Match filtering a time-lapse data set utilizing the surface-consistent method

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CREWES Technical talk

Outline

- Surface-consistent hypothesis
- What's a surface-consistent matching filter?
- Examples
- Conclusions & FW
- Acknowledgements

Surface-consistent hypothesis

The surface-consistent model:

the seismic trace can be modeled as

$$d_{ij}(t) \approx s_i(t) * r_j(t) * h_k(t) * y_l(t) \qquad (1)$$

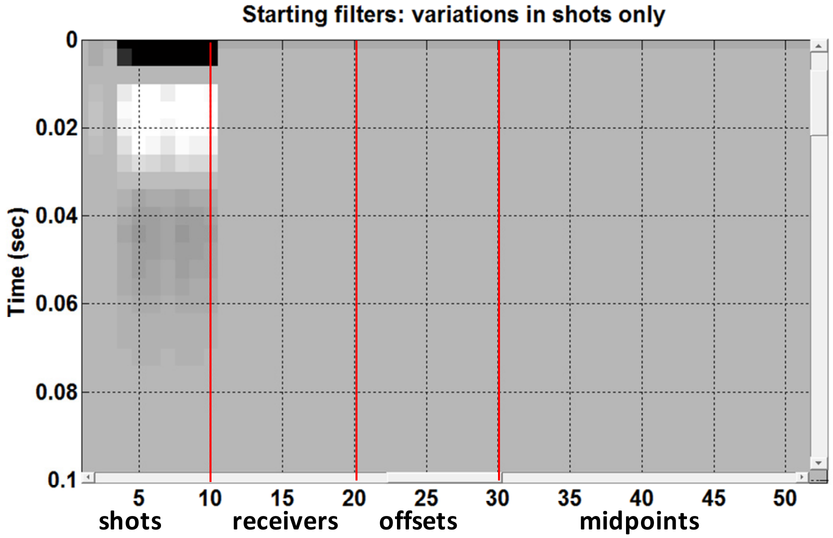
where

- d_{ij} : seismic trace
- s_i : source response at location *i*
- r_j : receiver response at location *j*
- h_k: offset response at location *k; k=|i-j|*
- y_l: subsurface response at *l; l=(i+j)/2*

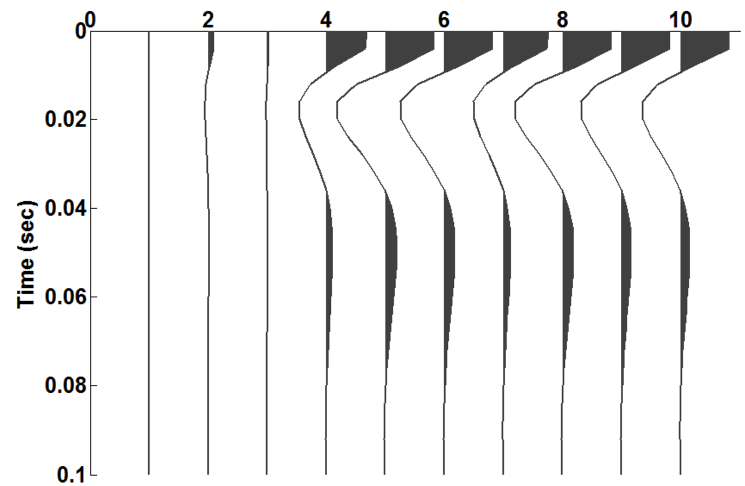
<u>FACT :</u> the model is reasonable <u>approximation</u> of the seismic trace that is easy to compute.

Forward modeling

Input model (4-components)



