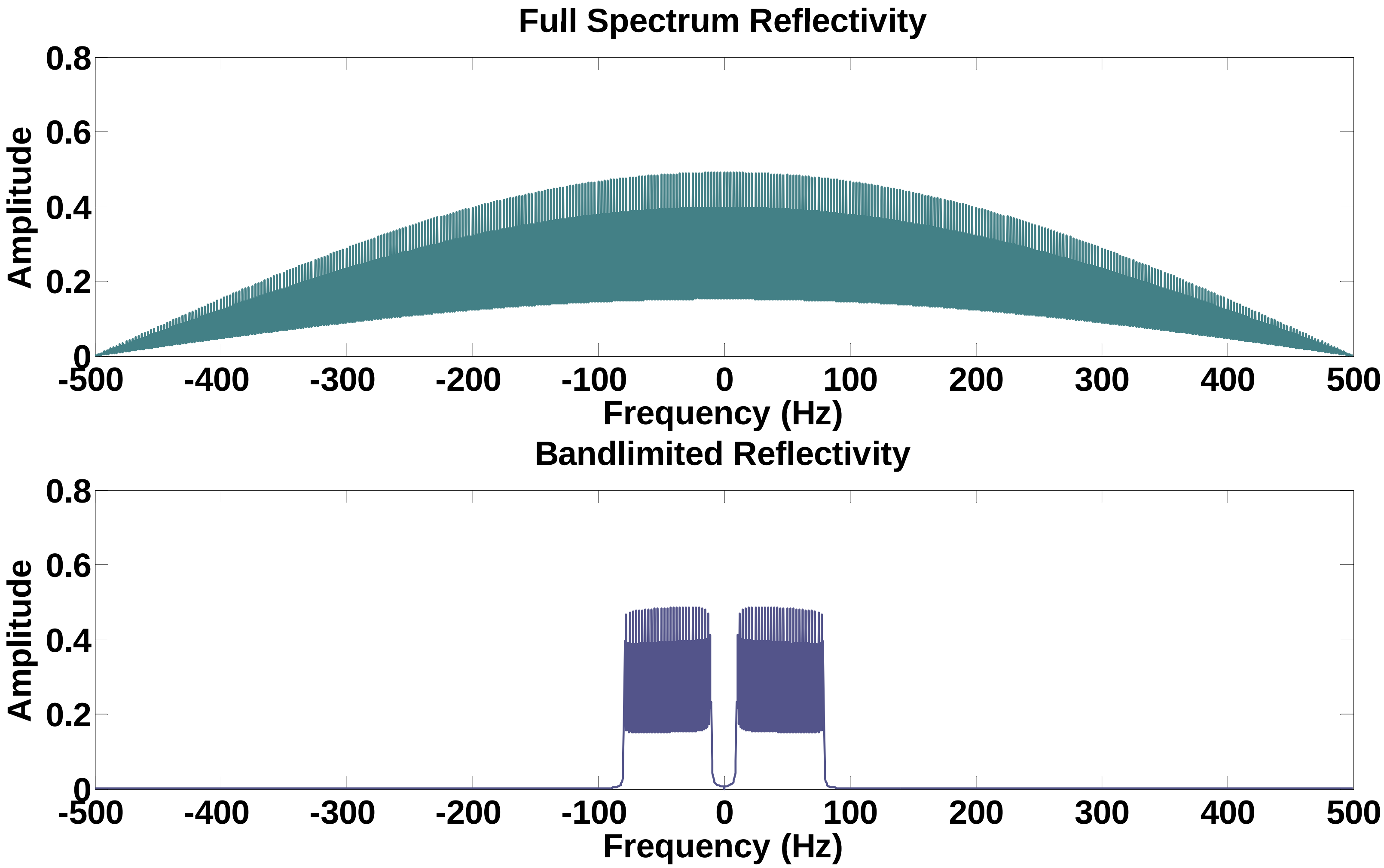
How low can you go? Finding low frequencies in various places – Hussar example

Heather Lloyd & Gary Margrave

Outline

- Why do we need low-frequencies and where did they go?
- How do we get low-frequencies back?
  - Borrow them
  - Predict them
  - Record them
- Low-frequency conclusions

Full Spectrum & Band-Limited Reflectivity

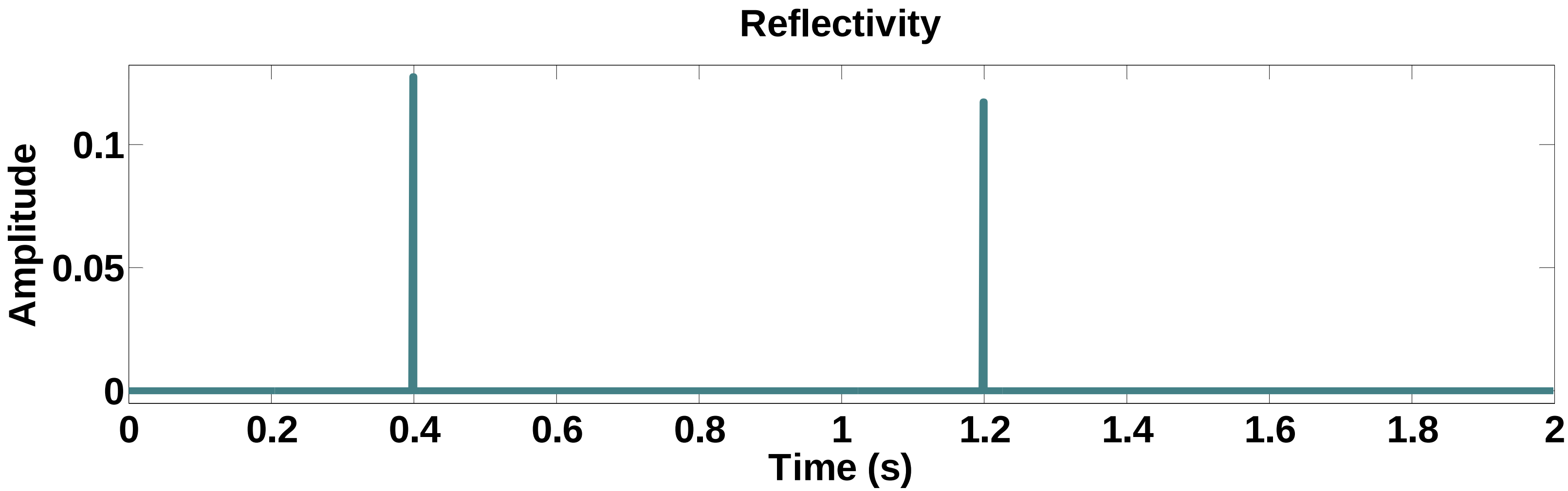


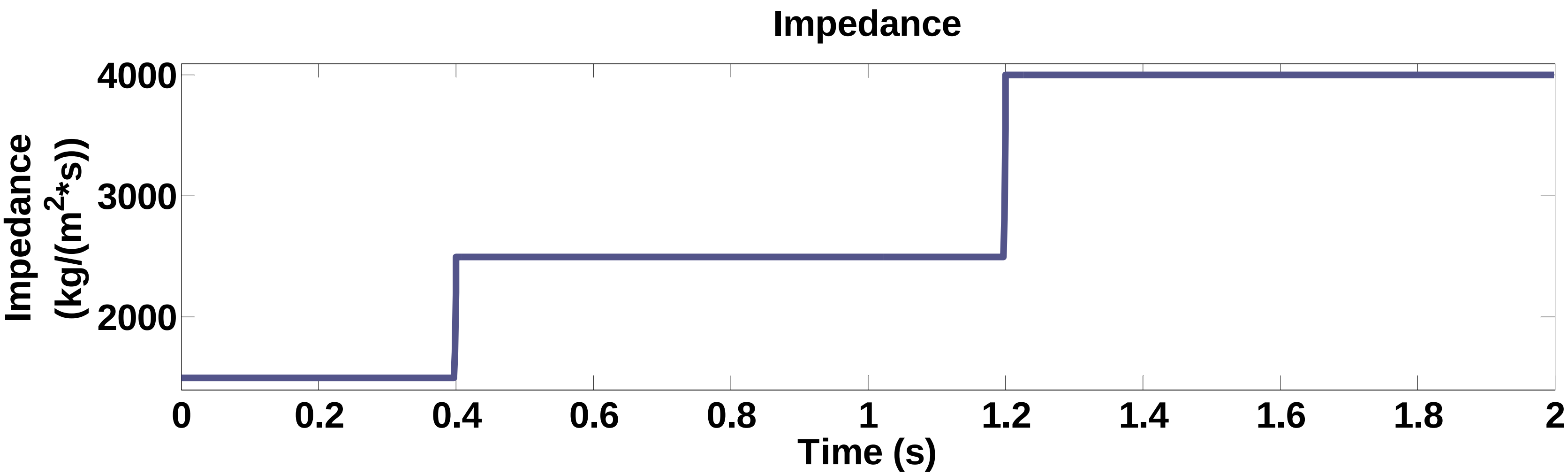
Recursion Formula

$$I_j = I_0 e^{\sum_{k=0}^{j} r_k}$$

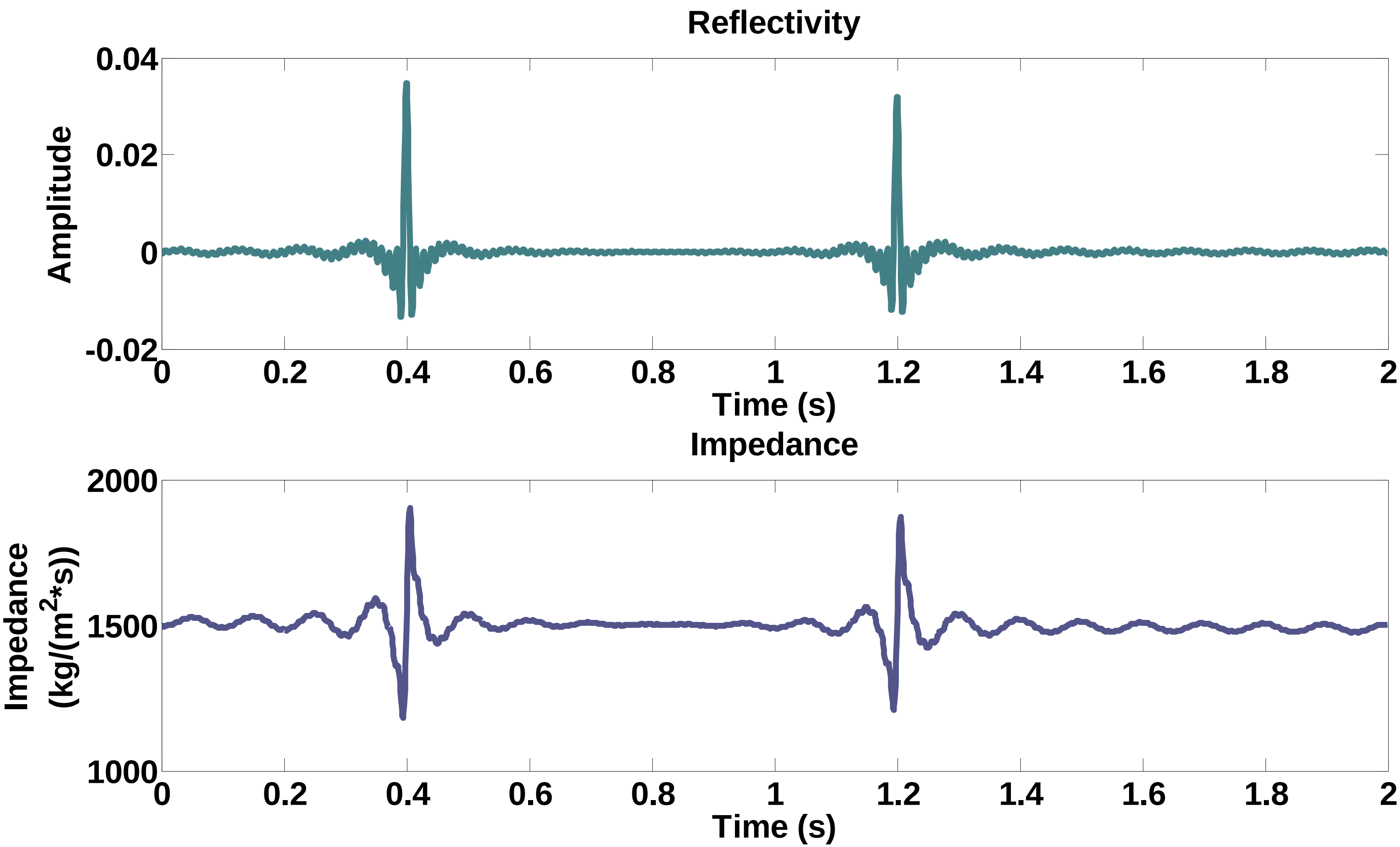
(Oldenburg et al., 1983).

