Verification of seismic modeling using laboratory ultrasonic data

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Overview

1. Introduction
2. Physical modeling
3. Finite-difference modeling
4. Results
5. Conclusions

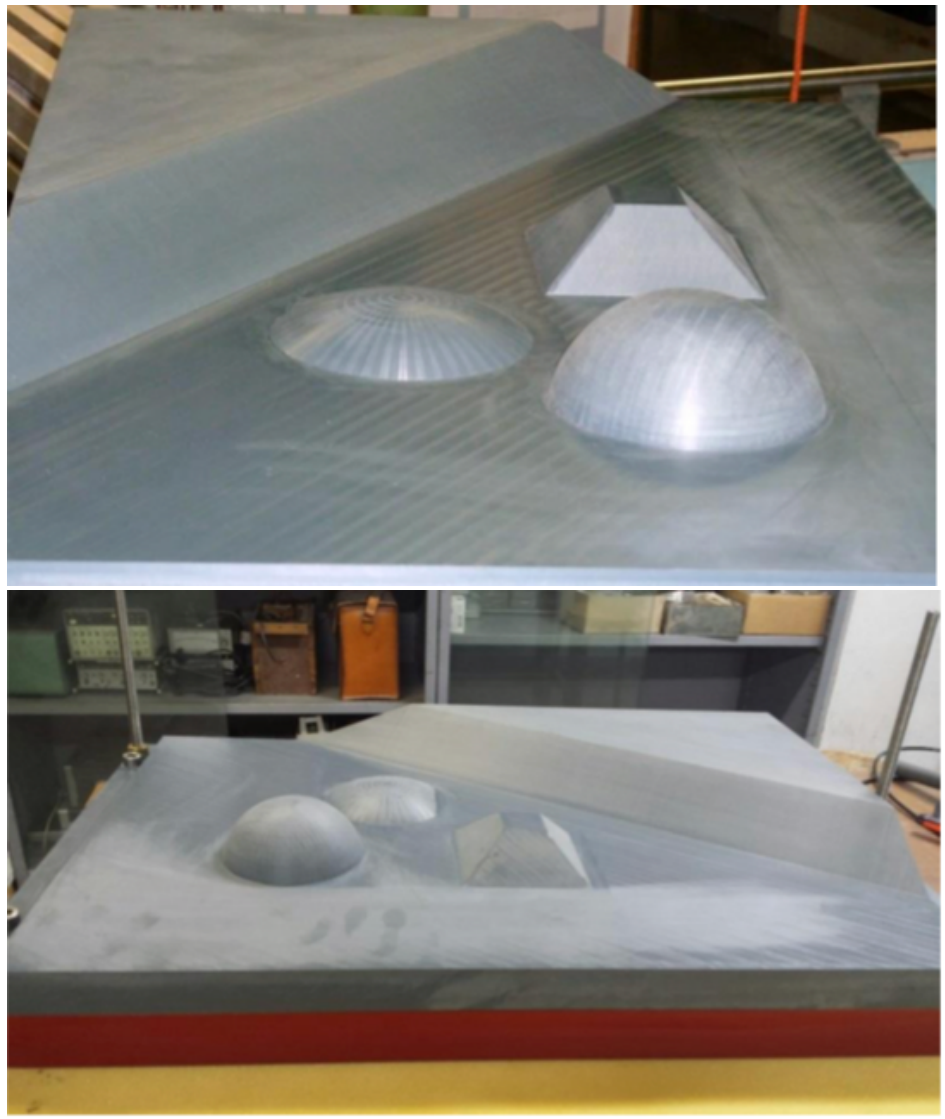
Introduction

- Finite-difference modeling is extensively used in imaging and inversion of seismic data
- The use of high-order spatial derivatives apparently allows the use of coarse grids
- Acceptable run-times even for very large models using modern CPUs and GPUs
- Simple and efficient coding
- Models represented by simple regular grids

Introduction

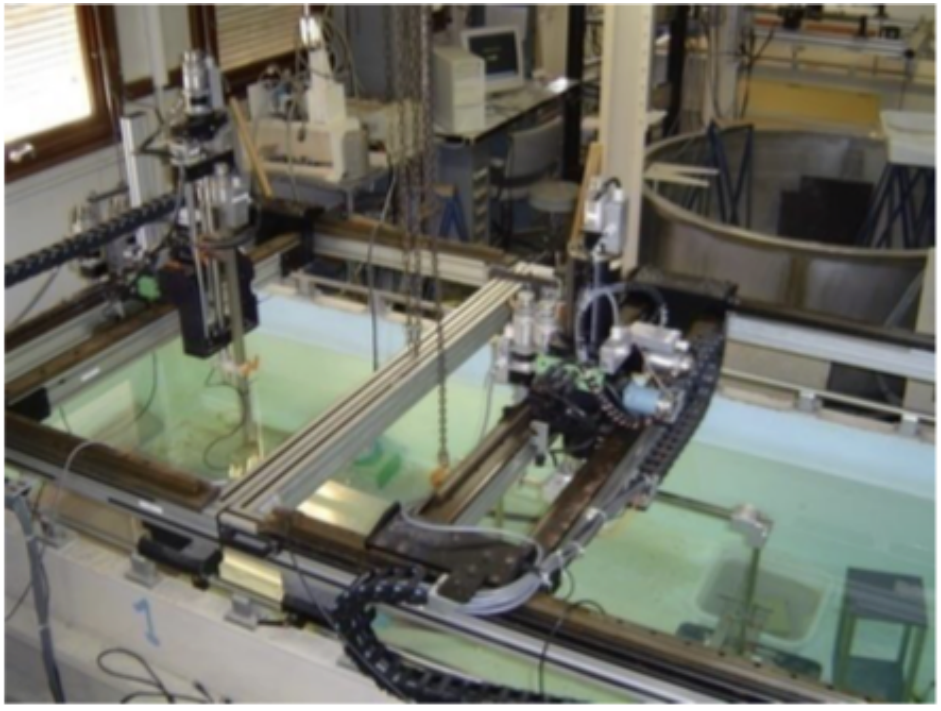
- Complex, curved interfaces are difficult to represent with regular grids
- Plane, sloping layers are known to be problematic for finite-difference methods
- There is a need for calibrating finite-difference modeling against data from known models

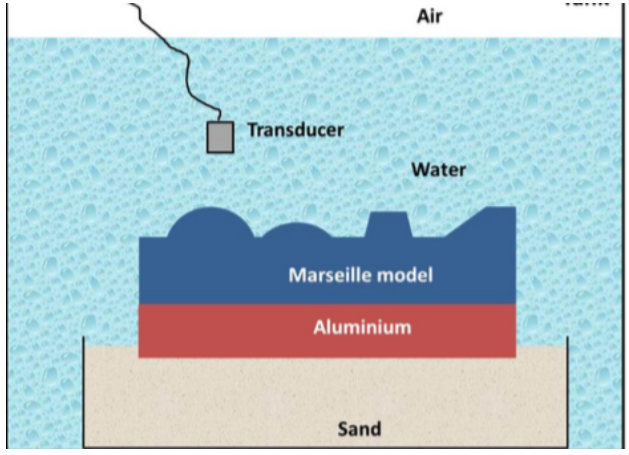
The BENCHIE model



(courtesy of Favretto-Cristini, 2015,[1])

The BENCHIE model

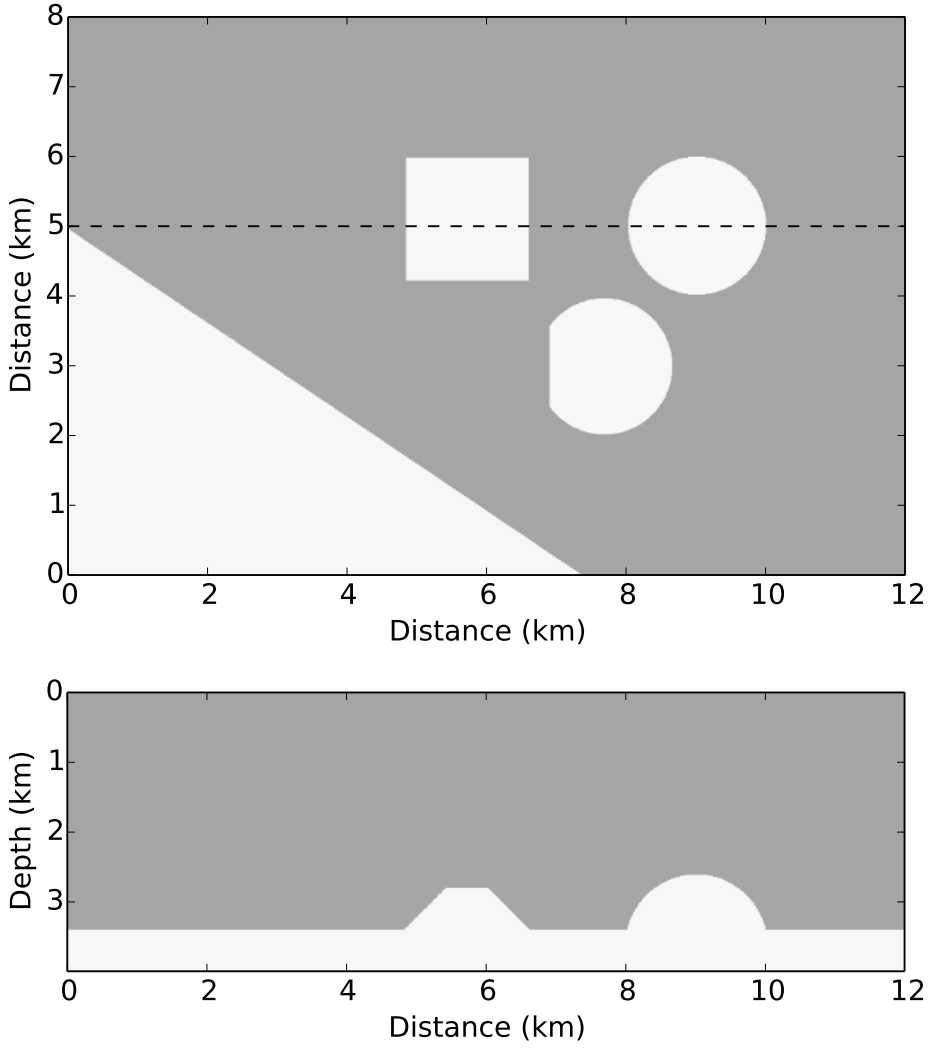




(courtesy of Favretto-Cristini, 2015,[1])

The BENCHIE model

Scale factor: 20000

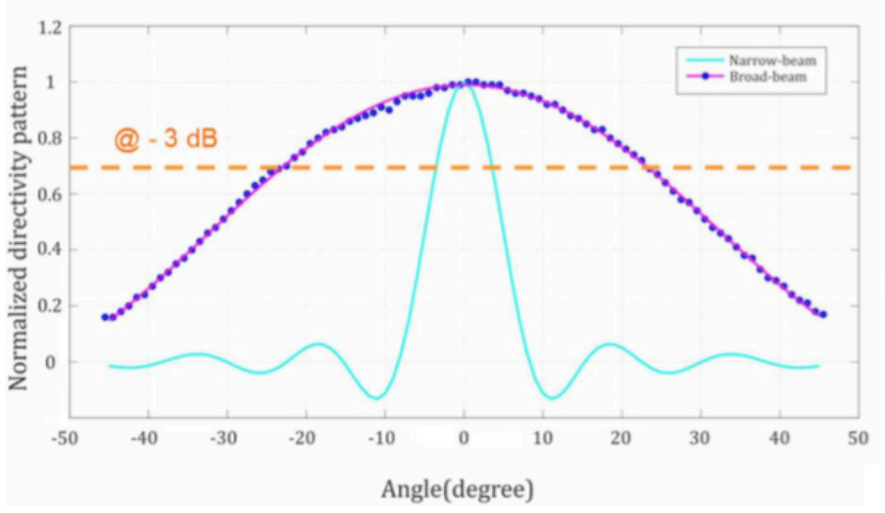


The BENCHIE model

Physical properties

Material	V_p	V_s	Density	Q_p	Q_s
Water	1480	0.0	1000	∞	∞
PVC	2220	1050	1412	42	32

