HEAVY OIL
SPE INTERNATIONAL HEAVY OIL CONFERENCE & EXHIBITION
6–8 December 2016
Hilton Kuwait Resort, Mangaf, Kuwait

SPE International
Society of Petroleum Engineers

SPE-184089-MS
Integrated Geophysical Reservoir Monitoring for Heavy Oil

H. Passalacqua, ACK, Kuwait
K. Strack, KMS Technologies, Houston, Texas

OUTLINE

1. Enhanced Oil Recovery
2. Hardware
3. Field Setup
4. Focused Source EM
5. Feasibility
6. Modeling
7. Conclusions

Enhanced oil recovery challenged by the knowledge of the oil/water front

- Limited geophysical techniques have been used for this application.
- Changes of the physical characteristics of the reservoir during production can be imaged by geophysical measurements taken at different times, also called 4D Geophysics.
- One of the biggest advantages of the usage of Geophysics for this purpose is the imaging of the reservoir away from the wellbore, improving the lateral continuity of the reservoir models.
- Seismic reflection methods have been used for this purpose with mixed results.
- Reservoirs under water flood or steam injection are particularly adequate to be monitored by Electromagnetic Methods.

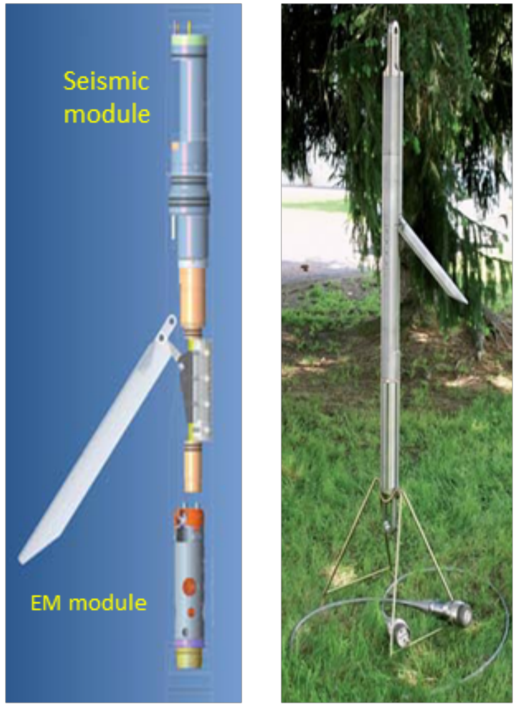
EM Methods offer several advantages over other geophysical techniques

- Very sensitive to temperature changes. For a temperature change of 100 °C resistivity changes of 150% and P-wave velocity of 33%.
- Allows the tracking of the steam injection away from the injection wells.
- Several times less expensive than seismic techniques.
- Faster data acquisition and processing.
- Shallow reservoirs allow higher frequency content.
- Possibility of tailoring the techniques to the target by choosing the right method.
- Fast field deployment.
- These techniques can be used with different geometries: from the ground surface, downhole, in a surface-to-borehole array or in borehole-to-surface array.

Reservoir Seal Integrity

- Seal integrity can be an issue for shallow reservoirs submitted to steam injection.
- The injection of steam produces an increase in the original pressure of the reservoir creating potential problems to the integrity of the cap-rock.
- The production of fractures produces small amounts of seismic energy measurable with micro-seismic sensors.

