Internal multiple prediction in the time and offset domains

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Overview

- **Multiple**: Seismic energy that has been reflected more than once (SEG wiki)
  - **long-path multiple**: arrives as a distinct event
  - **short-path multiple**: arrives so soon after the primary that it merely adds tail to the primary (i.e., changes the waveshape).

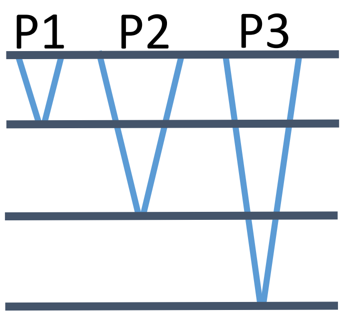
- For this project the focus is internal long-path multiple attenuation using the inverse scattering series

Objectives

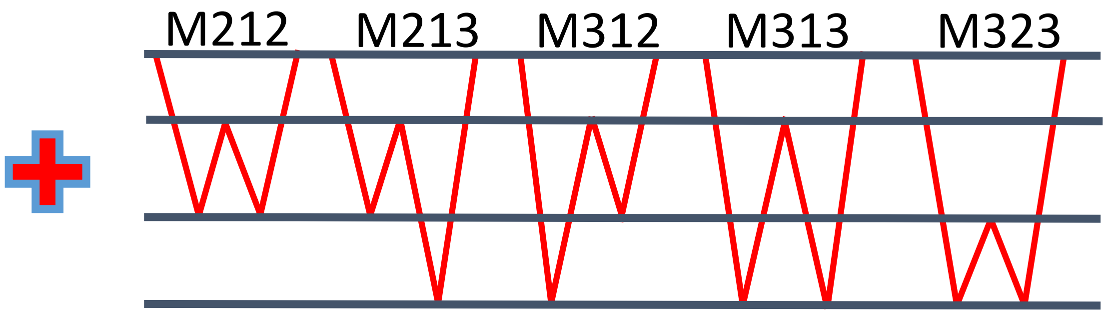
- **Goal of internal multiple prediction**:
  - Correctly predict the amplitudes of all internal multiples without predicting primaries
- **In practice**:
  - Optimal approximation to amplitudes and minimize artifacts of prediction
  - Prediction then input into adaptive subtraction

Internal Multiple Prediction

Primaries



Internal Multiples (first order)

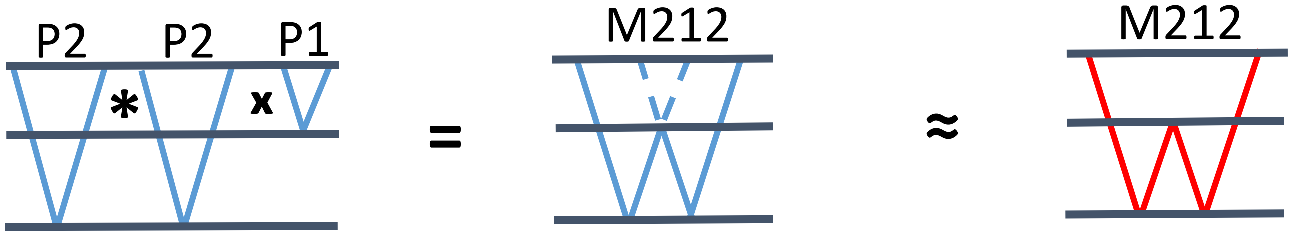


s_1 = Input Data

ε = Search limiting parameter

$$B_3(t) = \int_{-\infty}^{\infty} dt' s_1(t'-t) \int_{t'-(t-\varepsilon)}^{t-\varepsilon} dt'' s_1(t'-t'') s_1(t'')$$

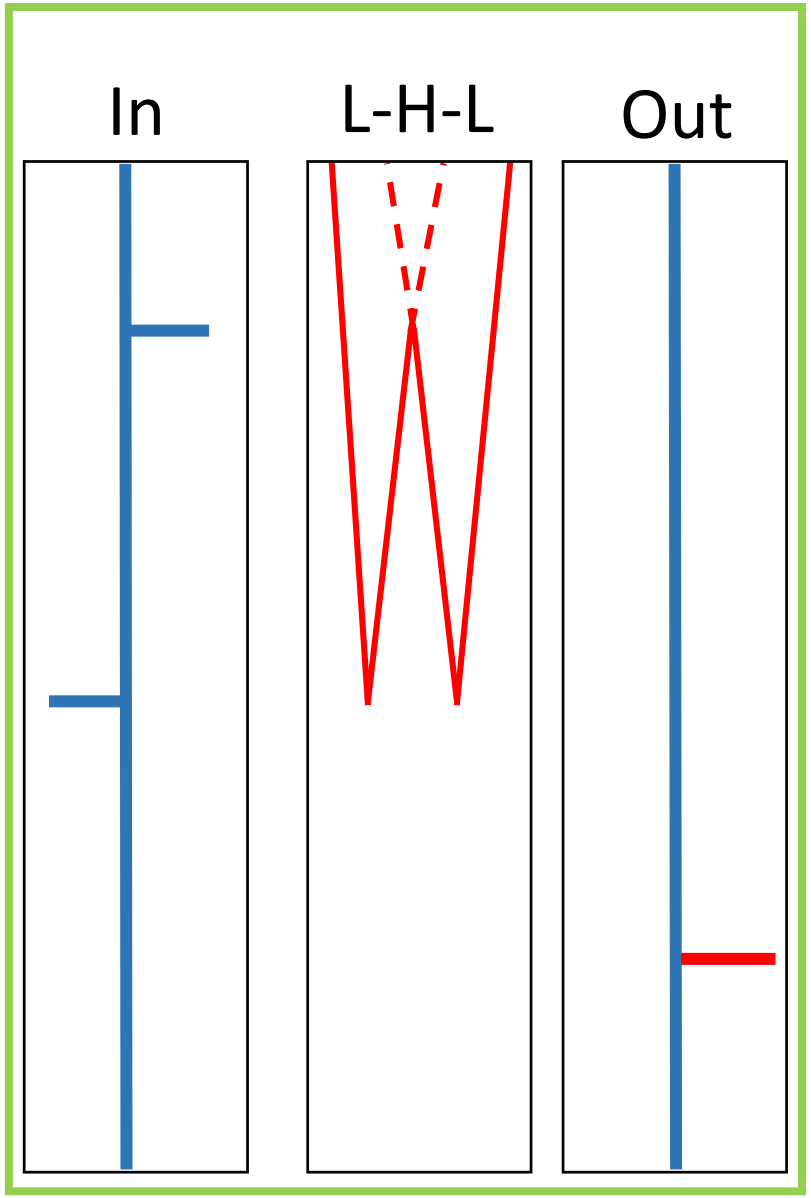
- Inverse Scattering Series
  - Only input data and epsilon required
  - Predict internal multiples from sub events in the data through integration limits