The BENCHIE model



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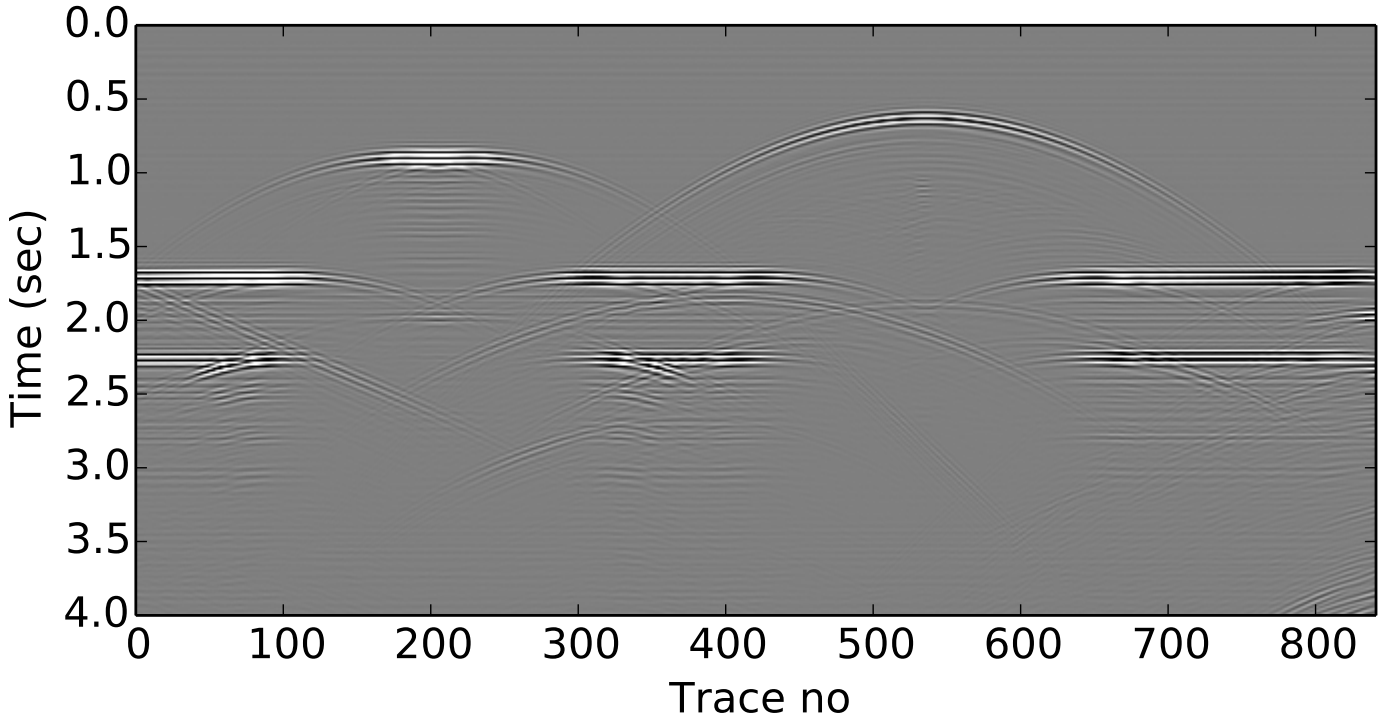


Finite-difference modeling

Visco-elastic equations

$$
\begin{aligned}
u_i(\mathbf{x},t) &= \partial_j \sigma_{ij}(\mathbf{x},t) \\
\sigma_{ij}(\mathbf{x},t) &= \lambda(\mathbf{x},t) * e_{kk}(\mathbf{x},t)\delta_{ij} + 2\mu(\mathbf{x},t) * e_{ij}(\mathbf{x},t) + q_{ij}(\mathbf{x},t) \\
e_{ij}(\mathbf{x},t) &= \frac{1}{2}[\partial_j u_i(\mathbf{x},t) + \partial_i u_j(\mathbf{x},t)] \qquad (1)
\end{aligned}
$$

Where

- $\mathbf{x}, t$: Space, time
- $u_i(\mathbf{x},t)$: Displacement vector i
- $\sigma(\mathbf{x},t)$: Stress tensor
- $\lambda(\mathbf{x},t), \mu(\mathbf{x},t)$: Lameé parameters
- $q_{ij}(\mathbf{x},t)$: Source tensor

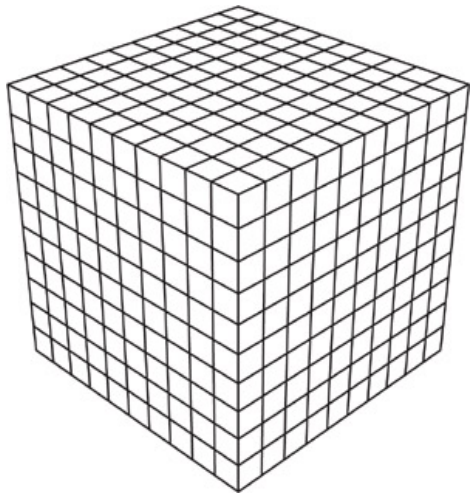
Finite-difference modeling

The Finite-difference method solves the Visco-elastic equations by approximating derivatives with finite-differences

$$\partial_x u \approx \frac{1}{\Delta x} \sum_{l=1}^{8} \alpha_l [u(\mathbf{x} + l\Delta x) - u(\mathbf{x} - (l-1)\Delta x)] \tag{2}$$

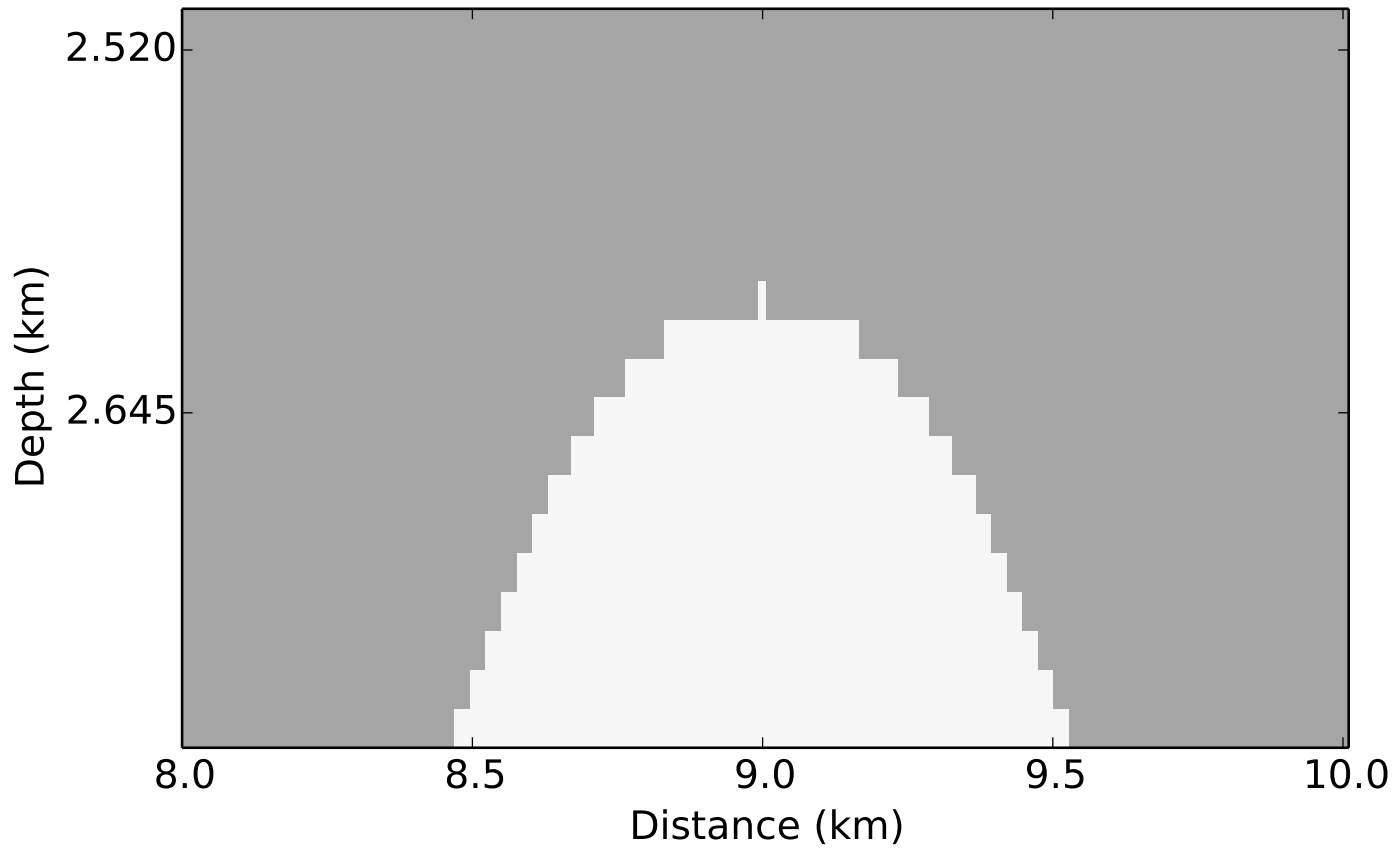
Where

- u: Wavefield
- α: Precomputed coefficients
- Δx: Distance between grid-points
- Grid size: 600 x 400 x 300 (approx 100 Mill gridpoints)

