

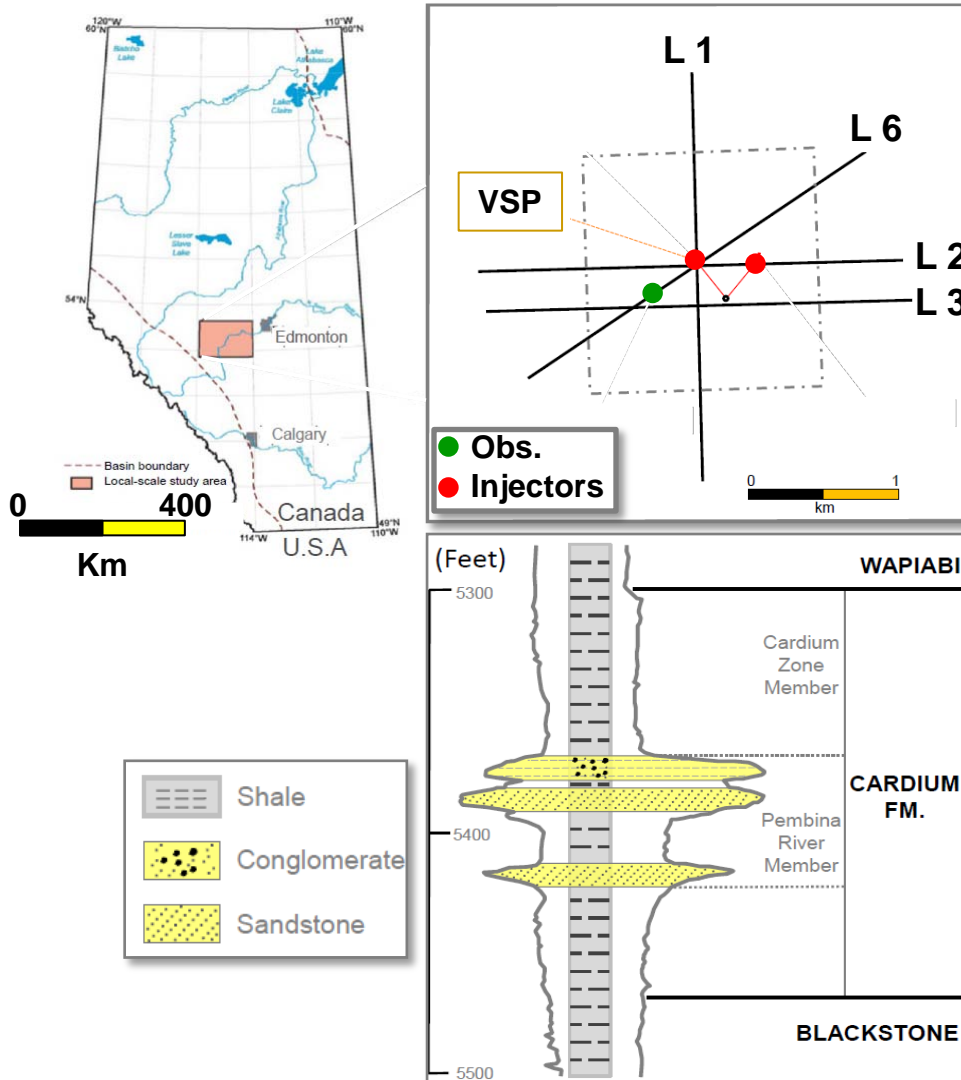
**Violet Grove time-lapse revisited:
an application of surface-
consistent matching filters**

**Mahdi Almutlaq
Dr. Gary Margrave**

Outline

- Violet Grove data
- What are the objectives?
- Review the “**Surface-consistent matching filters” or **SCMF****
- Examples
- Conclusions

Violet Grove

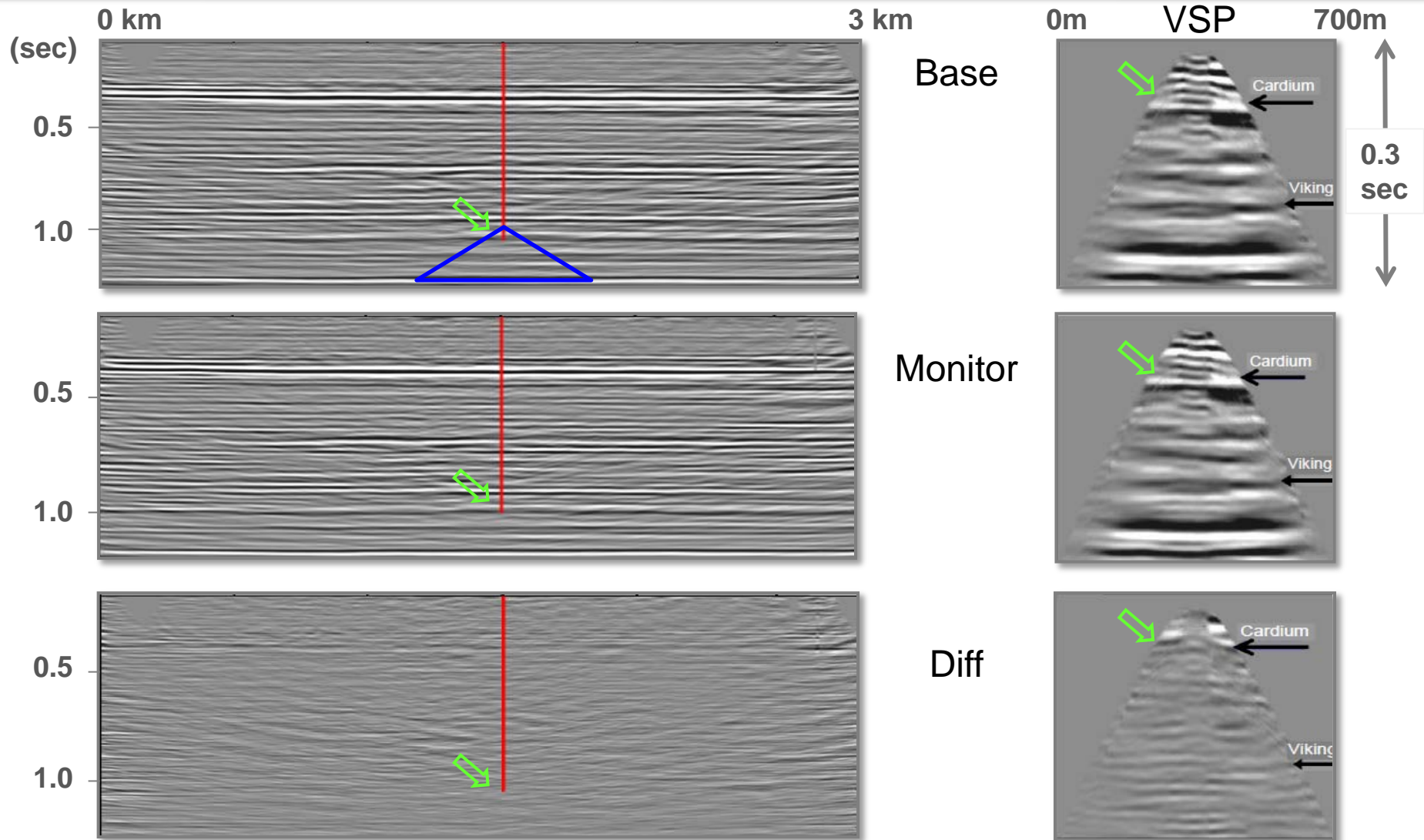


PERIOD/SERIES	EPOCH/STAGE	GROUP	LITHOLOGY	FORMATION/MEMBER
UPPER CRETACEOUS	Campanian to Maastrichtian	EDMONTON GROUP	Sandstone	
			BELLY RIVER GROUP	Sandstone
	Santonian to Campanian			Shale
LOWER CRETACEOUS	Albian to Santonian	COLORADO GROUP	Sandstone	Cardium SSt.
				Second White Speckled Shale
	Albian	MANNVILLE GROUP	Sandstone	Viking
Jurass.				

Data acquisition

Phase	Seismic Data	Date	Injected CO ₂ (tonnes)
I (baseline)	i. Line 1 (north-south) ii. Lines 2 and 3 (east-west) iii. Fixed-array VSP (8 geophones)	March 2005	0
II (1 st monitor)	i. Line 1 (north-south) ii. Lines 2 and 3 (east-west) iii. Fixed-array VSP (8 geophones)	December 2005	15,000
III (2 nd monitor)	i. Line 1 (north-south) ii. Lines 2 and 3 (east-west) iii. Fixed-array VSP (8 geophones) vi. Addition of - (a) 16-level VSP (b) southwest-northeast 2D line (line 6).	March 2007	60,000

Violet Grove: seismic



Objectives

- When to perform surface-consistent matching filters (SCMF) in prestack processing?
- Compute the 4-components SCMF.
- Apply the SCMF.