Full Spectrum Inversion/model

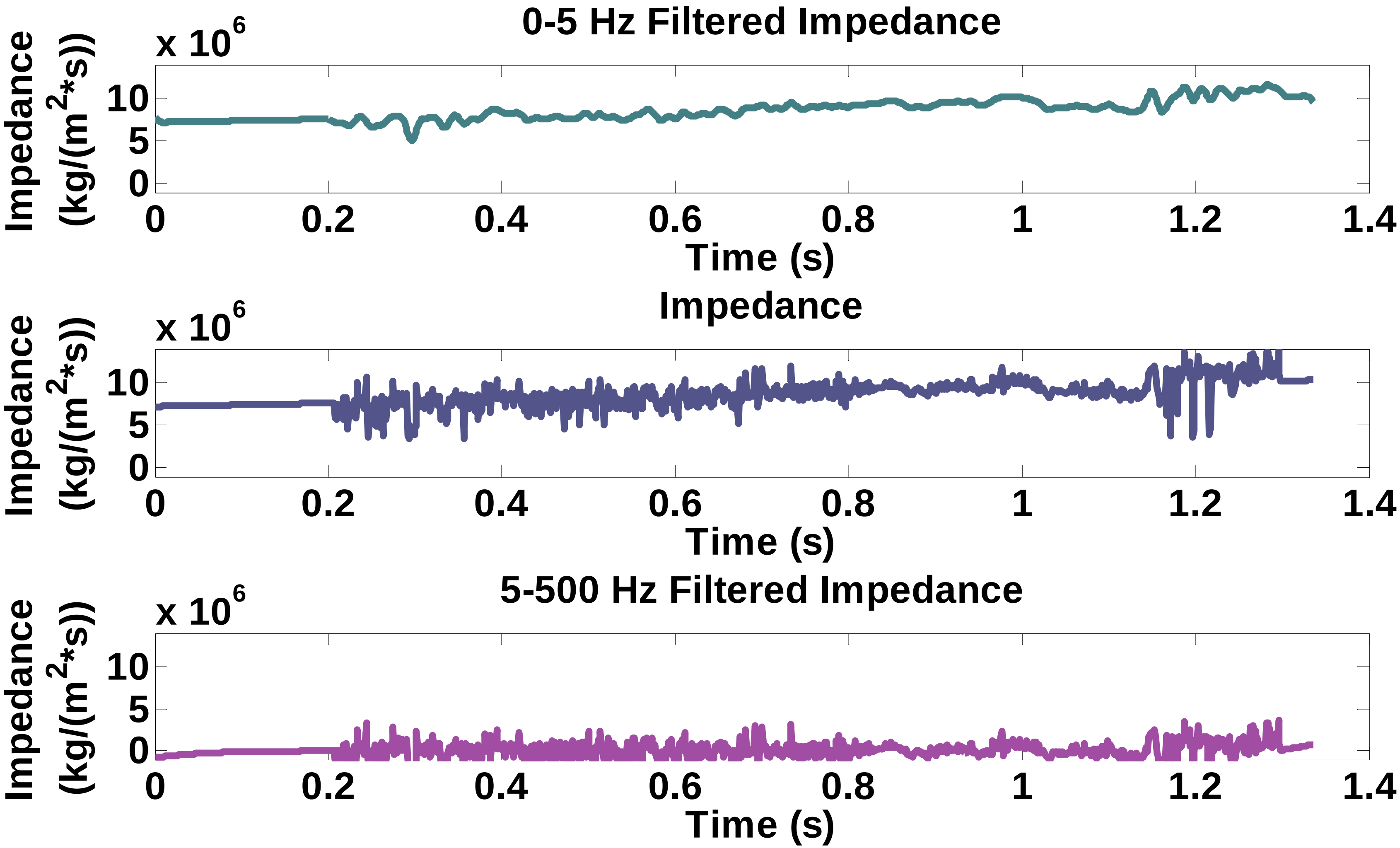




Band-Limited Inversion



Real Well Log Example



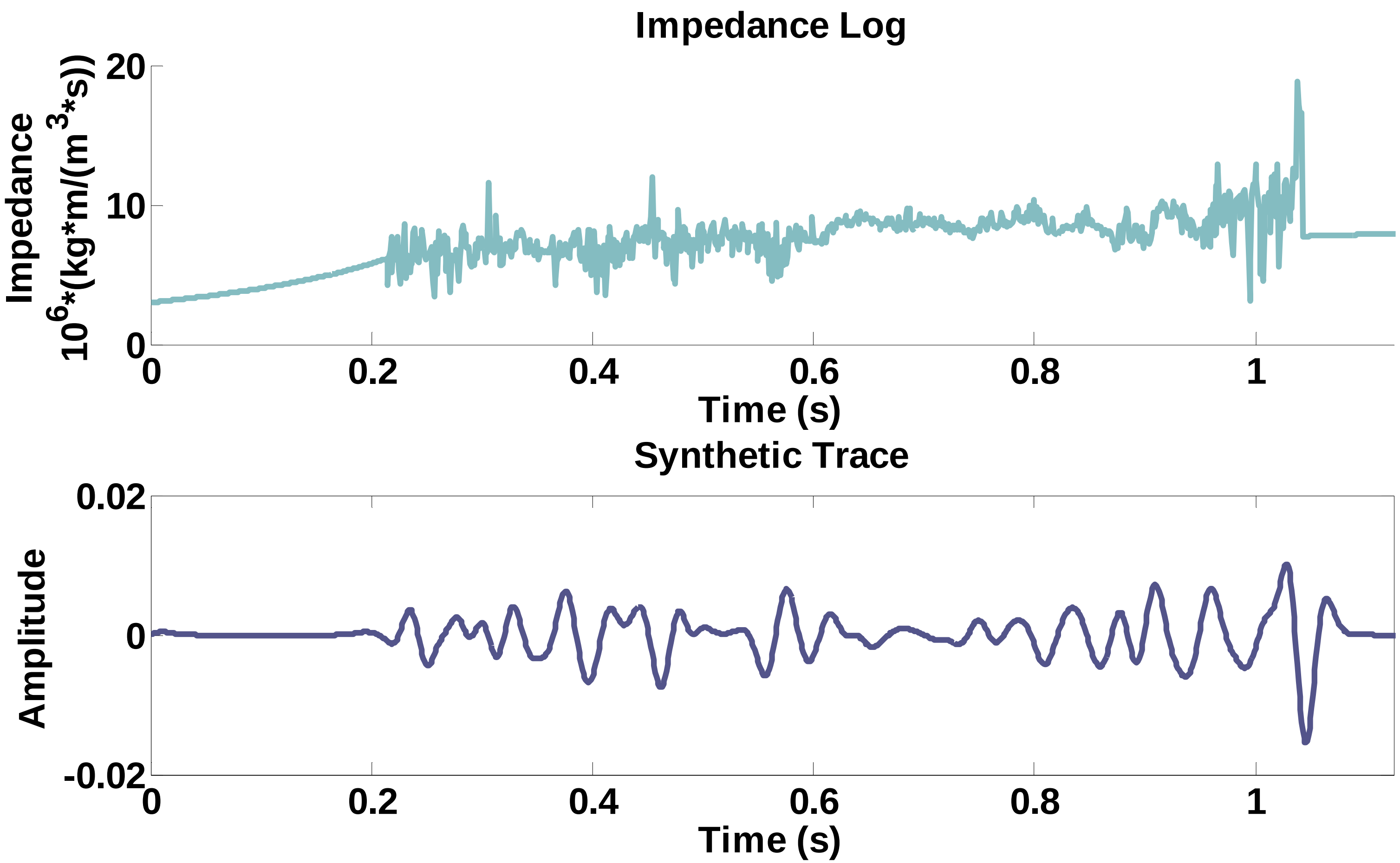
(From Lindseth 1979).

How do we get low-frequencies back?

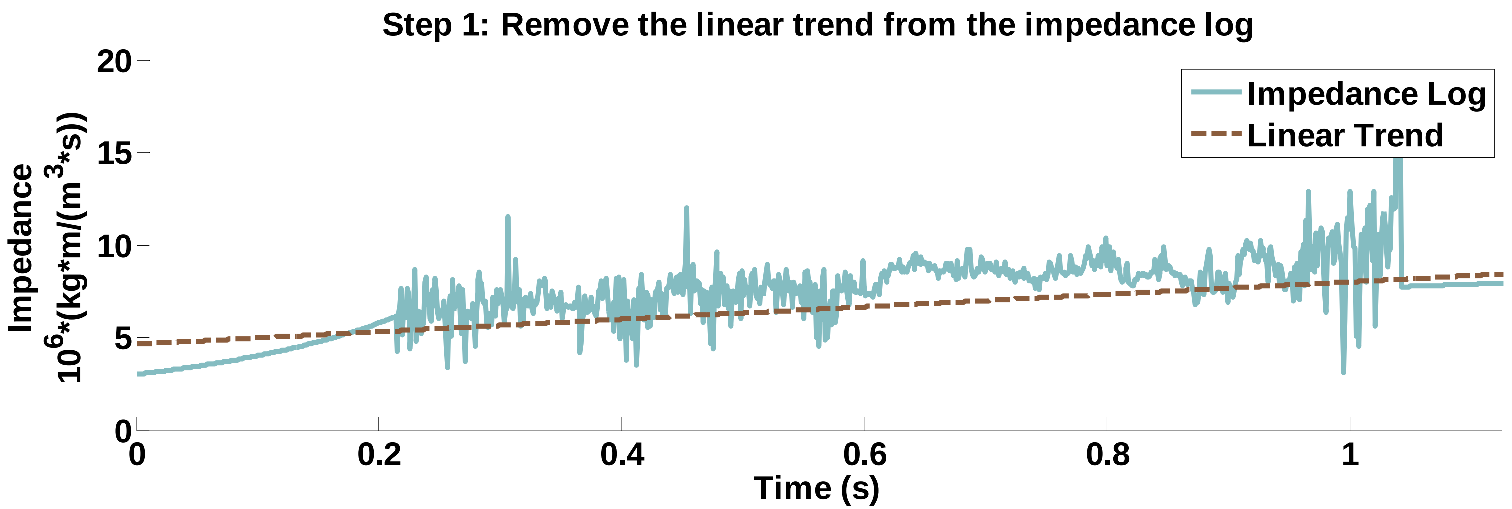
- Model them
- Borrow them
- Predict them
- Record them

