Using high power CSEM during the Energy Transition

K. Strack. Feb. 2nd 2022

KMS Technologies

Our target objectives

- Most reservoirs in energy industry are:
  - Between 1000 – 5000 m depth
  - Results must be reconciled with logs
- MT – measurements are biased towards conductors (horizontal current flow)
- CSEM - electric field biased toward resistors
- CSEM - magnetic field biased toward conductors
- → You want it ALL!

For > 1 km with CSEM depth you need > 100 KVA (resistivity dependent)

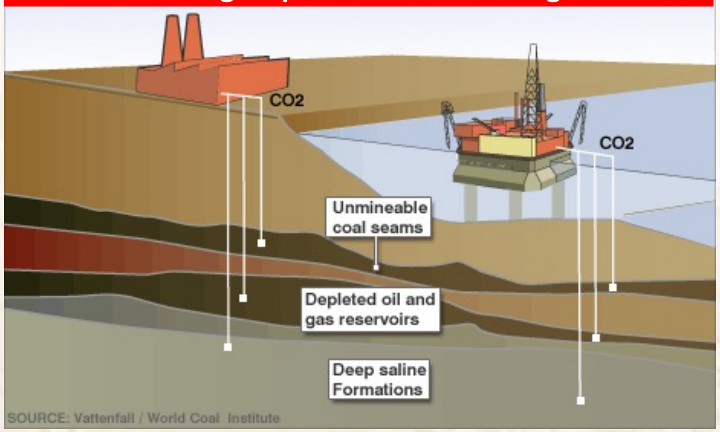
How can Electromagnetics support the energy transition?

- **Carbon storage**
  - Monitoring CO_2 injection
- **Renewables**
  - GREEN energy – geothermal (exploration, monitoring)
- **Towards ZERO footprint**
  - EOR → higher recovery factor → lower carbon footprint/barrel

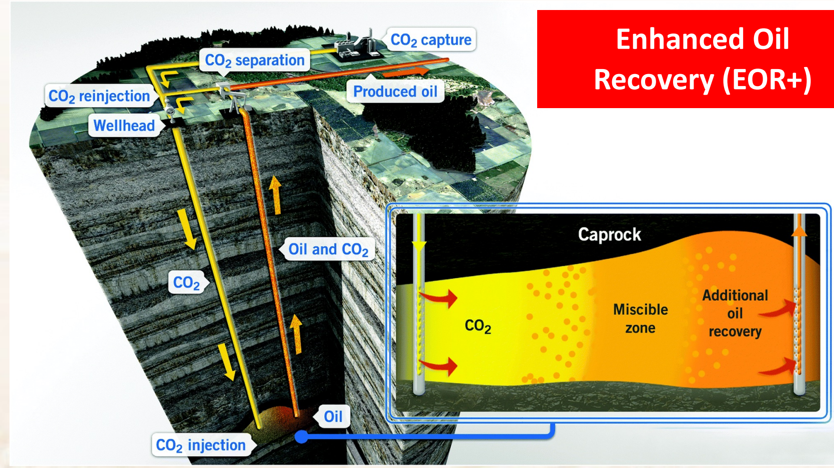
How can Electromagnetics support the energy transition?

Carbon Capture Utilization, Storage (CCUS)

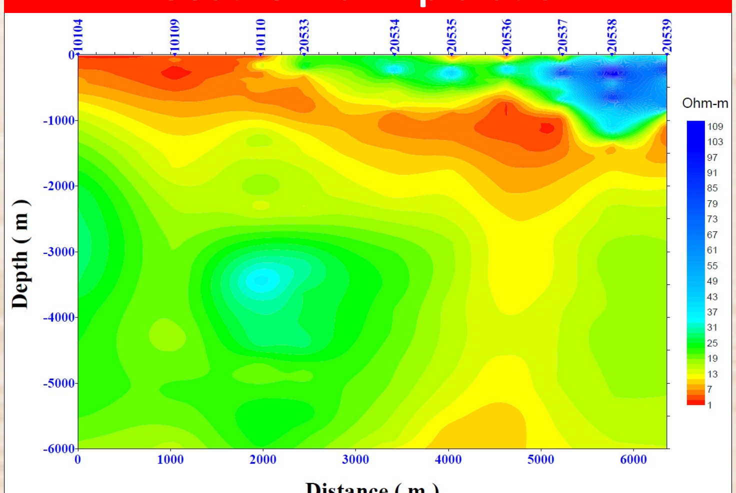
Geologic options for CO2 storage



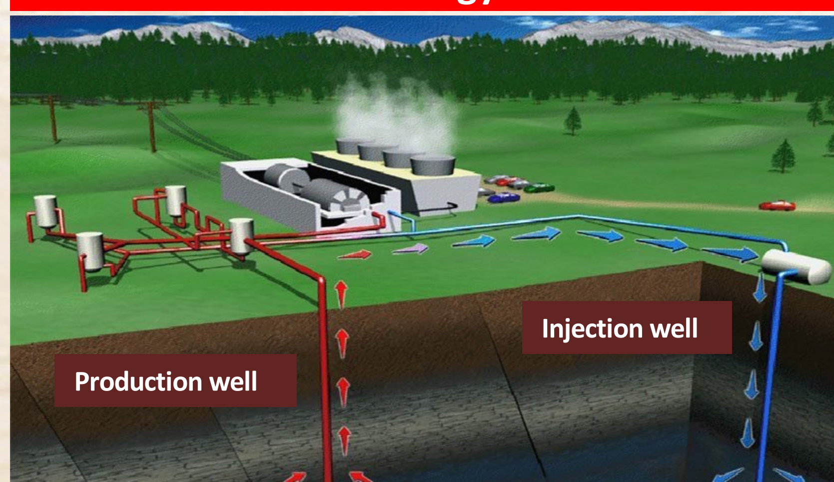
Enhanced Oil Recovery (EOR+)



Geothermal Exploration



Geothermal Energy Production



How can Electromagnetics support the energy transition?

- **Carbon storage**
  - Monitoring CO_2 injection
- **Renewables**
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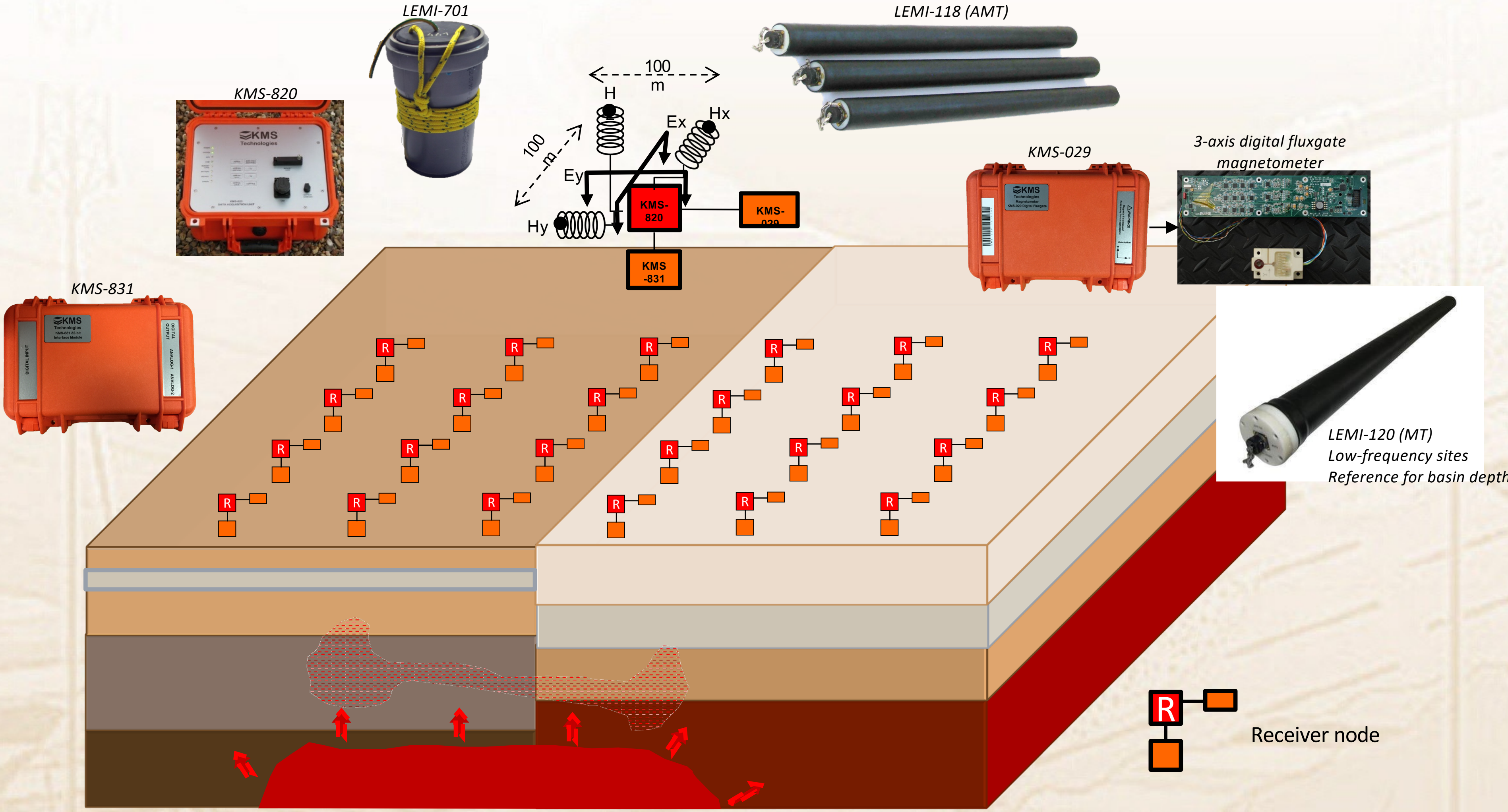
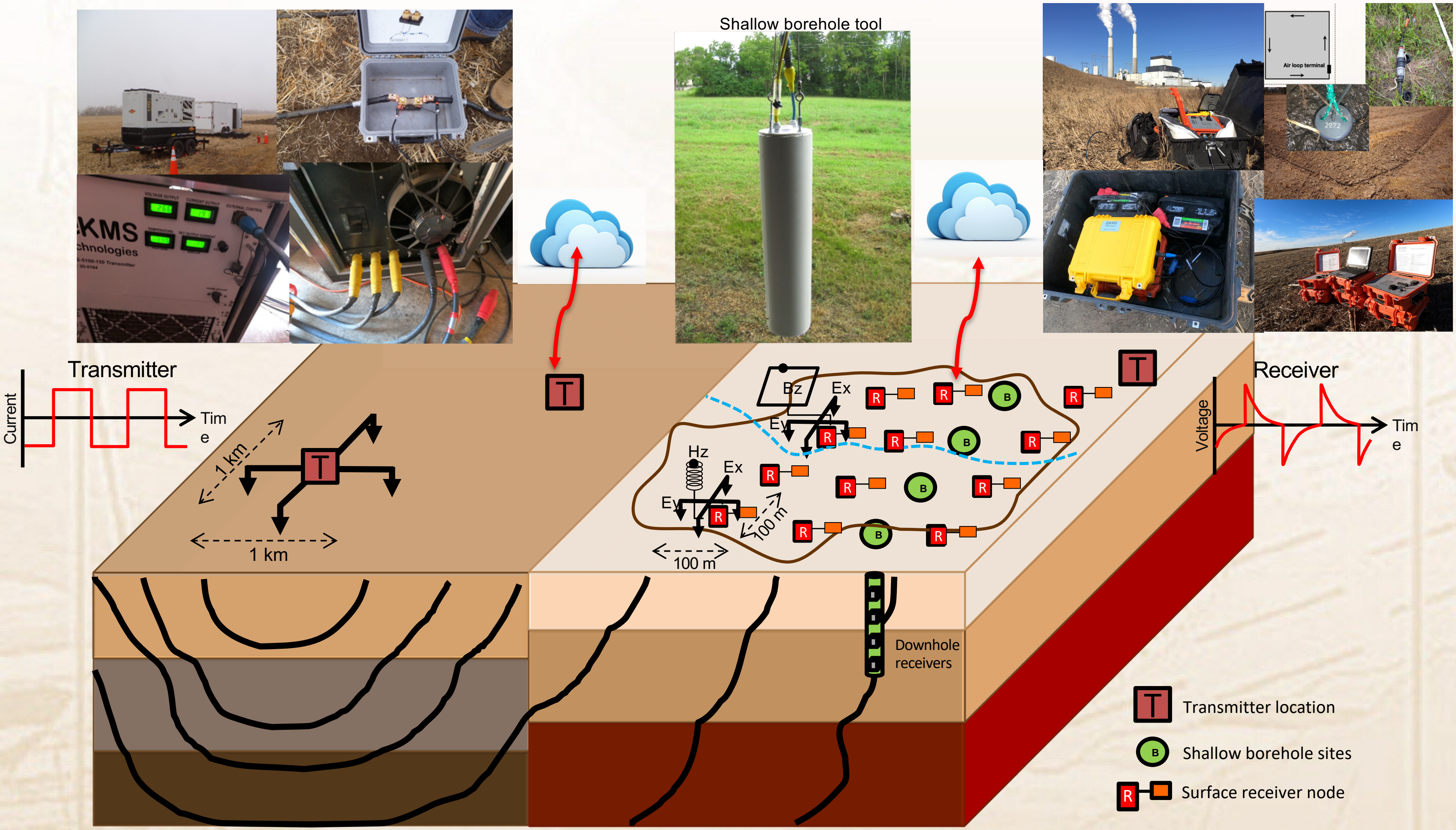
Setting the scene >> Technology >> Examples
Basic building blocks