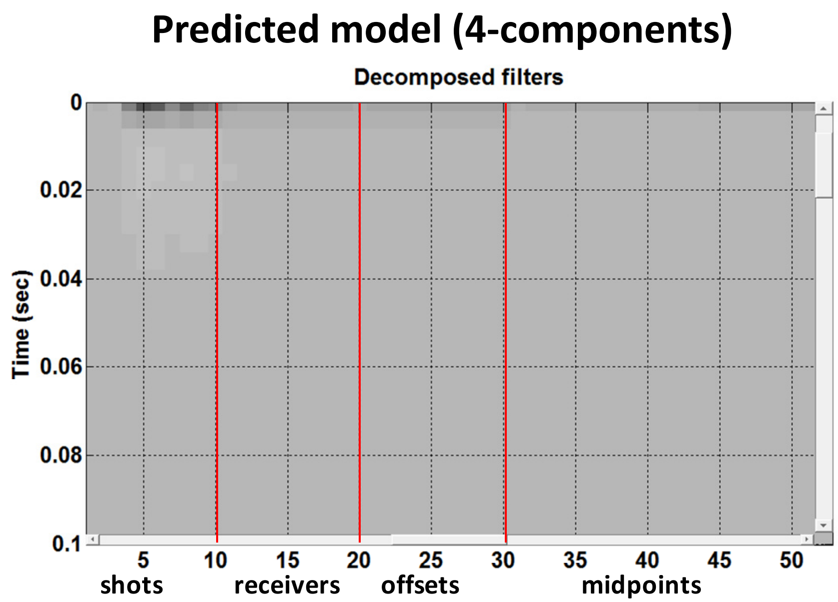
Data

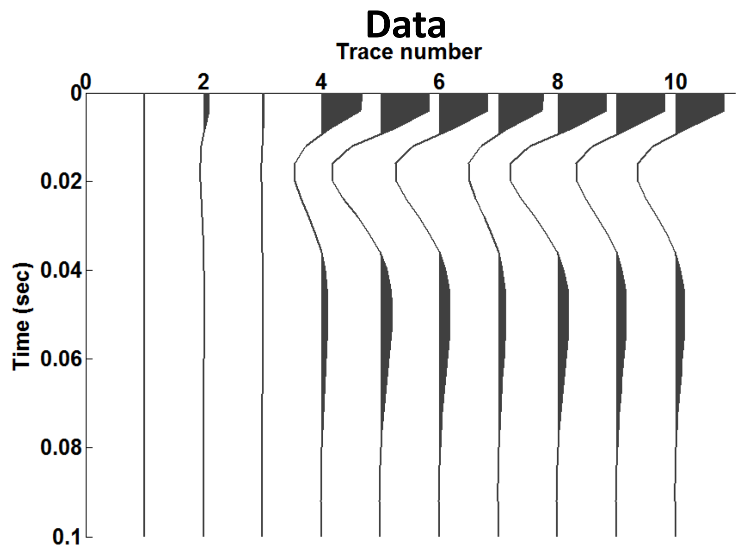


$$\tilde{s}_i(t) * r_j(t) * h_k(t) * y_l(t) \approx d_{ij}(t)$$

Forward model

Inverse modeling





$$\underline{\underline{G}}\,\underline{x} = \underline{d}$$

$$\underline{x} = \begin{bmatrix} s_i & r_j & h_k & y_l \end{bmatrix}^T$$

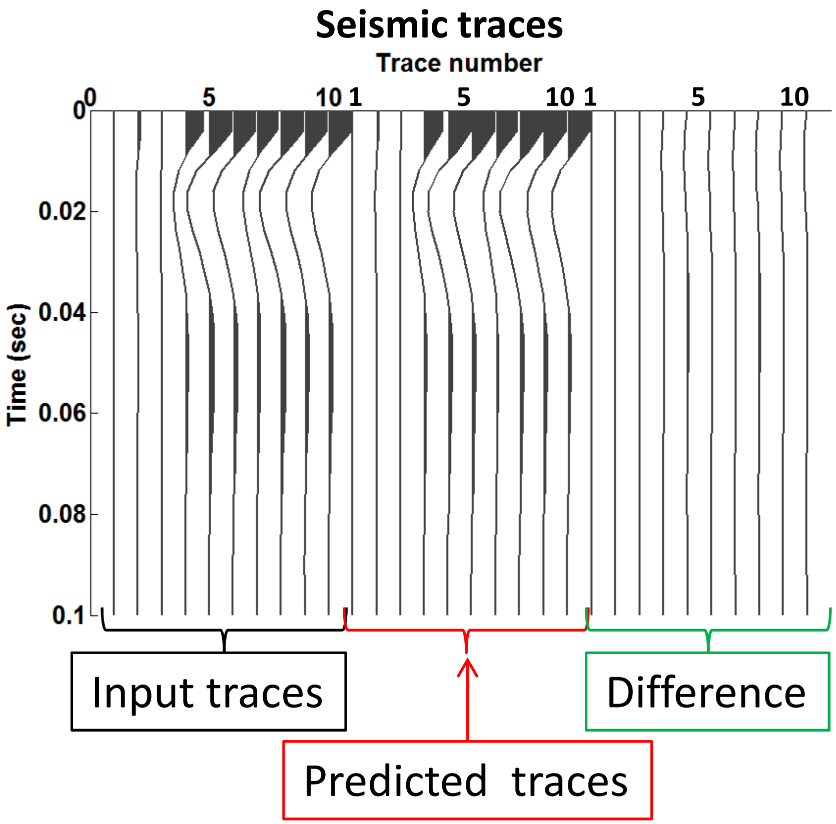
$$\underline{x} = (\underline{\underline{G}}^T \underline{\underline{G}})^{-1} \underline{\underline{G}}^T \underline{d}$$

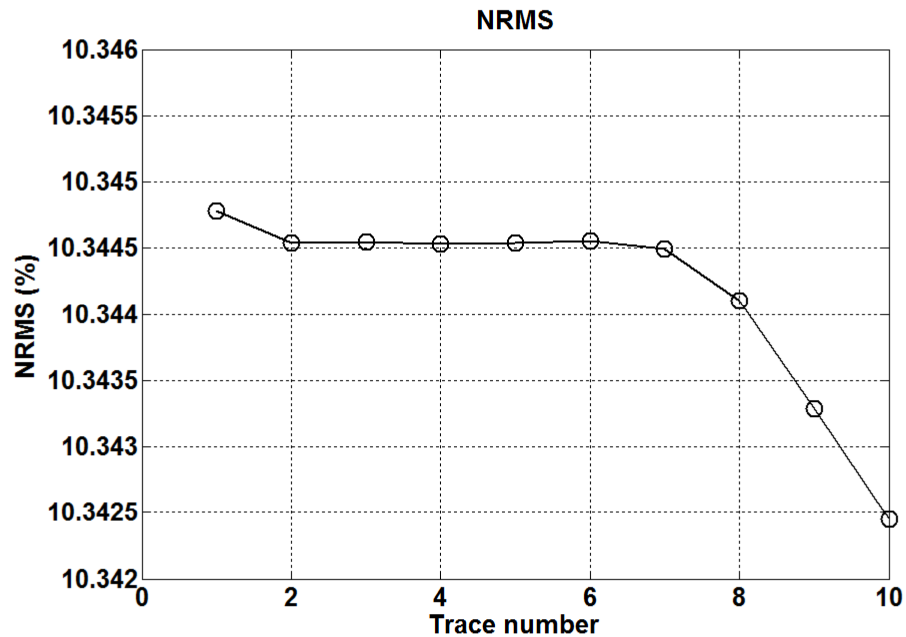
$$s_i(t) * r_j(t) * h_k(t) * y_l(t) \approx d_{ij}(t)$$

$\longleftarrow$ Inverse model

<u>FACT :</u> Seismic data geometry matrix has <u>no unique inverse</u> due to singularity of the square matrix G^TG, where G contains the positions of four-components above.

Difference





$$NRMS = 200\left[\frac{rms(base - monitor)}{rms(base) + rms(monitor)}\right]$$

NRMS vs. Time shift

$$D_1(t) = a\sin(2\pi ft)$$

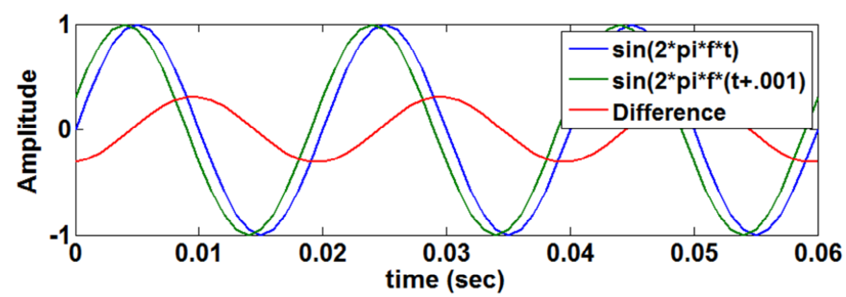
$$D_2(t) = a\sin(2\pi f(t+\delta t))$$

$$\delta D(t) = D_1(t) - D_2(t) = a(2\pi f\,\delta t)\cos(2\pi ft)$$

$$NRMS = 200\left[\frac{a(2\pi f\,\delta t)RMS[\cos(2\pi ft)]}{a.RMS[\sin(2\pi ft)] + a.RMS[\sin(2\pi f(t+\delta t))]}\right]$$

$$\boxed{NRMS(\%) = 100[2\pi f\,\delta t]}$$

F (Hz)	Time shift δt (ms)	NRMS (%)
50	0.001	31.4
50	0.002	62.8

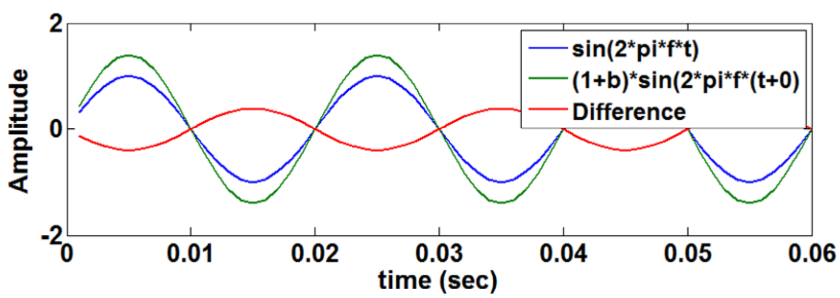


NRMS vs. Amplitude

$$D_1(t) = \sin(2\pi f t)$$
$$D_2(t) = (1+b)\sin(2\pi f t)$$
$$\delta D(t) = D_1(t) - D_2(t) = b\sin(2\pi f t)$$
$$\boxed{NRMS(\%) \approx 100 * b}$$