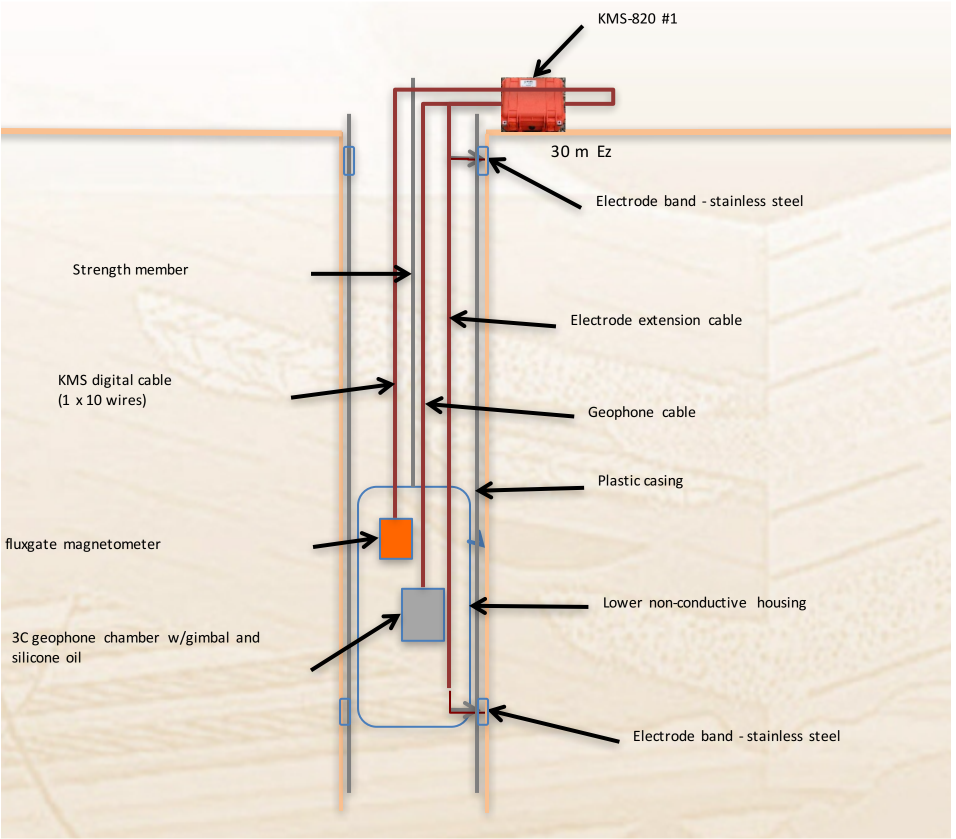
Electromagnetic Hardware

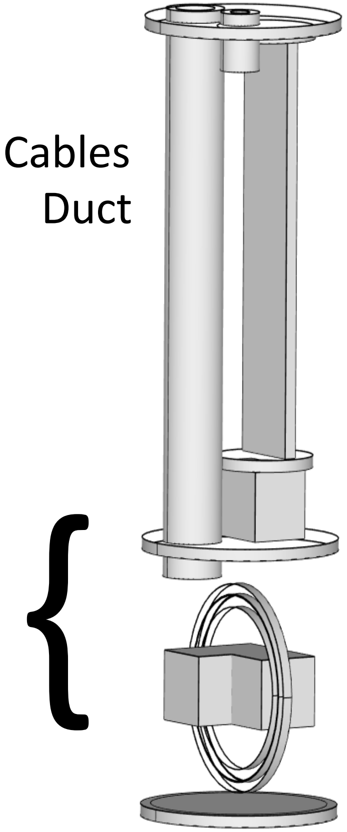


Combined seismic and EM node
For 9- days operation

Shallow borehole tool

- Monitoring: larger anomalies with shallow boreholes





Field Setup

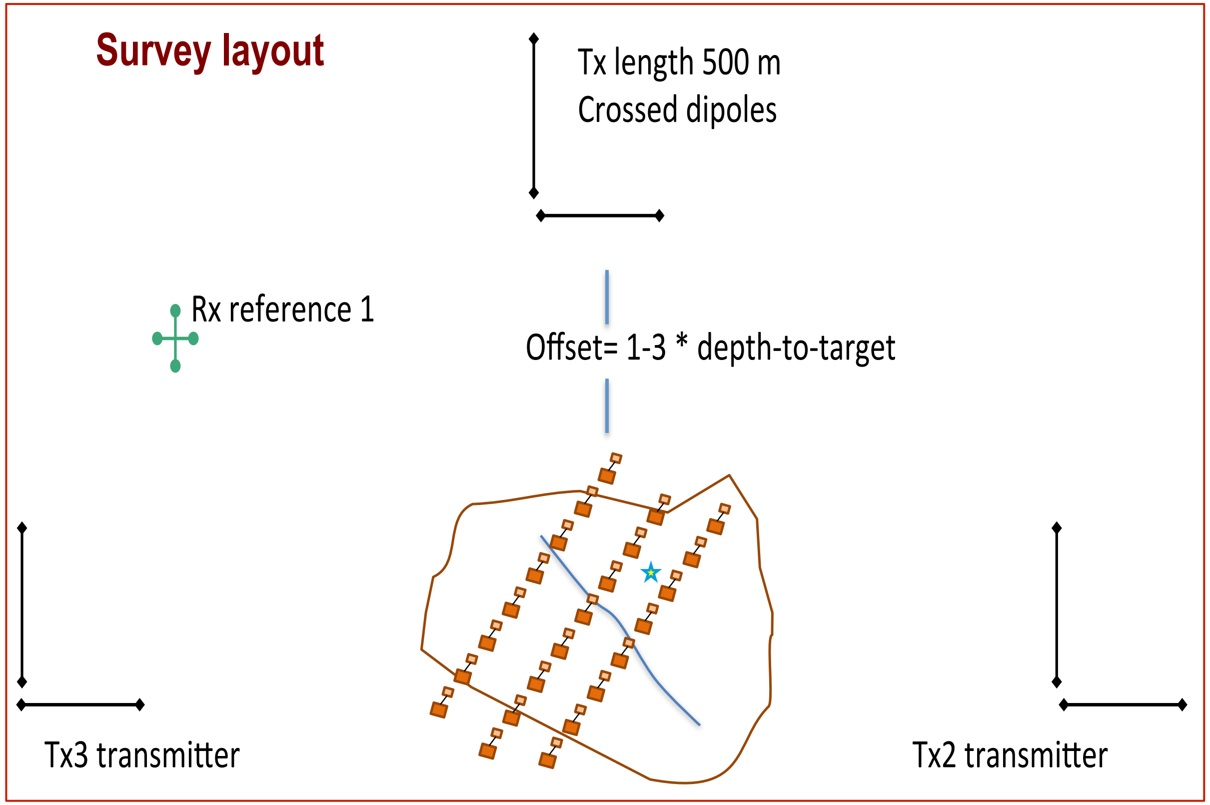
Microseismic sensors

Site	KMS instrument	Ex & Ey	Hz	3C fluxgate H	3C geophone	Shallow borehole tool
	820	x	x	x	x	x
	831	x			x	

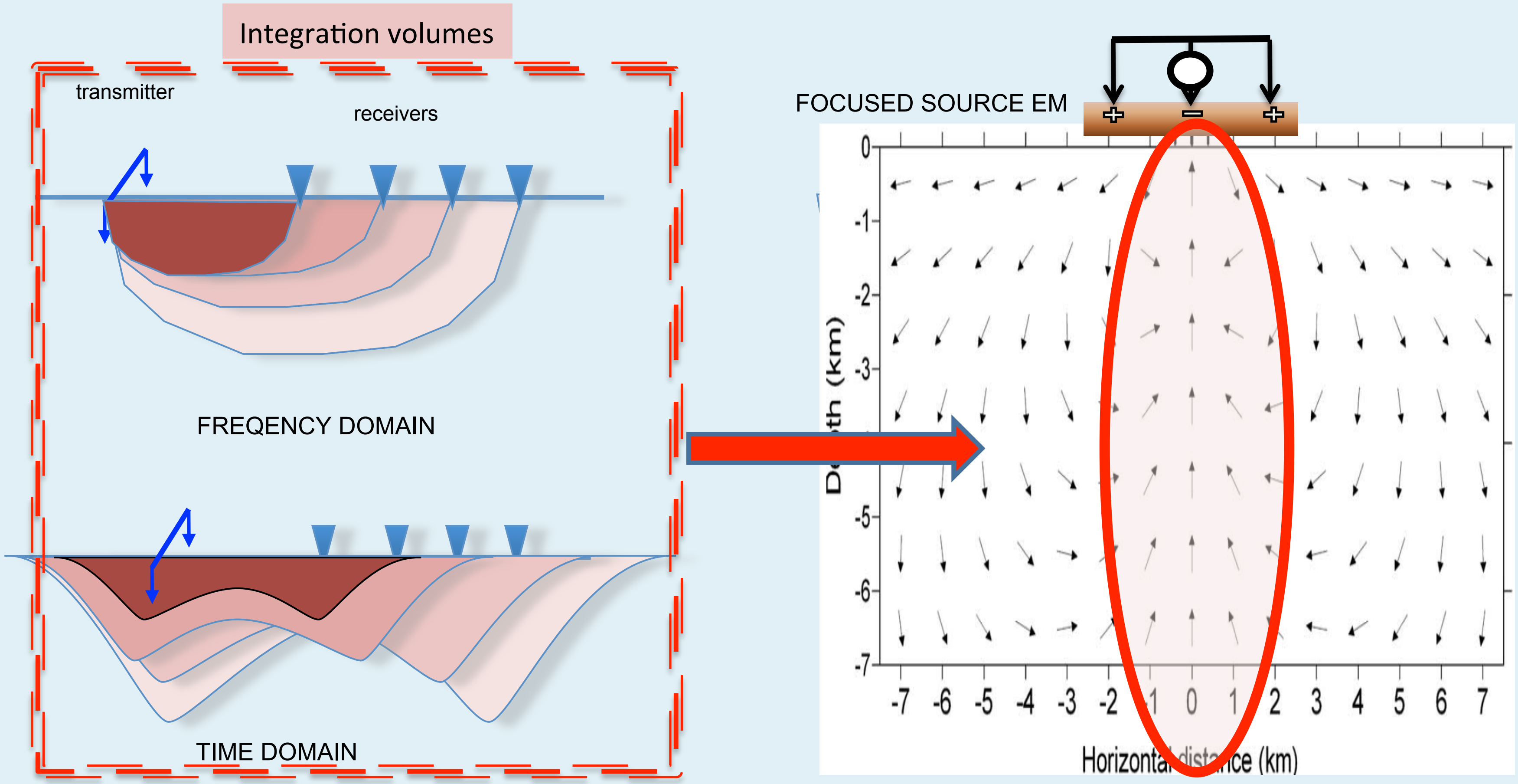
E – electric field sensors

H – magnetic field sensors

Shallow Borehole Tool – KMS-888 includes 3C seismic, 3C magnetic & 3C electric sensors

