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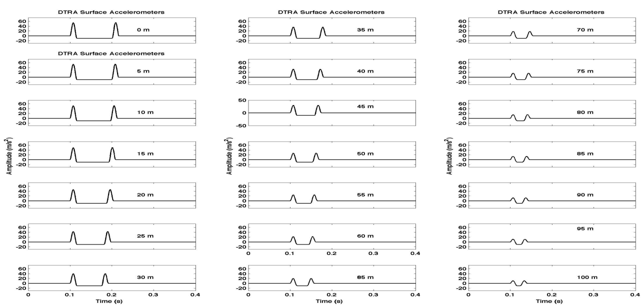

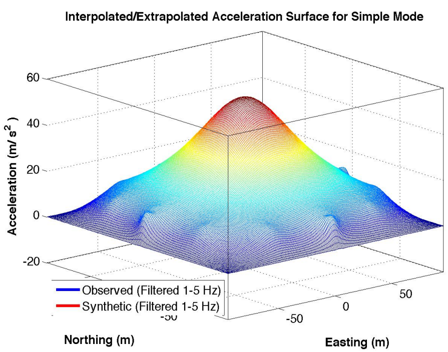

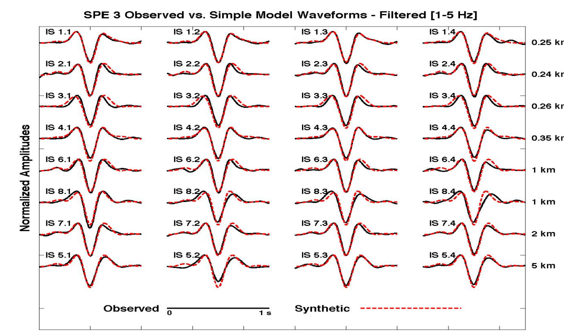

Spall Effects on Infrasound Generation

Kyle R. Jones[1] and Rod Whitaker[2], Arthur Rodgers[3]

Souheil Ezzedine[3]

[1]Sandia National Labs [2]Los Alamos National Laboratory

[3]Lawrence Livermore National Laboratory

AGU December 2014

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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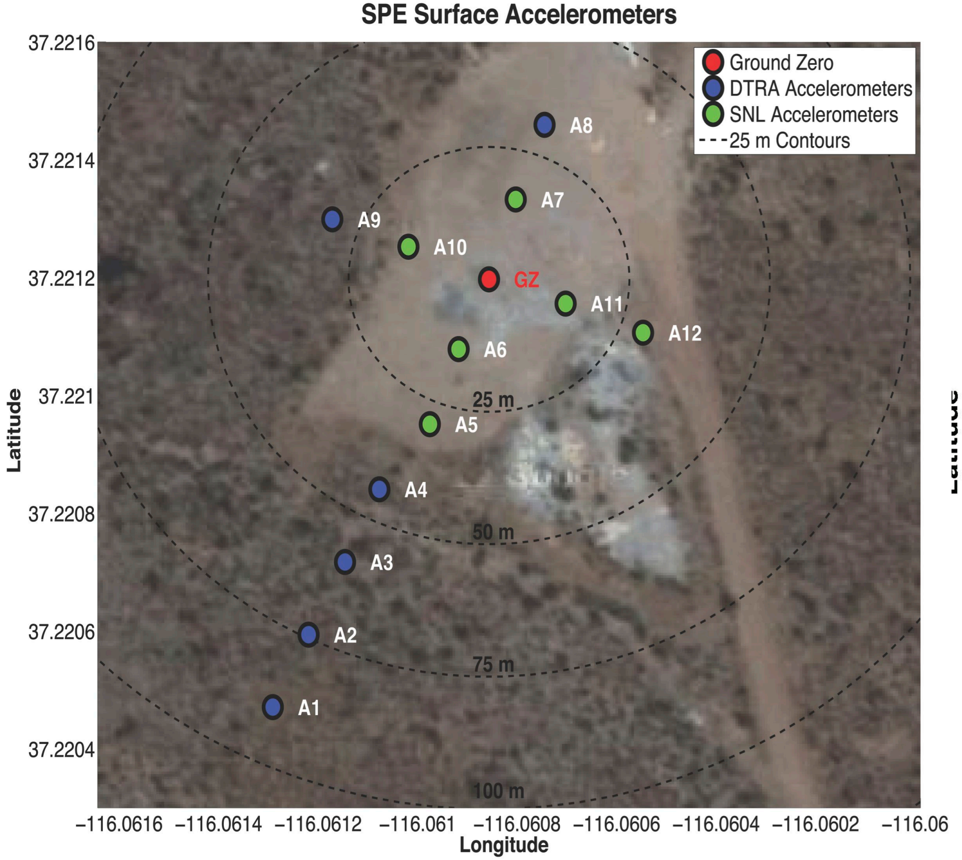
Collaborators

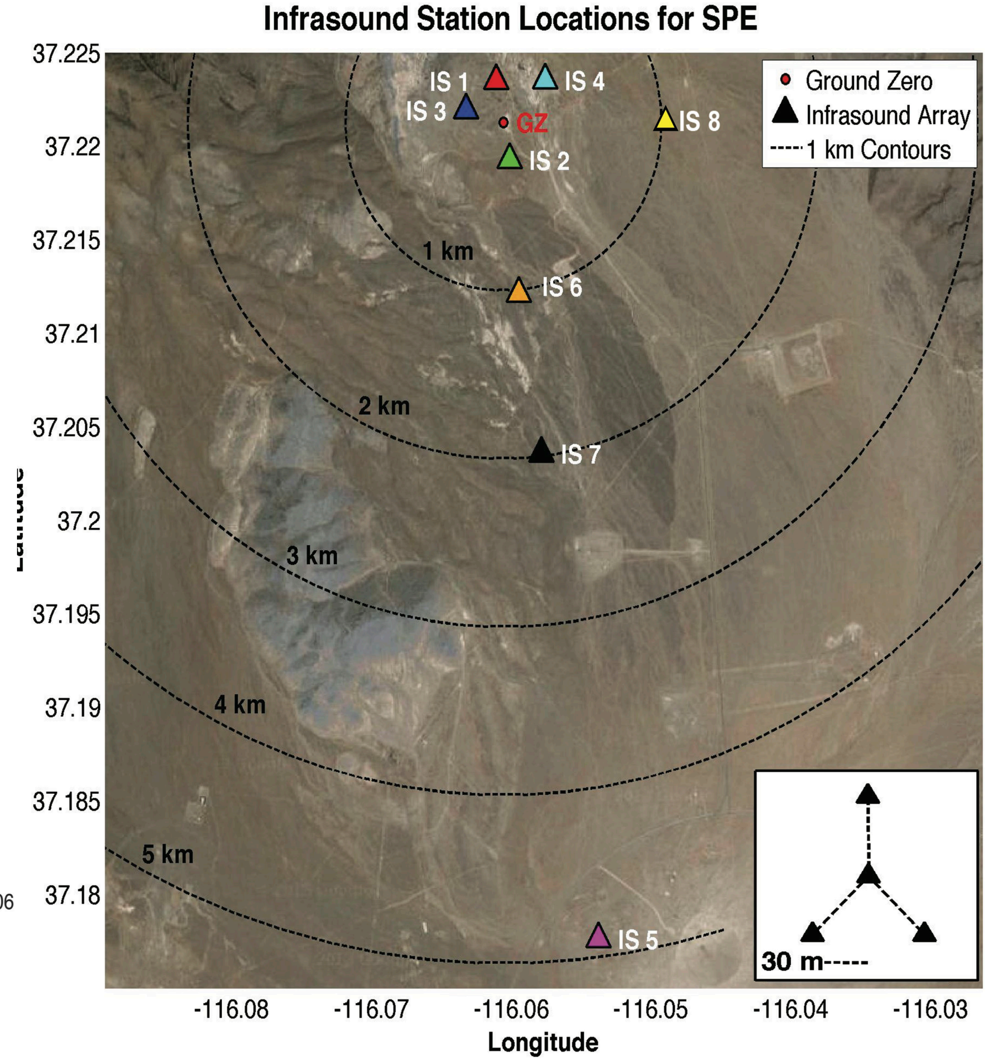
- Rod Whitaker
  - Los Alamos National Laboratory
- Arthur Rodgers and Souheil Ezzedine
  - Lawrence Livermore National Laboratory
- Bob White
  - National Security Technologies

Motivation

- Develop a simple infrasound model for underground explosions
- Determine if spall imparts a unique signature on the acoustic signal
- Used surface accelerations and the Rayleigh Integral to produce synthetic infrasound traces
  - Modeled SPE 2 and SPE 3 (GJI Publication)
- Generate synthetic surface accelerations
  - Simple surface acceleration and spall models [Stump (85), Patton (90)]
  - Full finite-difference hydrodynamic solution for surface accelerations (GEODYNE-L)
- Continue to use the Rayleigh Integral
  - Fast and efficient with very good results (input dependent)