Assuming amplitude change is small

a	b	NRMS (%)
1.0	0.1	9.5
1.0	0.6	46



Small amplitude difference
Large amplitude difference

Surface-consistent matching filters (SCMF)

For two repeated data sets, their surface-consistent model is:

$$d1_{ij}(t) \approx s1_i(t) * r1_j(t) * h1_k(t) * y1_l(t) \qquad (2)$$

$$d2_{ij}(t) \approx s2_i(t) * r2_j(t) * h2_k(t) * y2_l(t) \qquad (3)$$

Q. Can we design a matching filter for these two data sets?

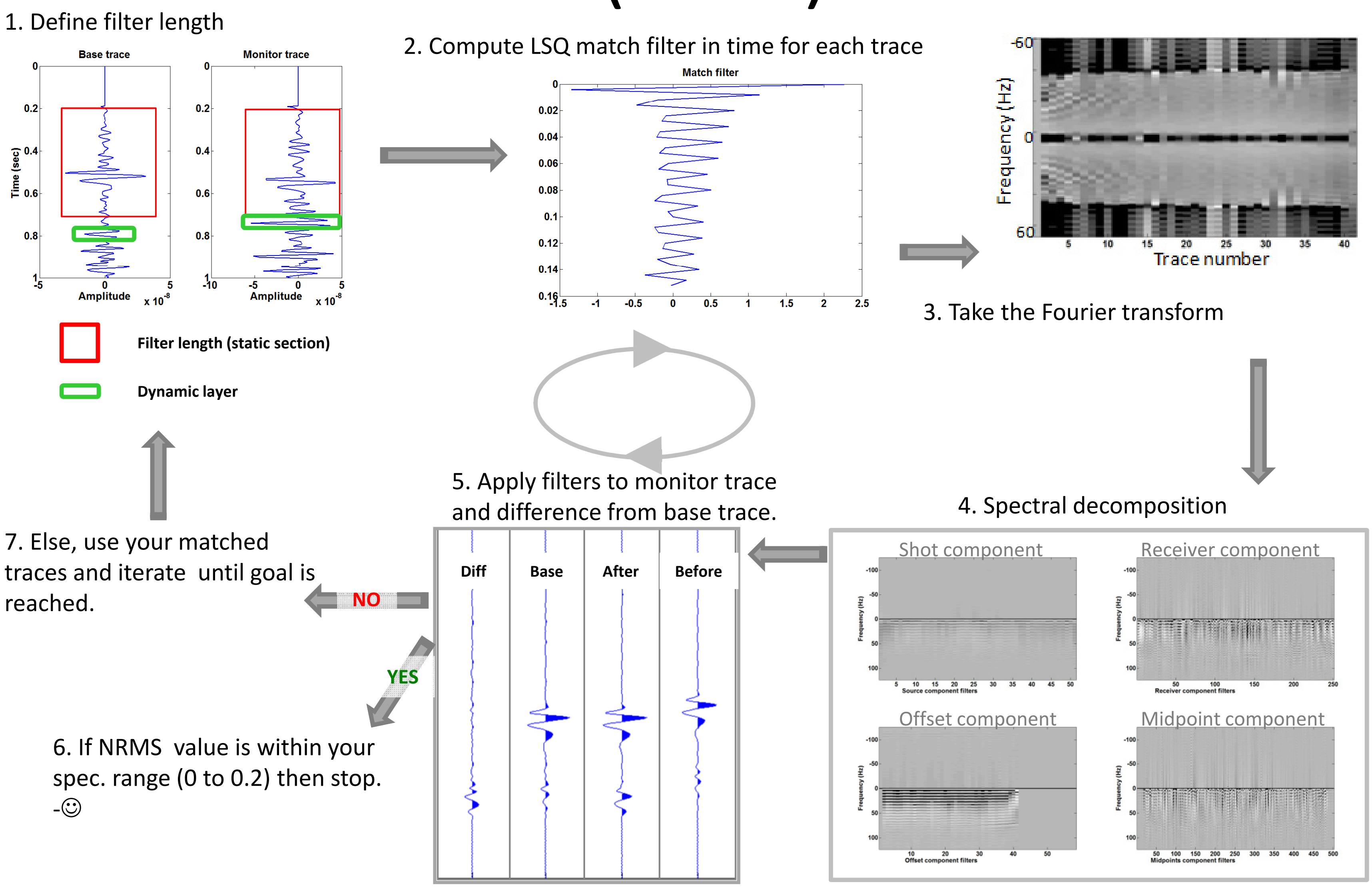
Matching filter concept:

$$m * s_1 = s_2 \xrightarrow{\text{Fourier domain}} M(\omega) = \frac{S_2(\omega)}{S_1(\omega)} \qquad (4)$$

Spectral ratio is an exact matching filter, but it is unstable in presence of noise.

<u>Alternatively:</u> solve the time-domain in LSQ & FT the solution which is a good approx to the spectral ratio.

Surface-consistent matching filters (cont')