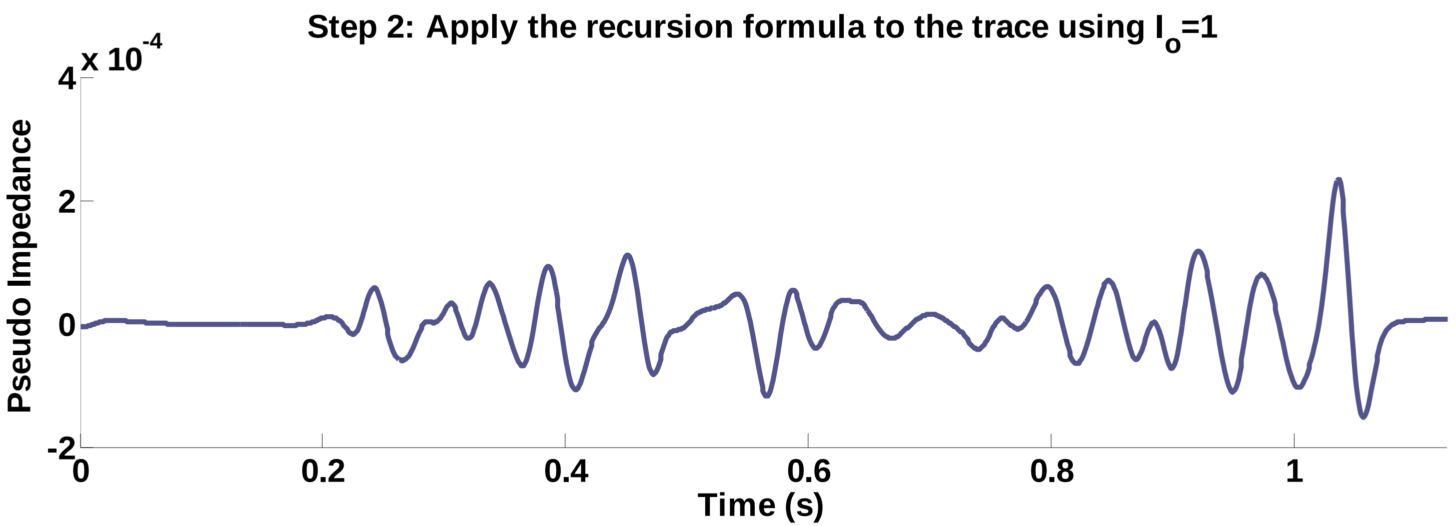
Borrow Them

Borrow low-frequencies using BLIMP

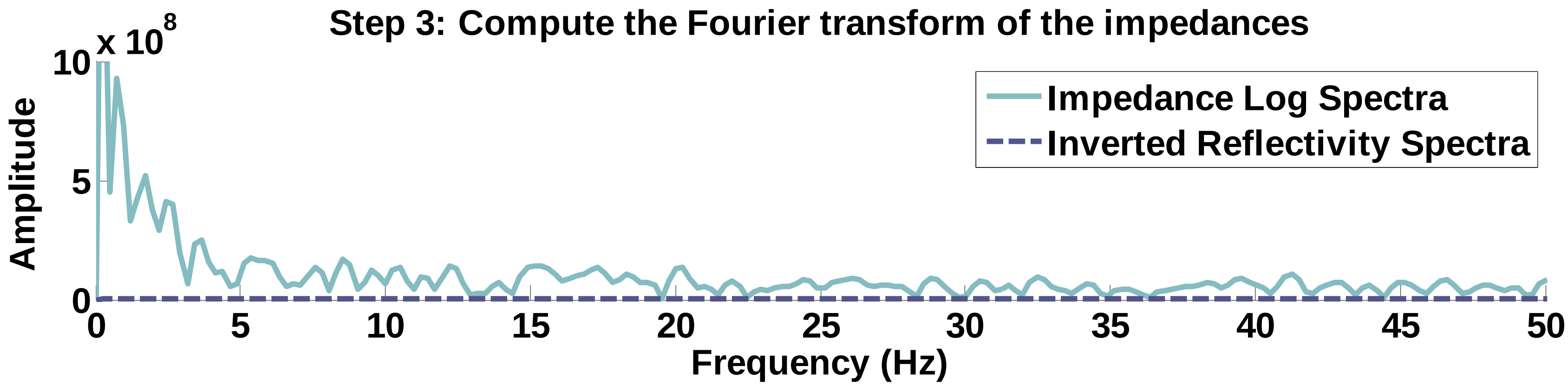


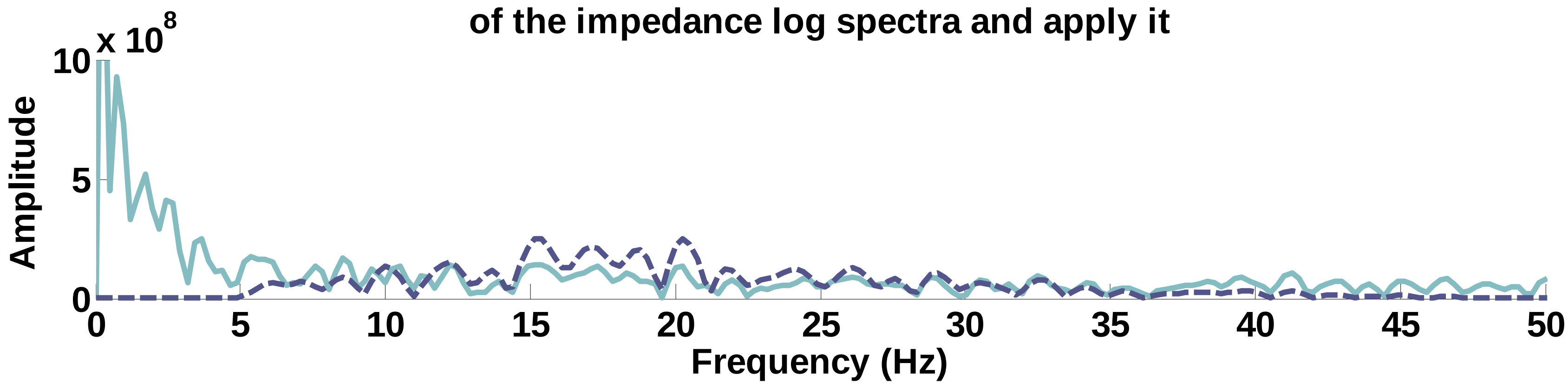
BLIMP Steps 1 & 2



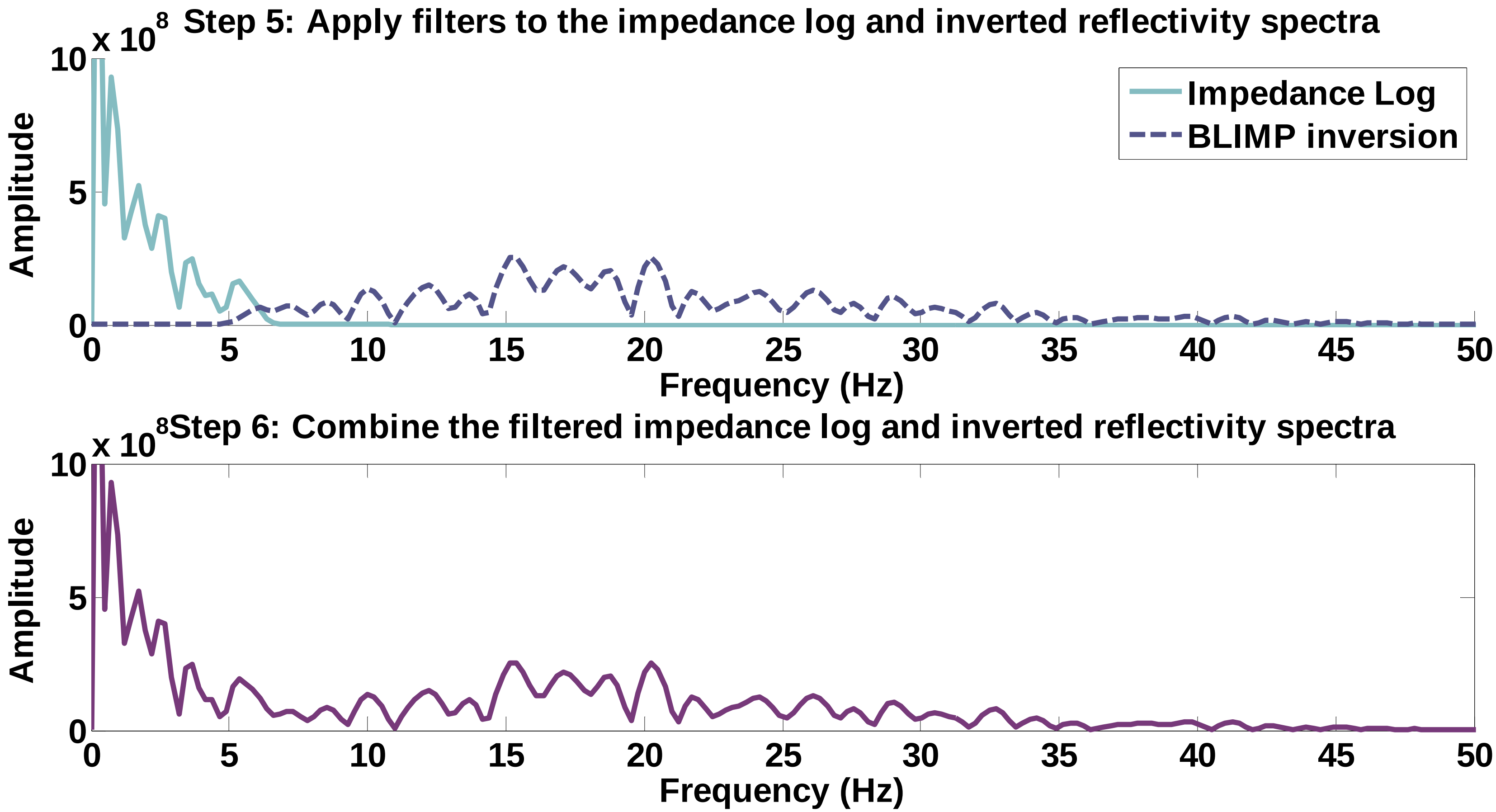


BLIMP Steps 3 & 4

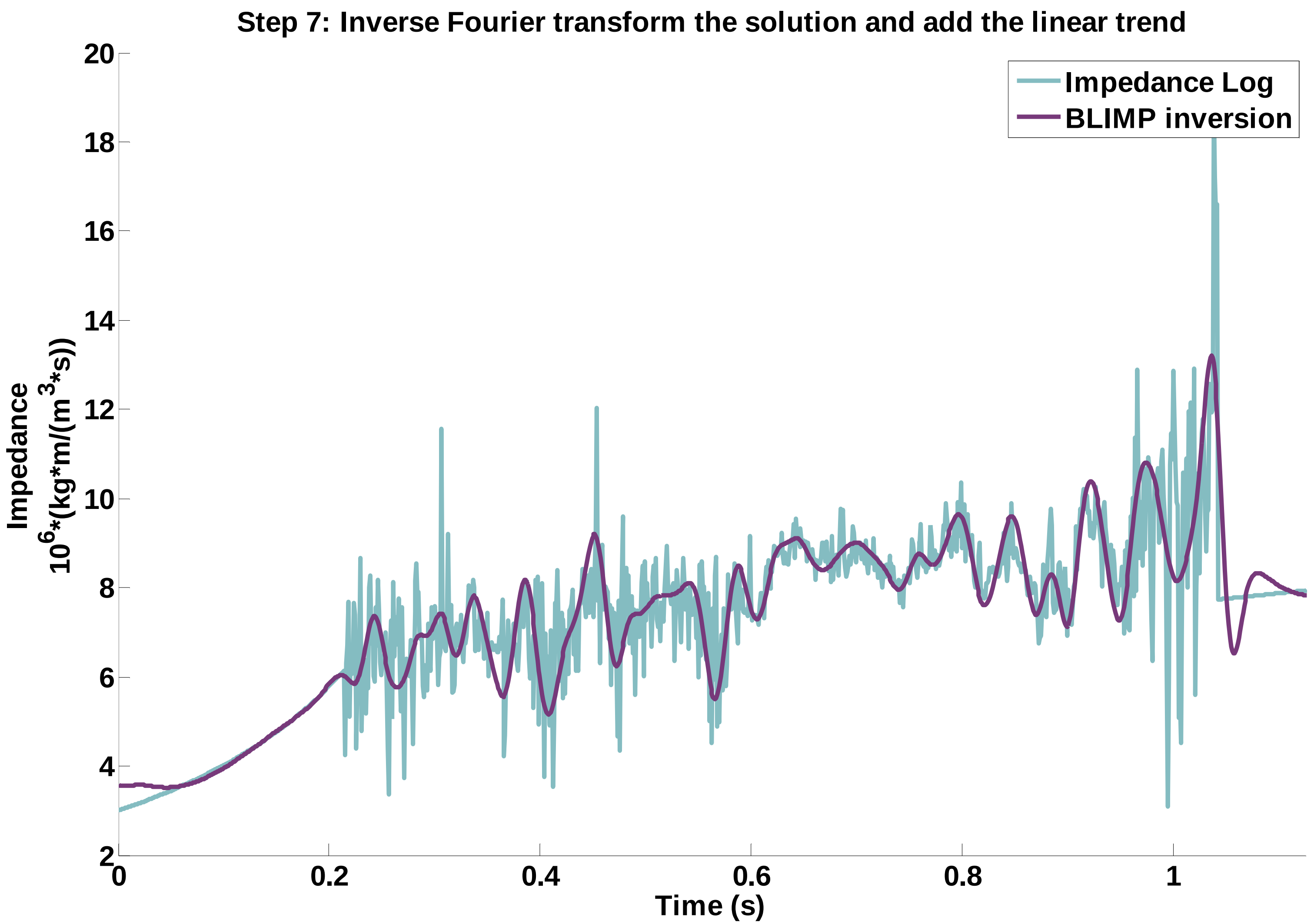




BLIMP Steps 5 & 6



BLIMP Step 7


Step 7: Inverse Fourier transform the solution and add the linear trend
Impedance Log
BLIMP inversion
Impedance
10^6*(kg*m/(m^3*s))
Time (s)
20
18
16
14
12
10
8
6
4
2
0
0.2
0.4
0.6
0.8
1

BLIMP Inversion Problems

- Sensitive to low-frequency cut-off
- Best applied to one trace or a model without structure
- Relies heavily on log information

Predict Them

Prediction Filters

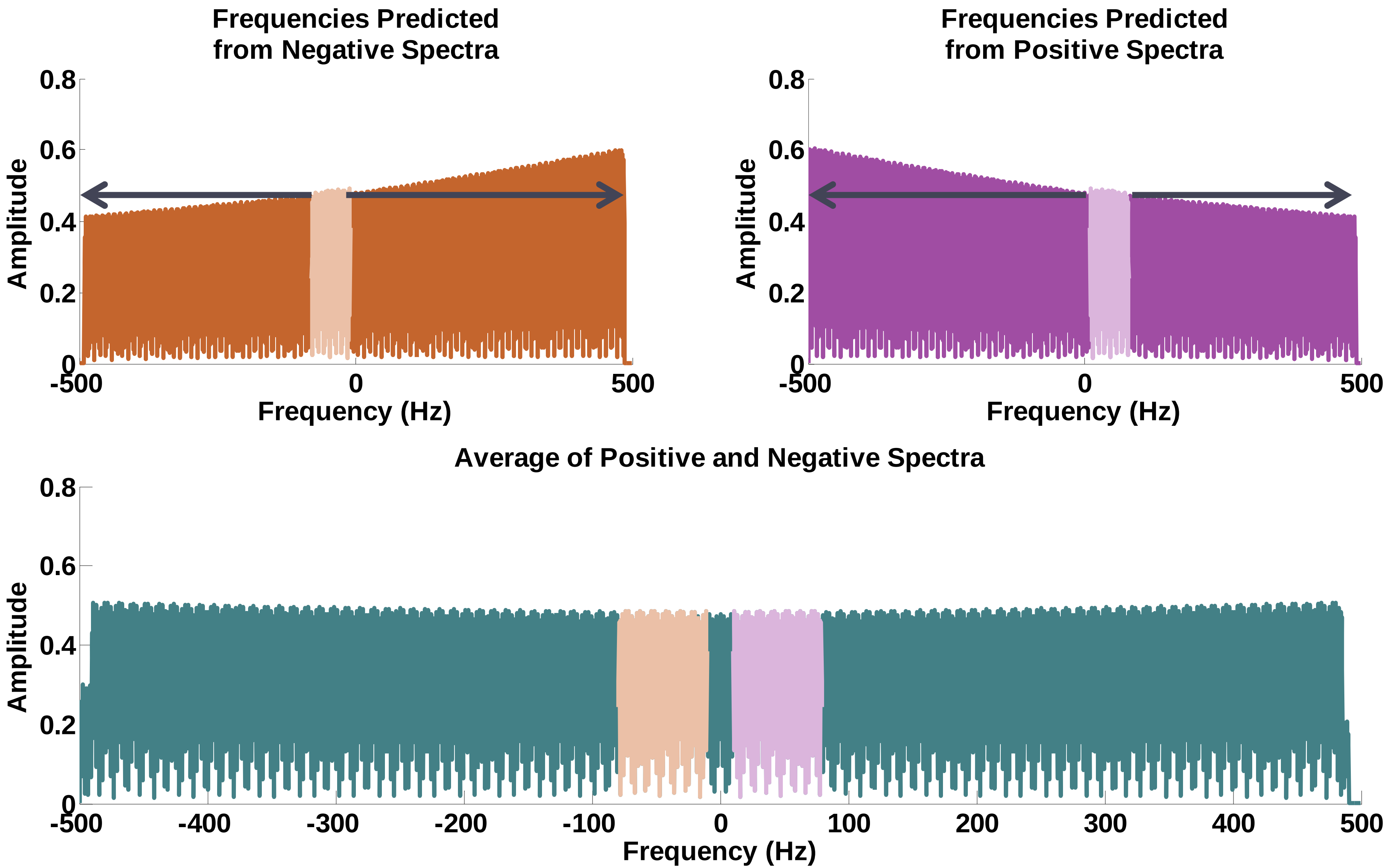
One-Lag Prediction Filter

$$\begin{bmatrix} d_0 & 0 & \cdot\cdot & 0 \\ d_1 & d_0 & \cdot\cdot & 0 \\ \vdots & \vdots & \ddots & 0 \\ d_m & d_{m-1} & \cdot\cdot & d_0 \end{bmatrix} \times \begin{bmatrix} a_0 \\ a_1 \\ \vdots \\ a_n \end{bmatrix} = \begin{bmatrix} d_1 \\ d_2 \\ \vdots \\ d_{m+1} \end{bmatrix}$$

