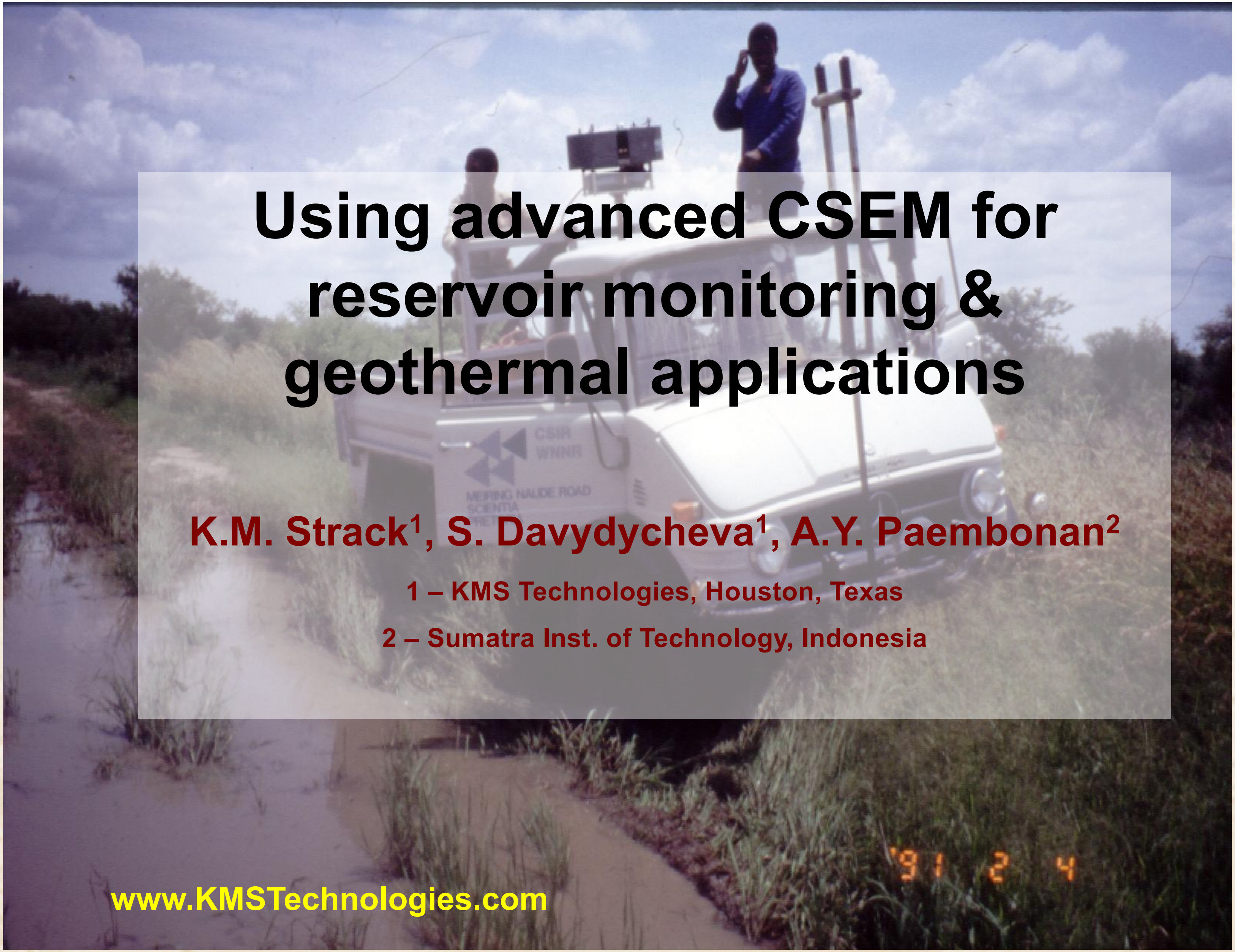

Using advanced CSEM for reservoir monitoring & geothermal applications

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COLLEGE OF PETROLEUM ENGINEERING & GEOSCIENCES

CIPR COLLOQUIUM

Using advanced CSEM for reservoir monitoring & geothermal applications

SPEAKER

Kurt Strack

BIOGRAPHY: Dr. **K.M. Strack** is president of KMS Technologies specializing in integrated seismic/electromagnetic technology for land & marine exploration, appraisal drilling and production monitoring. KMS is pioneering borehole, borehole-to-surface, and marine electromagnetics to link with the 3D seismic Earth model. Kurt also serves as Adjunct Professor in the Earth and Atmospheric Geoscience Department and Electrical Engineering Department at the University of Houston, Mahidol University Bangkok, and at Yangtze University, Wuhan China. He was Chief Scientist for Baker Atlas where he built the Research Department and supported the development of numerous new logging tools. Prior to that Kurt pioneered LOTEM development and advanced borehole geophysics technologies in Germany, Australia and the USA. Kurt received a Ph.D. from the University of Cologne and a M.Sc. from Colorado School of Mines. He has over 35 experience in the geothermal and oil industry and received many international awards for his work.

Kurt has over 200 publications, 1 textbook & authors/co-authors more than 40 patents. He received a Fulbright scholarship and numerous international grants/awards. His interest is integrating geophysics with other disciplines, technology transfer and project development. .

Dr. K. Strack can be reached at *Kurt@kmstechnologies.com*

"Reservoir monitoring is gaining increasing importance for hydrocarbon and geothermal reservoirs to improve recovery factors and understand fluid movement including fluid induced reservoir changes. Similar, it can be applied to monitoring volcanoes' magna movements and aid for volcano eruption prediction.

In order to see variations at percentage level much more detailed attention is required at all data handling stages. During acquisition, more effort is required to obtain long term stable transmitter and receiver site including not only daily monitoring of contact resistance but also controlling them during the acquisition process to better than 1%. Because of the large dynamic range of the signal highly accurate reference level with active adjustment before the transmitted signal is necessary. When processing the data, a feedback loop between filter selection and noise suppression in the reservoir signal band allows you to optimize the filter and to reduce their effect on the anomaly itself. When modeling for a sedimentary environment, anisotropy is the biggest cause for error and misinterpretation. It can be derived before the survey from exiting logs using end members derived from the log based on the interaction of the layers on reservoir scale. We are using real field measurements for feasibility and as potential misinterpretation examples to illustrate the severance of these issues."

DATE
Monday, Oct. 28th, 2019

TIME
Noon – 13:00 PM

LOCATION
Building 76, Room 1226
King Fahd University of
Petroleum & Minerals,
Dhahran 31261
Kingdom of Saudi Arabia

CIPR Colloquium is a weekly event of the Center for Integrative Petroleum Research of the College of Petroleum Engineering & Geosciences at KFUPM. It provides KFUPM, Saudi Aramco, and DTV researchers and scientists with the opportunity to get together and discuss upstream technical matters in a collegial relaxed setting. Students are encouraged to attend and engage.

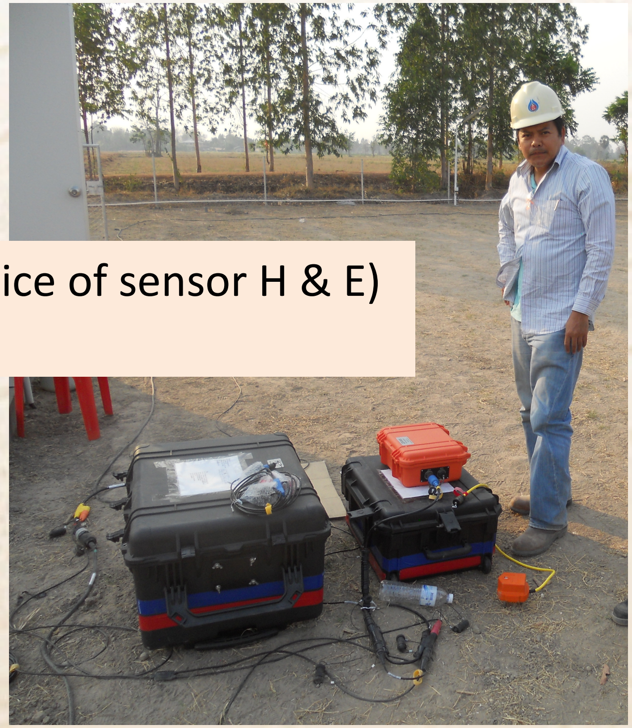
Disecting the topic… I …Geothermal & Hydrocarbons

Commonality between Geothermal & Hydrocarbons

- Both benefits from 4D monitoring (cost, reservoir integrity & quality)
- Permanent installations have highest value (4D seismic & induced seismicity monitoring)
- Similar depth range (1 km to 4 km)