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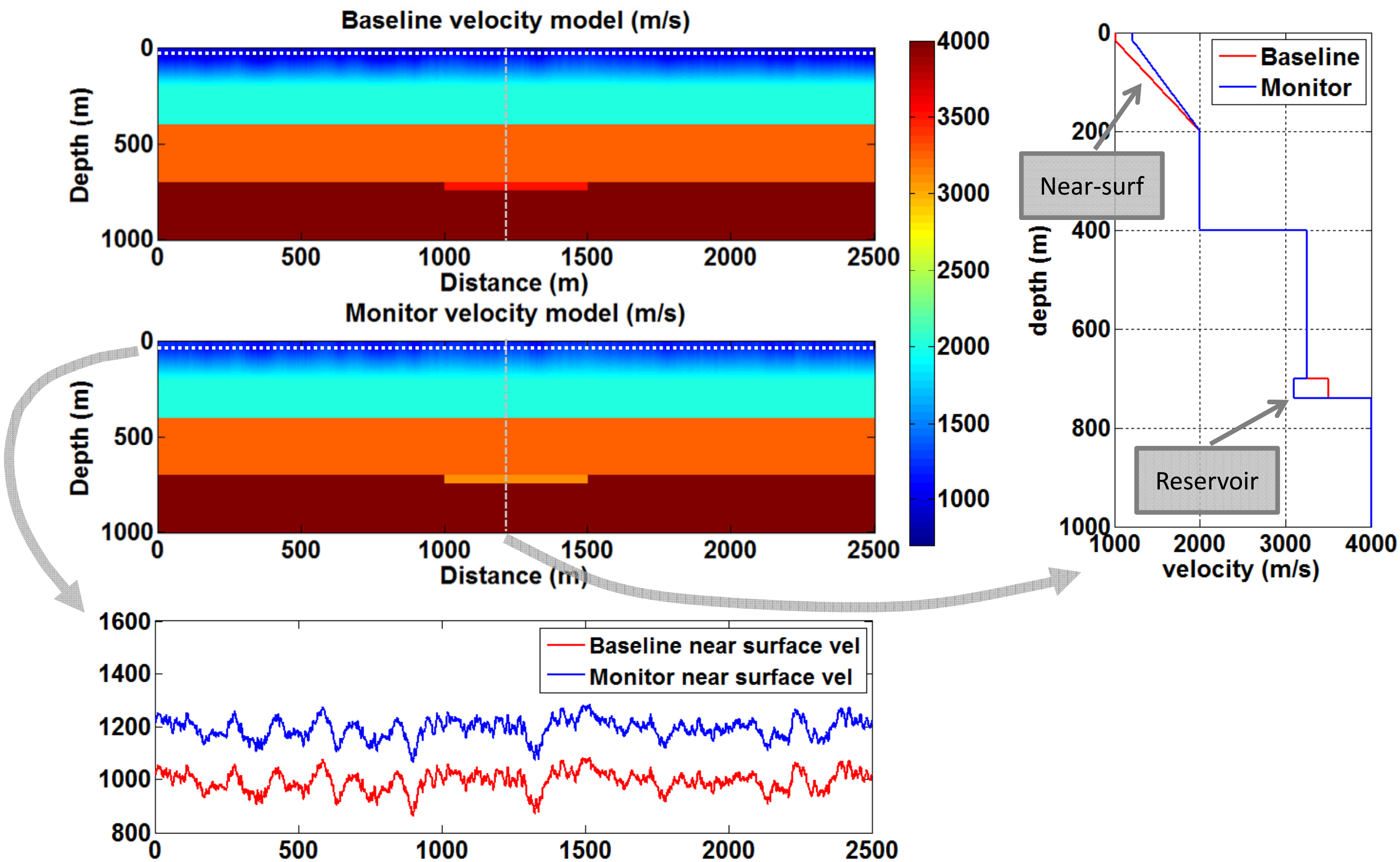
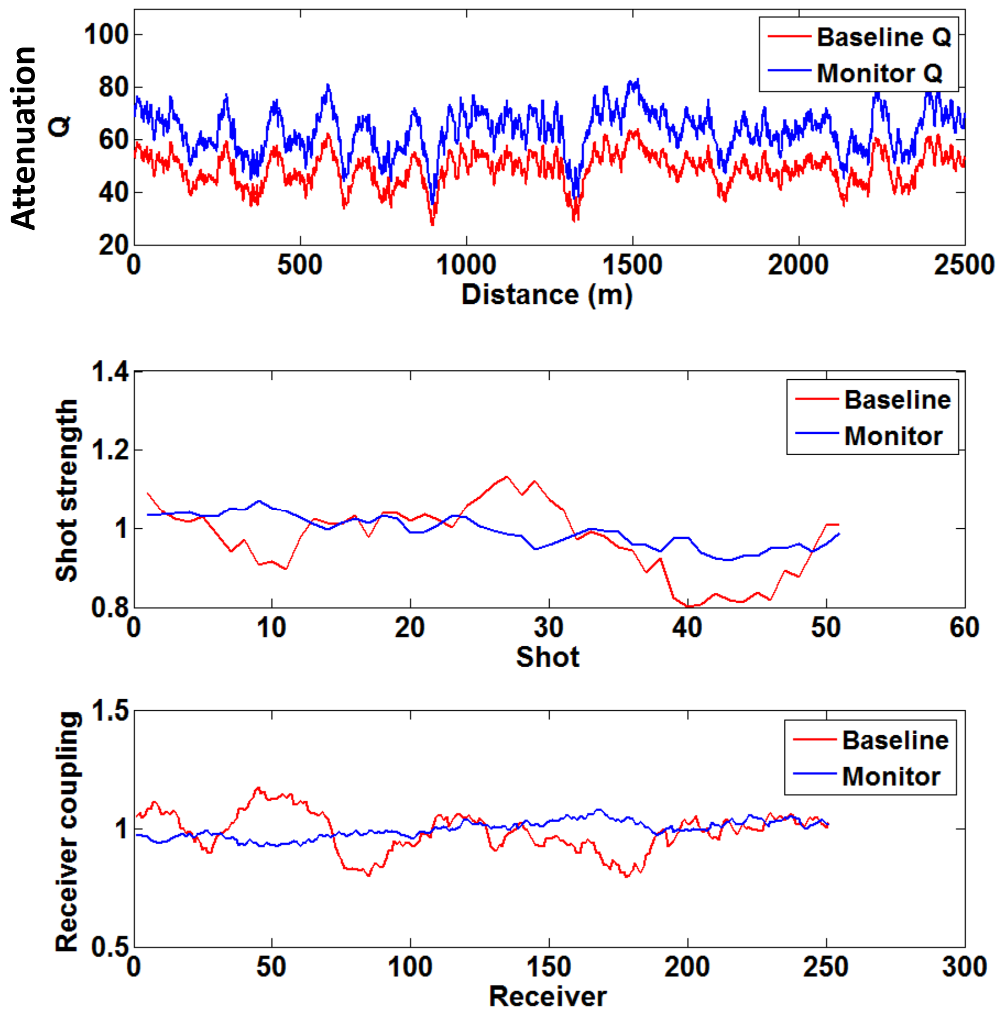
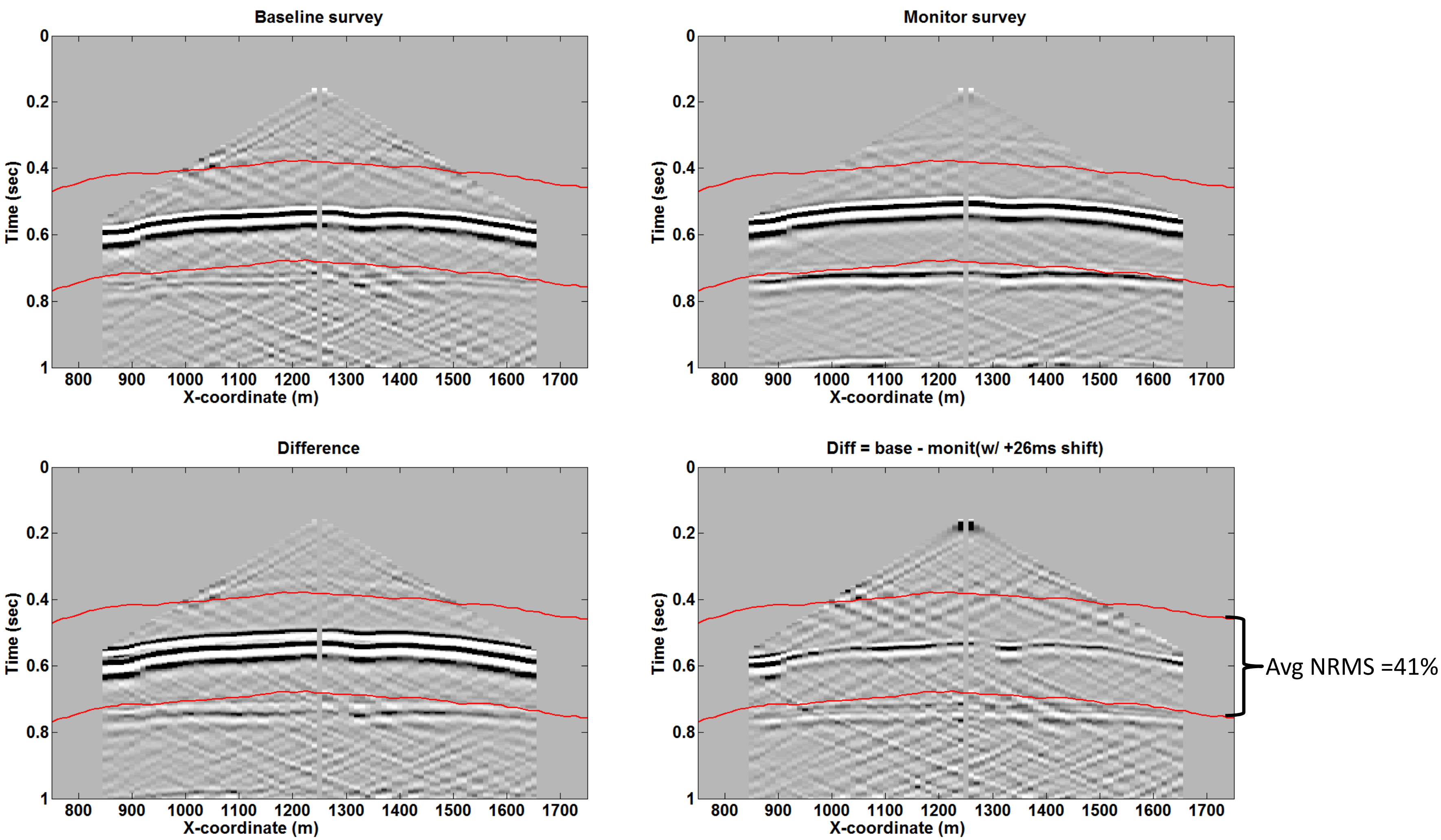
Two earth models



