BALKAN GEOPHYSICAL SOCIETY 11 CONGRESS
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Array electromagnetics for reservoir fluid monitoring

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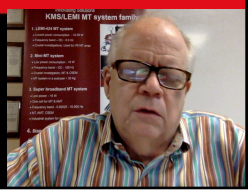
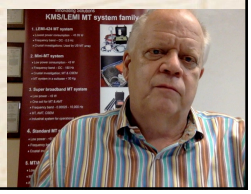


1

Background >>> Array EM >>> Case studies >>> Summary
Outline

- Background
- Array EM fluid monitoring workflow - what are the issues
- Case studies:
  - Waterflood in SE Asia
  - CO_2 pilot in Northern US
- Summary



2

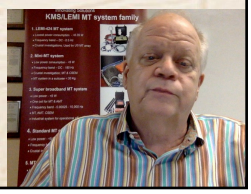
Background >>> Array EM >>> Case studies >>> Summary
Definitions

Reservoir fluid monitoring:…. NEEDS time-lapse

- Enhanced Oil Recovery – EOR → Increase recovery factor
  - Define boundaries oil-water
  - Monitor reservoir seal
- CCUS – Carbon capture, utilization & storage:
  - Where does the dissolve CO_2 go?
- Geothermal:
  - Production optimization
  - Monitor induced seismicity

Array electromagnetics (EM):

- EM measurements carried out by an array of receivers
  - Use synchronicity for better data
  - Higher spatial coverage for better resolution



3

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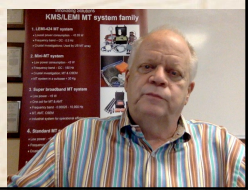
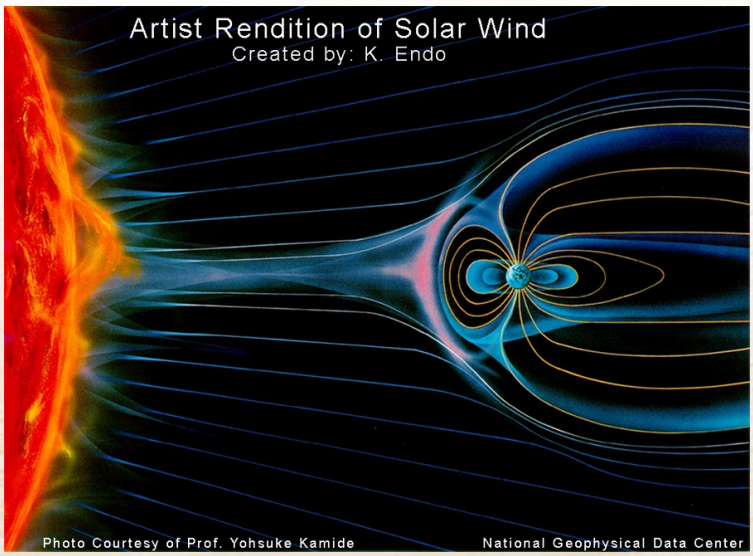
The methods

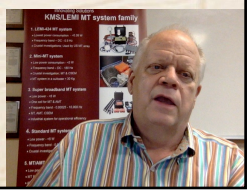
- Magnetotellurics – passive method
  - Good for basin structure, overthrust, sub-basalt, sub-salt
- Controlled Source Electromagnetics (CSEM)
  - the ONLY way to get vertical current flow
  - more detail than magnetotellurics



4

Background >>> Array EM >>> Case studies >>> Summary
Source of the MT field





5

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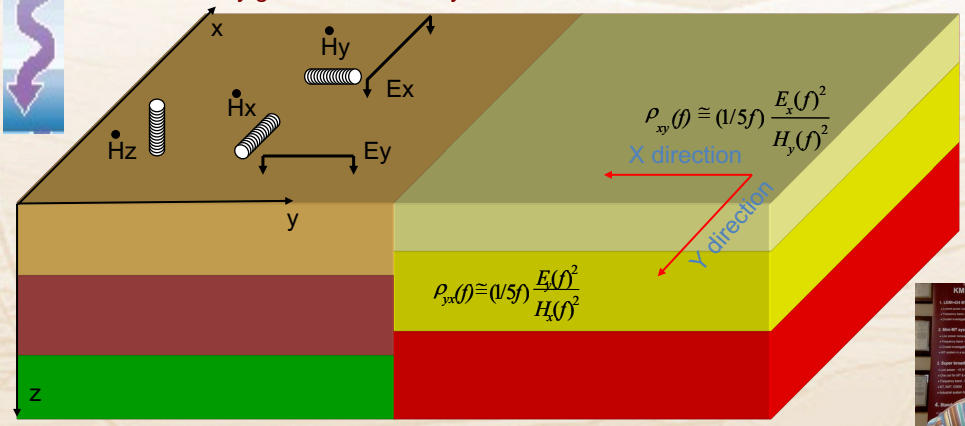
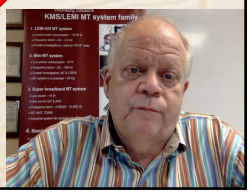
Land Magnetotellurics