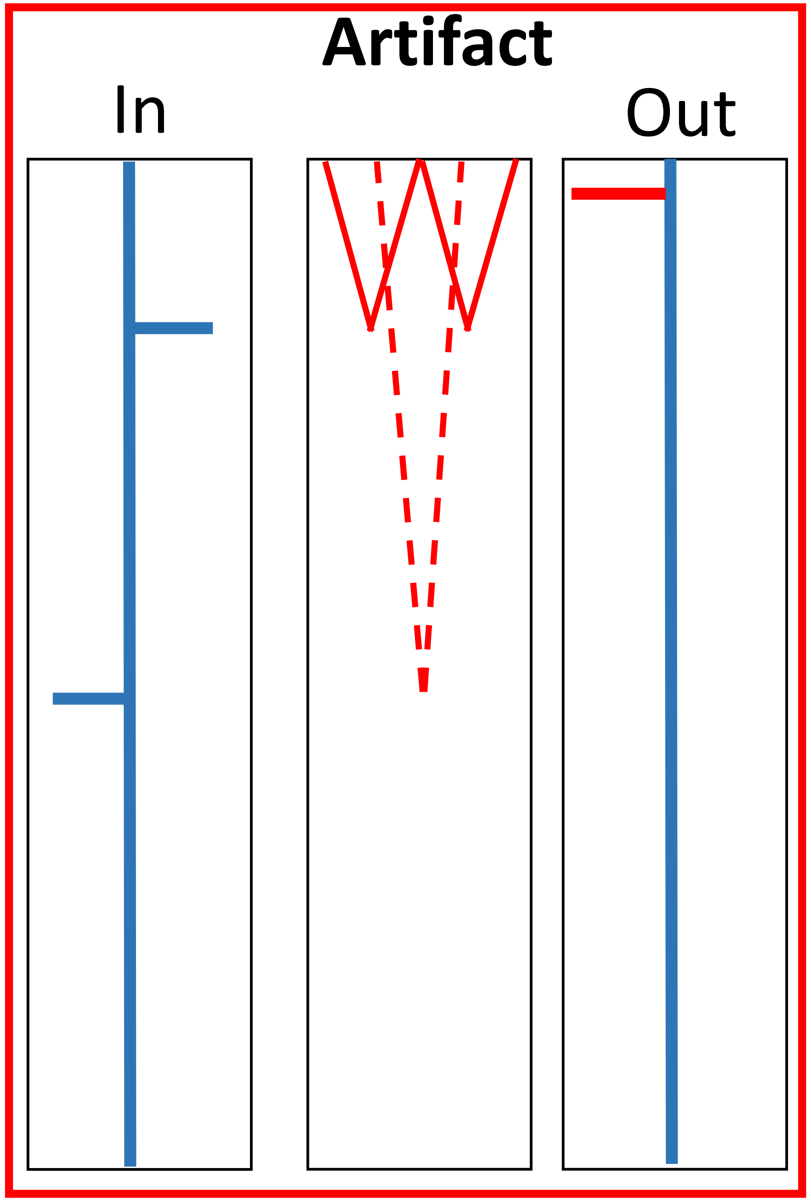


Amp = $T_{01}R_2T_{10}\,T_{01}R_2T_{10}R_1$ Amp = $T_{01}R_2R_1R_2T_{10}$ Error = $T_{01}T_{10}$

Lower-higher-lower (L-H-L) Criteria

- Display schematic with reflectivities
- Integration limits control event combinations
  - Ensure lower-higher-lower criteria is met (L-H-L)
- This limits the prediction to internal multiples without any additional artifacts

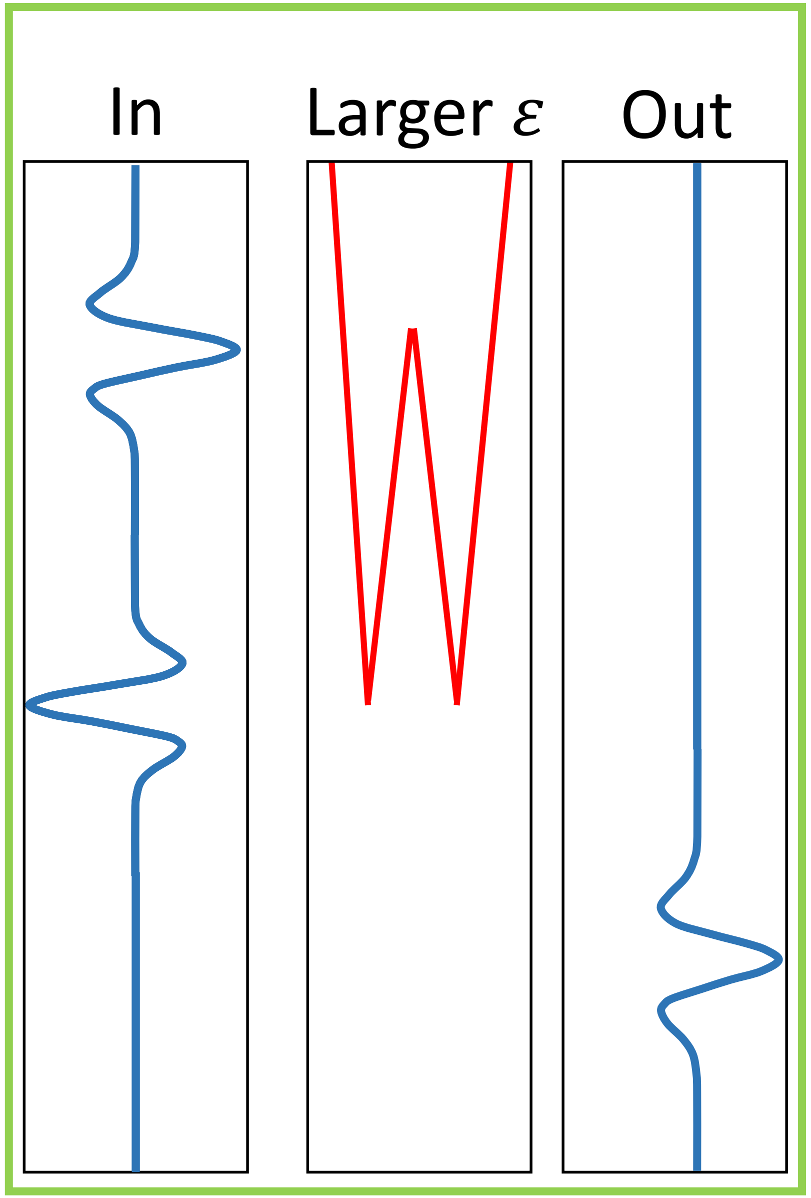


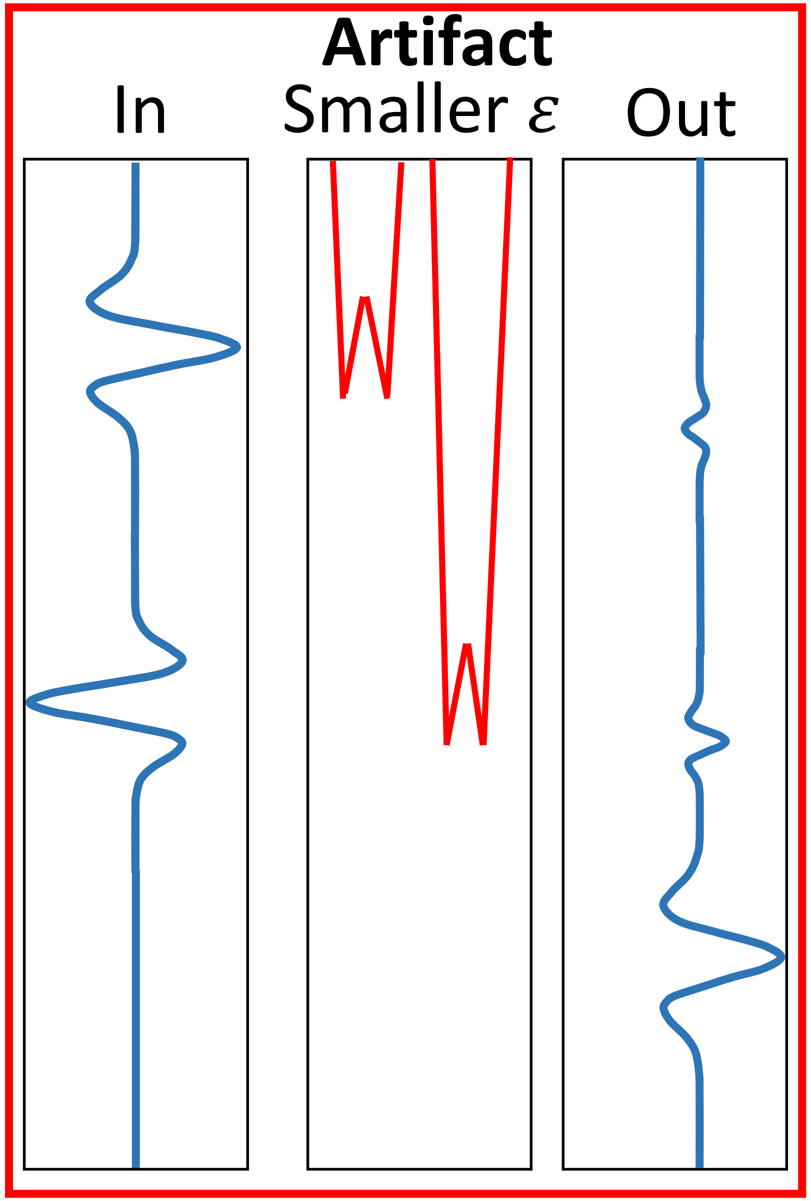


Epsilon (ε)