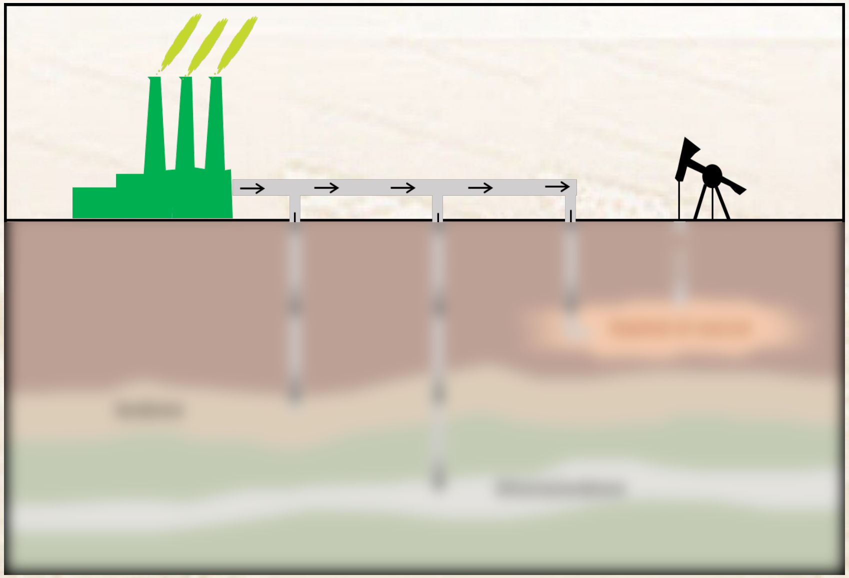
Controlled source EM improves accuracy



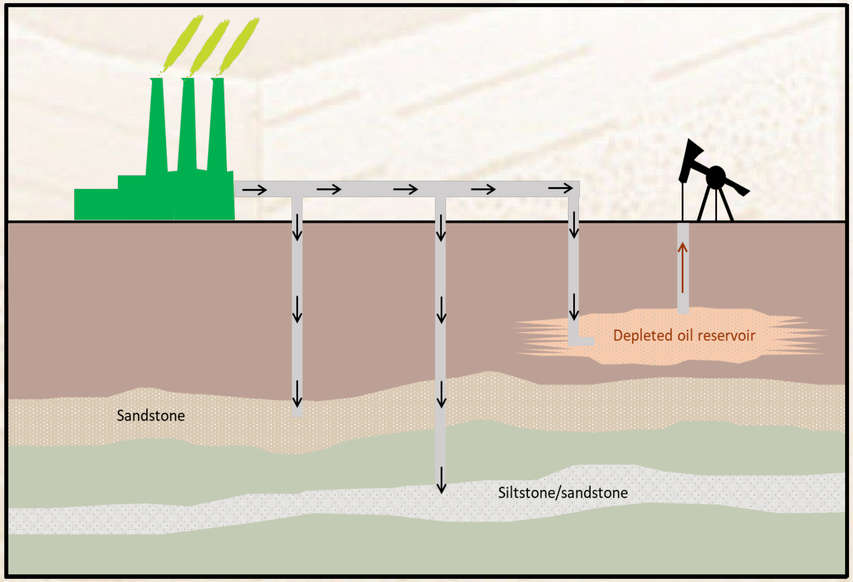
Modified after Hoerdt

Controlled source EM gives sharper pictures

MT



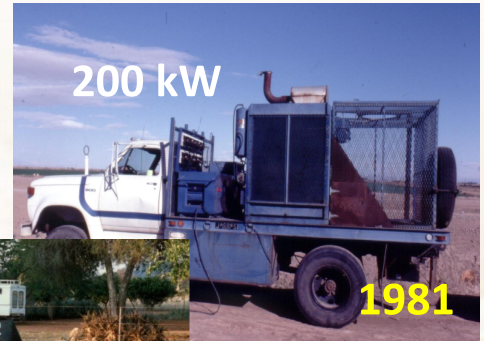
CSEM

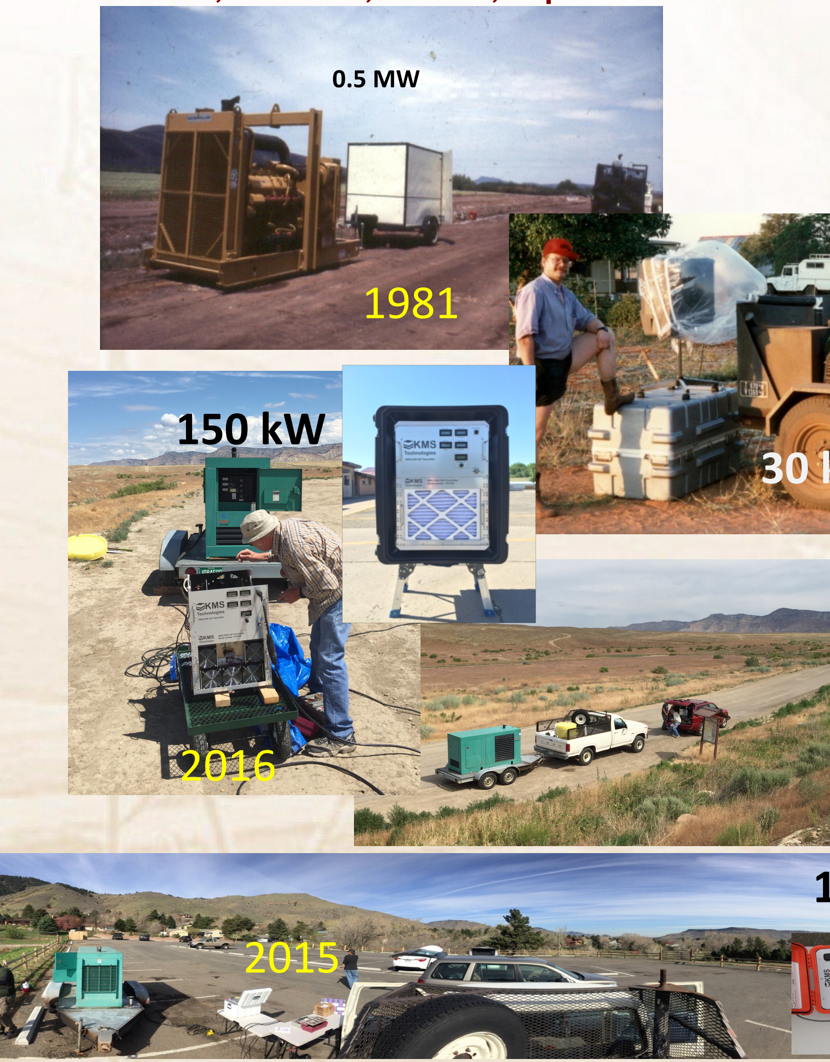


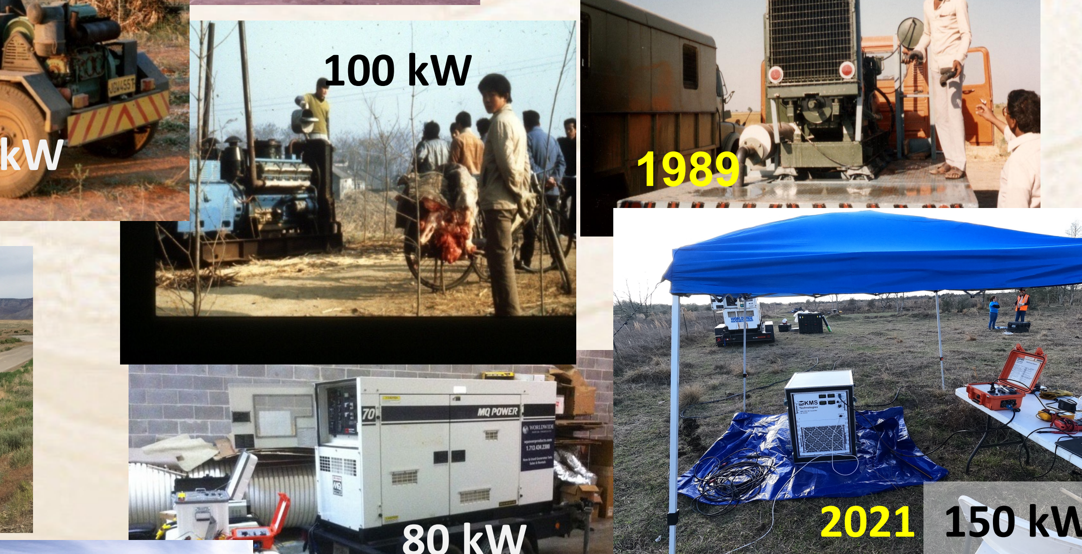
Large surface source

Transmitters since 1981… as KMS since 2015

Azerbajian, USA, Germany, Turkey, South Africa, China, India, Australia, Indonesia, Ireland, Israel, Italy, Saudi Arabia, Thailand, Mexico, Japan