Measures natural variation of EM field source: ionosphere & world wide thunderstorm activity;

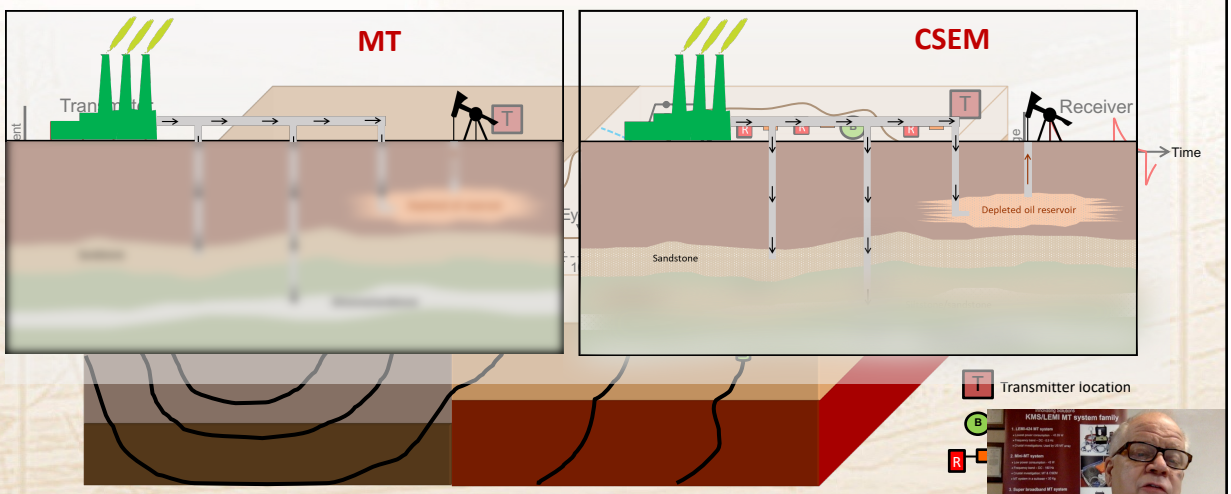
Source field can be handled as vertical incident plane wave, influenced by ground conductivity.

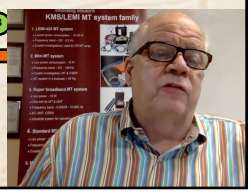




6

Background >>> Array EM >>> Case studies >>> Summary
Land CSEM





7

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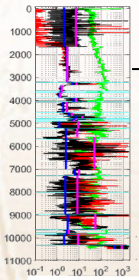
Designing Baseline Survey workflow

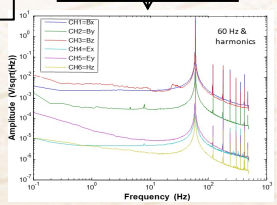


Input data
well-logs, geology, seismic horizons; additional surveillance

Rock physics
Determine reservoir parameter variations

Field noise measurements

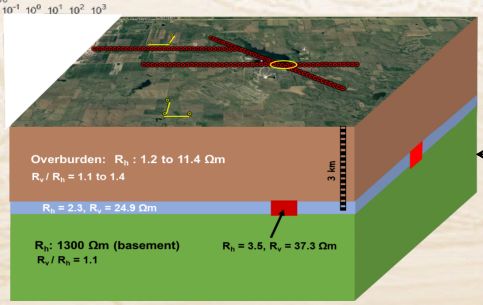
3D Feasibility
Link data with variations