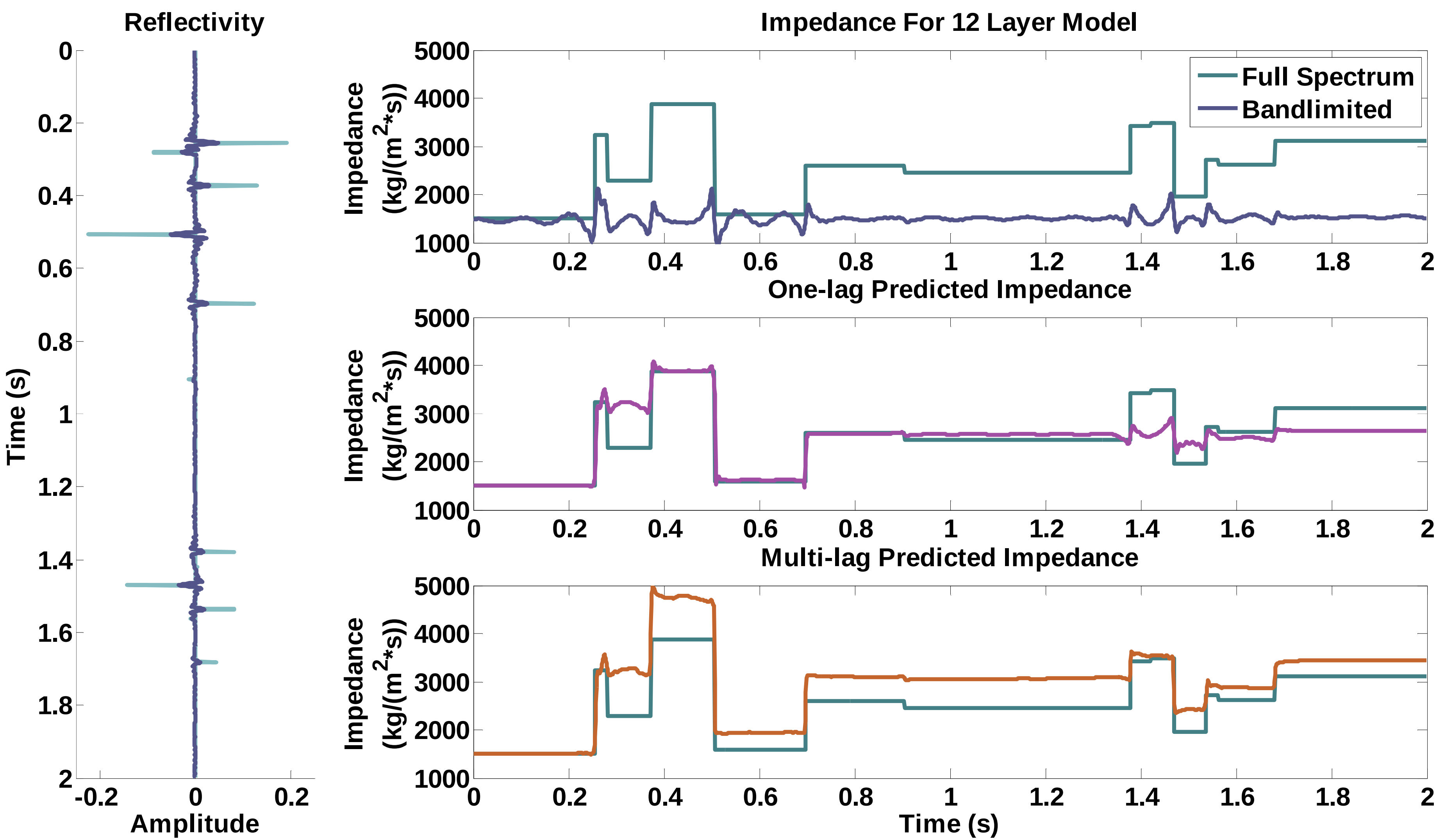
Multi-Lag Prediction Filter

$$\begin{bmatrix} d_0 & 0 & \cdot\cdot & 0 \\ d_1 & d_0 & \cdot\cdot & 0 \\ \vdots & \vdots & \ddots & 0 \\ d_m & d_{m-1} & \cdot\cdot & d_0 \end{bmatrix} \times \begin{bmatrix} a_0 \\ a_1 \\ \vdots \\ a_n \end{bmatrix} = \begin{bmatrix} d_{lag+1} \\ d_{lag+2} \\ \vdots \\ d_{lag+m} \end{bmatrix}$$