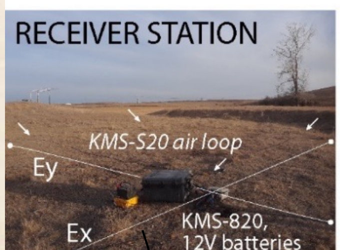


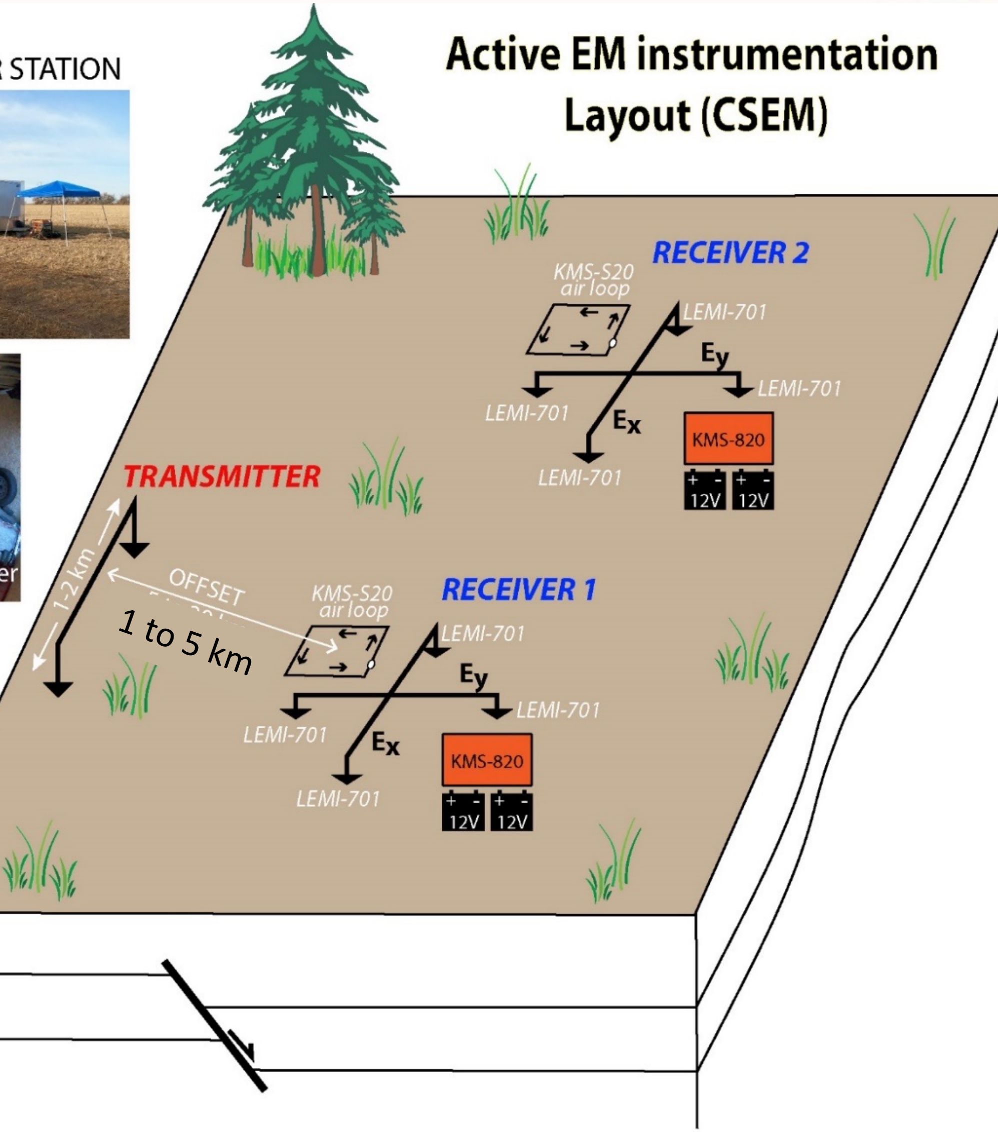




CSEM instrumentation

TRANSMITTER STATION

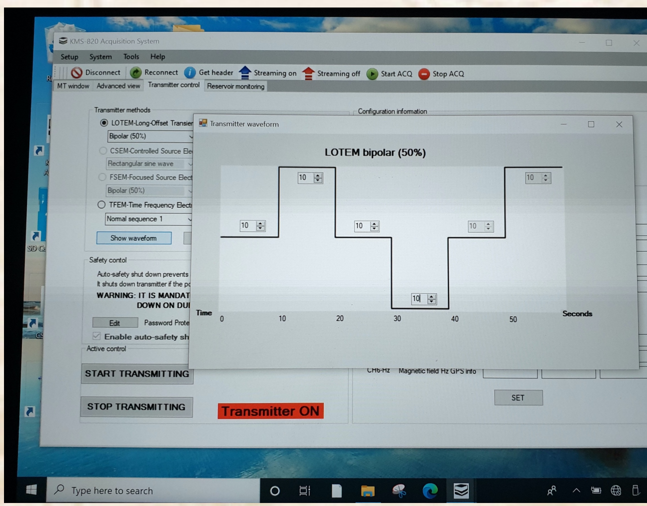




MT and CSEM system- Saudi Arabia

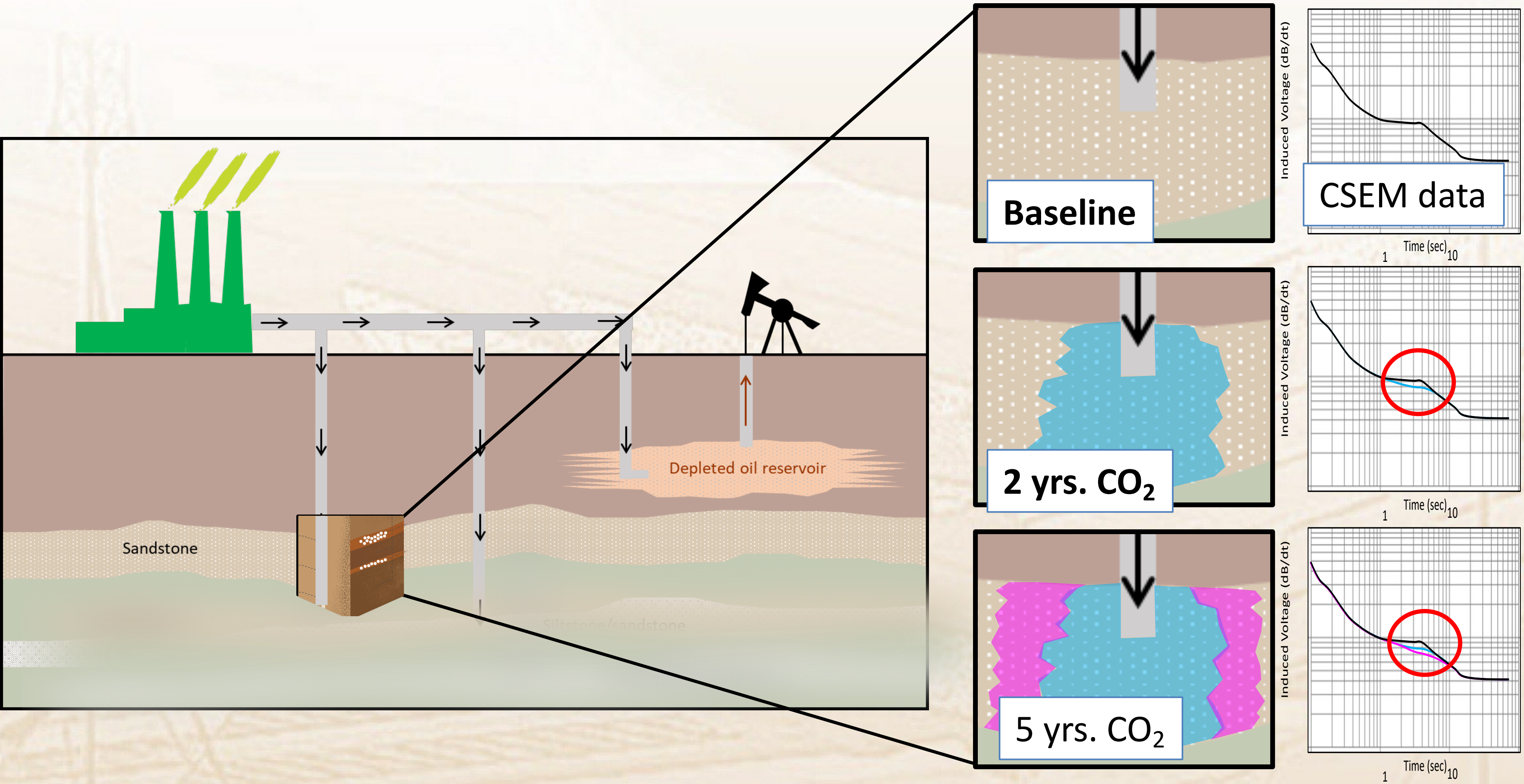
Setting the scene >> **Technology** >> Examples

CSEM instrumentation in Saudi



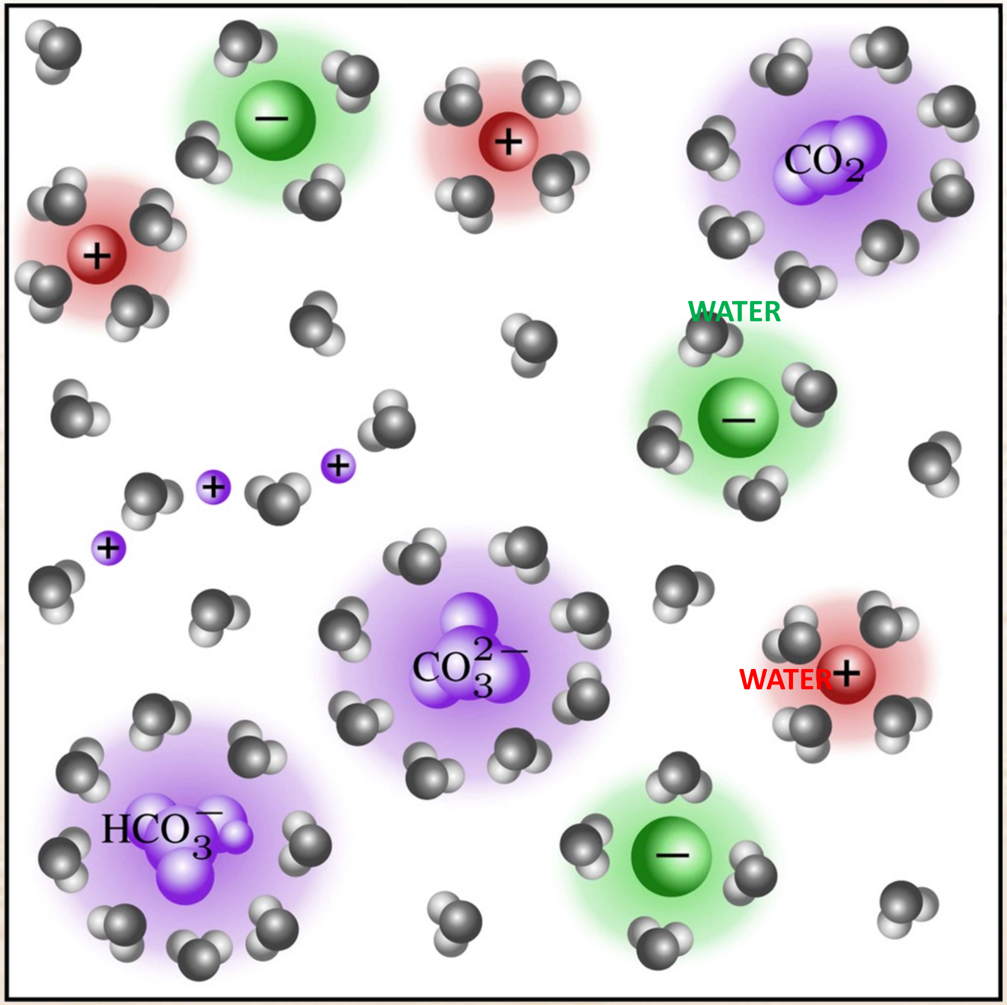
Current video

Carbon capture applications



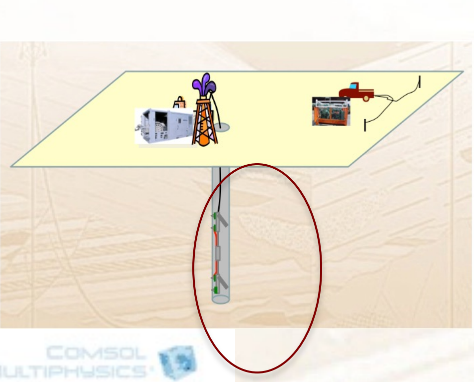
CCUS: CO2 influence on resistivity

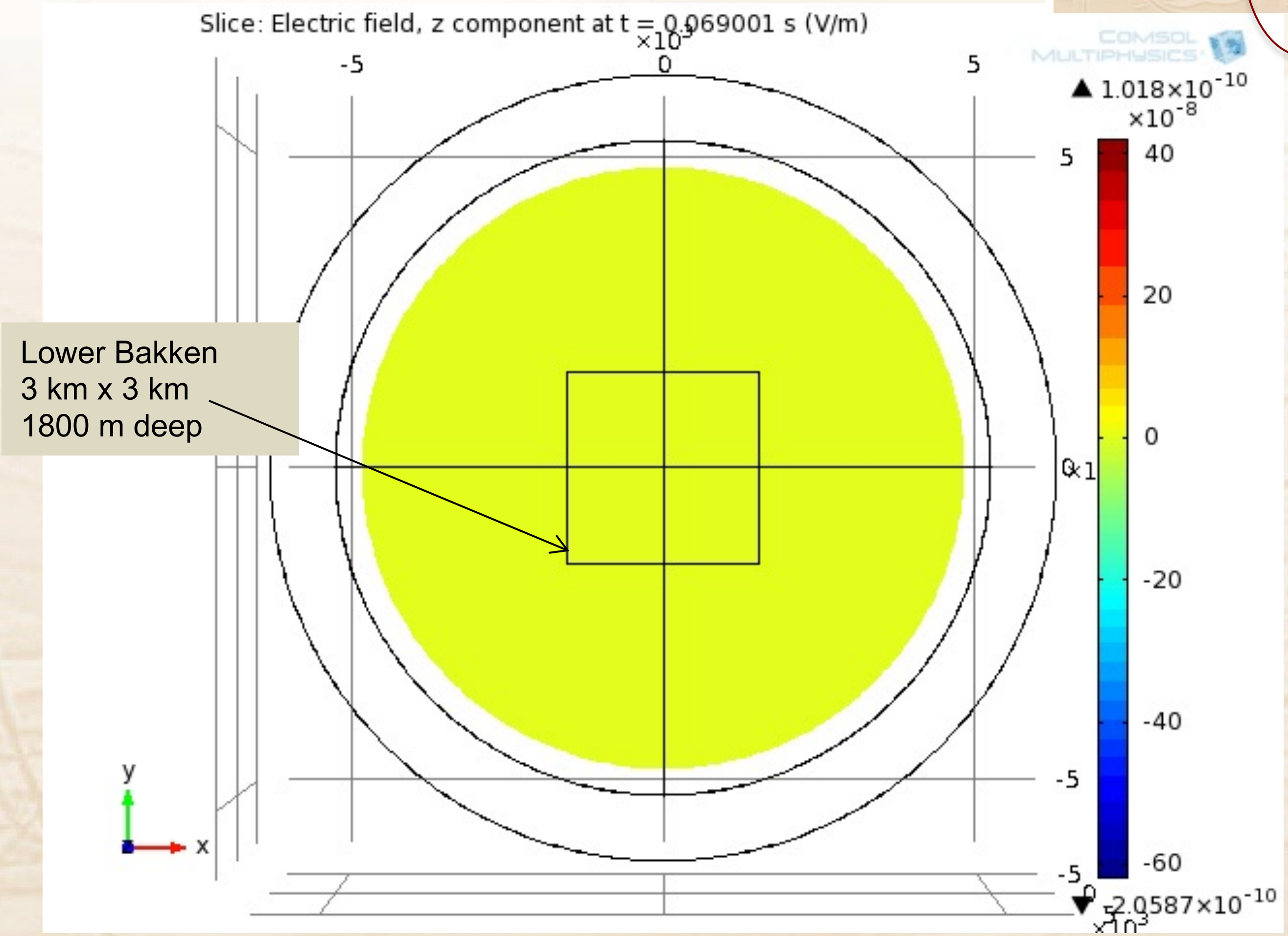
- @ normal brine salinity → fluids are more resistive (6 -50 times)
- @ low salinity (≤ 5,000 ppm) → more conductive

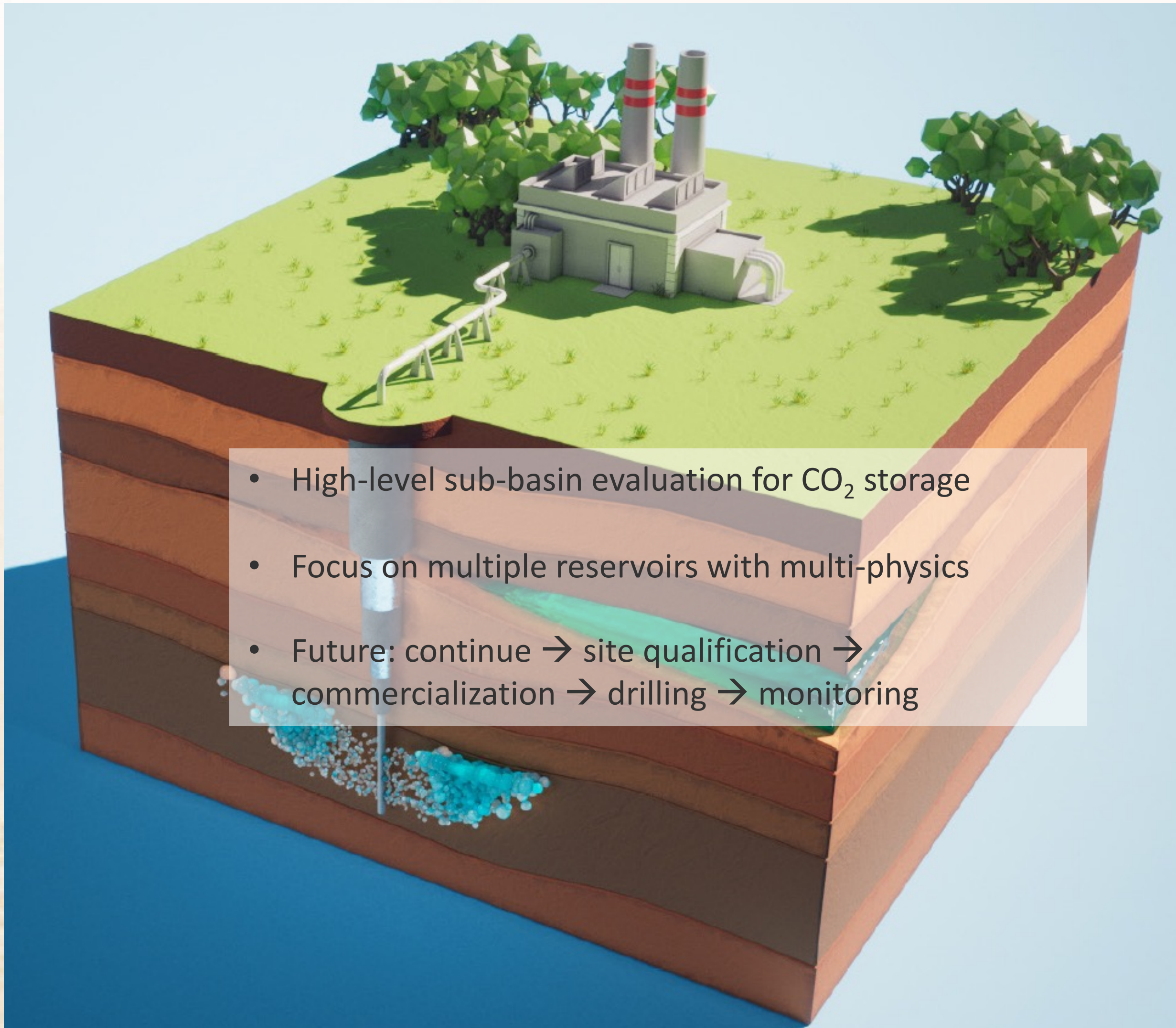


After Boerner et al., 2015

CCUS: What happens when we inject a current?