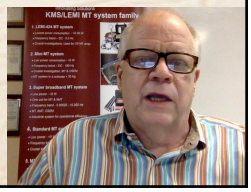


Define pilot
→ 2-3 monitoring cycles
→ BASELINE

Evaluate / decide

Baseline survey

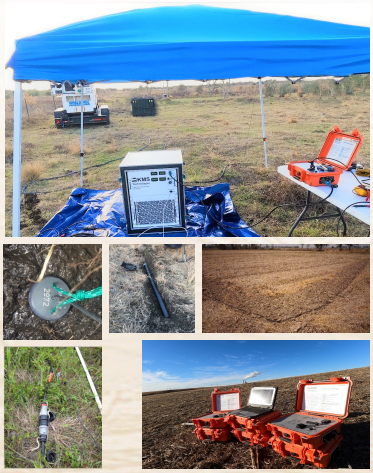


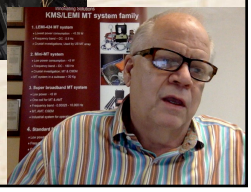


8

Background >>> **Array EM** >>> Case studies >>> Summary

Acquisition hardware





9

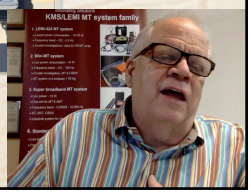
Background >>> Array EM >>> **Case studies** >>> Summary

195 channel CSEM/microseismic monitoring EXAMPLE

RESERVOIR MONITORING

ARRAY Electromagnetics

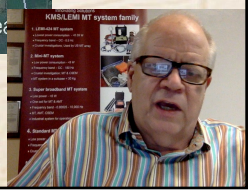
- 195 channels, wifi, wireless or LAN
- 3C magnetic field (DC to 40 kHz)
- 3C microseismic
- 2C electric fields
- Shallow borehole (microseismic/EM)



10

Background >>> **Array EM** >>> Case studies >>> Summary

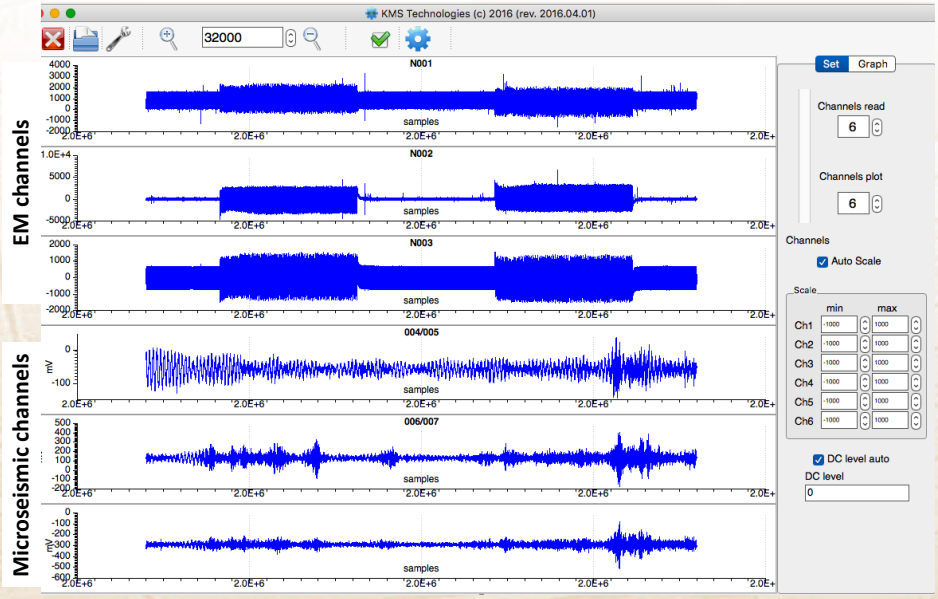
SE Asia, waterflood: survey area

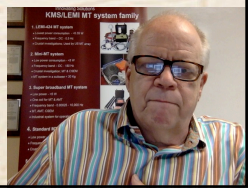


11

Background >>> **Array EM** >>> Case studies >>> Summary

SE Asia, waterflood: raw data example, microseismic/EM

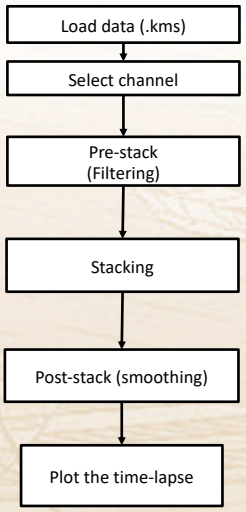


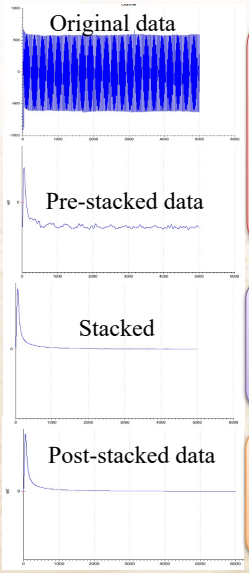


12

Background >>> Array EM >>> **Case studies** >>> Summary

SE Asia, waterflood: data processing

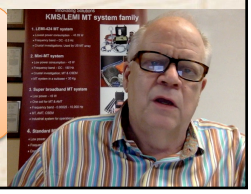




Filtering
- Harmonic Noise
- Harmonic noise filters: Low pass filter
- Power line harmonic : 50 Hz
- threshold:3.00
- Smoothing
- Low pass filter : time domain
- Cut off frequency: 15 Hz
- Averaging filter: Recursive average = 0.01,T/2 smoothing

