Towards a surface consistent match filter (SCMF) for time-lapse processing

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SUMMARY

- This paper presents a new idea for designing a match filter for processing time-lapse seismic data in a surface consistent manner.
- The surface consistent model is extended to designing match filters to equalize two seismic surveys in least square sense.
- The frequency-domain surface-consistent equations are similar to those for surface consistent deconvolution except the data term is the spectral ratio of two surveys (monitor and baseline).
- We built a time-lapse synthetic dataset (baseline and monitor) whose subsurface (the reservoir) is unchanging but which show surface-consistent variability.
- Initial results are encouraging but suggest that our software is not yet optimal.

DISCUSSION

- The four-component surface consistent decomposition:

$$P_{ijkl}(\omega) = S_i(\omega)R_j(\omega)H_k(\omega)Y_l(\omega)$$

where P_{ijkl} = the seismic trace; ω = angular frequency

S_i = represent source consistent effect; i = source index

R_j = represent receiver consistent effect; j = receiver index

H_k = offset component; $k = |\ i - j\ |$

Y_l = midpoint component; $l = (\ i + j\ )/2$

- The surface consistent match filter

Survey # 1: $$P_{ij1}(\omega) = S_{i1}(\omega)R_{j1}(\omega)H_{k1}(\omega)Y_{l1}(\omega) \quad (1)$$

Survey # 2: $$P_{ij2}(\omega) = S_{i2}(\omega)R_{j2}(\omega)H_{k2}(\omega)Y_{l2}(\omega) \quad (2)$$

$$\frac{P_{ij2}(\omega)}{P_{ij1}(\omega)} = \frac{S_{i2}(\omega)R_{j2}(\omega)H_{k2}(\omega)Y_{l2}(\omega)}{S_{i1}(\omega)G_{j1}(\omega)H_{k1}(\omega)Y_{l1}(\omega)} \quad (3)$$

Taking the logarithm of both sides and for simplicity substituting S_i for Si_2/Si_1 and so on for the other terms:

$$\ln\left(\frac{P_{ij2}(\omega)}{P_{ij1}(\omega)}\right) = \ln\big(S_i(\omega)\big) + \ln\big(R_j(\omega)\big) + \ln\big(H_k(\omega)\big) + \ln\big(Y_l(\omega)\big) \quad (4)$$

Following Wiggins et al. (1976), equation (4) can be written:

$$\frac{P_{ij2}(\omega)}{P_{ij1}(\omega)} \rightarrow \boldsymbol{p}(\omega) = \boldsymbol{G}\boldsymbol{x}(\omega)\ with\ \boldsymbol{x}(\omega) = \begin{pmatrix} \boldsymbol{s}(\omega) \\ \boldsymbol{r}(\omega) \\ \boldsymbol{h}(\omega) \\ \boldsymbol{y}(\omega) \end{pmatrix} \quad (5)$$

where $\boldsymbol{p}$ is the data vector, $\boldsymbol{x}$ represents the unknown parameter vectors, and $\boldsymbol{G}$ is the geometry matrix which contains the positions of the four-components.