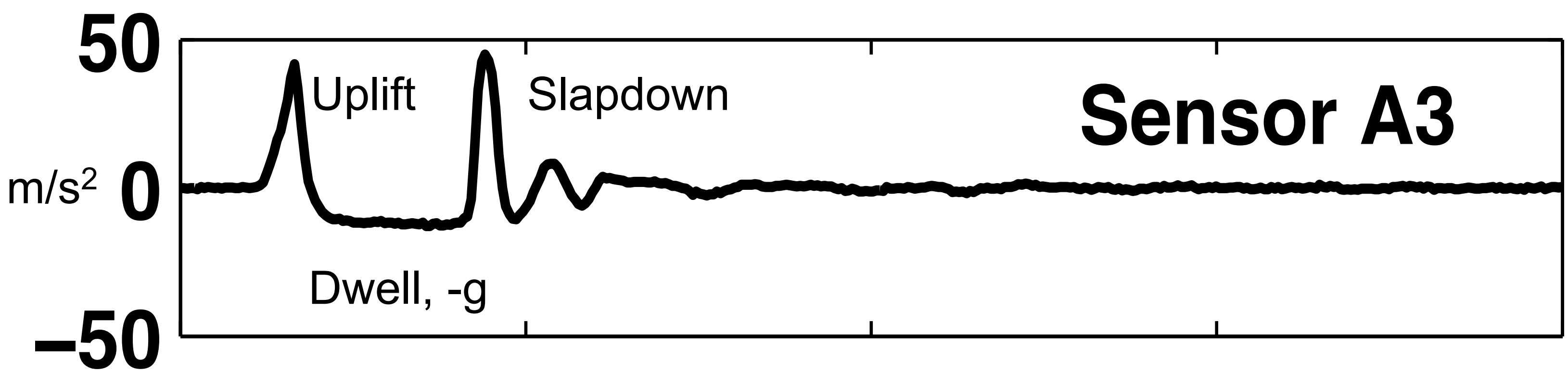
SPE Infrasound Array and Surface Accelerometer Locations





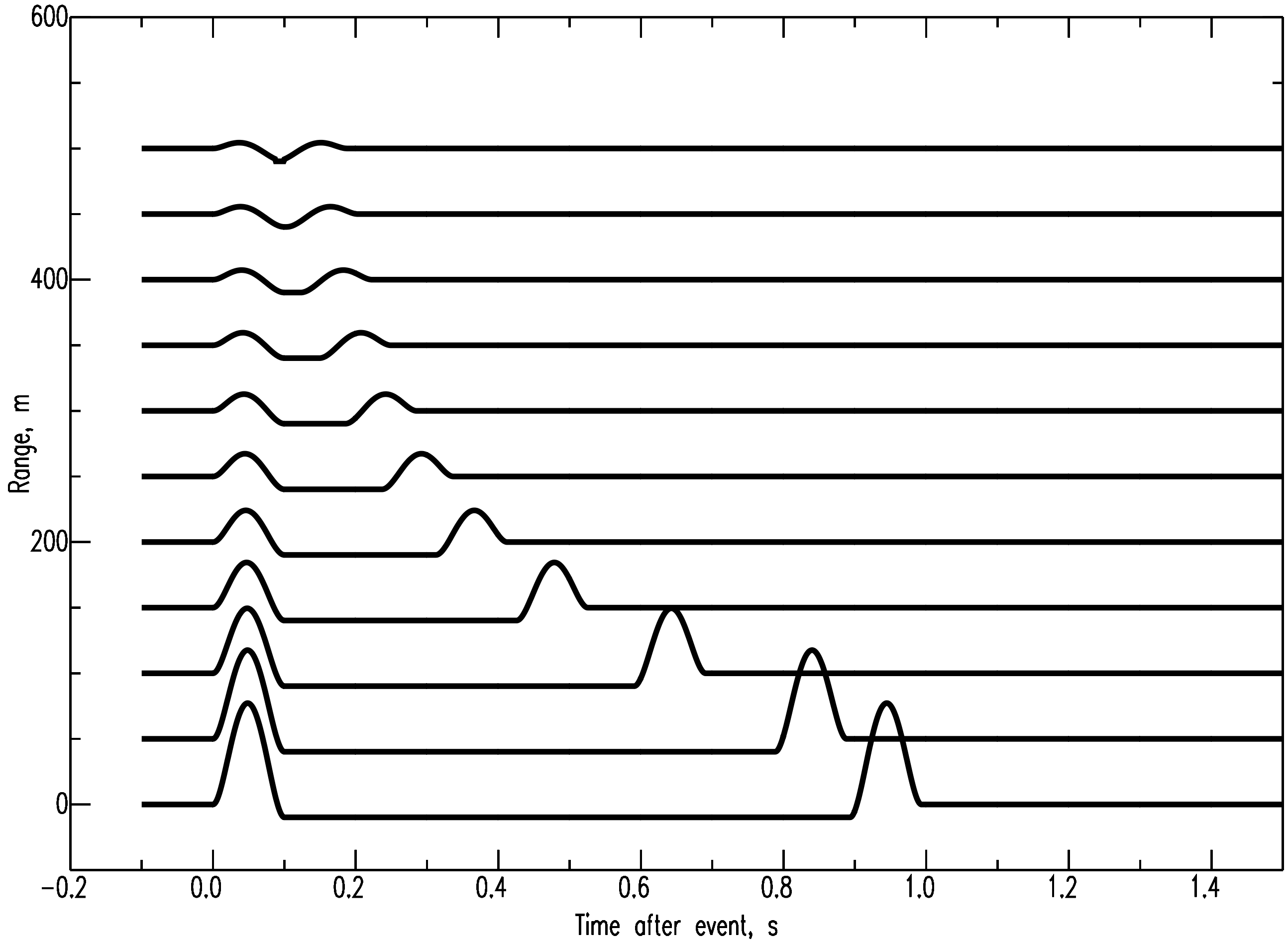
SPALL

- Spall occurs when layer(s) of rock above explosion separate and are sent in free fall
- Describes the force or acceleration near explosion ground zero
  - Uplift = initial pulse, uplift of spall layer
  - Dwell = free fall, -g
  - Slapdown = spall layer reconnects
- Spall model follows
  - Stump (1985) for the time-dependence
  - Patton (1990) for the scaling of peak velocity, acceleration, dwell time, etc…