Differences

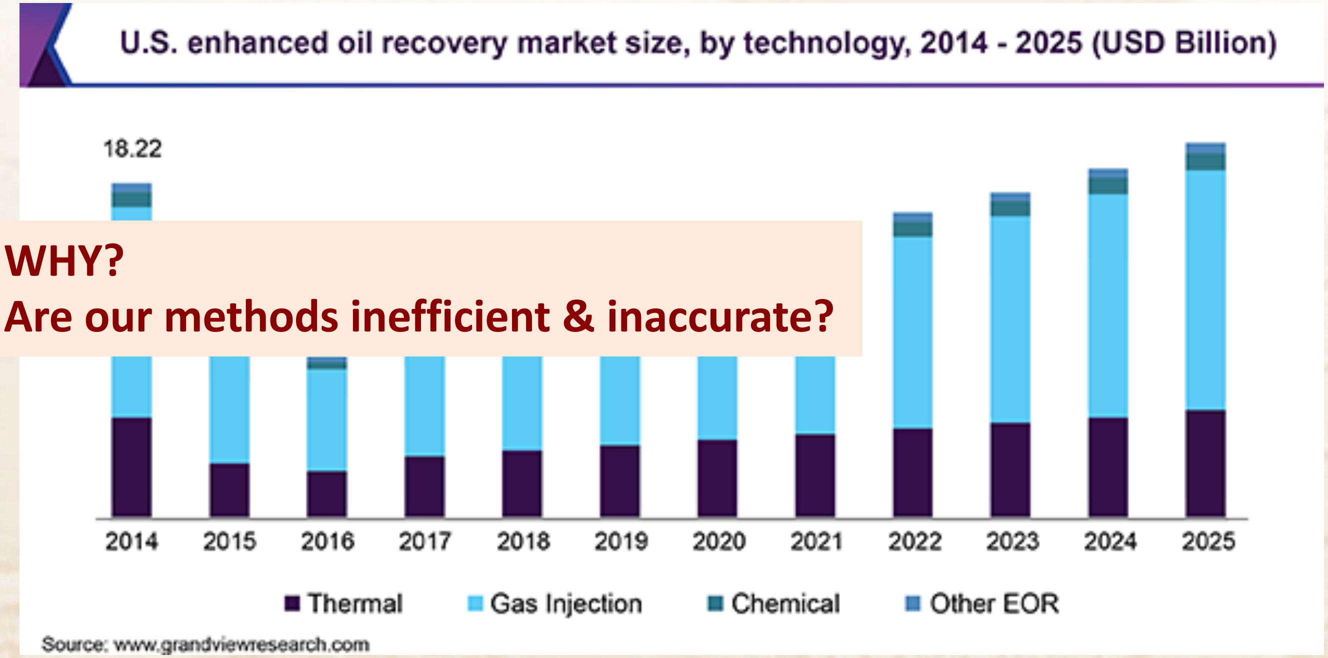
- Hydrocarbons: resistive (oil) & conductive (water) targets
- Geothermal: mostly conductive target



→ Always image conductive & resistive targets (→ choice of sensor H & E)

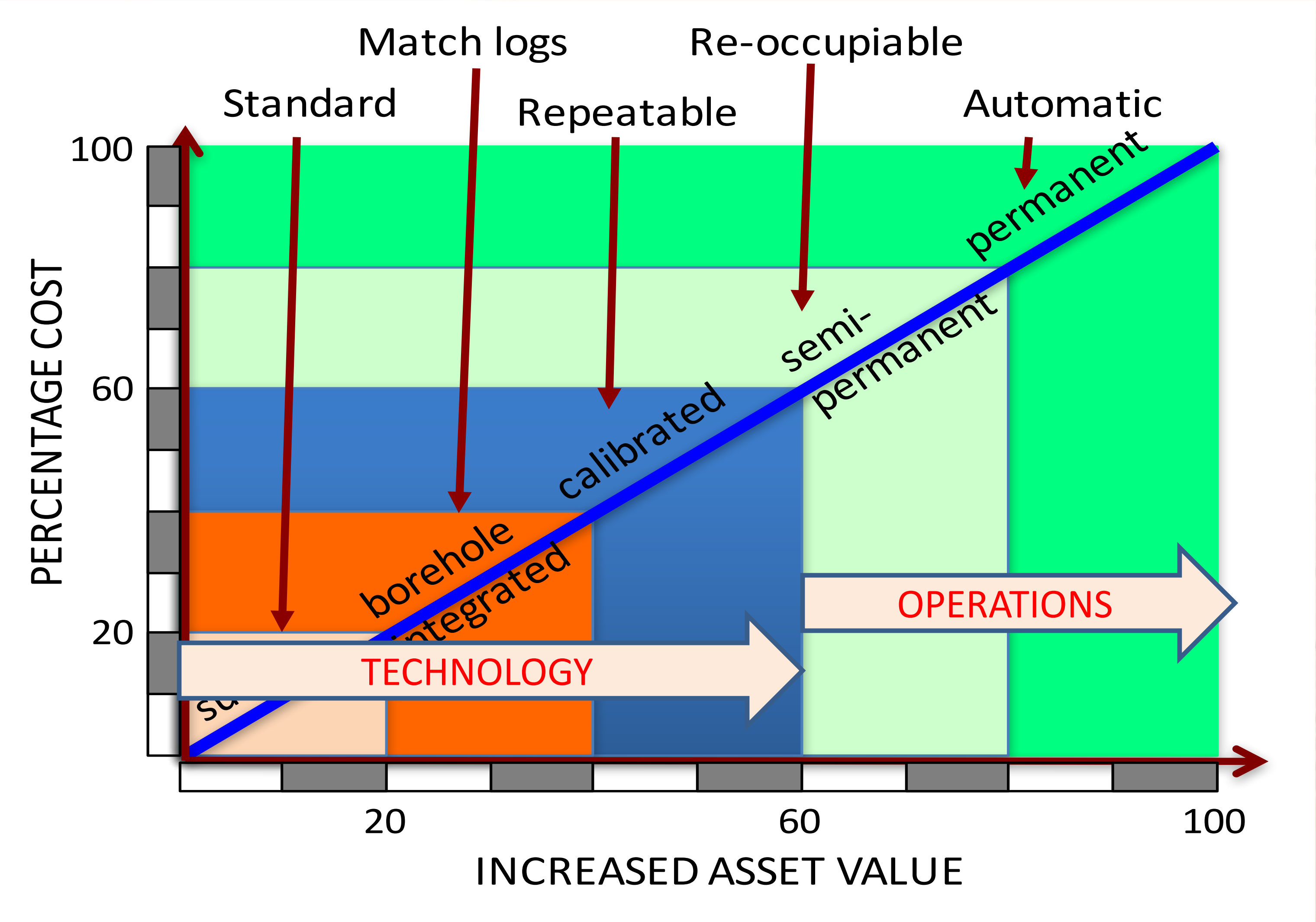
Disecting the topic… II .. Reservoir monitoring @ June 2019

- EOR market alone: recovering to 20 BUSD by 2025
- Little to no geophysics (except thermal)
- Seismic images boundaries; EM images fluids



WHY?
Are our methods inefficient & inaccurate?

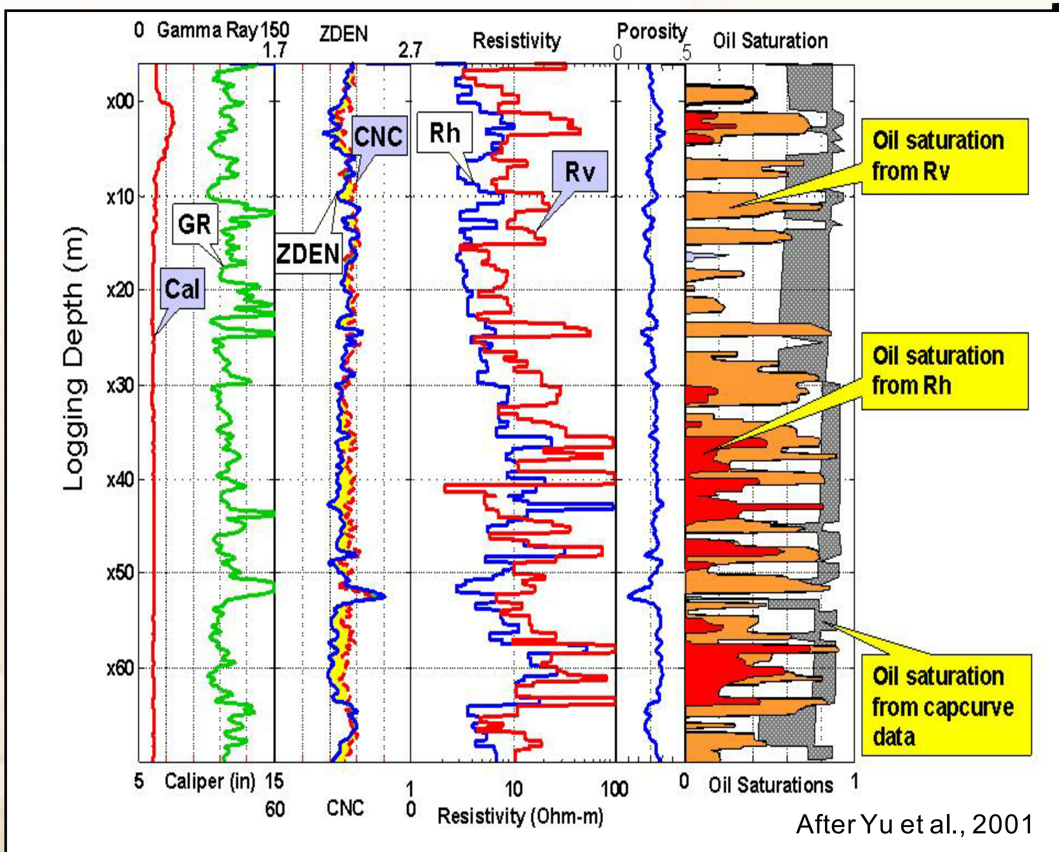
Background & issues >> the system >> requirements >> examples
Geo-technology cost versus ASSET value