Match filters \leftrightarrow Spectral Ratios

To match two traces

$$m(t) * d_2(t) = d_1(t)$$

\Rightarrow

$$\sum_t (m(t) * d_2(t) - d_1(t))^2 = \min$$

In freq. domain:

$$\hat{m}(\omega) = \frac{\hat{d}_1(\omega)}{\hat{d}_2(\omega)}$$

match filters in time domain \Leftrightarrow spectral ratio in freq. domain

A stable trace-by-trace match filter:



Surface-consistent equations

Baseline survey, any trace

$$d_1(t) = s_1(t) * r_1(t) * h_1(t) * y_1(t)$$

Monitor survey, corresponding trace

$$d_2(t) = s_2(t) * r_2(t) * h_2(t) * y_2(t)$$

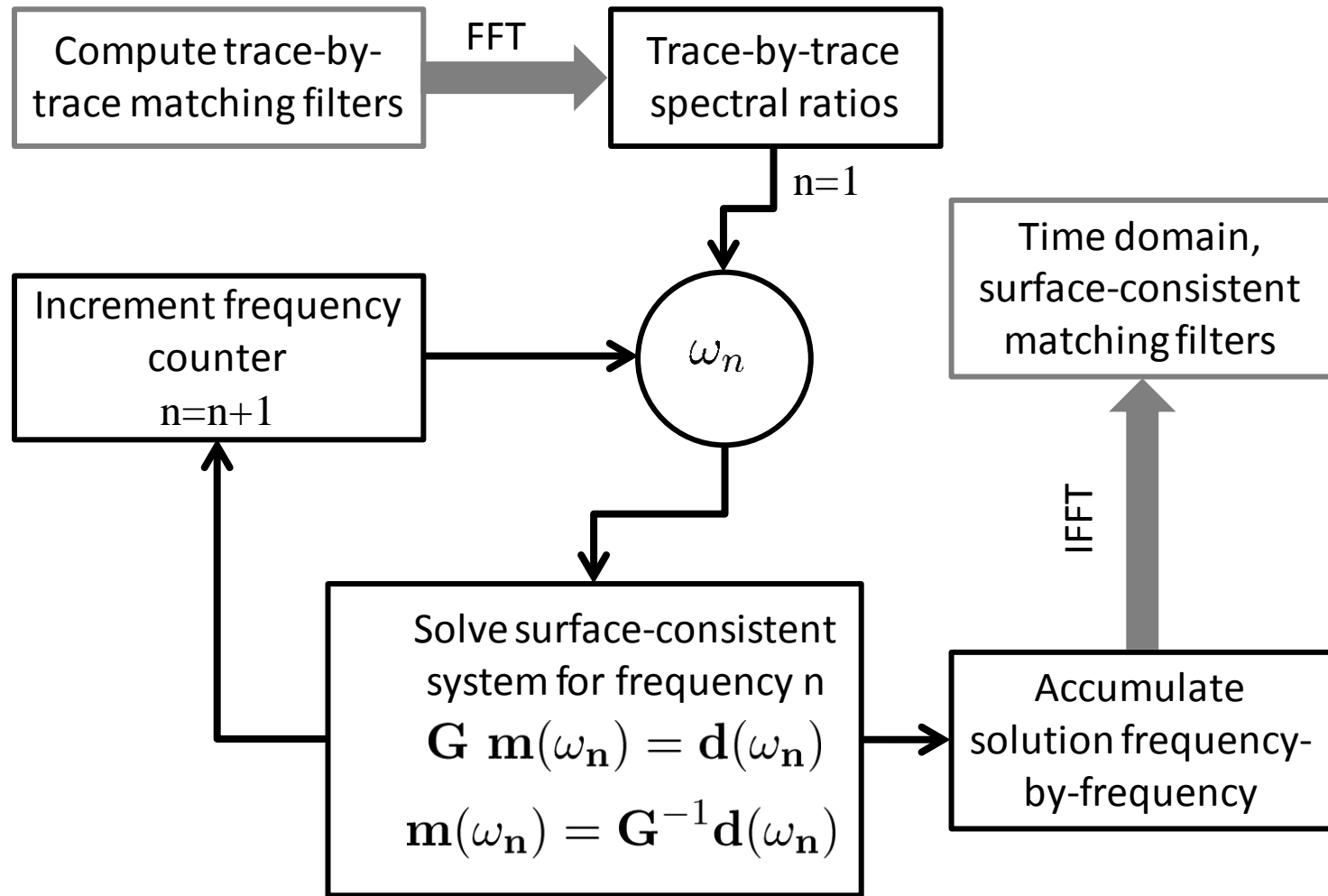
In the log-frequency domain

$$\underbrace{\log \frac{\hat{d}_1(\omega)}{\hat{d}_2(\omega)}}_{\text{Data log-spectral ratio}} = \underbrace{1 \log \frac{\hat{s}_1}{\hat{s}_2}(\omega) + \log \frac{\hat{r}_1}{\hat{r}_2}(\omega) + \log \frac{\hat{h}_1}{\hat{h}_2}(\omega) + \log \frac{\hat{y}_1}{\hat{y}_2}(\omega)}_{\text{Sum of surface-consistent terms, one equation per frequency per trace}}$$

Data log-spectral ratio

Sum of surface-consistent terms, one equation per frequency per trace

Algorithm workflow



Outline

- Violet Grove data
- What are the objectives?
- Review the “Surface-consistent matching filters” or **SCMF**
- **Examples**
- Conclusions

1. SUMMARY

- This paper details the idea presented last year on designing a matching filter for processing time-lapse seismic data in a surface-consistent manner.
- We extend the surface-consistent data model to the case of designing matching filters to equalize two seismic surveys in the least-squares sense.
- The frequency-domain surface-consistent design equations are similar to those for surface-consistent data modeling, but that the data term is replaced by the difference between the two surveys.
- Since taking spectral ratios is not surface-consistent, we design matching filters in the time domain.
- Fourier transform the time-domain matching filter design equations.
- We decompose the matching filter into source and receiver components.
- We show how the matching filter can be applied to time-lapse data.

2. THEORY

2.1: SURFACE-CONSISTENT MODEL

- The seismic trace can be modeled as:

$$d_{ij}(t) \approx \underbrace{s_i(t)}_{\text{Near surface effects}} * \underbrace{r_j(t)}_{\text{Subsurface effects}} * y_i(t) \quad (1)$$

d_{ij} : the seismic trace; t is time; and $*$ for convolution

2.2: MATCHING FILTERS

- To match two traces

$$m(t) * d_1(t) - d_2(t) \Rightarrow \sum_i (m(t) * d_1(t) - d_2(t))^2 = \min \quad (2)$$

- In frequency domain:

$$\hat{m}(\omega) = \frac{\hat{d}_1(\omega)}{\hat{d}_2(\omega)} \quad (3)$$

Poster: Surface-consistent matching filters: application to time-lapse data (synthetic example)

3. CONSTRUCTION

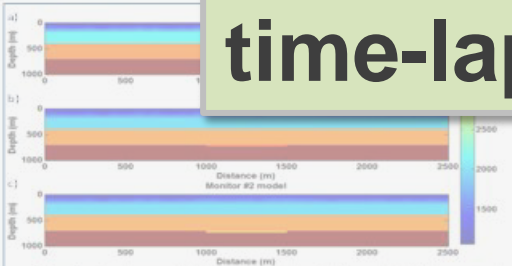


FIG. 1: Baseline model (a) and monitor # 1 model (b) have similar subsurface but differ in near-surface velocity. Monitor # 2 model (c) is similar to (b) except the subsurface (reservoir) is different.

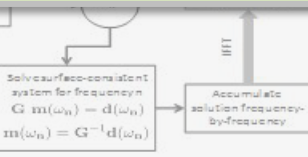


FIG. 2: Algorithm workflow.



FIG. 4: An example of a shot from base survey, same shot from monitor, their difference, and finally the difference between the baseline and the monitor after adding 26ms shift to align the middle reflector.

4. EXAMPLE

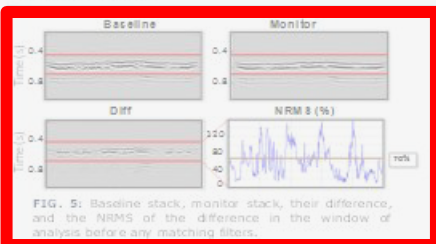


FIG. 5: Baseline stack, monitor stack, their difference, and the NRMS of the difference in the window of analysis before any matching filters.

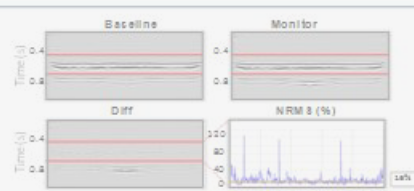


FIG. 6: Baseline stack, monitor stack, their difference, and the NRMS of the difference in the window of analysis after applying matching filters and correcting the residual statics.