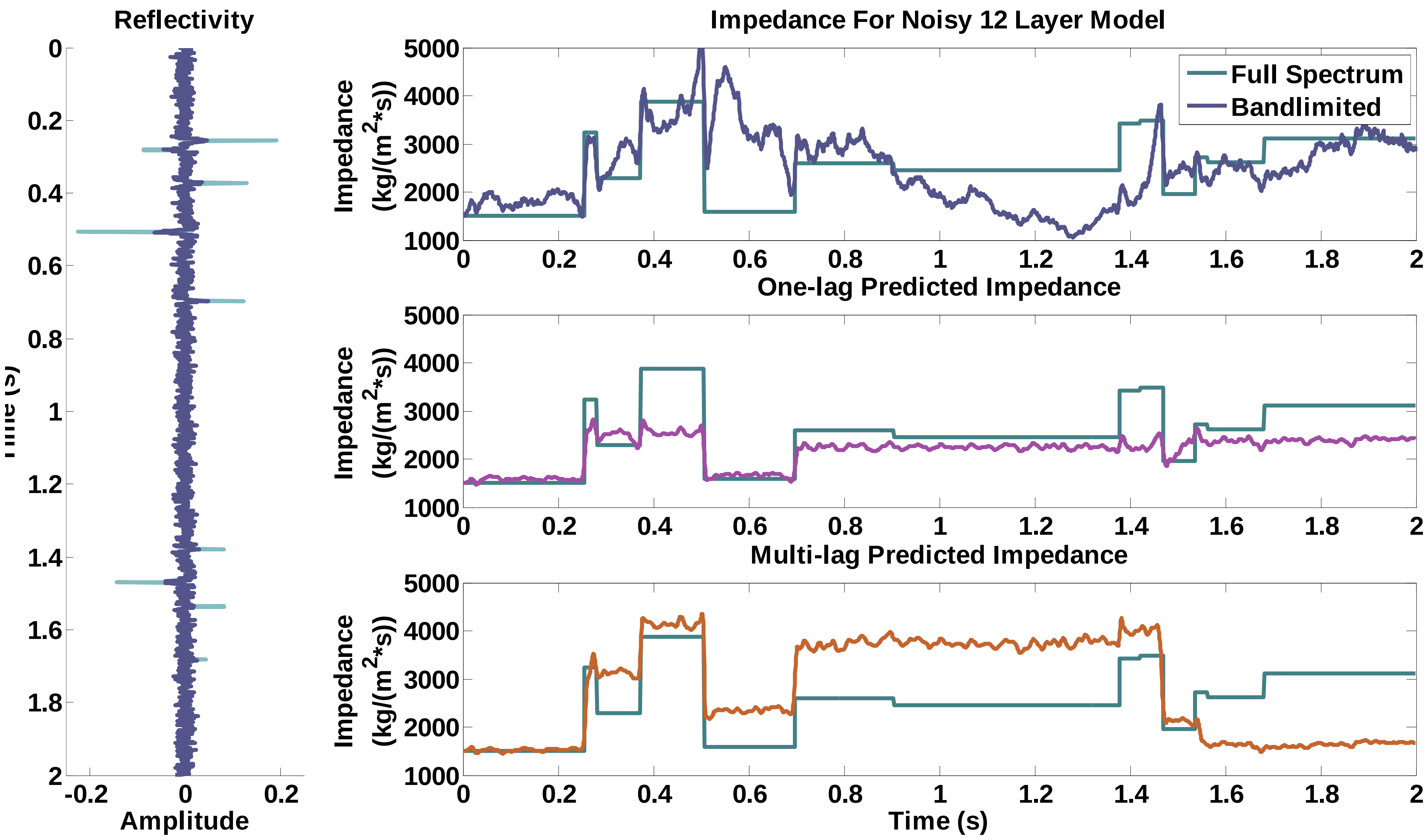
Prediction Filters



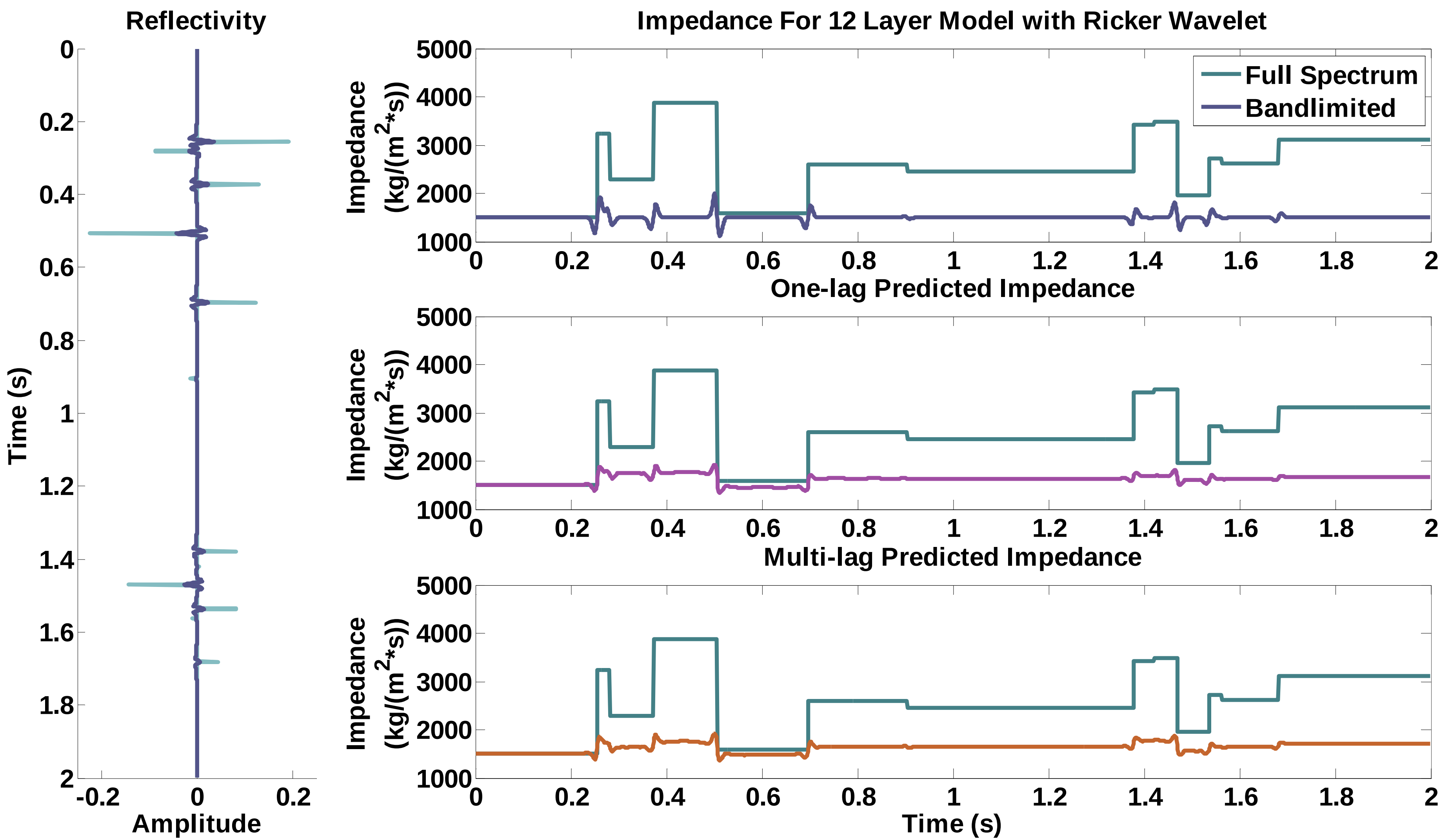
12 Layer Model



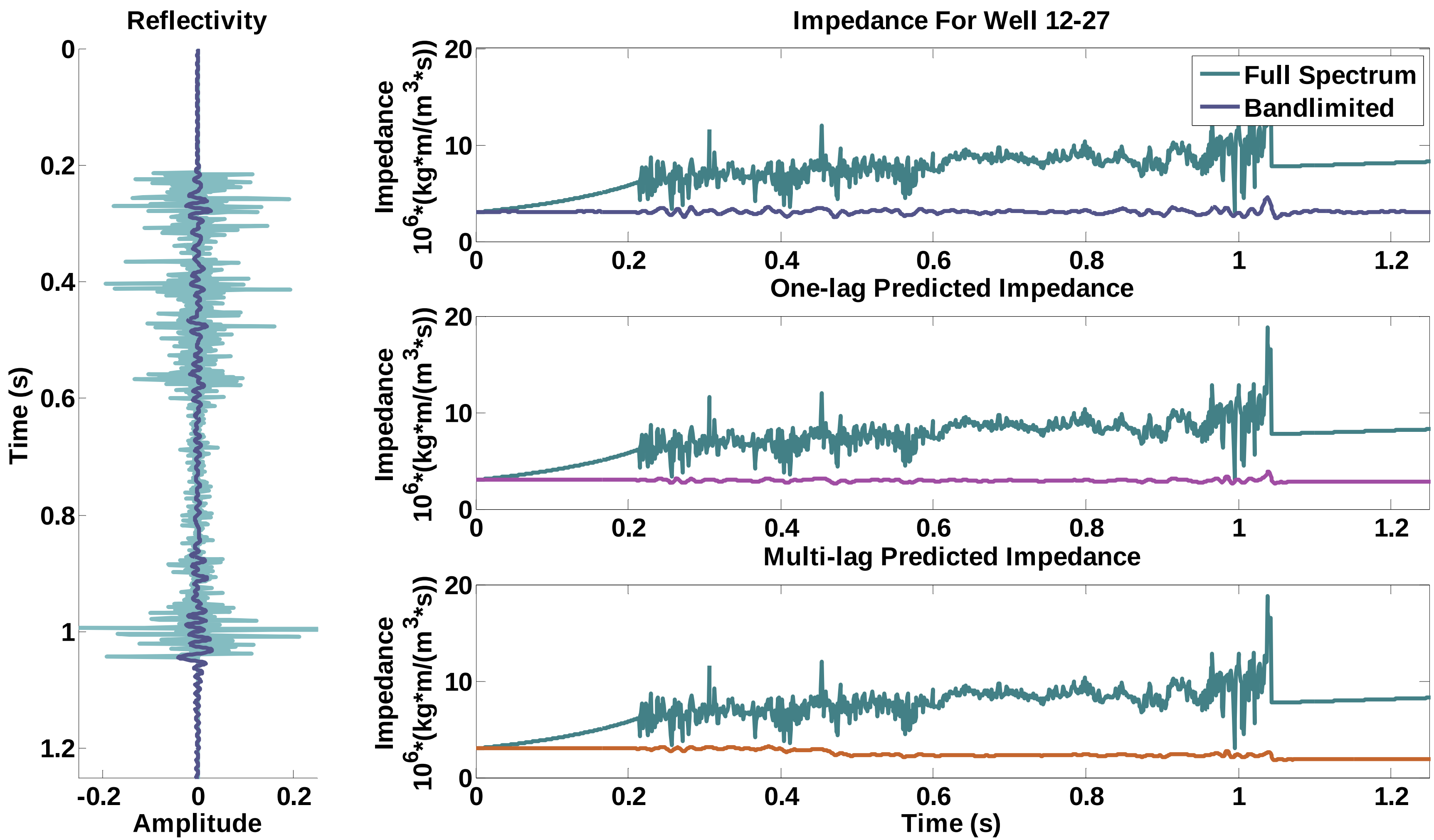
12 Layer Model with Noise



12 Layer Model with Ricker Wavelet



Well 12-27

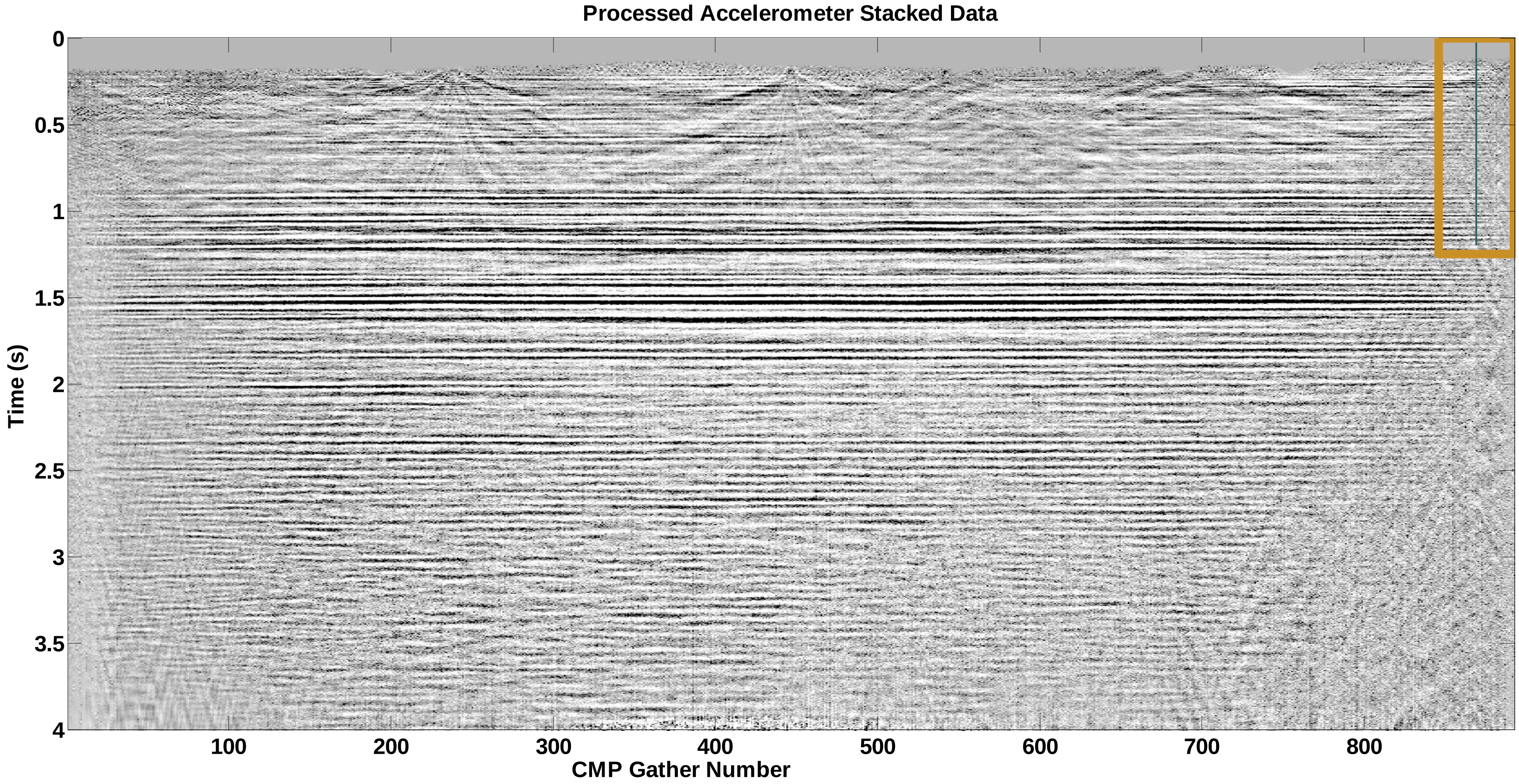

Reflectivity
Time (s)
0
0.2
0.4
0.6
0.8
1
1.2
-0.2
0
0.2
Amplitude
Impedance For Well 12-27
Impedance
10^6*(kg*m/(m^3*s))
20
10
0
0
0.2
0.4
0.6
0.8
1
1.2
Full Spectrum
Bandlimited
One-lag Predicted Impedance
Multi-lag Predicted Impedance
Time (s)

Prediction Filter Problems

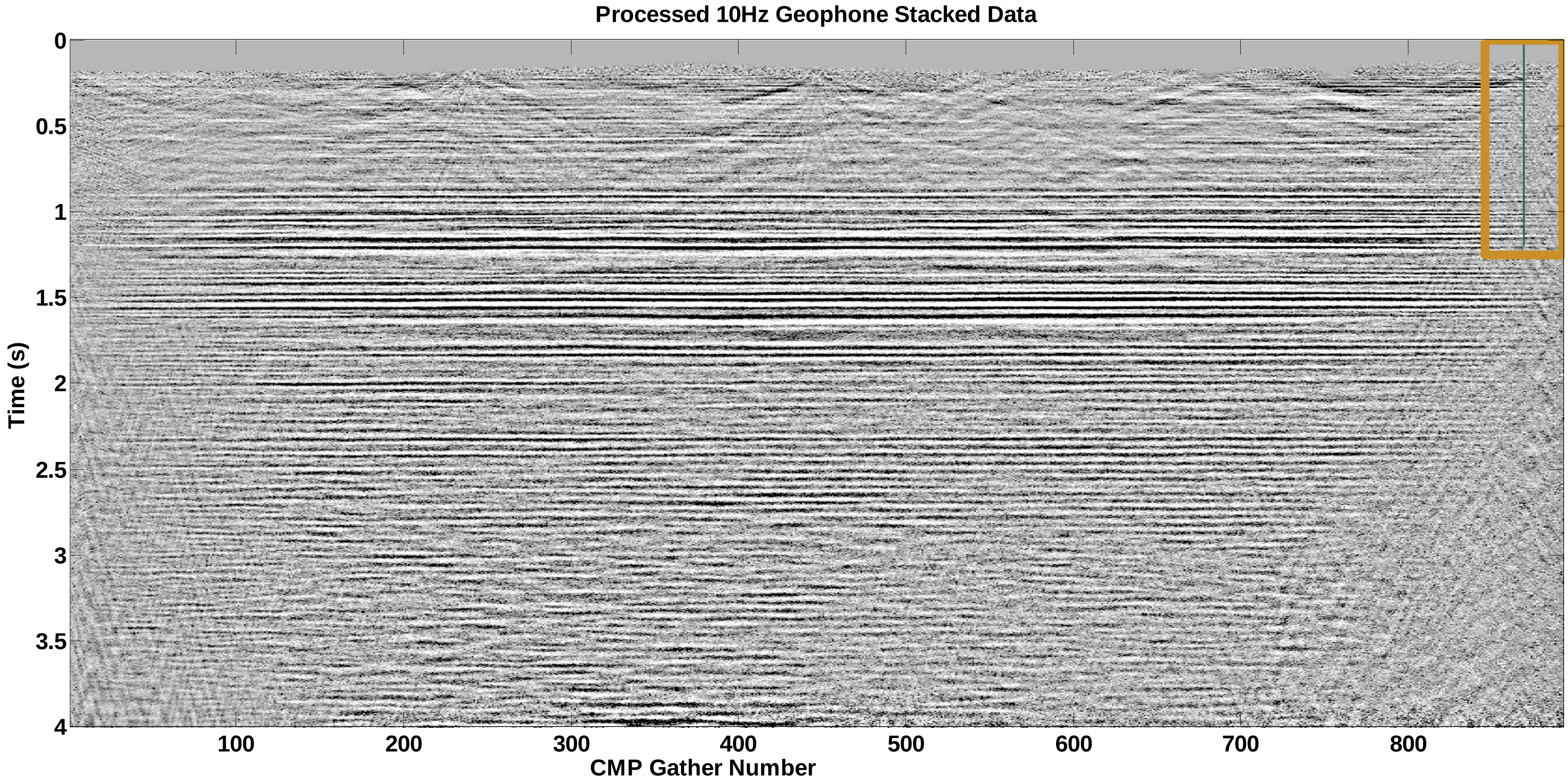
- Sensitive to spectra curvature
- Sensitive to Noise
- Sensitive to prediction filter length
- Sensitive to complicated models