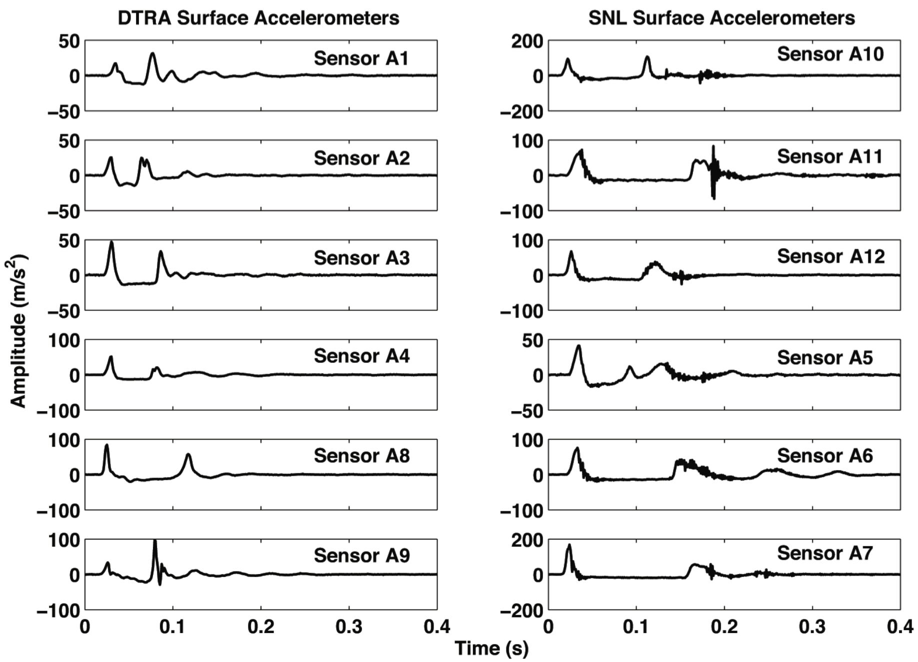
SPALL

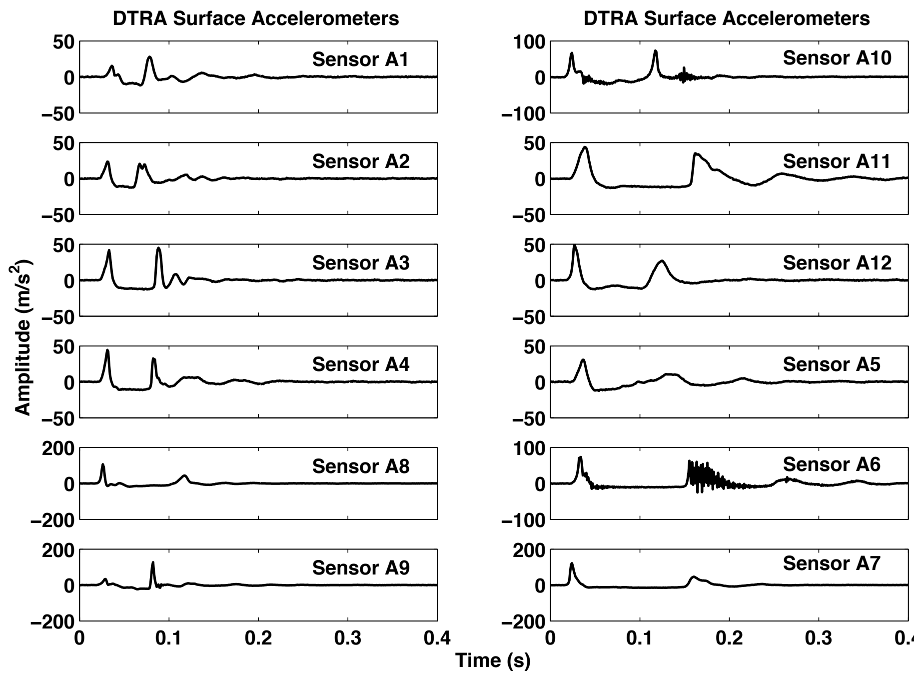
- Peak accelerations decay away from GZ
- Dwell time decreases away from GZ



RI Modeling with Observed Acceleration Data

- Modeled SPE-2 and SPE-3
  - Fundamentally similar shots in the same borehole
  - SPE-2 45.7 m DOB, 363 SDOB, 997 kg TNT equiv.
  - SPE-3 45.8 m DOB, 376 SDOB, 905 kg TNT equiv.

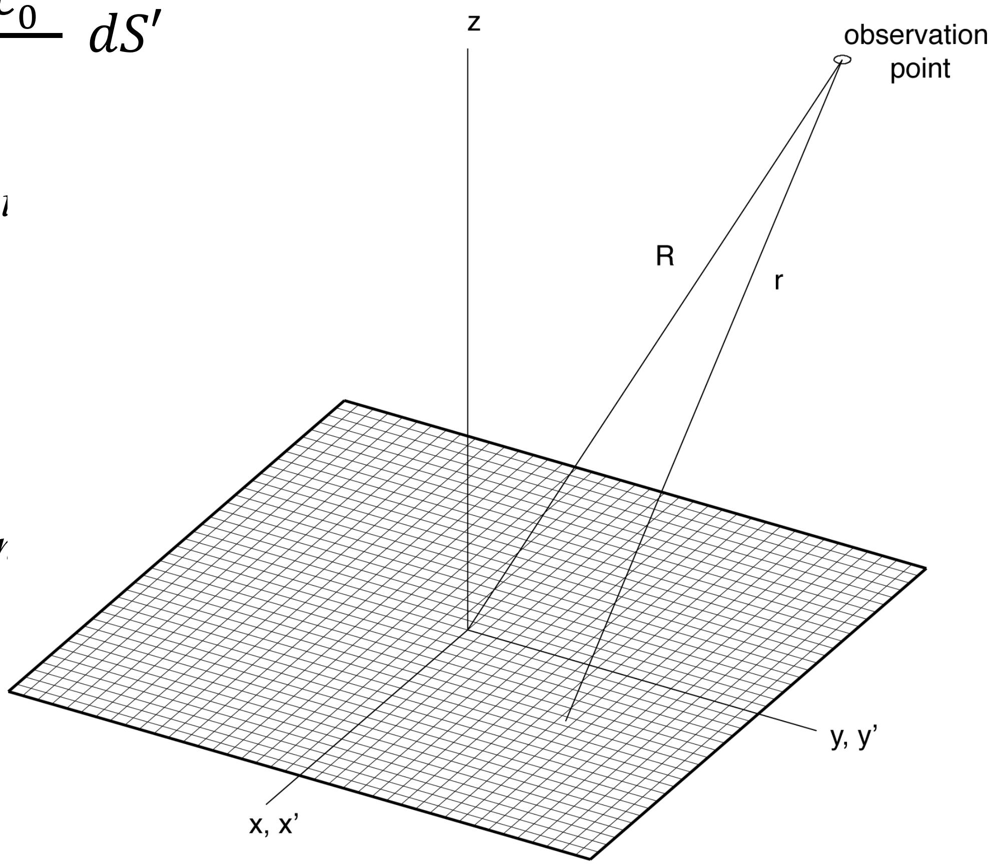




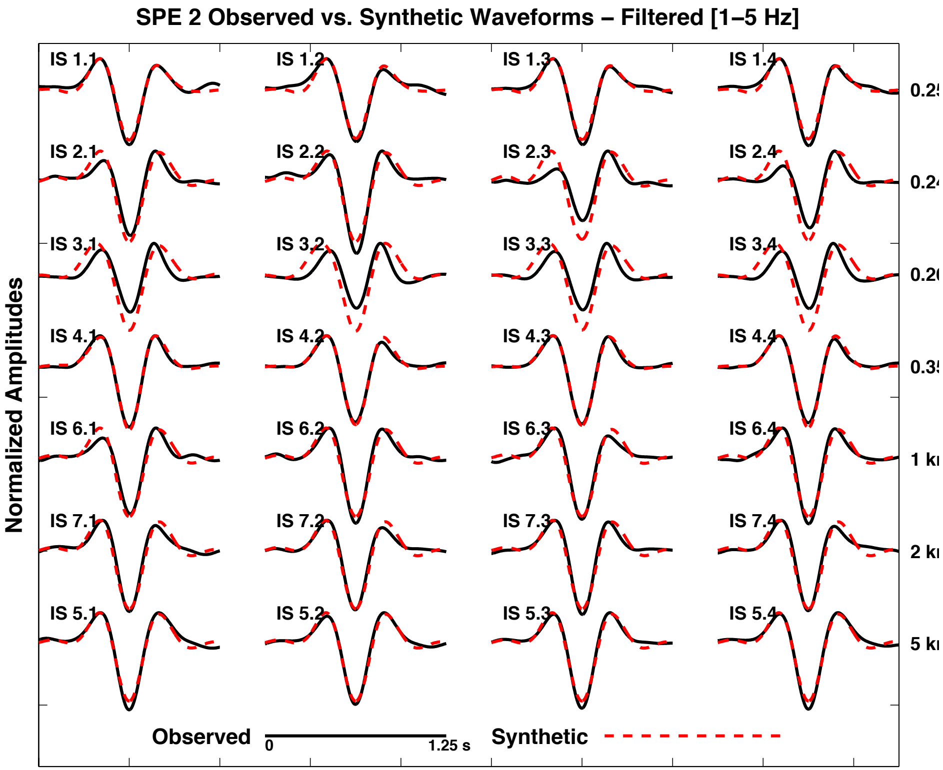
RI Modeling with Observed Acceleration Data

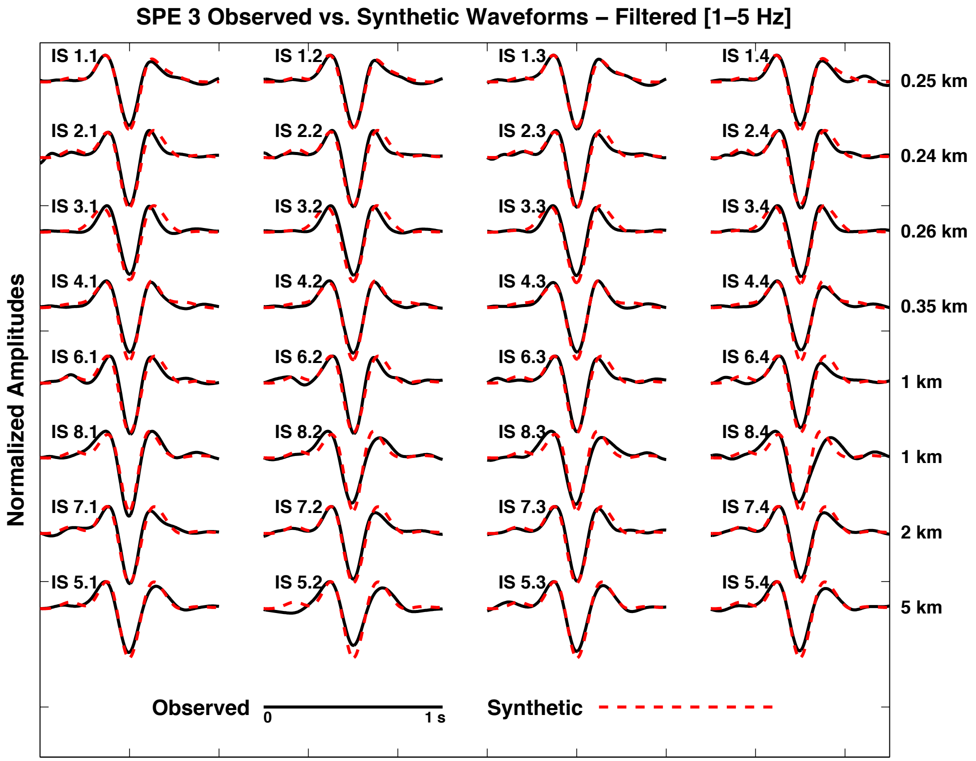
$$p(x,y,z;t) = \frac{\rho_0}{2\pi}\int_{S'} \frac{\dot{u}_z(x',y',t-\frac{r}{c_0})}{r}\,dS'$$

p(x, y, z, t) = pressure at observation poi
x, y, z = location of observation point
x', y' = location on baffle (2D)
S' = baffle surface
$u_z(x', y', t)$ = baffle element velocity, vertical component
$\mathring{u}_z(x', y', t)$ = baffle element acceleratior vertical component
r = range from baffle element to observation point
ρ_0 = density of air
c_0 = sound speed of air

