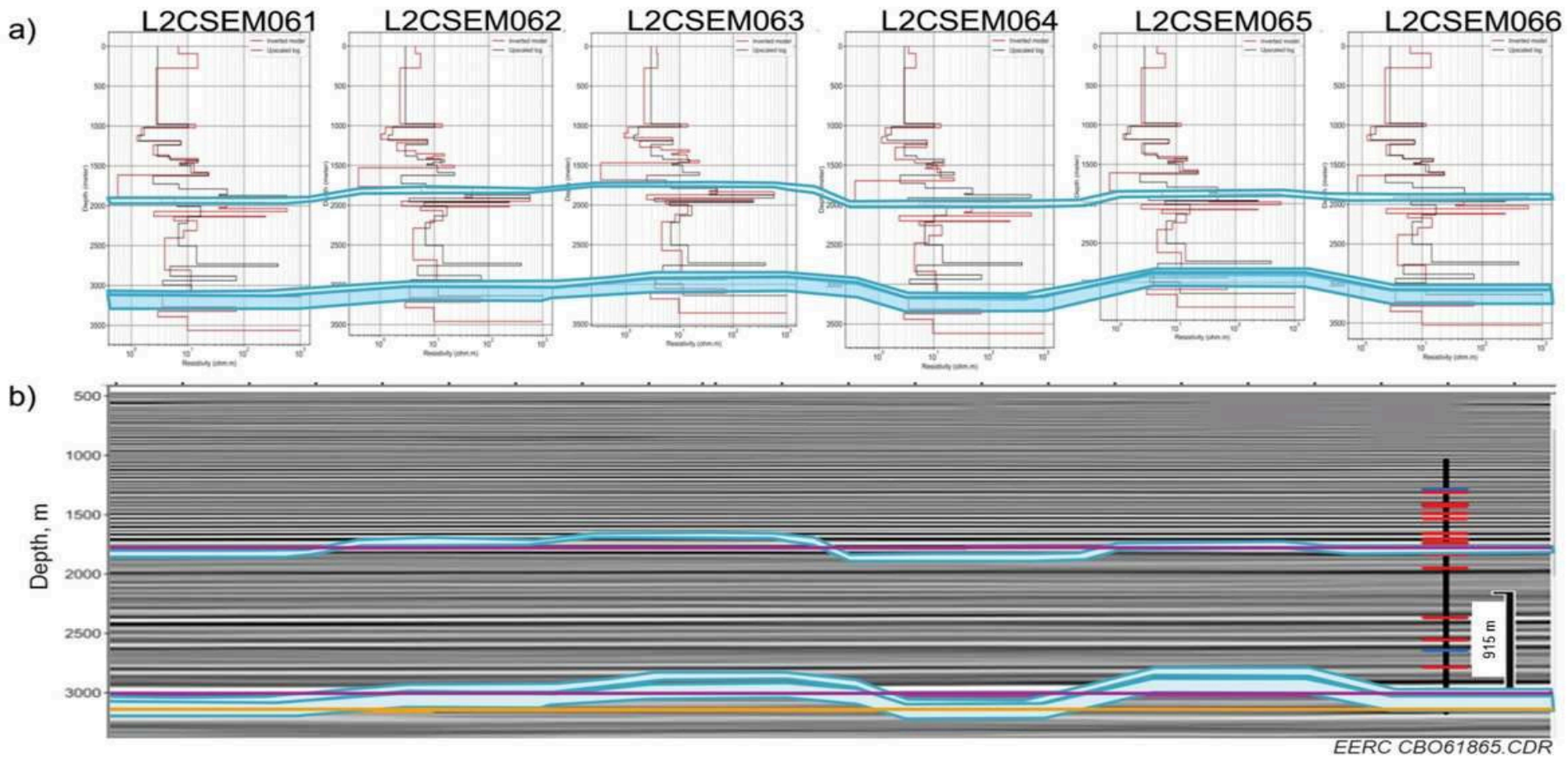
CO_2 pilot: CSEM Line 2 versus seismic



EOR: Equipment and highlight

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RESERVOIR MONITORING

ARRAY Electromagnetics

- 195 channels, wifi, wireless GPS
- 3C magnetic field (DC to 40 kHz)
- 3C microseismic
- 2C electric fields
- Shallow borehole (microseismic/EM)

- Selected oil field & wells
- Carried out 3D feasibility & noise test
- Built system & calibrated
- Field test

Colorado 2015 CSEM transmitter test

- 100 KVA transmitter up-scalable
- Flexible input. (DC to 3 phase AC)
- Array system integrated