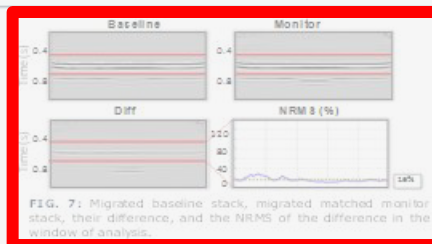


FIG. 7: Migrated baseline stack, migrated matched monitor stack, their difference, and the NRMS of the difference in the window of analysis.

6. ACKNOWLEDGMENTS

- The authors thank the sponsors of CREWES and Carbon Management Canada (CMC) for their continued support of this project, CREWES staff and students for their assistance, especially David Henley, Dr. Pat F. Daley and Faramak Mahmoudian for their comments. Almutlaq expresses his gratitude to Saudi Aramco for the financial support of his PhD program.

REFERENCES:

Please see Almutlaq and Margrave 2012 CREWES report for complete list of references.

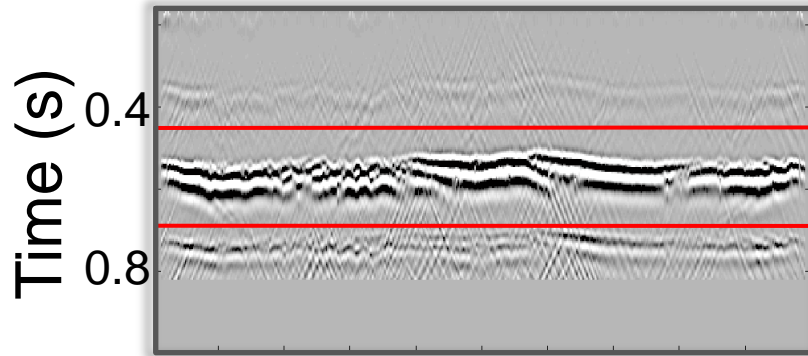
5. CONCLUSIONS

- SCMF computation is analogous to other SC methods EXCEPT the data term is spectral ratio of 2 surveys.
- We computed a trace-sequential MF in time by LSQ & FT the result which is a stable approximation to spectral ratio.
- SCMF is designed to match one data set to another in a time-lapse experiment.
- SCMF reduced NRMS values from 70% to 16%.
- Maximized time-lapse seismic repeatability.

Before SCMF

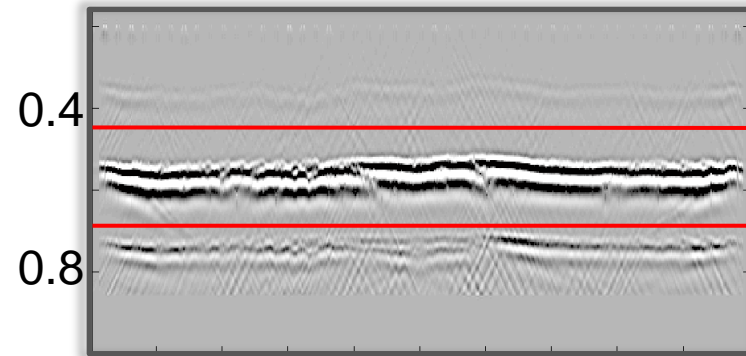
(a)

Baseline

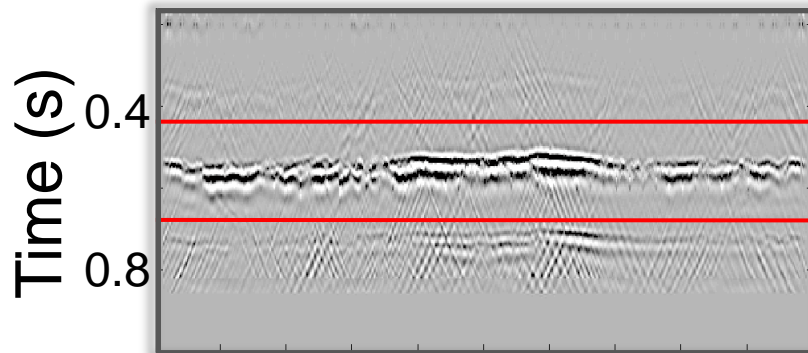


(b)

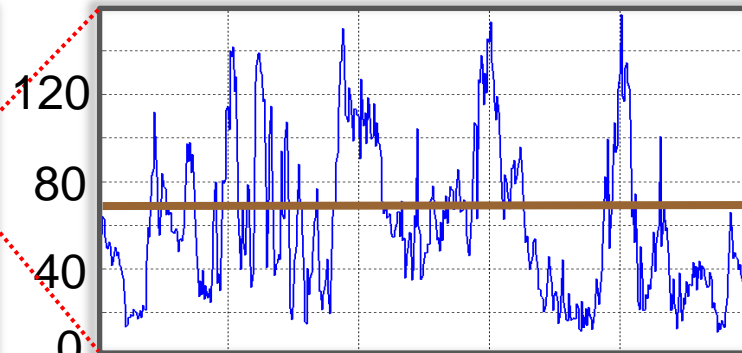
Monitor



Diff



NRMS (%)



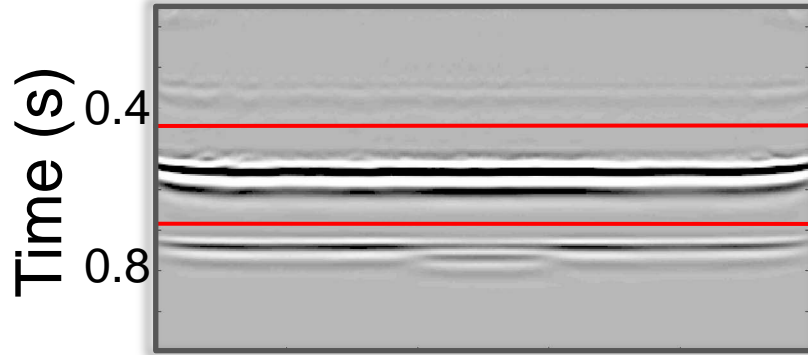
70%

$$NRMS(\%) = 200 \left[\frac{rms(a - b)}{rms(a) + rms(b)} \right]$$

After SCMF

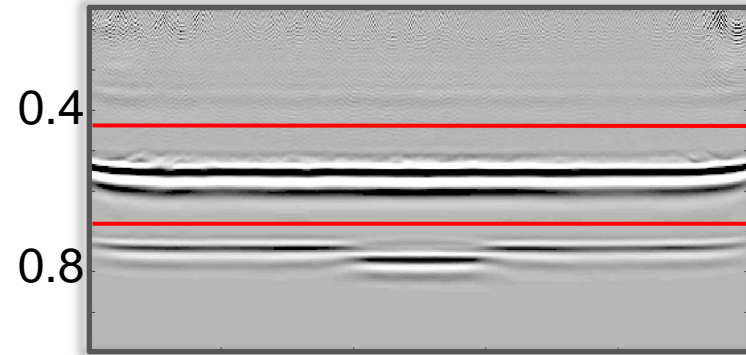
(a)

Baseline

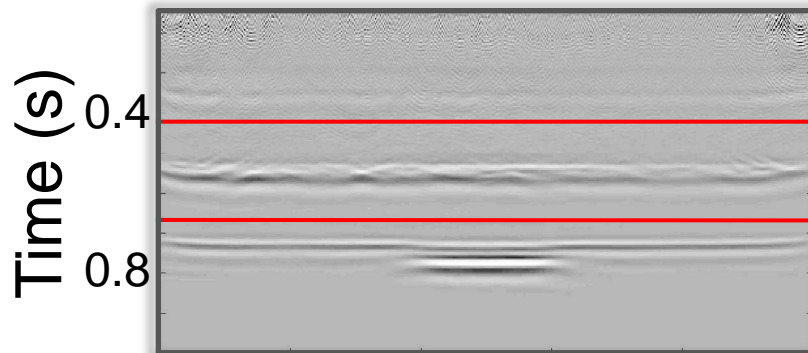


(b)

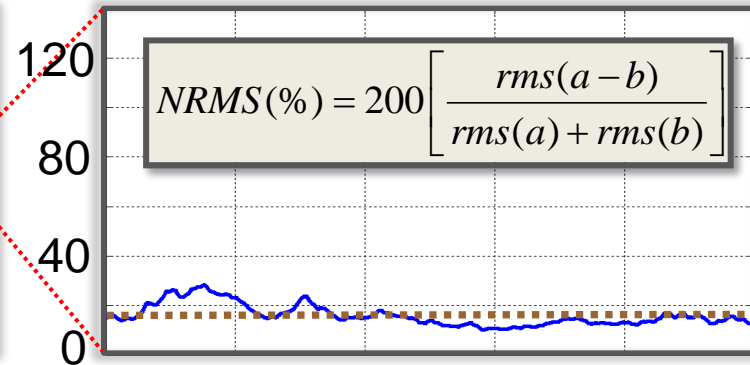
Monitor



Diff



NRMS (%)



