NUMERICAL SIMULATION OF AQUIFER DETECTION USING LOW FREQUENCY PULSED RADAR

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MOTIVATION

- Explore capabilities of low frequency subsurface radar

- Model commercial 3MHz system built by Adrok Inc.

- Low frequency radar systems (1-5MHz) used for km range imaging:
  - Mars
  - Antarctica

- How far can we see through rock with such a system?

SIMULATED EXPERIMENTS

- Measure sensor sensitivities and noise levels

- Measure ground parameters in-situ through limestone

- Physical model: Sensors + ground + Maxwell equations

- Implement numerical simulator:
  - FDTD Maxwell + ground model in 1D
  - Raytracing in 2D
  - FDTD 2D/3D under development

- Insert measured sensor + ground parameters into model

- Perform virtual experiments + data analysis

CASE STUDY

- Goal is to detect aquifer depth D=350m and further down

- Aquifer under limestone

- At depth D can we
  - Detect round trip time of reflection from aquifer?
  - Measure velocity in medium? (CMP/WARR triangulation)

- How much stacking needed?
  - How deep can we see with a 1 day long scan?

- How long should the CMP/WARR line be?
  - How many points need to be sampled on scan line?

- What's the best signal processing method? (Not covered here.)

MODEL PARAMETERS

- Up to depth D:
  - Limestone: dielectric ϵ_r=6 + random fluctuations (std 0.25)
  - Conductivity σ=0.075mS/m
  - Debye relaxation time 0.4ns

- Aquifer at depth D:
  - ϵ_r=40, σ = 0.1S/m

- Noise level 1% of peak radar pulse maximum

- All except random fluctuations measured parameters
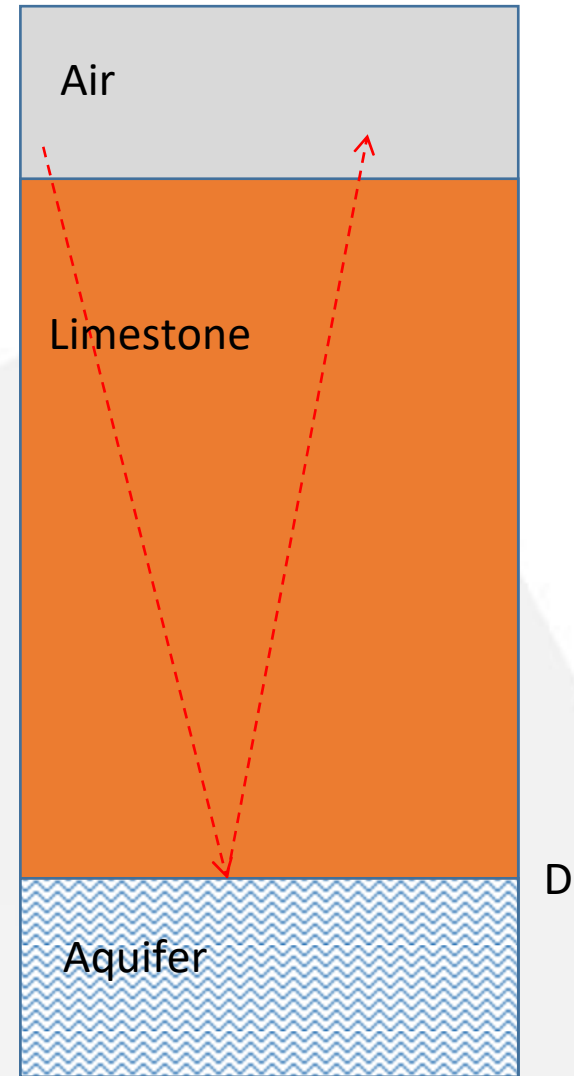
DATA PROCESSING