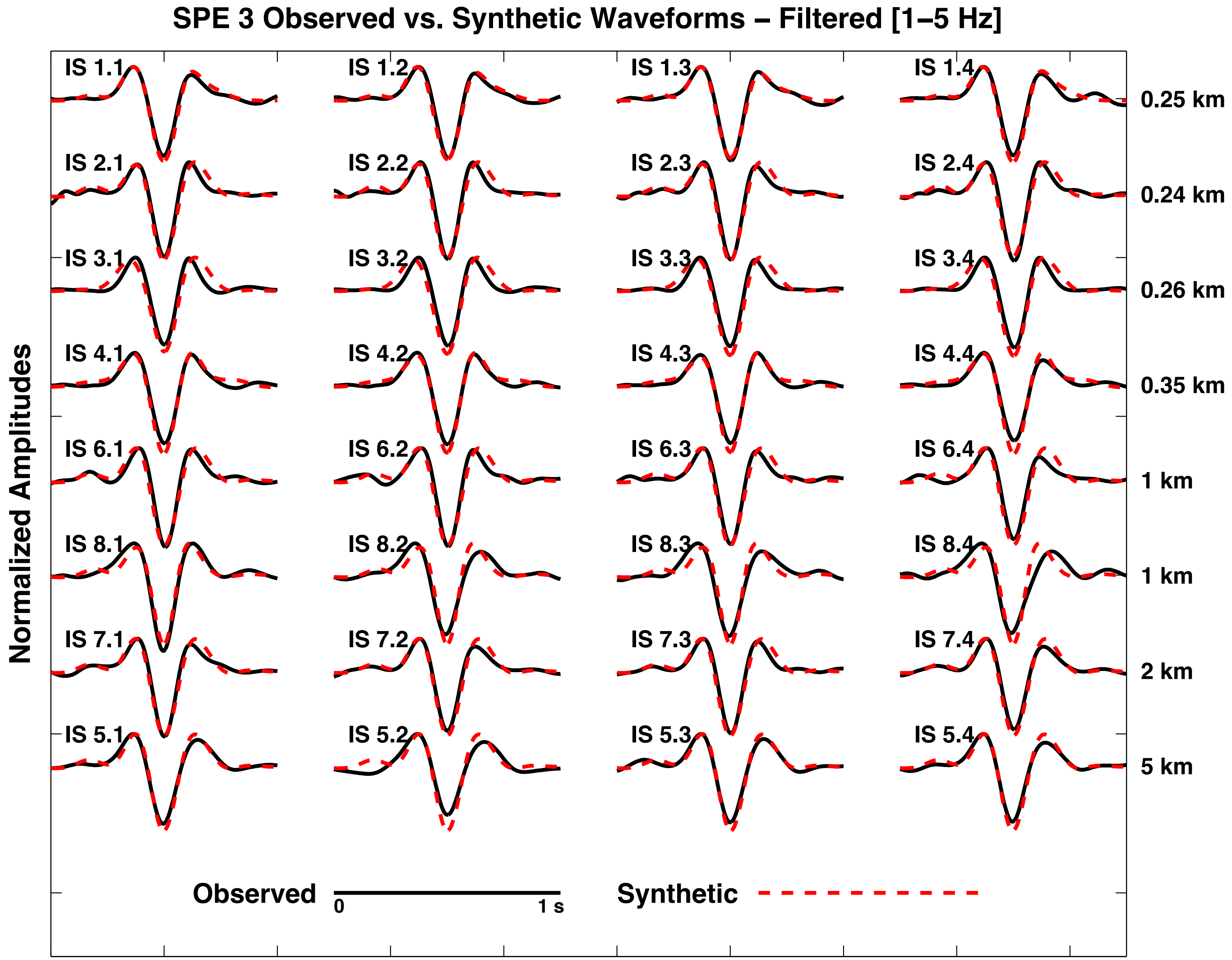


RI Modeling with Observed Acceleration Data





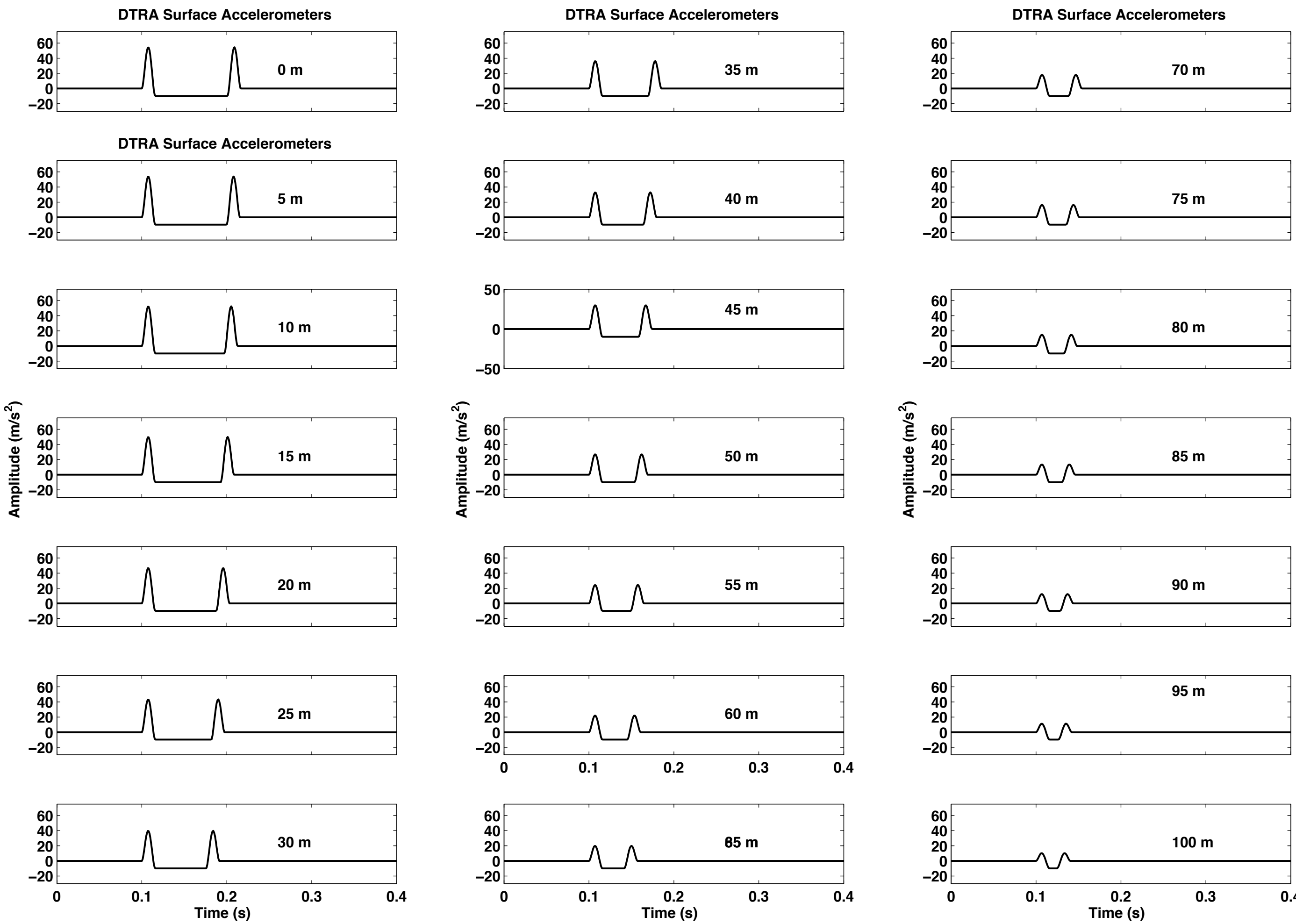
RI Modeling with Observed Acceleration Data