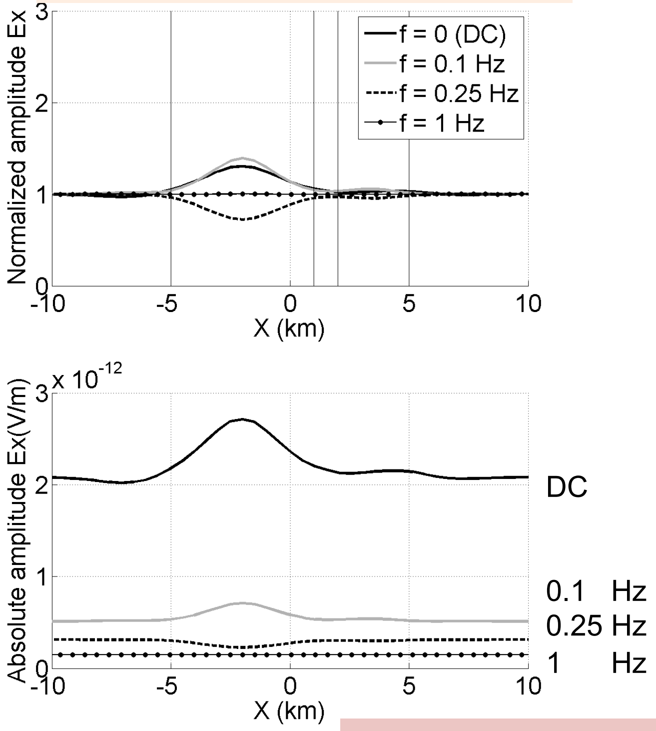


FSEM: Focused source solution to volume imaging

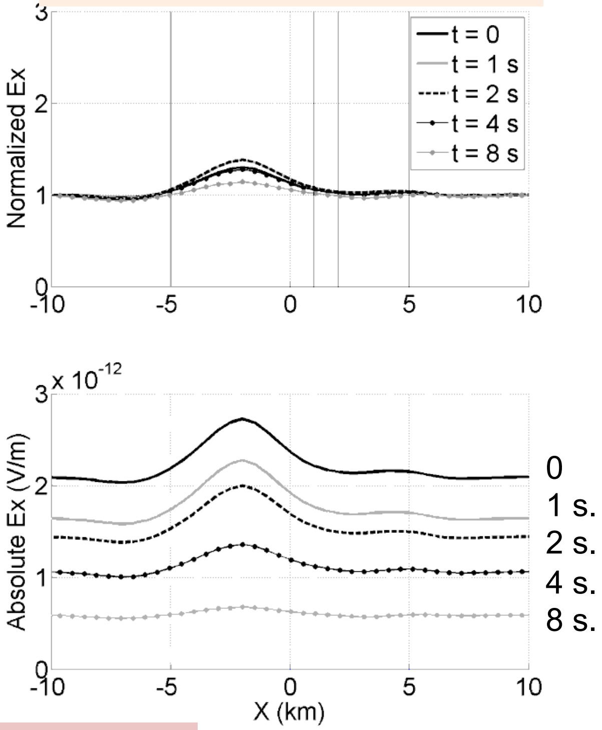


Focused Source versus CSEM

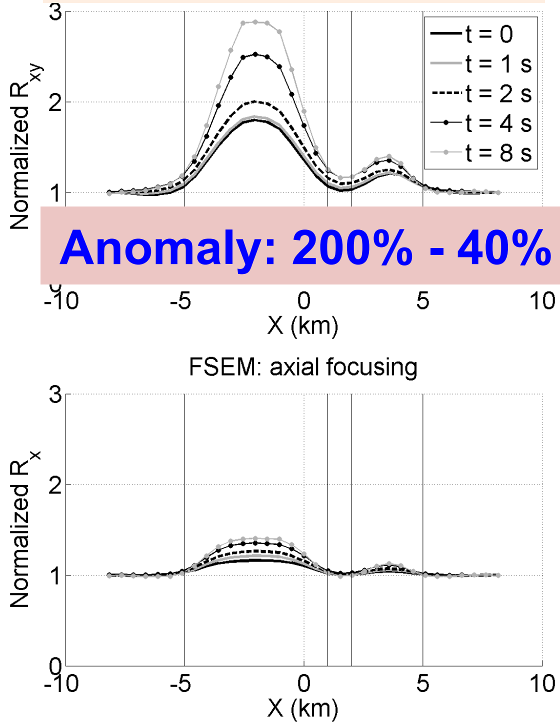
Frequency domain CSEM



Time domain CSEM



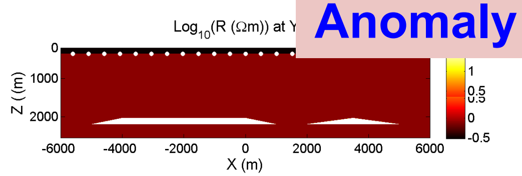
Focused Source EM