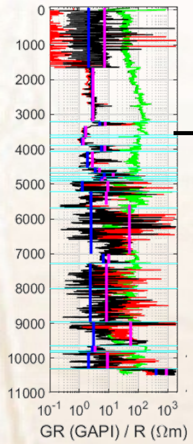






- High-level sub-basin evaluation for CO_2 storage
- Focus on multiple reservoirs with multi-physics
- Future: continue → site qualification → commercialization → drilling → monitoring

CSEM feasibility workflow



Input data
well-logs, geology, seismic horizons; additional surveillance

Rock physics
Determine reservoir parameter variations

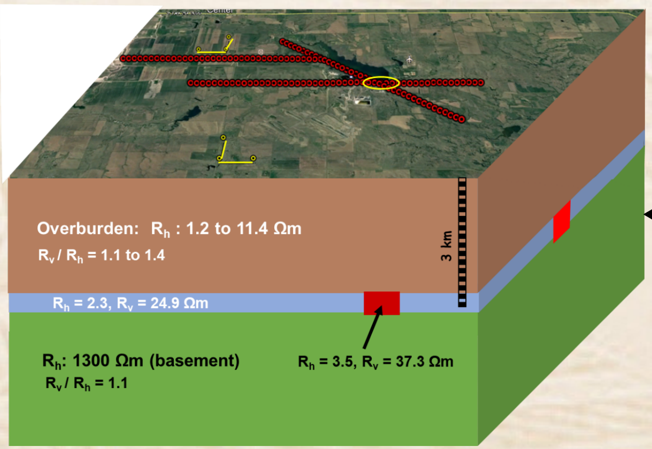
Feasibility
Link data with variations

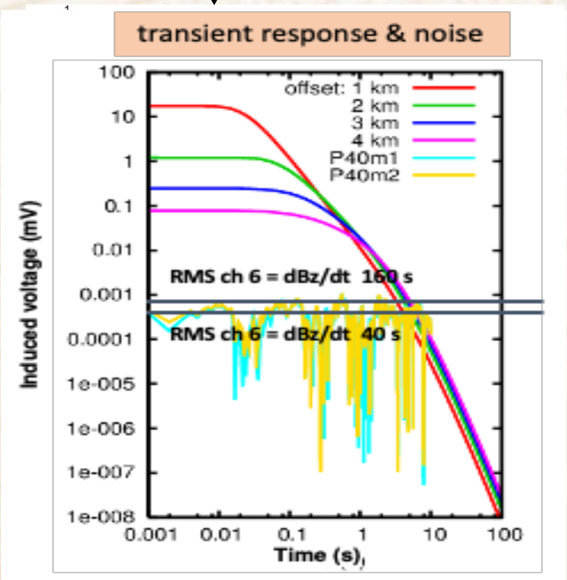
Field noise measurements

Define pilot
→ 2-3 monitoring cycles
→ BASELINE

Evaluate / decide

Baseline survey

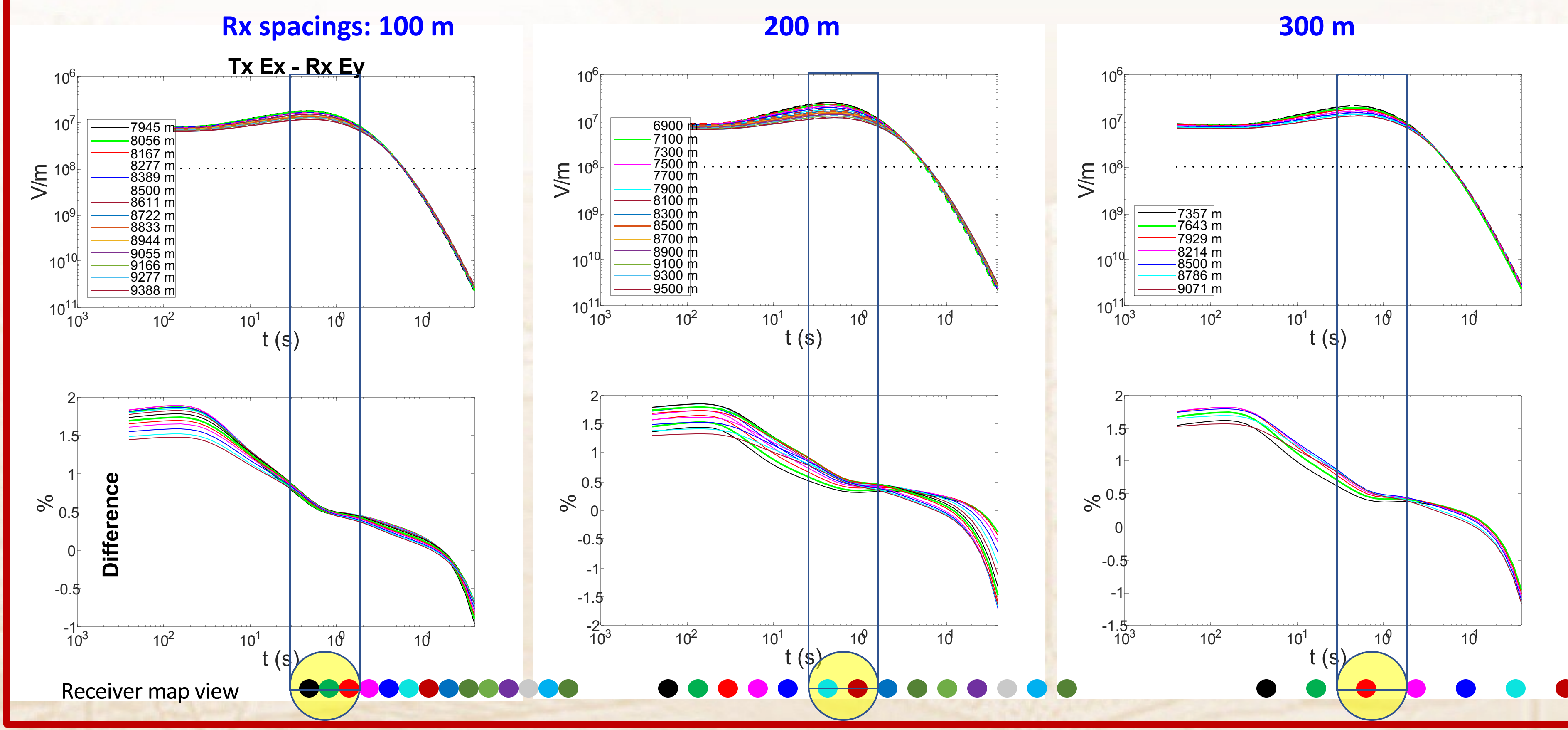




CSEM CO2 feasibility: Defining station spacing Ey-Ey

Brook Creek 3D Modeling Results (Tx Ey – Rx Ey)

150 m CO_2 injection radius

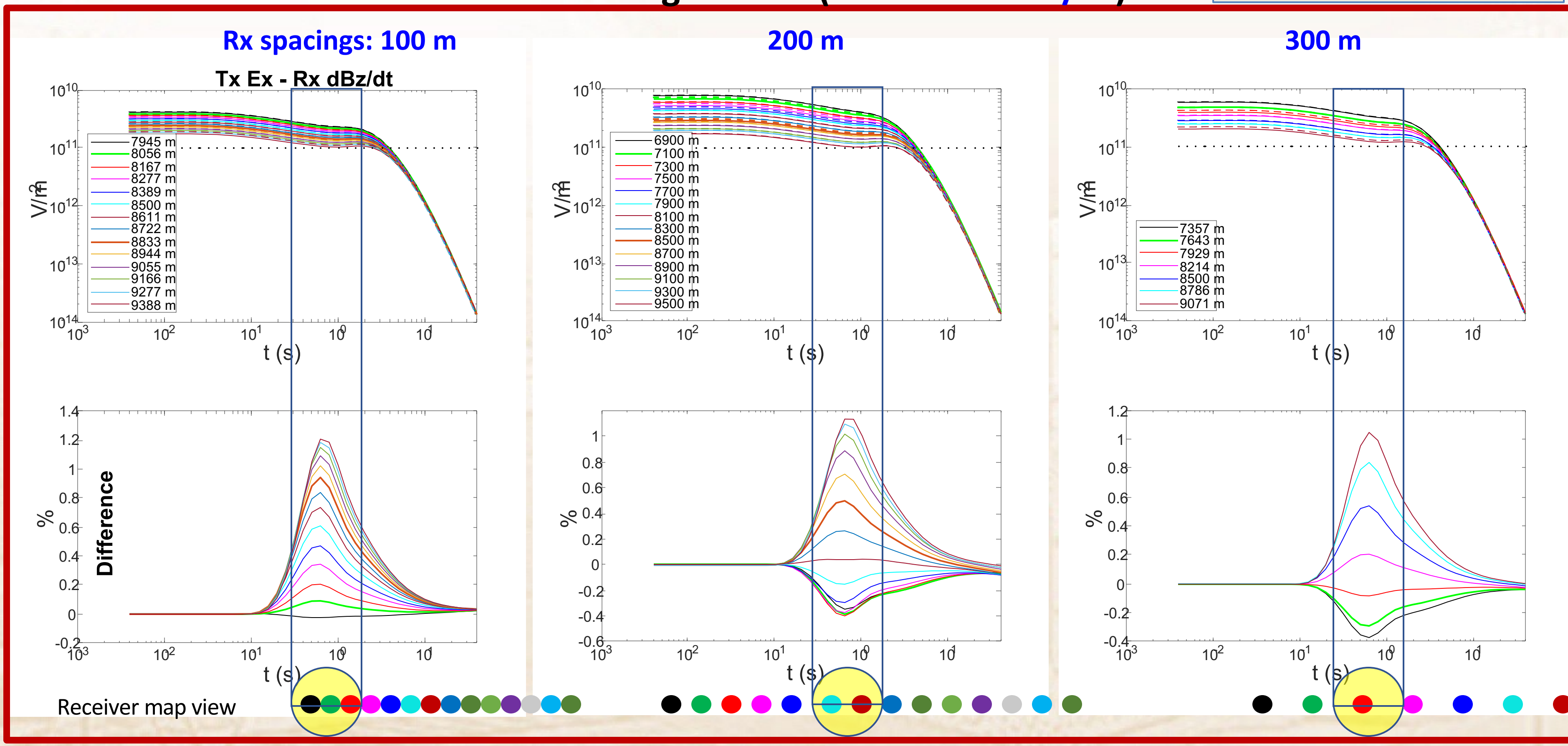


After Barajas-Olalde et al., 2021

CSEM CO2 feasibility: Defining station spacing dBz/dt

Brook Creek 3D Modeling Results (Tx Ex – Rx dBz/dt)

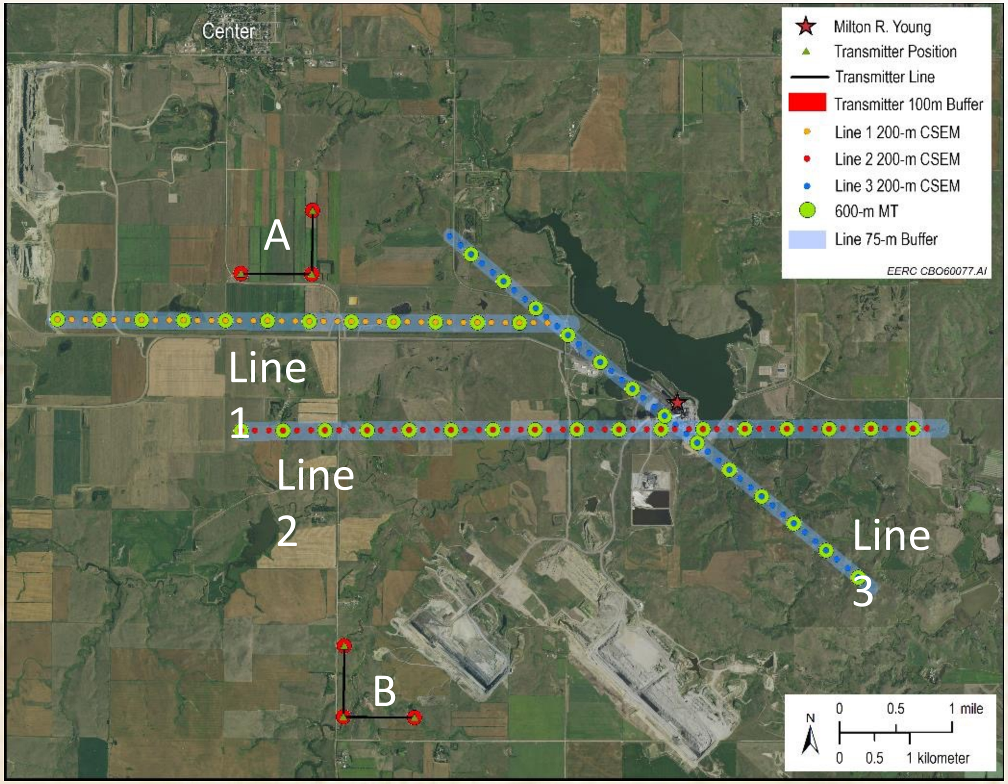
150 m CO_2 injection radius



After Barajas-Olalde et al., 2021

CSEM: acquisition layout

- **MT**
  - To measure the model's baseline background resistivity
  - 42 Stations, 600 m spacing
  - Remote station near Grand Forks, North Dakota
- **CSEM**
  - 124 Stations, 200 m spacing
  - Two transmitter sites (A & B), 400 A
  - Time domain
  - Varies waveform → > 700 sites
- 24 hours operation – 6 weeks
- No equipment breakdowns
- Real-time data upload for QA
- Production: Pickups: 24, deployment:16, fully recorded sites:17 / day