Stacking
- Trimmed mean
- T/2 additional stacking

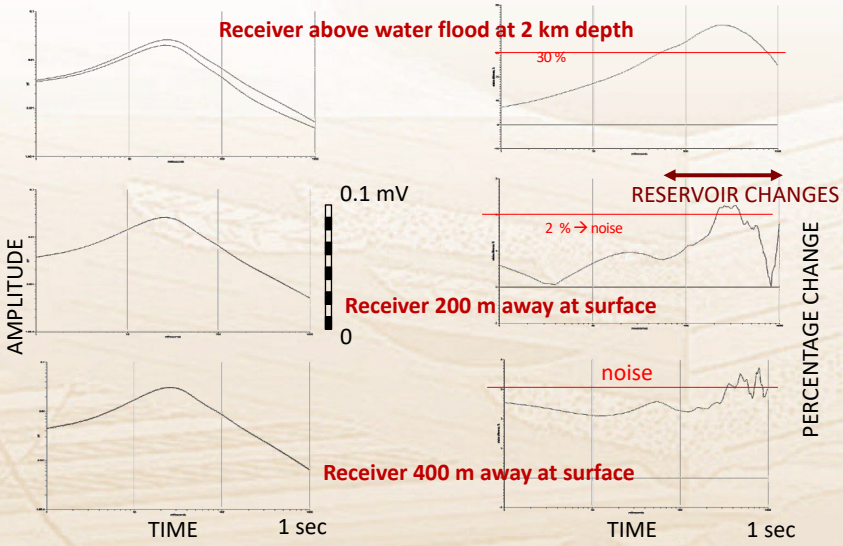
Smoothing & time lapse
- Recursive average filter
- DC-level adjust



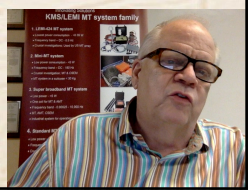
13

Background >>> Array EM >>> **Case studies** >>> Summary

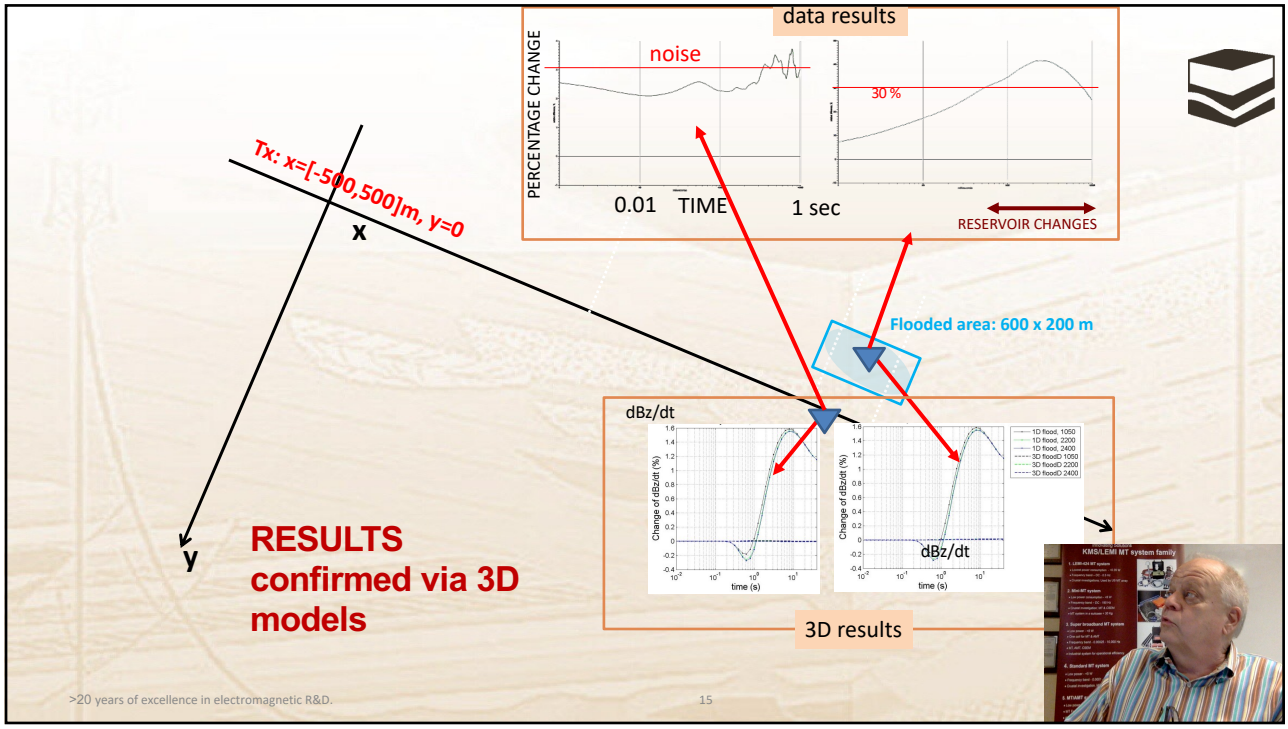
SE Asia, waterflood, magnetic field response