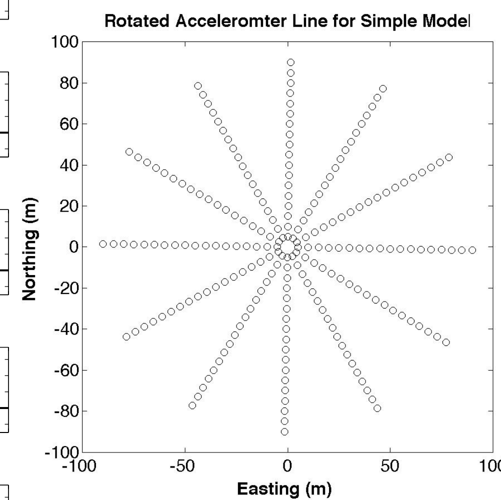


RI Modeling with Simple Acceleration/Spall Model

- LLNL computed this model for SPE-3
- W = 905.0e-6 # yield in kiloton
- DOB = 45.8   # depth-of-burial in meters
- TR = 0.0156   # rise time, half duration of initial acceleration pulse
- C = 4500   # compressional wave speed, m/s
- RHO = 1970   # density, kg/m**3
- Computed the acceleration in m/s/s at ranges = 0, 100 m, step = 5 m

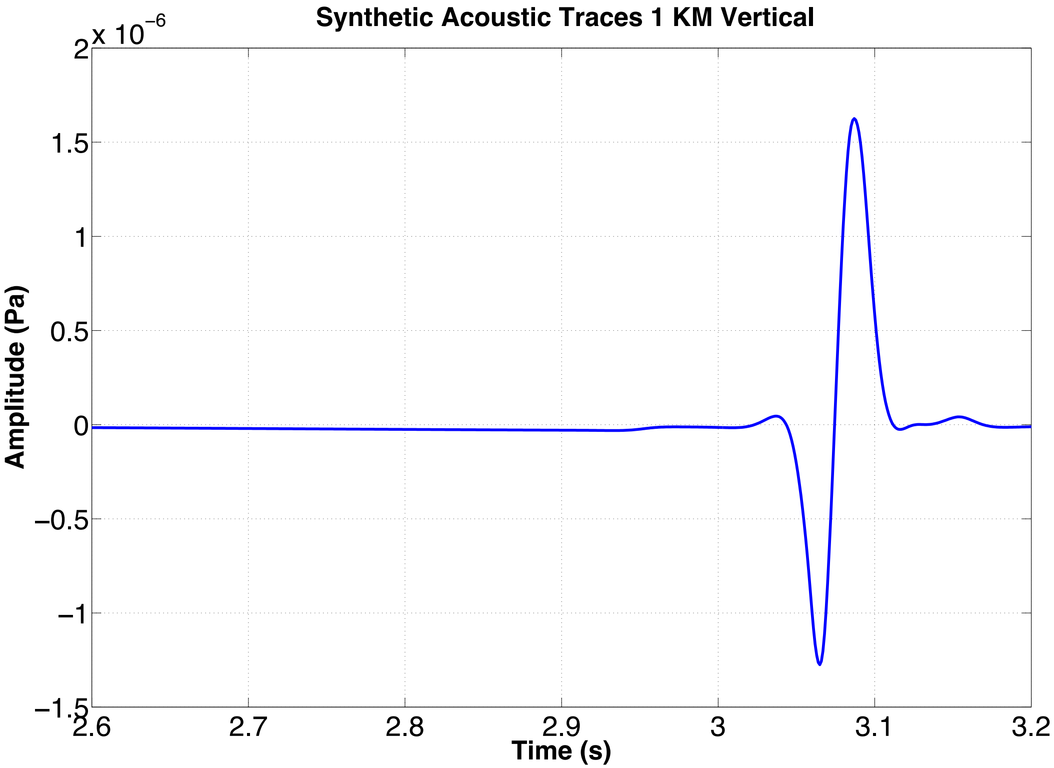
RI Modeling with Simple Acceleration/Spall Model