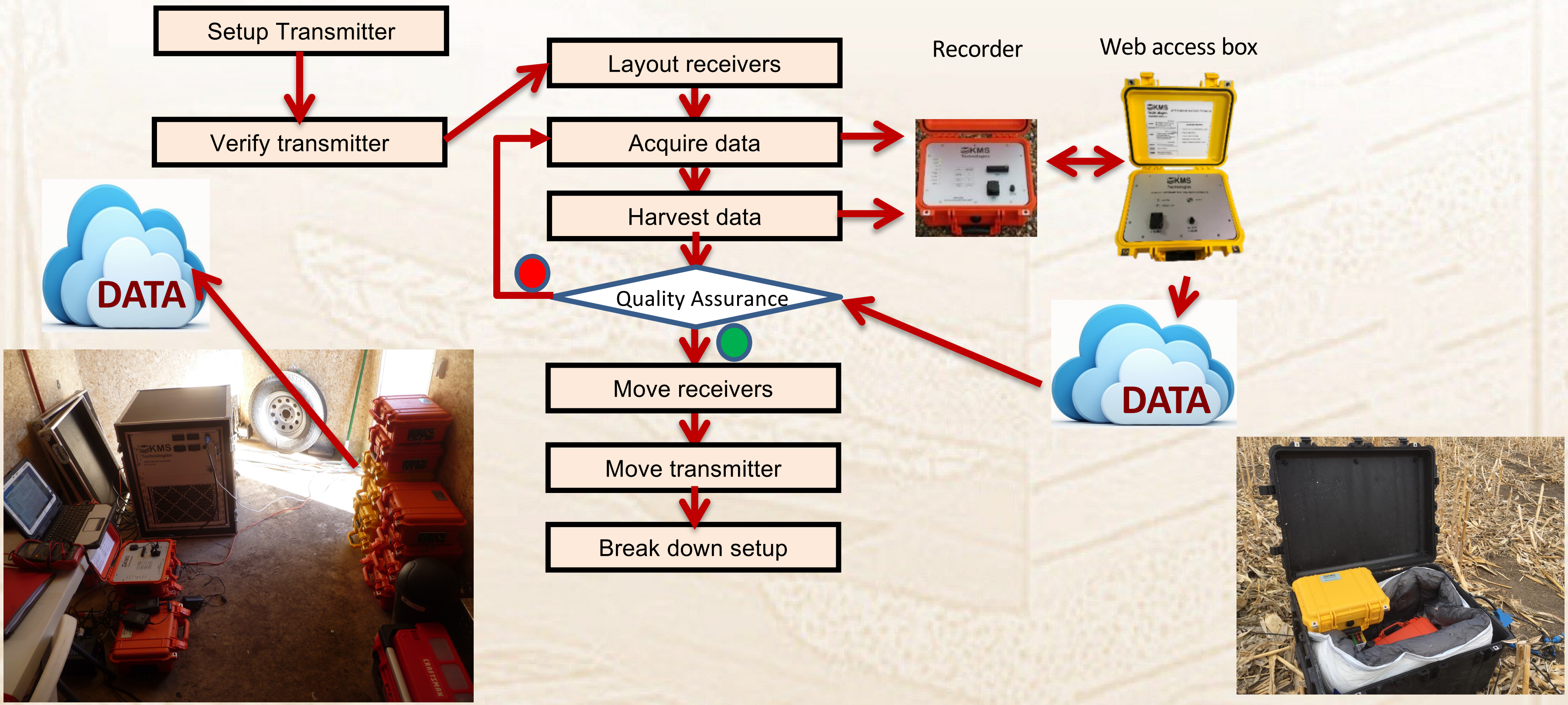


After Barajas-Olalde et al., 2021

North Dakota CO2 project: Acquisition options

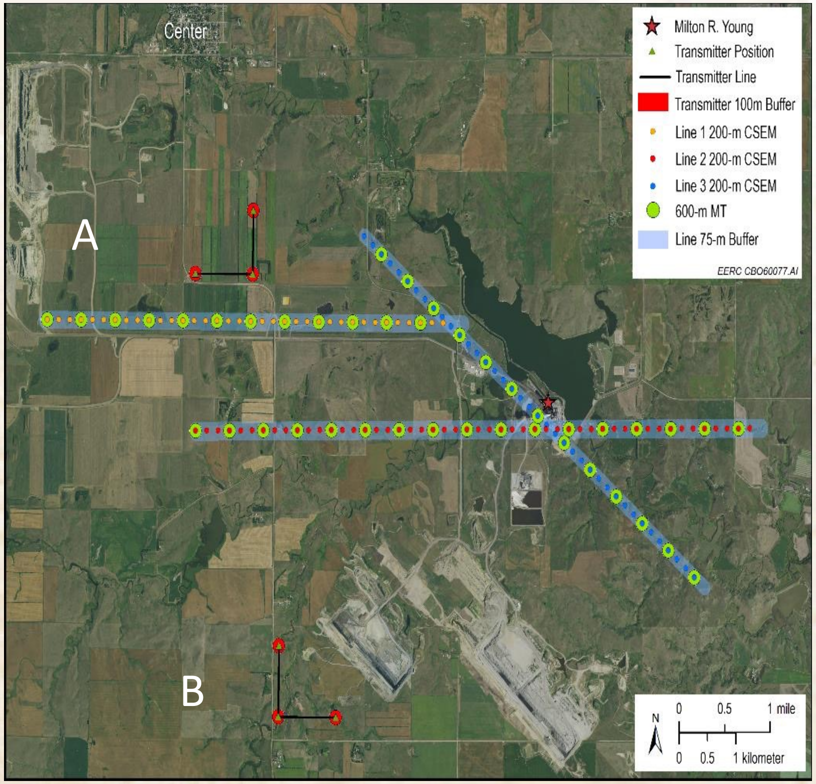
- 24 hours operation for CSEM (versus Standard: Night – MT &. Day CSEM)
  - More routine less operational problems
  - Generator stays warm
  - Electrode pit remain stable
  - High production rate
  - Q/A via Cloud enabled receivers
- **CON 24/7:** Processing more complex as data must be demerged by transmission cycle and then remerged with transmitter current

CO2 survey: acquisition workflow

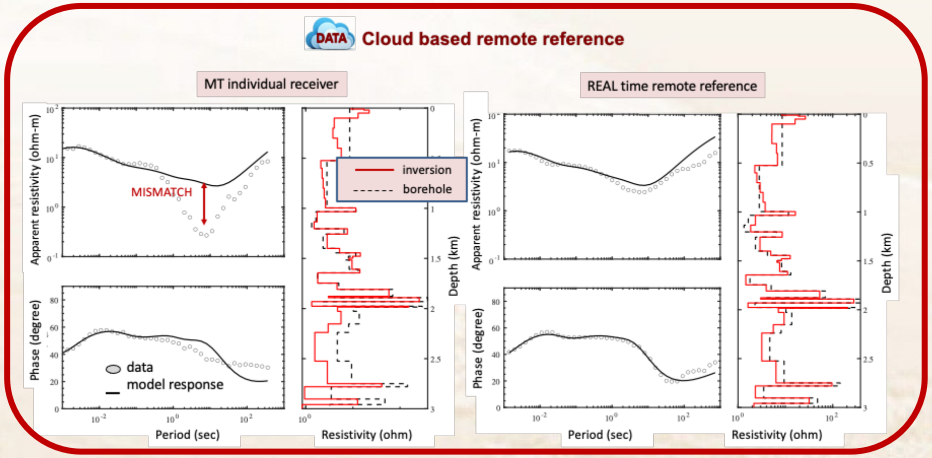


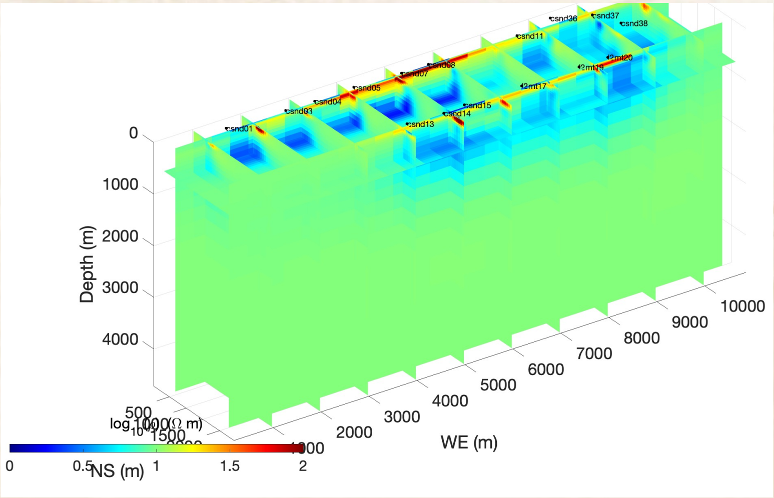
CSEM: How do we quality control the data?

- How do we QC data?
  - Large data sets (350)
  - Measurement error < 0.5%
  - Processing error larger
  - Inversion model smooth
- Avoid extra processing
- Calibrate against borehole
- 3D model match data



CO2 acquisition: MT results. Quality Assurance RR & 3D model





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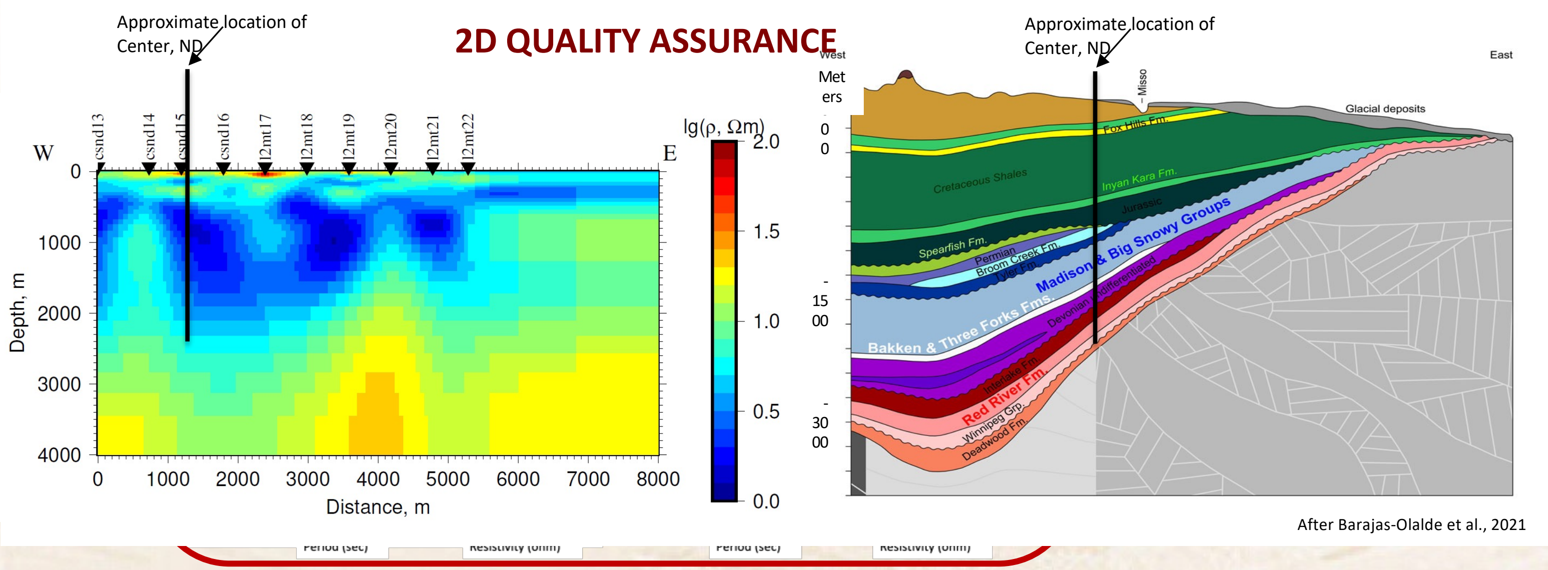
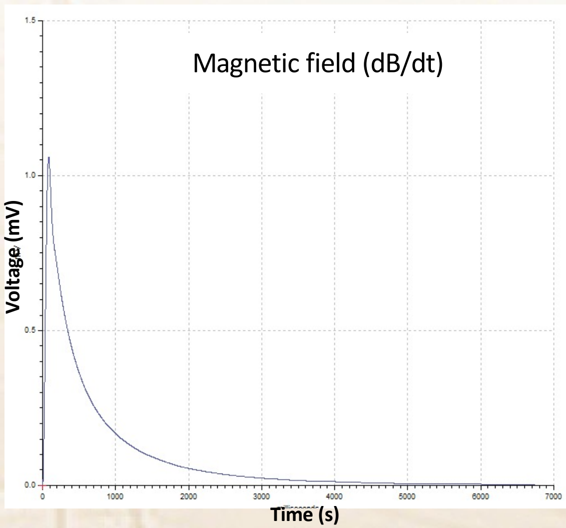
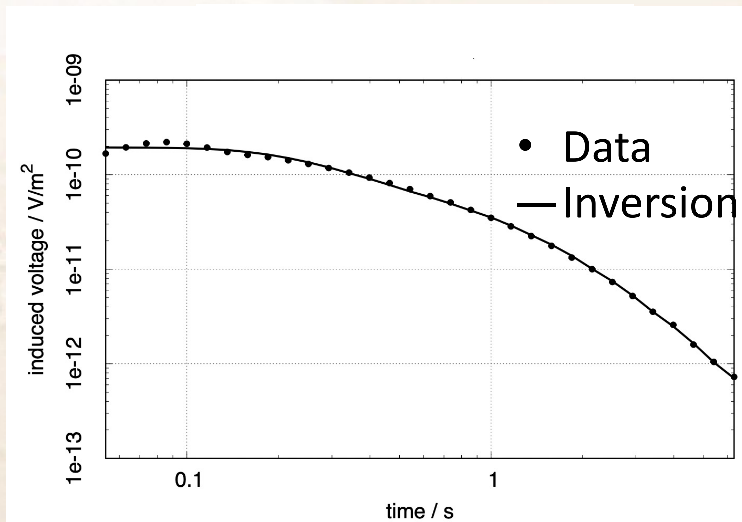
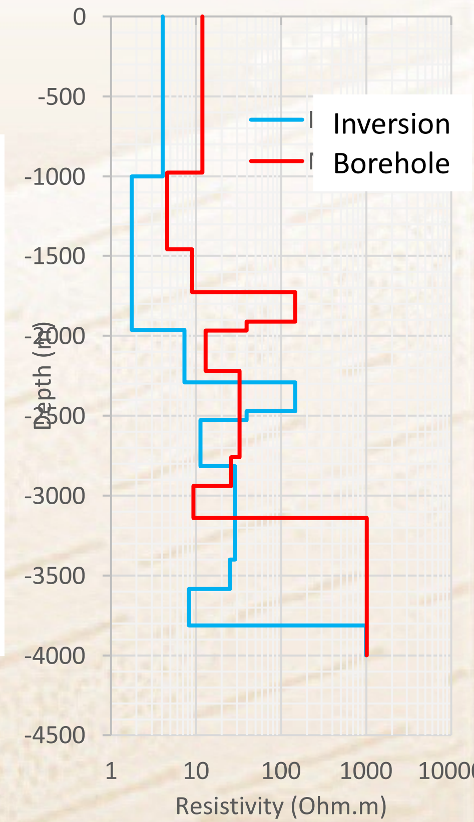