Other non-repeatable parameters

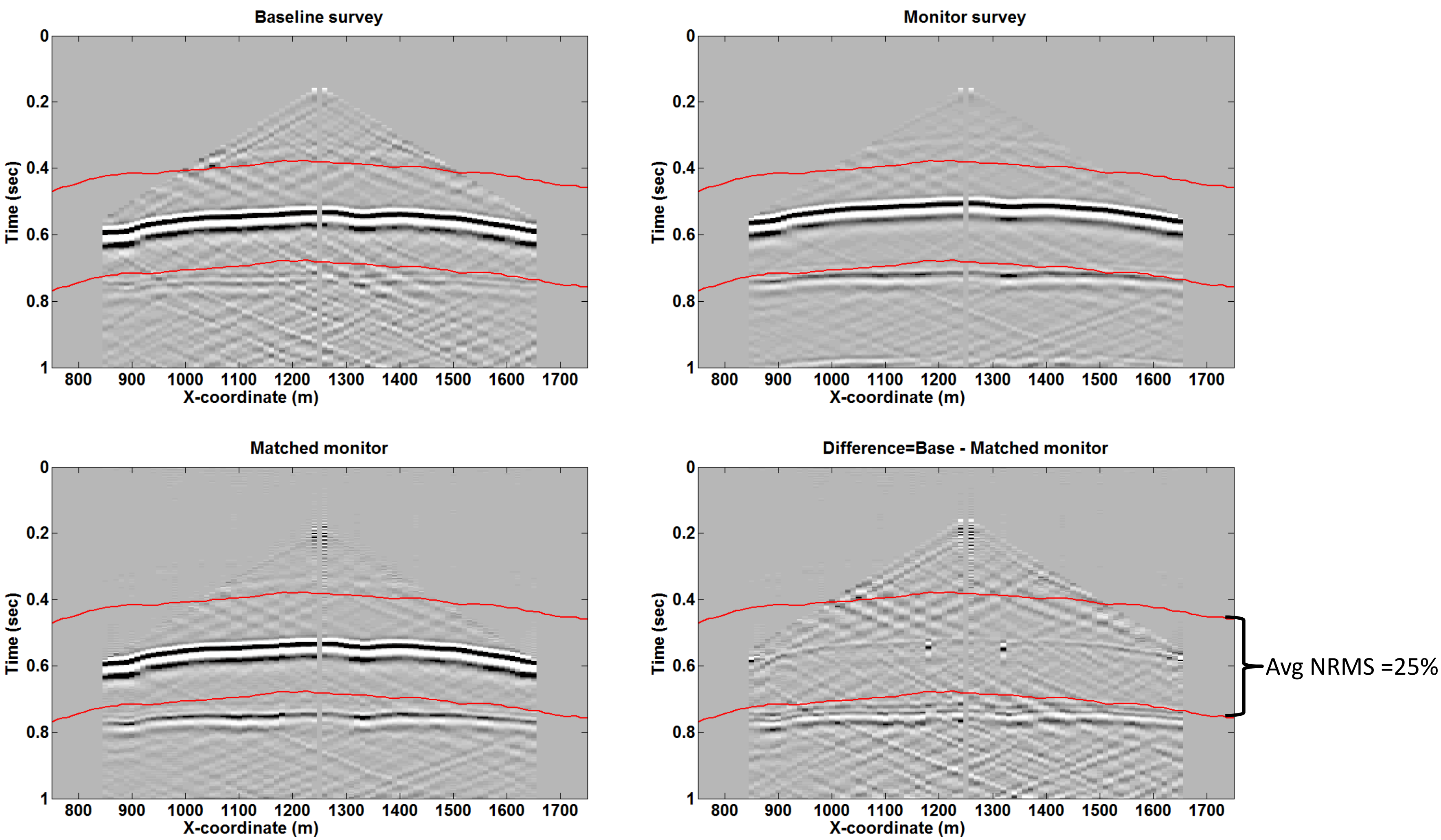


Raw shot: before match filtering



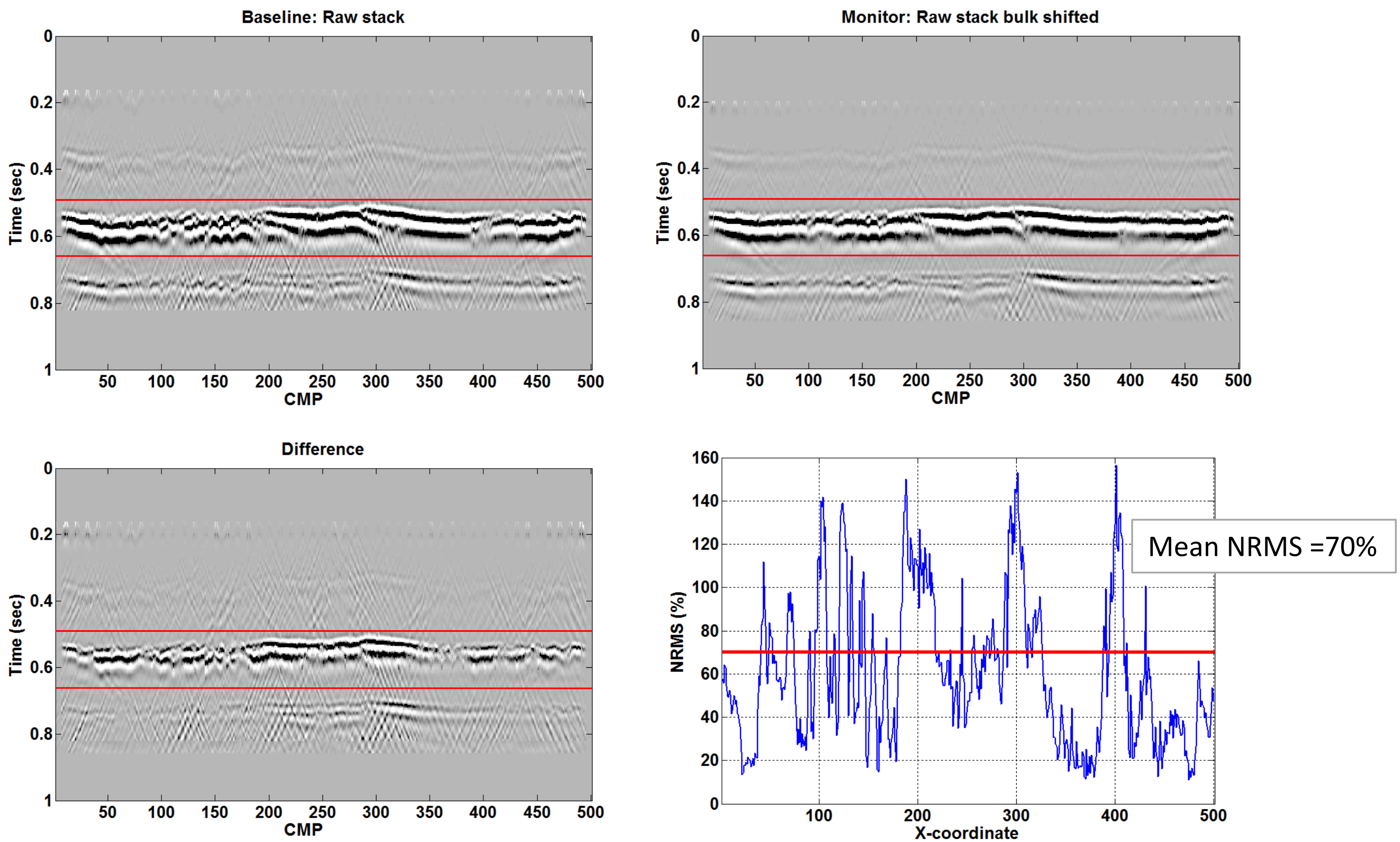