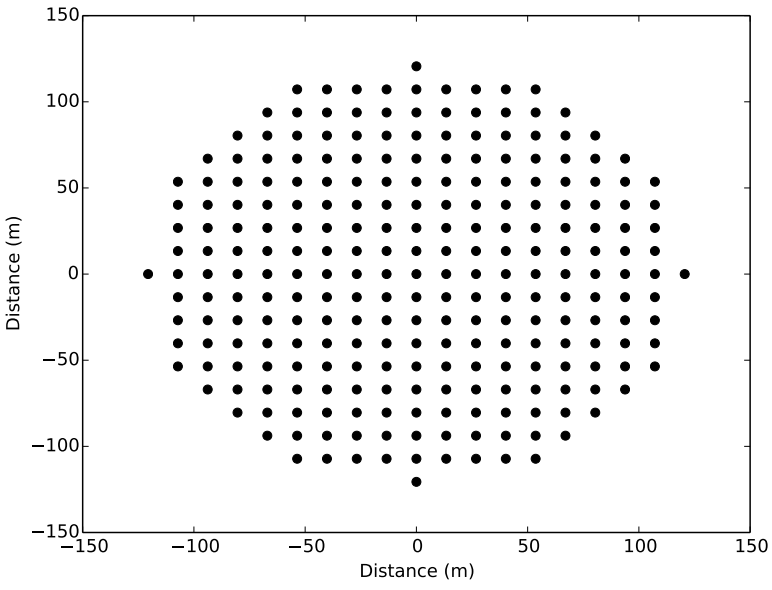


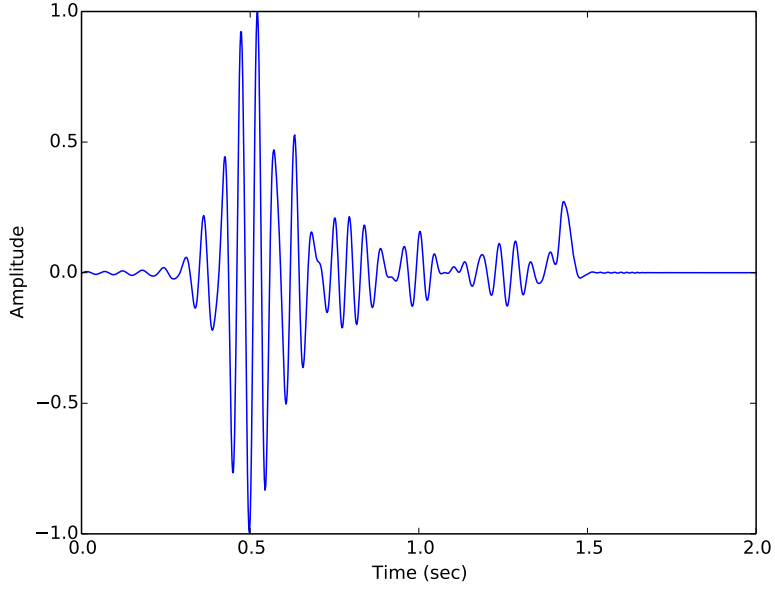
Finite-difference modeling

Use $\Delta x = 10$m giving grid-points/wavelength $= 4.0$



Finite-difference modeling

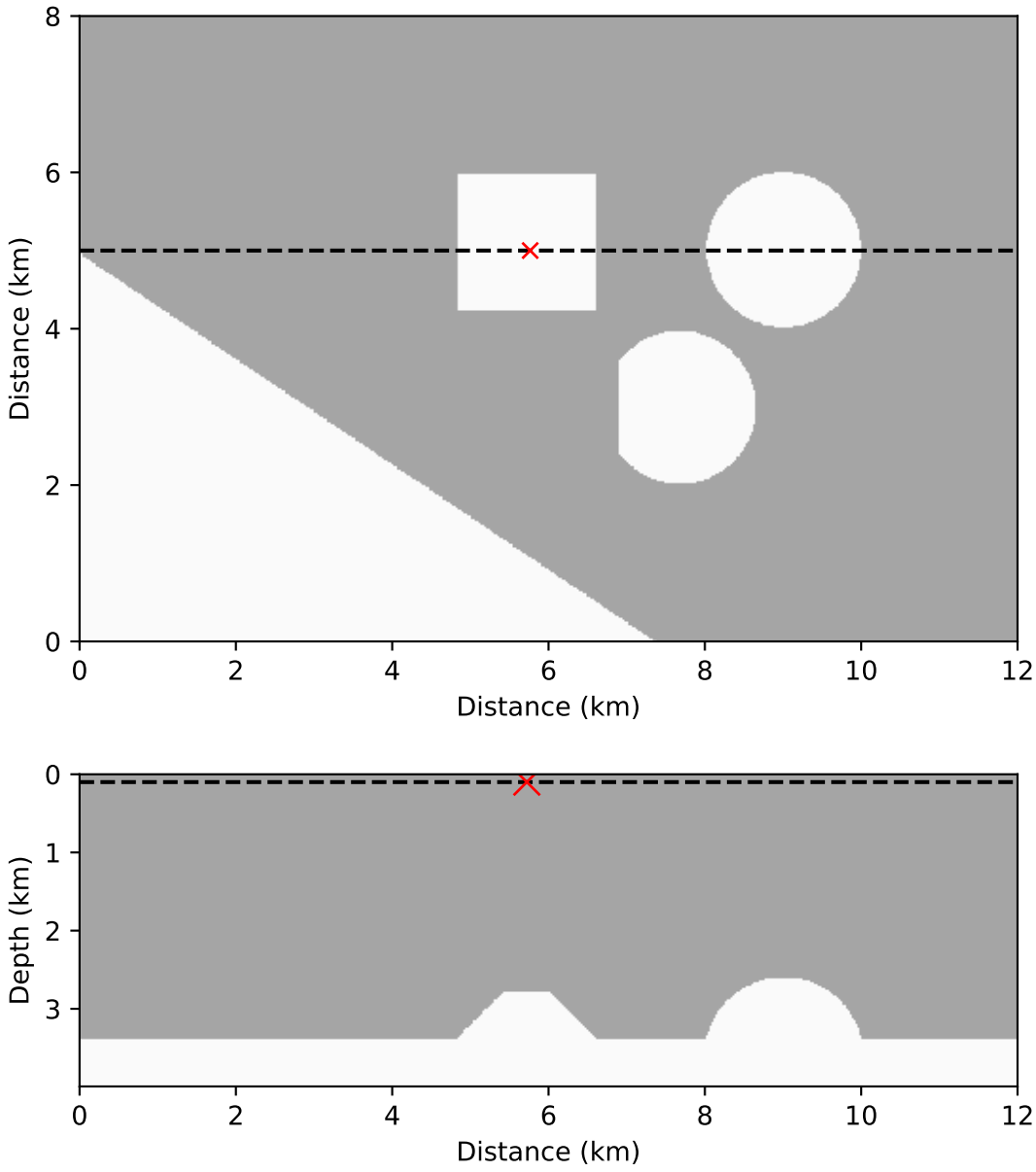




Spectral Element (SEM) modeling

- Finite element method
- Wavefield described via Lagrange interpolants
- 6th order basis functions
- Hexaedral mesh

