Stanford Exploration Project, Report 113, July 8, 2003, pages 277–285

Coherent noise suppression in electroseismic data with non-stationary prediction-error filters

Seth Haines and Antoine Guitton[1]

ABSTRACT

Non-stationary prediction-error filters (PEF's) provide an effective means for separating signal from coherent noise in electroseismic data. The electroseismic signal is much weaker than the noise, so we can not rely on windowing, transforms, or other alterations of the original data to create models for the PEF estimation. Instead, we design signal PEF's using the physical predictability of the phenomena, and estimate noise PEF's using portions of the original data. This technique is effective on synthetic and real data.

INTRODUCTION

Electroseismic phenomena produce two forms of energy: the interface response signal, and the coseismic noise (Haines and Guitton, 2002). Electroseismic data processing must attenuate the coseismic noise in order to reveal the interface response. In short, the signal is composed of flat events (the interface response has virtually zero moveout) while the noise (coseismic energy) has moveout similar to seismic data. The object is to remove the curved energy so that it does not contaminate the final stack of the gather. We employ the signal/noise separation technique described by Guitton (2003) to test its effectiveness in electroseismic processing. The basic approach is to estimate non-stationary prediction-error filters (PEF's) for the signal and the noise, and to use these PEF's in an iterative signal/noise separation following Guitton et al. (2001).

The electroseismic signal is far weaker than the noise so we can not hope to obtain an adequate model for the estimation of signal PEF's by muting in the parabolic radon transform (PRT) domain, or other alterations of the original data. We can, however, take advantage of the fact that the amplitude pattern of the signal can be easily modeled. It is the pattern of the potential (V) of a dipole field:

$$V(x,z) = \frac{qd}{4\pi\epsilon_0}\frac{z}{(x^2+z^2)^{3/2}}, \tag{1}$$

as measured at a horizontal offset x from a dipole at depth z, where q is the magnitude of the electrical charges, d is the distance between the two separated charges, and ϵ_0 is the electrical permittivity of the Earth. Using a velocity model to provide the relationship between depth

[1]**email:** shaines@pangea.stanford.edu, antoine@sep.stanford.edu

and travel time, and making basic assumptions about the size of the Fresnel zone producing the dipole, we can compute a model of the relative amplitude measured at various locations for events corresponding with any given travel time. This amplitude pattern may be used directly in the estimation of one-dimensional (in the offset direction) PEF's (since such a one-dimensional PEF contains no wavelet information), or we can use the amplitude pattern to scale synthetic wavelets to be used as models for PEF estimation. Thus if we have a velocity model for a particular study area, we can estimate non-stationary signal PEF's to target any interface response events that may be in the data without the need for *a priori* knowledge of their arrival times. We use simple physics [equation (1)] to design general signal PEF's, and use components of the original data to design noise PEF's. We show that these non-stationary PEF's provide an effective means for separating the interface response signal from the coseismic noise in synthetic and real electroseismic data.

SYNTHETIC ELECTROSEISMIC DATA

We begin by testing the processing approach on simple synthetic data containing three interface response events, three coseismic arrivals, and a small amount of random noise (Figure 1a). For our first processing example we chose models for the PEF estimation (Figure 1c and d) that simply contain amplitude-normalized versions of the events in the synthetic data, plus random noise. For the noise model, this choice is not entirely unrealistic; horizontal geophone data collected with electroseismic data closely resembles the coseismic noise in the electroseismic record (Garambois and Dietrichz, 2001) and could be used in this capacity. For the signal model, this choice is rather unrealistic, as we would generally be looking for previously unknown interface response signal that might be entirely obscured by coseismic and background noise. The purpose of this first example is to verify that the method is effective, and this is demonstrated by the final result shown in Figure 1b. Virtually all of the coseismic noise has been removed, leaving only the interface response energy.