EOR: Survey plan

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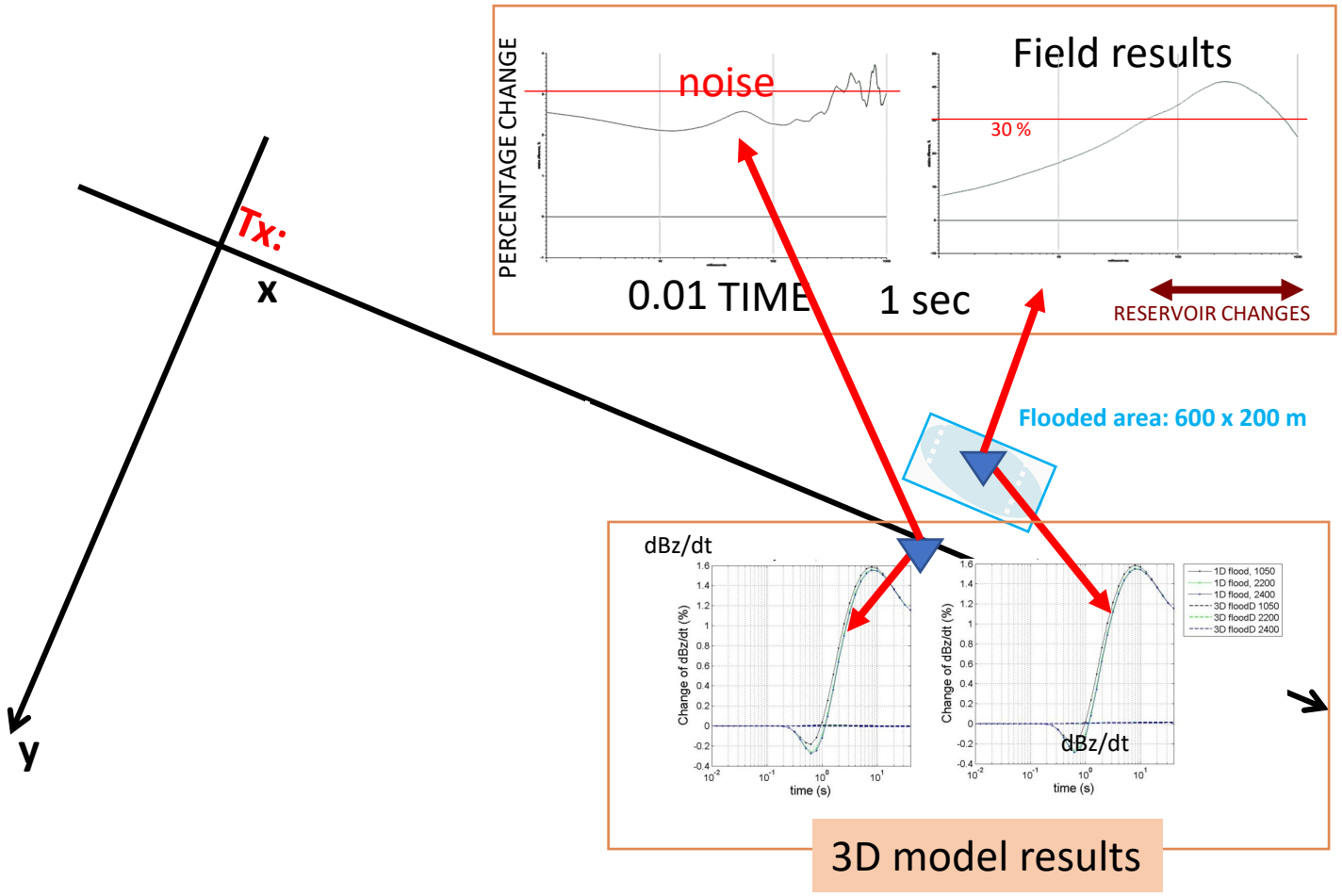
EOR: 3D model results

Background & physics >> Methods **>> Examples** >> issues & path forward



Conclusion: Using EM for FLUID monitoring

- EM is a key methods for fluid monitoring
- CCUS has strong resistivity contrast (months)
- EOR has a sharp resistivity contrast (days)
- HIGH power CSEM since anomaly small
- CSEM: Technology is here – commercial
- Future Cloud based and AI enabled for real time monitoring
- Challenge: small anomaly → high repeatability requirements
  → **ADD BOREHOLE**

- **Data can very certified to borehole scale via 3D anisotropic models**

Thank You!

Other talks on the subject

Monday 9:10 am Carbon Theater Pavilion Booth 2122

Geophysical Tools for MMV During CO_2 Sequestration

Peter M. Duncan, MicroSeismic, Inc.

Tuesday 10:20 am Carbon Theater Pavilion Booth 2122

Geophysical Tools for MMV During CO_2 Sequestration

Peter M. Duncan, MicroSeismic, Inc.

Thursday W-15 11:00 am. The Role of Geophysics in Sustainable Energy and Carbon Neutrality — Geothermal, Wind, Hydrogen, and CCUS

Controlled Source EM use towards the energy transition

Kurt Strack, KMS Technologies et al.

Thursday W-9 4:20 pm Measure, Monitor, Validate (MMV) in the Geophysical Realm of New Energy

Quality analysis of baseline time-lapse CSEM data in the CarbonSAFE project, North Dakota

C. Barajas-Olalde, University of North Dakota, EERC et al.

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Thanks to EERC & KMS Technologies staff