Results



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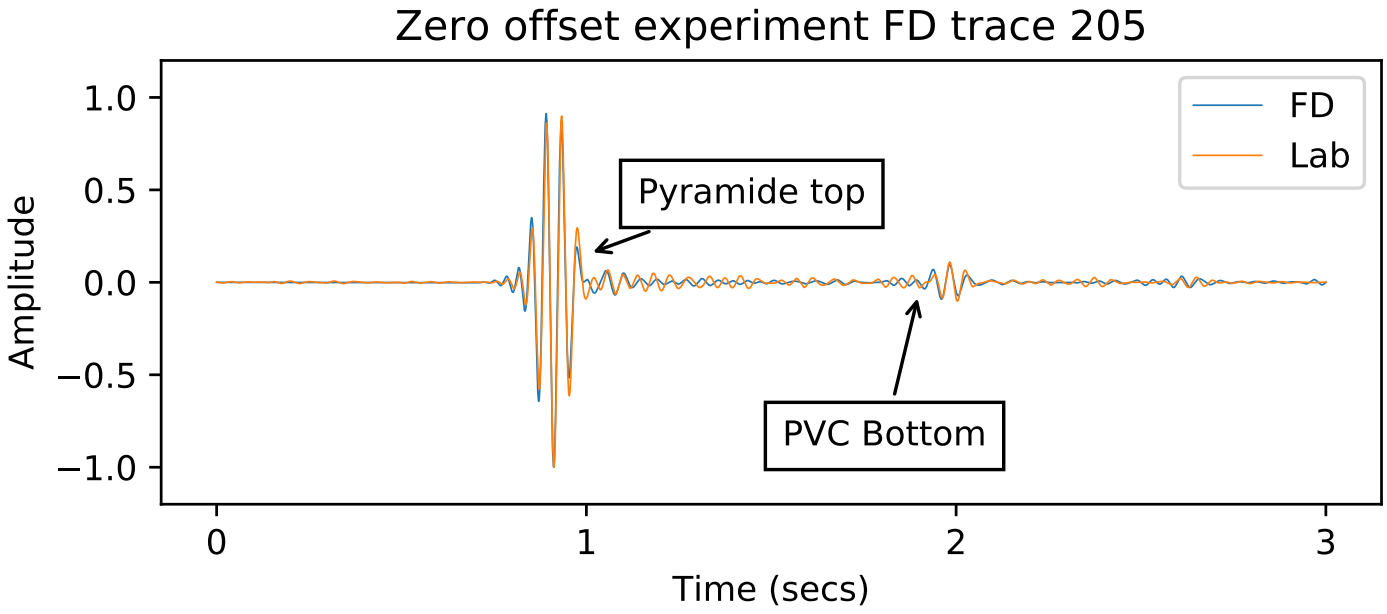
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Lab
Pyramide top
PVC Bottom
Amplitude
Time (secs)
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−0.5
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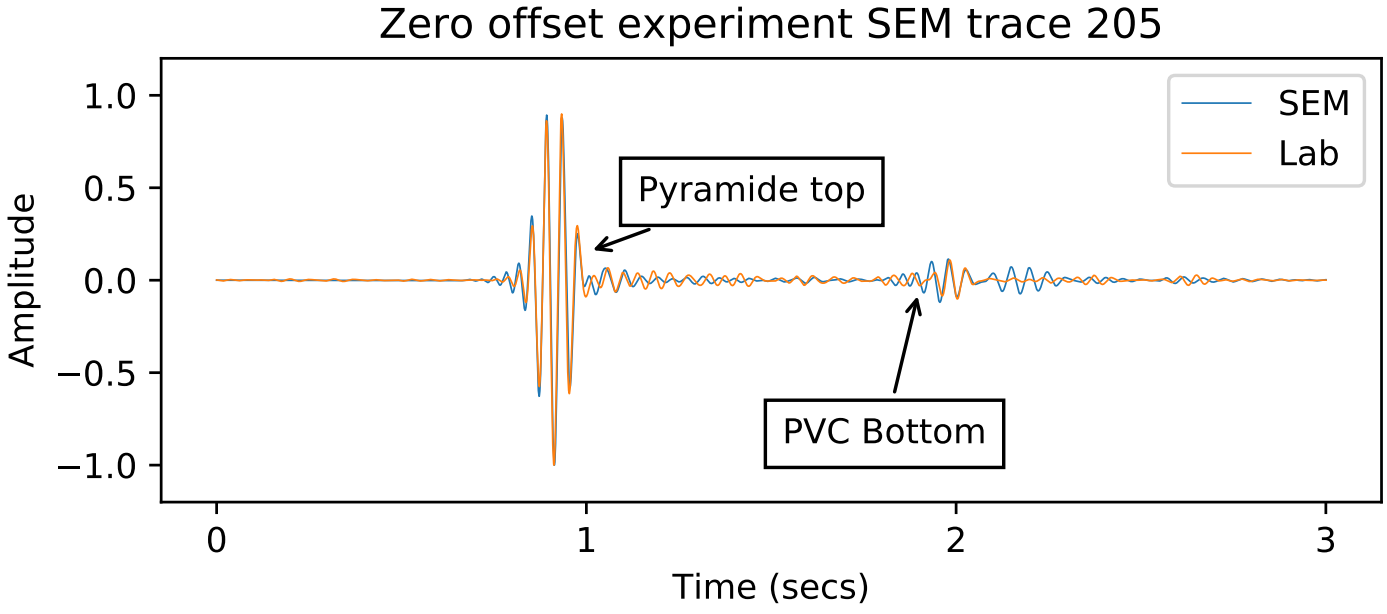
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SEM
Lab
Pyramide top
PVC Bottom
Amplitude
Time (secs)
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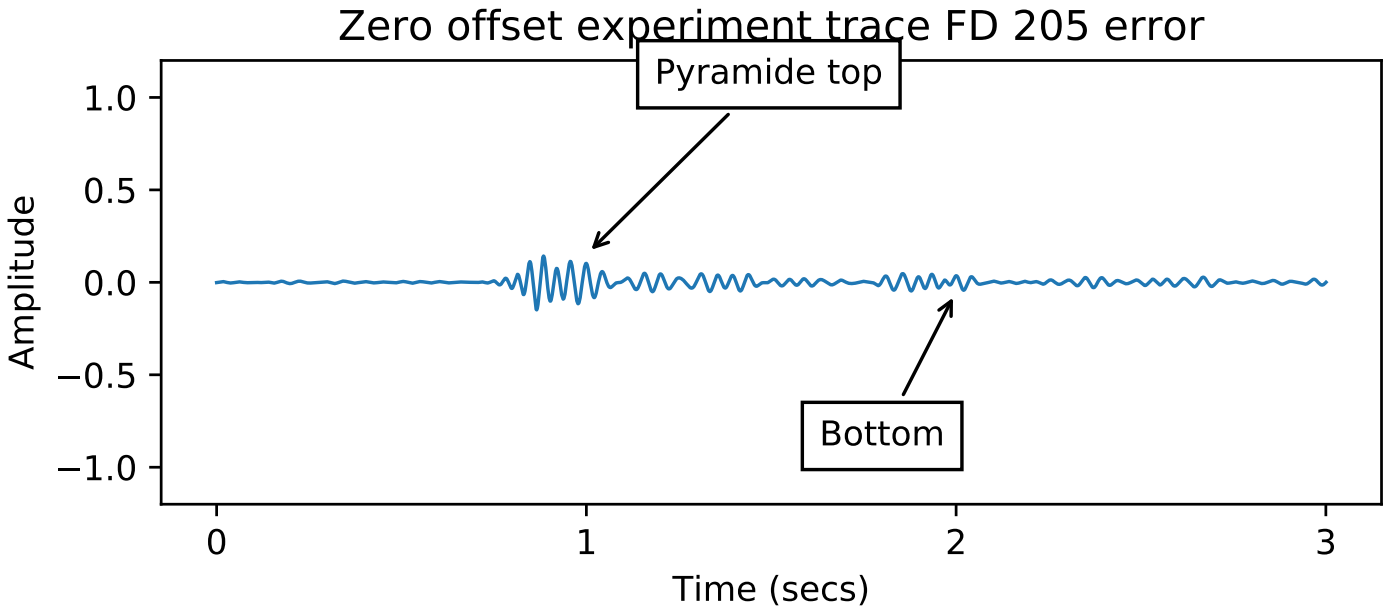
Results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Pyramide top
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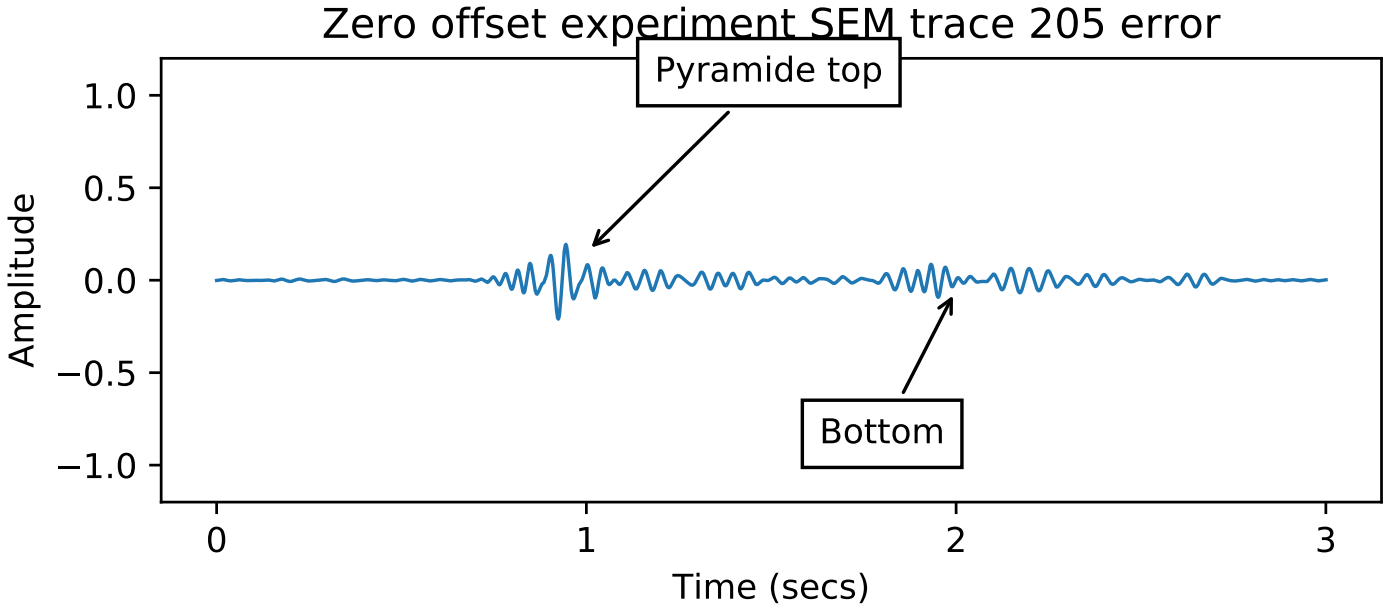
Time (secs)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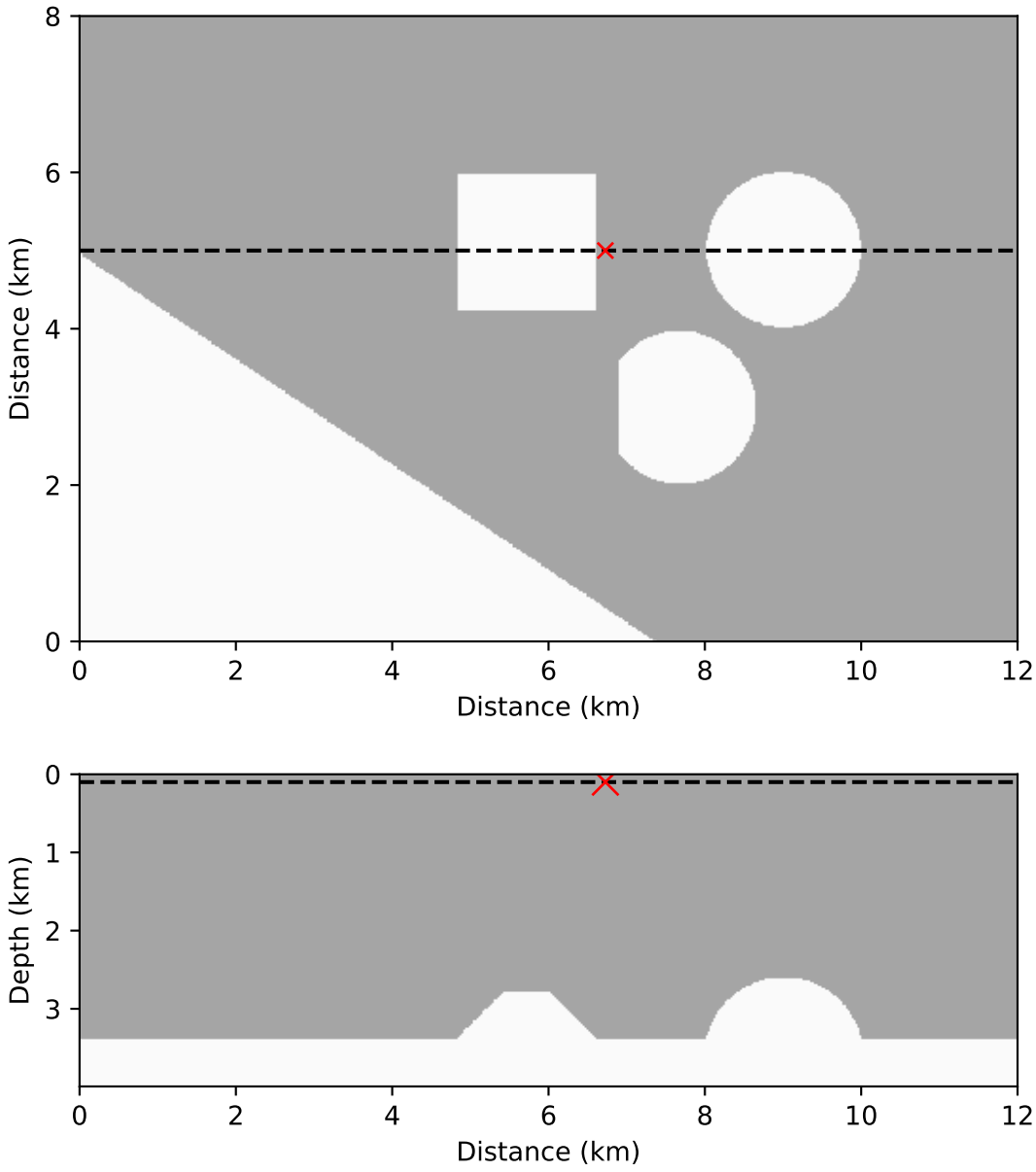
Time (secs)