Processing steps

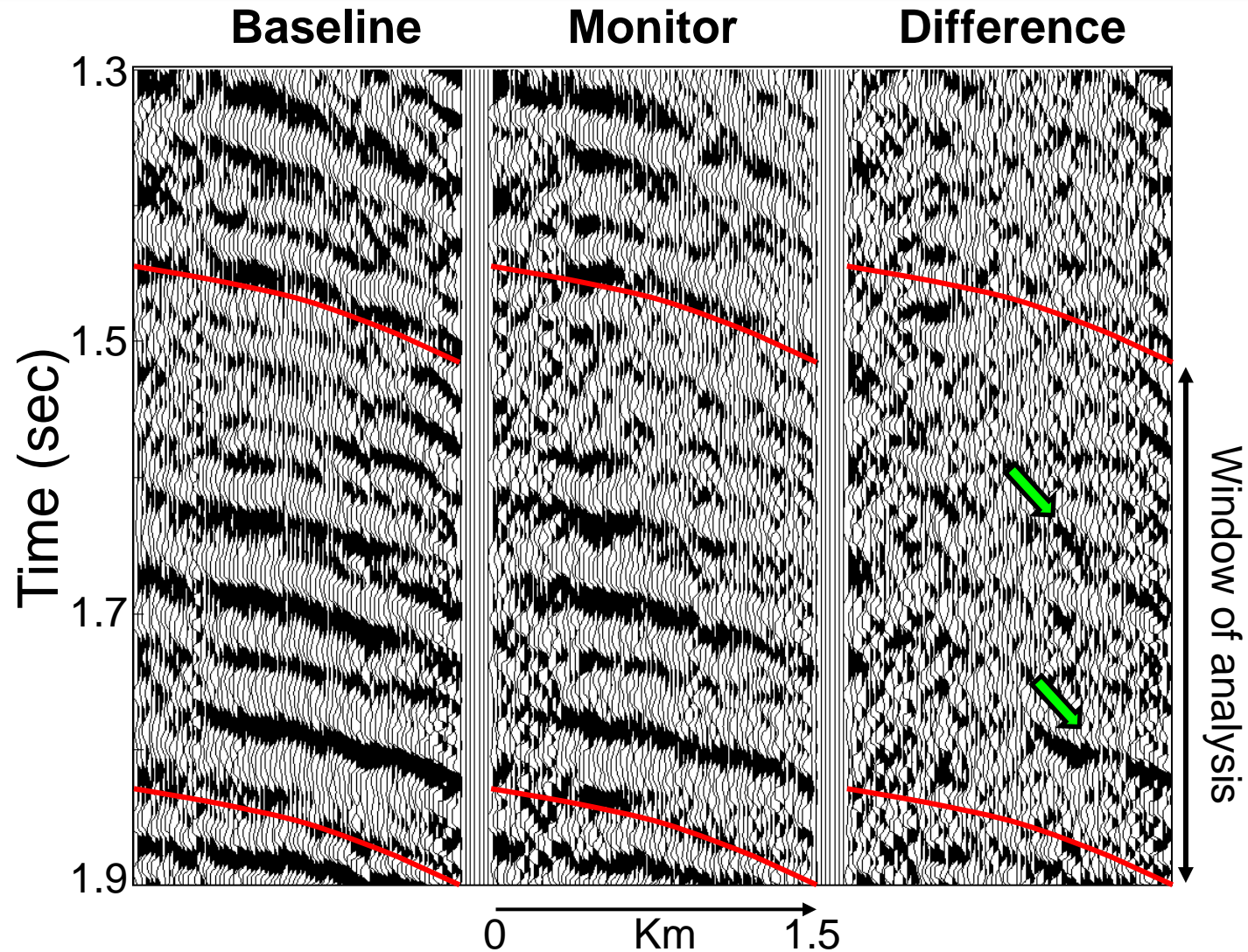
Baseline

- Geometry assignment
- Ground roll attenuation
- Trace edits + mute
- Amplitude recovery
- Surf.-consis. Amp. Corr.
- Surf.-consis. spiking decon.
- -
- **Velocity analysis**
- Surf.-consis. residual statics
- CDP stacking
- Post stack kirk. migration

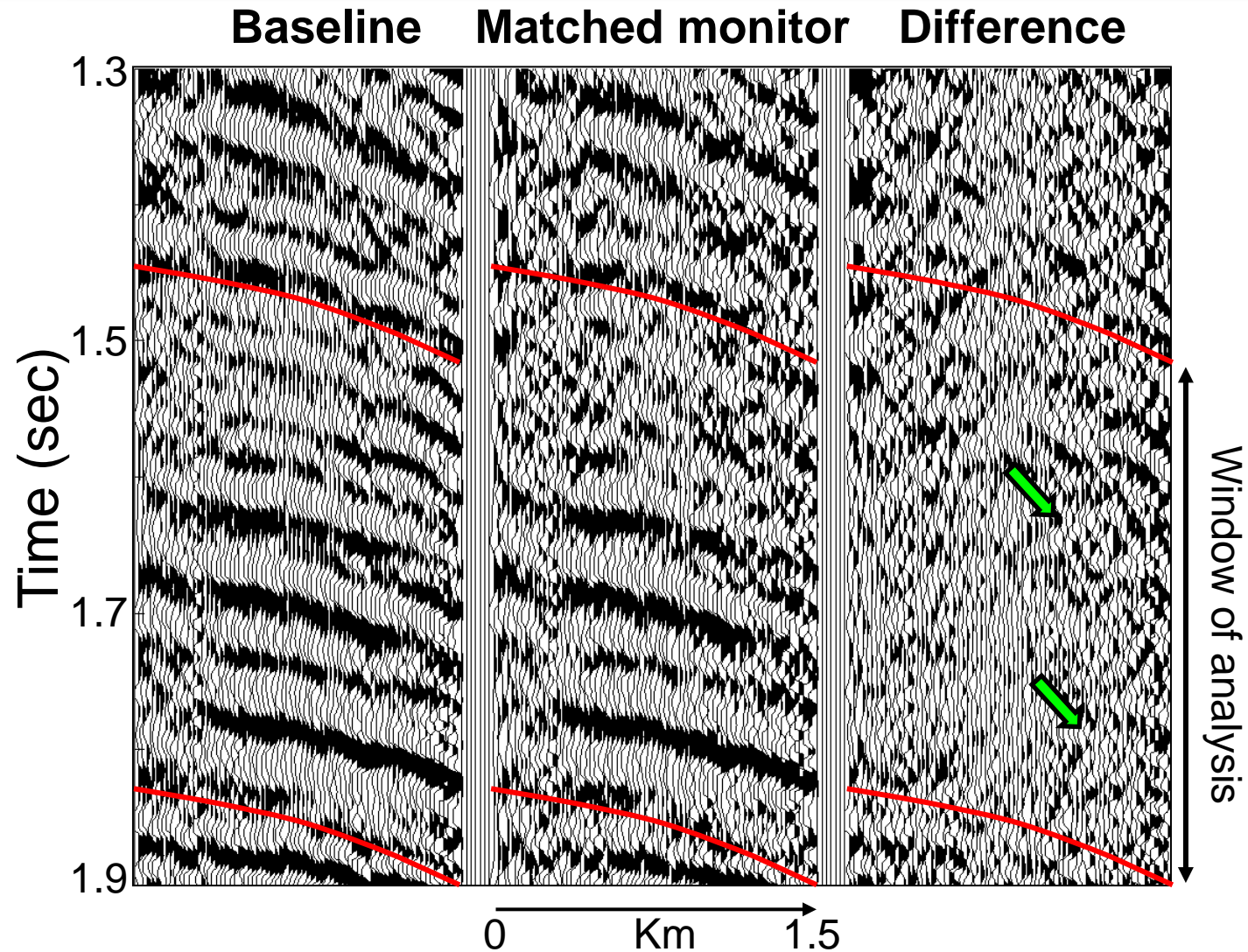
Monitor

- Geometry assignment
- Ground roll attenuation
- Trace edits+ mute
- Amplitude recovery
- Surf.-consis. Amp. Corr.
- Surf.-consis. spiking decon.
- **Surf.- consis. matching filters**
- -
- Surf.- consis. residual statics
- CDP stacking
- Post stack kirk. migration