- Detect time of reflection from STARE scan
  - Transmitter/Receiver stationary, scan repeatedly and stack
  - 10000 scans/min
- Measure velocity for time→depth conversion
  - CMP or WARR line, Transmitter/Receiver at varying distances (e.g., 1-100m)
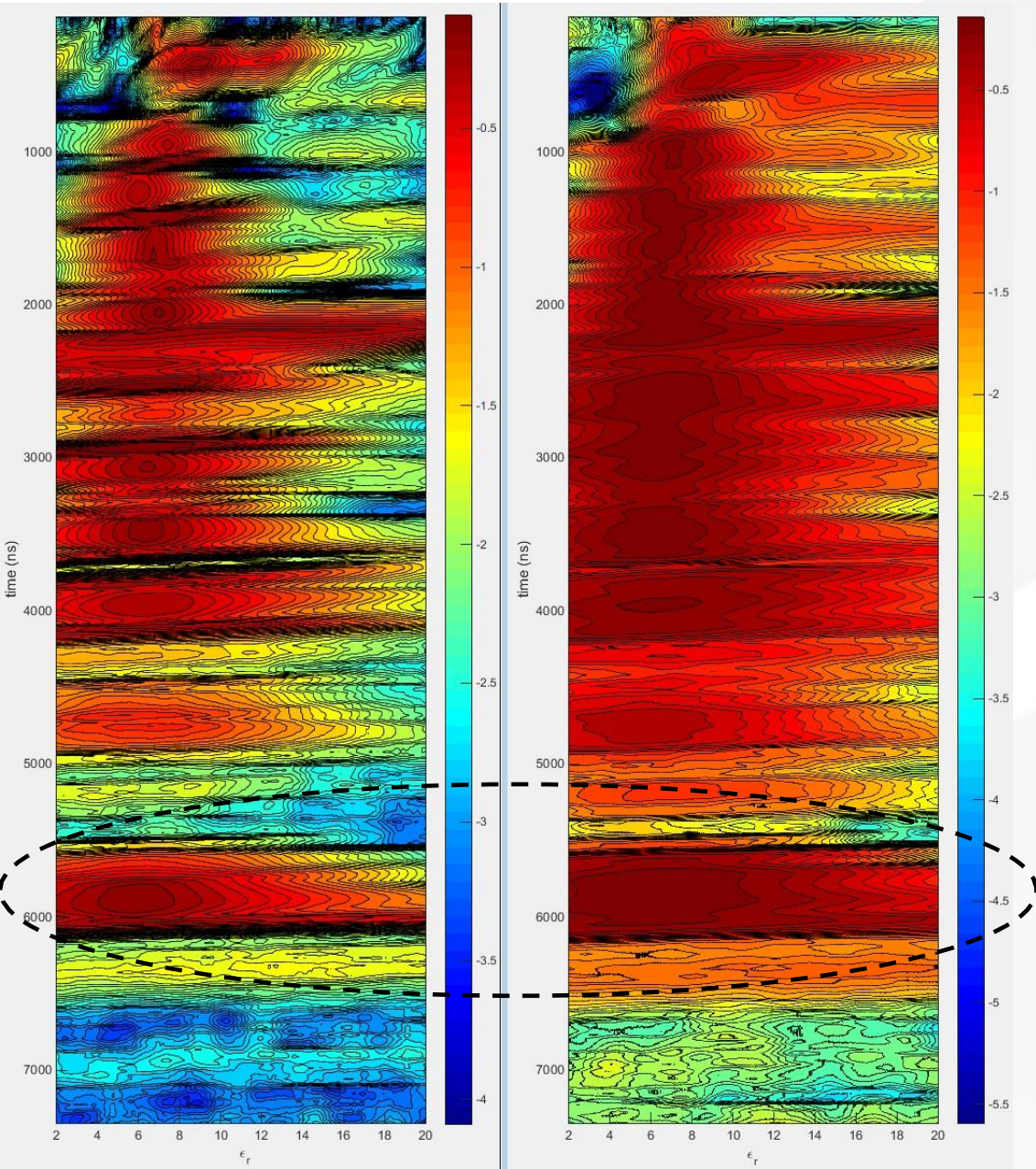
STARE SIGNAL PROCESSING
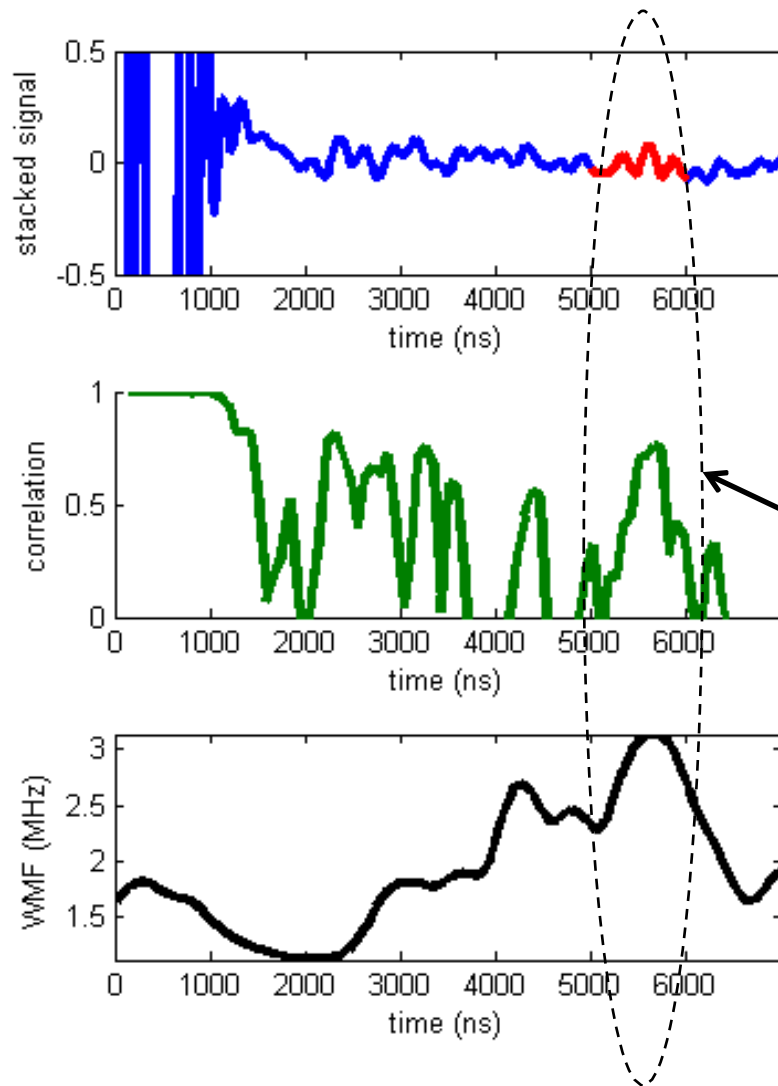
To identify strong reflectors.