MODEL BUILDING AND RESULTS

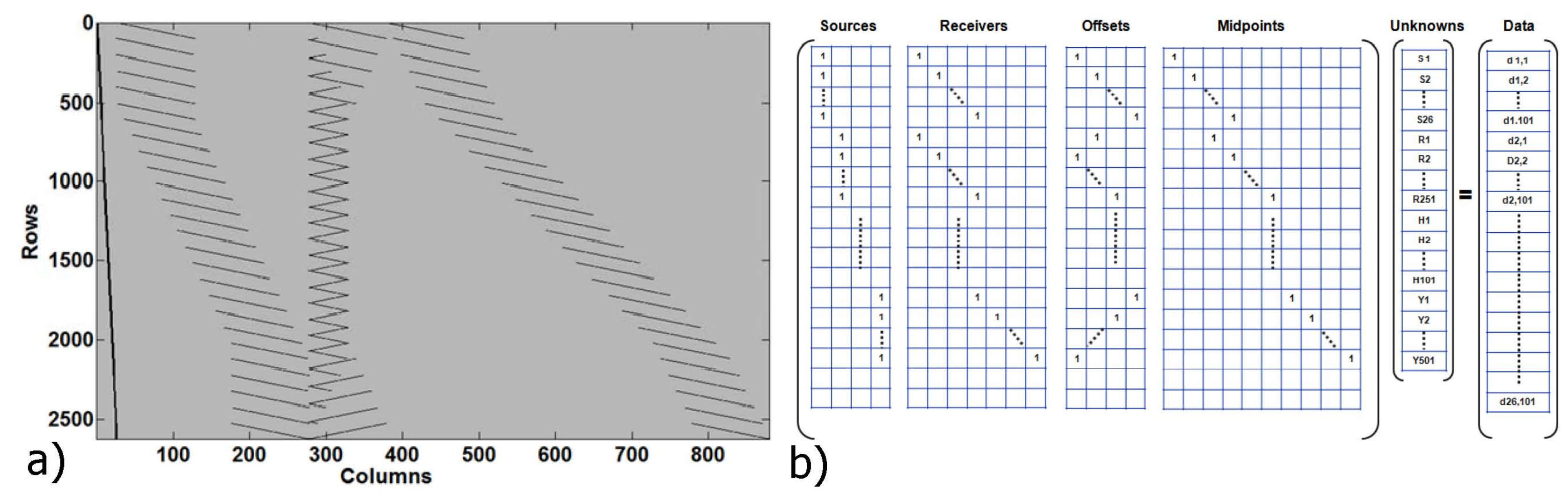

FIG. 1. A plot of the geometry matrix $\boldsymbol{G}$ is shown in (a) where the source positions are in columns 1 – 26, receivers in 27 – 277, offsets in 278 – 378, and midpoints in 379 – 879. (b) shows the structure of the system of linear equation described in equation 5. Note in this system we have more data (# rows =2626) than we have unknowns (# cols =879).

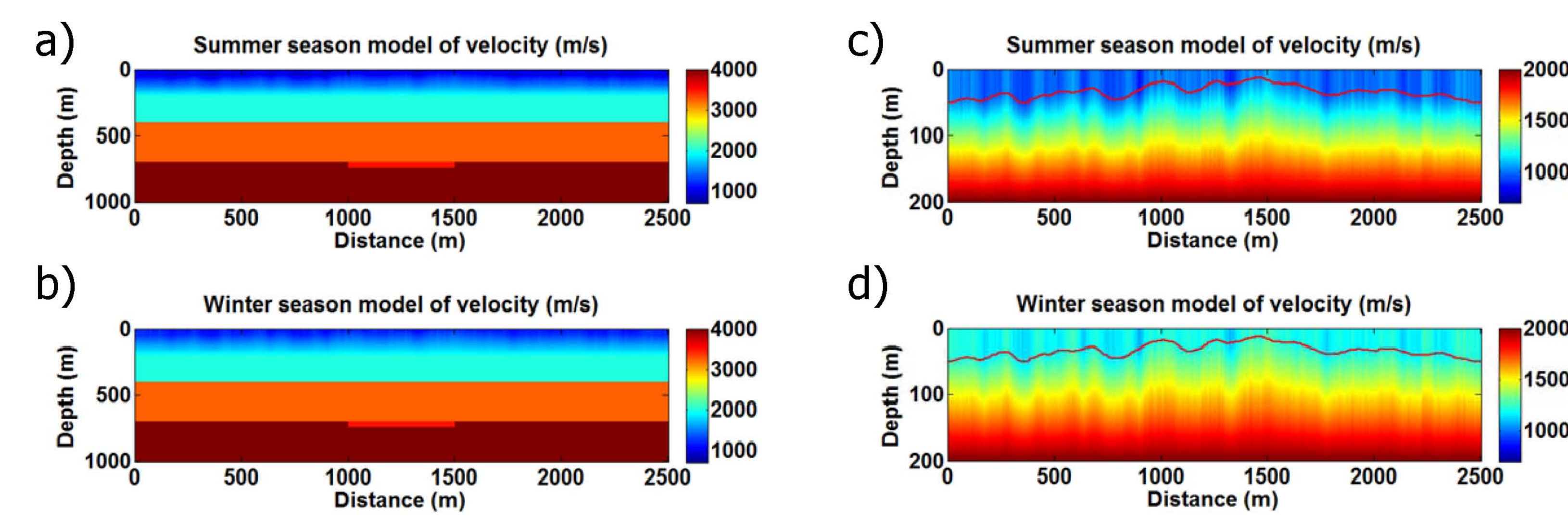

FIG. 2. A simple model whose subsurface (the reservoir) is unchanging but which show surface-consistent variability between the summer season (a) and the winter (b). The near-surface velocity changes is shown in (c) and (d).