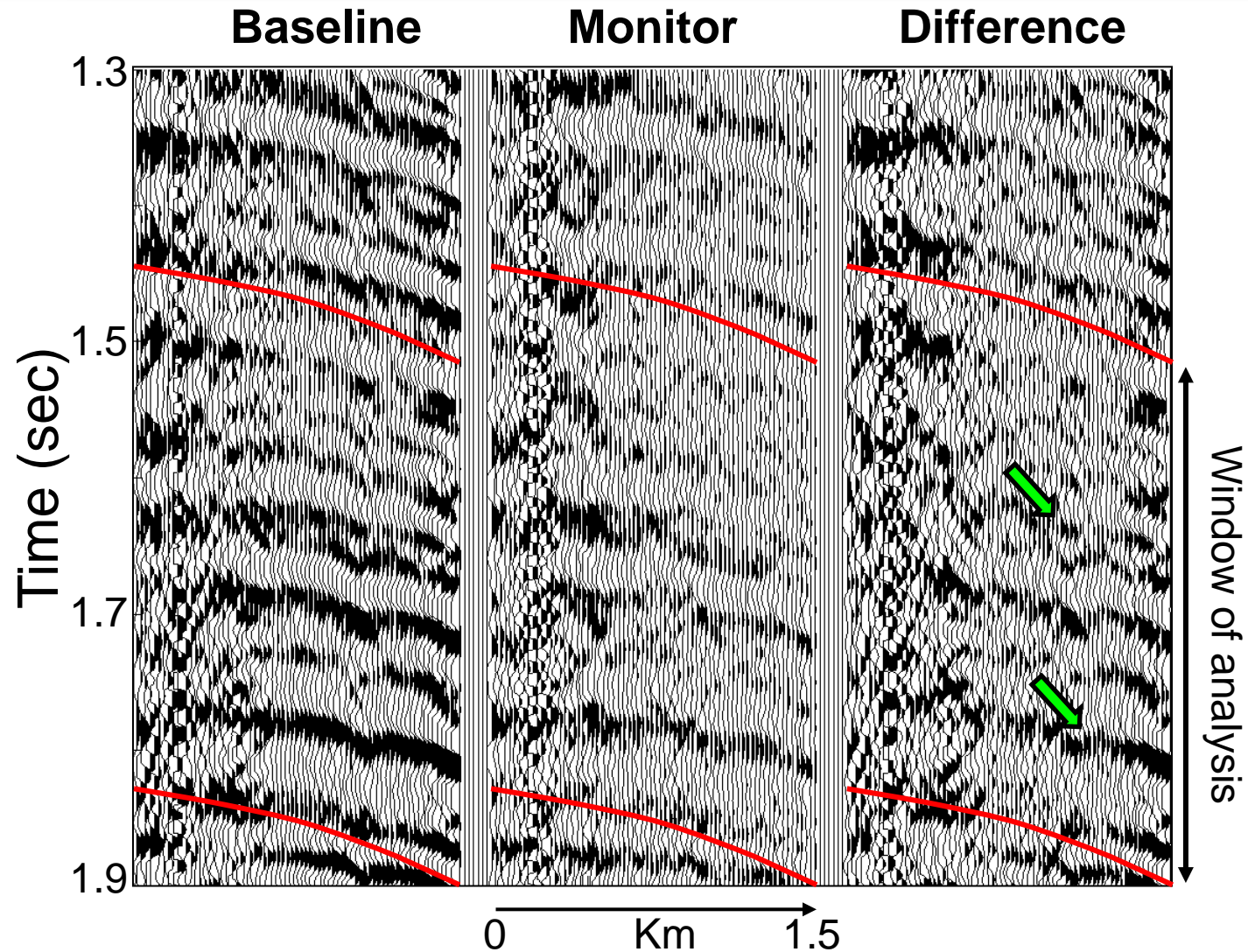
Prestack: before SCMF



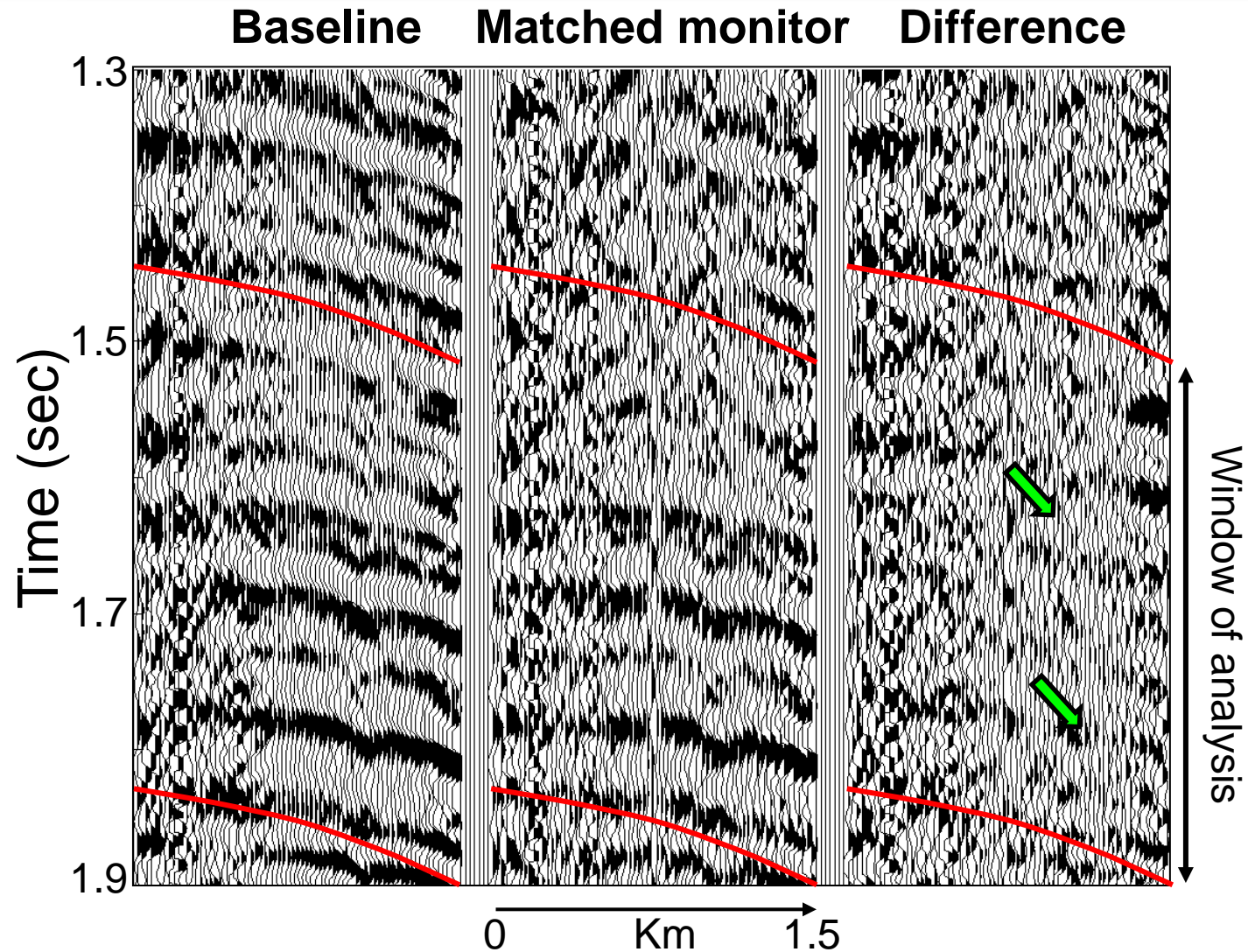
Prestack: after SCMF



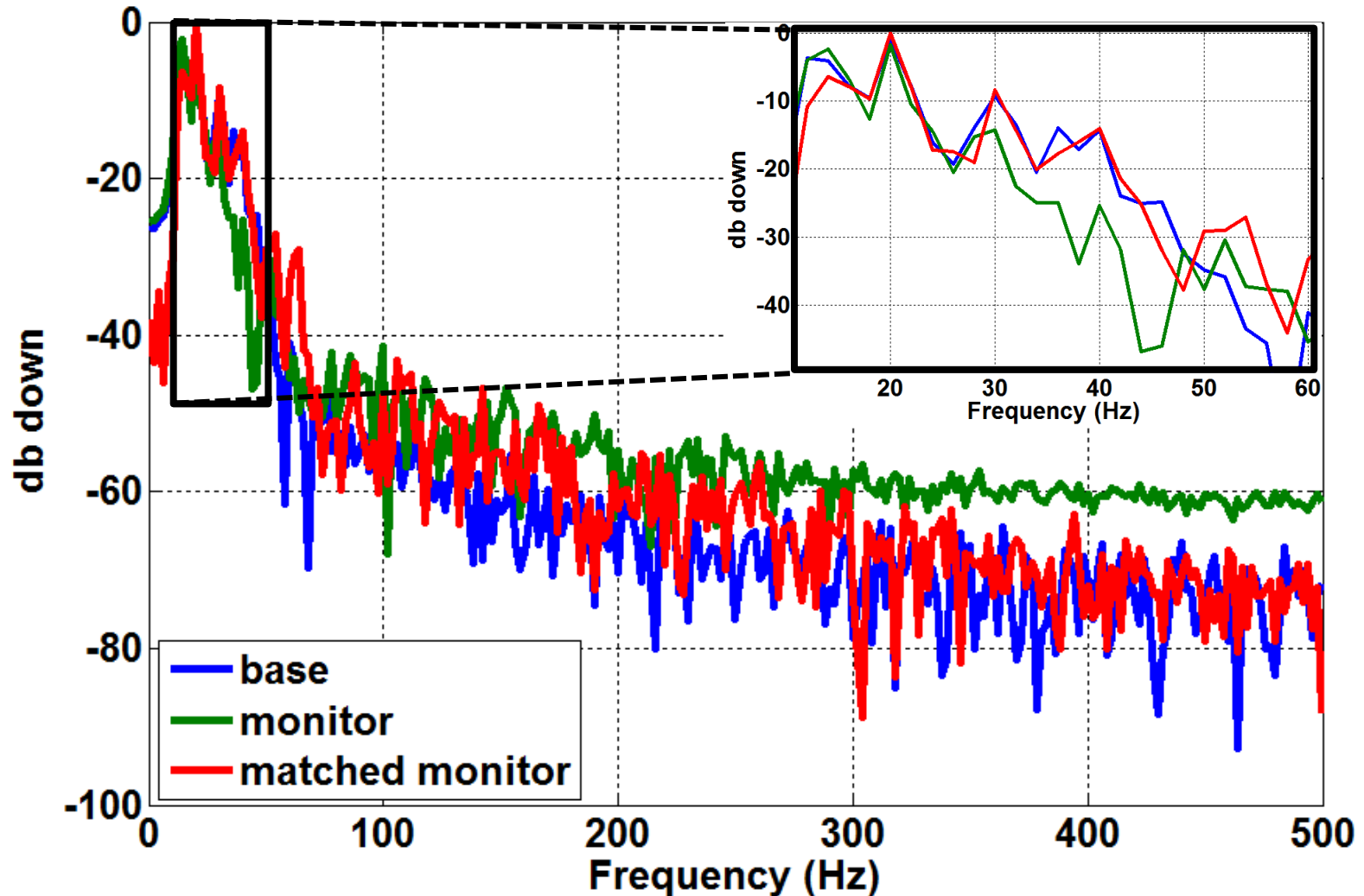
Prestack: before SCMF



Prestack: after SCMF

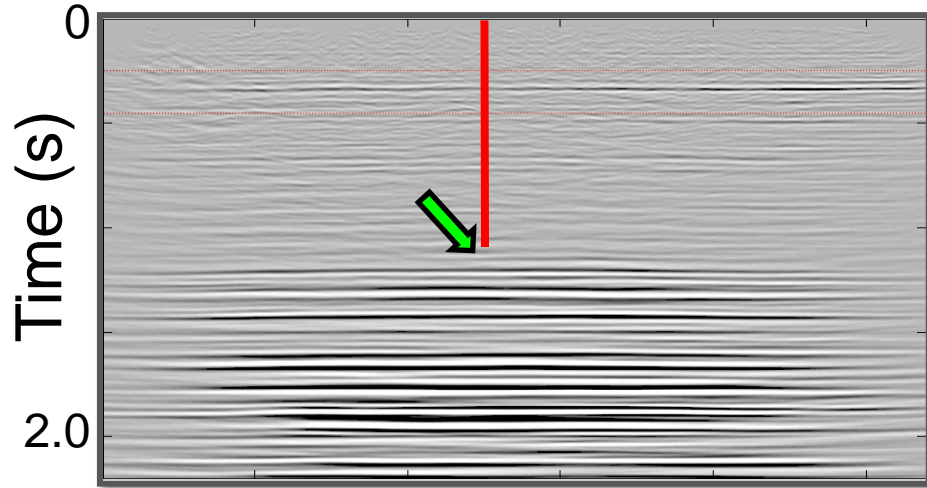


Amplitude spectrum

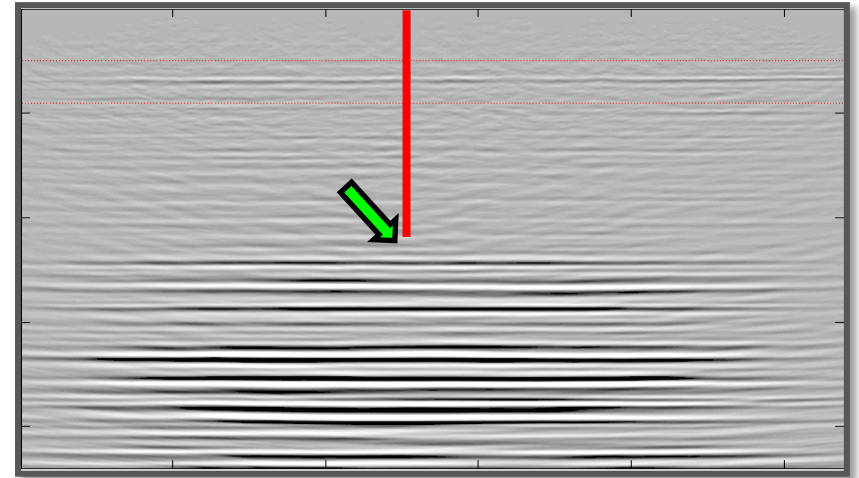


Before SCMF

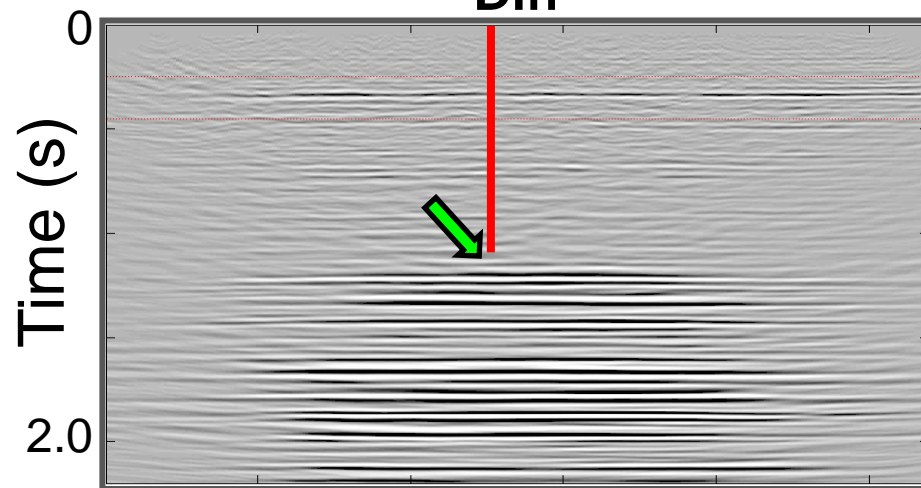
Baseline