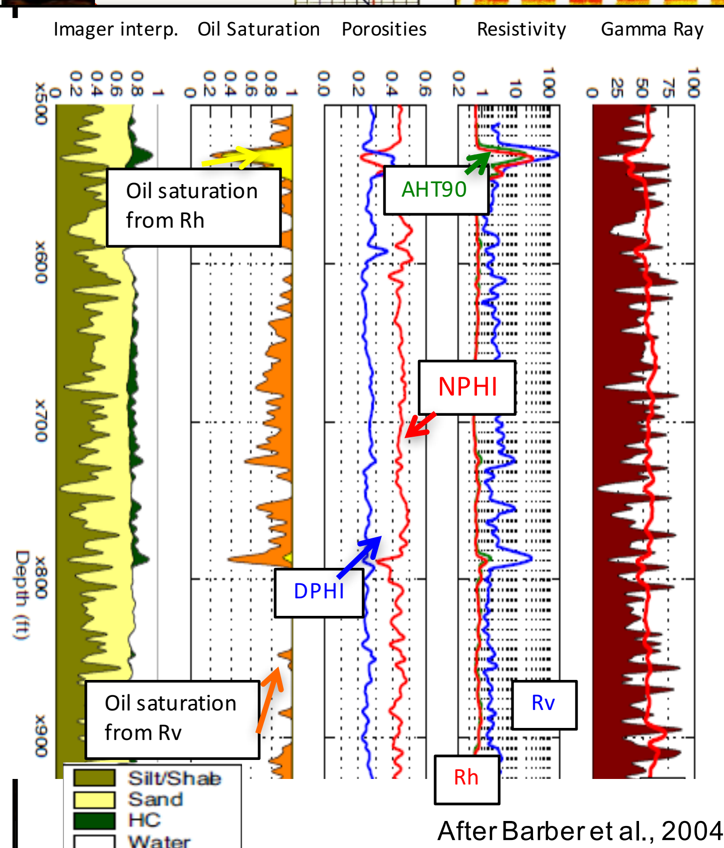


Pitfall: ANISOTROPY our biggest problem

23 m

2.5 m





Sub-laminations

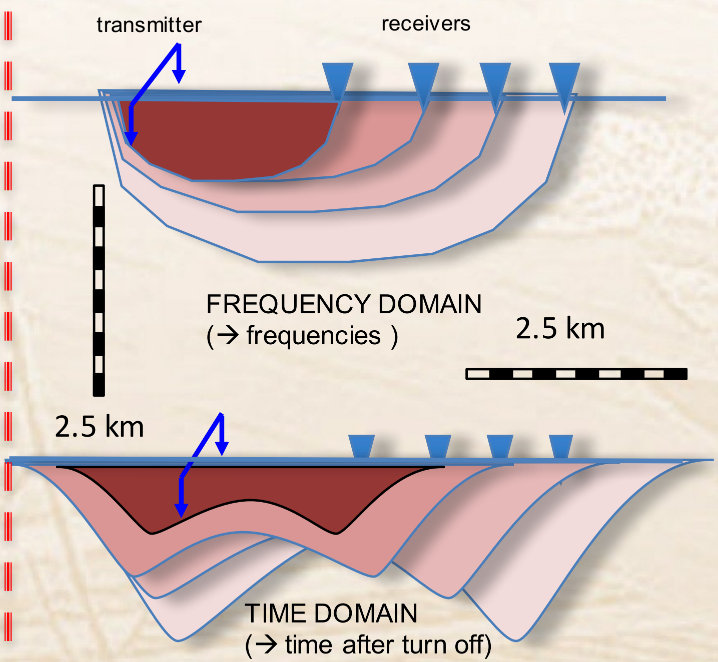
laminations

Logging tool

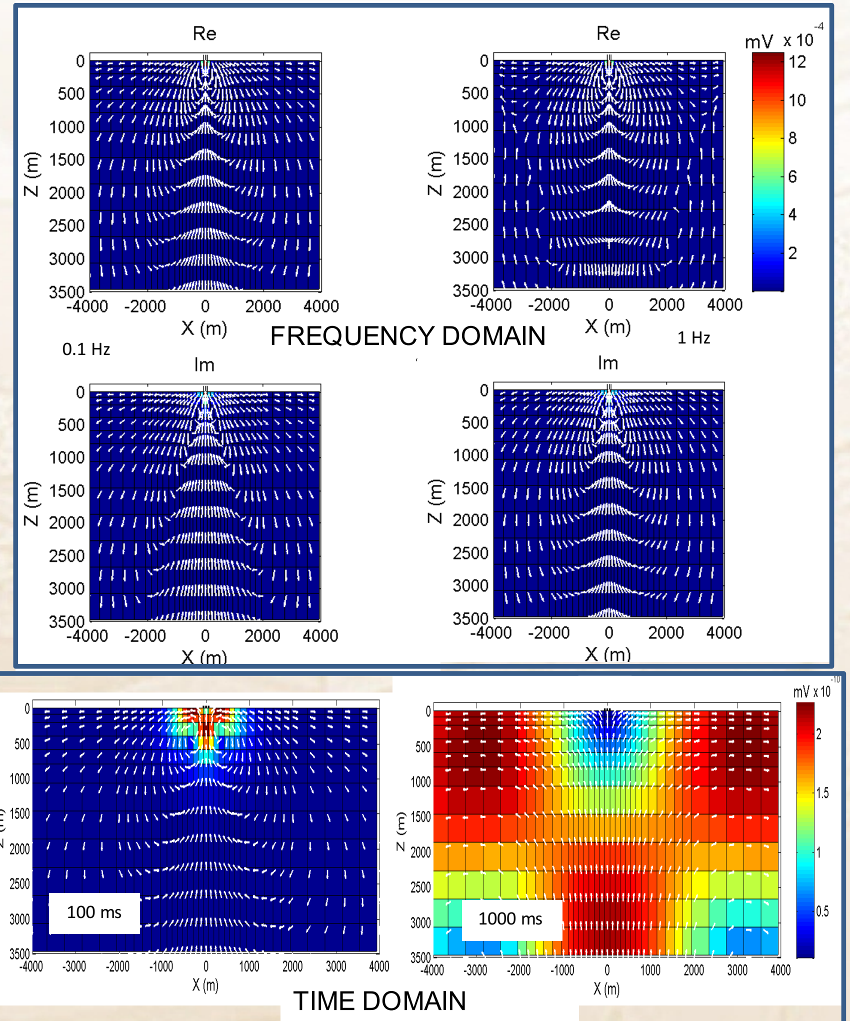
Courtesy Baker Atlas

Pitfall: Where does the information come from?..