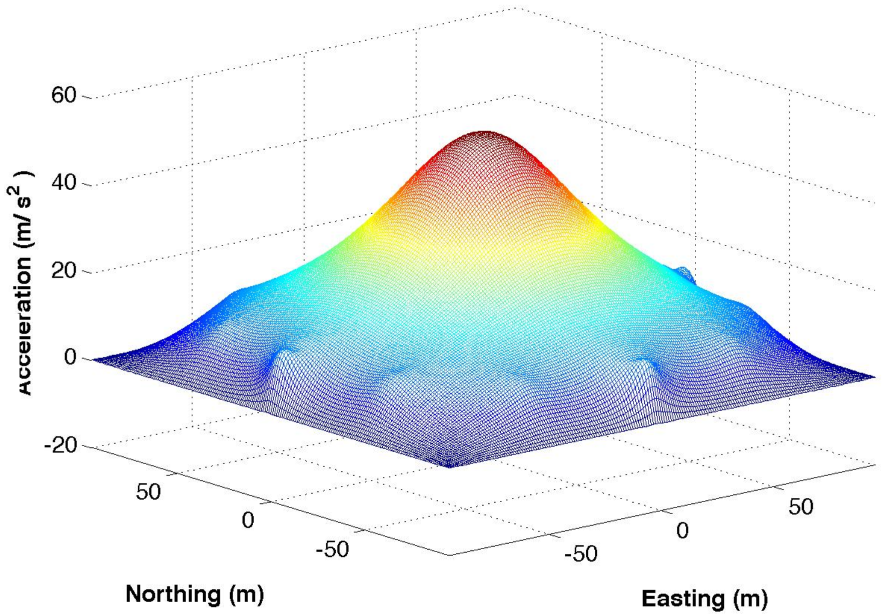




RI Modeling with Simple Acceleration/Spall Model

1 KM Directly Overhead

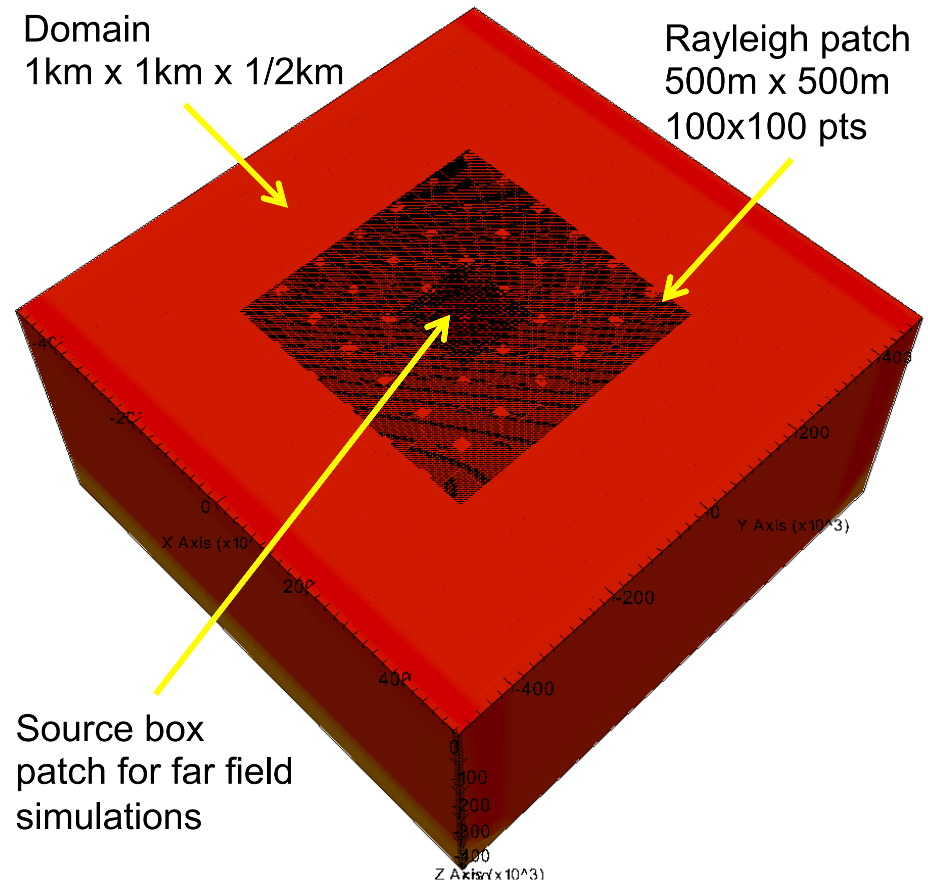




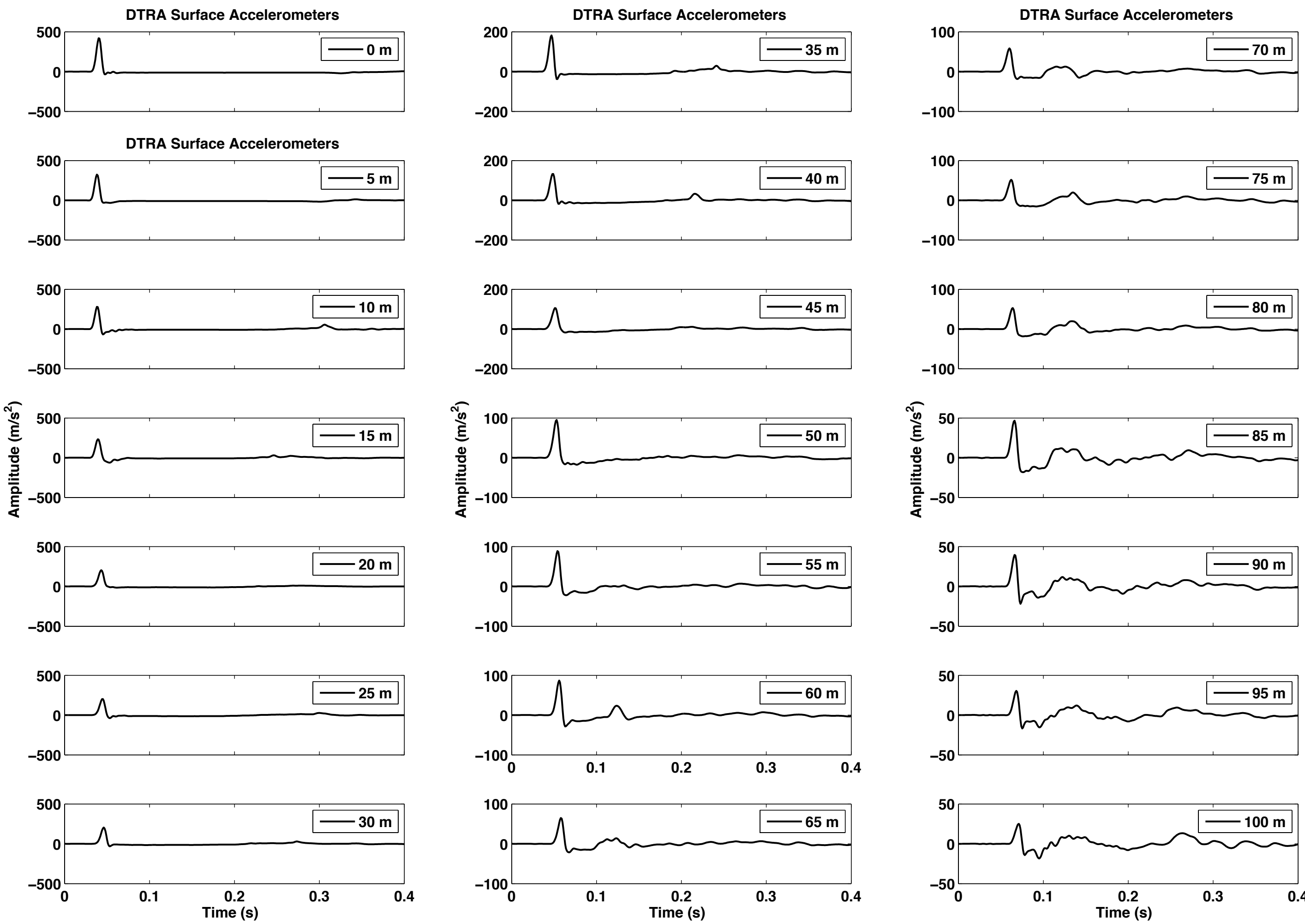
Acceleration Surface at Peak Acceleration

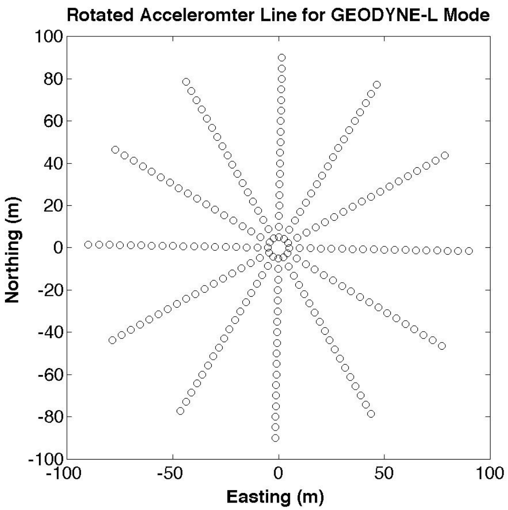
RI Modeling with GEODYNE-L Hydrodynamic Model

- Domain
  - 1x1 km^2 x ½ km
  - Rayleigh patch (surface gauges)
    - $(½ \text{ km})^2$
    - 100 x 100 stations
    - 5 m apart
- SPE3 geological setting
  - 2 granitic layers (weak & strong)
  - Joints are included no faults
  - Yield = SPE3
- Outputs
  - Velocity profiles
  - Acceleration profiles
  - Displacement profiles



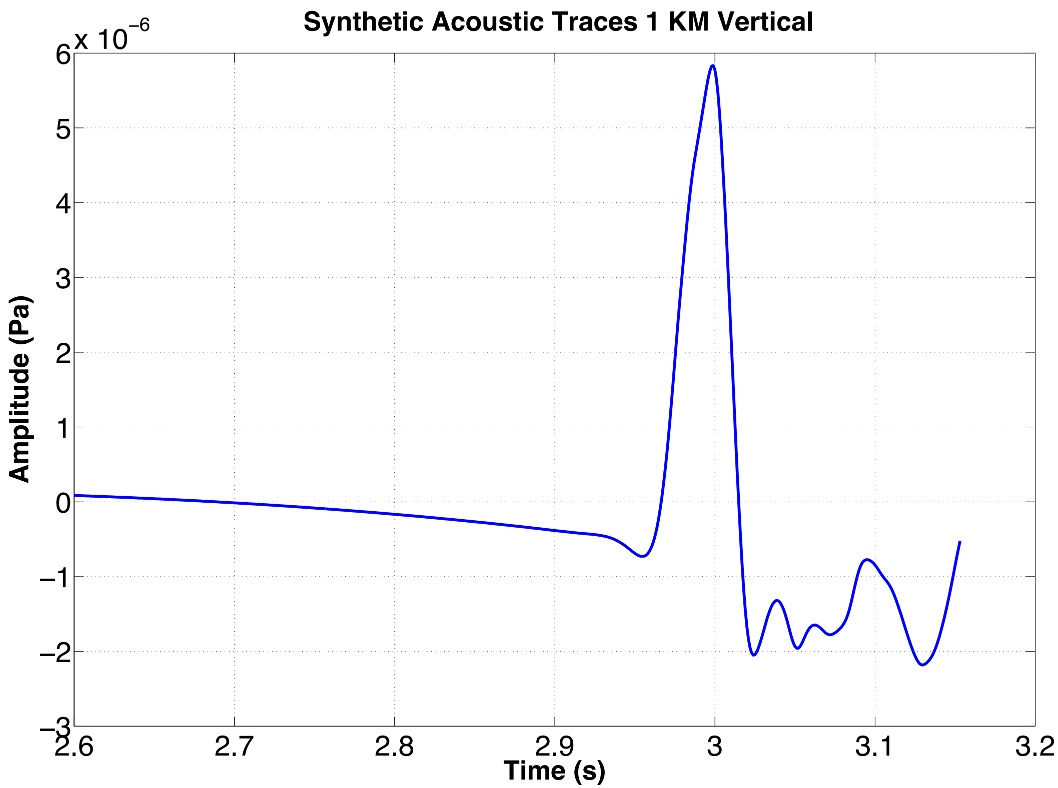
RI Modeling with GEODYNE-L Hydrodynamic Model