ε = Search limiting parameter

- If output domain varies from input
  - Difficult to vary epsilon
  - Original algorithm (ω)
- If output domain is the same as input
  - Can use nonstationary epsilon
  - Purpose of (t, x) algorithm derivation





1D Time Domain Internal Multiple Prediction

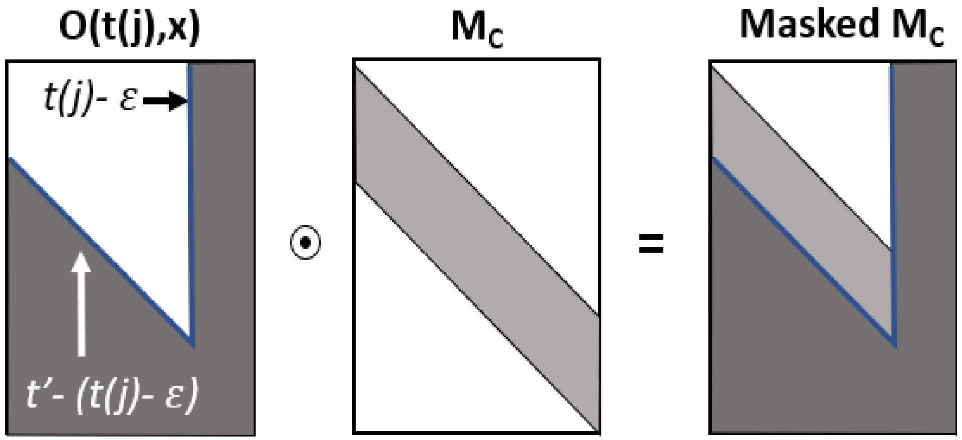
Time Domain Algorithm

$$B_3(t) = \underbrace{\int_{-\infty}^{\infty} dt' s_1(t'-t)}_{M_R} \underbrace{\int_{t'-(t-\varepsilon)}^{t-\varepsilon} dt'' s_1(t'-t'') s_1(t'')}_{M_C}$$

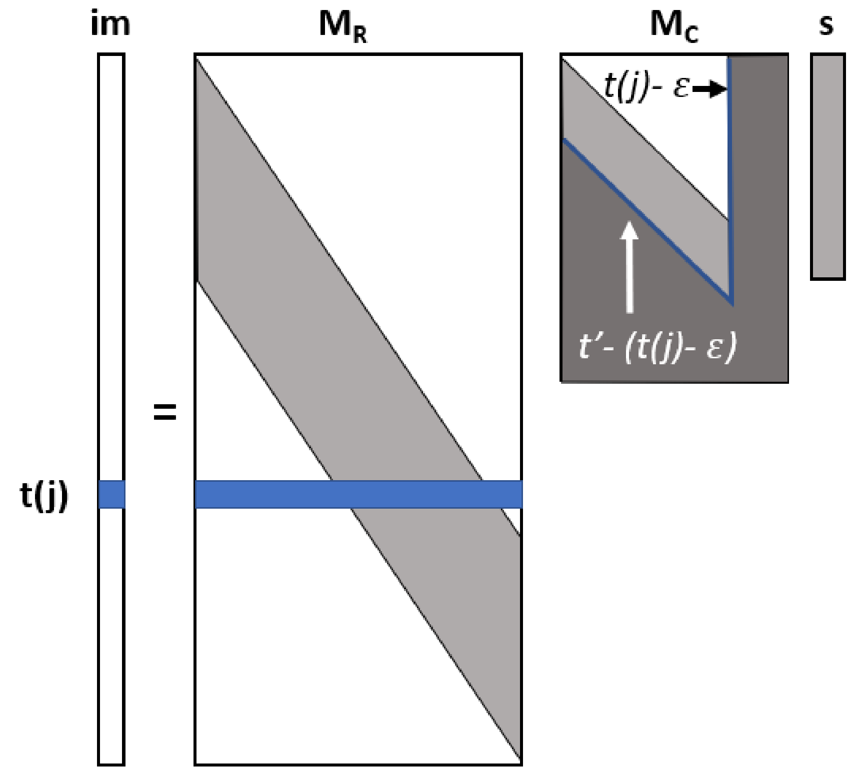
Convolution

$$(f * g)(t) = \int_{-\infty}^{\infty} f(\tau) g(t-\tau) d\tau$$

Integration Limits and epsilon

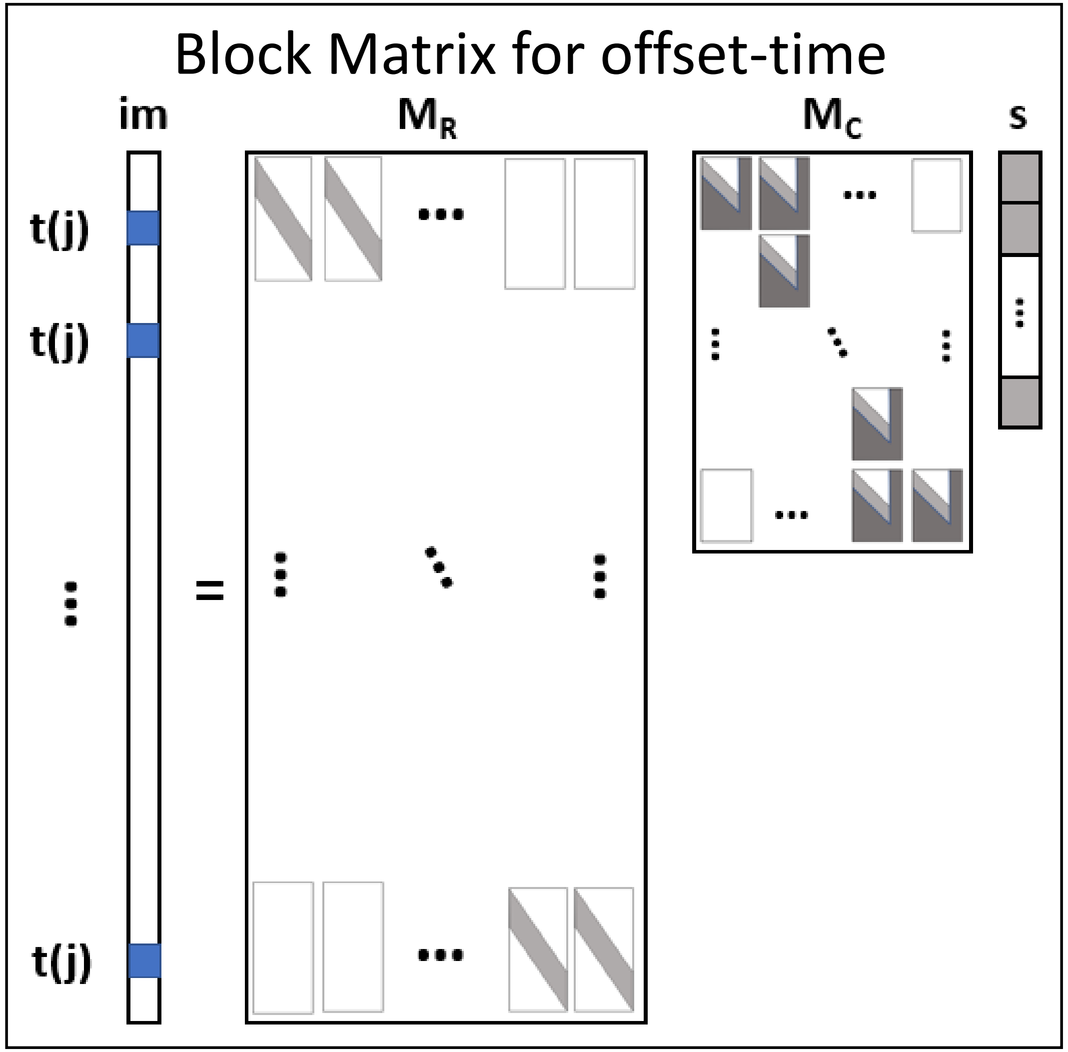


Convolution Through Matrix Multiplication



- Internal multiples are predicted for every time step
- Epsilon can vary for every time step