CSEM monitoring: CSEM Quality Assurance – Hz matched against log

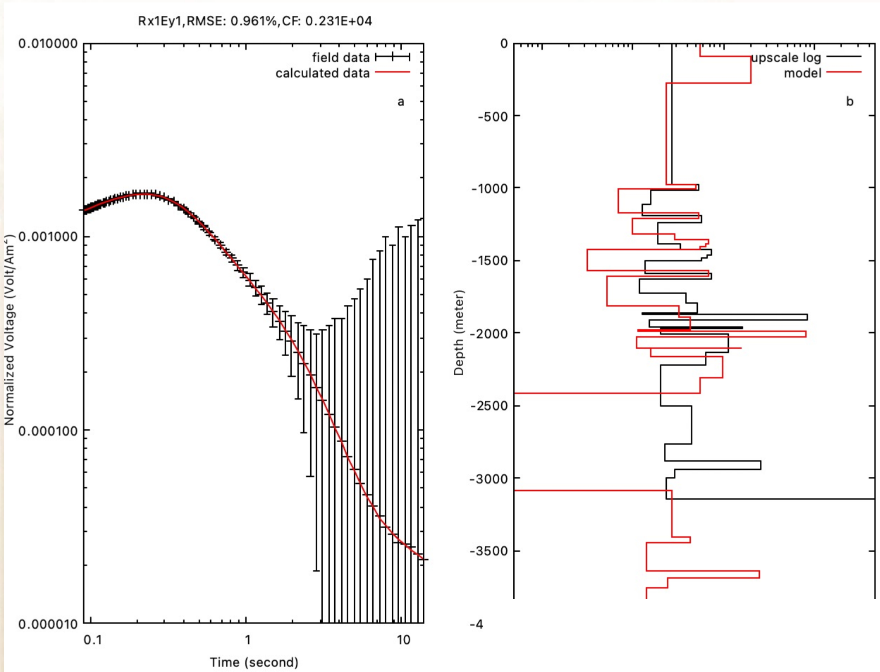
Stacked data

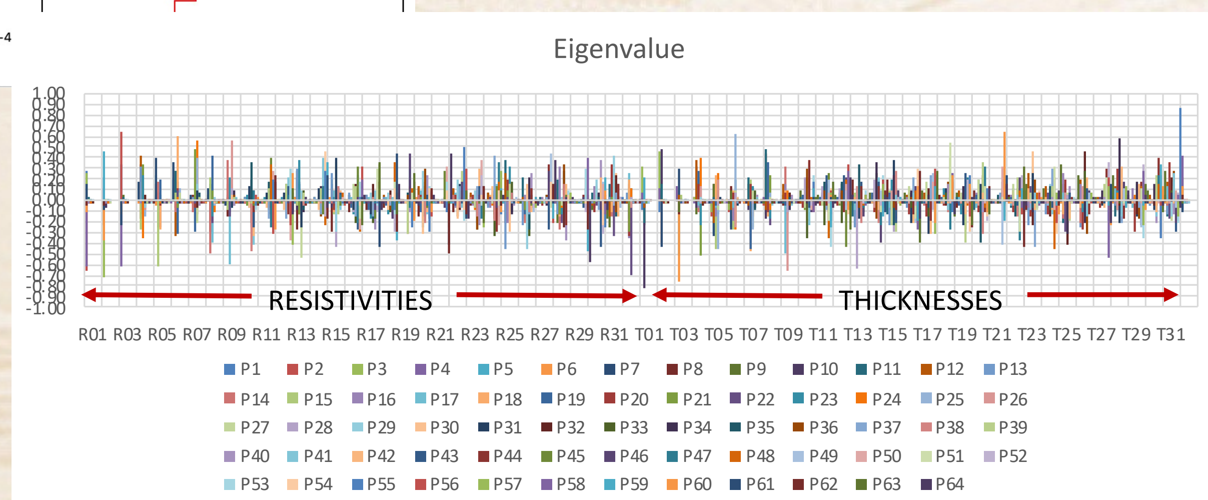






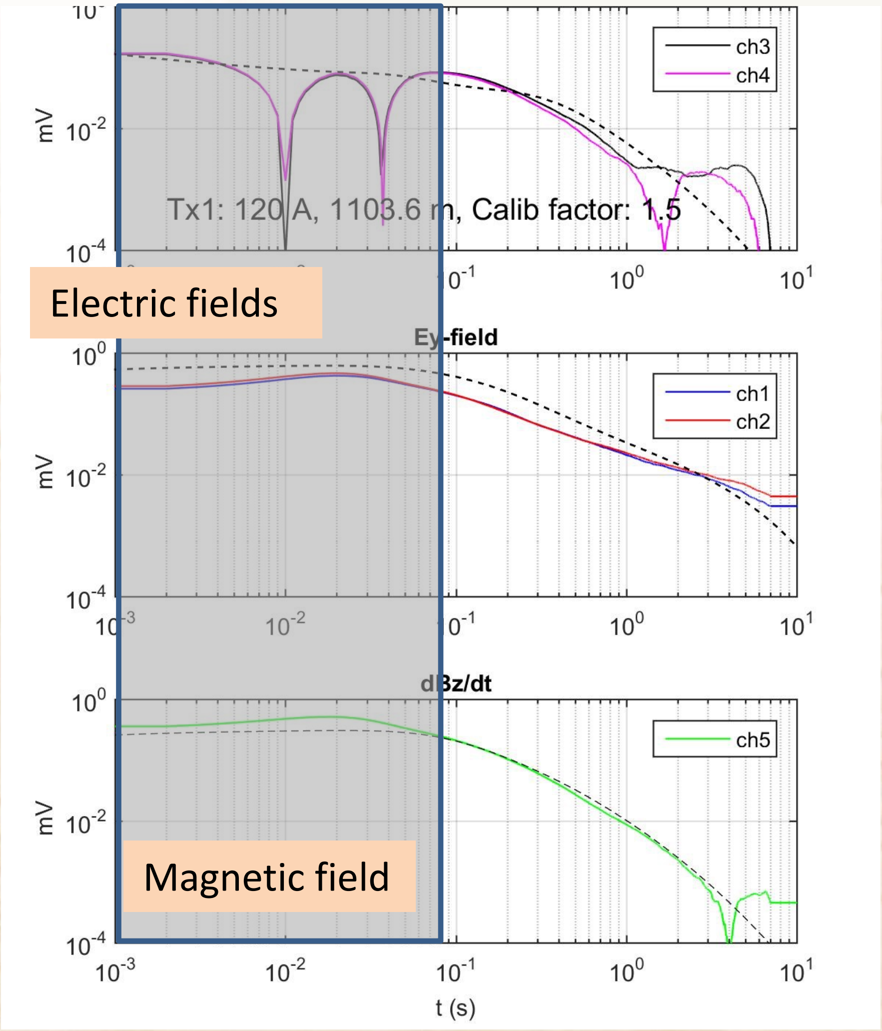
CSEM monitoring: CSEM QA - electric field matches log





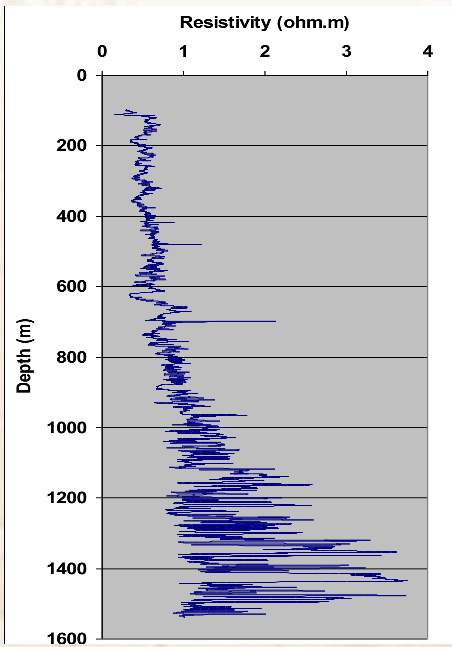
CSEM monitoring: 3D anisotropic model to QC data

- Model response match data in all components
- (in)consistencies points to flaws in workflows
- **RESULT**: reduced processing, more data driven processes

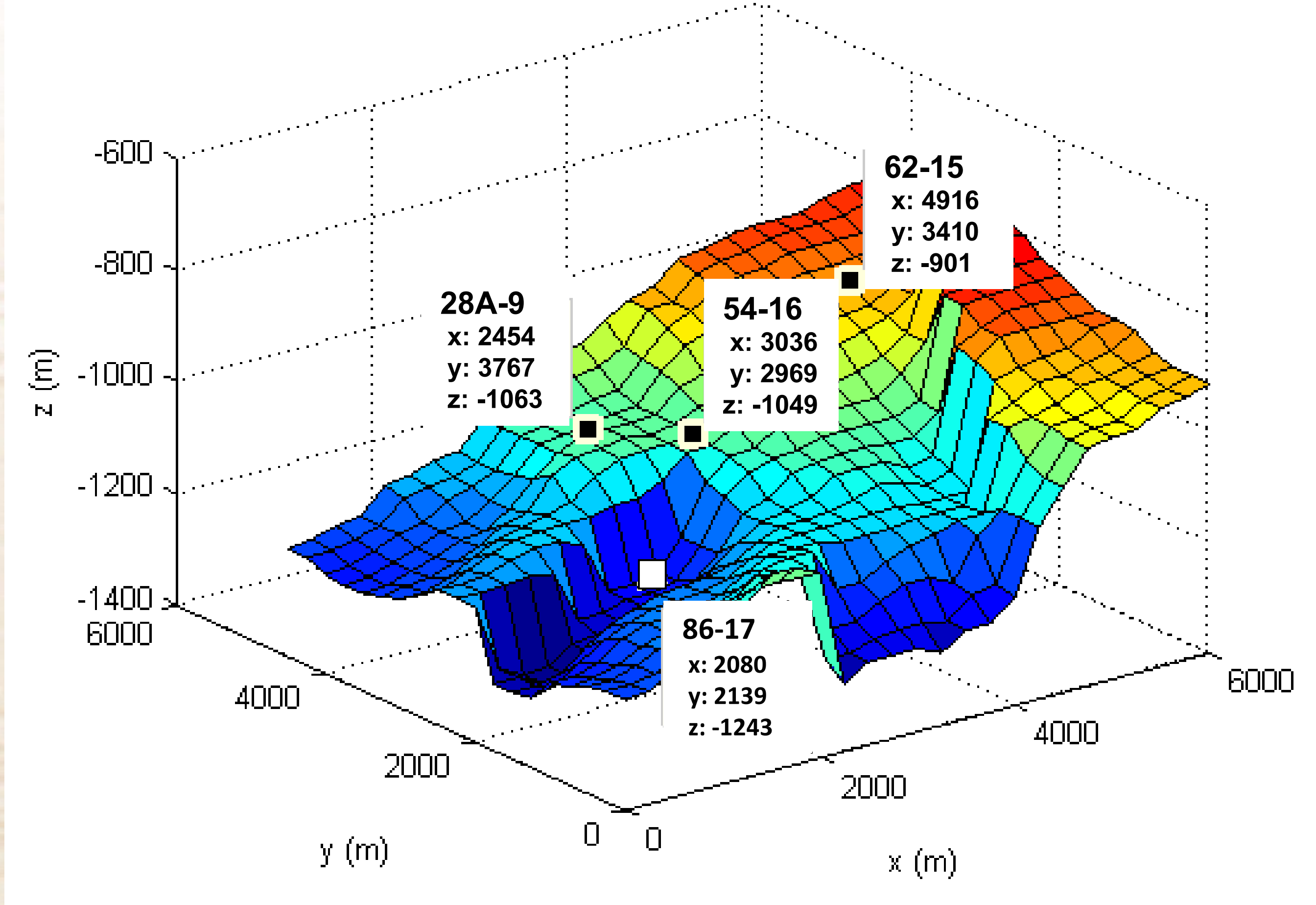


Geothermal reservoir monitoring: a priori

difficult log



Complex reservoir boundaries (seismic)



Geothermal reservoir monitoring: 3D Feasibility

Feasibility workflow for reservoir monitoring

Target objectives
reservoir → measurements

Input data:
- well log data
- geologic information
- seismic horizons
- noise measurements

ANISOTROPY

NOISE field data

Noise data analysis:
- noise level, spectra
- sensor analysis
- various test acquisition

Build 3D model

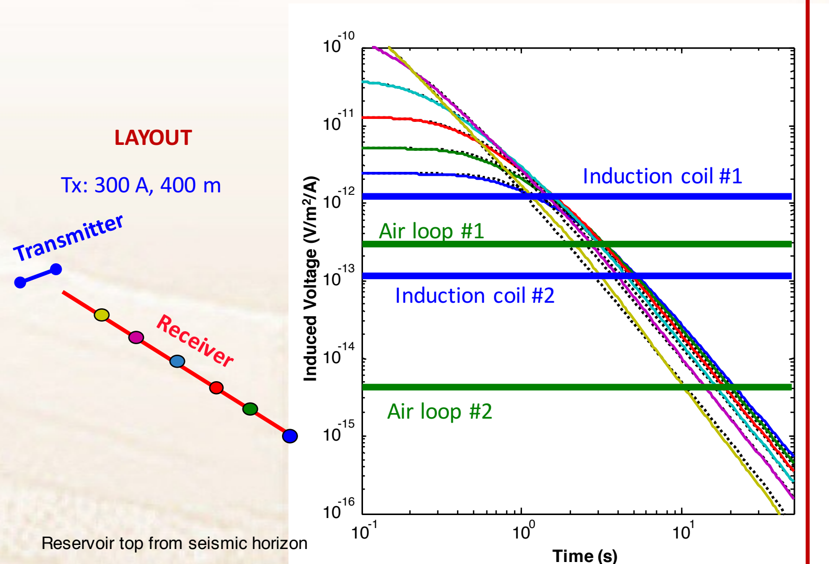
Verification of 3D modeling
- benchmarking