Traces in stack (500 traces) highly correlated near reflection.

Frequency content consistent with return from 3MHz component of pulse.

(This is from real experiment, water reflector at known distance of 350m.)

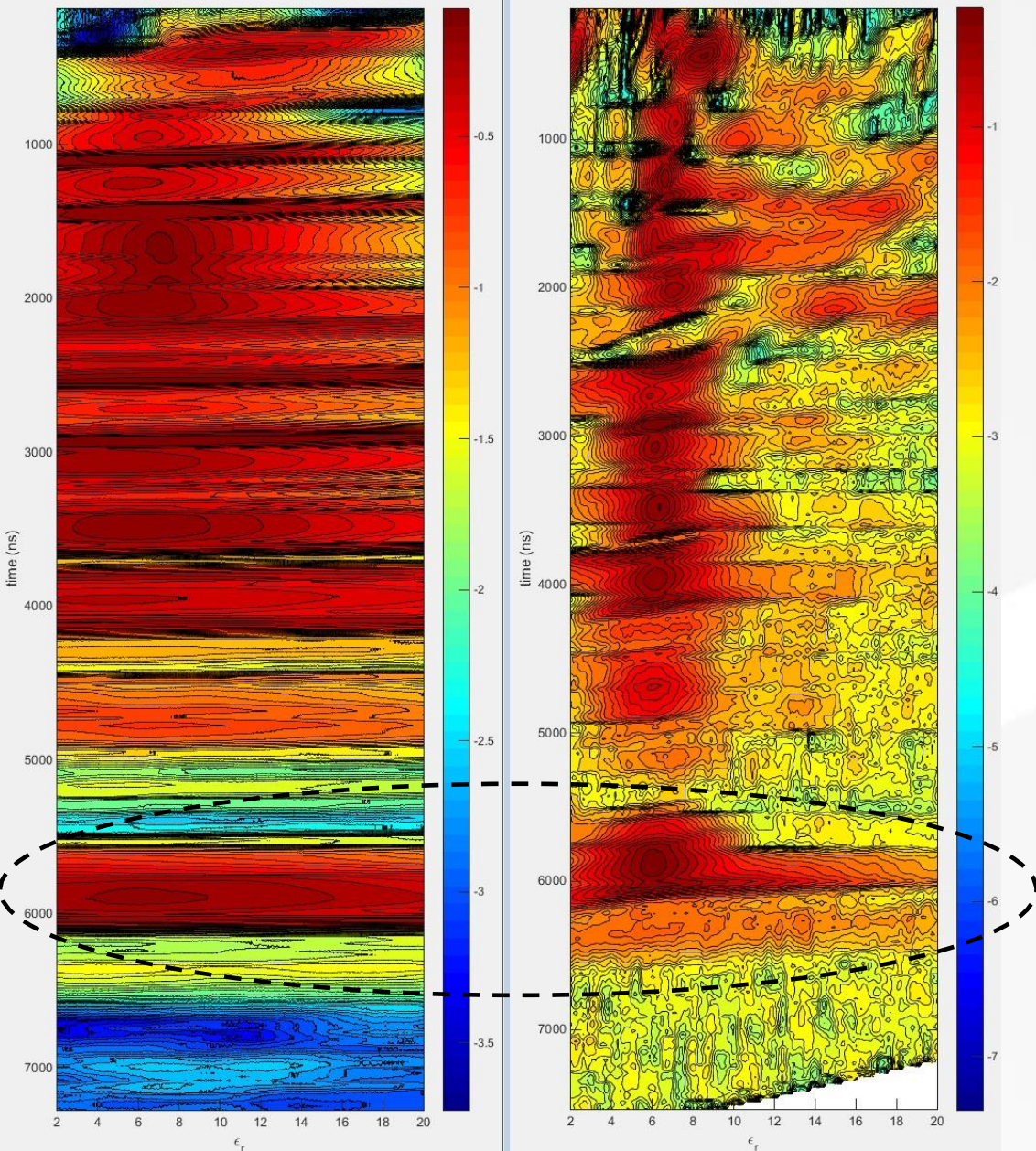# VELOCITY SPECTRUM ANALYSIS TO DETERMINE VELOCITY

Semblance based velocity spectrum displays, translated to dielectric. Read off dielectric visually.

In example aquifer at t=5800ns, $\epsilon=6$, gives D=355m (350m actual depth). 100m scan line.

Right: standard semblance

Left: improved resolution by extracting phase with Hilbert transform

EFFECT OF SCAN LINE LENGTH

Same for 50m (left) and 200m (right) scan line.

Conclusion: 50m not enough, 200m near perfect, 100m good practical compromise for field experiment.