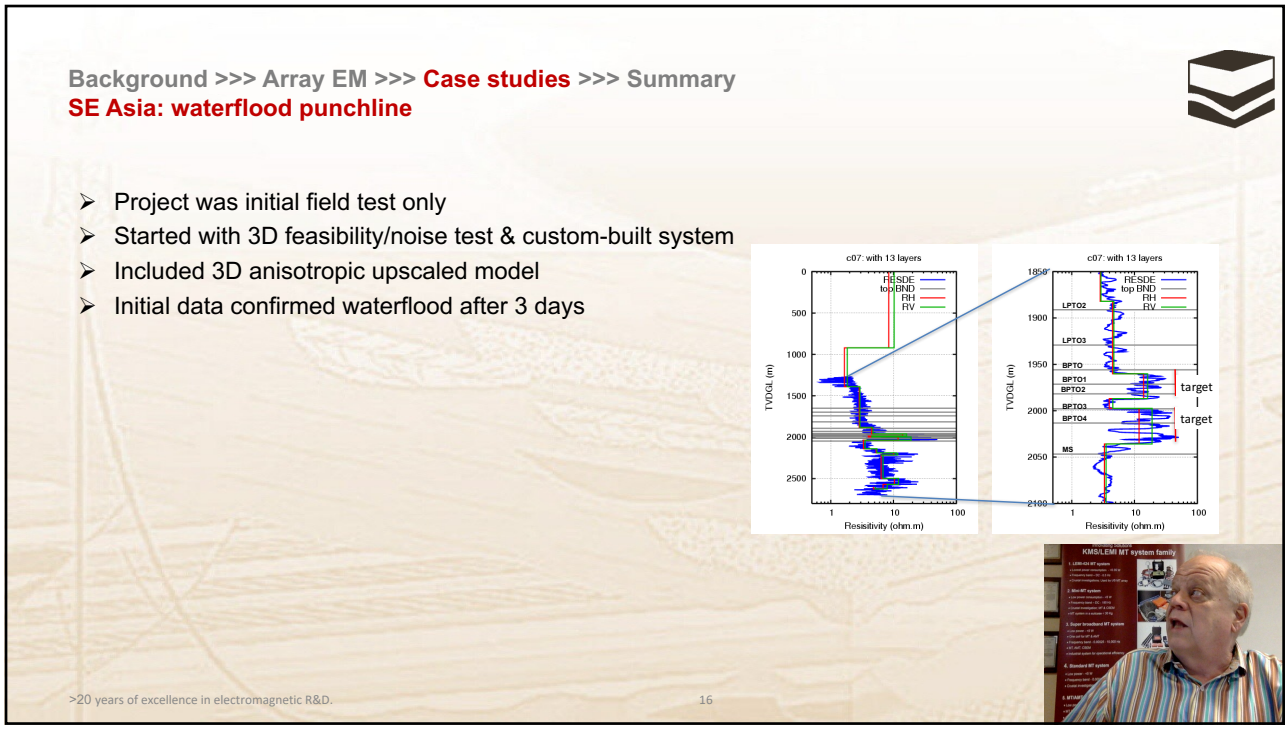
Courtesy A. Paembonan



14

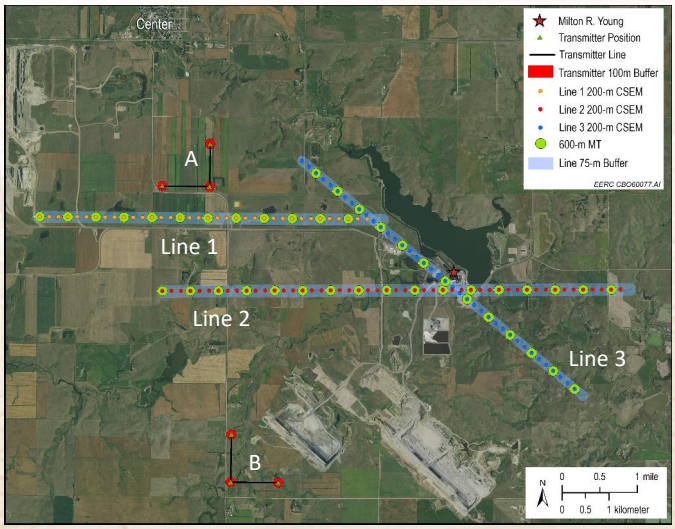

data results
PERCENTAGE CHANGE
noise
30 %
0.01
TIME
1 sec
RESERVOIR CHANGES
Tx: x=[-500,500]m, y=0
x
y
Flooded area: 600 x 200 m
dBz/dt
Change of dBz/dt (%)
time (s)
1D flood, 1050
1D flood, 2200
1D flood, 2400
3D floodD 1050
3D floodD 2200
3D floodD 2400
dBz/dt
3D results
RESULTS
confirmed via 3D
models
>20 years of excellence in electromagnetic R&D.
15

15


Background >>> Array EM >>> Case studies >>> Summary
SE Asia: waterflood punchline
Project was initial field test only
Started with 3D feasibility/noise test & custom-built system
Included 3D anisotropic upscaled model
Initial data confirmed waterflood after 3 days
c07: with 13 layers
RESDE
top BND
RH
RV
TVDGL (m)
Resistivity (ohm.m)
LPTO2
LPTO3
BPTO
BPTO1
BPTO2
BPTO3
BPTO4
MS
target