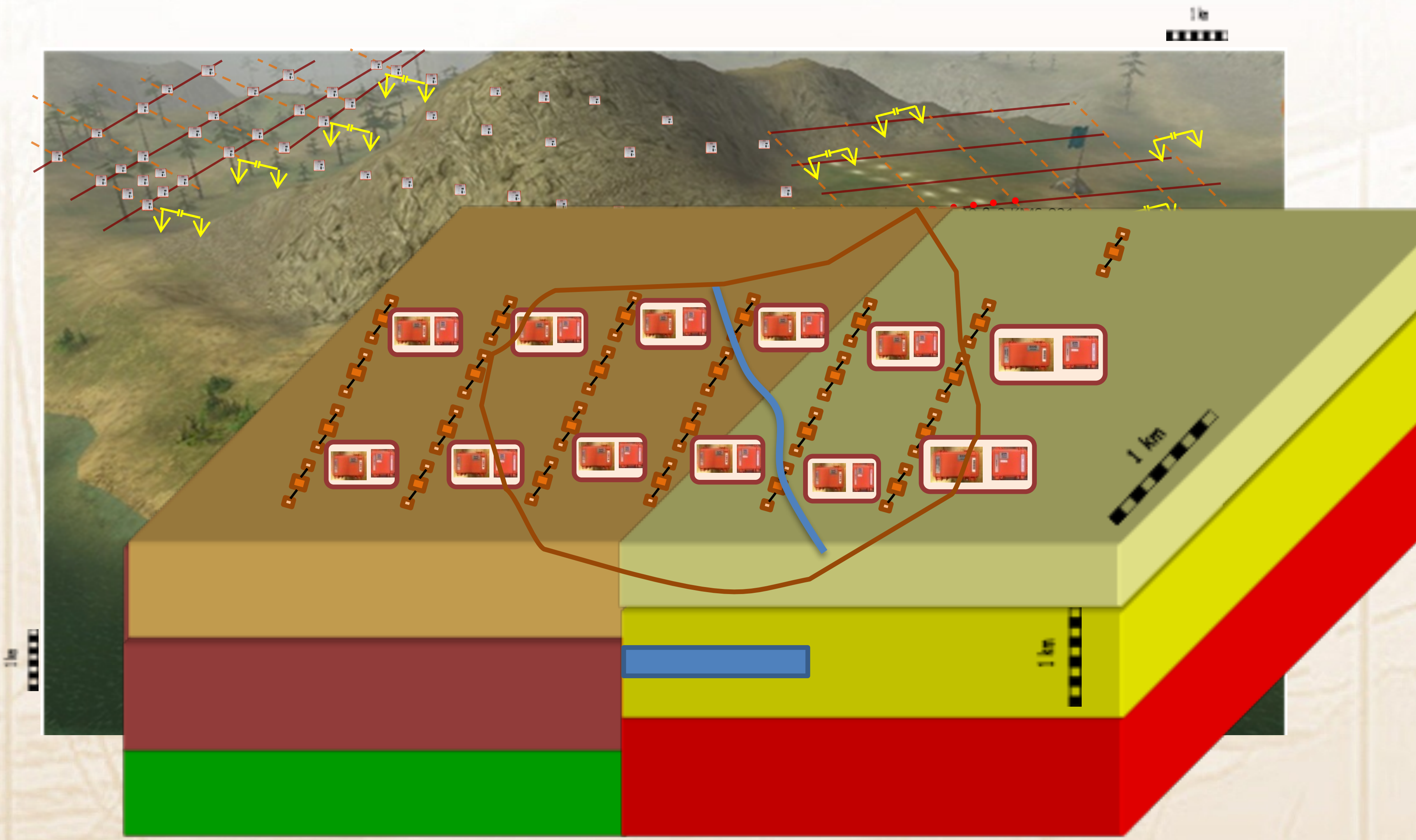
Sensitivity density



Focused Source EM electric fields



Exploration & monitoring layouts



Receiver: New ARRAY acquisition → better images

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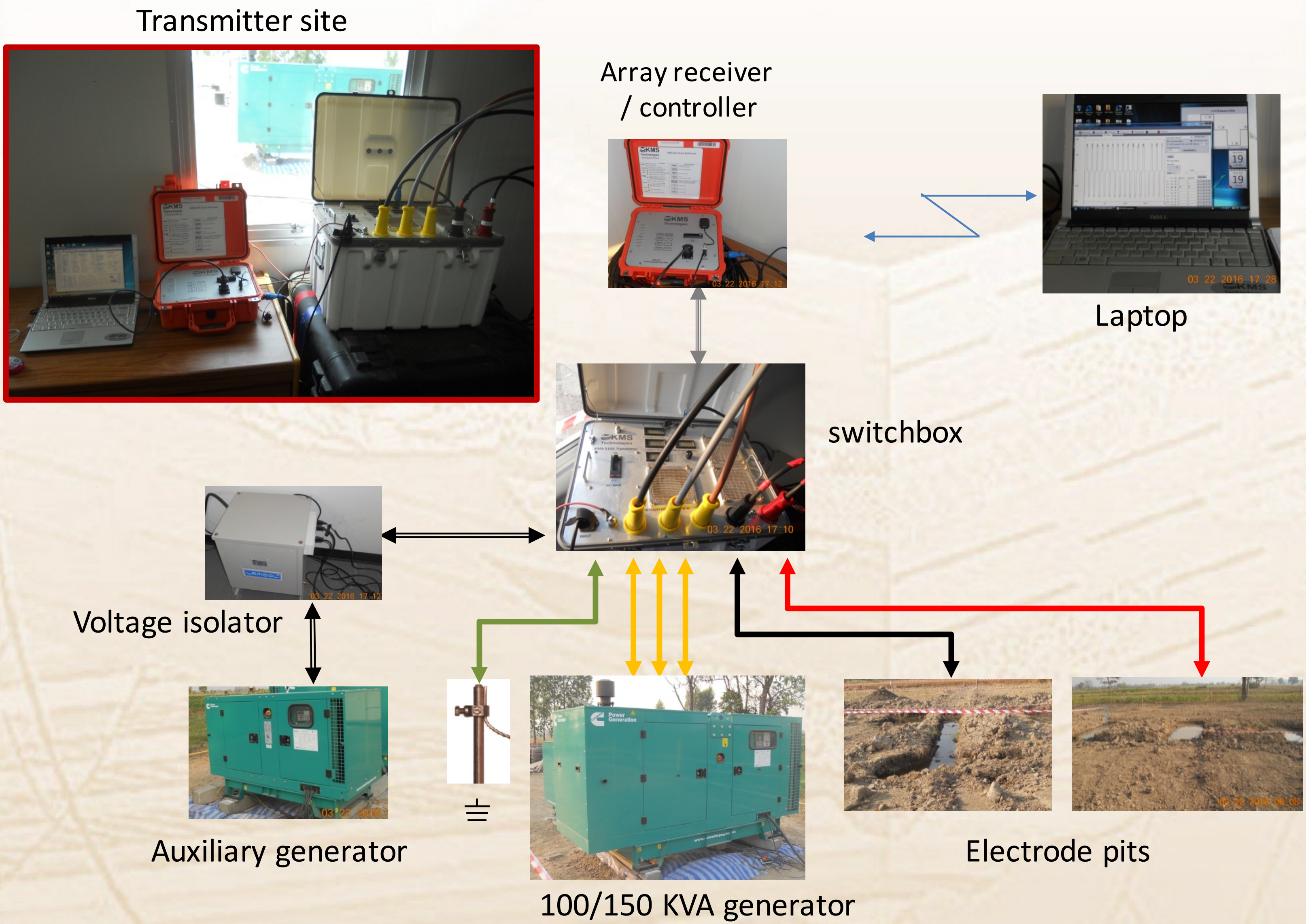
Transmitter: log time stable current controlled



KMS array system history

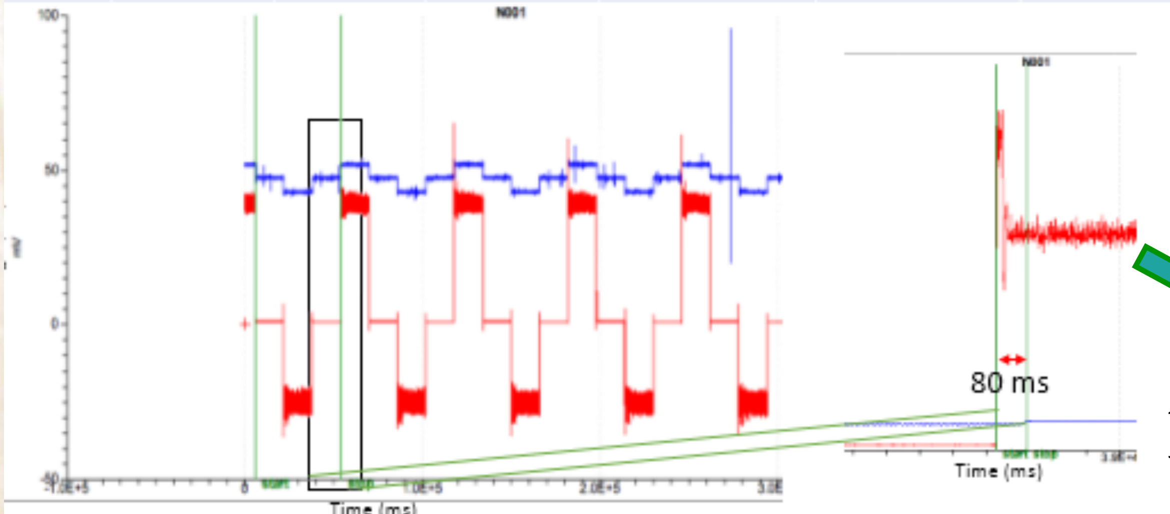
- Developed s
  - Large char
  - Industrial s
- 2008: purch A
- Since 2010
- 2014: addec) & 150 KVA)
- 2015: addec
- Can be usec ismic in single receiver dro
- HERE: high ORING
  - geophysica

Acquisition system requirements

- Receiver:
  - Continuous recording
  - EM/seismic @ high sampling rate
  - Amplifiers very stable
  - Active bias for CSEM
  - NOISE FREE data streaming
- Transmitter:
  - Electrode plants very stable with time
  - Current control < 0.5%
  - Current timing control & **verification only for monitoring**
  - Multiple safety circuits (failure & operations)
    - Electric circuitry
    - Wire cut - SAFETY
    - Waveform/current adopted
    - Controller (KMS-820) adopted

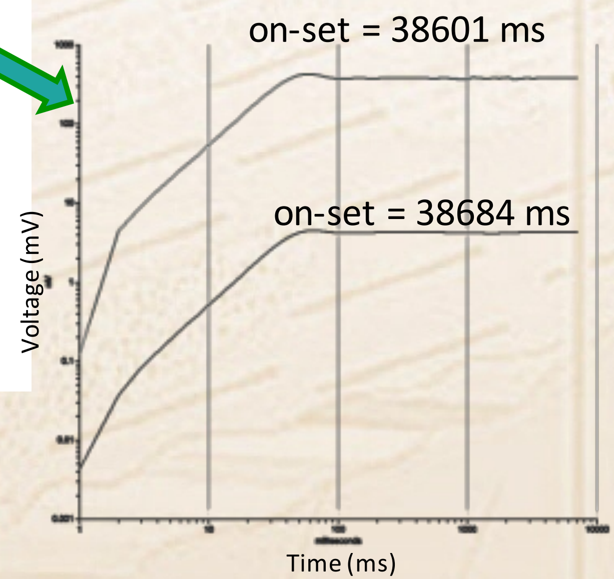
Transmitter timing: correct and verify

Data	Tx on-set (ms)	Rx on-set (ms)	Time shift (ms)	Start time	End time	Remarks
Raw	38630	38710	80	6/30/2016 9:35:45 PM	6/30/2016 9:54:45 PM	
Process	38601	38684	83	6/30/2016 9:35:45 PM	6/30/2016 9:54:45 PM	

