Surface-consistent matching filters: application to time-lapse data

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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 deconvolution except that the data term is the spectral ratio of two surveys.
- Since taking spectral ratios poses a challenge, we design the matching filters in a least-squares sense in the time domain and Fourier transform the result.
- We decompose the result into four surface-consistent components: source, receiver, offset, and midpoint.
- We show how the algorithm works on a synthetic data.

2. THEORY

2.1: Surface-consistent model

- The seismic trace can be modeled as:

$$d_{ij}(t) \approx \underbrace{s_i(t) * r_j(t)}_{\text{Near surface effects}} * \underbrace{h_k(t) * y_l(t)}_{\text{subsurface effects}} \qquad (1)$$

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

s_i : represent source consistent effect, i source index

r_j : represent receiver consistent effect, j = receiver index

h_k : offset response, $k = | i - j |$

y_l : subsurface response, $l = (i + j)/2$

This hypothesis is commonly used to solve: statics problem, deconvolution, amplitude balancing and phase-rotation.

2.2: Matching filters

- To match two traces

$$m(t) * d_2(t) = d_1(t) \quad \Rightarrow \quad \sum_t \left(m(t) * d_2(t) - d_1(t)\right)^2 = \min \qquad (2)$$

- In frequency domain:

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

- Match filters in time domain is spectral ratio in frequency domain

2.3: Surface-consistent matching filters

- Equation (1) can be written for two seismic surveys in time-lapse data:

$$\underbrace{\log \frac{\hat{d}_1(\omega)}{\hat{d}_2(\omega)}}_{\text{Data spectral ratio}} = \underbrace{\log \frac{\hat{s}_1}{\hat{s}_2}(\omega) + \log \frac{\hat{r}_1}{\hat{r}_2}(\omega) + \log \frac{\hat{h}_1}{\hat{h}_2}(\omega) + \log \frac{\hat{y}_1}{\hat{y}_2}(\omega)}_{\text{Product of surface-consistent terms}} \qquad (4)$$

- The left side of equation (4) is a match filter that can be applied to monitor survey (#2) to match is to baseline survey (#1).