target
>20 years of excellence in electromagnetic R&D.
16

16

Background >>> Array EM >>> Case studies >>> Summary
Northern US, CO_2 injection: survey area



Baseline measurements:

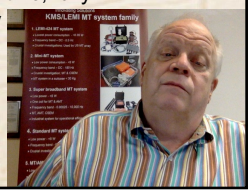
MT

- For model's baseline background resistivity
- 42 Stations, 600 m spacing
- Remote station 100 miles from study area

CSEM

- 124 Stations, 200 m spacing, total different recordings > 700
- Two transmitter sites (A & B), each 2 directions
- Time domain

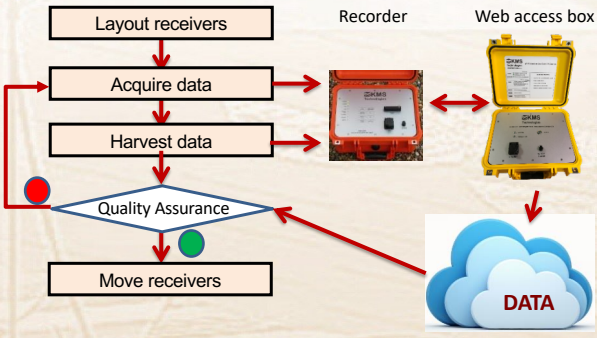
- 24 hours operation – 6 weeks
- No hardware breakdowns (-20^0 C!!)
- **Real-time data upload for QA**
- Pickups: 24, deployment:16, fully recorded sites: 17 / day



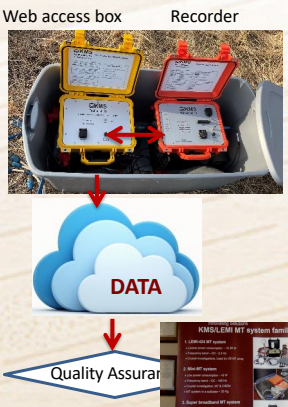
17

Background >>> Array EM >>> Case studies >>> Summary
Northern US, CO_2 injection: MT with remote reference acquisition