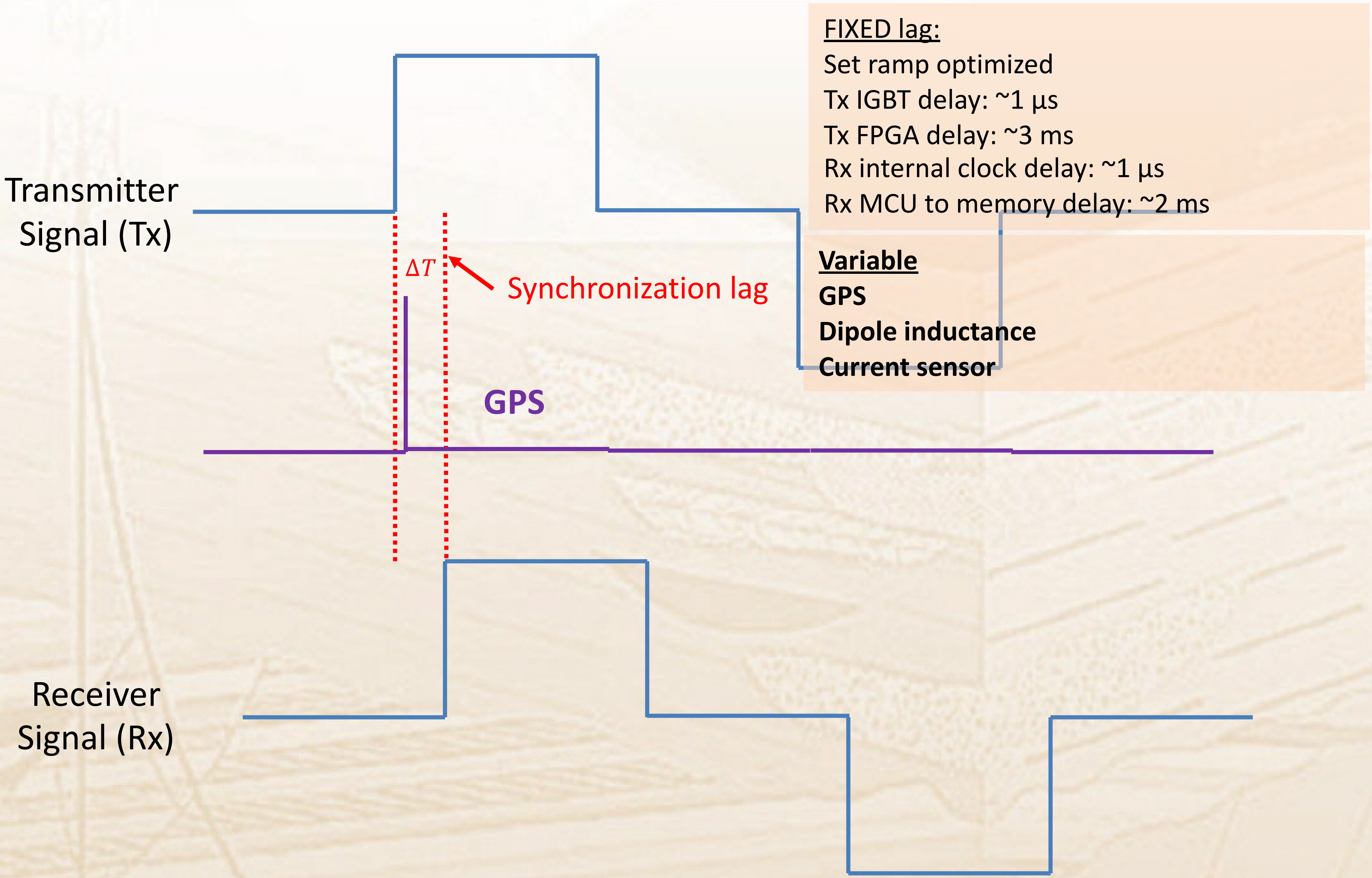


NOTE!

Tx and Rx data with same start time and end time



Transmitter signal timing diagram

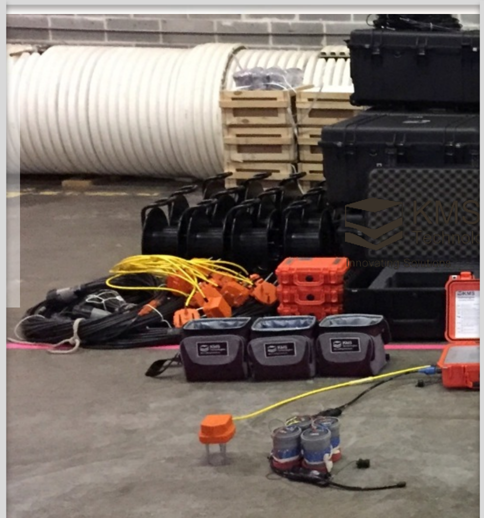


195 channel monitoring system

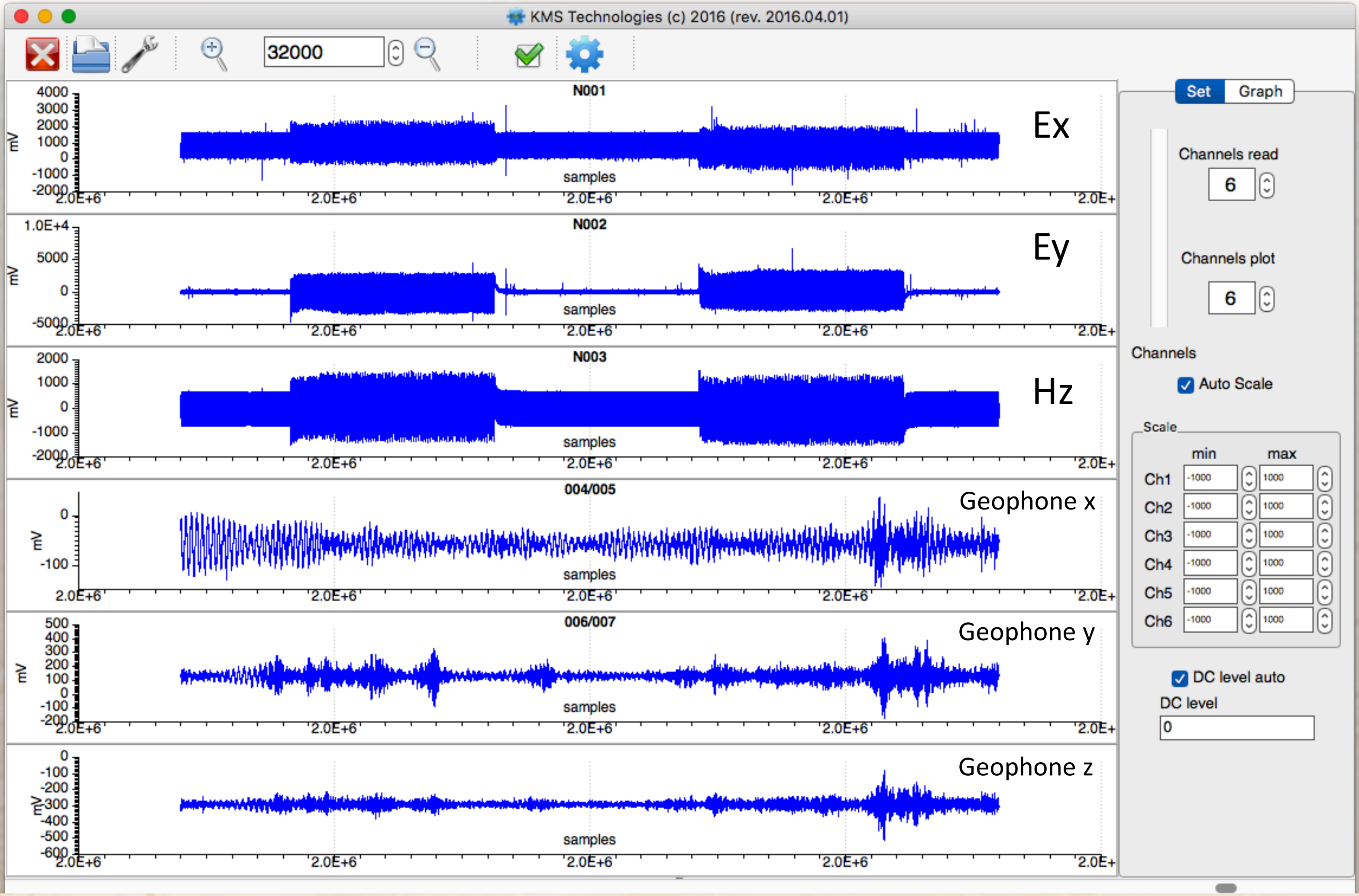
RESERVOIR MONITORING

ARRAY Electromagnetics

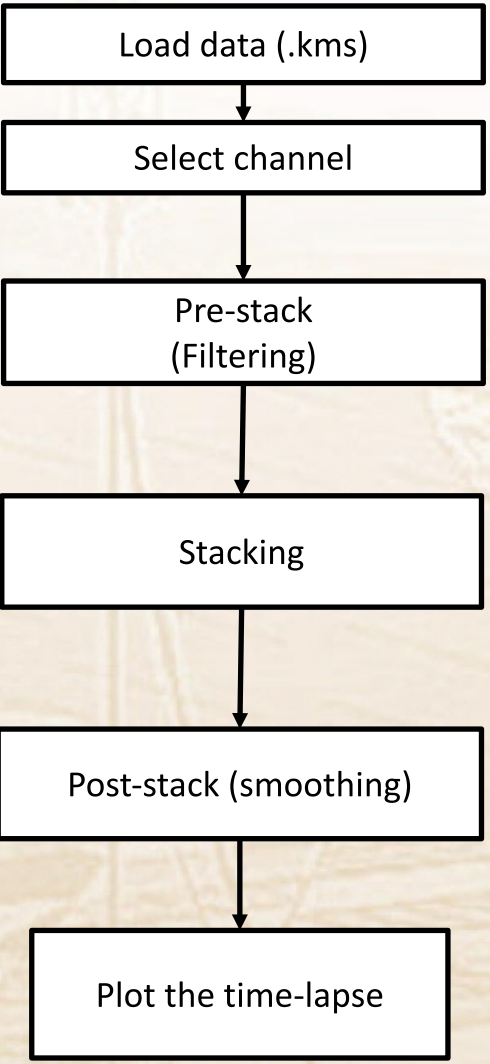
- 195 channels, wifi, wireless or LAN
- 3C magnetic field (DC to 40 kHz)
- 3C microseismic
- 2C electric fields
- Shallow borehole (microseismic/EM)