1.5D Time-Offset Internal Multiple Prediction

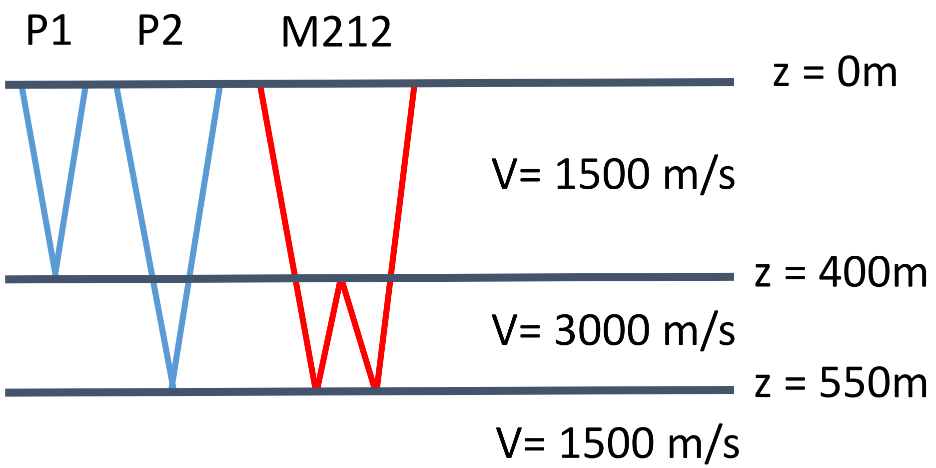


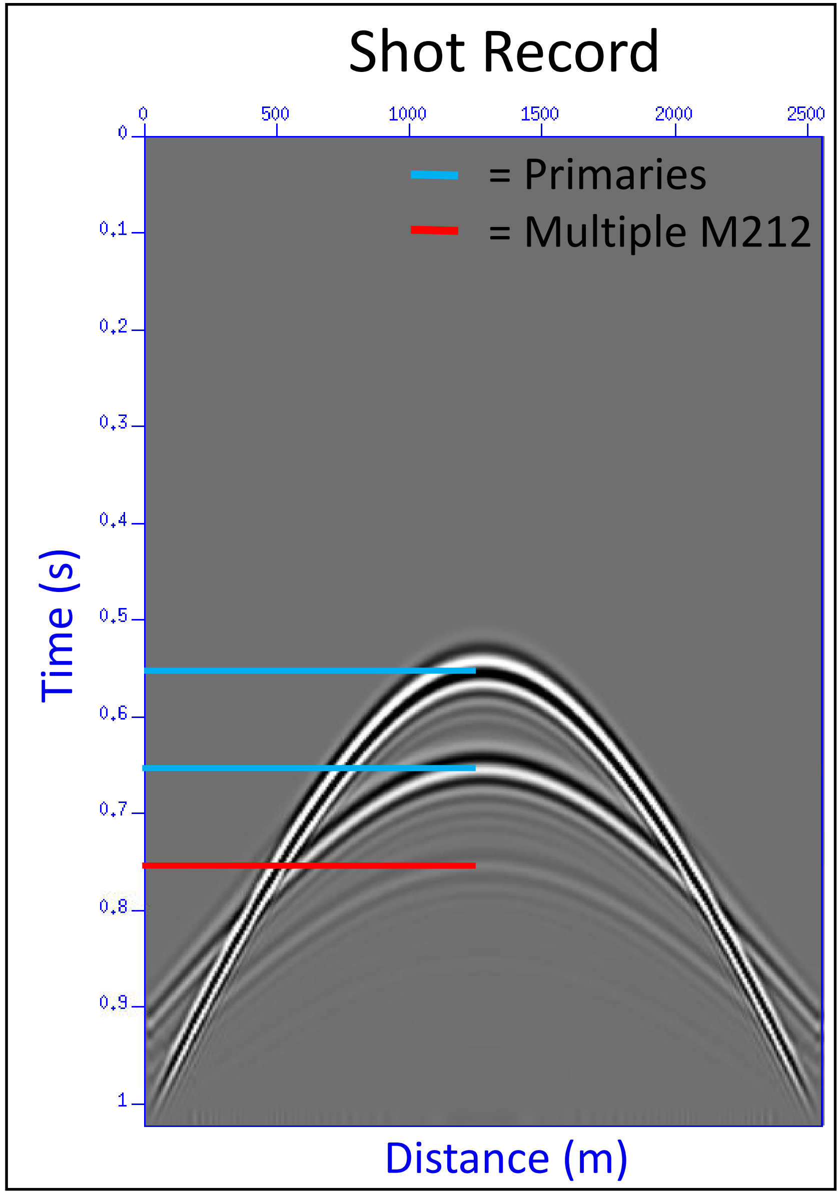
- Computing convolutions in both time and space
- This is completed through a 2D convolution
- The mask matrix which is set by epsilon can vary in both time and space

$$B_3(x,t) = \int dx' \int dt' s(x - x', t' - t) \int dx'' \times \int_{t'-(t-\varepsilon)}^{t-\varepsilon} dt'' s(x' - x'', t' - t'') s(x'', t'')$$

1.5D time offset Domain Prediction

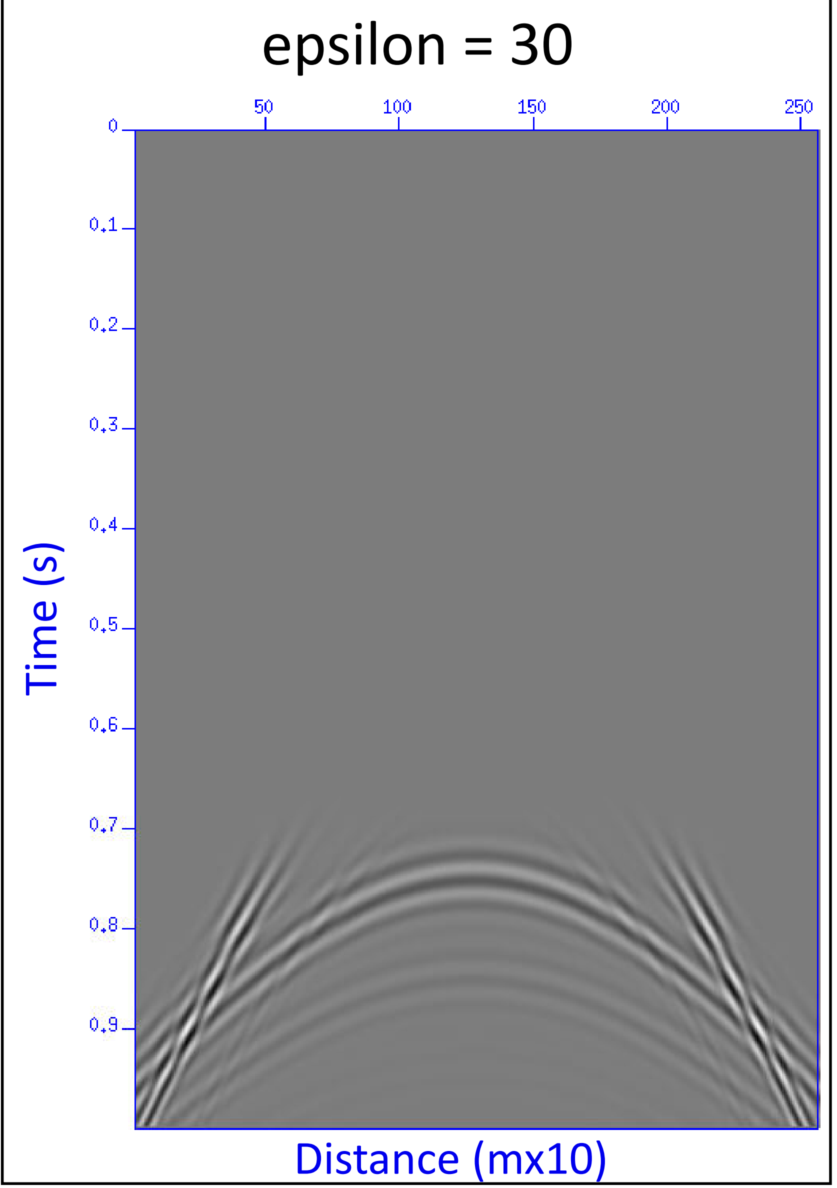
- Shot record created using finite difference modeling in MATLAB with CREWES Toolbox