Record Them - Dynamite

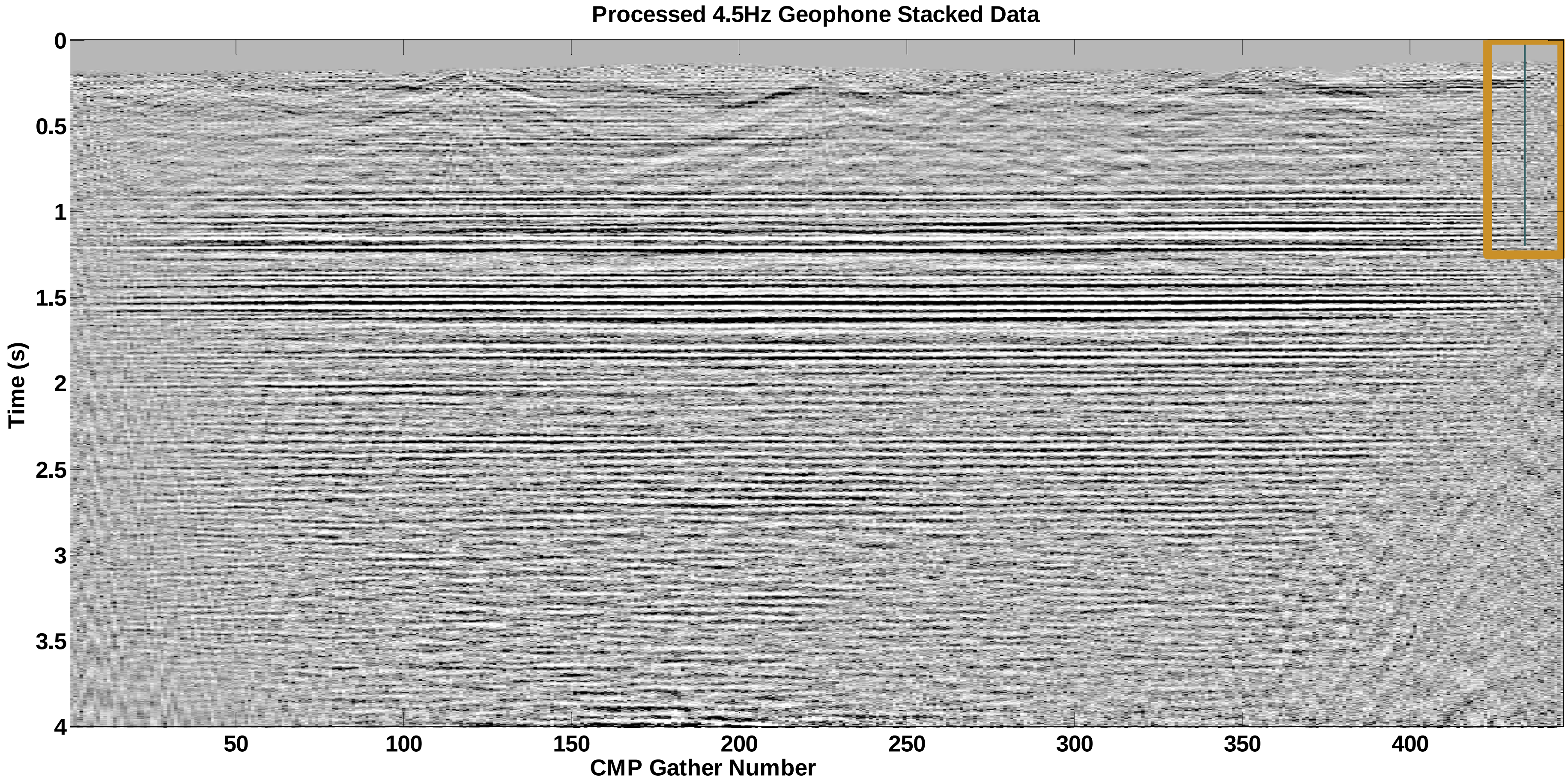
Accelerometer CMP Stacks



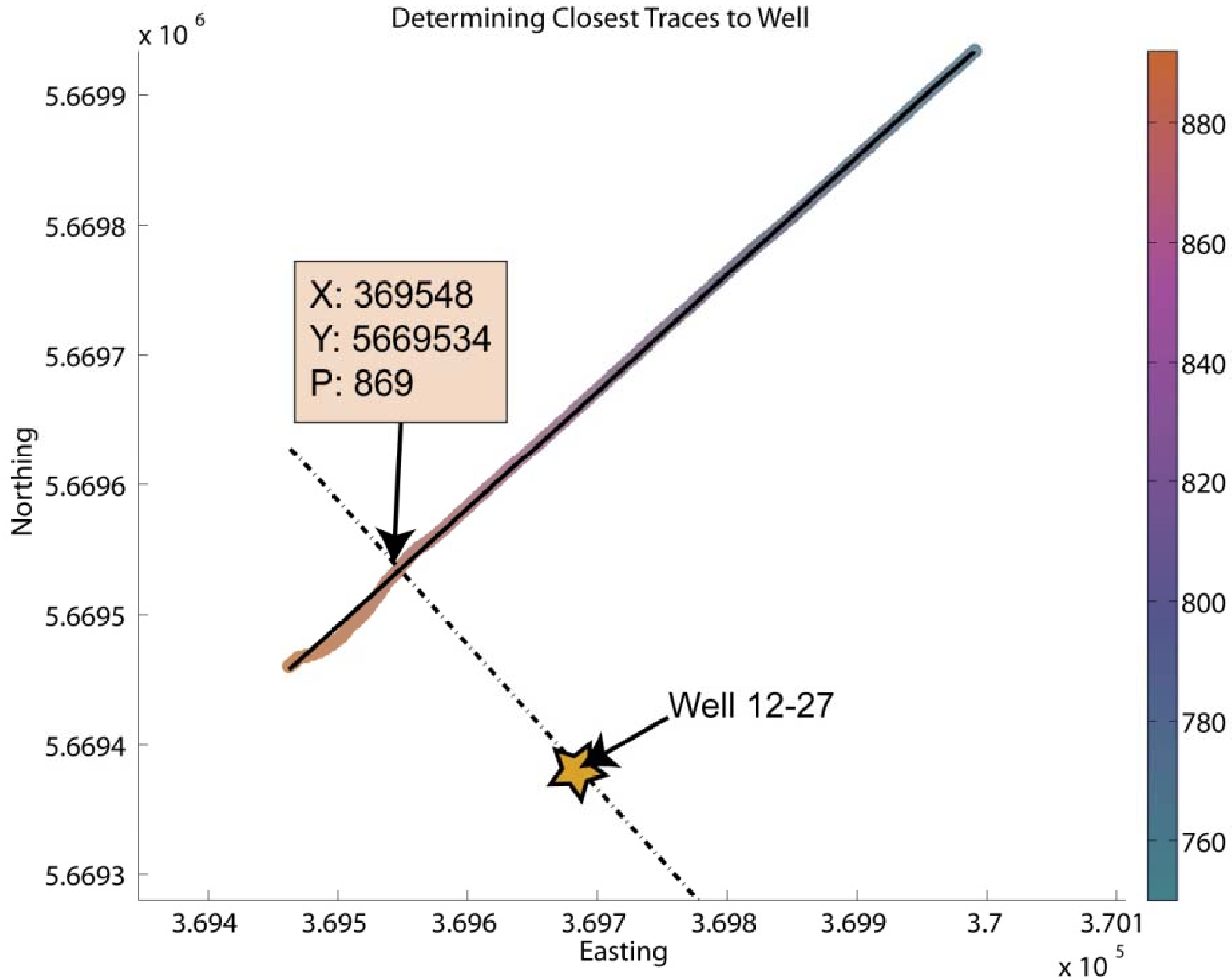
10Hz Geophone CMP Stacks

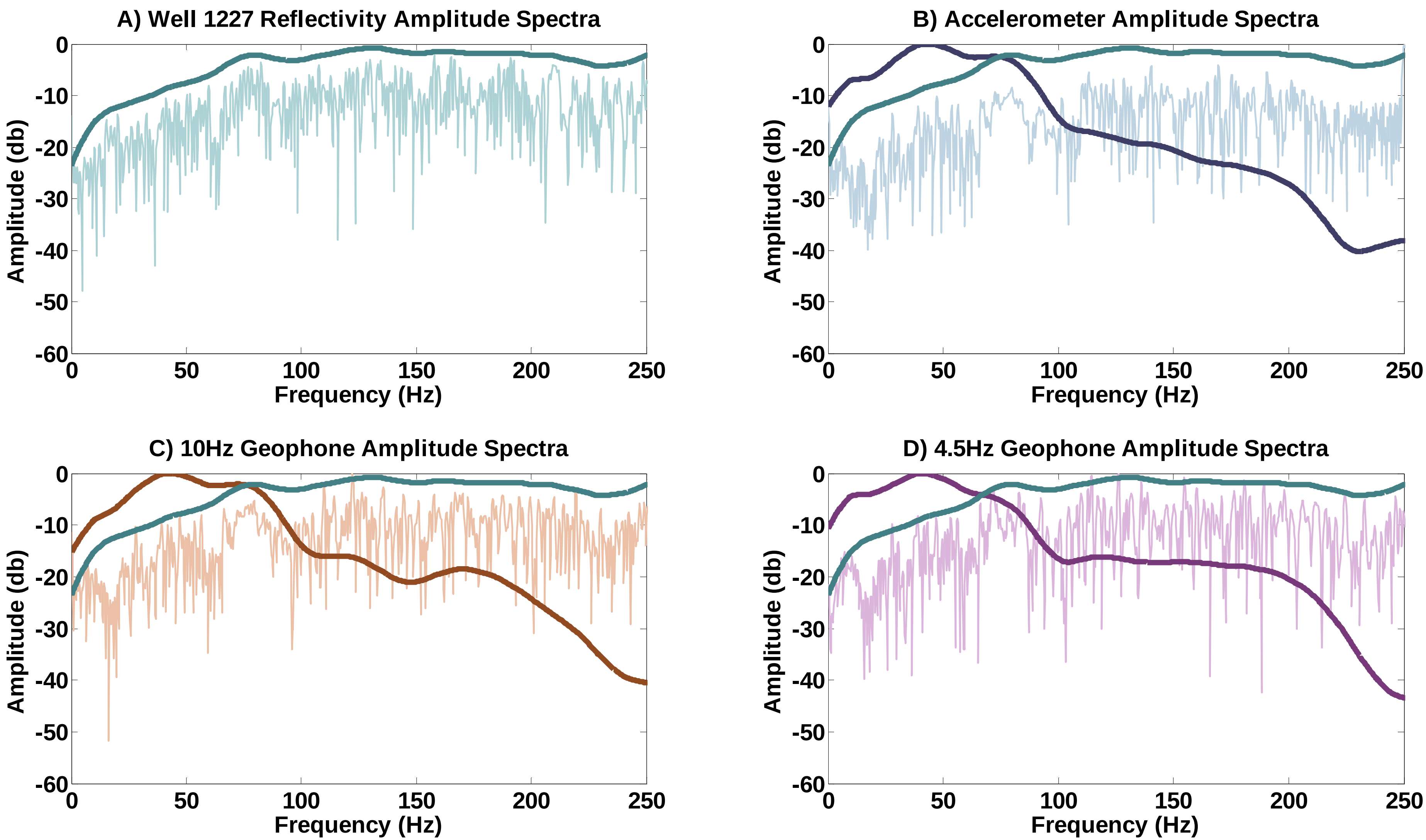


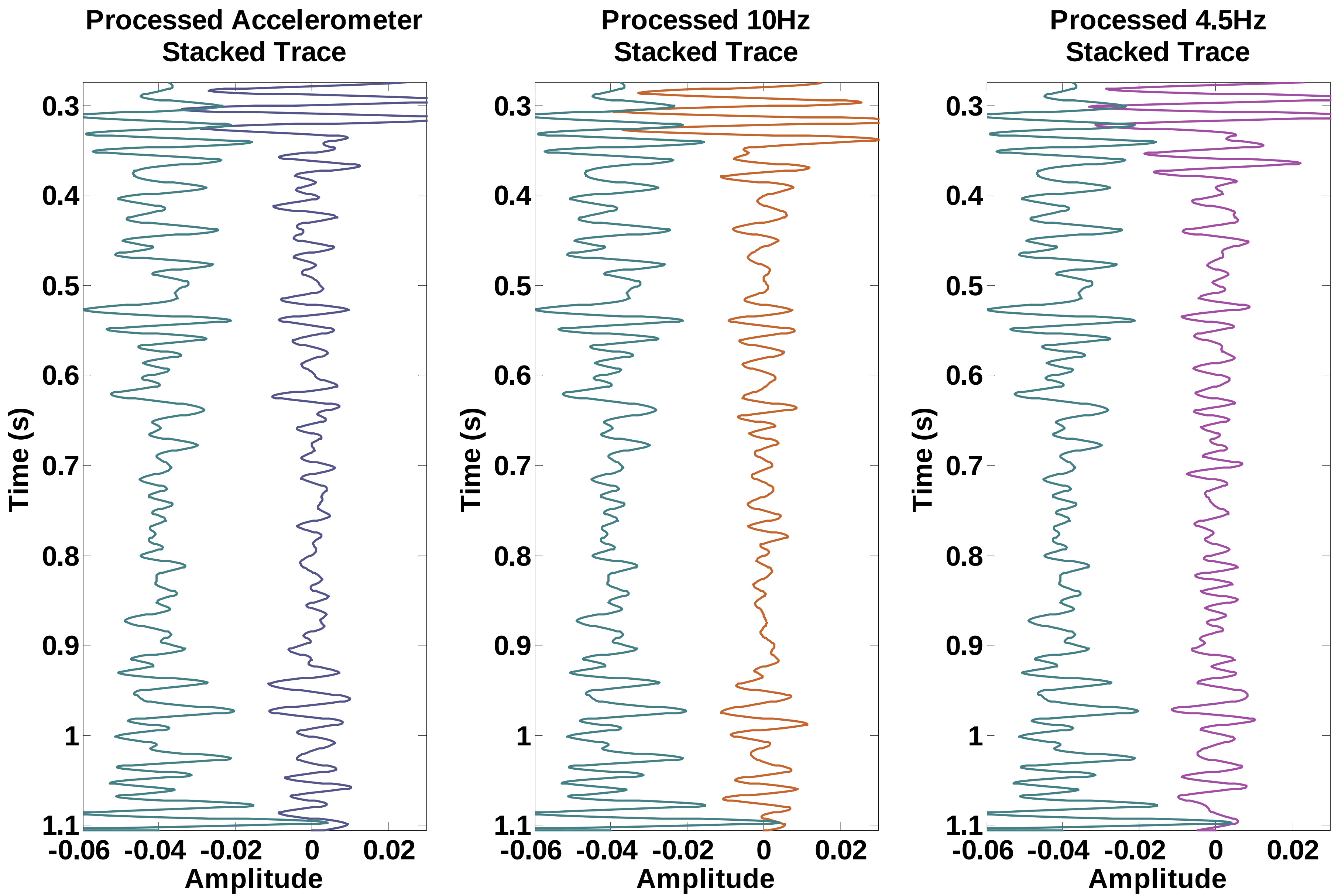
4.5Hz Geophone CMP Stacks

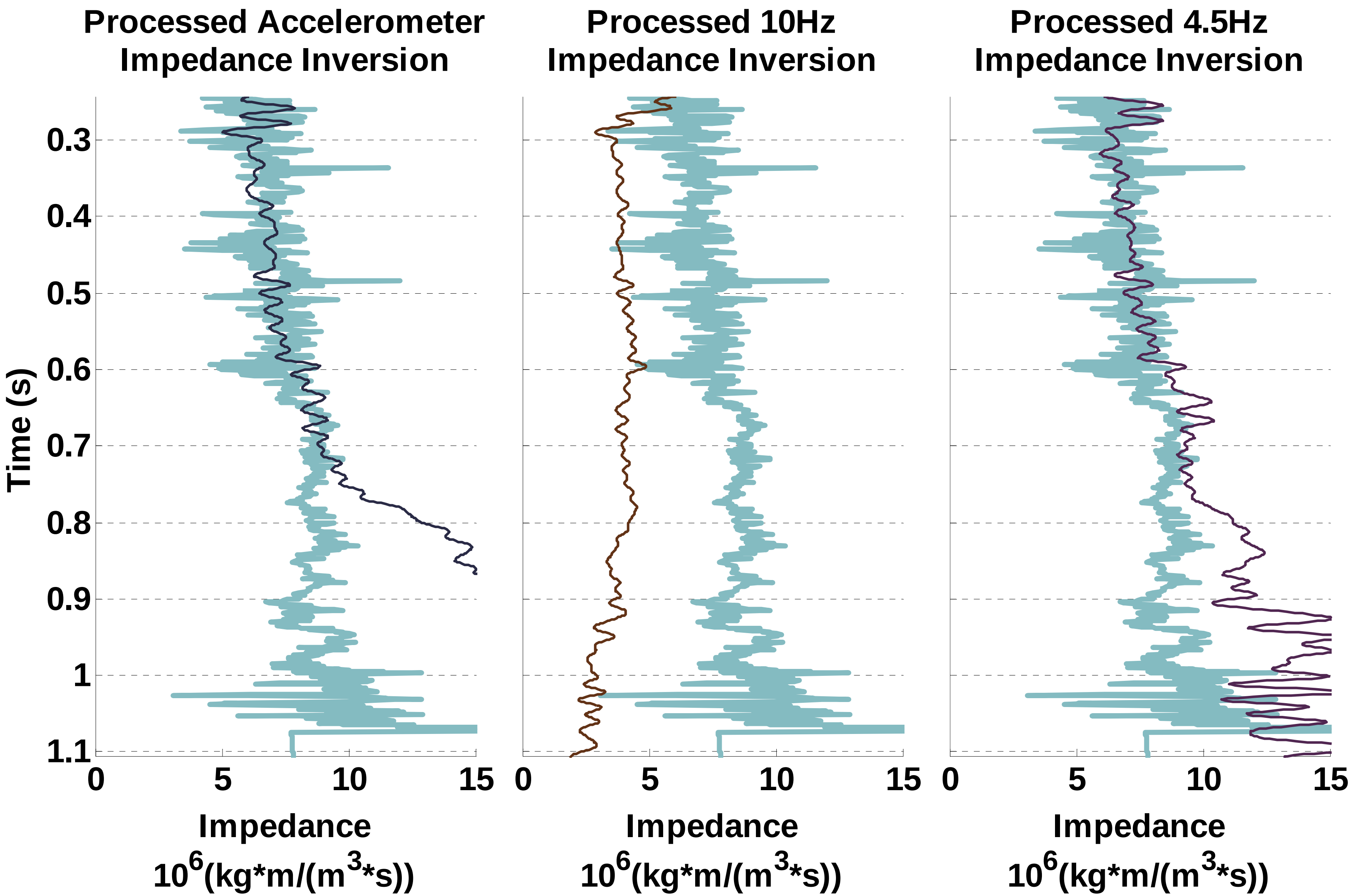


Creating the Stacked Traces

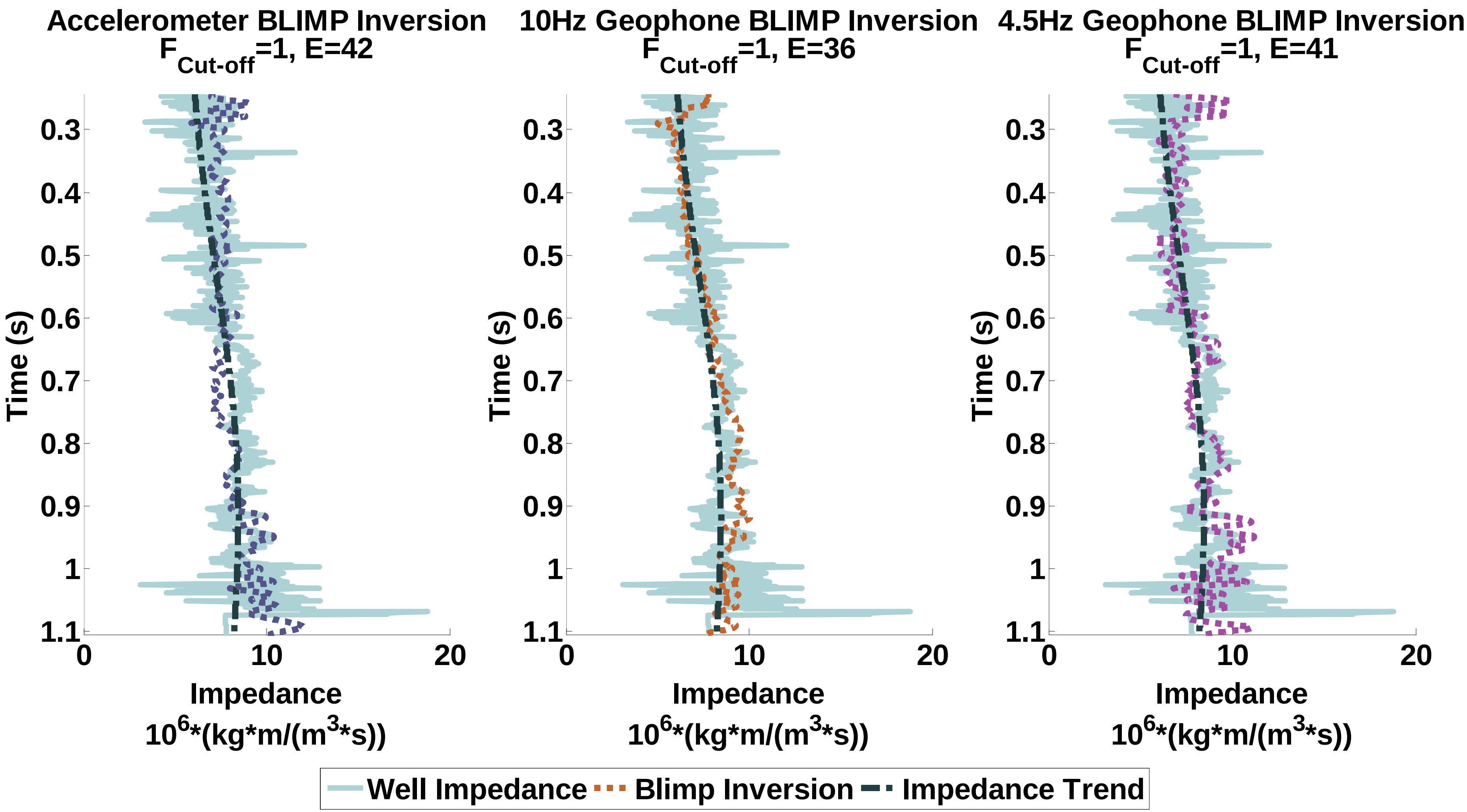



A) Well 1227 Reflectivity Amplitude Spectra
B) Accelerometer Amplitude Spectra
C) 10Hz Geophone Amplitude Spectra
D) 4.5Hz Geophone Amplitude Spectra