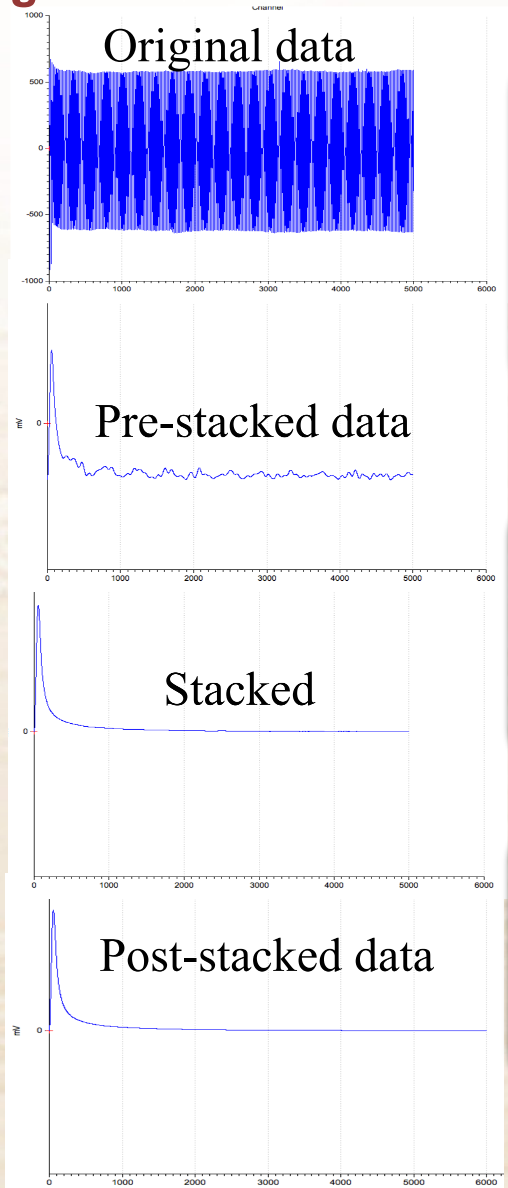


Reservoir Monitoring: Raw data example: microseismic/EM monitoring



Reservoir 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

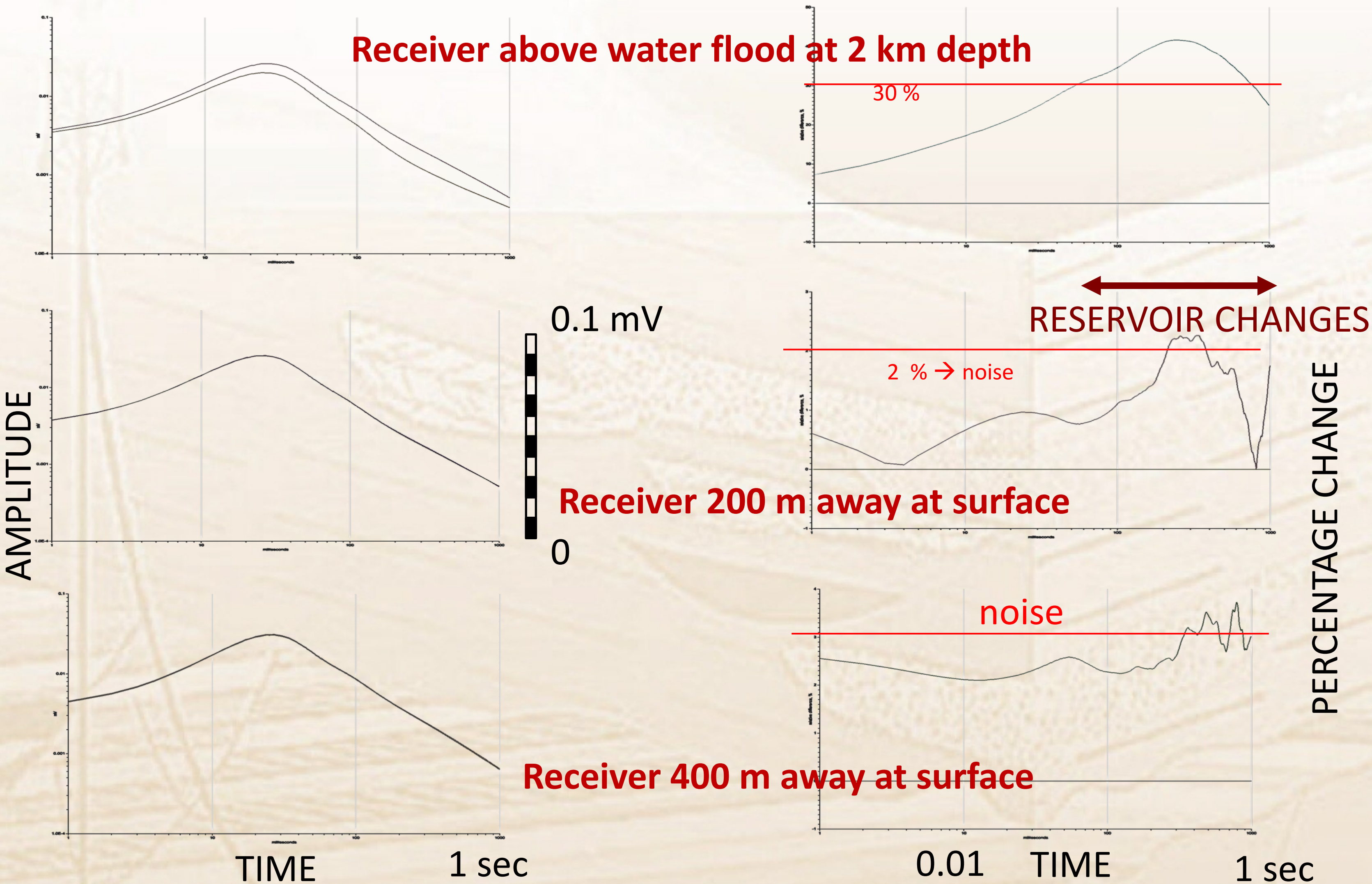
Stacking

Trimmed mean
T/2 additional stacking

- **Smoothing & time lapse**

Recursive average filter
DC-level adjust

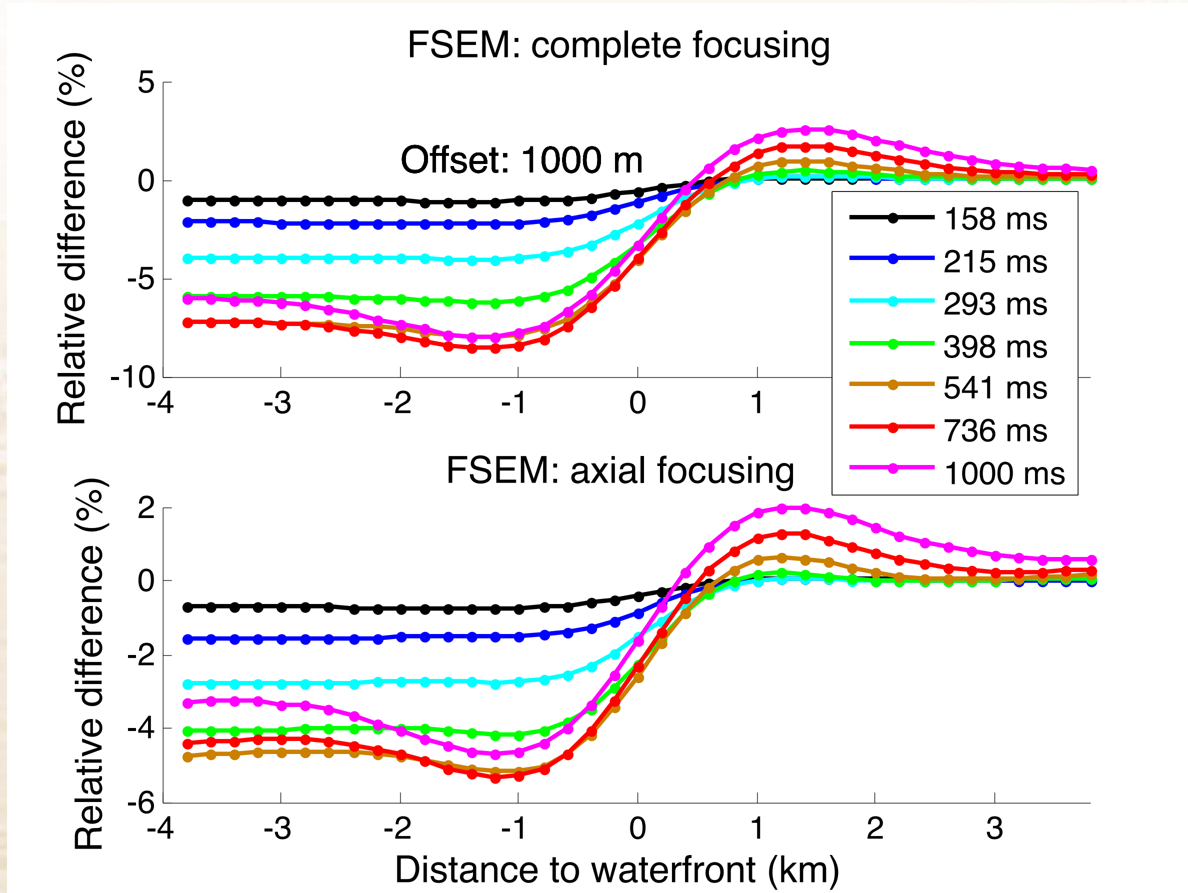
Reservoir Monitoring: Magnetic field sees water flood influence