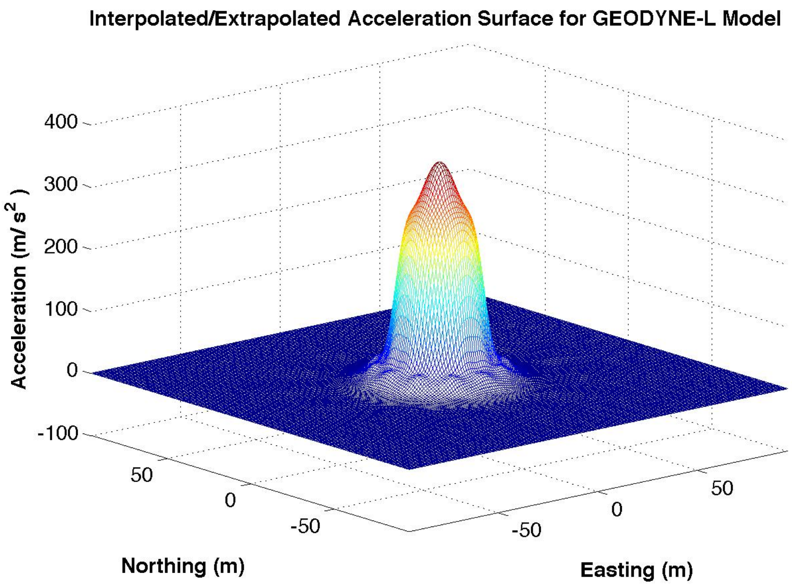




RI Modeling with GEODYNE-L Hydrodynamic Model

1 KM Directly Overhead

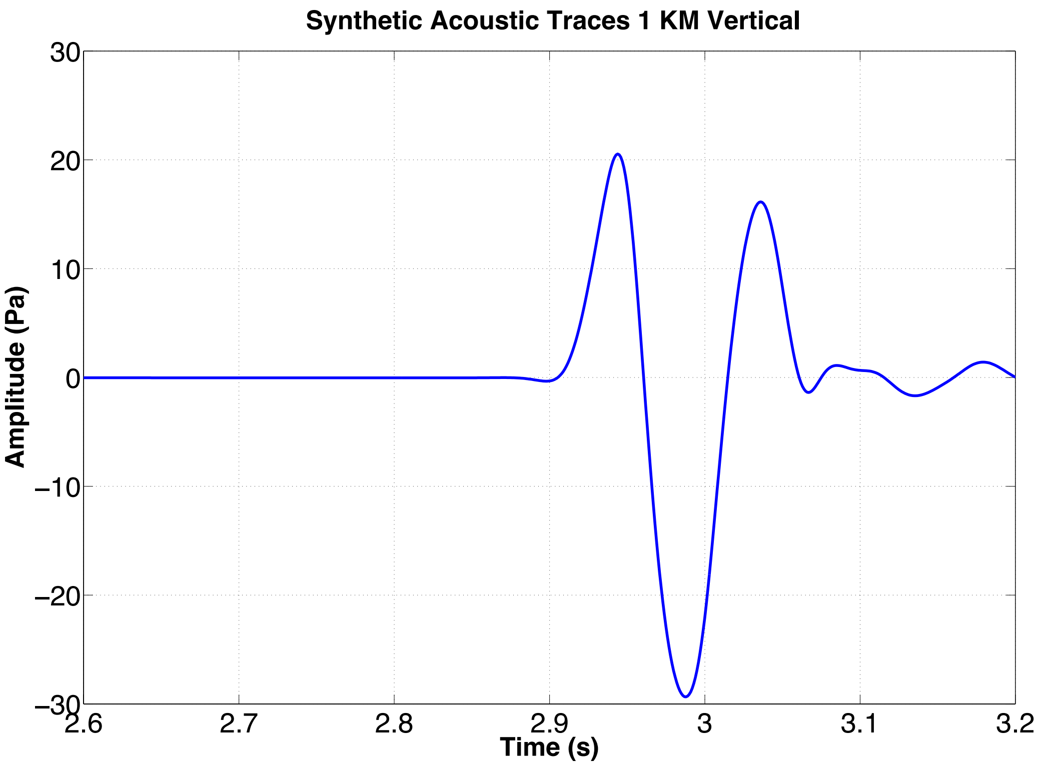


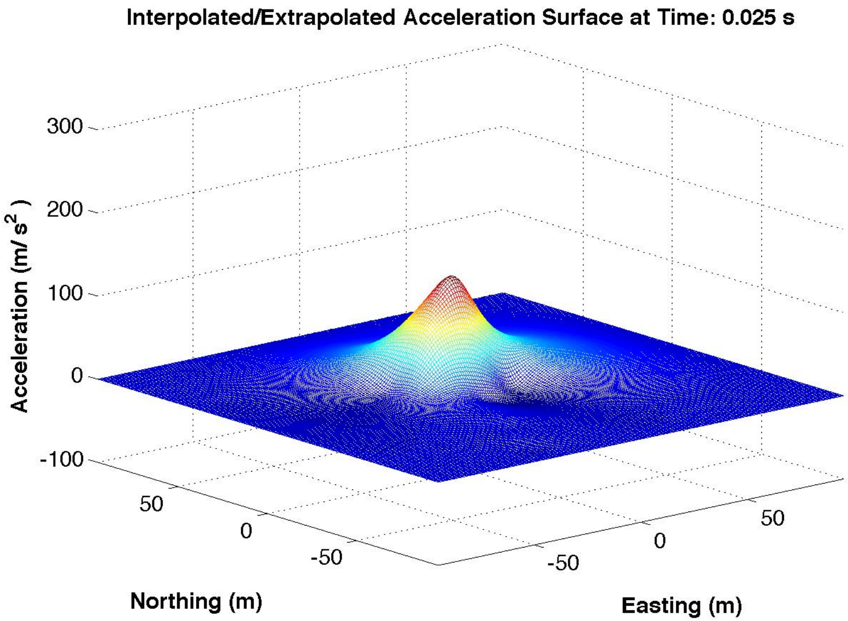


Acceleration Surface at Peak Acceleration

RI Modeling with Observed Surface Accelerations (SPE – 3)

1 KM Directly Overhead

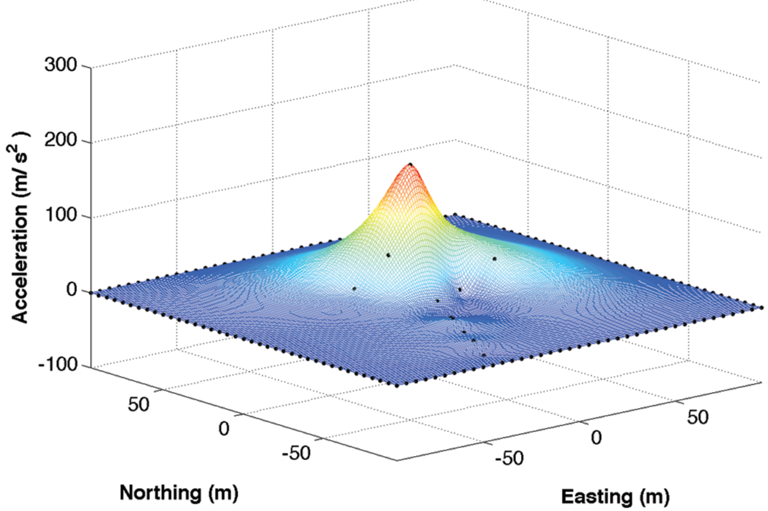




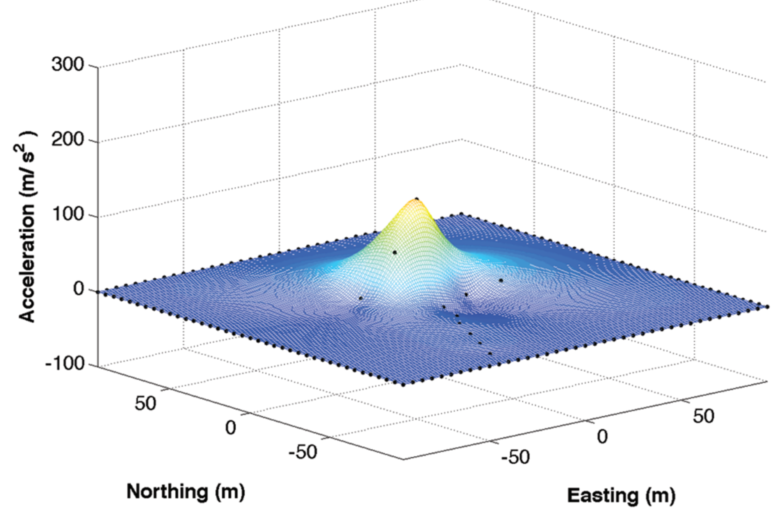
Acceleration Surface at Peak Acceleration