Results



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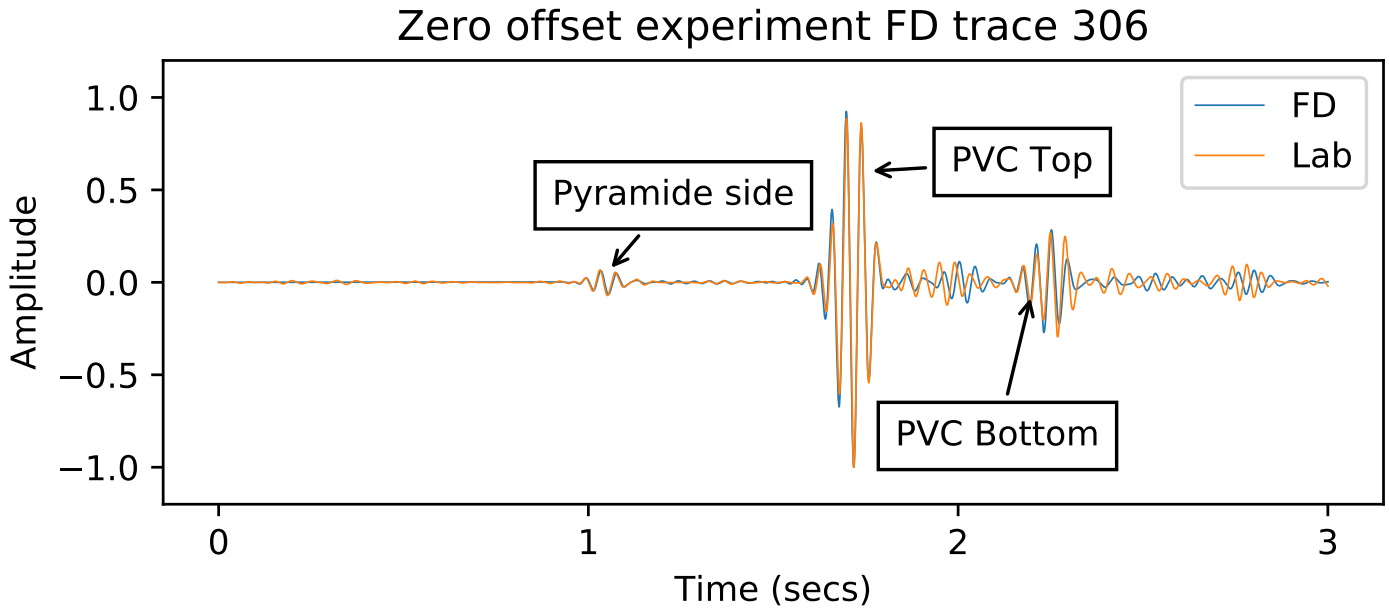
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FD
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PVC Top
PVC Bottom
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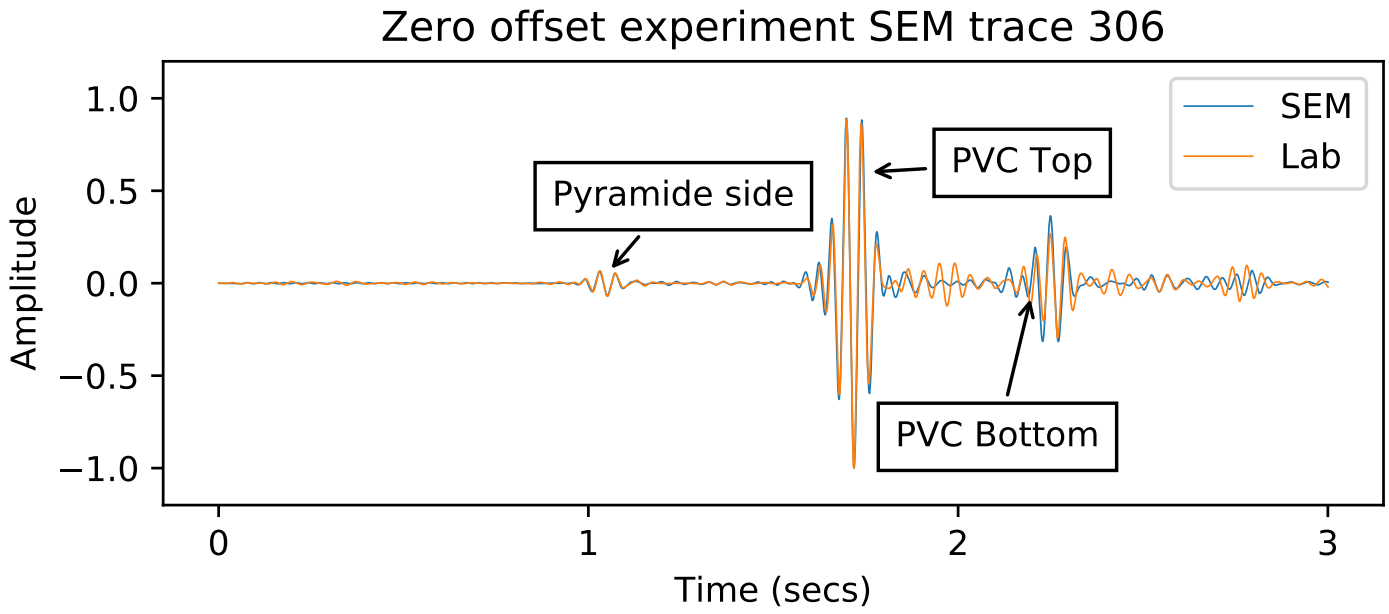
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Amplitude
Time (secs)
SEM
Lab
Pyramide side
PVC Top
PVC Bottom
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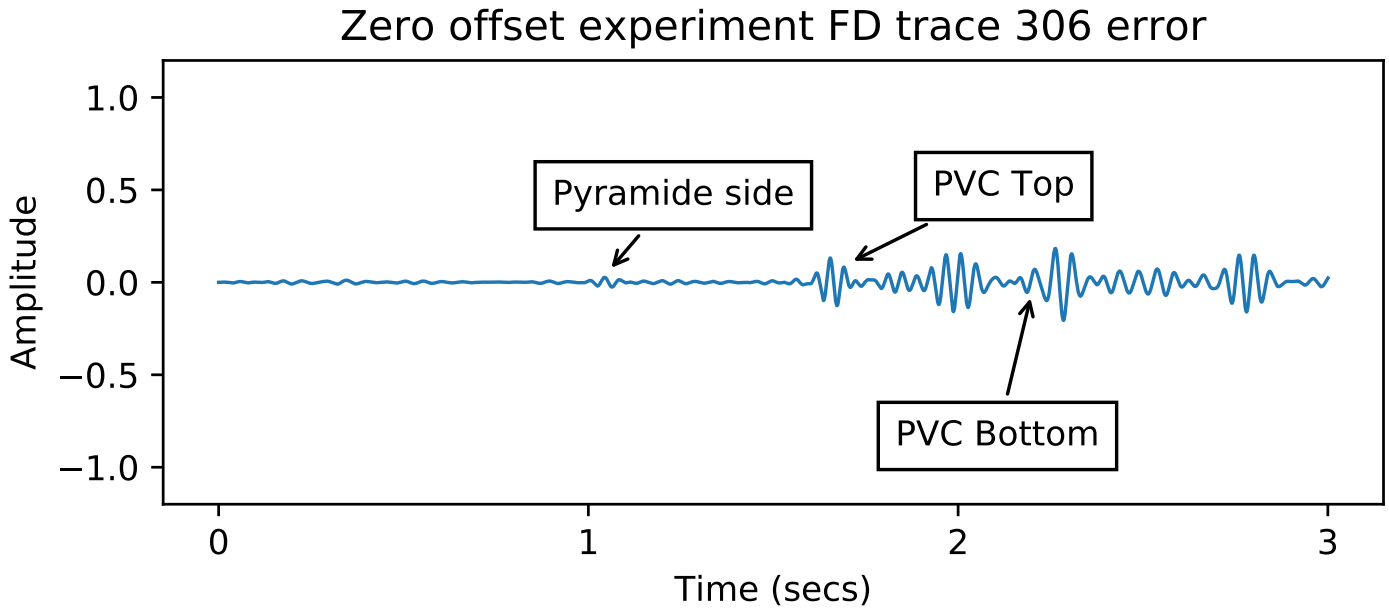
Results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Pyramide side
PVC Top
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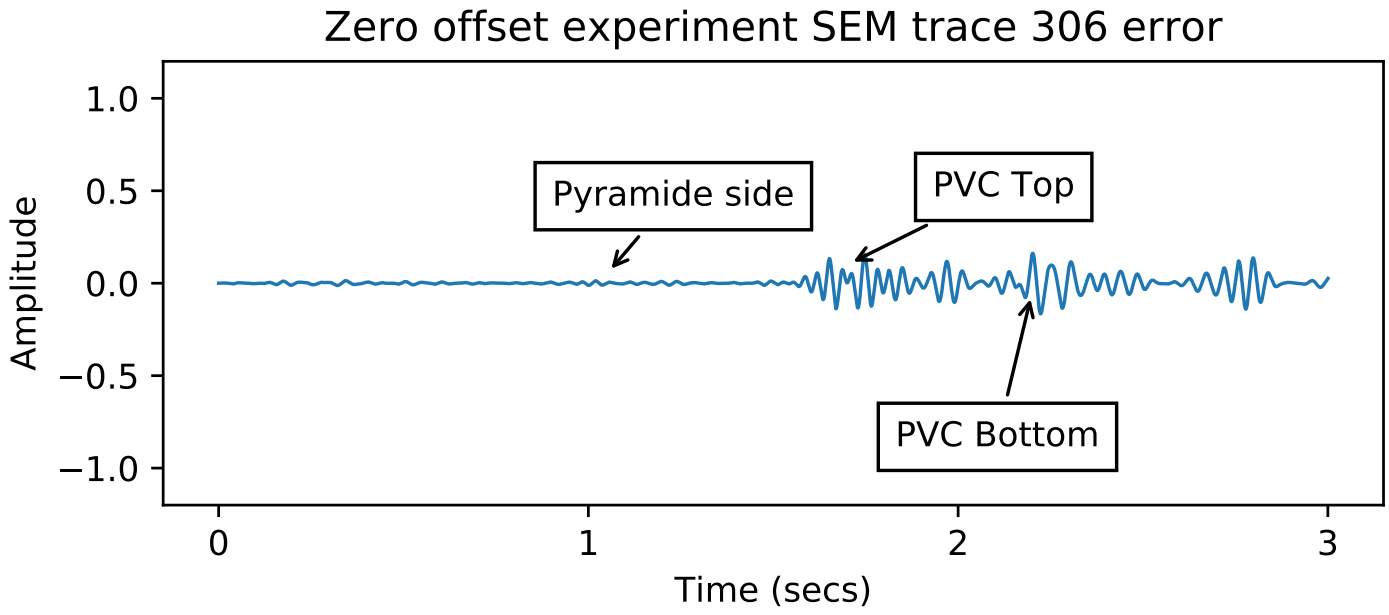
Time (secs)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Pyramide side
PVC Top
PVC Bottom
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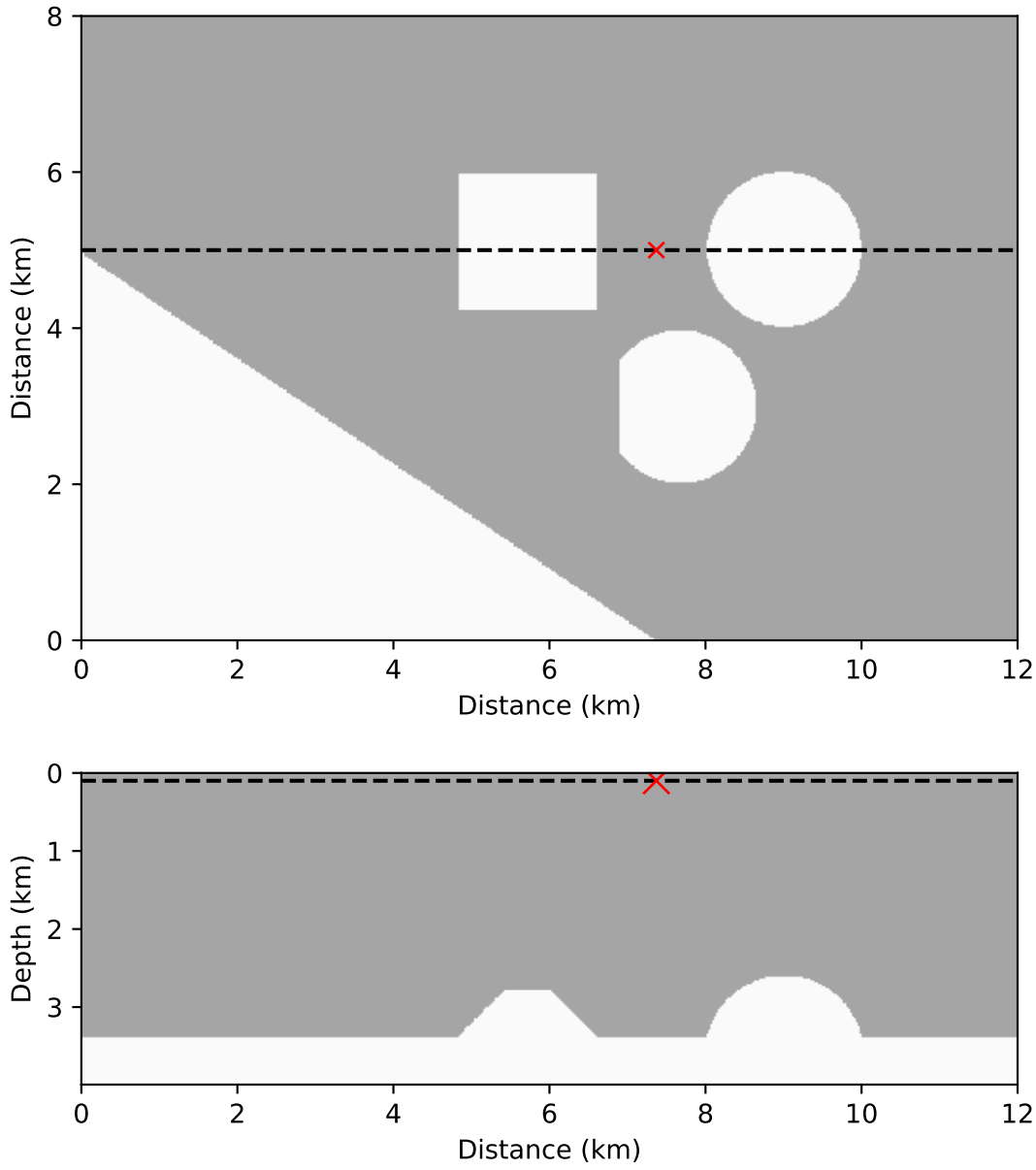
Time (secs)