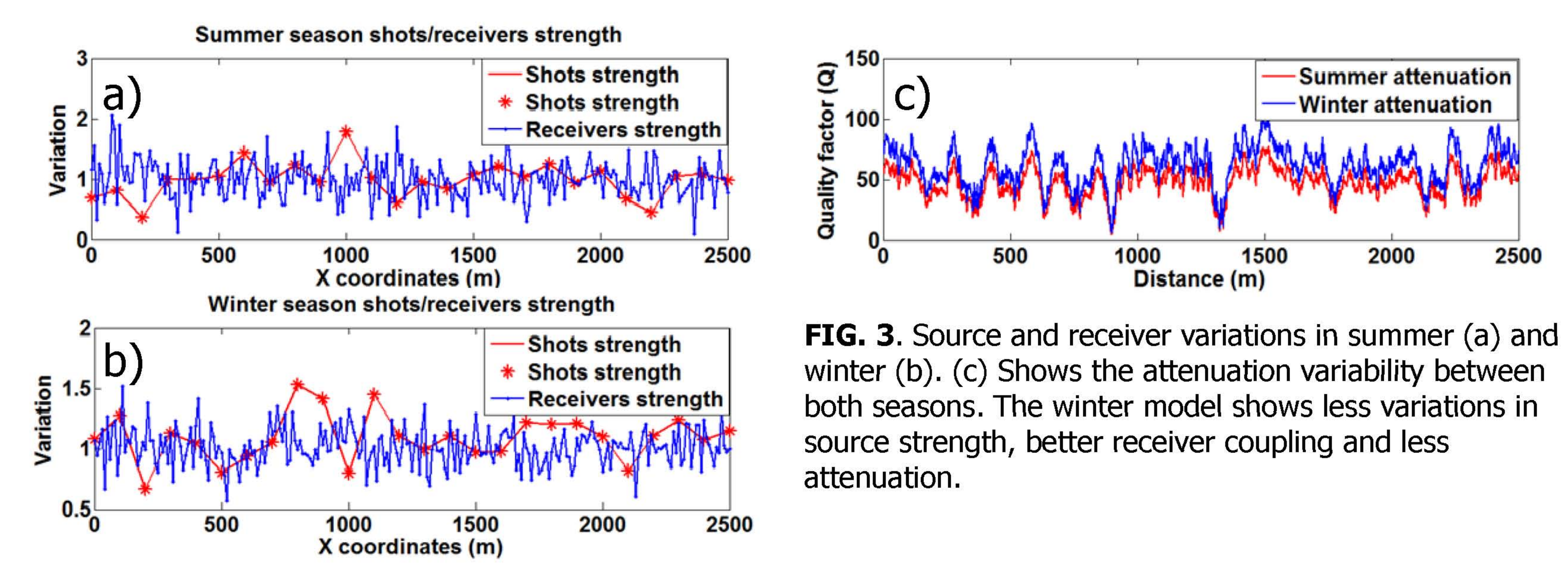

FIG. 3. Source and receiver variations in summer (a) and winter (b). (c) Shows the attenuation variability between both seasons. The winter model shows less variations in source strength, better receiver coupling and less attenuation.