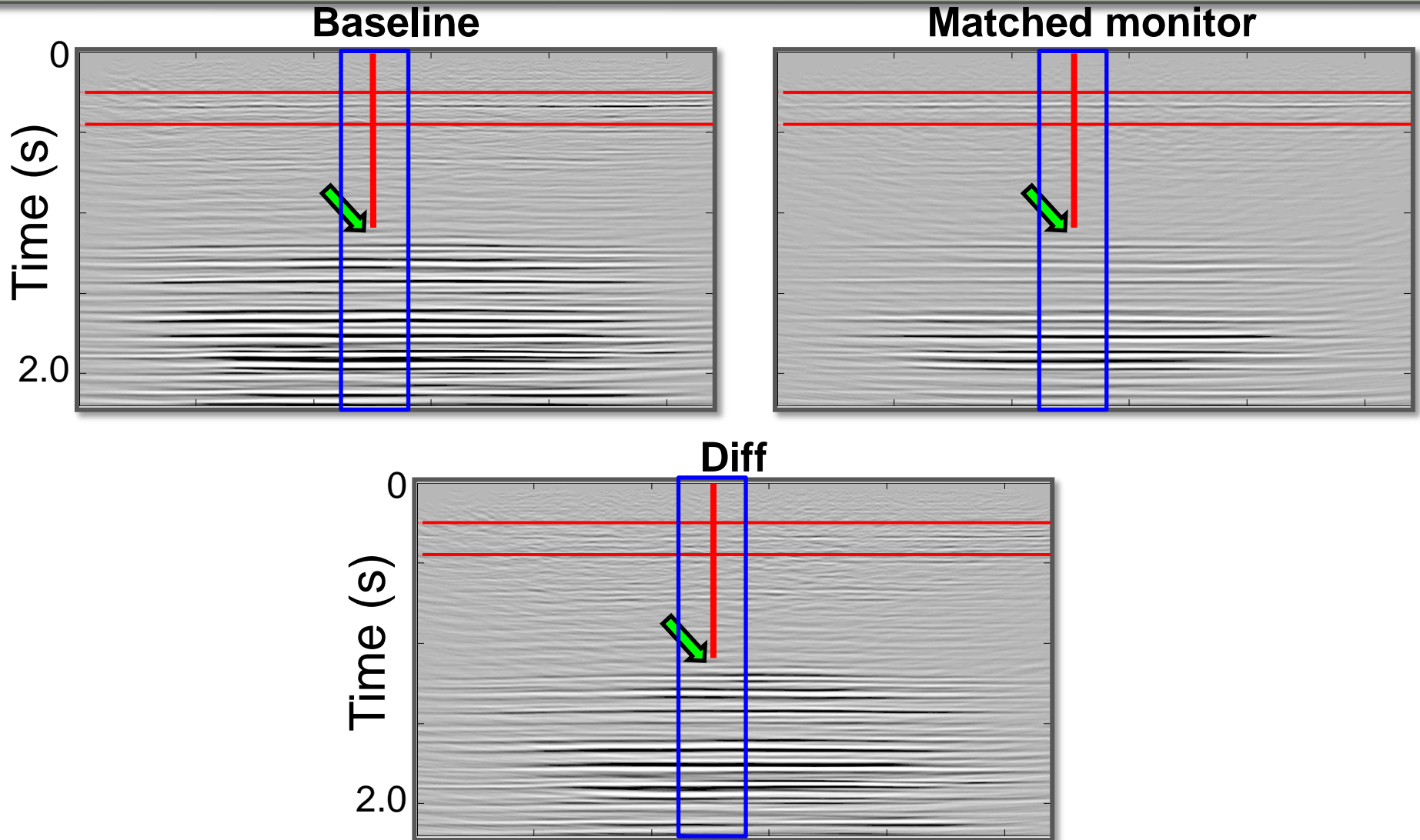
Monitor



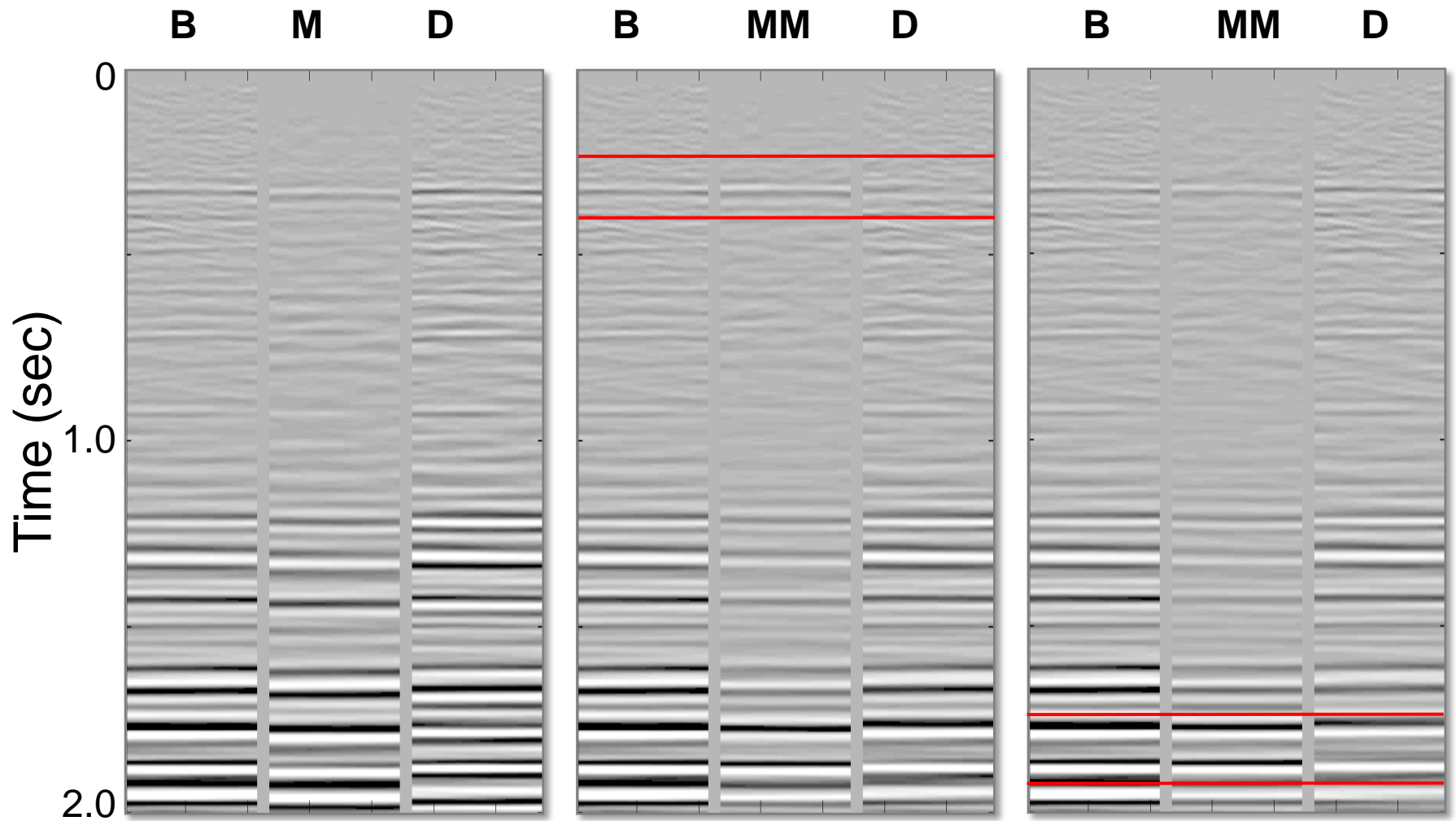
Diff



After SCMF



More comparisons



Conclusions

- SCMF computation is analogous to other SC methods **EXCEPT** the data term is spectral ratio of **2** surveys.
- SCMF is designed to match one data set to another in a time-lapse experiment.
- SCMF reduced NRMS values from 70% to 16% in synthetic data set.