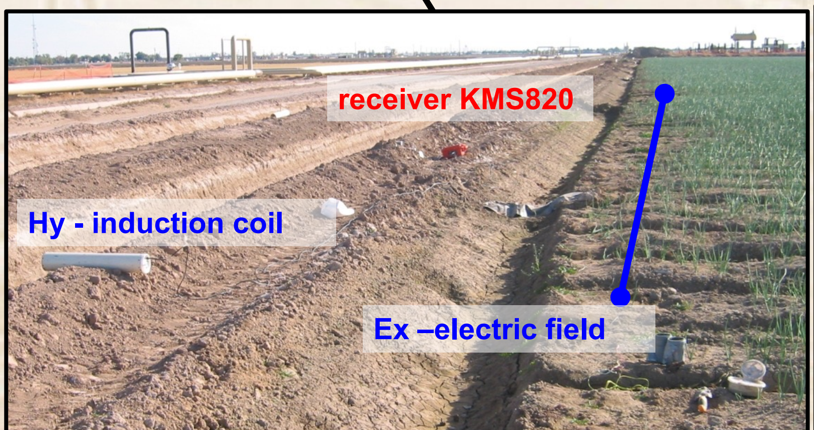
Define target variations
- fluid substitution
- add wells as available

Analyze results

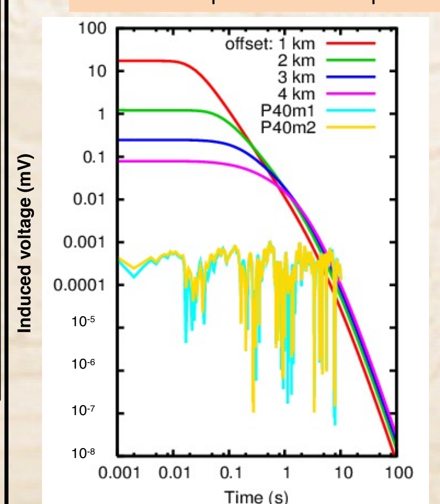
Survey layout, sensor choices, sensor parameters, survey plan

3D model + sensor + noise + acquisition simulation





3D CSEM response & noise spectra



EOR monitoring: water flood

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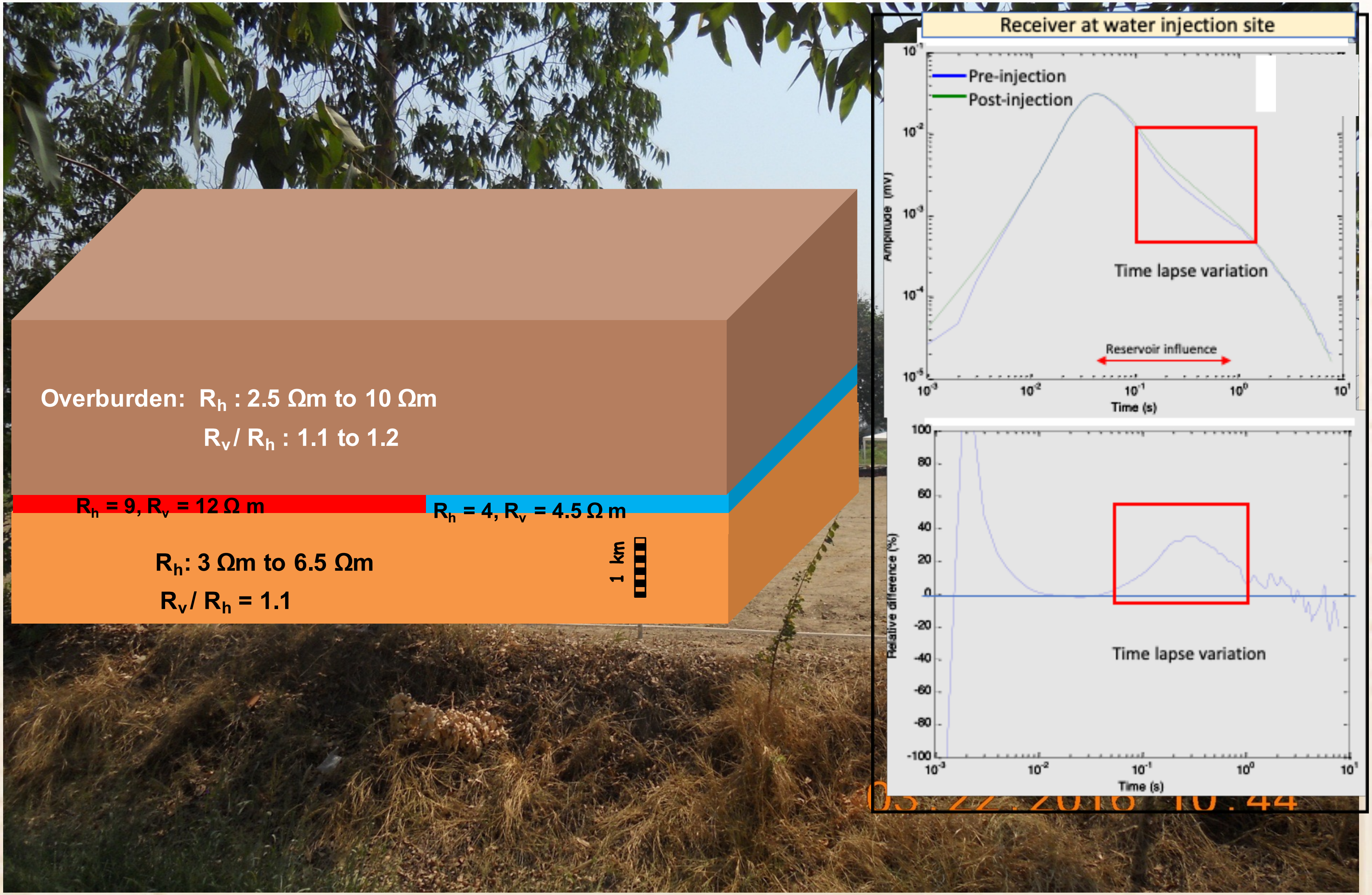
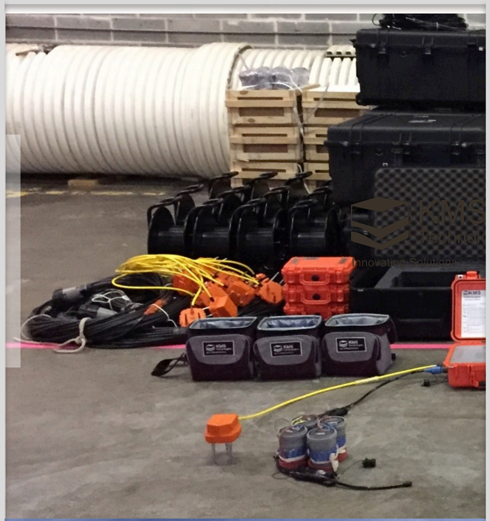


EOR monitoring: 195 channel monitoring system

RESERVOIR MONITORING

ARRAY Electromagnetics

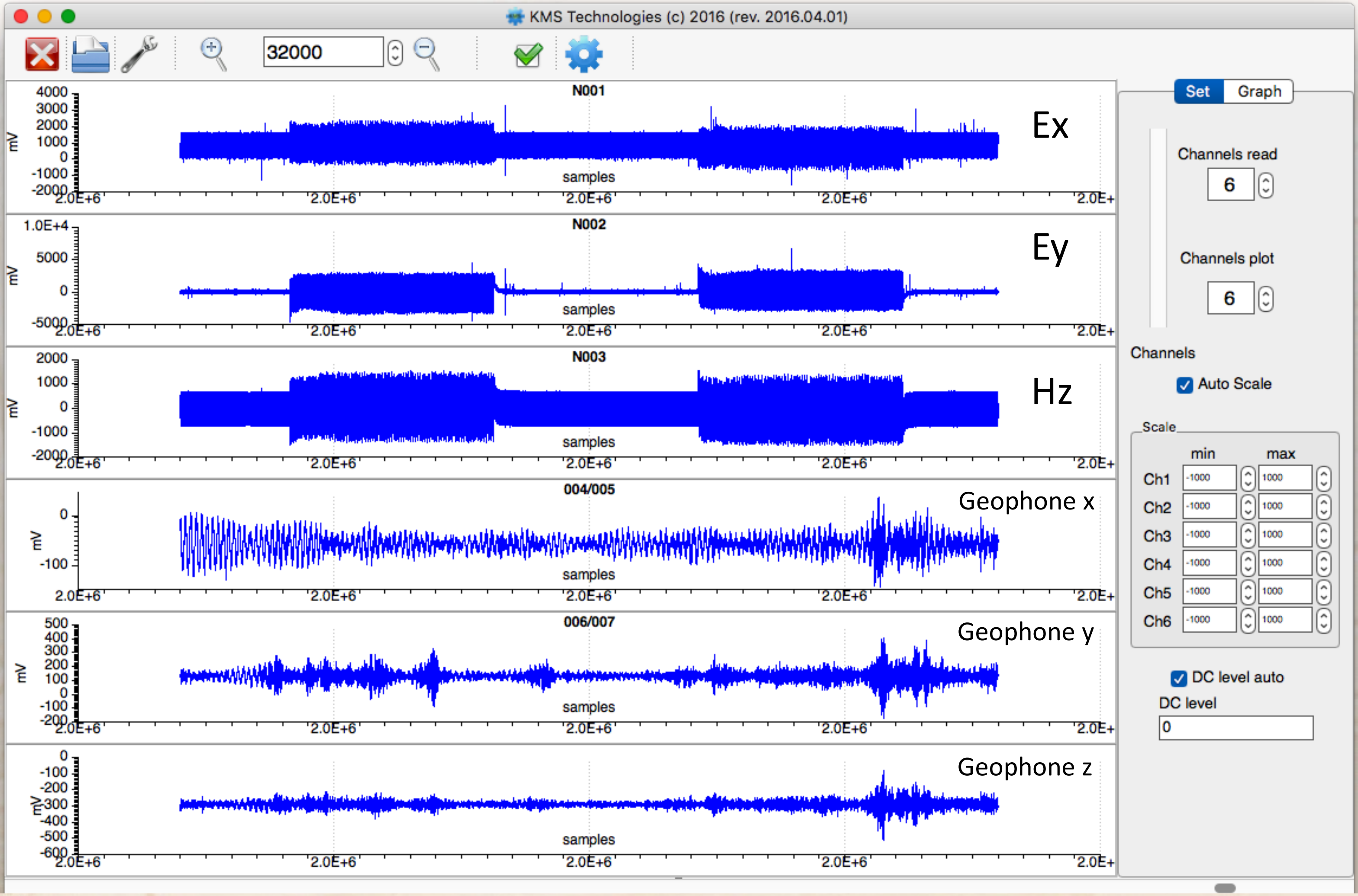
- 195 channels, wifi, wireless or LAN
- 3C magnetic field (DC to 40 kHz)
- 3C microseismic
- 2C electric fields
- Shallow borehole (microseismic/EM)



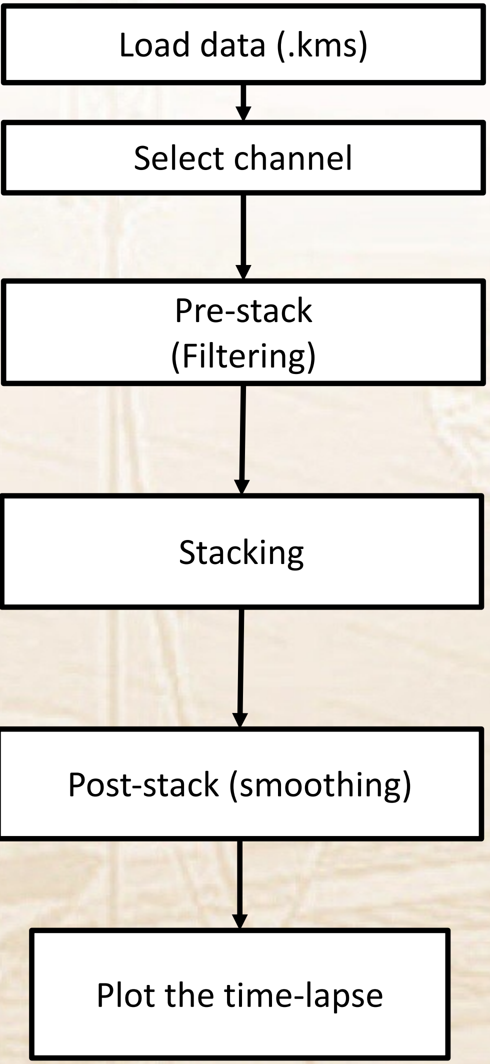
2015 CSEM transmitter test

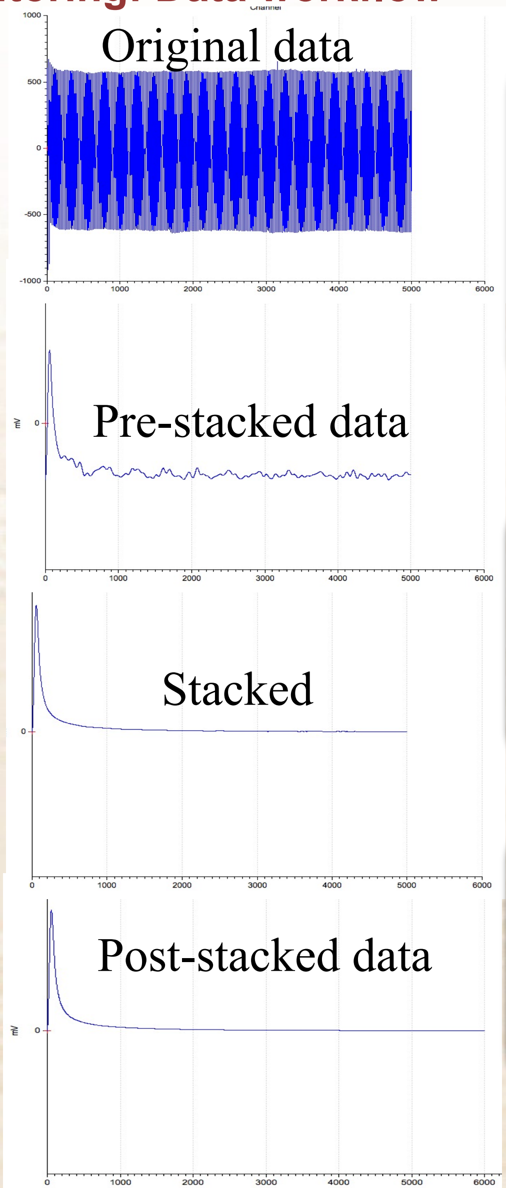
- 100 KVA transmitter up-scalable
- Flexible input. (DC to 3 phase AC)
- Array system integrated