Our second synthetic processing example (Figure 2a) employs the same data and noise model as Figure 1, and a more general signal model. We use the amplitude pattern predicted by equation (1) to produce a model for signal PEF estimation (Figure 2c). We normalize the amplitude pattern in the time direction so that the PEF estimation equally considers deeper and shallower parts of the amplitude pattern. Because we use one-dimensional PEF's (Haines and Guitton, 2002), this choice of signal model is quite reasonable. If we were to use two-dimensional signal PEF's, we could not use this model as the PEF's would be trying to model waveform information that is not present in the model. An alternative option would be to use the amplitude pattern (Figure 2c) to scale synthetic wavelets, and then to estimate 2-D signal PEF's on that model. But this approach would lose some generality as we would have to assign particular arrival times to those arrivals, and is not necessary since we find one-dimensional PEF's to be at least as effective as two-dimensional PEF's. The final result (Figure 2b) is nearly as good as that of Figure 1b, and shows that the generality of this choice of signal model does not bring with it a significant degradation of the final result.

Our third synthetic example (Figure 3) adds an important element of realism to the syn-

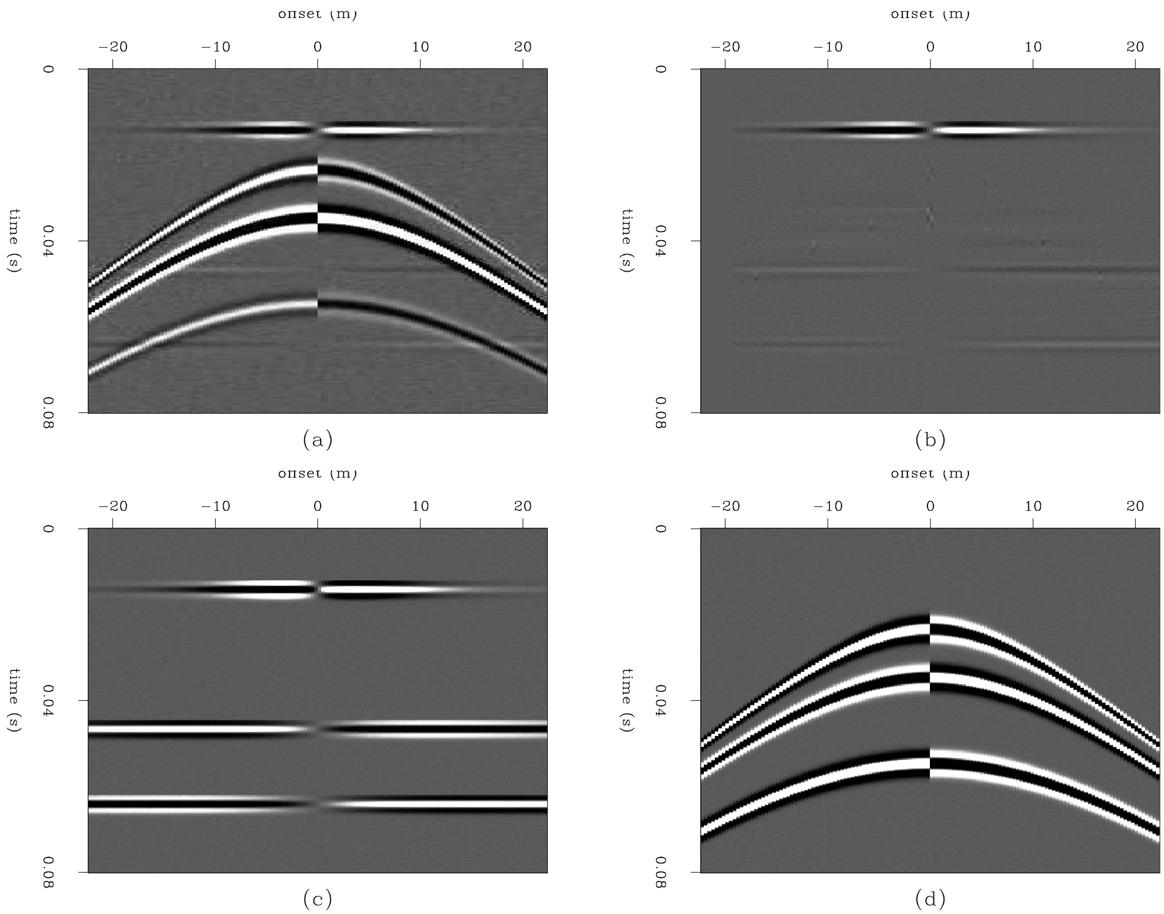

Figure 1: a) Simple synthetic data, with horizontal interface response events created using equation (1) and an arbitrary velocity function. Coseismic noise is created with the same velocity function. b) Result after non-stationary PEF signal/noise separation. c) Normalized version of synthetic interface response, used as model used for the estimation of the signal PEF's. d) Normalized version of coseismic noise, used as model for the estimation of the noise PEF's. shaines2-NS_1fig [ER,M]