DEPTH LIMIT WITH A 1 DAY LONG SCAN

- Simulation results indicate 600m maximum depth

- STARE need 250000 stack to detect reflection time

- WARR needs a 200m line with 20 sampling points
  - 250000 stack at each sampling point

- Can be done in about 10 hours including setup

- Depth estimation error 5%

D=600M 250000 STACK STARE
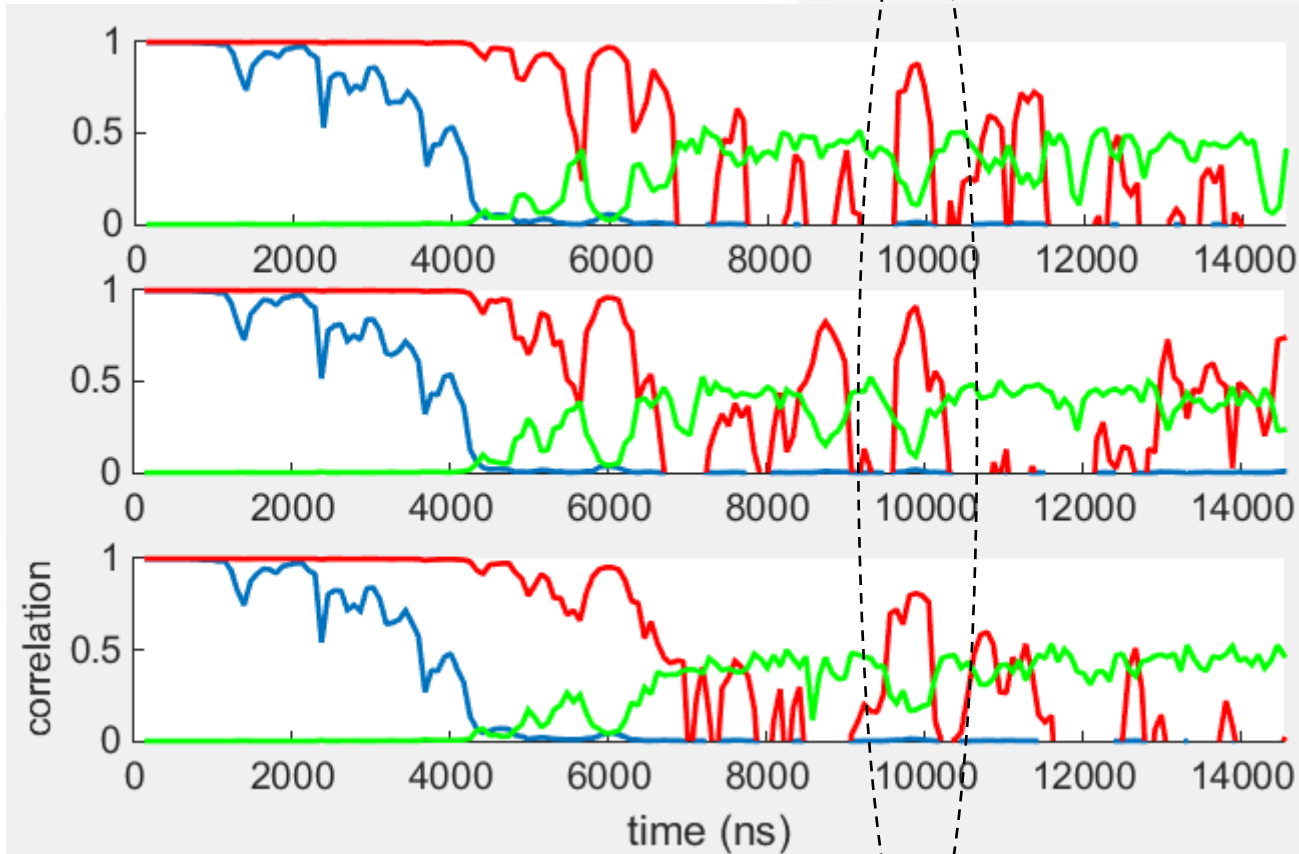
Noise causes random correlations.

Replicate experiment, and look for persistent peaks.