Amplitude (db)
Frequency (Hz)
0
-10
-20
-30
-40
-50
-60
0
50
100
150
200
250

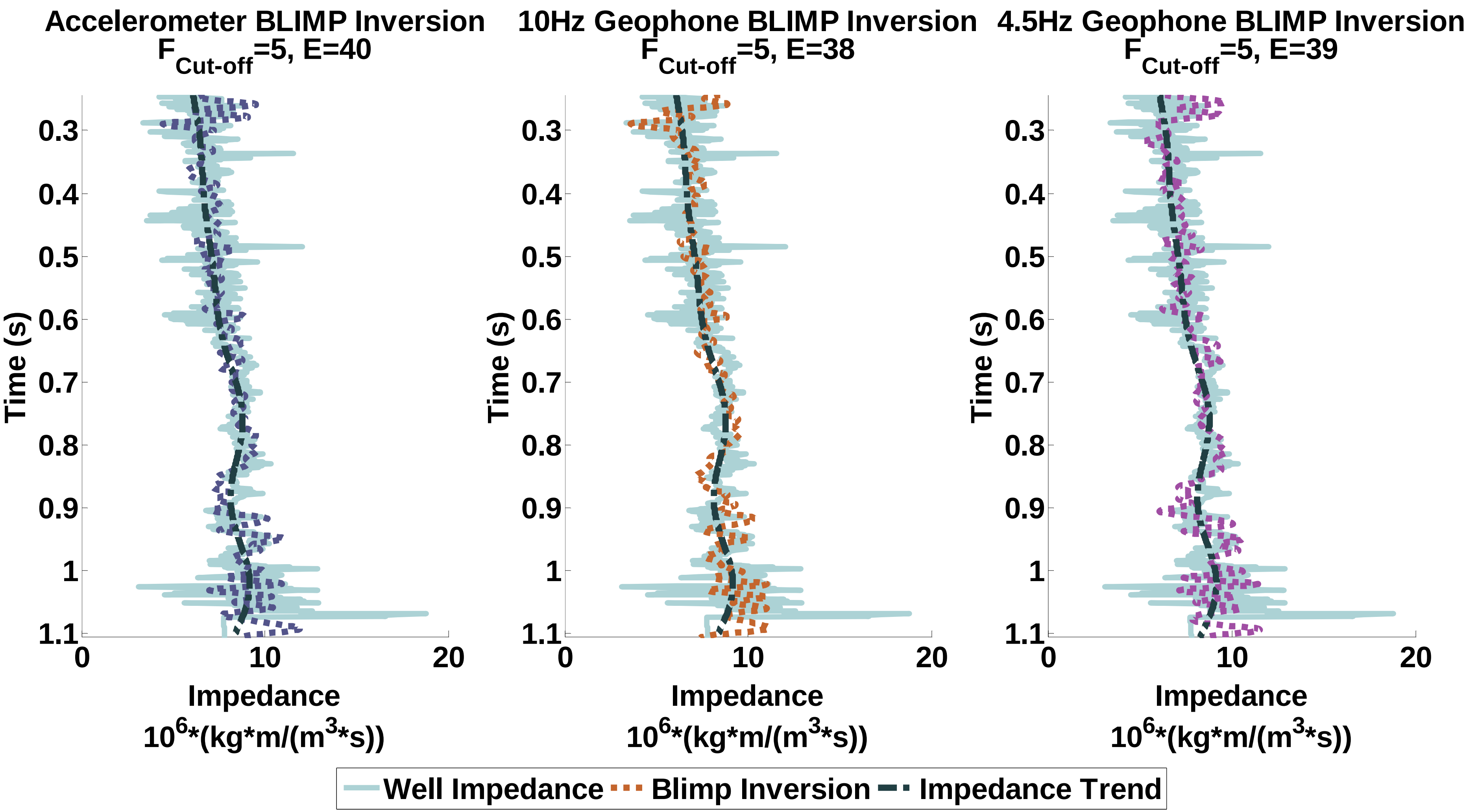

Processed Accelerometer Stacked Trace
Processed 10Hz Stacked Trace
Processed 4.5Hz Stacked Trace
Time (s)
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
-0.06
-0.04
-0.02
0
0.02
Amplitude


Processed Accelerometer Impedance Inversion
Processed 10Hz Impedance Inversion
Processed 4.5Hz Impedance Inversion
Time (s)
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
0
5
10
15
Impedance
10^6(kg*m/(m^3*s))