Study area



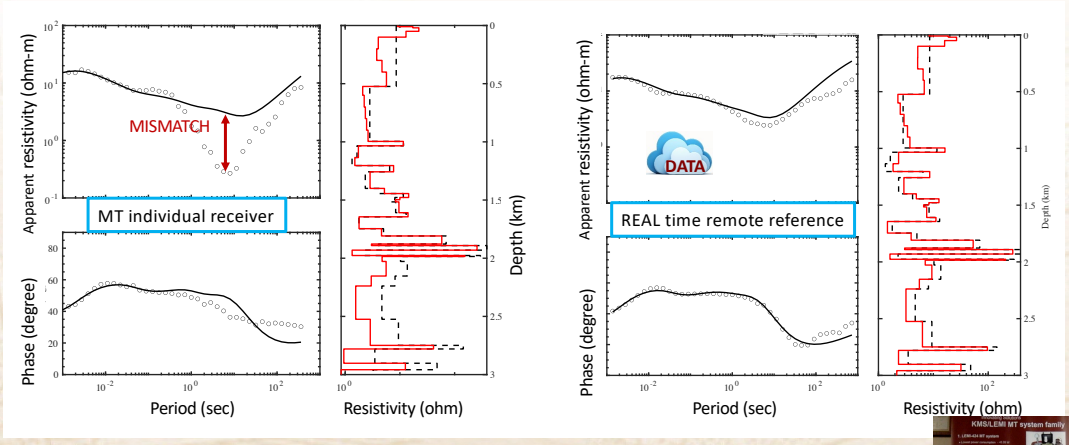
Remote Station 300 miles away



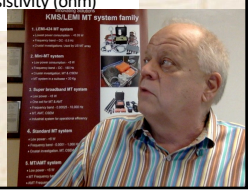
18

Background >>> Array EM >>> Case studies >>> Summary

Northern US, CO_2 injection: MT data inversion – Cloud connected



Observed data
Inverted model response
Initial resistivity model
Inverted model



19

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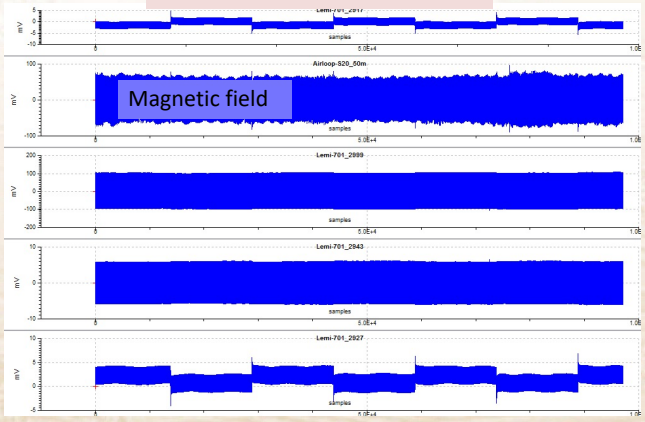
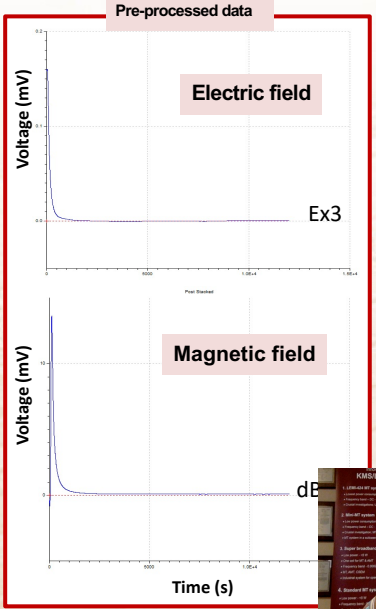
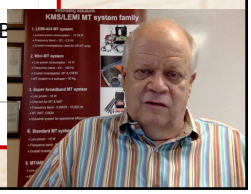
Northern US, CO_2 injection monitoring: Data QA