Acceleration Surfaces

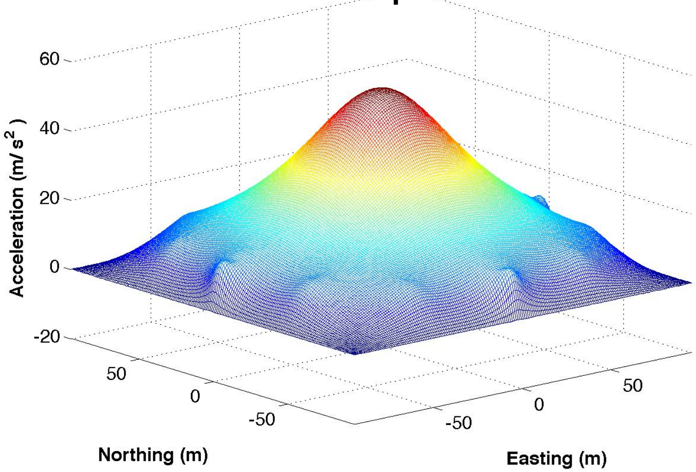
SPE - 2



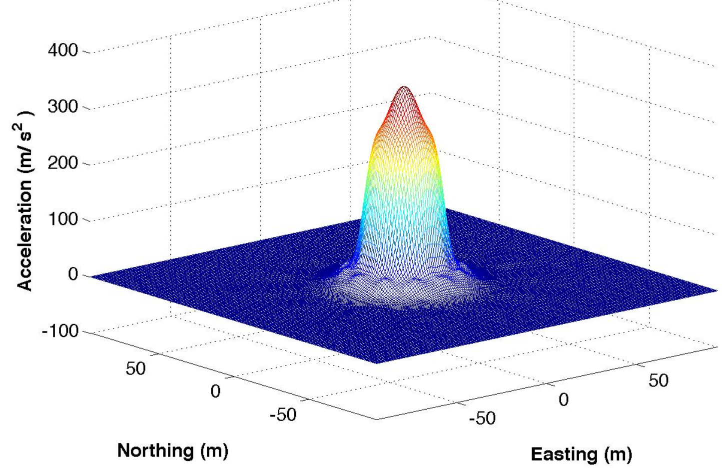
SPE - 3



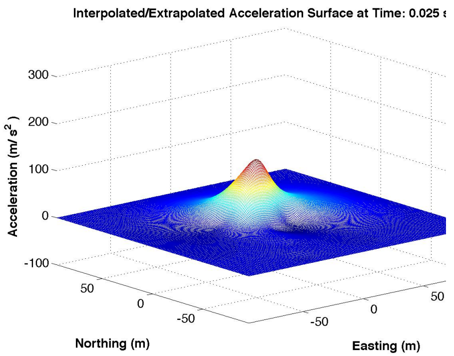
SPE – 3 Simple Model

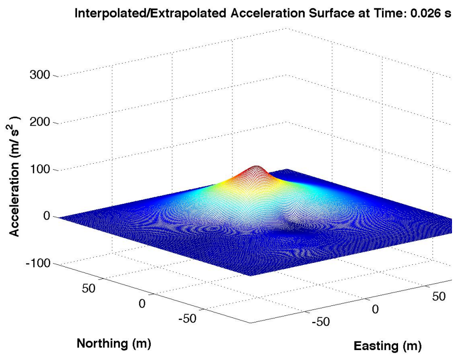


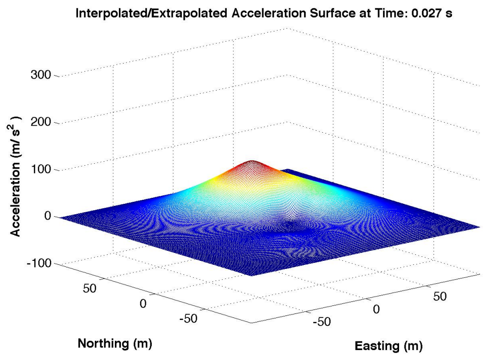
SPE – 3 GEODYNE –L Model

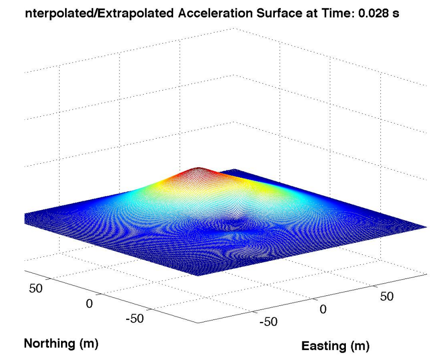


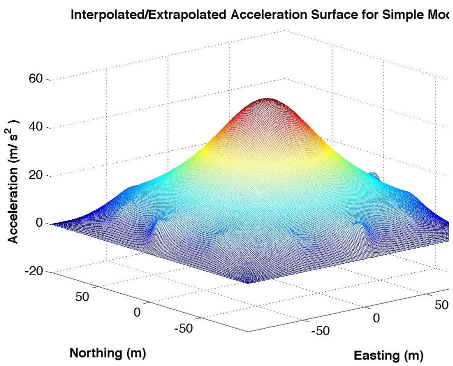
Acceleration Surfaces

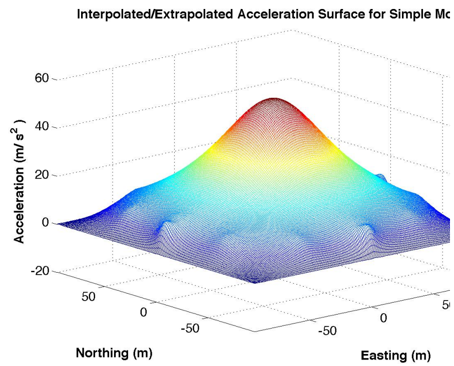


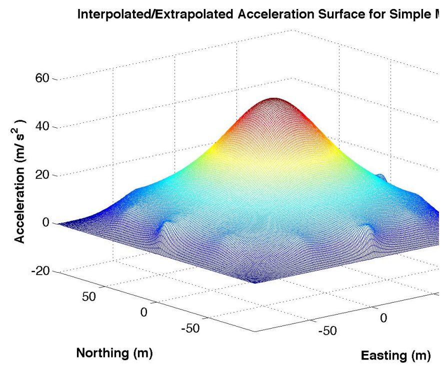


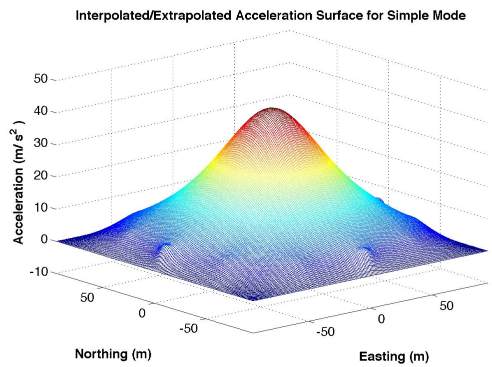


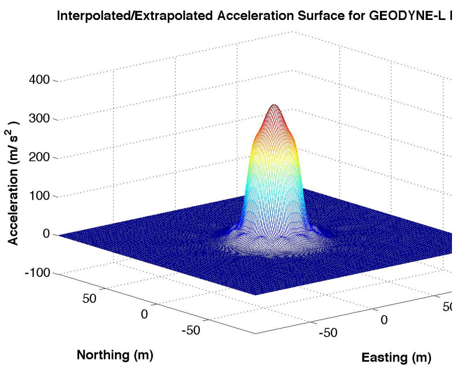


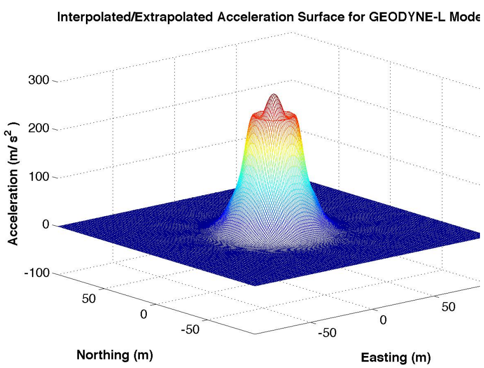


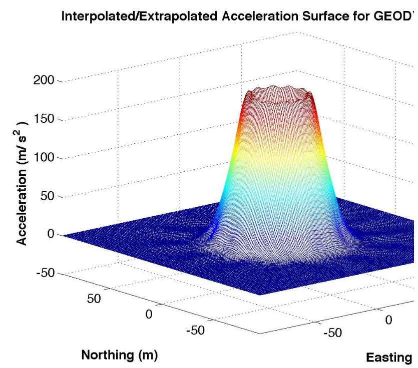


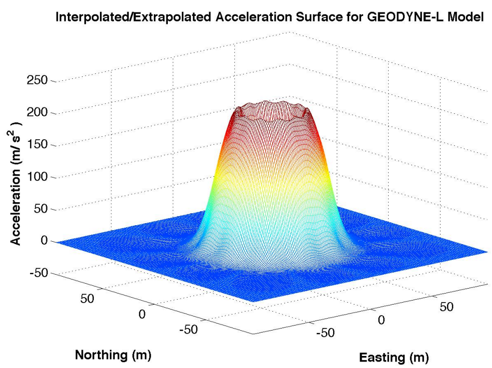












Observations (so far)

- Getting the spall (rise time, dwell time and slapdown) correct is imperative and greatly impacts the generated acoustic signal
- RI does a good job of reproducing the acoustic signal from surface acceleration data but is highly input dependent
- The simple and GEODYNE – L models aren't yet capturing the physics of the underground explosion to accurately reproduce the acoustic signal

Future Work

- More hydrodynamic modeling with our simple model and GEODYNE-L
  - Need to determine the correct parameters that match the observed signals and amplitudes
- Knowing that spall greatly effects the acoustic waveform we need to continue to vary the spall parameters and observe the changes to the acoustic waveform
- SPE 4’ – Explosion to minimize spall
- Use Hexacopter airborne infrasound platform to directly measure vertical waveform during future shots
- GJI Publication
  - “**Modeling infrasound signal generation from two underground explosions at the Source Physics Experiment using the Rayleigh integral**“

Questions?

Arrowsmith et. al 2014 (in review)