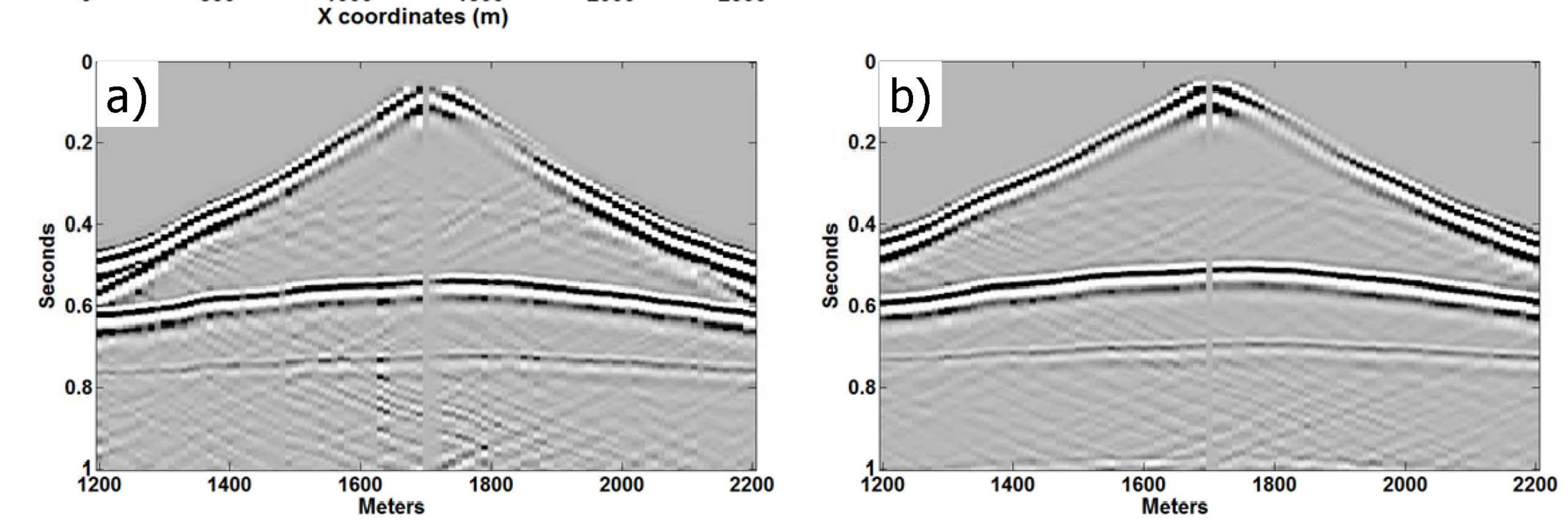

FIG. 4. Illustrates a comparison of the same shot record (exact shot location and exact geophones) for both summer (a) and winter (b) surveys (shot # 17).

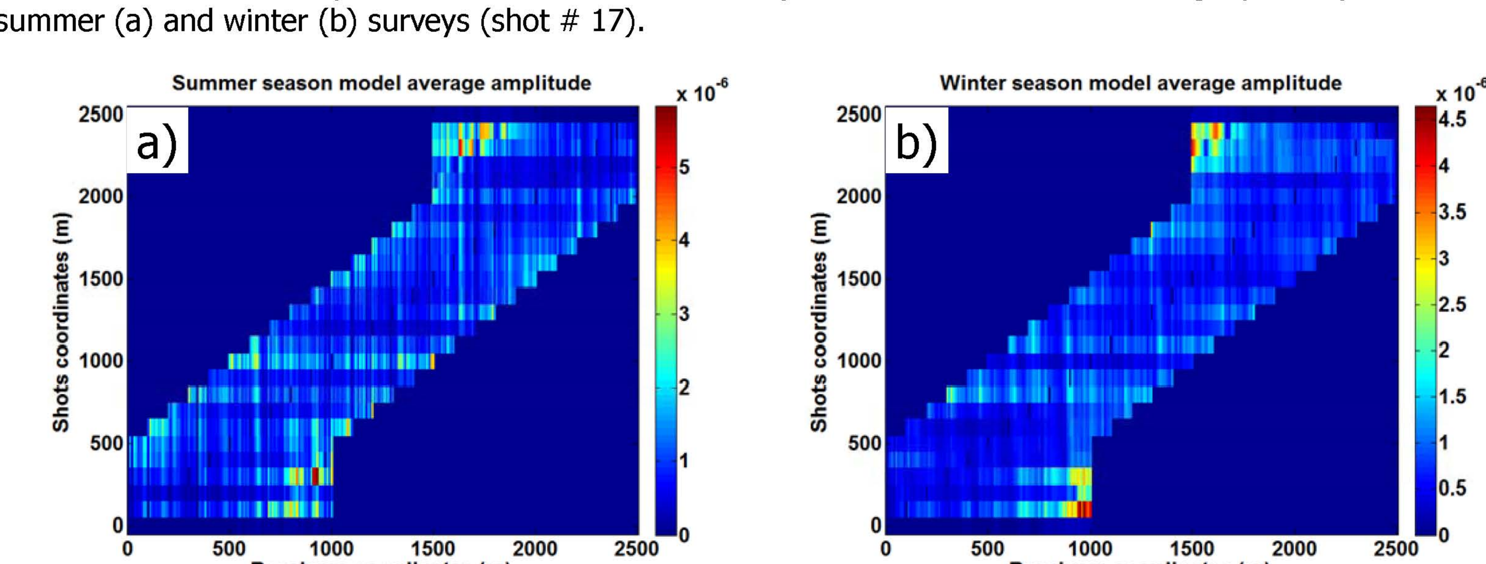

FIG. 5. Shows the extracted average amplitude which is taking from a time window around the middle reflector. The summer surface consistent variability for source and receiver is shown in (a) and the winter variability is in (b).