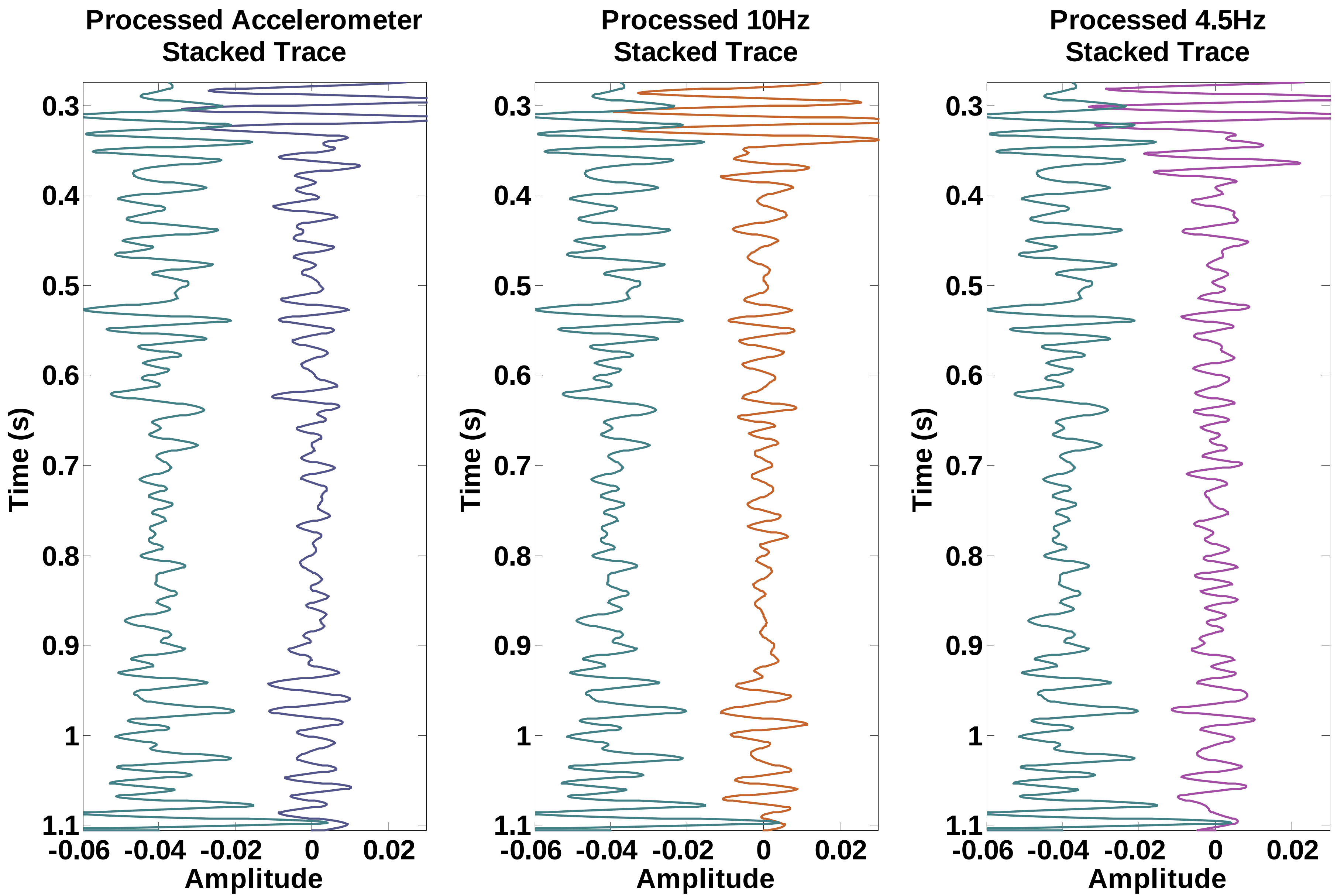
BLIMP – 1Hz cut-off

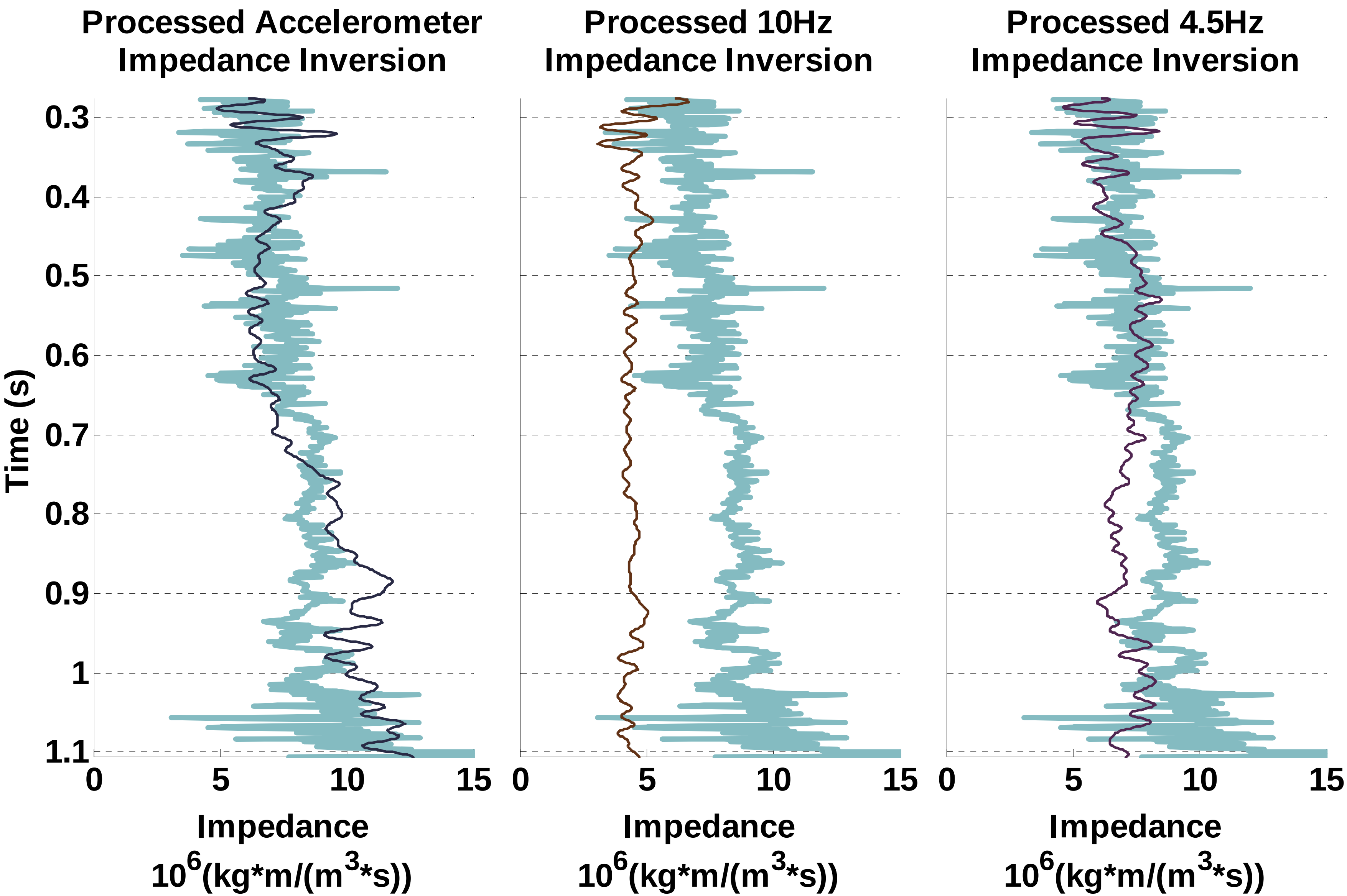


BLIMP – 5Hz cut-off

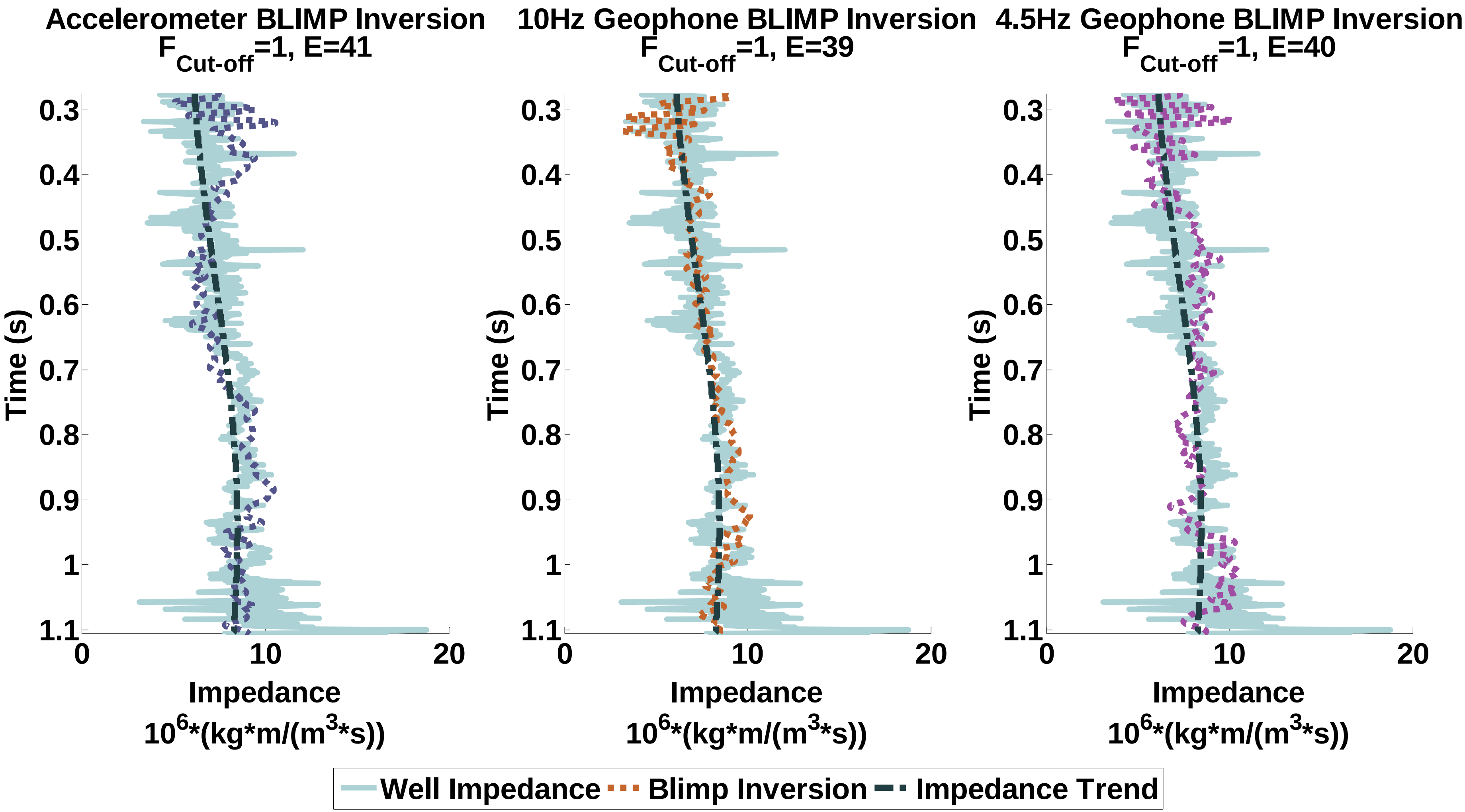


Record Them - INOVA Low-Dwell

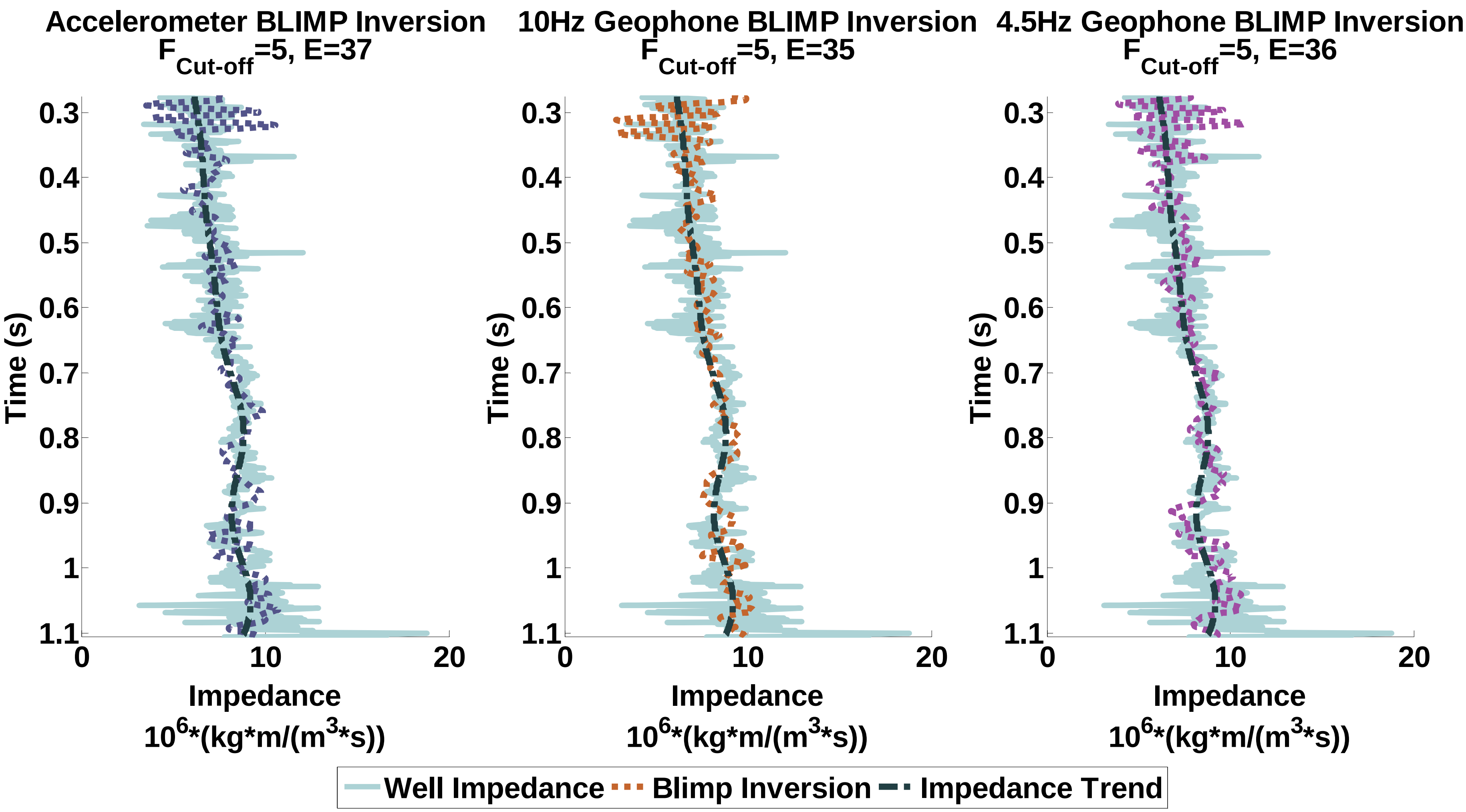

Processed Accelerometer Stacked Trace
Processed 10Hz Stacked Trace
Processed 4.5Hz Stacked Trace
Time (s)
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
-0.06
-0.04
-0.02
0
0.02
Amplitude


Processed Accelerometer Impedance Inversion
Processed 10Hz Impedance Inversion
Processed 4.5Hz Impedance Inversion
Time (s)
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
0
5
10
15
Impedance
10^6(kg*m/(m^3*s))

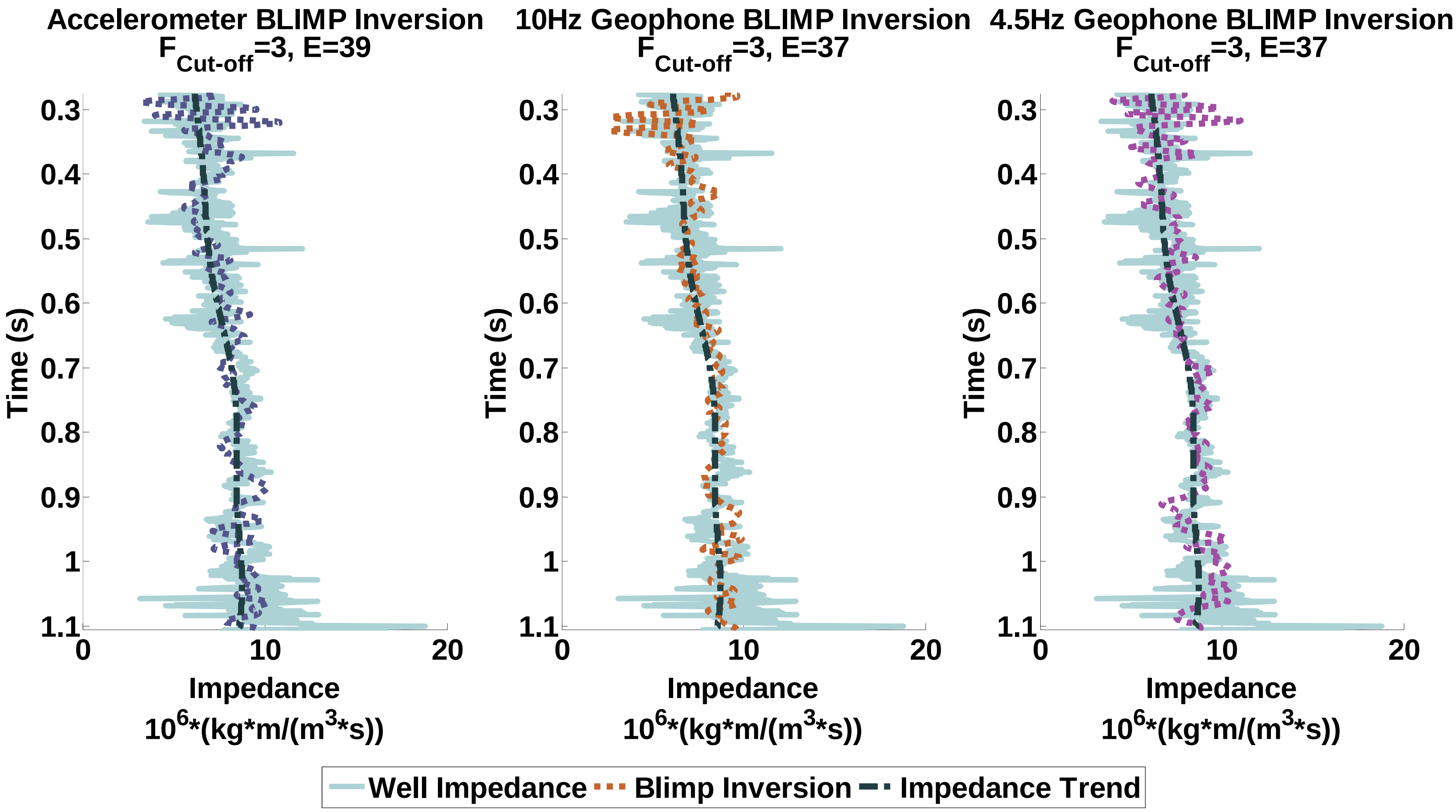
BLIMP 1Hz cut-off



BLIMP 5Hz cut-off



BLIMP 3Hz cut-off



Conclusions

- BLIMP inversion relies heavily on the low frequencies of the well impedance and is very sensitive to the low frequency cut-off value.
- Prediction filter low frequency recovery methods are good for simple models with flat wavelets currently this method is not suitable for wells or real data.
- Recording lower frequencies in the field is possible even down to 1Hz but some well information is still required.

References

- Oldenburg, D. W., Scheuer, T., and Levy, S., 1983, Recovery of the acoustic impedance from reflection seismograms: Geophysics, Vol. 48, No. 10.
- Lindseth, R. O., 1979, Synthetic sonic logs – a process for stratigraphic interpretation: Geophysics, Vol. 44, No. 1.
- Ferguson, R. J. and Margrave, G. F., 1996, A simple algorithm for bandlimited impedance inversion: CREWES Research Report, Vol. 8, No. 21.

Acknowledgements

- Helen Isaac
- Kris Innanen
- Husky Energy, INOVA and Geokinetics
- Kevin Hall
- Peter Gagliardi, Faranak Mahmoudian, Chris Bird, Steve Kim, Diane Lespinasse
- Laura Baird
- CREWES students, staff & faculty
- CREWES Sponsors