thetic data. Electroseismic data is collected using electrode dipoles pounded into the Earth. The coupling of these electrodes with the ground is hardly uniform and results in amplitude variations between adjacent traces. We simulate this coupling variation by multiplying each trace of the synthetic by a random scalar (between 0.7 and 1.0), producing the data shown in Figure 3a. We use the same signal and noise models as in the previous example (Figure 2), and obtain the result shown in Figure 3b. This result contains more remnant coseismic noise than the previous examples, but the interface response energy is significantly stronger, and would dominate a stack of the gather.

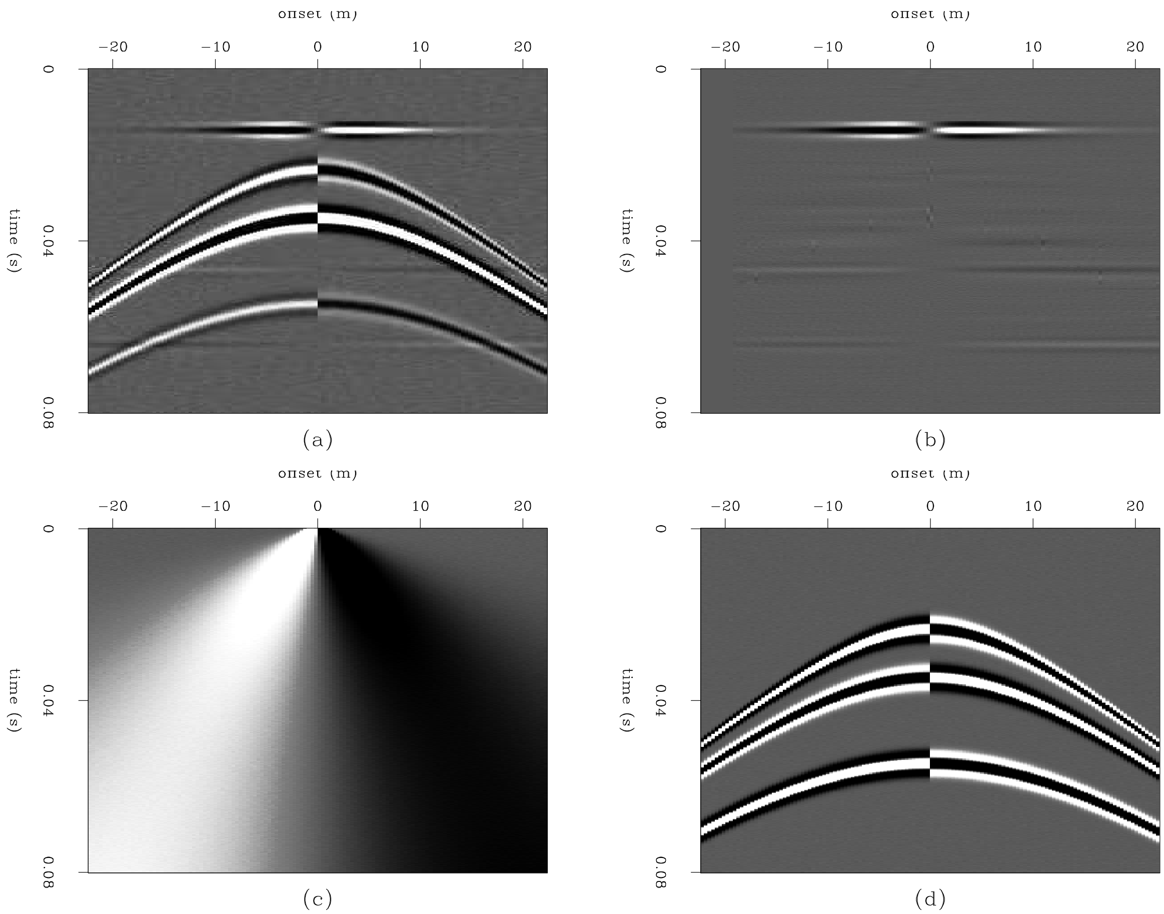

Figure 2: a) Synthetic data, same as Figure 1a. b) Result after signal/noise separation. c) Model used for estimation of signal PEF's, based on equation (1). d) Normalized version of coseismic noise, used as model for estimation of noise PEF's. shaines2-NS_3fig [ER,M]