- Successfully reduced most of the observed difference inside the window of SCMF in Violet Grove data set.
- Maximized time-lapse seismic repeatability.

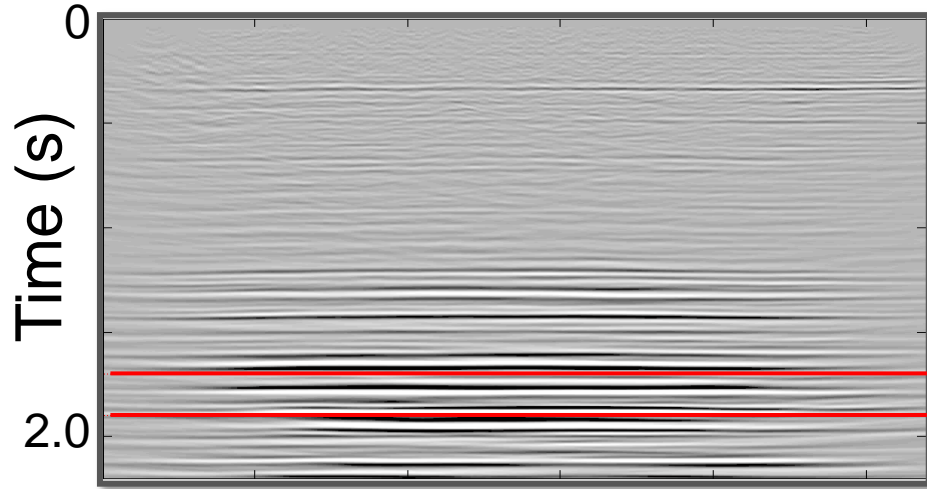
Acknowledgements

- CREWES & all the sponsors.
- A special thanks to Saudi Aramco for generously sponsoring Almutlaq's PhD program.
- Thanks to Dave Henley, Kevin Hall, Helen Isaac and Faranak Mahmoudian for their help.