Results



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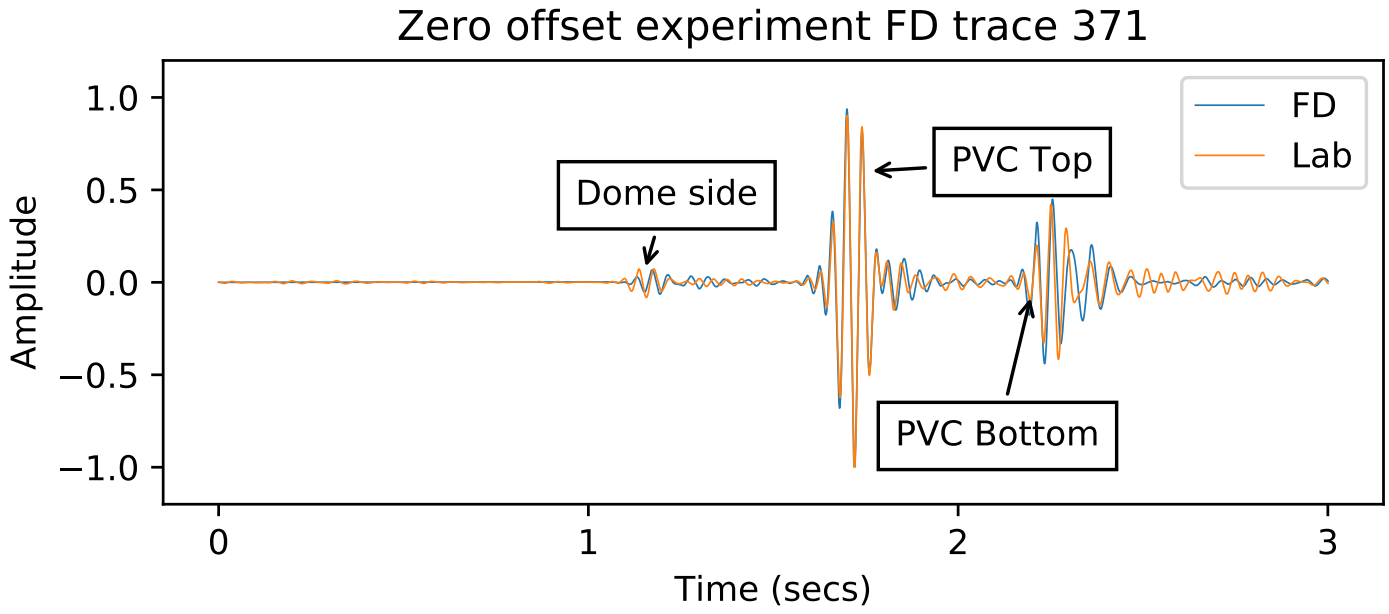
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Time (secs)
FD
Lab
Dome side
PVC Top
PVC Bottom
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−1.0
0
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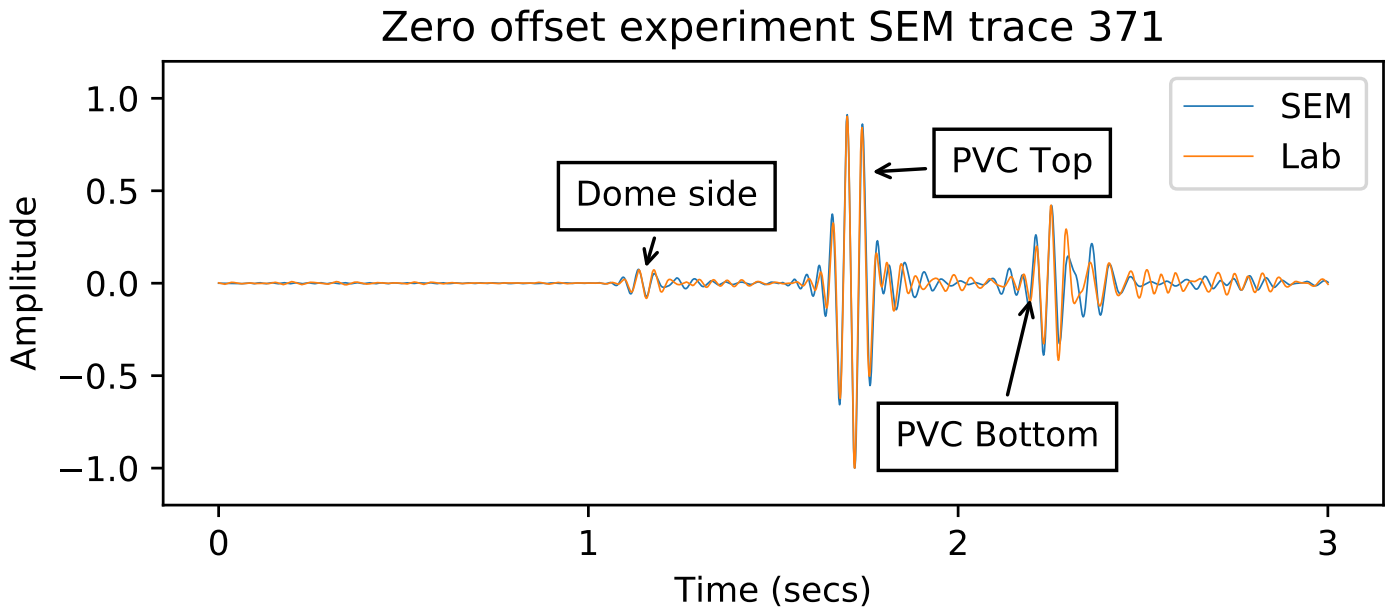
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Amplitude
Time (secs)
SEM
Lab
Dome side
PVC Top
PVC Bottom
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−1.0
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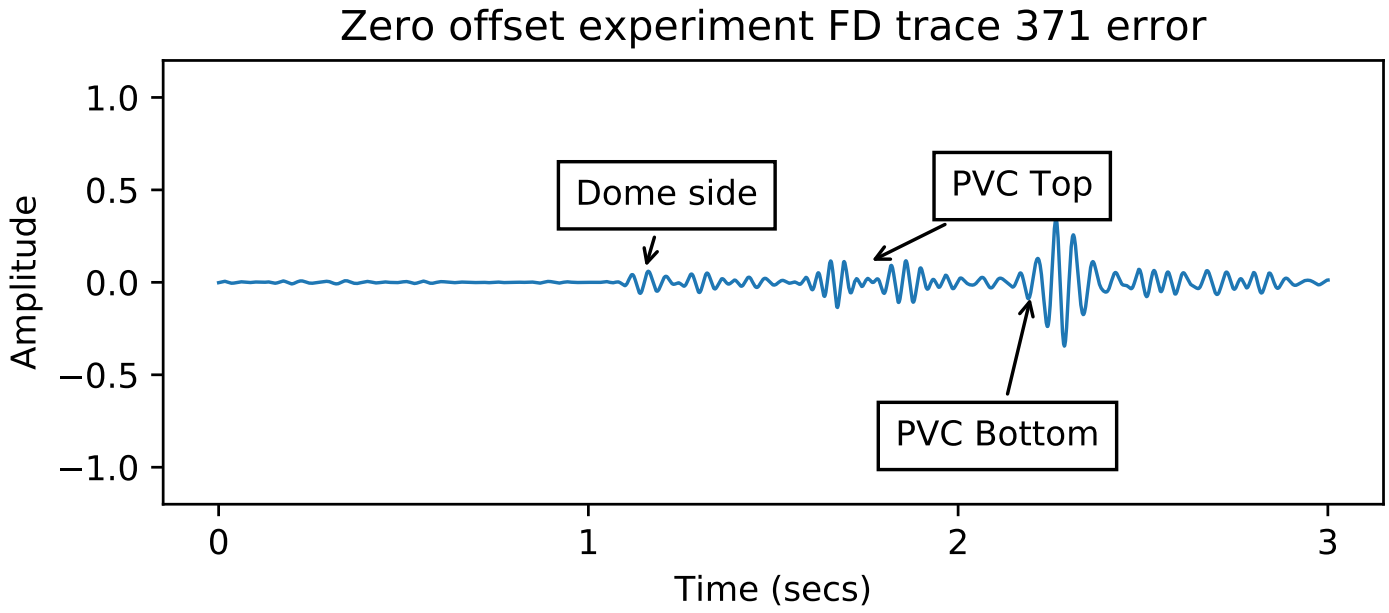
Results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Dome side
PVC Top
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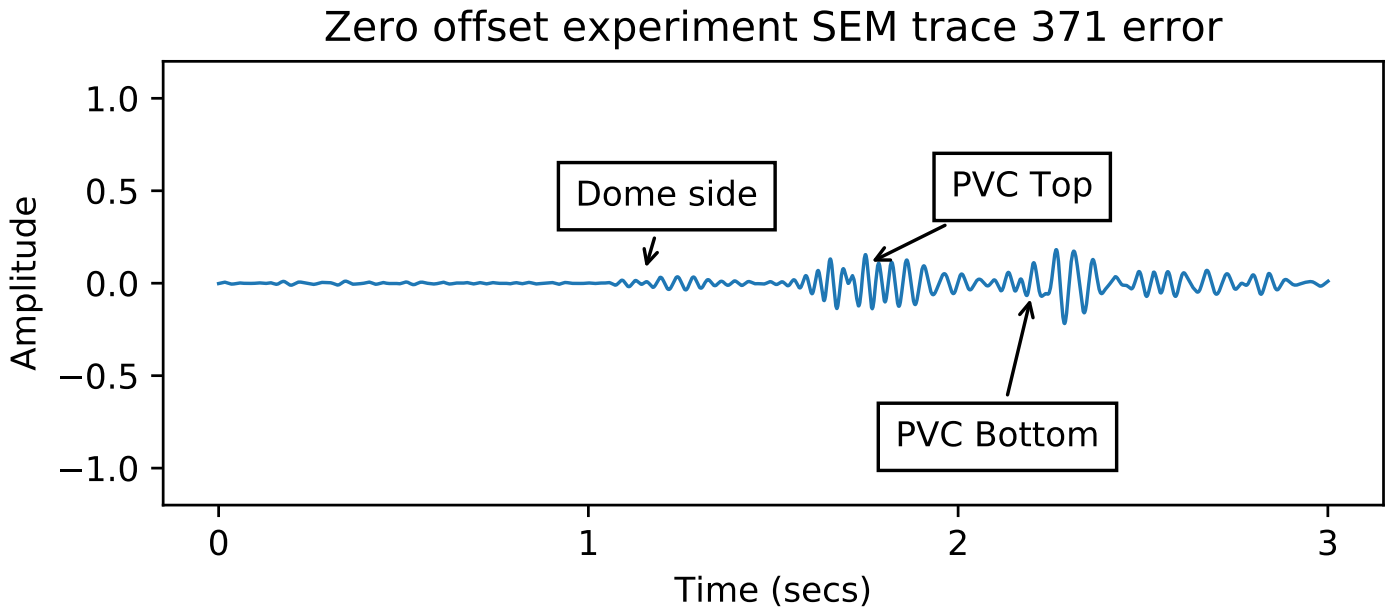
Time (secs)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Dome side
PVC Top
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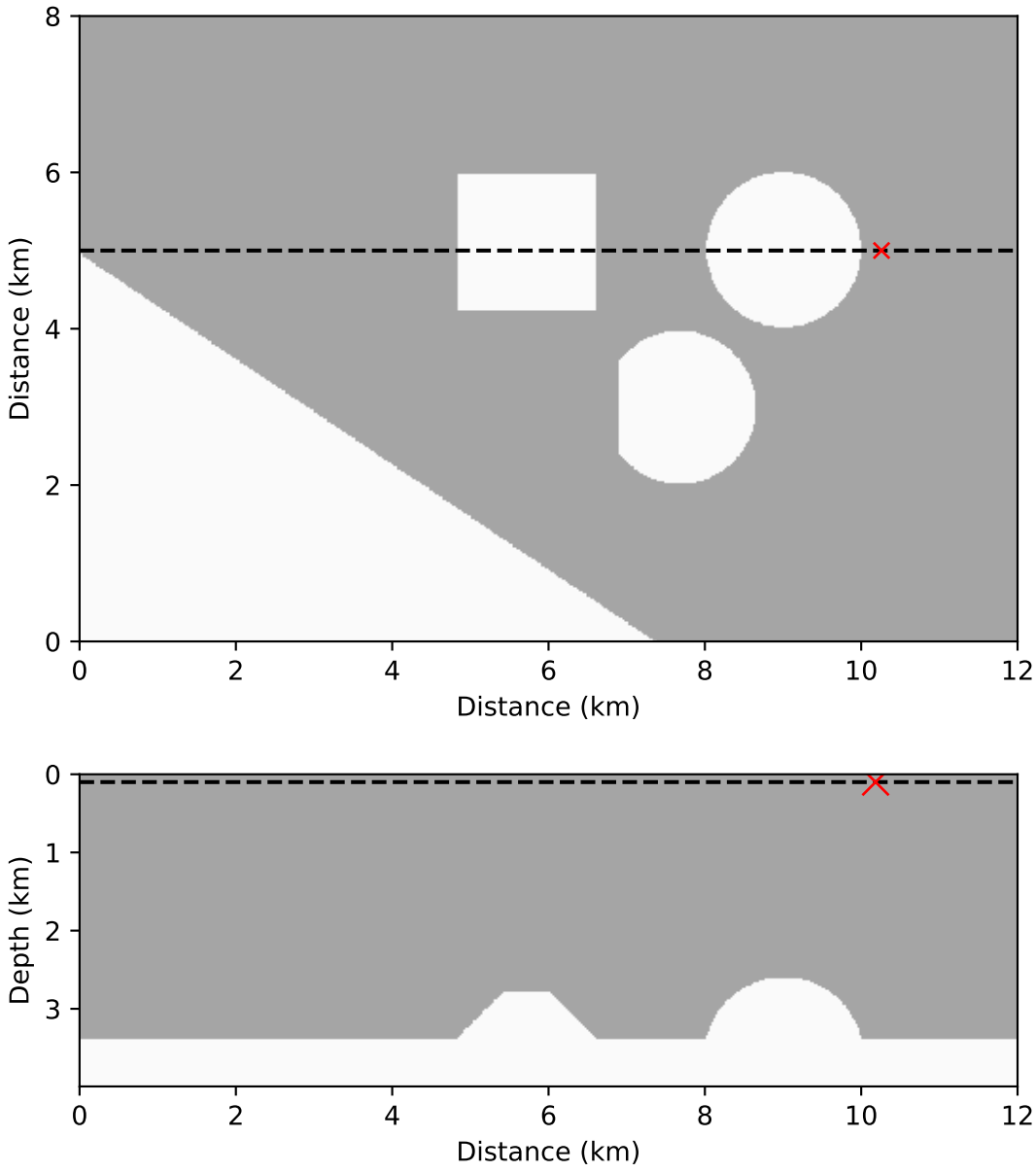
Time (secs)