REAL ELECTROSEISMIC DATA

We next test non-stationary PEF's on real data (Figure 4a). This 48-channel shot gather was constructed by interleaving two 24-channel gathers that were collected according to the methods described by Haines et al. (2003) and Haines and Guitton (2002). The shot point is the same for the two records, and the receiver positions are shifted by half the receiver spacing for the second record. Thus the resulting 48-channel record has half the original receiver spacing, and provides a test gather that can be processed more easily than the original 24 channel records. The shot point is in the center of the dipole receiver line, in the geometry that would be used for a typical survey. The gather shown in Figure 4a has been pre-processed to remove 60 Hz energy and eliminate high- and low- frequency background noise.

Using the coseismic energy as a guide, we establish a basic velocity function to be used with equation (1) for the determination of the model to be used for signal PEF estimation (Figure 4c). For estimation of the noise PEF we use a windowed version of the original data

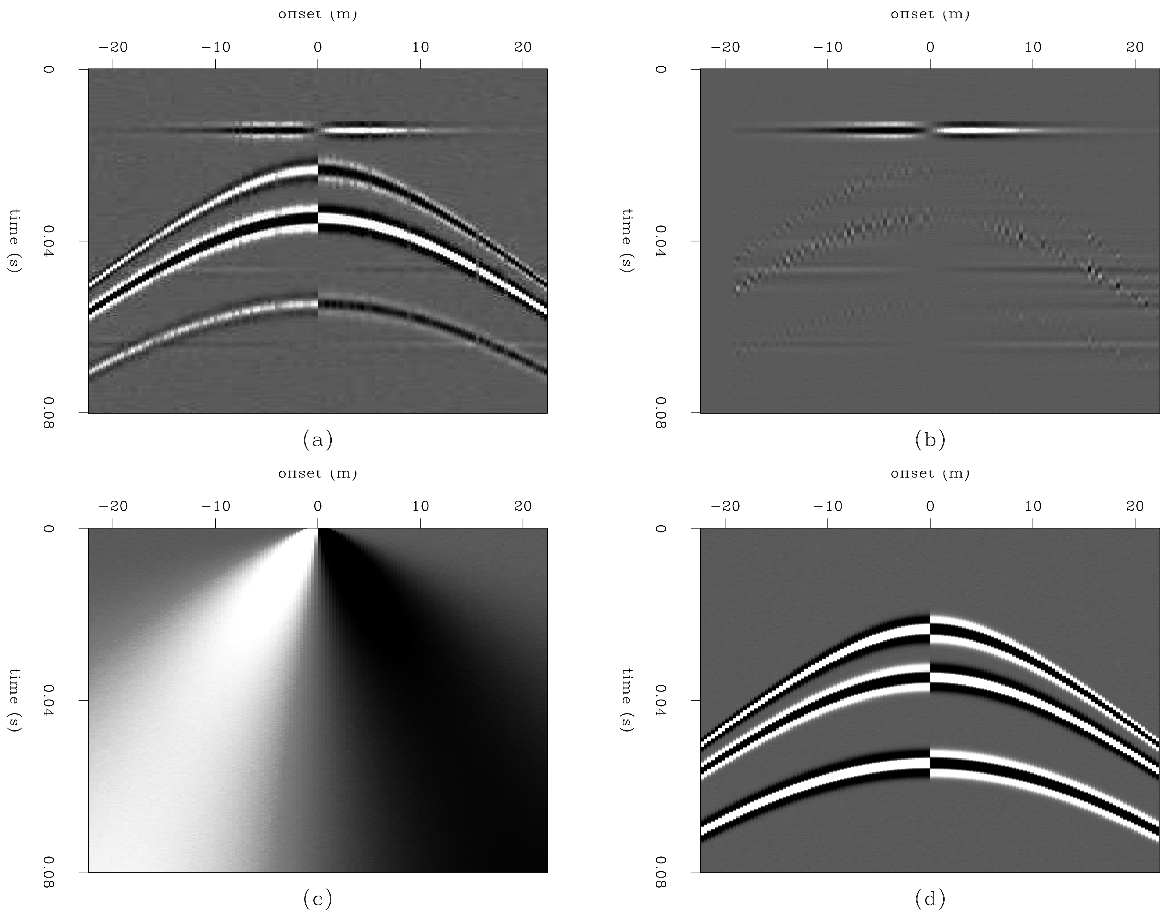

Figure 3: a) Synthetic data, same as Figure 1a, but each trace is multiplied by a random number to simulate the imperfect electrode coupling that impacts electroseismic data. b) Result after signal/noise separation. c) Model used for estimation of signal PEF's, based on equation (1). d) Normalized version of coseismic noise, used as model for noise PEF estimation. shaines2-NS_4fig [ER,M]

file, shown in Figure 4d. This choice of noise model is effective, as shown by the final result (Figure 4b), but is somewhat unrealistic, as we would ideally be looking for signal within the noisy part of the data and would not want our noise PEF estimation to be impacted by any signal in the estimation model. A better choice would be to use horizontal geophone data, but the data collected to complement this record is of insufficient quality to be used as a model for PEF estimation. Though not shown here, results using geophone data as a model for noise PEF estimation contain considerably more coseismic noise. The final result (Figure 4b) shows that the signal noise separation effectively removed the bulk of the coseismic energy, leaving two interface response events in the first 0.01 seconds of the record, and predominantly random noise in the lower part of the record.