Difference = Baseline – monitor (before match filtering)

Raw shot: after match filtering

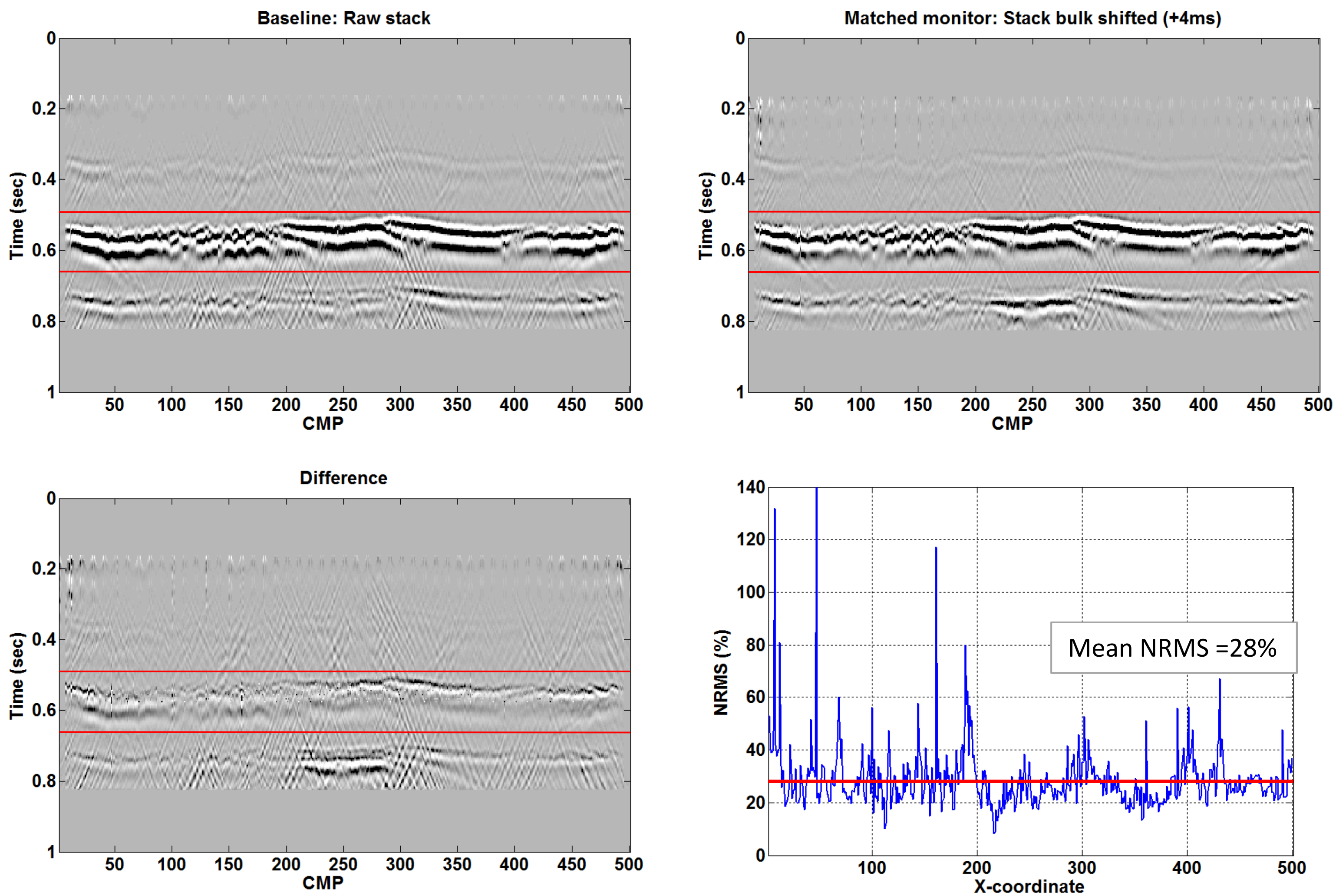


Difference = Baseline – monitor (after match filtering)