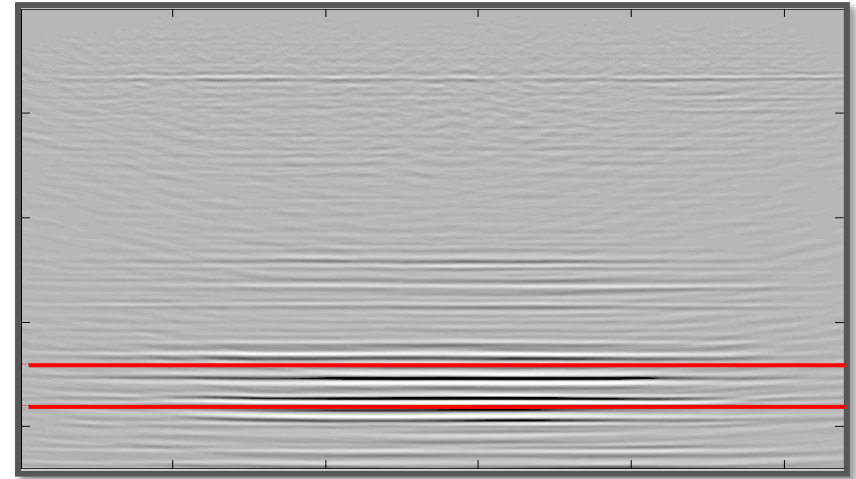


After SCMF

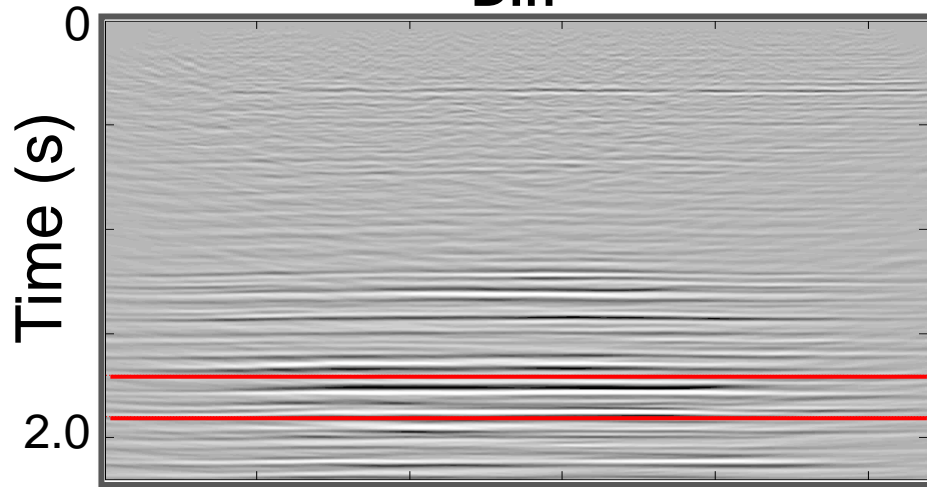
Baseline



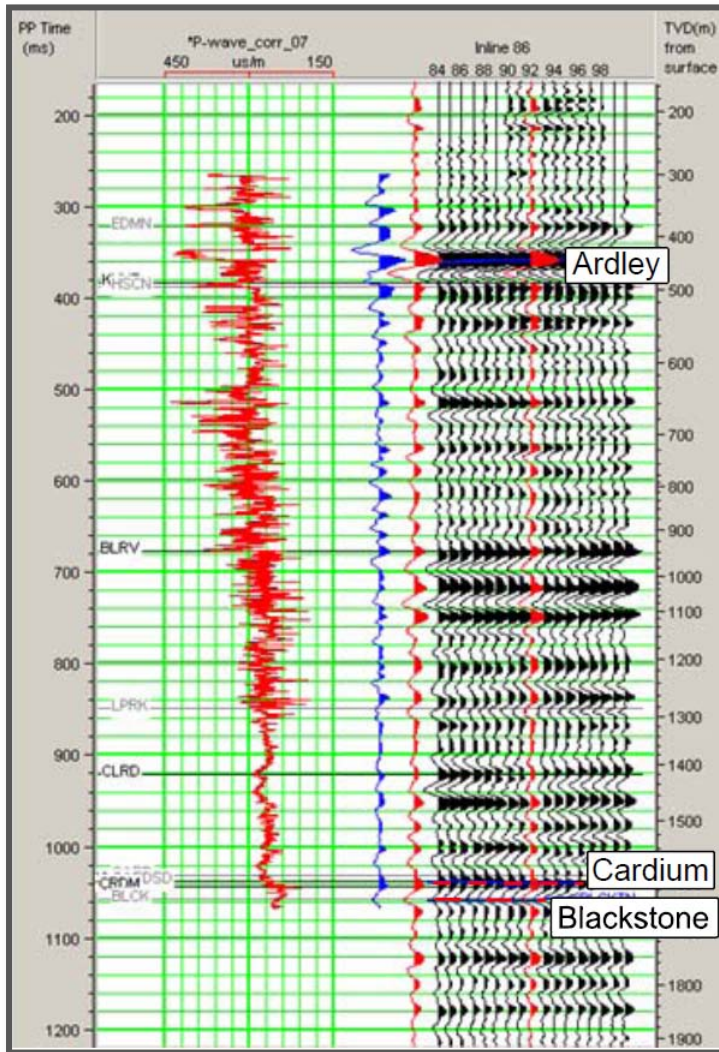
Matched monitor



Diff



Well-tie



2006 vs 2012 processing

Table 3: The standard processing work flow of the surface seismic data set (Lu et al., 2006).

→ Done
→ Not done

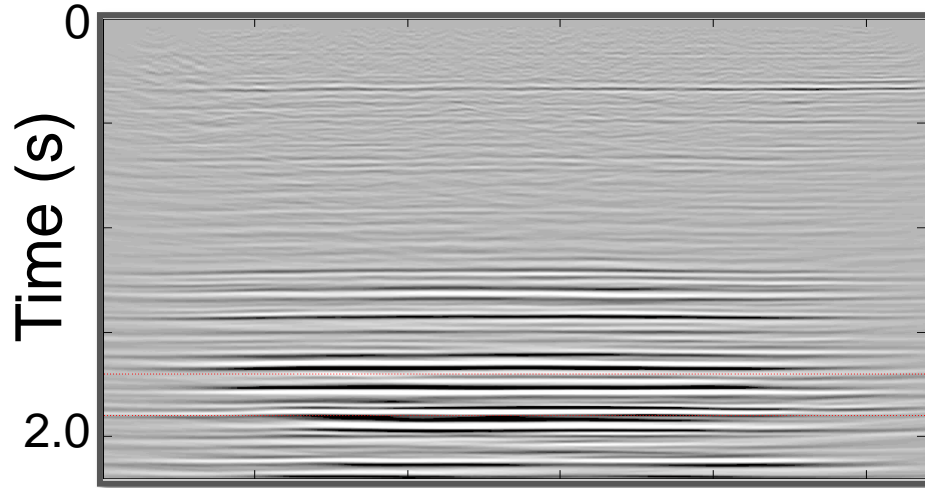
Processing work flow for the PP data	
→	Geometry assignment
→	Ground roll attenuation
→	Trace edits
→	Amplitude recovery
→	Minimum phase deconvolution
→	Tomographic structure statics
→	Velocity analysis
→	Surface-consistent residual statics
→	Spectral whitening
→	Mute and trim statics
→	Surface-consistent scaling
→	CDP stack
→	F-X noise attenuation
→	Poststack kirchhoff migration
→	Bandpass filter

Table 4: Processing work flow of Line 1.

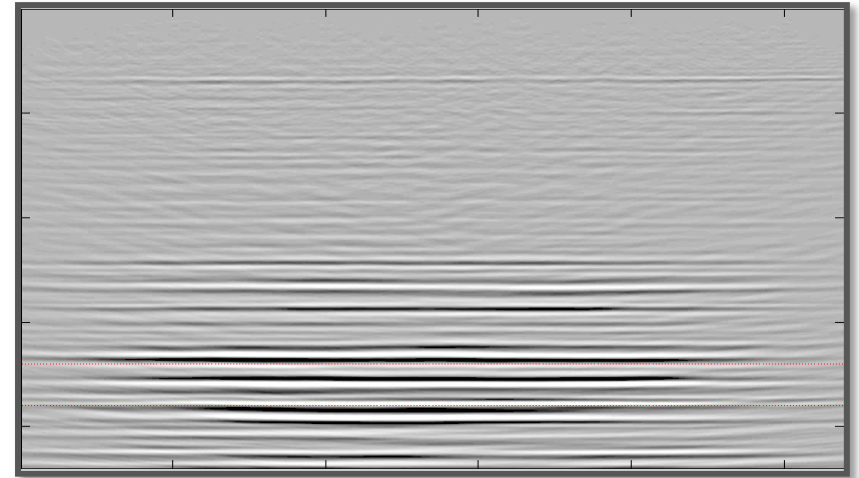
Baseline	Monitor
Geometry assignment	Geometry assignment
Ground roll attenuation	Ground roll attenuation
Trace edits	Trace edits
Amplitude recovery	Amplitude recovery
Surface consistent Amplitudes correction	Surface consistent Amplitudes correction
Surface consistent Spiking deconvolution	Surface consistent Spiking deconvolution
-	Surface consistent matching filters
Velocity analysis	-
Surface-consistent residual statics	Surface-consistent residual statics
CDP stack	CDP stack

Before SCMF

Baseline



Monitor



Diff