3. CONSTRUCTION OF MATCHING FILTERS

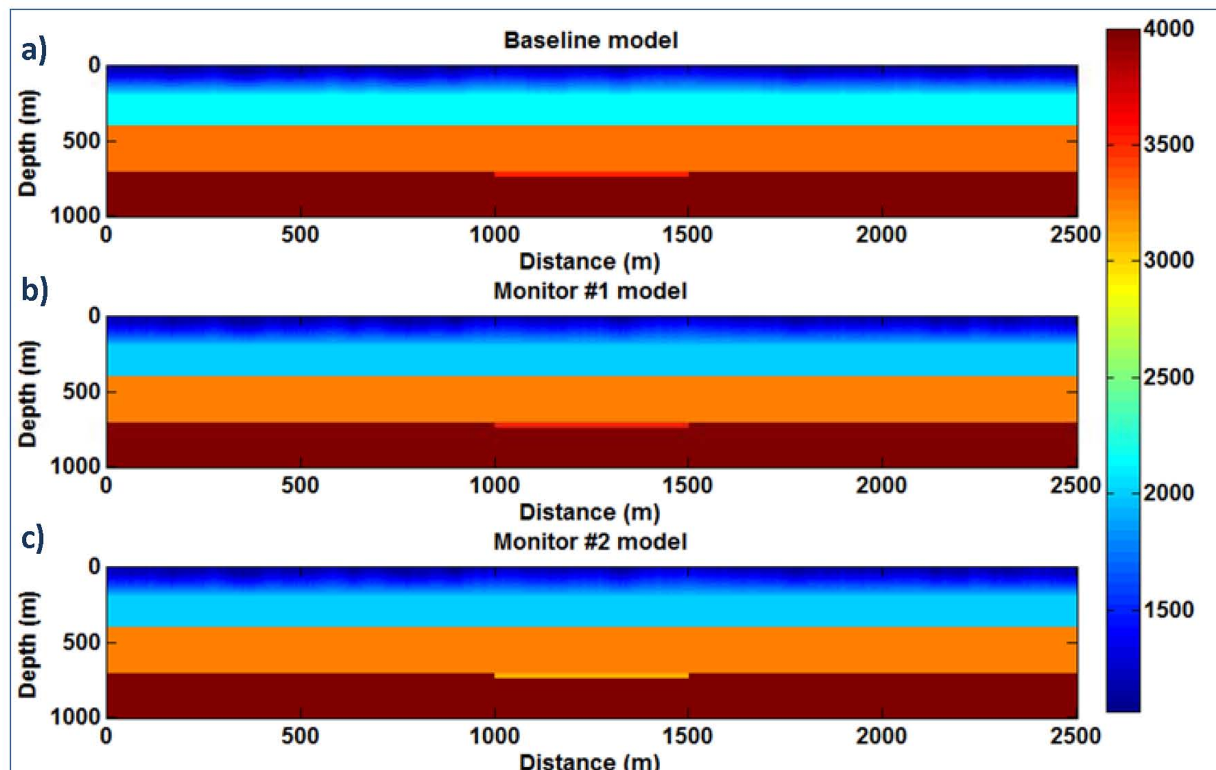

FIG. 1: Baseline model (a) and monitor # 1 model (b) have similar subsurface but differ in near-surface velocity. Monitor # 2 model (c) is similar to (b) except the subsurface (reservoir) is different.

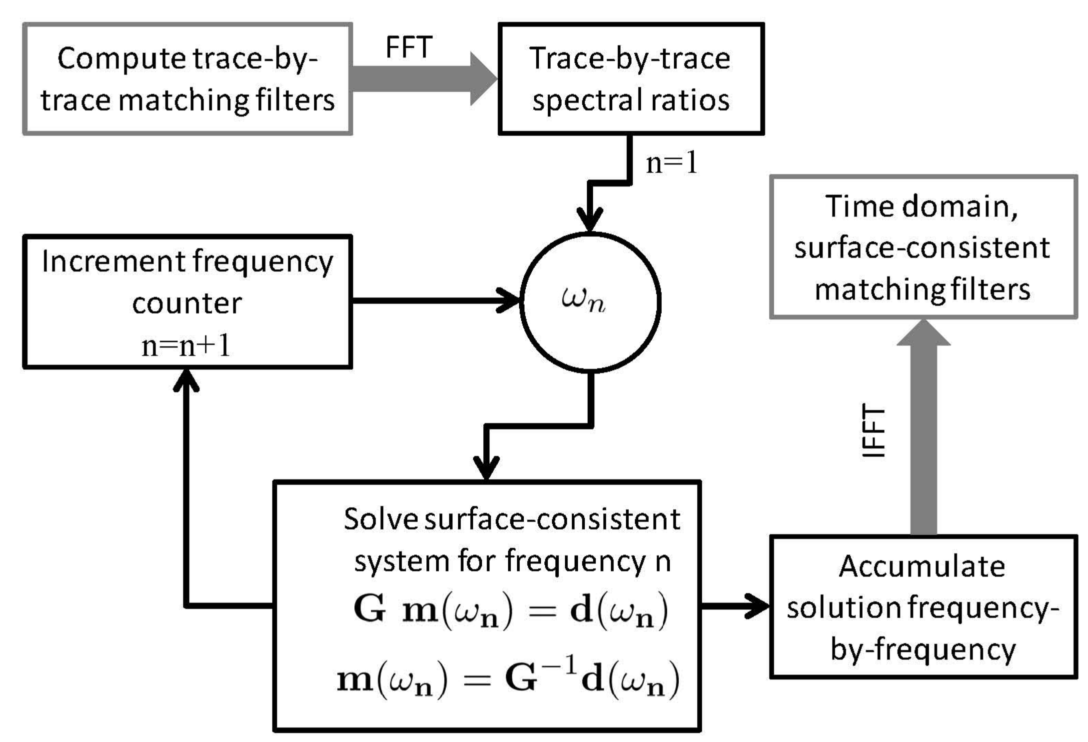

FIG. 2: Algorithm workflow.