Courtesy A. Paembonan

3D anisotropic models for FSEM/shallow borehole tool verification

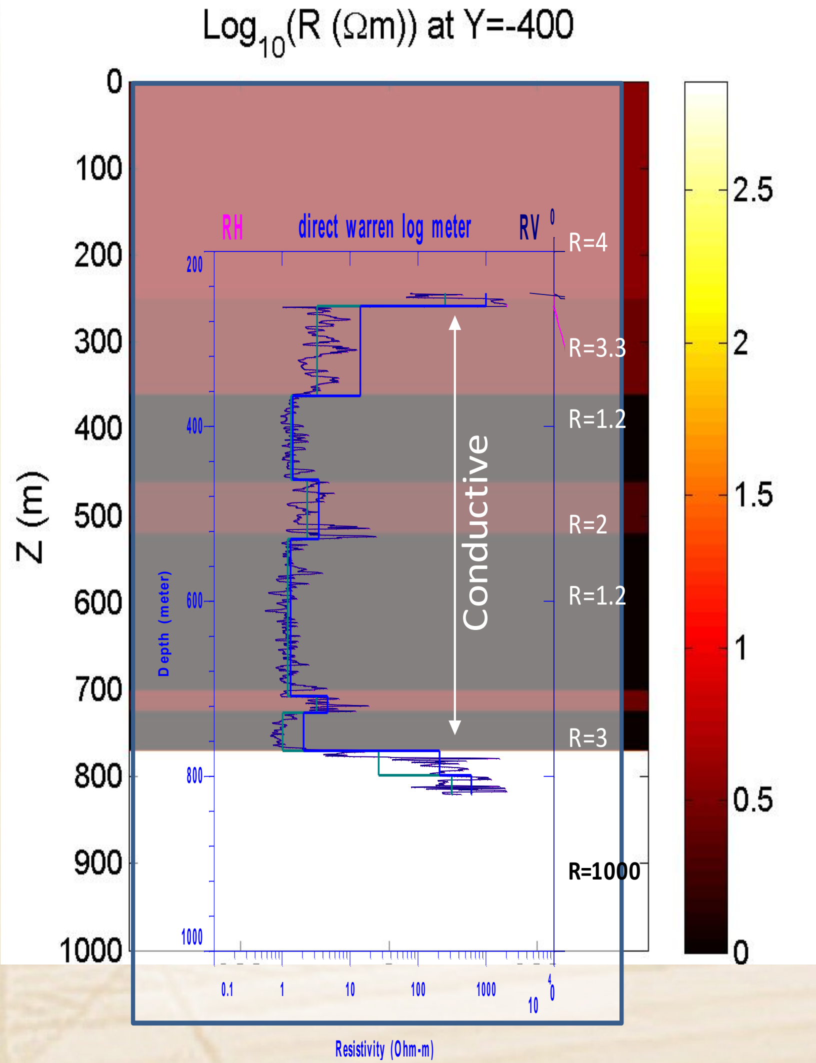
- Anomaly approx.10%
- Physics similar to Ez (shallow borehole tool)
- More field trials needed

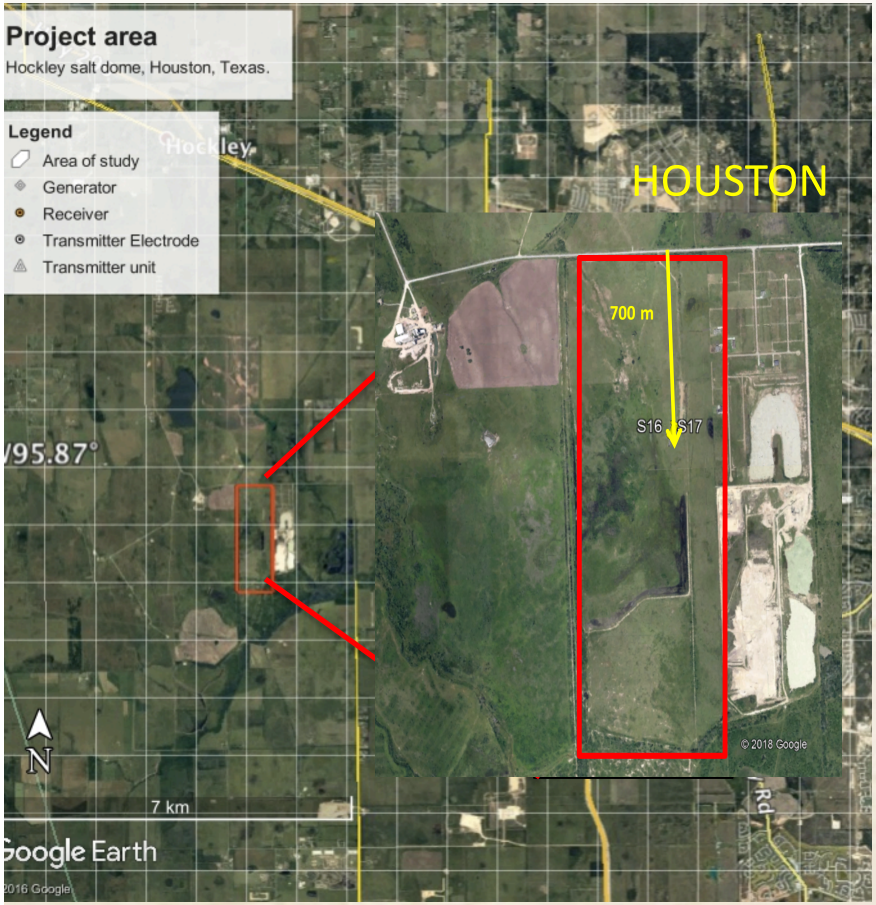


Reservoir Monitoring: summary

- Carefully log integration & 3D model confirms observed anomaly
- Data from initial test → room for improvements
- Water flood seen in MAGNETIC field
- 3D anomaly discrepancy points to current channeling
- Would need improved image focus

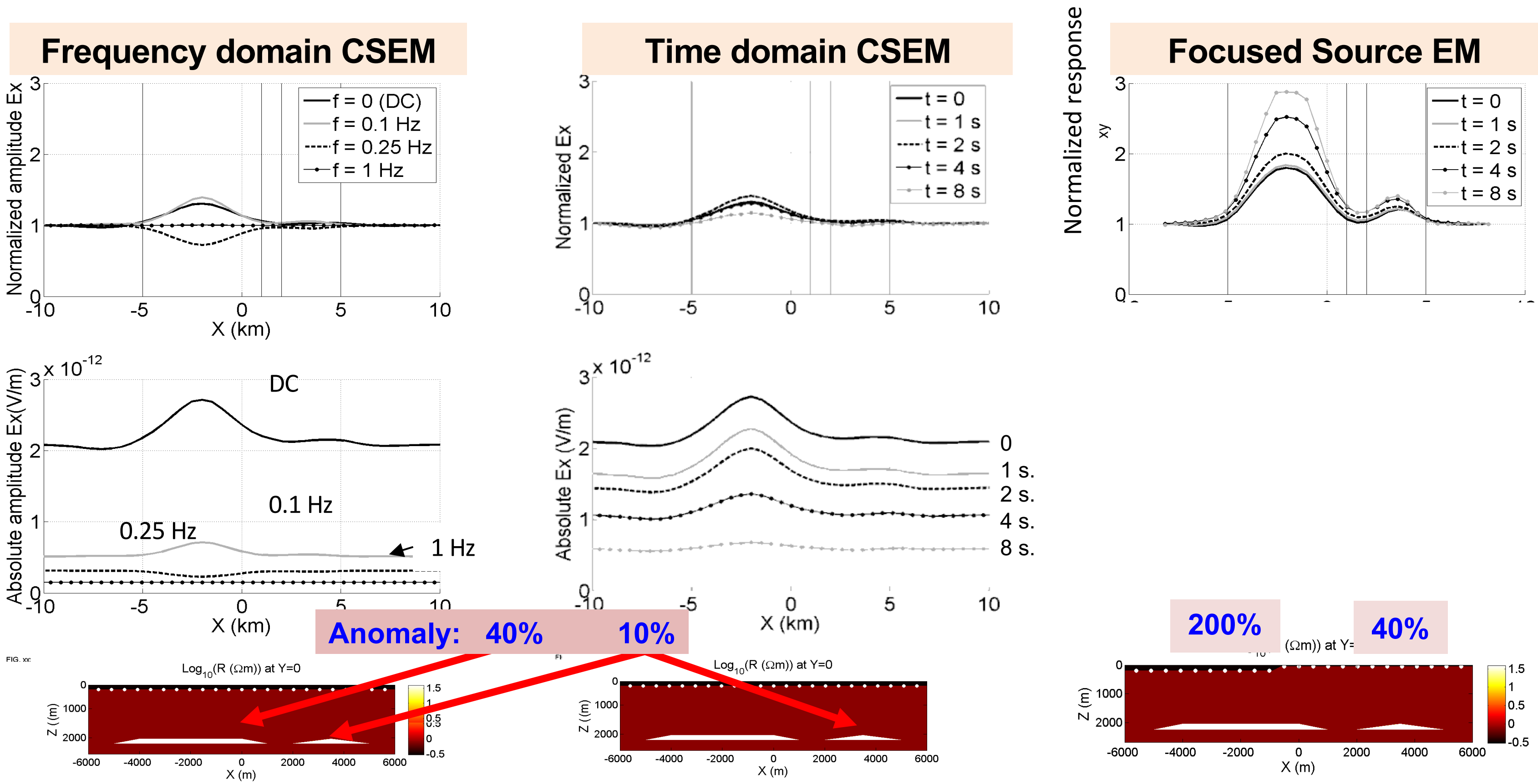
IMAGE FOCUS EXAMPLE: Hockley salt dome 10 km W of Houston