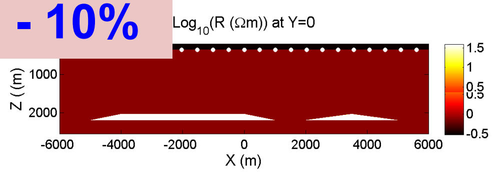


Anomaly: 200% - 40%

Anomaly: 40% - 10%

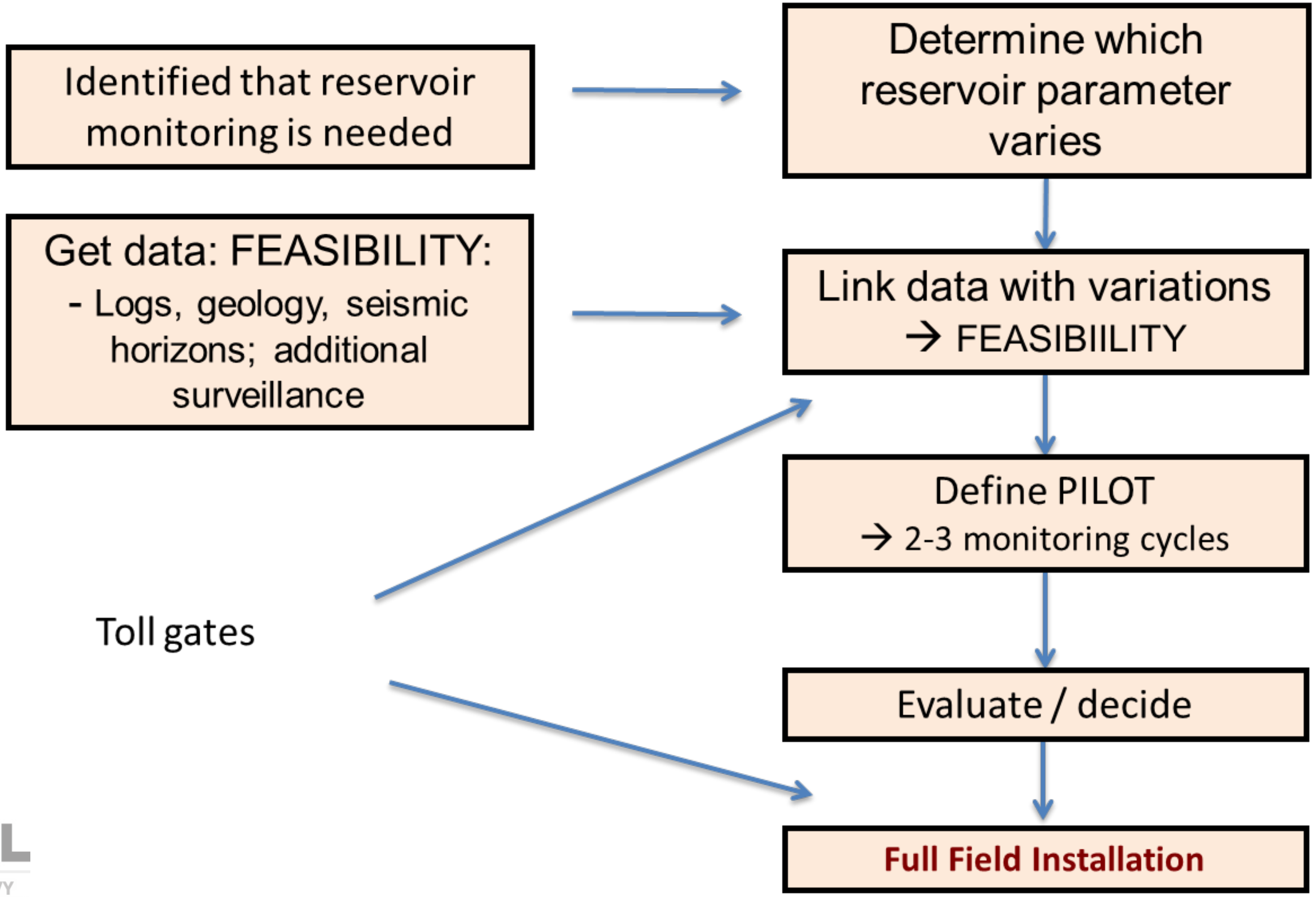
FIG. xx



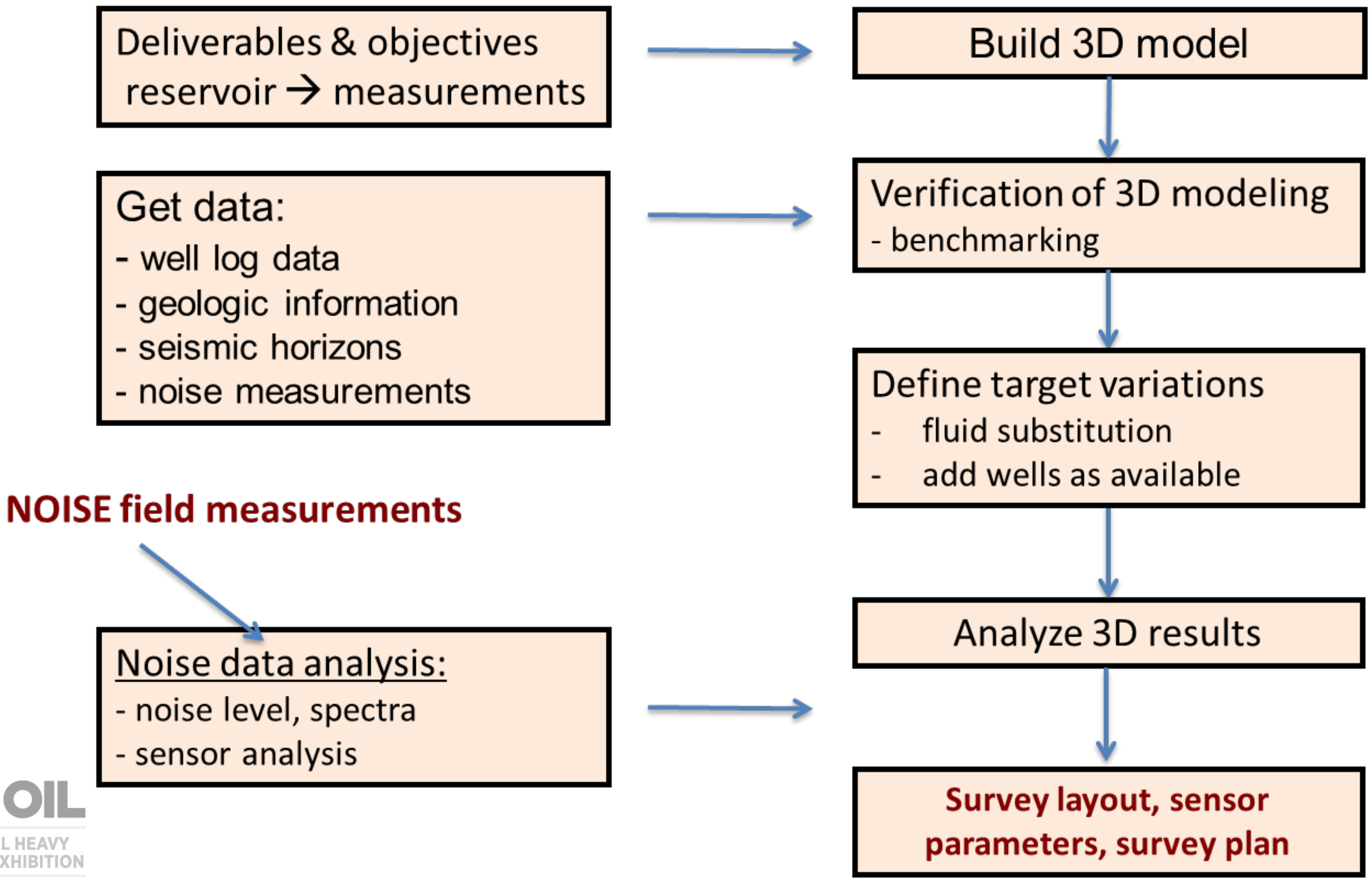


- **Smaller reservoir can be detected**
- **Higher spatial resolution**

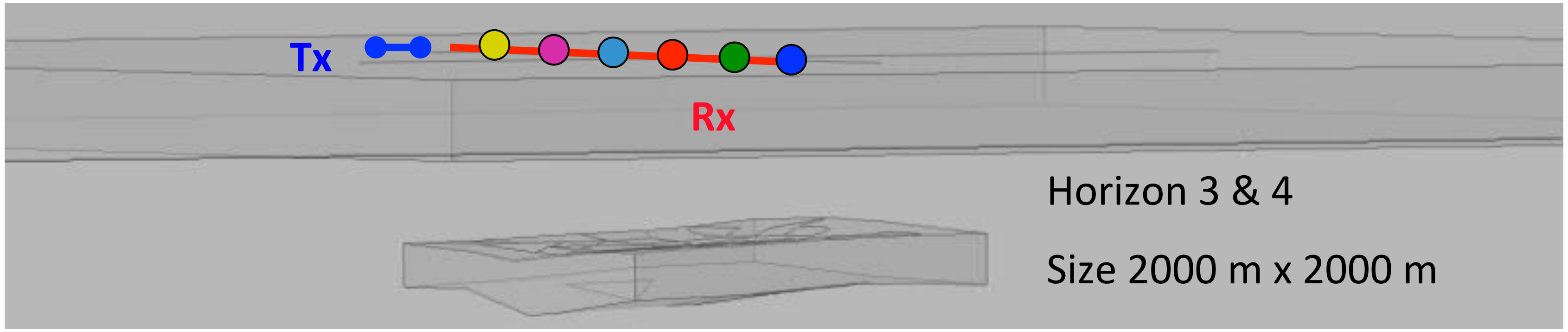
Reservoir Monitoring: Problem to Implementation Workflow