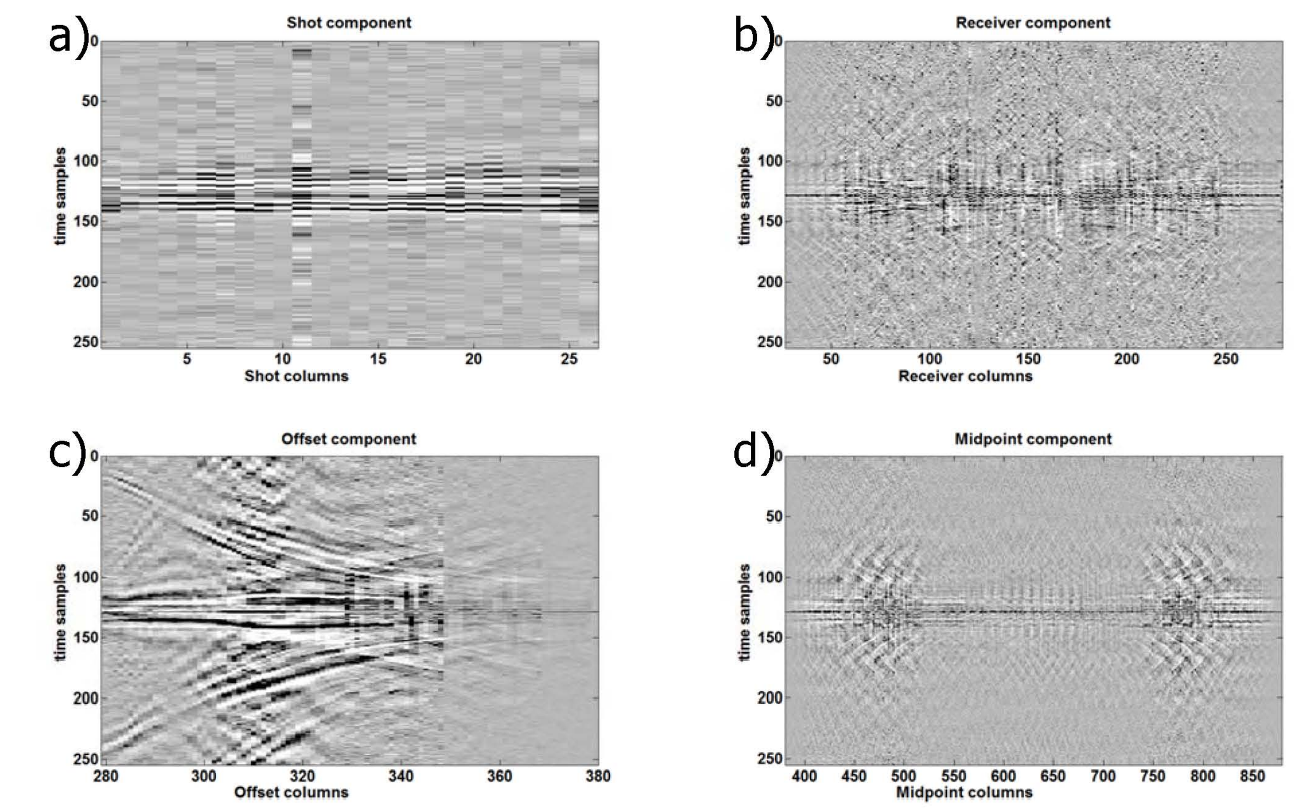

FIG 6. Shows the shot components (a), receiver components (b), offset components (c), and midpoint components (d).