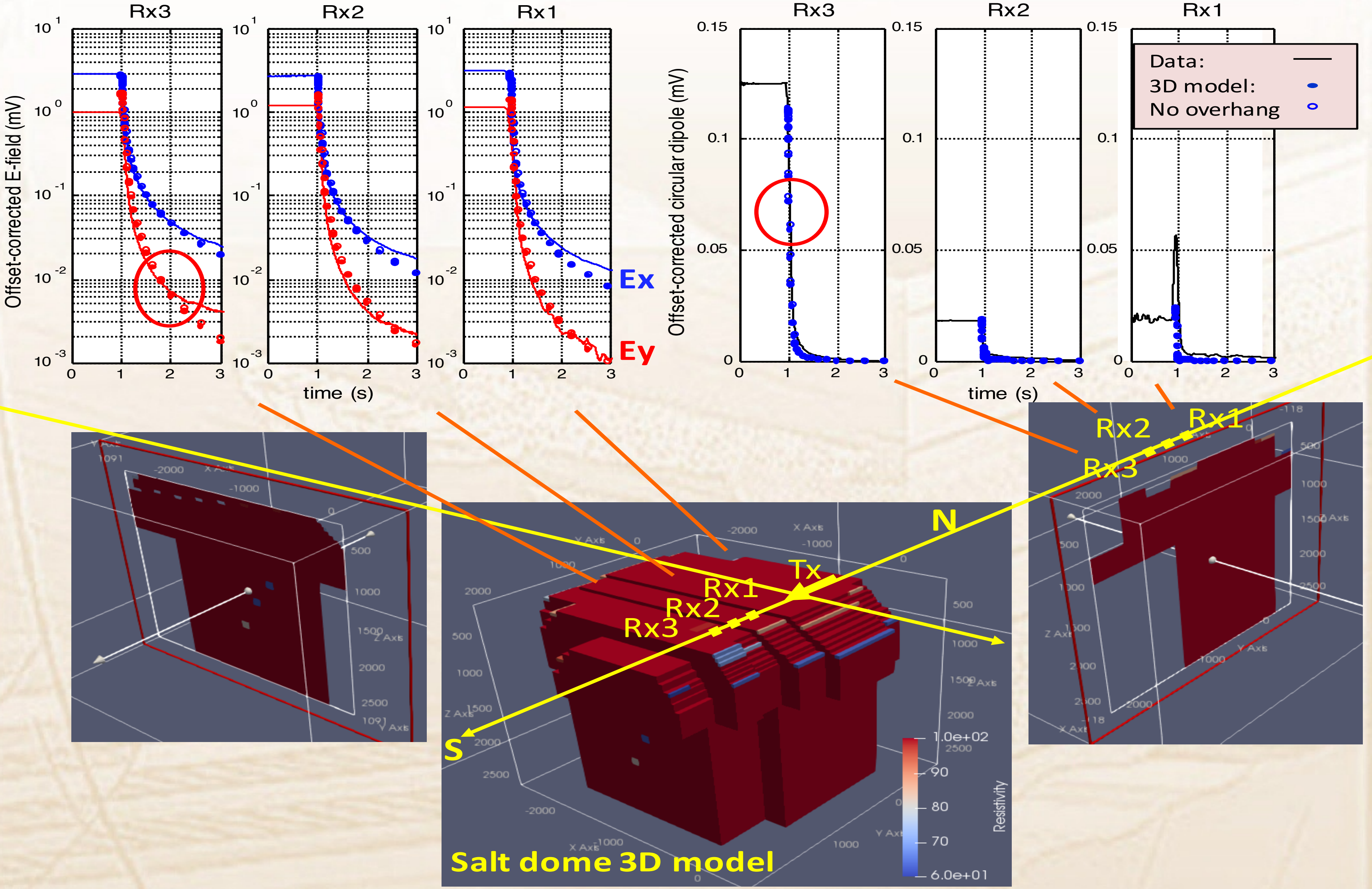


Hockley salt dome 10 km W of Houston

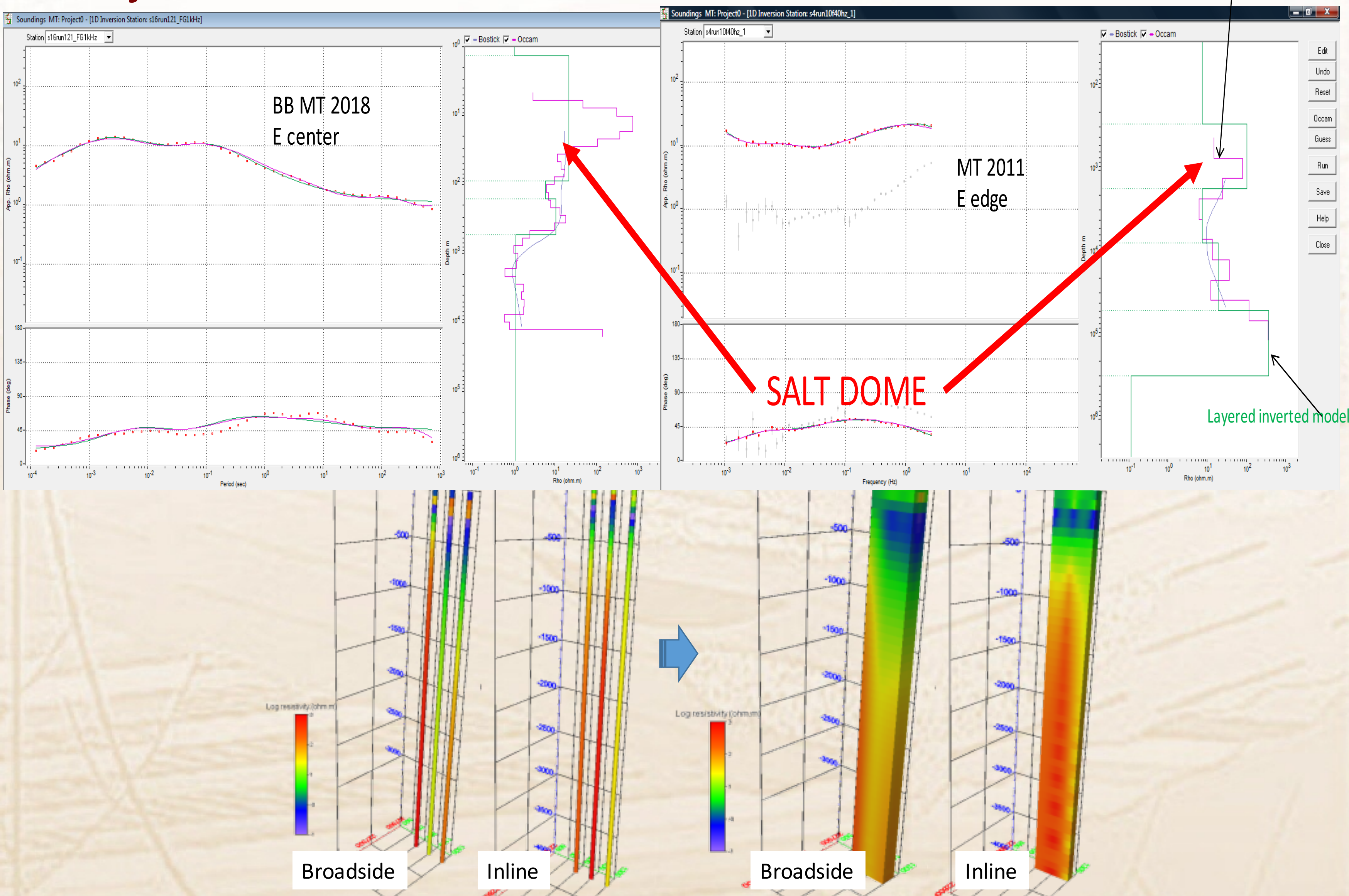
Conventional CSEM versus Focused Source EM



Hockley salt dome: Focused 3D anisotropic model



Hockley salt dome: Lotem & MT inversions



Hockley salt dome: Summary

- Focused Source EM (FSEM) sees overhang
- Consistent for Dipole-dipole, Lotem & MT, but both are 1d wi unknown image focus
- More data will be acquired

- We have addressed the accuracy issue with EM system to get repeatable data
- Image focus can be improved via FSEM (similar with shallow borehole tool)
- Anisotropic 3D models are required

THANK YOU

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...and all KMS staff.

All technology protected by US & Foreign patents
(see KMS Technologies website)