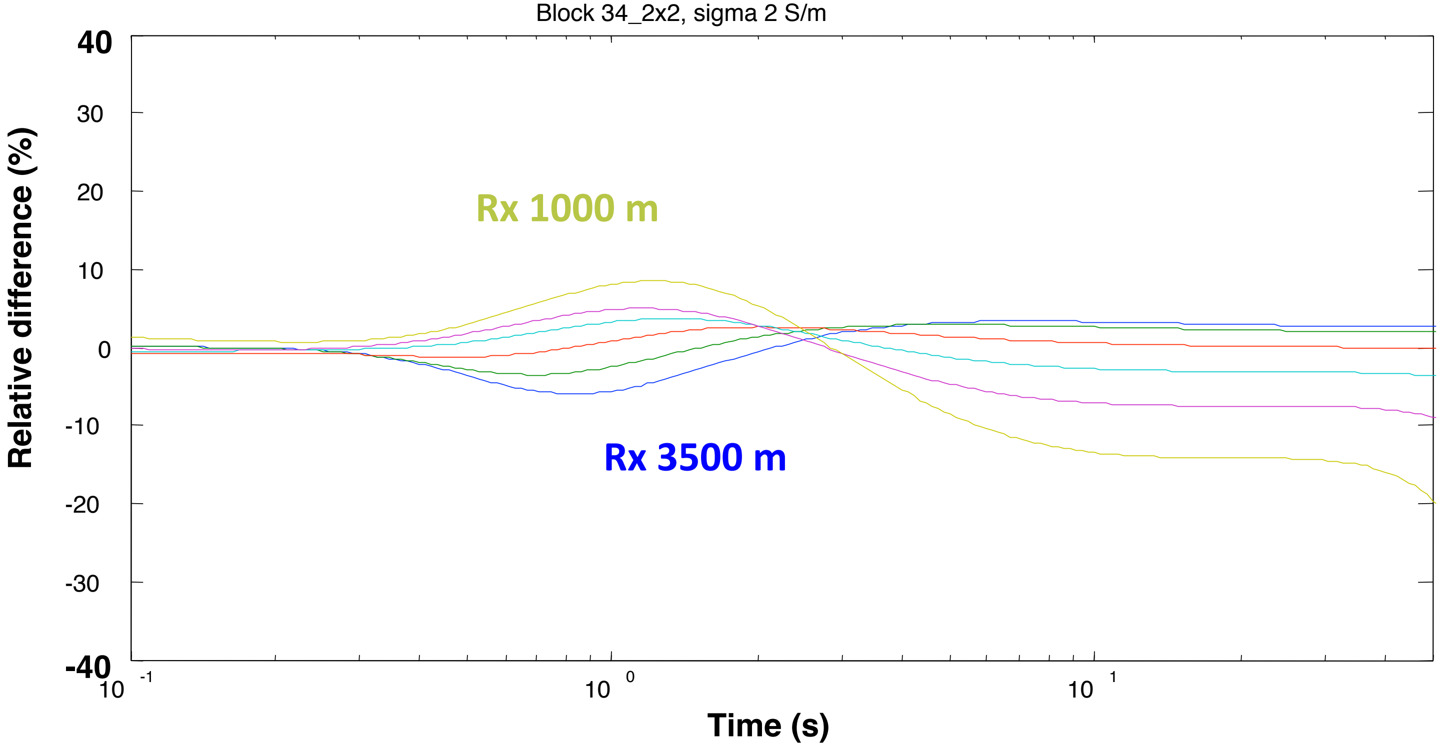


Feasibility workflow for reservoir monitoring

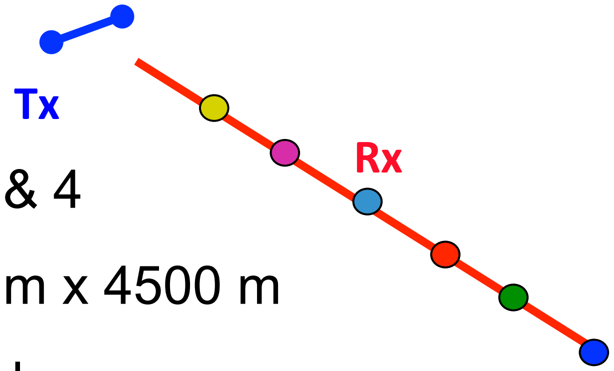


3D reservoir: relative difference





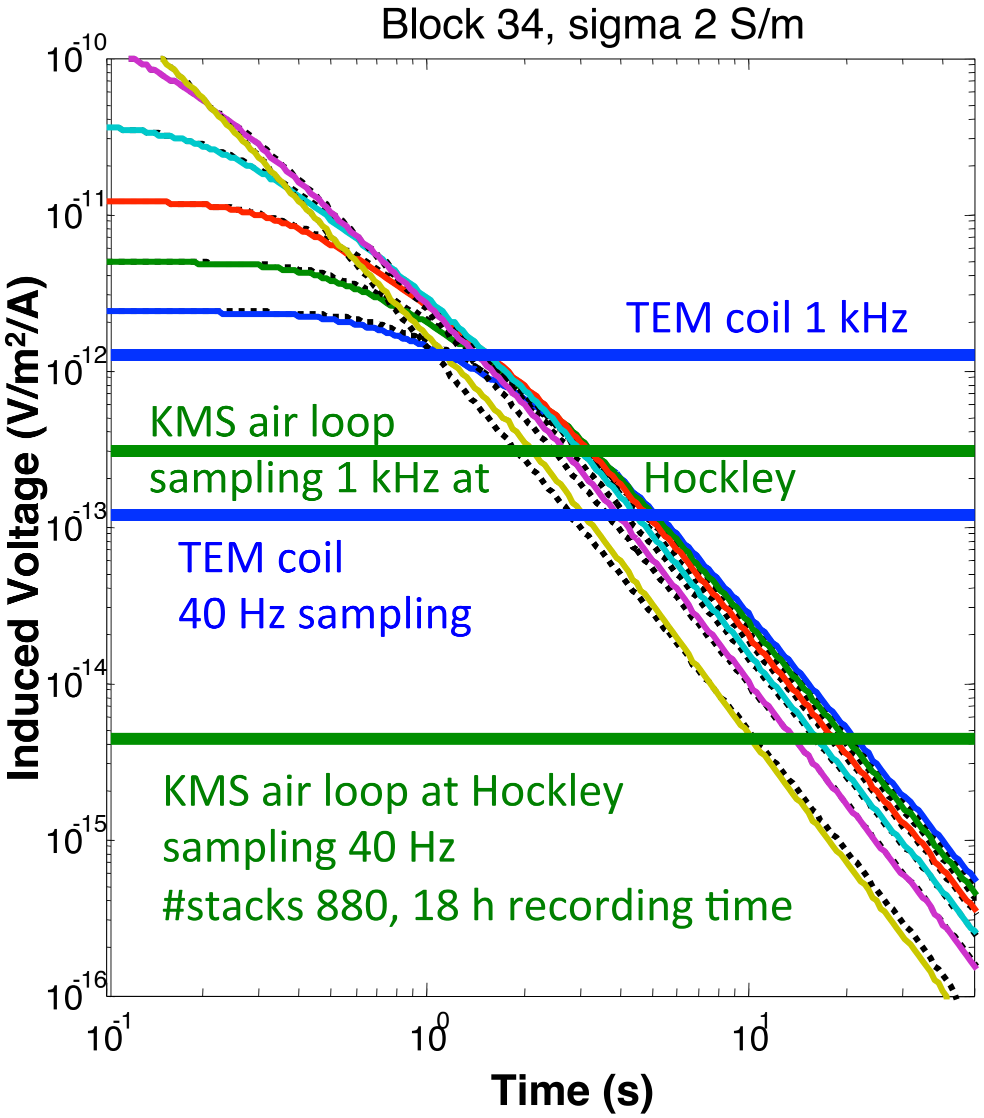
Transients with expected noise levels



Horizon 3 & 4

size 6000 m x 4500 m

whole block



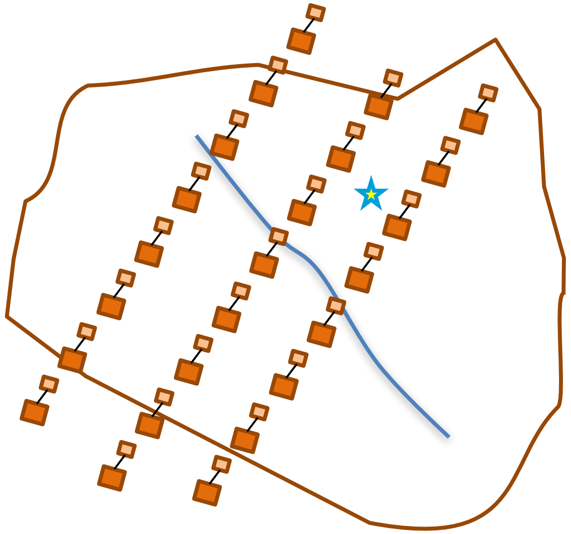