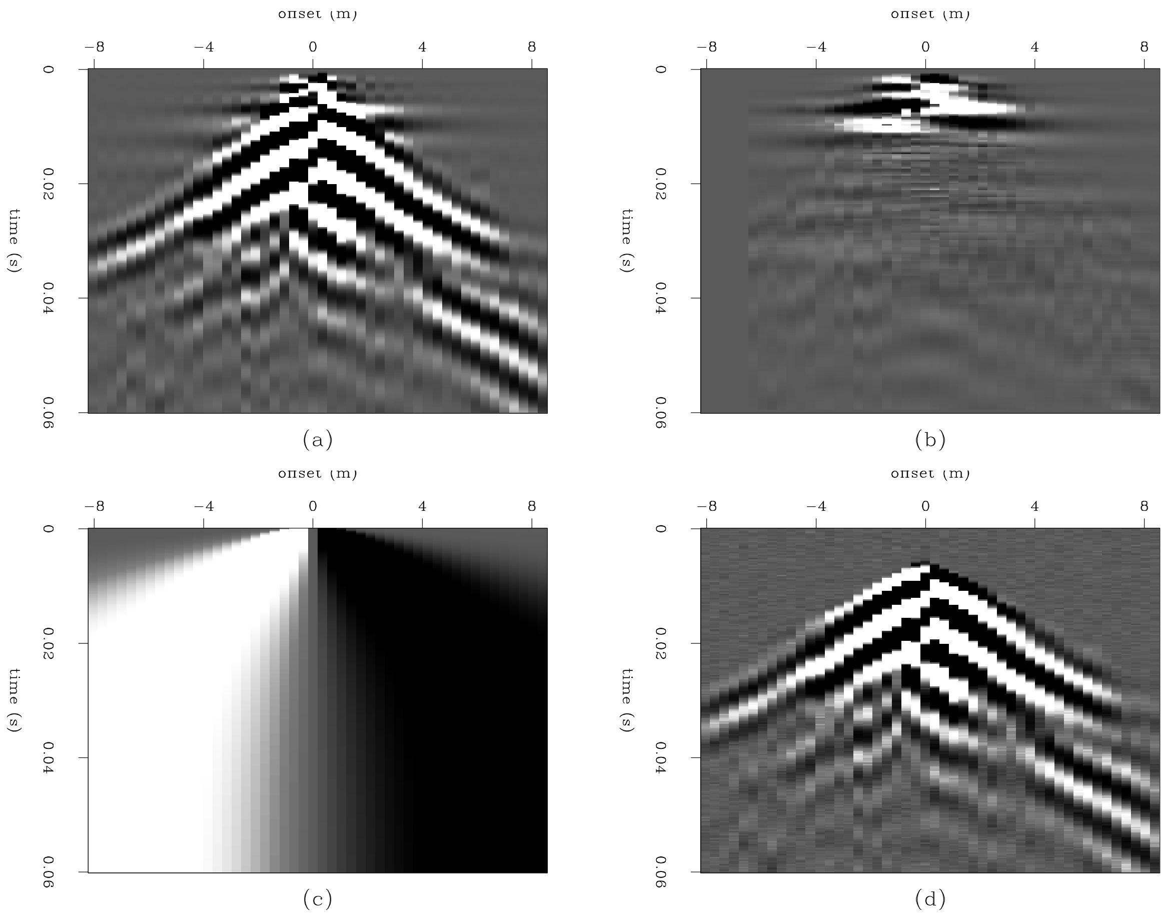

Figure 4: a) Field data after pre-processing. b) Result after signal/noise separation. Note that coseismic energy is almost entirely removed. c) Model used for estimation of signal PEF, based on equation (1). d) Muted version of field data, used as model used for estimation of noise PEF. shaines2-NS_r1fig [ER,M]

CONCLUSIONS AND FUTURE WORK

We have shown that non-stationary PEF's provide an effective means for the electroseismic signal/noise separation. We demonstrate that the physics of the problem can be used to develop models for PEF estimation in this case where the signal may be so much weaker than the noise that alterations of the data cannot produce suitable models. The generality of this approach is important in electroseismic signal processing, as it enables us to attenuate the strong coherent noise and enhance previously obscured signal, without any *a priori* knowledge of the signal. These results are far superior to those obtained with f-k filtering, stationary PEF's (Haines and Guitton, 2002), or other means. The real data example shown here is encouraging, and indicates that the development of an effective, fully general, algorithm for processing electroseismic data is an attainable goal. The next major step toward a generally applicable algorithm is the development of a better model for noise PEF estimation. One likely option is horizontal geophone data, as it should closely resemble the coseismic noise. The surprisingly poor quality of the horizontal data collected as part of this project makes it unsuitable for such a use, but is likely due to the poor condition of the geophones. We plan to collect additional data using better quality geophones, and hope to find that these data can be used for noise PEF estimation.