Results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Distance (km)
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Depth (km)
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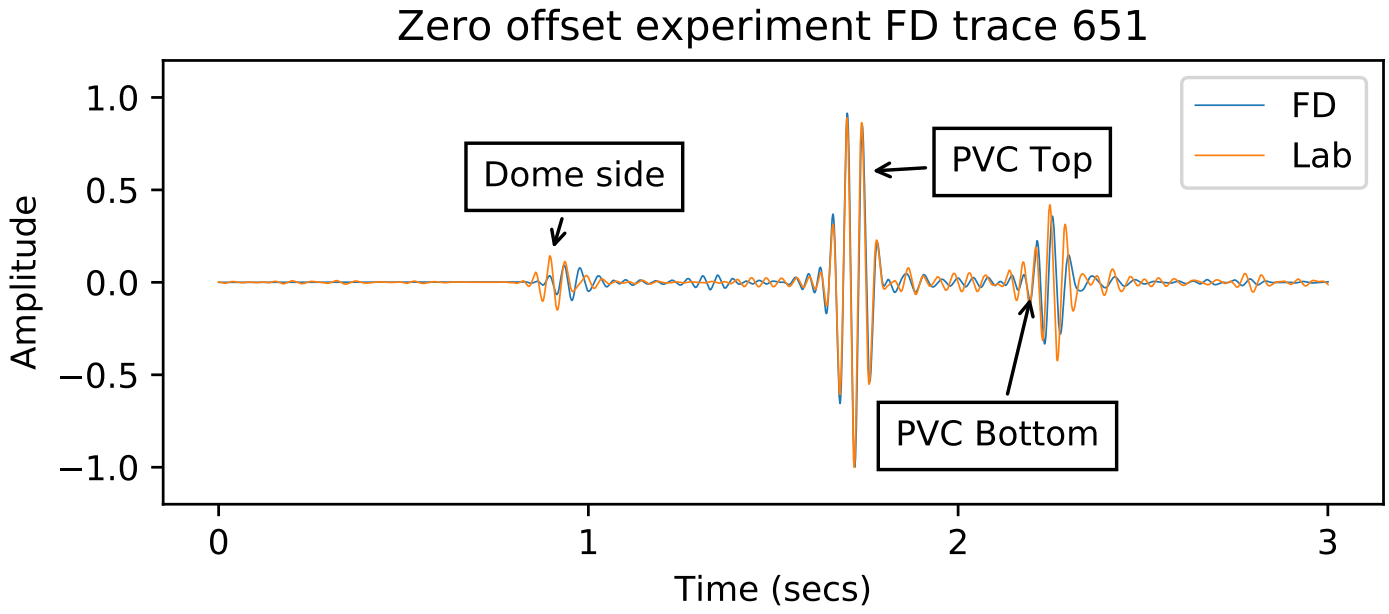
Distance (km)

Results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Time (secs)
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Dome side
PVC Top
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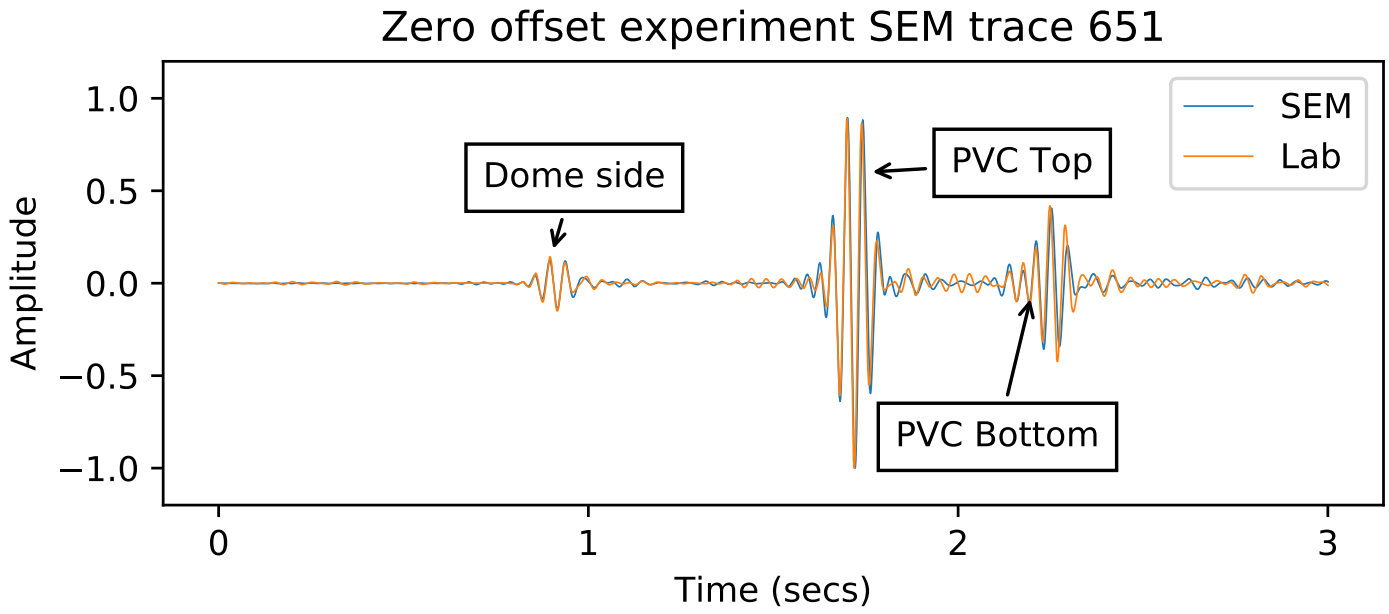
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Amplitude
Time (secs)
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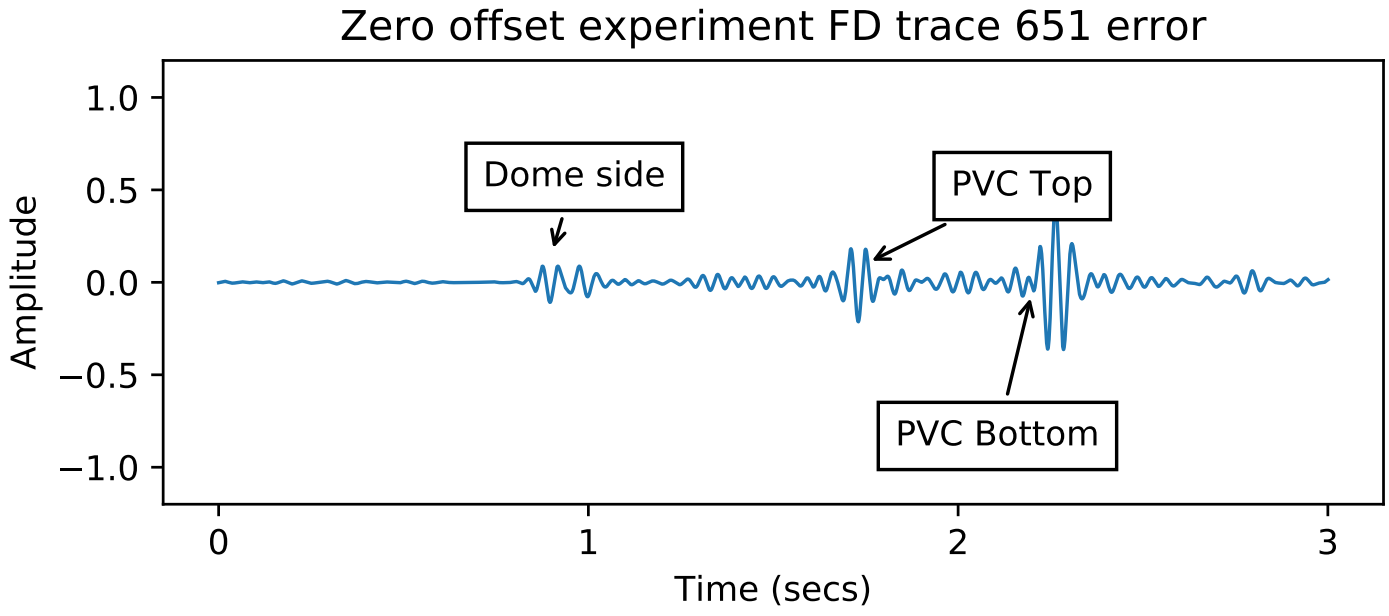
Results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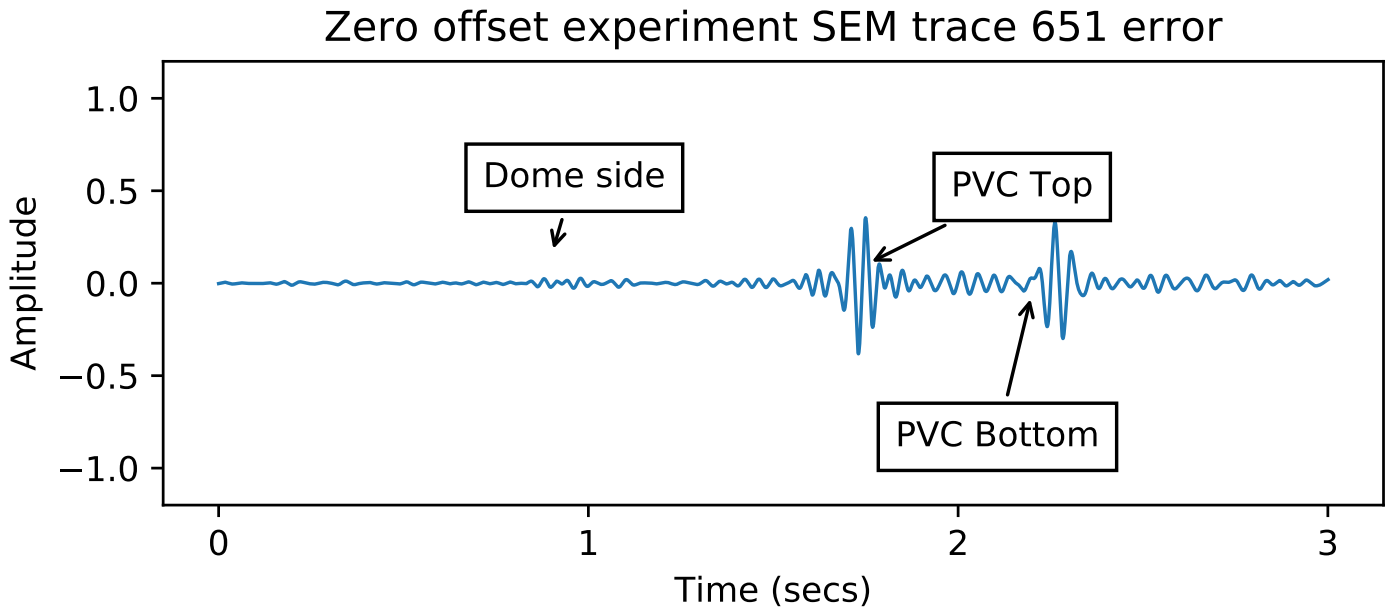
Time (secs)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Dome side
PVC Top
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Time (secs)