Tx -current:

300 A
2x longer than 200 m
2x switch step over

= 1200 A

nio Passalacqua

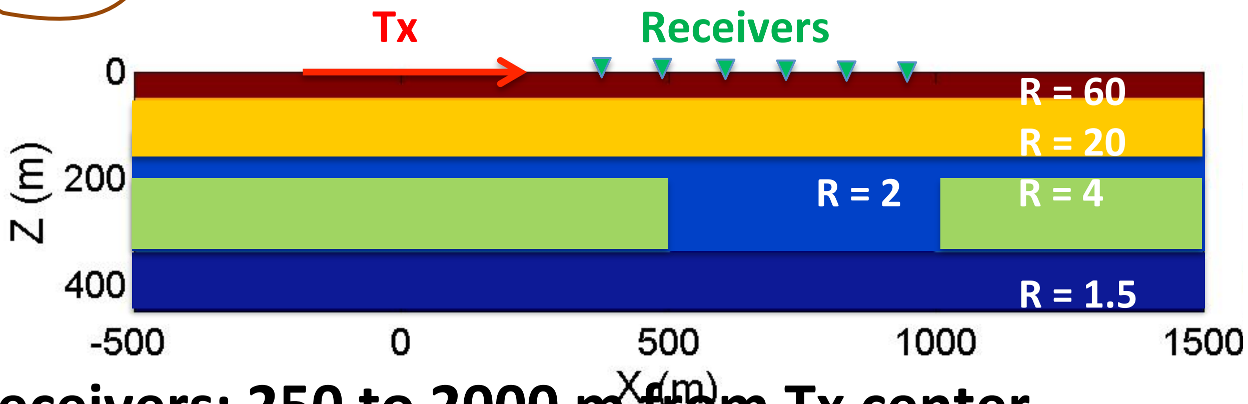
Fluid Substitution Model



Flooded area top view: square 500x500 m

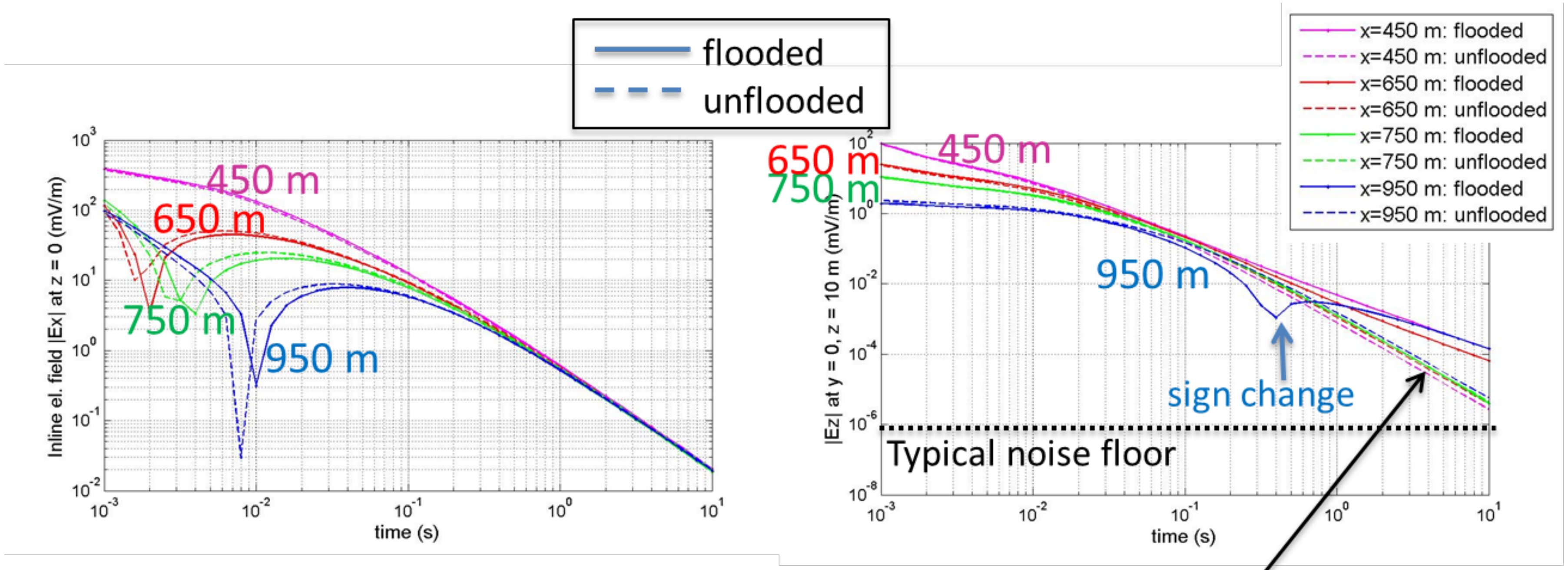
Oil-saturated rocks (R = 4, green) substituted with water-saturated rocks (R=2, blue)