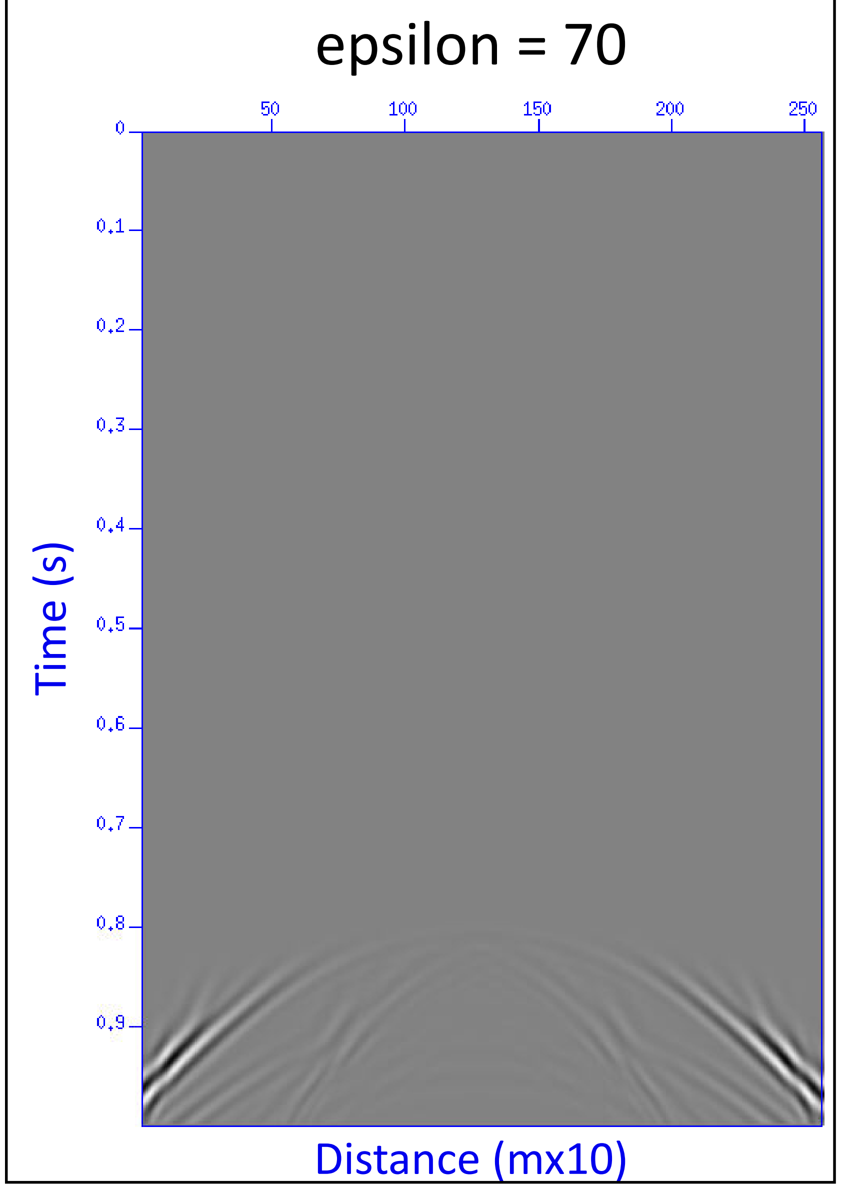


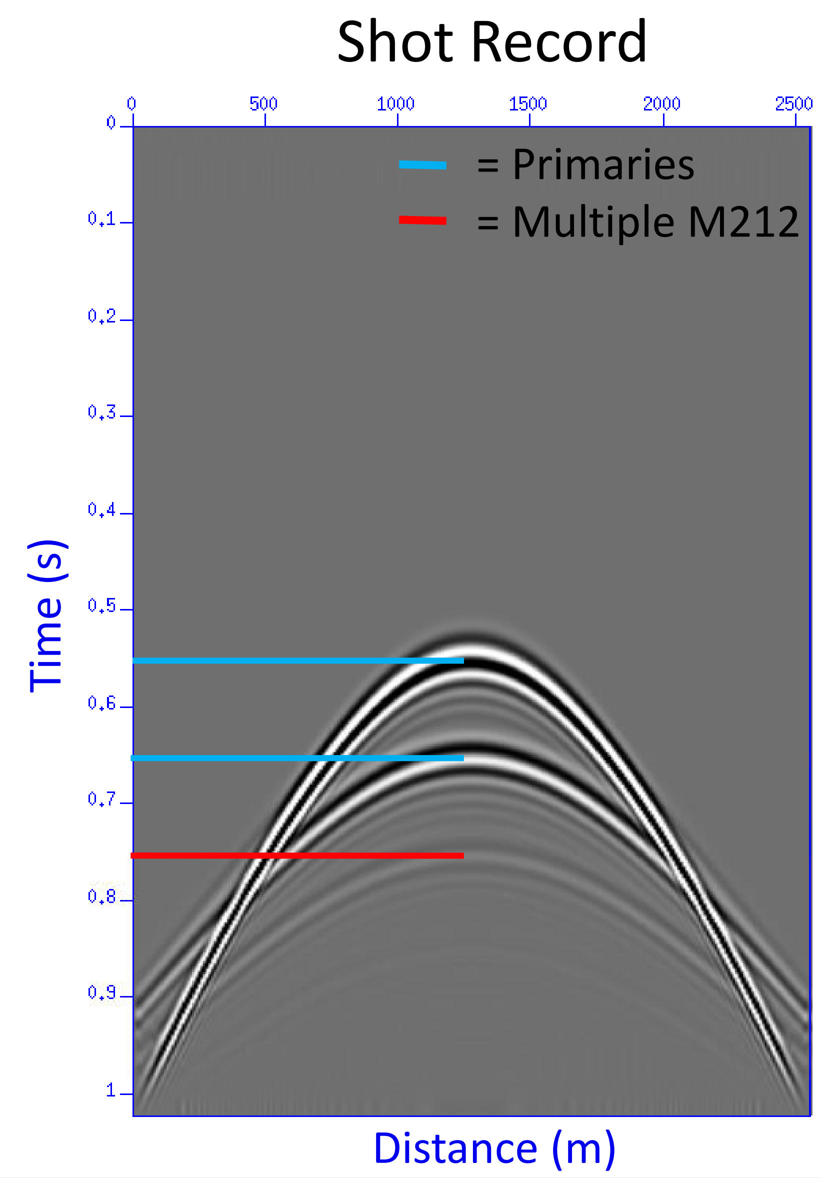


- Created Shot record with significant first order multiple
- Will demonstrate prediction with different epsilon values
- Due to the time-offset domain epsilon can be nonstationary