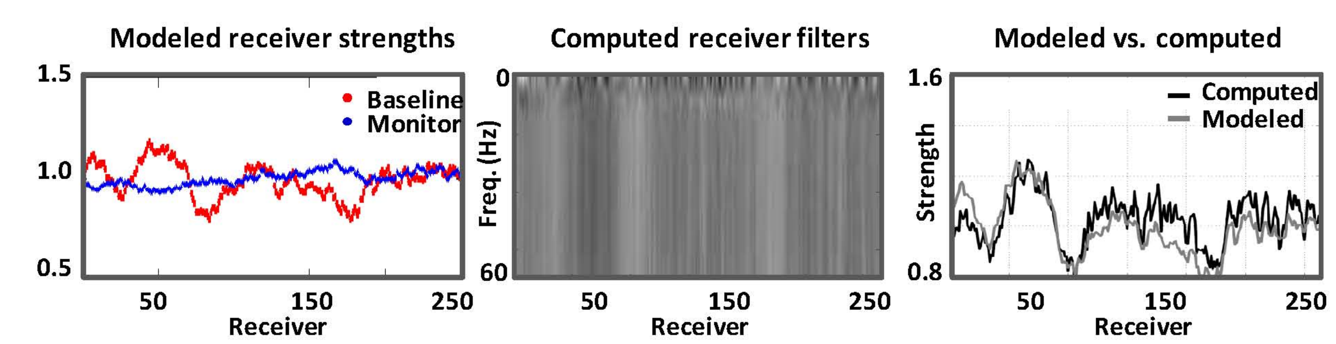

FIG. 3: A comparison of the receiver filter strengths as modeled in the acquisition and the computed strengths from the decomposed received filters.

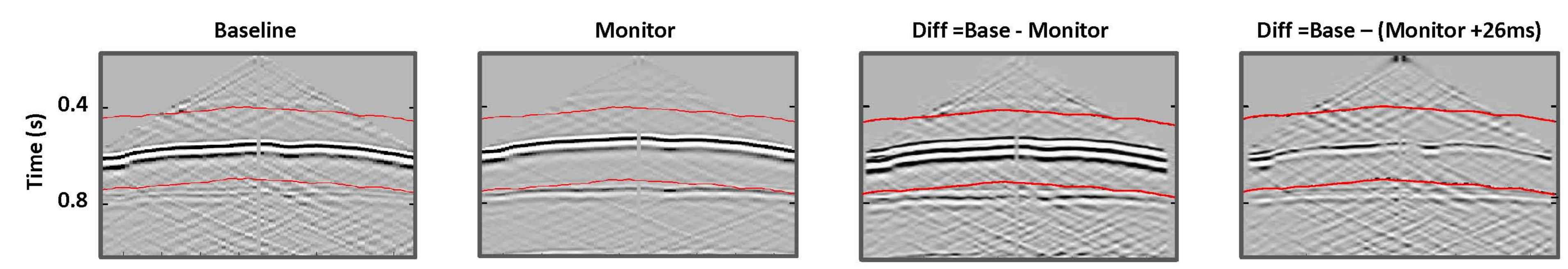

FIG. 4: An example of a shot from base survey, same shot from monitor, their difference, and finally the difference between the baseline and the monitor after adding 26ms shift to align the middle reflector.

4. EXAMPLE

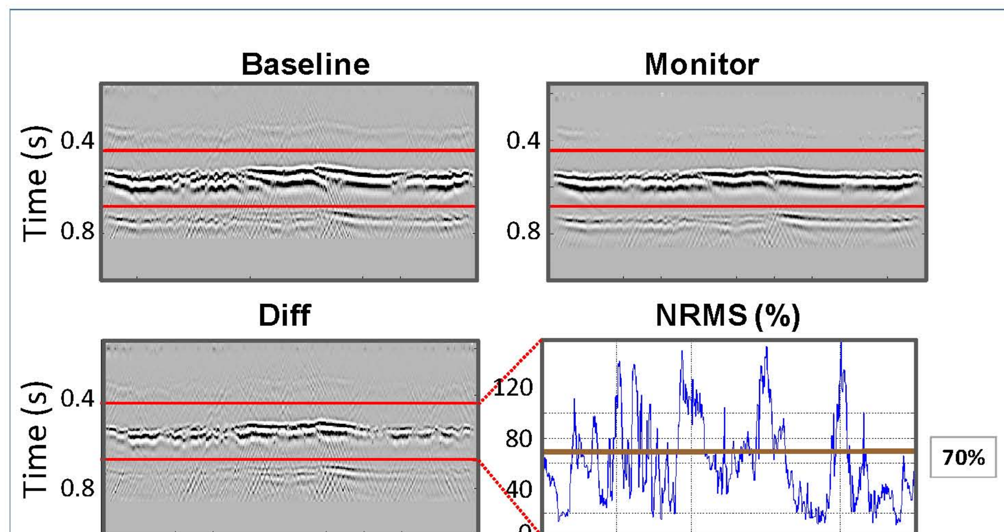

FIG. 5: Baseline stack, monitor stack, their difference, and the NRMS of the difference in the window of analysis before any matching filters.