Flooded area vertical cross-section



- **Receivers: 250 to 2000 m from Tx center**
- **Ex, Ez, dBy/dt**
- **(Other components = 0 due to the medium & setup symmetry)**

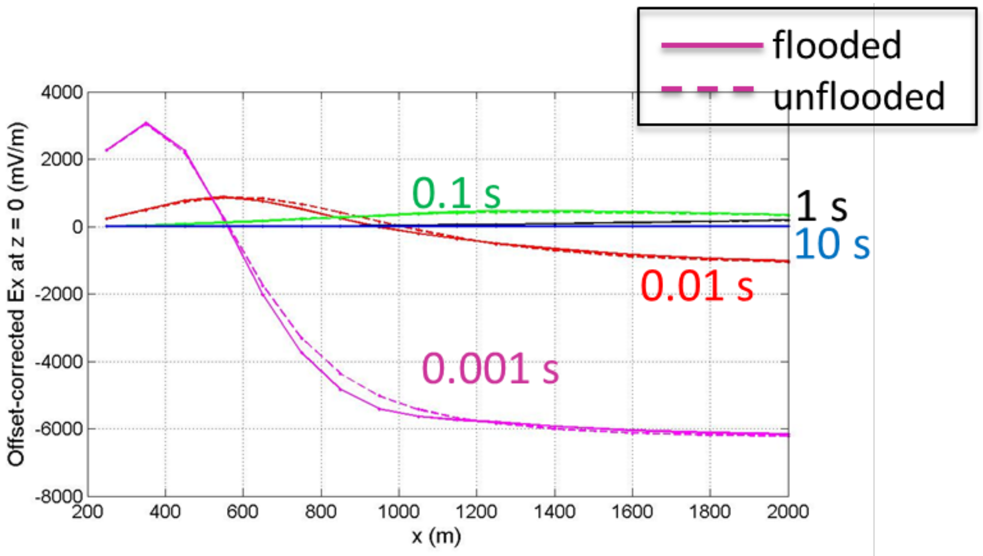
Electric field Ex (z = 0) & Ez (z = 10 m)

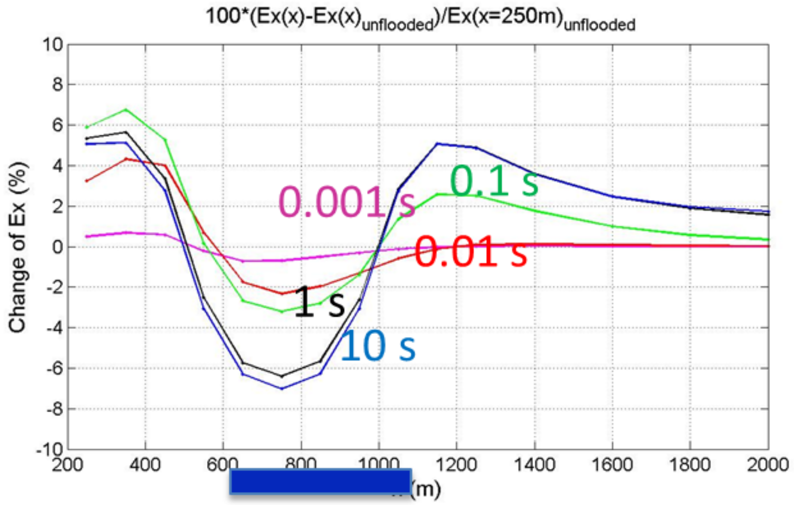


Ex: late-time effect not seen in log. Scale.

Ez: late-time effect significant (many times); seen well above the noise floor.

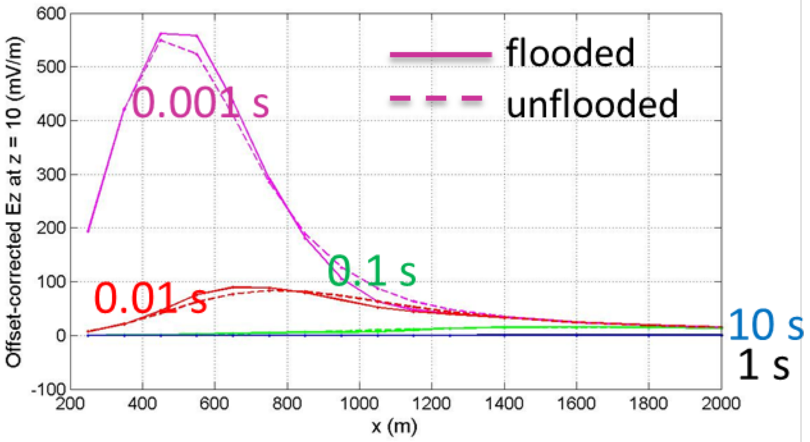
Electric field Ex (z = 0) as function of distance