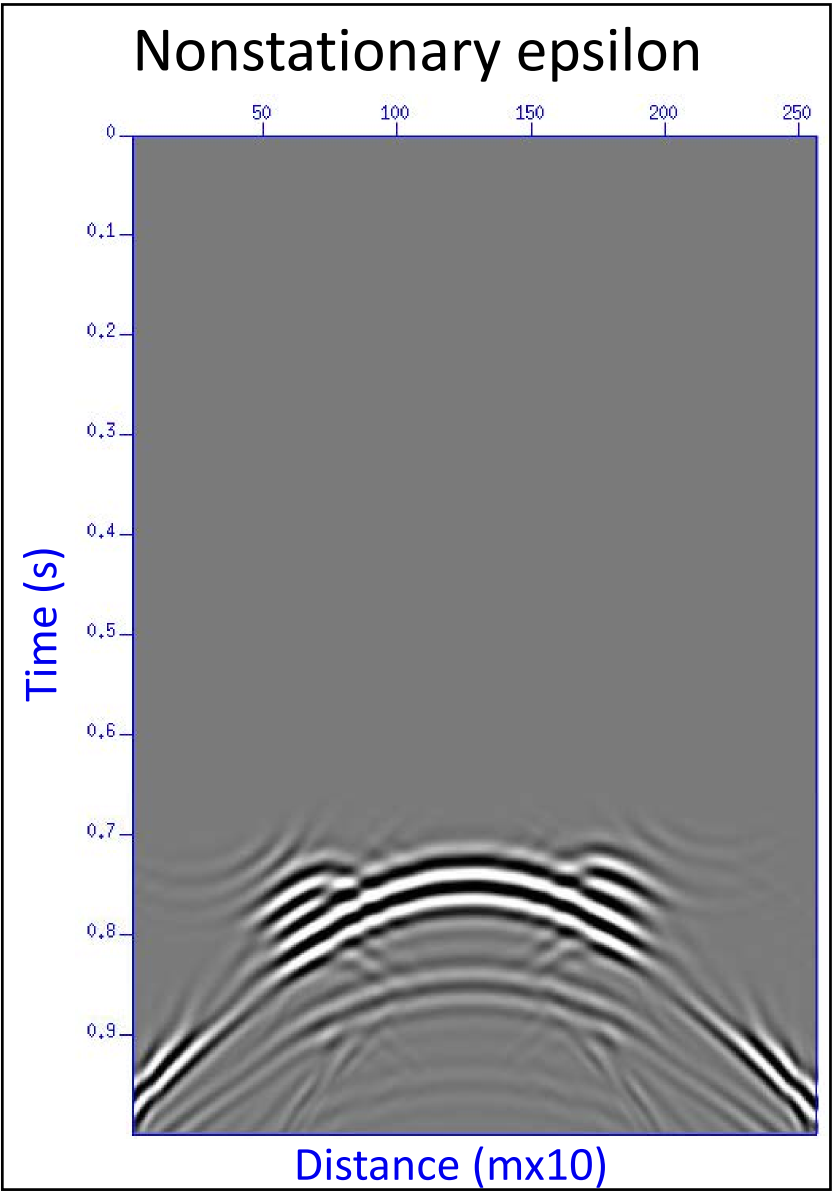
Stationary epsilon

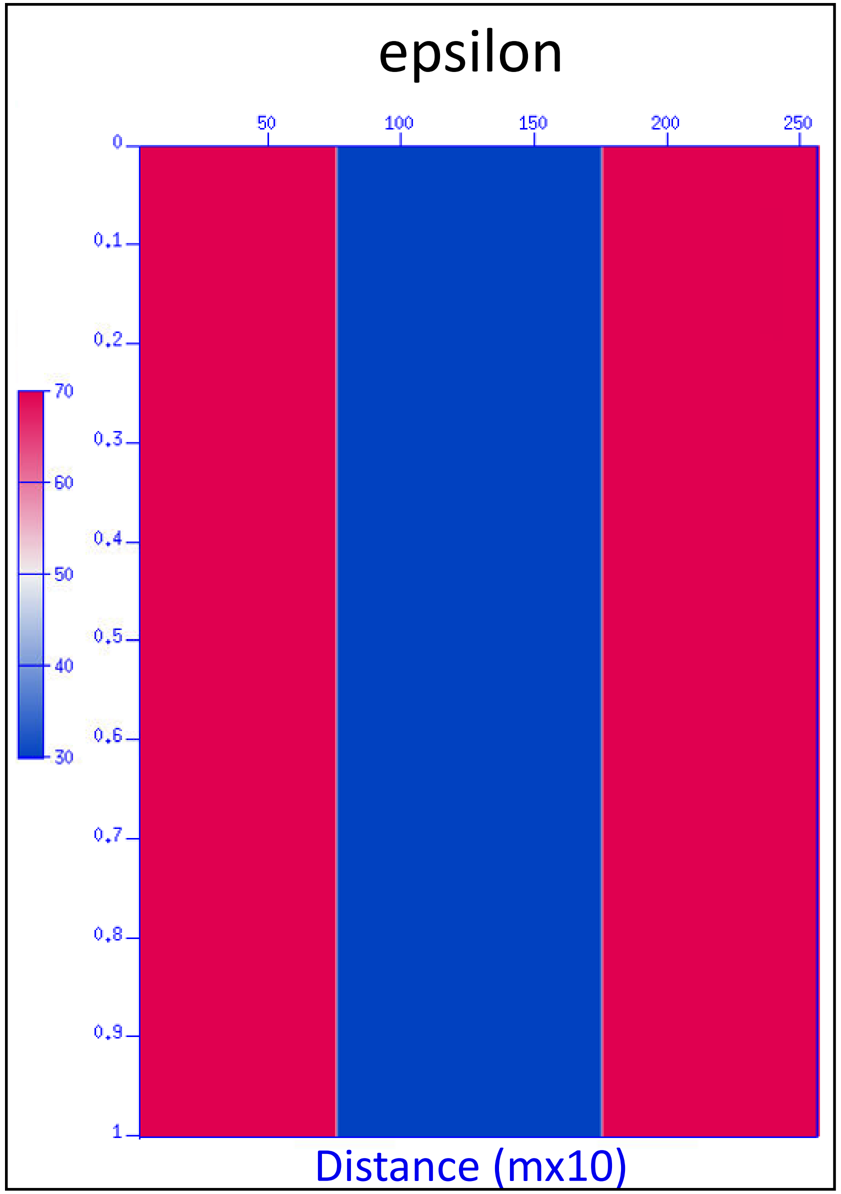


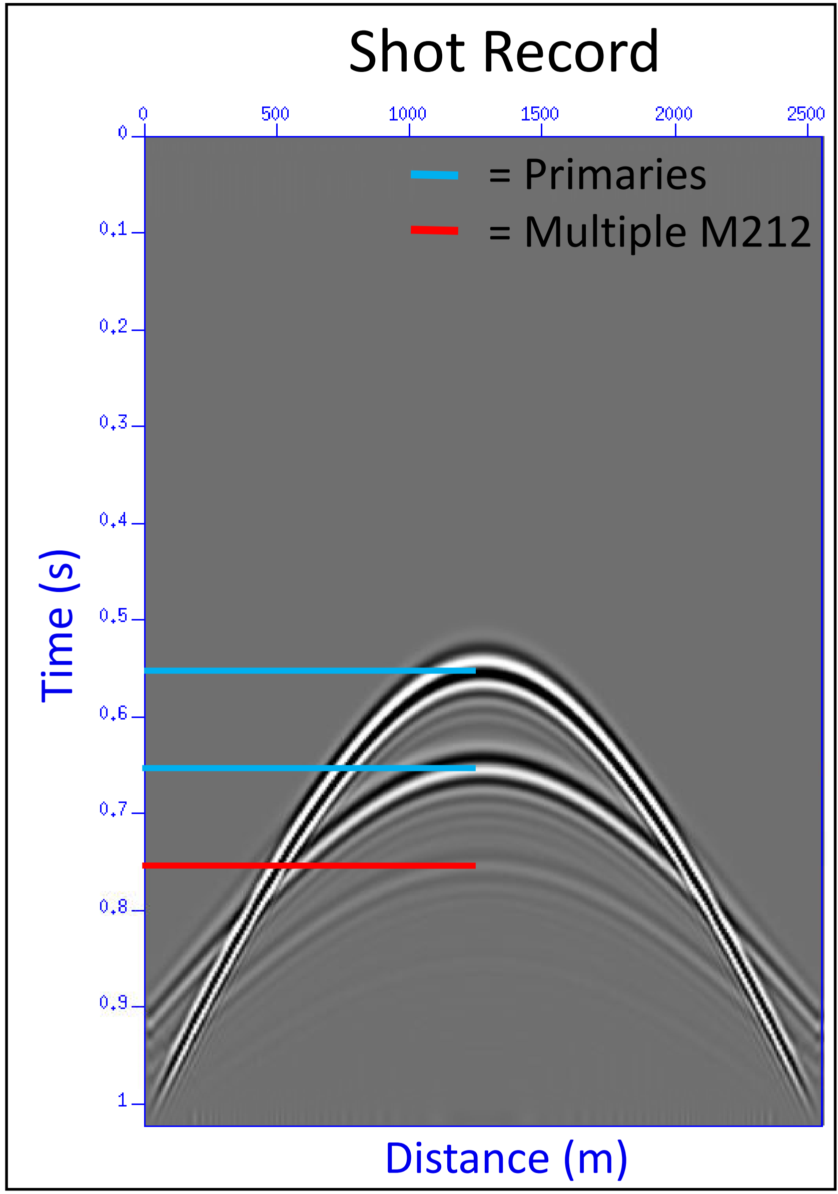




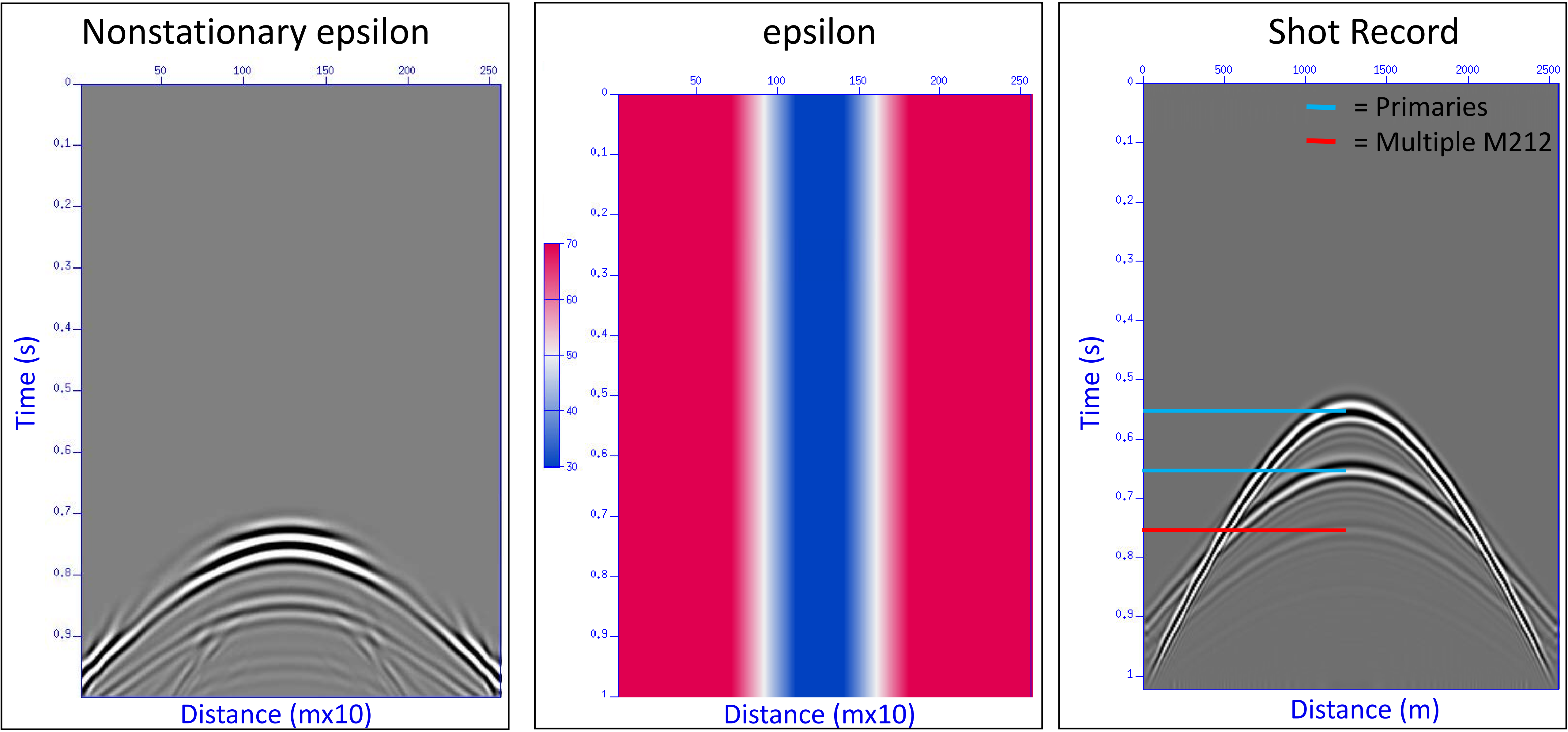
Spatially Variant epsilon



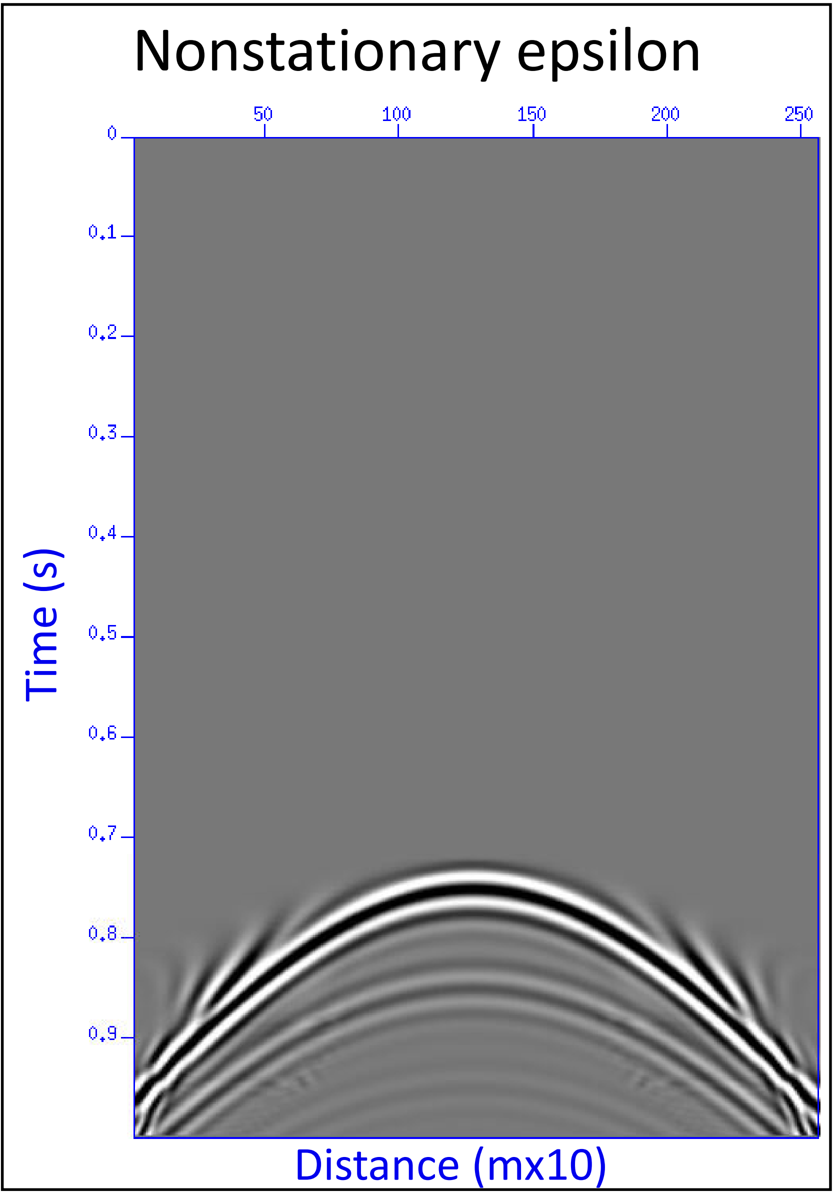


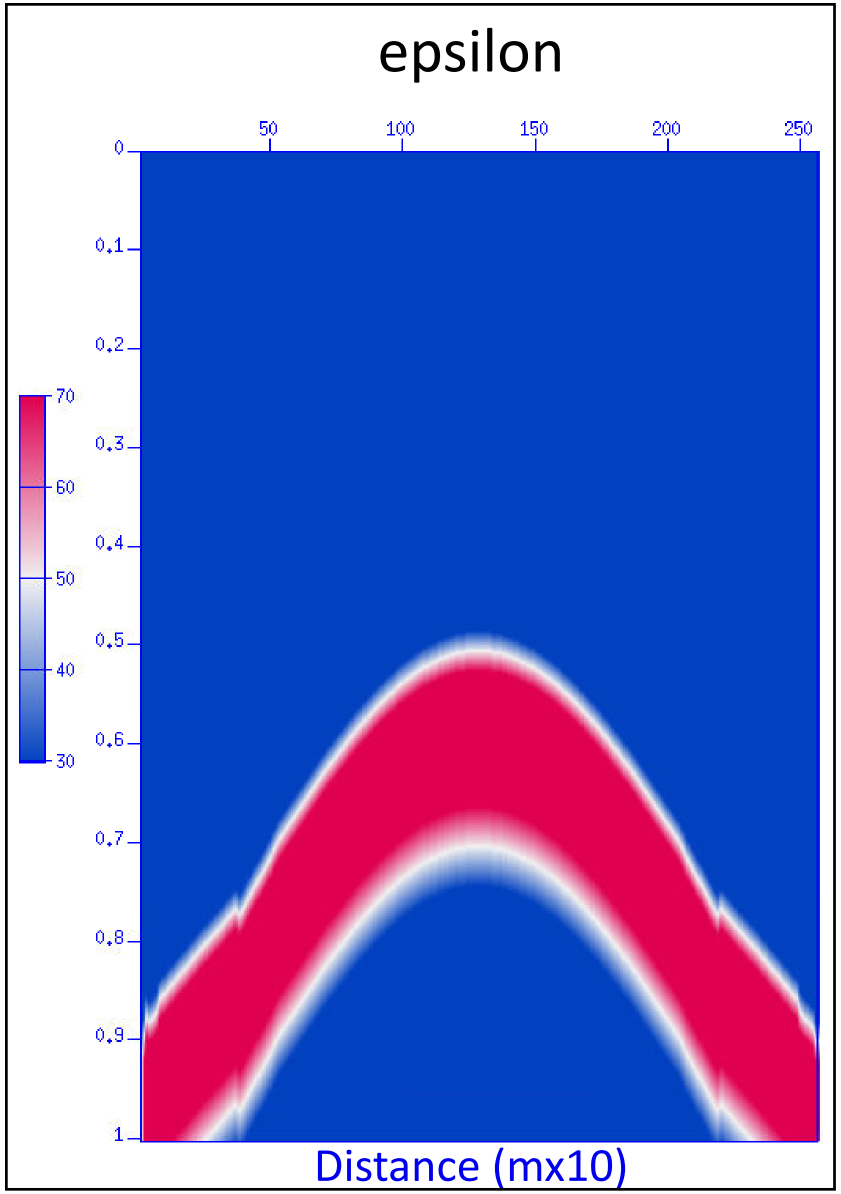


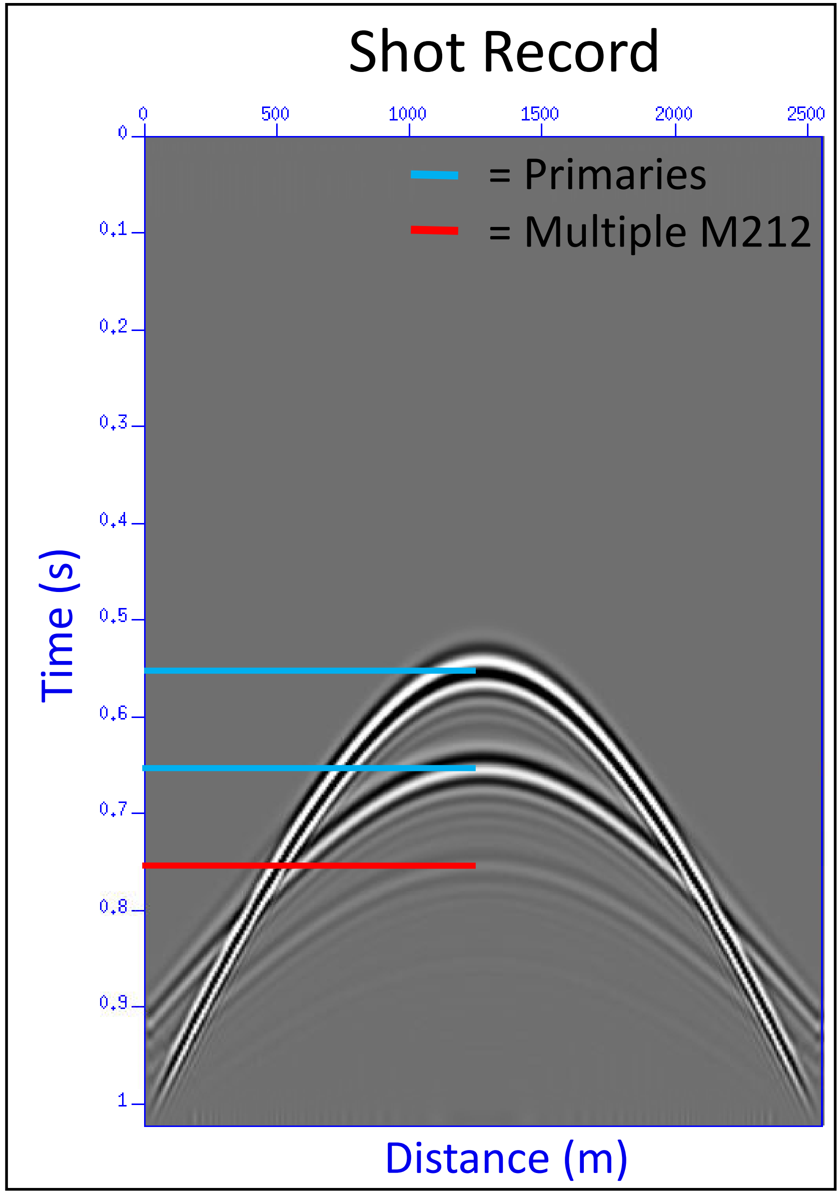
Spatially Variant epsilon with Taper



Nonstationary epsilon







Conclusions and future work

Conclusions:

- Highly flexible formulation which allows for the determination of an epsilon schedule
- In 1.5D time space domain was able to reduce artifacts through nonstationary epsilon

Future Work:

- Further tests of offset-time domain varying the seismic model parameters
- Reduce computational expense
- Goal of project is to implement the method on land seismic data
    - How to calculate epsilon schedule?
    - How to manage irregular spatial sampling?
    - What stage of seismic processing workflow to apply multiple attenuation?
        - Amplitude recovery/gain, statics, deconvolution, …

Acknowledgments

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Questions?