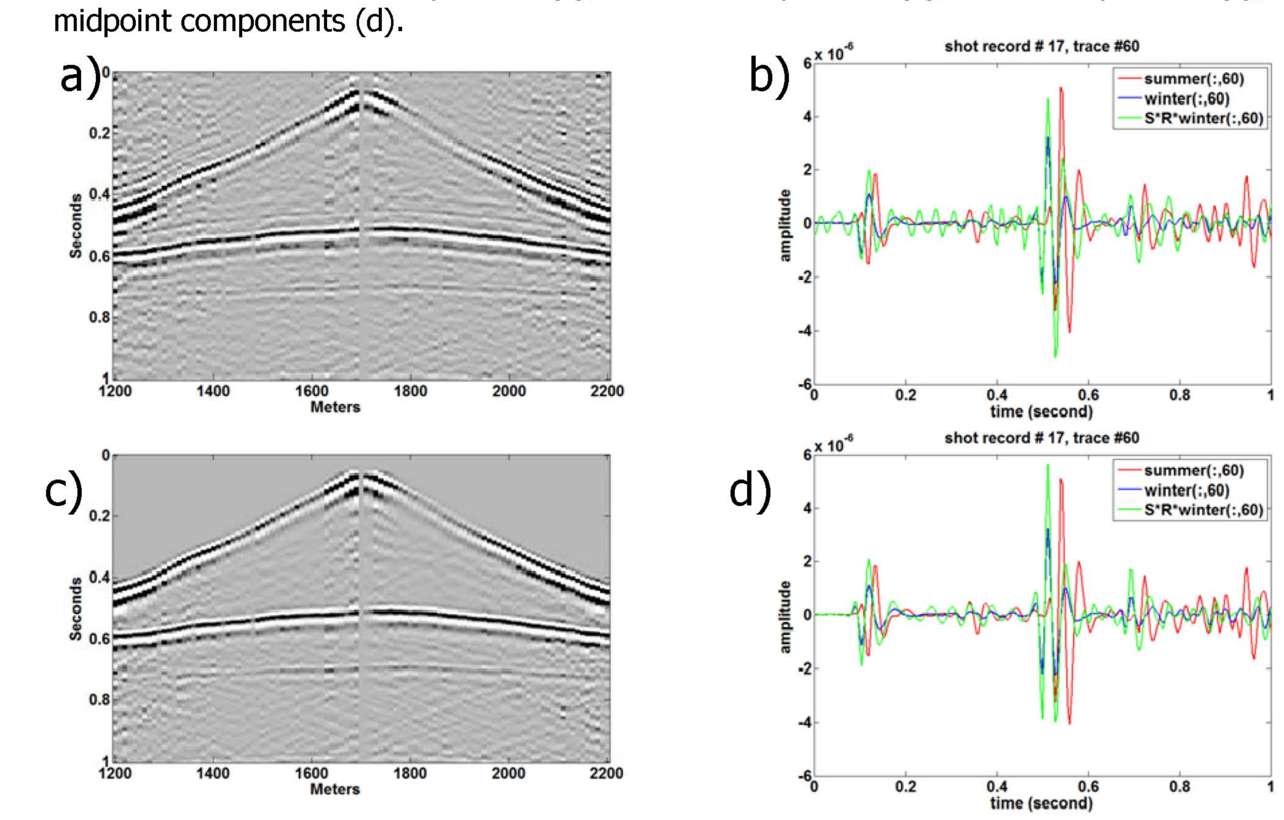

FIG. 7. Shows shot record # 17 from the winter survey with source and receiver filters applied. Note that the noise introduced by the non-causal operator above first-break (a). (b) Consists of a single trace from shot record # 17 comparing the summer survey (red), the winter survey (blue), and the source and receiver operator applied to the winter survey (light green). (c) is the same as (a) but with minimum phase operator applied. (d) Shows same traces as (b) but note the noise level is less. The problem of time delay remains unsolved.

CONCLUSIONS

- This is a new idea for designing a match filter in a surface consistent manner.
- The surface consistent model is extended to designing match filters to equalize two seismic surveys.
- We have built a very useful synthetic dataset that contains a baseline and a monitor survey with surface consistent seasonal variations built into the model.
- Initial results are encouraging but suggest that our software is not yet optimal.

FUTURE WORK

- Correct for the time delay problem which is currently not accounted for by the operators.
- Review the offset and midpoint operators and reduce the noise observed above and below the center of the operators.
- Once the code is working, apply to a real dataset.

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