Discussion and Conclusions

- Experimental problems with measurements of source directivity
- Experimental problems with measurements of source/receiver positions

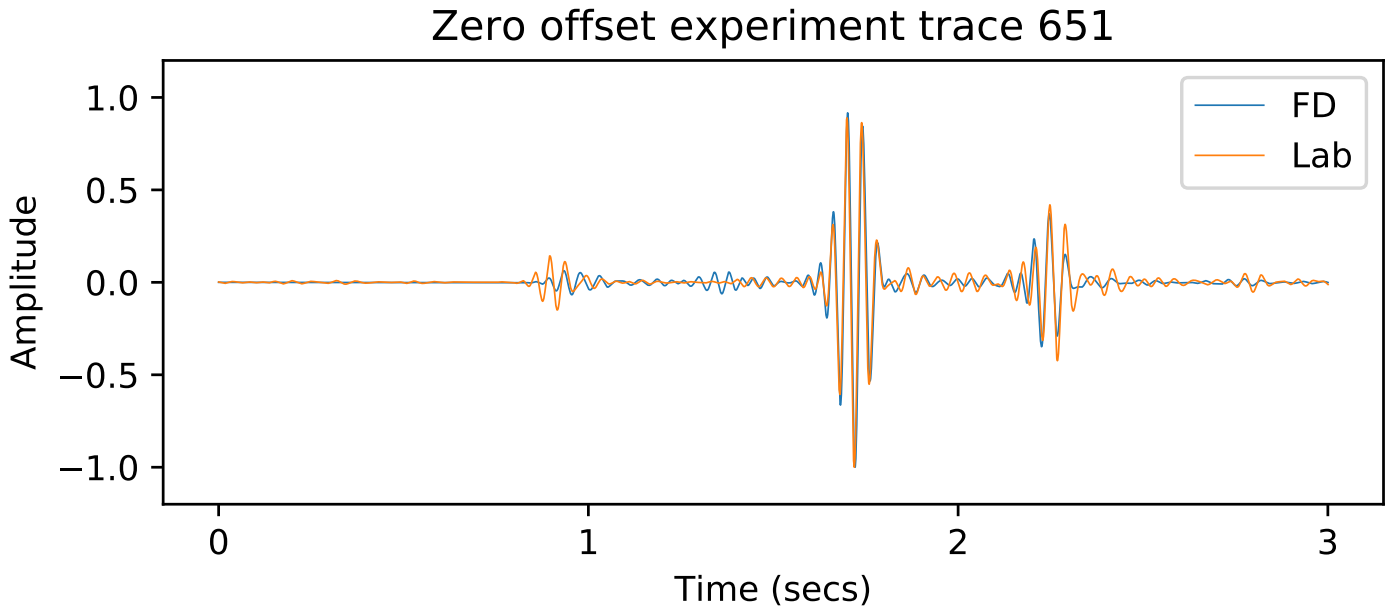
- Computational effort for SEM modeling 1611 CPU-hours
- Computational effort for FD modeling 27 CPU-hours (desktop PC with Gaming GPU card)

- Coarse grid Finite-difference gives reasonable results for simple structures
- Coarse grid Finite-difference not accurate for spherical surface

References

[1] Nathalie Favretto-Cristini and Paul Cristini. Benchmarking of numerical methods dedicated to wave propagation and wave-based imaging against laboratory data in complex environments description of the experimental set-up & data acquisition zero-offset & multi-offset data at 500 khz nathalie favretto-cristini & paul cristini version 1. Technical report, Laboratory of Mechanics and Acoustics-Marseilles (LMA), 2015.

Results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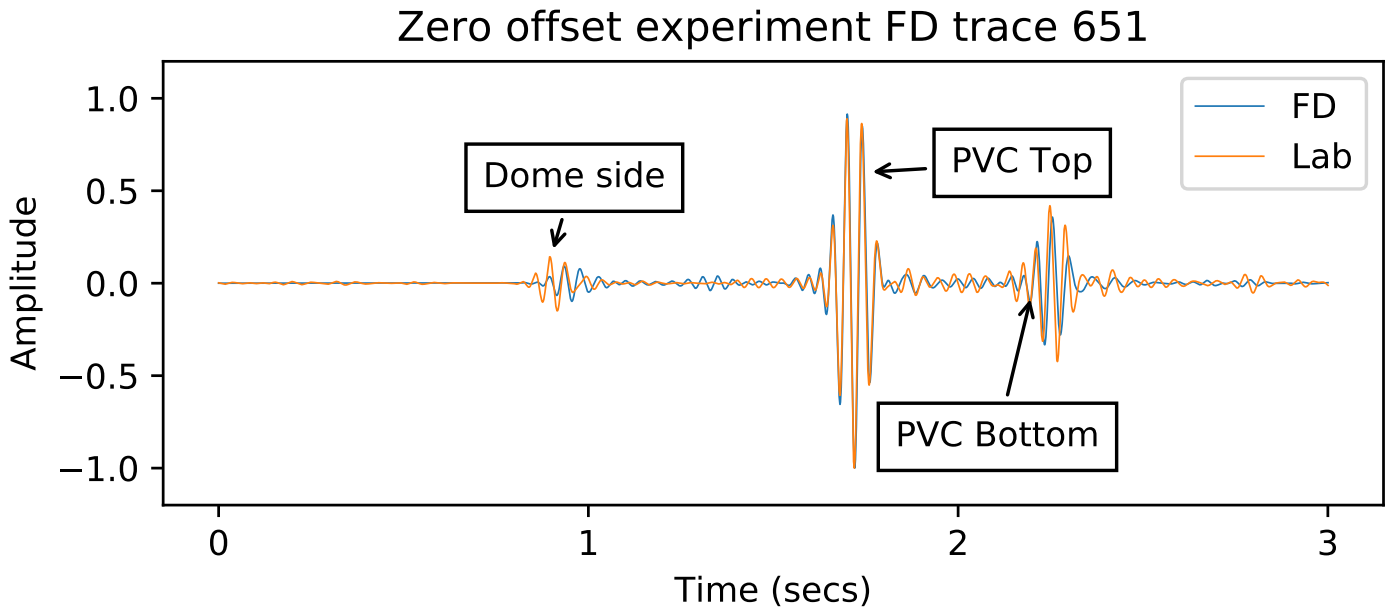
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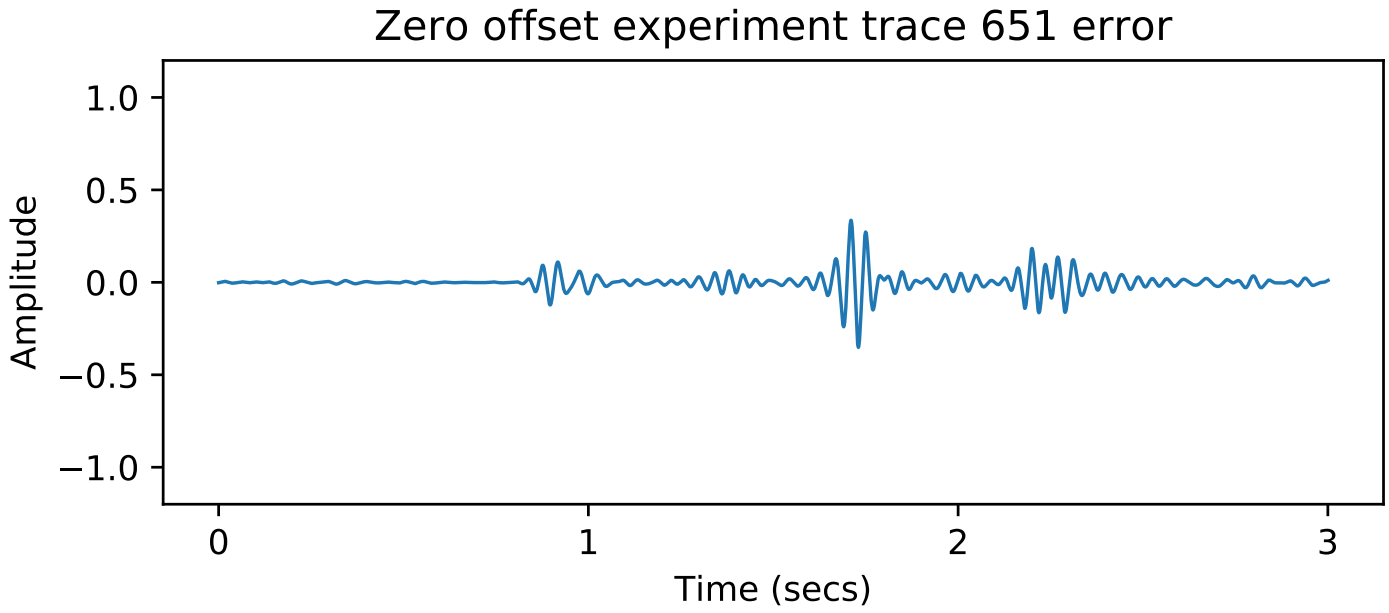
Results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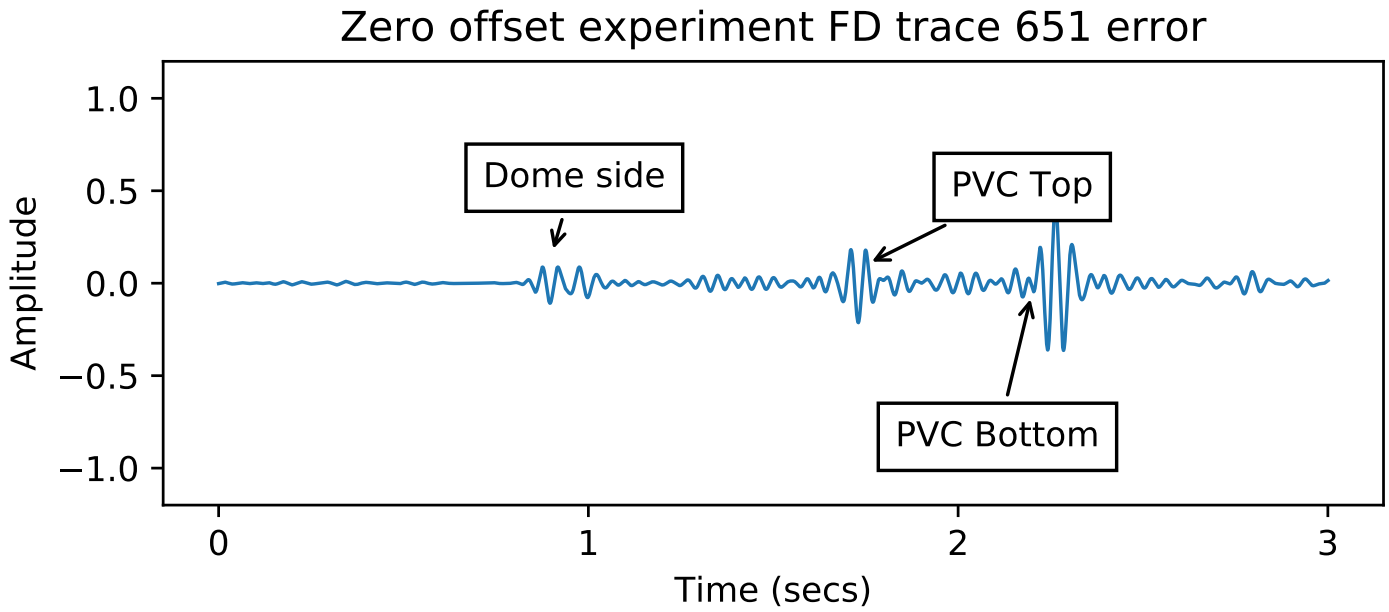
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Time (secs)