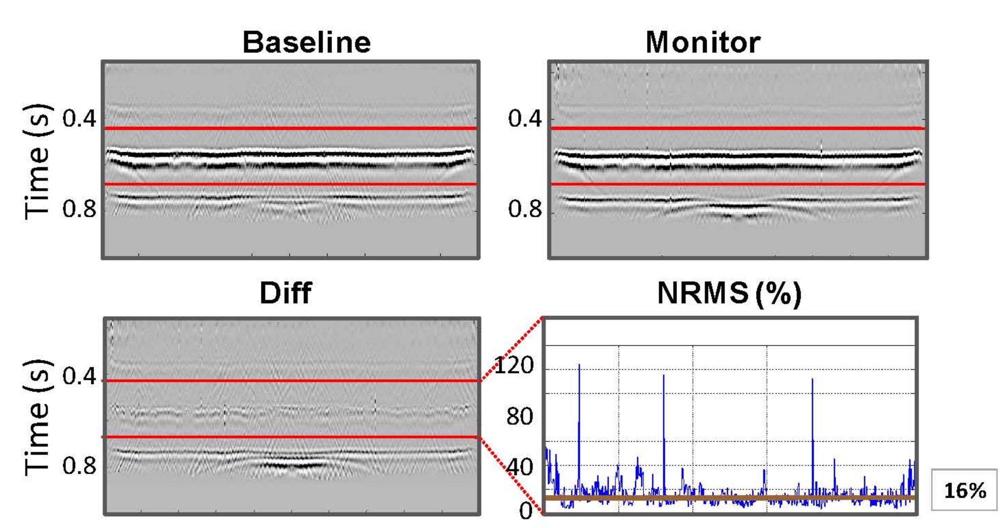

FIG. 6: Baseline stack, monitor stack, their difference, and the NRMS of the difference in the window of analysis after applying matching filters and correcting the residual statics.

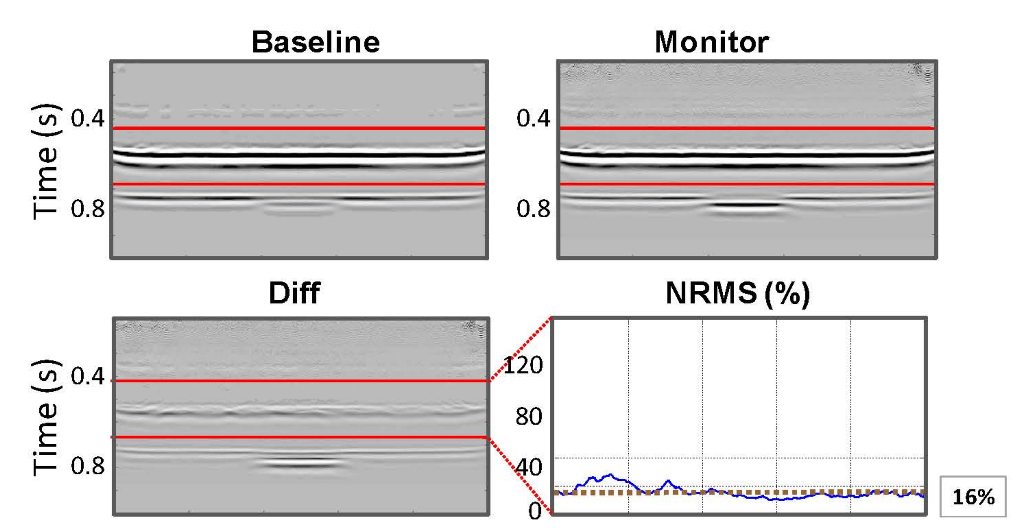

FIG. 7: Migrated baseline stack, migrated matched monitor stack, their difference, and the NRMS of the difference in the window of analysis.

5. CCONCLUSIONS

- 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.

6. ACKNOWLEDGMENTS

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References:

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