D=600M WARR, 200M SCAN LINE, 20 SAMPLE POINTS
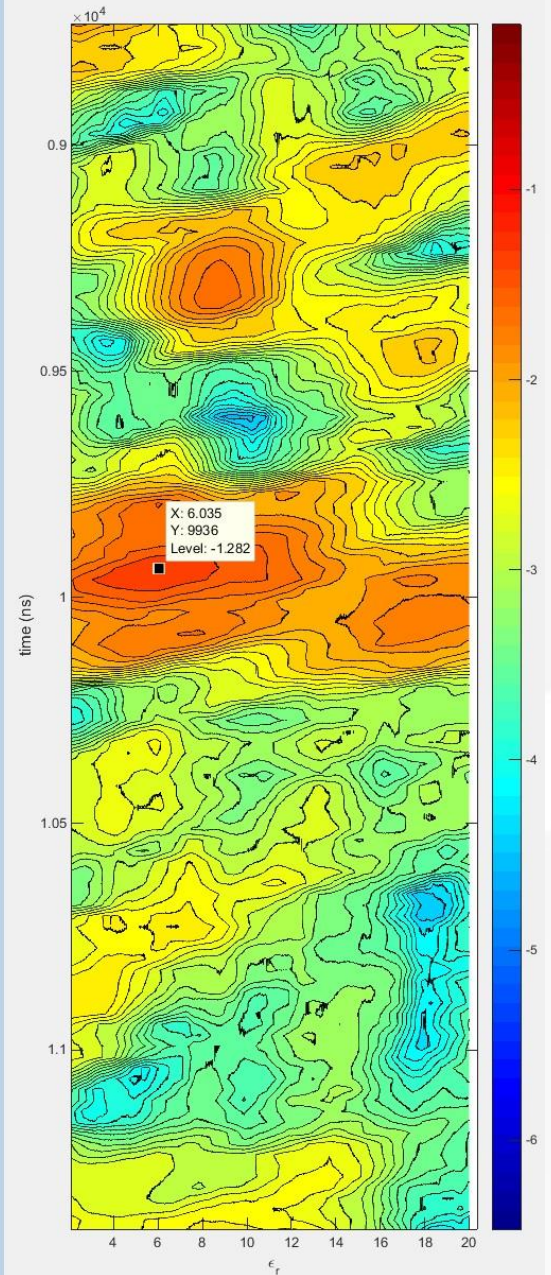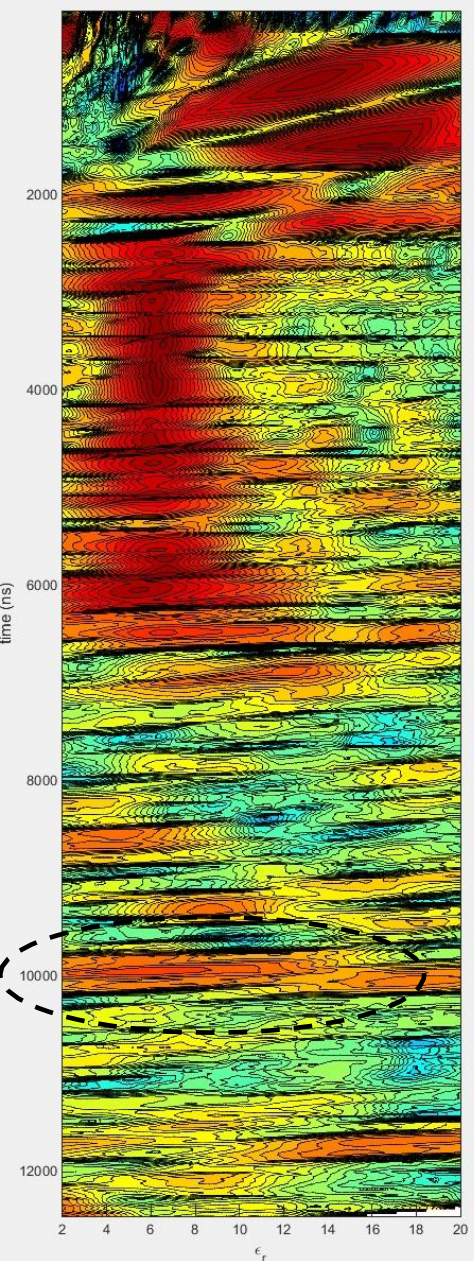
Lose signal at about 6000ns, peak at (10000ns, $\epsilon=6$) faint but detectable.