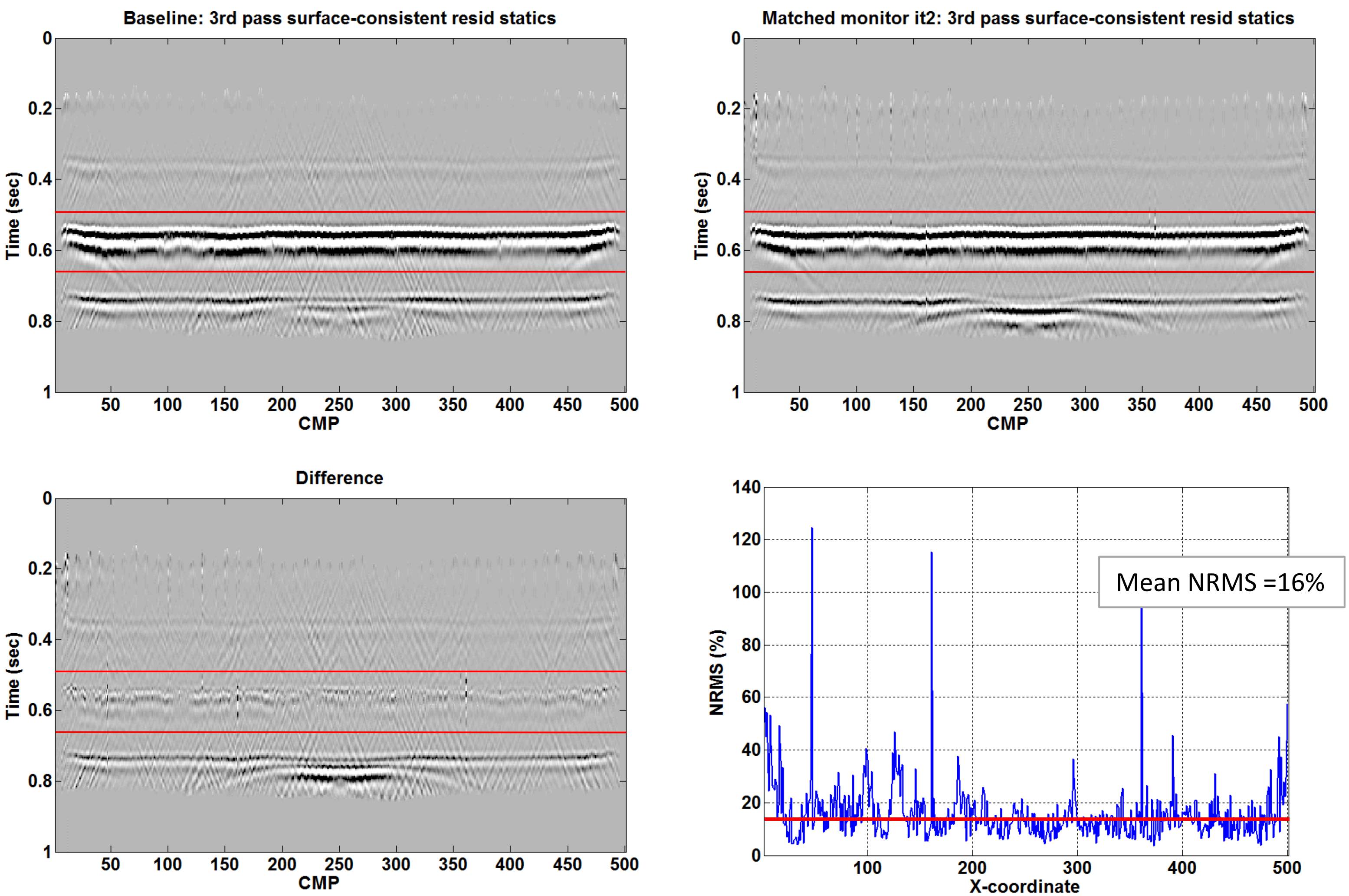
Raw stack: before match filtering



Stack: after match filtering

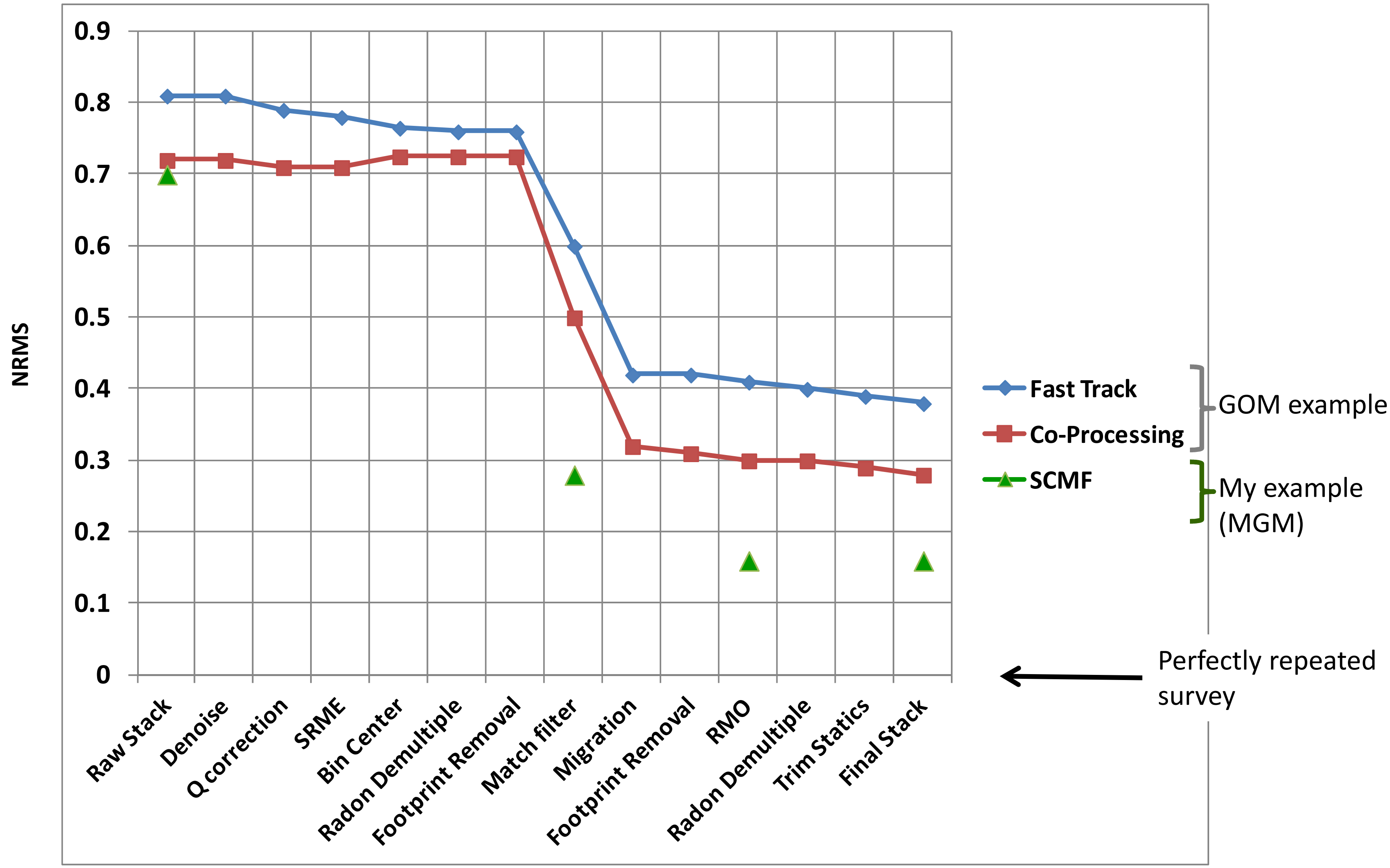


Stack: After match filtering & statics



Not: 3rd iteration of statics was not necessary. Match filtering was iterated 2 times.

NRMS values: GOM vs. MGM

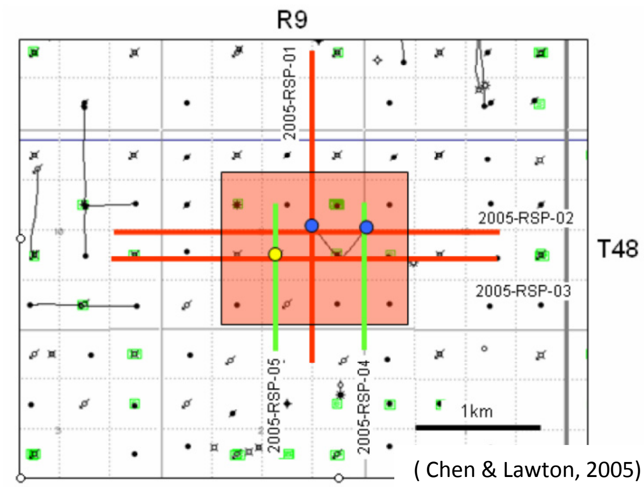


(modified plot from Helgerud et al., TLE 2011)

Conclusions

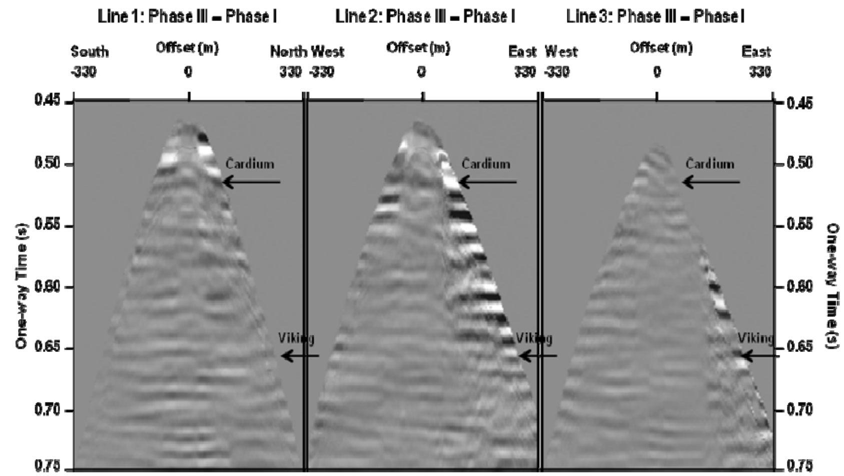
- Surface-consistent matching filter is analogous to other surface-consistent methods (decon, statics , ...), except the data term is spectral ratio of 2 surveys.