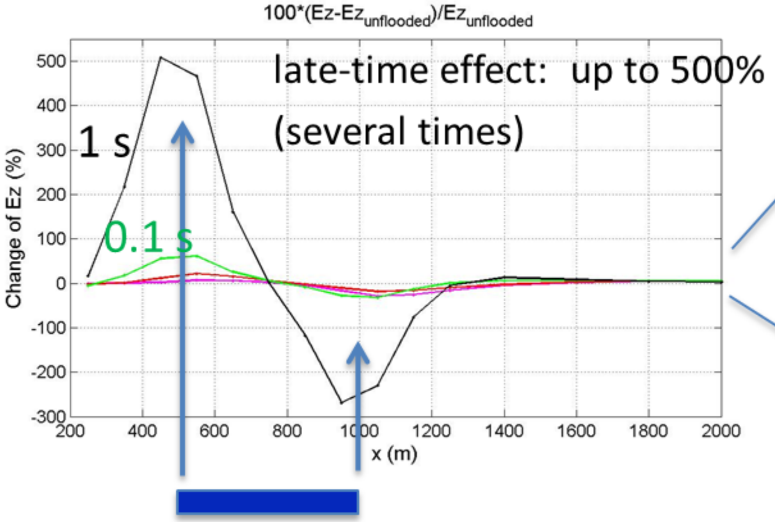


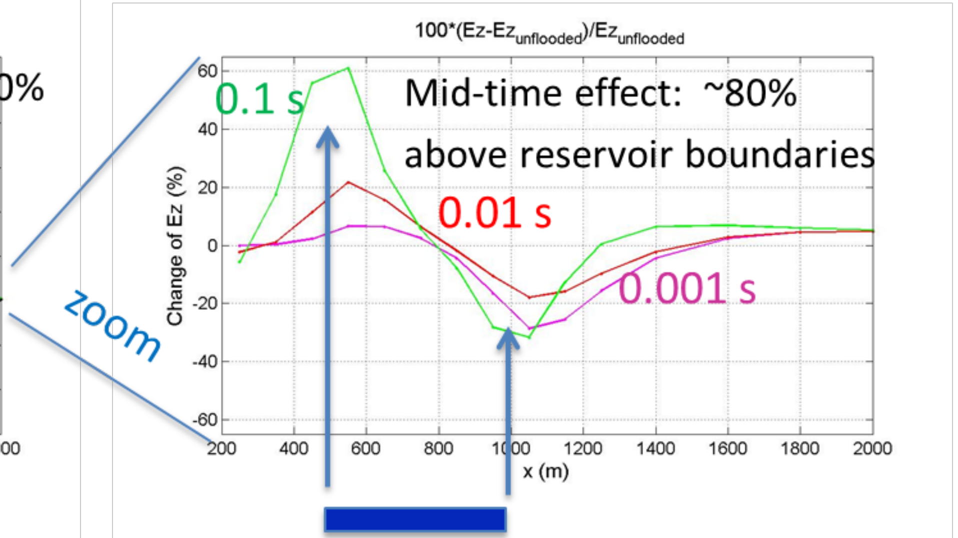
Late-time effect:
7% reduction
above reservoir.

Electric field Ez (z = 10 m) as function of distance

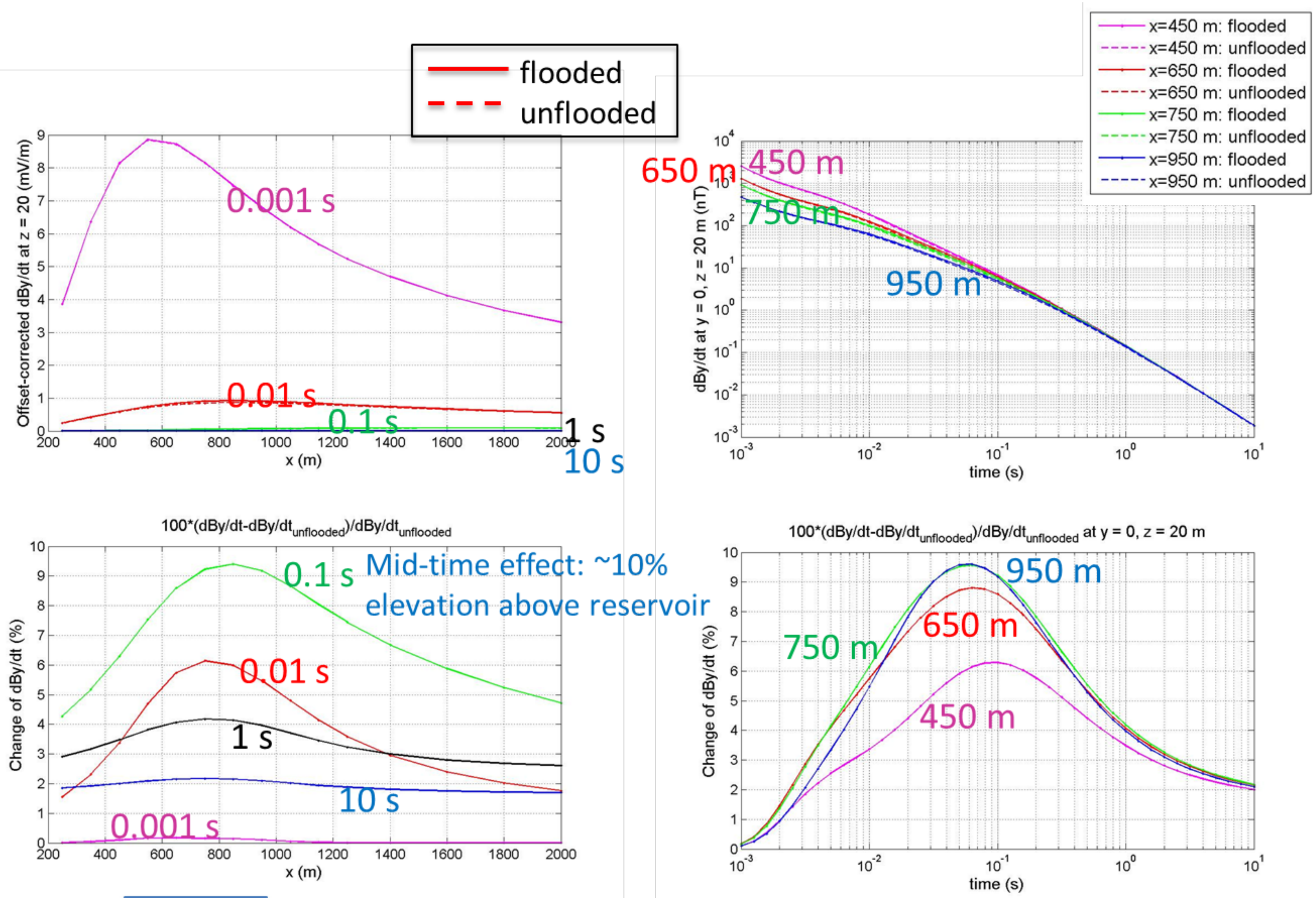


Water-flooded area contour may be determined with great accuracy





Magnetic field dBy/dt at z = 20 m, in shallow borehole



Conclusions

- The mapping of the steam front in an EOR process improves the recovery factor as it allows the optimization of flooding.
- Among the geophysical methods, electromagnetic methods are the most suitable methods for this task as they allow fluid imaging in a 4D measurement approach.
- A complete new generation of technology exist including new array acquisition hardware, transmitter, shallow borehole sensors, processing and 3D interpretation methods.
- 3D numerical modeling have shown that the electrical anomalies produced by the fluid substitution are measurable in the field.
- Using these tool for Feasibility study we can reduce the risk to carry out Pilot for steam flooding and greatly contribute to the production effort.

Acknowledgements

- We appreciate the support of T. Hanstein and S. Davydycheva of KMS Technologies for performing the noise tests and 3D modeling.

- Over the years we have received support from many companies. They included: Aramco, BP, DeepLook consortium (BP, Chevron, ConocoPhillips, Shell), ENI, Ormat, PTTEP, Shell, WellDynamics.

- We also thanks our organizations for permitting to publish this paper.