Some care required in interpretation due to spurious peaks caused by noise.

CONCLUSIONS

- Simulations useful for experimental design/feasibility study
- Prior to field work we can:
  - Determine amount of data needed
  - Determine WARR/CMP setup (scan length, sampling)
  - Determine if goal is achievable
  - Validate signal processing methods
  - Estimate expected interpretation errors
  - Suggest equipment improvements
- Example of aquifer detection under limestone: 600m practical limit

PEOPLE

Joel Jansen   **Teck Resources**

Michael Robinson ⎤
Colin Stove   ⎬   **Adrok**
Gordon Stove   ⎦

Staff at Pend Oreille mine   **Teck Washington**
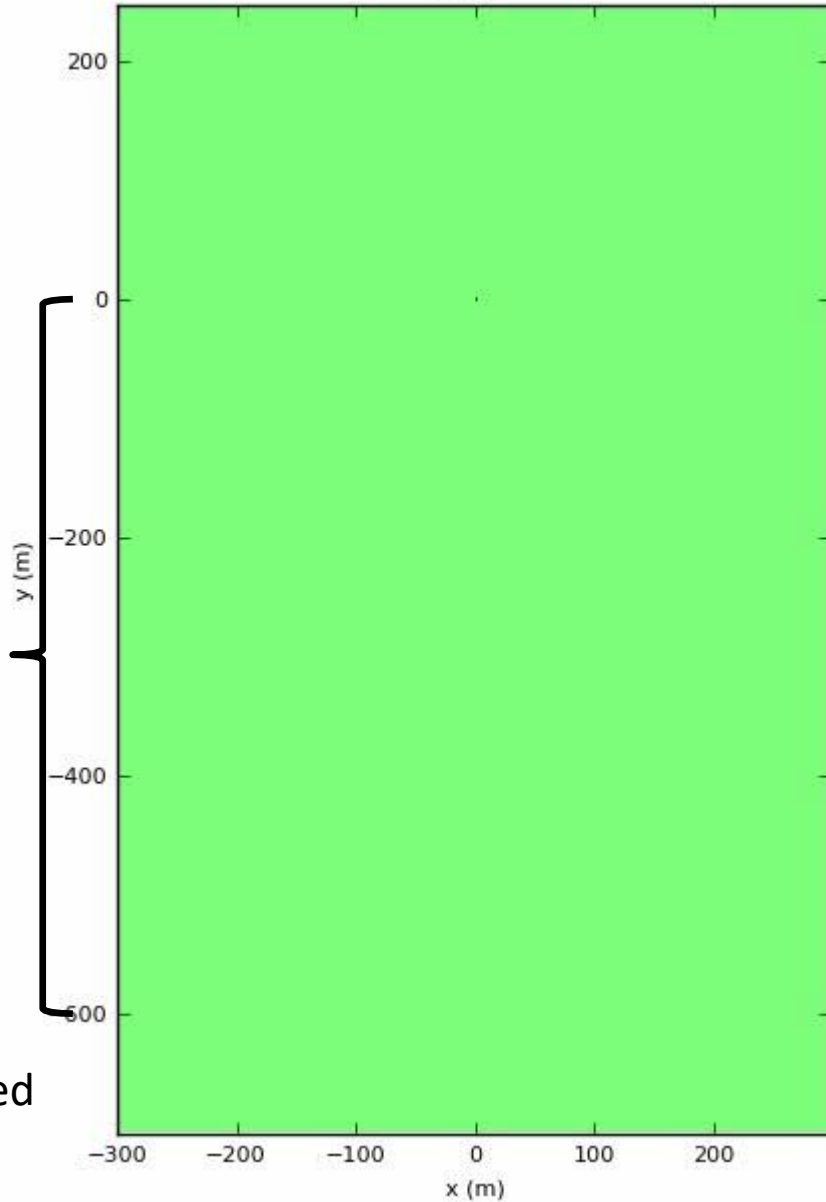
Just for fun: A preview of current work on 2D FDTD simulation.