- We compute MF in time in LSQ & FT the result which is an approx to spectral ratio.
- Spectral decomposition of trace-by-trace MF into surface-consistent operators; and
- small NRMS values → balanced amplitude, equalized phase & bandwidth, and small or no time-shifts
- ➔ we have a SCMF that can significantly reduce the non-repeatability observed in TL data sets.

Future work

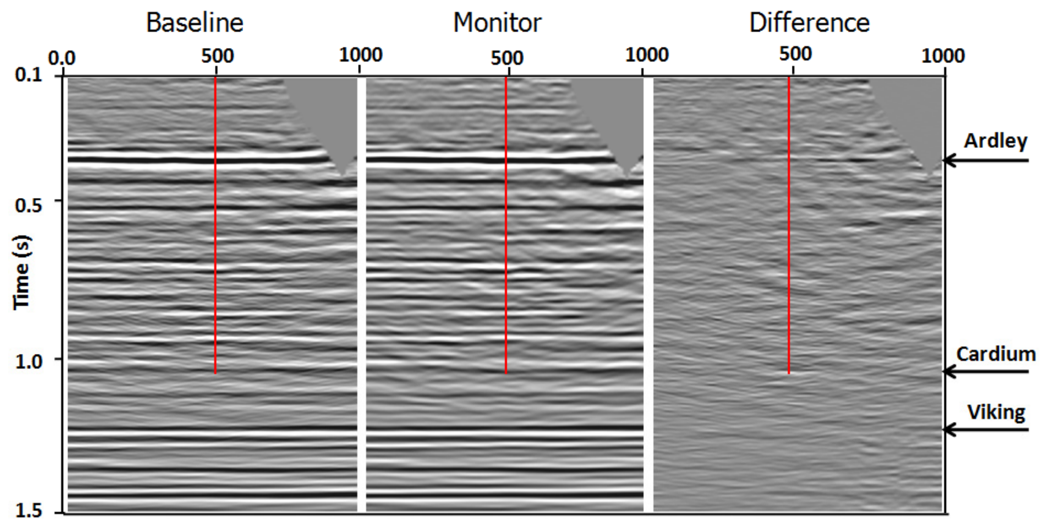


(Chen & Lawton, 2005)

Violet Grove



Walkway PP VSP data from the observation well (Alshuhail, et al., 2008)



Acknowledgements

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