Raw data - Time series L3 CSEM 087



Pre-processed data

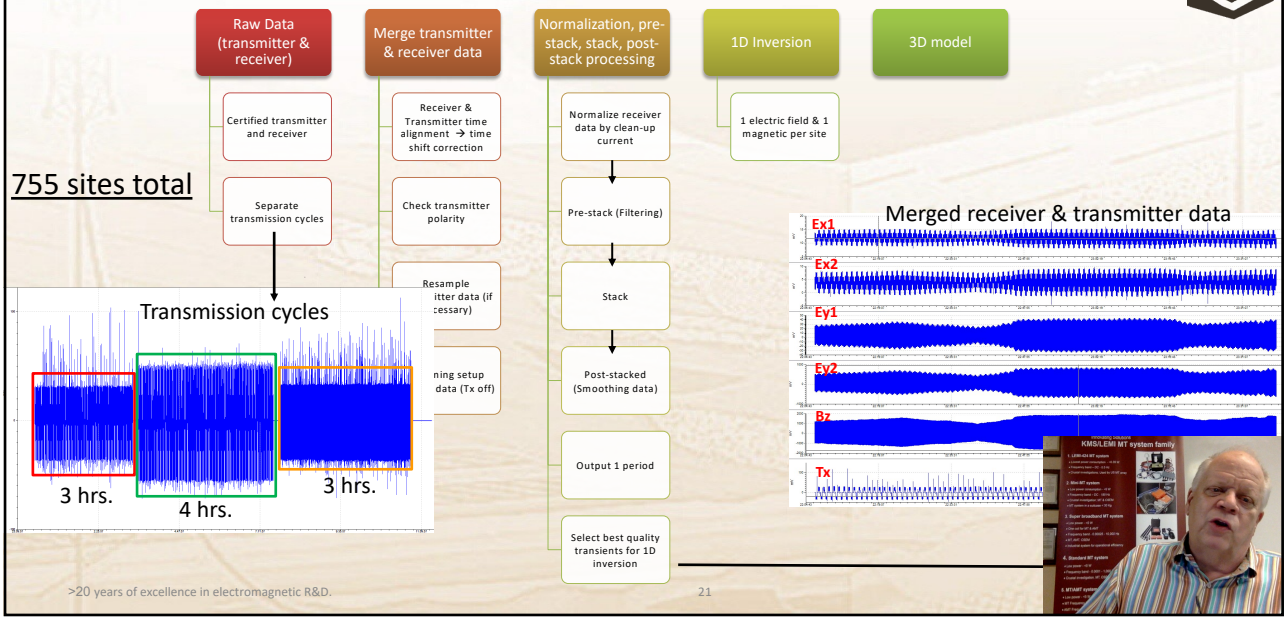




20

Background >>> Array EM >>> Case studies >>> Summary

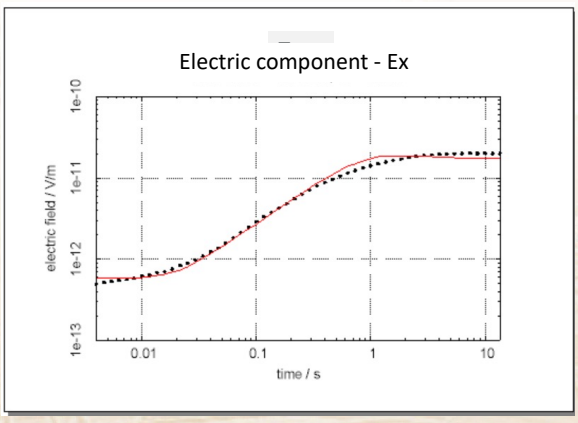
Northern US, CO_2 injection monitoring: CSEM processing workflow

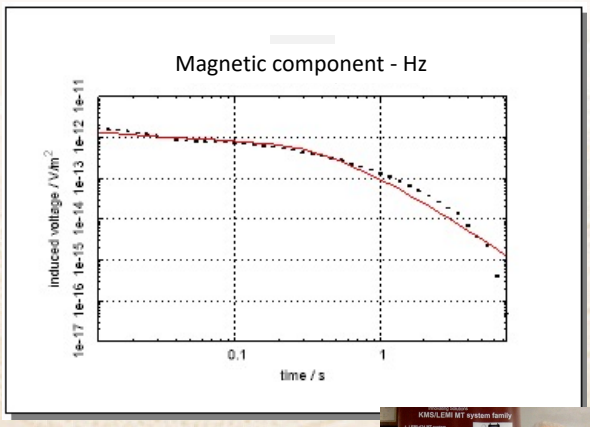


21

Background >>> Array EM >>> Case studies >>> Summary

Northern US, CO_2 injection monitoring: CSEM inversion example





Inversion examples: depth in similar range (slightly deeper) than model

Ongoing: check sensitivities to target and layering

22

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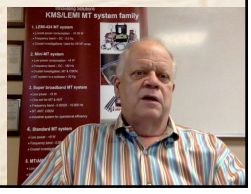
Conclusions

- EM methods proven as best geophysical fluid imaging method
- For waterflood, magnetic field sees the response of the waterflood
- A 3D feasibility workflow developed over 30 years proven effective
- Northern US is baseline measurement required extremely accurate measurement and data verification
- Real-time, cloud-based acquisition & processing will be key for future

23

Thank you!



24