Assuming that horizontal geophone data can effectively be used for PEF estimation, we suggest the following processing scheme for electroseismic data:

1. Pre-processing (60 Hz removal, frequency filtering).
2. Develop rough velocity model using coseismic and/or geophone data.
3. Estimate signal PEF on dipole amplitude pattern, using velocity model.
4. Estimate noise PEF on horizontal geophone data.
5. Use these non-stationary PEF's in the signal/noise separation outlined here.

ACKNOWLEDGMENTS

We are grateful to Steve Pride, Biondo Biondi, Jerry Harris, Simon Klemperer, and Art Thompson for guidance in this project. The work would not be possible without the generosity of the Geological Society of America, the American Association of Petroleum Geologists, the Stanford McGee Fund, the Achievement Rewards for College Scientists Foundation, Jim and Carolyn Pride, and the Stanford Exploration Project.

REFERENCES

Garambois, S., and Dietrichz, M., 2001, Seismoelectric wave conversions in porous media: Field measurements and transfer function analysis: Geophysics, **66**, no. 5, 1417–1430.

Guitton, A., Brown, M., Rickett, J., and Clapp, R., 2001, Multiple attenuation using a t-x pattern-based subtraction method: 71st Ann. Internat. Mtg, Soc. Expl. Geophys., Expanded Abstracts, 1305–1308.

Guitton, A., 2003, Multiple attenuation with multidimensional prediction-error filters: SEP–**113**, 57–74.

Haines, S., and Guitton, A., 2002, Removal of coherent noise from electroseismic data: SEP–**111**, 183–201.

Haines, S., Guitton, A., Biondi, B., and Pride, S., 2003, Development of experimental methods in electroseismics: 73rd Ann. Internat. Mtg., Soc. of Expl. Geophys., Expanded Abstracts, submitted.