EOR monitoring: Raw data example: microseismic/EM monitoring



EOR monitoring: Monitoring: Data workflow





Filtering

•Harmonic Noise
Harmonic noise filters: Low pass filter
Power line harmonic : 50 Hz
threshold:3.00
•Smoothing
Low pass filter : time domain
Cut off frequency: 15 Hz
Averaging filter: Recursive average = 0.01,T/2 smoothing

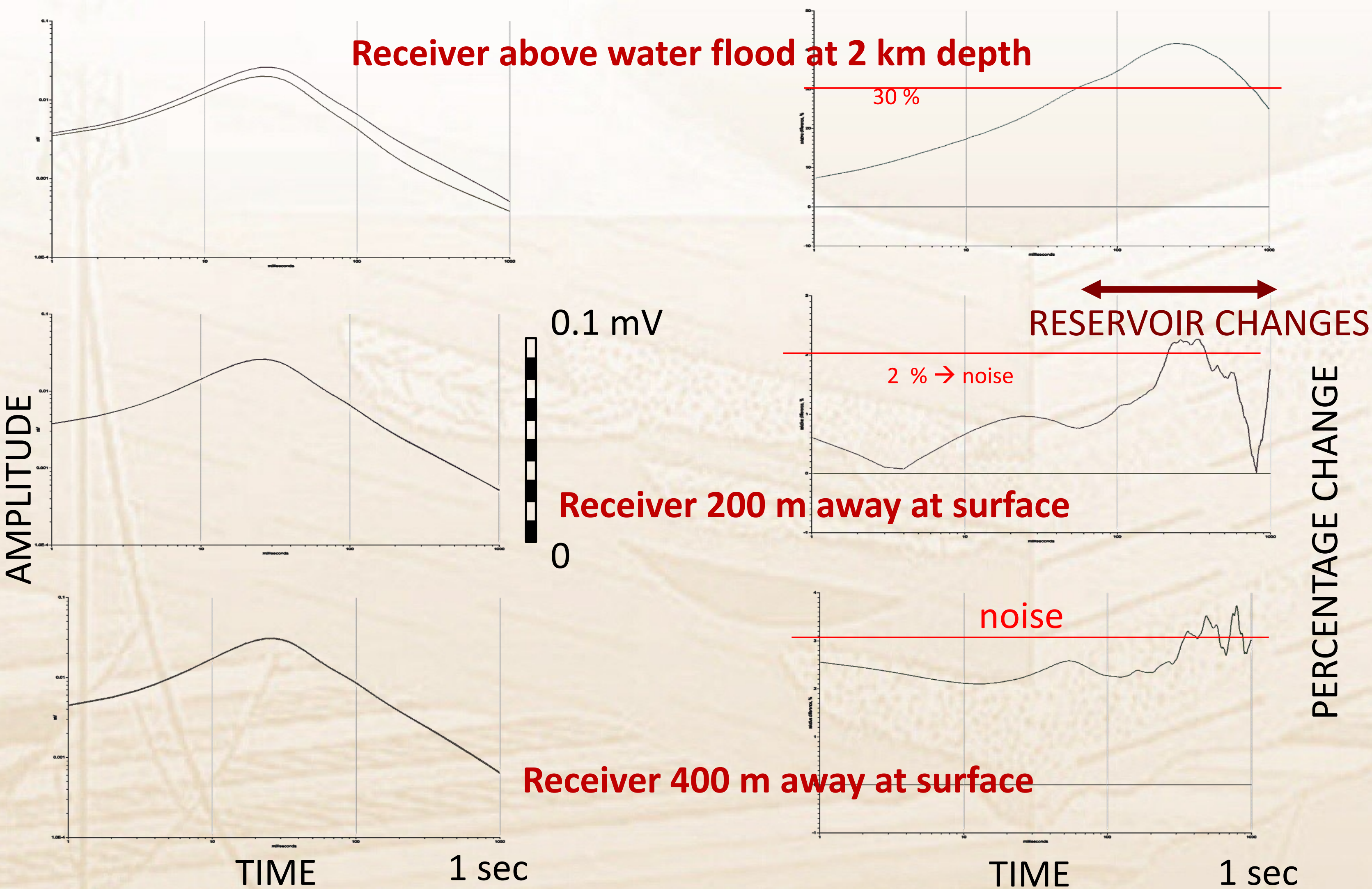
Stacking

Trimmed mean
T/2 additional stacking

- **Smoothing & time lapse**
  Recursive average filter
  DC-level adjust

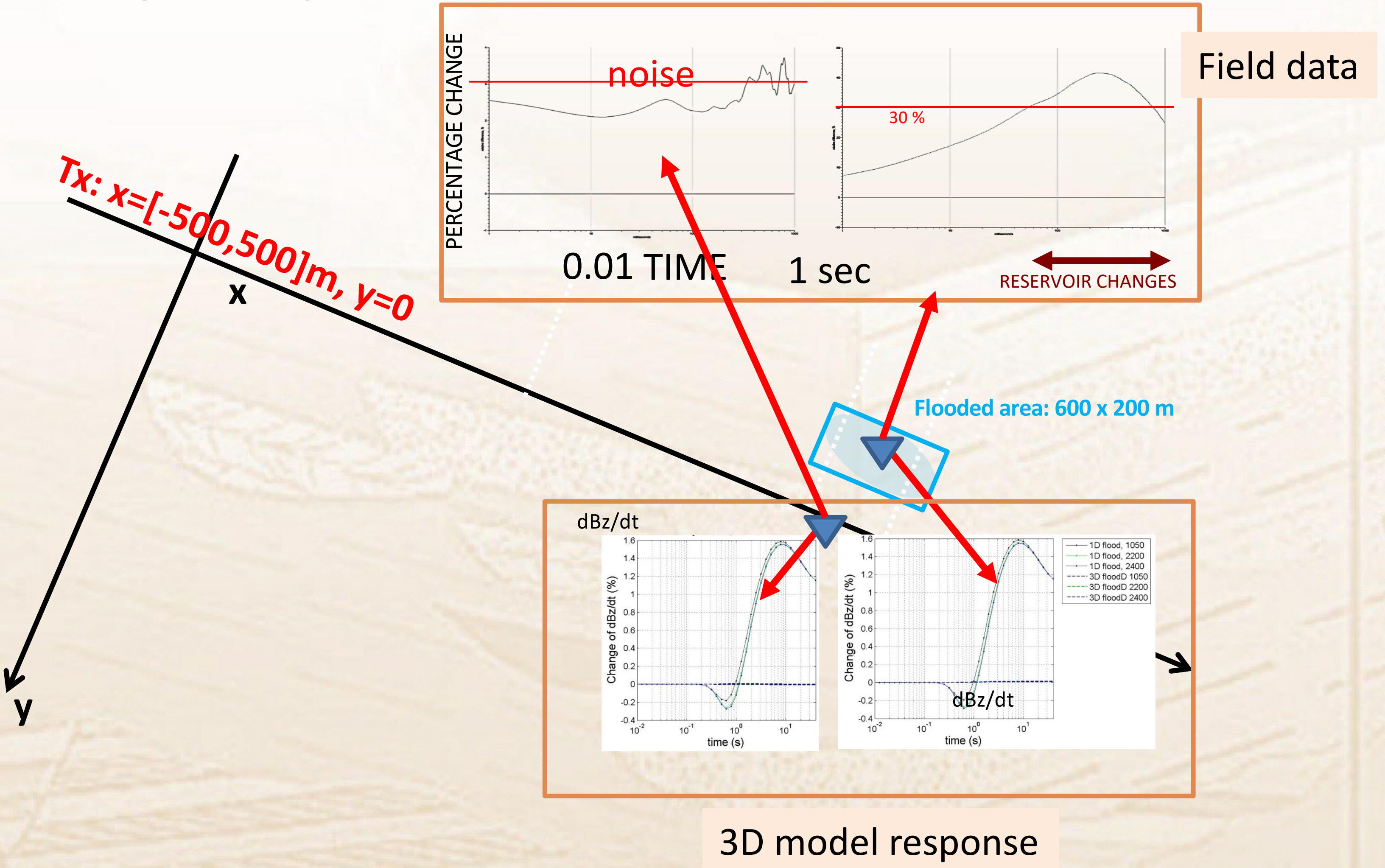
Courtesy A. Paembonan

EOR monitoring: Magnetic field sees water flood influence



Courtesy A. Paembonan

EOR monitoring: Field layout, time-lapse data results, 3D model explanation

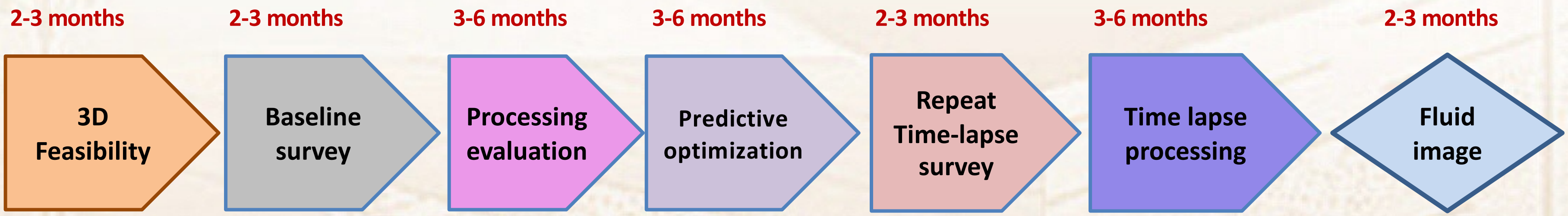


What will the future look like?

- EM has contribution to make to the energy transition
- Fluid imaging requires EM
- Monitoring points to CSEM
- BUT we need results FAST (24 hours) & CALIBRATED

Use the Cloud & AI/ML: the biggest time consumers

Reservoir monitoring workflow, approximate times & technical tasks



3D Feasibility

- Log analysis
- Upscale model
- Derive 3D anisotropic model
- Reservoir fluid variations
- Derive 3D modeling task
- **Perform 3D modeling** *
- **Analyze target variations** *

Baseline survey

- Receiver deployment
- Transmitter setup
- **Quality Assurance** *

Processing evaluation

- Data merge
- Processing
- Evaluation

Predictive optimization

- **3D modeling** *
- Noise merge
- Gen. synthetic data
- Processing
- Evaluate

Repeat Time-lapse survey

- Receiver deployment
- Transmitter setup
- **Quality Assurance** *

Time lapse processing

- Data merge
- Processing
- Focus anomaly

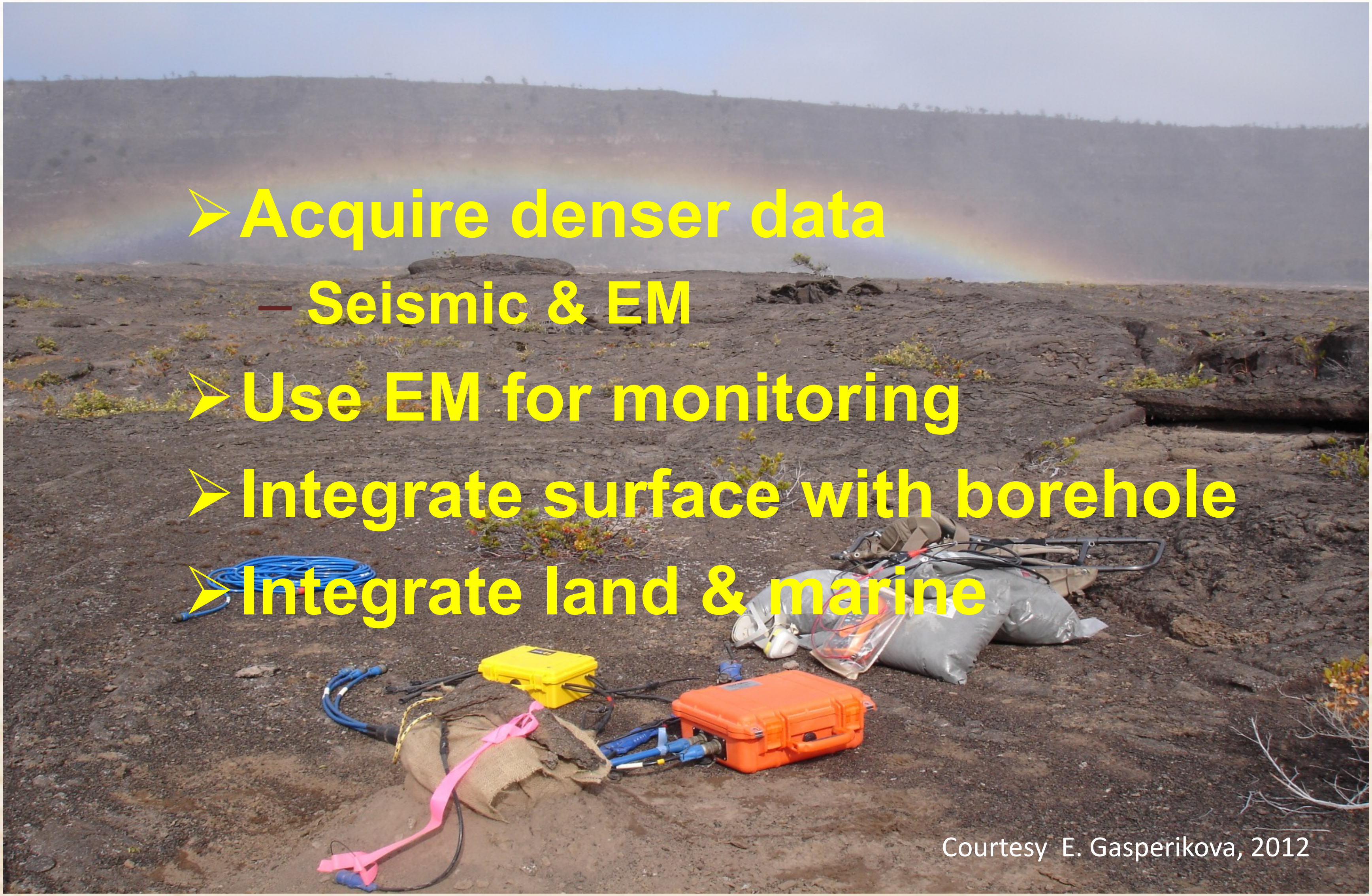
Fluid image

- **3D modeling** *
- Model adjustment
- Direct image
- Integration

* denotes time consuming tasks

FUTURE:

- **Acquire denser data**
  - **Seismic & EM**
- **Use EM for monitoring**
- **Integrate surface with borehole**
- **Integrate land & marine**



Courtesy E. Gasperikova, 2012