Making Marine Data From Land Data: suppressing 2-D surface noise on a 1-D line

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ABSTRACT

We model a land survey data line (t, x) to be a marine line with the addition of out-of-line $(x, y, z = 0)$ surface scatter. To begin, take a single surface line scatterer crossing the survey line at some angle. Its effect in the (t, x)-space is to add an upside-down Vee shaped event for every reflector. The many earth layers produce a stack of nested Vees, each the same but for a shift corresponding to the reflector depth and amplitude that of the reflector. Mathematically, the 2-D Vee patterns convolve on the 1-D layers. With many surface line scatterers we obtains many stacks. The making of marine data from land data is essentially a 2-D deconvolution problem. Luckily, in principle, 2-D PEFs can handle spatially aliased data (so long as there are not "too many" events). Luckily we also have recently developed techniques for nonstationary PEFs. Such PEFs facilitate curved surface scattering lines.

INTRODUCTION

In the 1980s the oil industry moved offshore. Drilling got a whole lot more expensive. Seismology got a whole lot cheaper. Hooray!

Now the industry is going back on shore. Uh, oh! Maybe we had better start thinking about land data again!

Land data is commonly understood to be really noisy. But this data is also known to be repeatable to good precision. The real trouble is that our ability to model such data is so poor. Although we say the data is noisy, we actually mean we don't have feasible modeling methods. A feasible method is one we can compute so readily that iterative fitting becomes practical.

I present here a feasible way to model land data. I model land data as marine data supplemented by surface scatterers. The surface scatterers could be *point* scatterers, but surface *line* scatterers are also a possibility. Indeed, surface line scatterers are more geologically plausible and lead to a more parsimonious parameter space.

MOTIVATION FROM AN OLD SURVEY LINE

The difference between land seismic data and marine seismic data is the complex near-surface land material. It affects waves both in transmission (statics) and by scattering. Upcoming waves mainly reflect back down, but they also scatter sideways into surface ground roll.

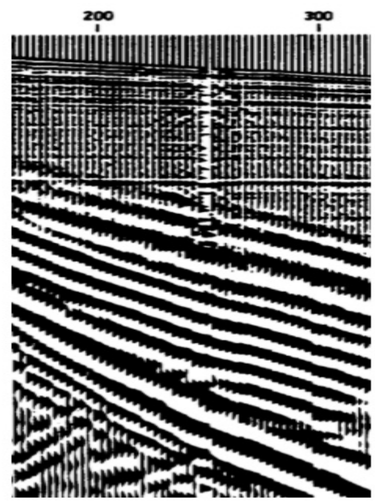

Figure 1: A bit of a shot gather with 3.4m receiver separation. Focus on the scatterer near the middle of the line near the top. See an upside-down Vee pattern. Each layer gives rise to a Vee. The slope of each Vee is about 130 m/s. That happens to match the slope of the second arriving ground roll train, theoretically a very shallow penetrating surface wave. [**NR**]

Figure 1 is windowed from an illustration on page 127 in my textbook BEI[1]. It shows a survey line (shot gather) containing a single strong surface scatterer, an object halfway down the line. Here the upcoming wave from each deep layer scatters waves outgoing and incoming (toward the shot). Thus the data shows a slow inverted Vee topped at each of the many subsurface reflectors.

That each reflector shows the same shaped Vee suggests statistical averaging to produce the best estimate of the 2-D Vee waveform. Vee patterns are highly predictable and destructible beyond aliasing by (t, x) filtering with a 2-D PEF (prediction-error filter). The scattering point source is defined by applying the inverse Vee filter.

This data shows only a single surface location scatterer making all the Vees, but we may presume that every other surface location along the survey line likewise scatters (or could scatter) more Vees. This gives a clear model for why land data looks so much noisier than marine data; furthermore it suggests a potential inversion: land data to marine data.

[1] `http://sep.stanford.edu/sep/prof/bei11.2010.pdf`

Out-of-line surface scatterers

We do not know whether this dataset results from a point scatterer on the survey line, or if there is a line scatterer intersecting the survey line. We need a model for 3-D data (an $(x, y, z = 0)$ surface containing scattering elements). We get it here next!

Consider a surface point scatterer off to the side of the survey line. Its consequences are not simple. There is no Vee response, instead there is the flank of a (t, x, y)-space hyperbola. The 3-D world suddenly looks far more complicated than the 2-D world. But, there is an escape! We have the option of parameterizing the surface scatterers by lines instead of points. This simplifies matters immensely. Which is better, lines or points?

It is easy to visualize line scatterers geologically. A river or fossil river in near surface sediments is defined by a curved line on the surface. Luckily, curving wavefronts have recently become an easily manageable complication in data processing. Using nonstationary PEFs we can destroy curved arrivals with a space-variable line-destruction PEF. Two numbers locate a point. Two numbers locate a line. Would lines normally allow a more parsimonious fitting than points? I think so.

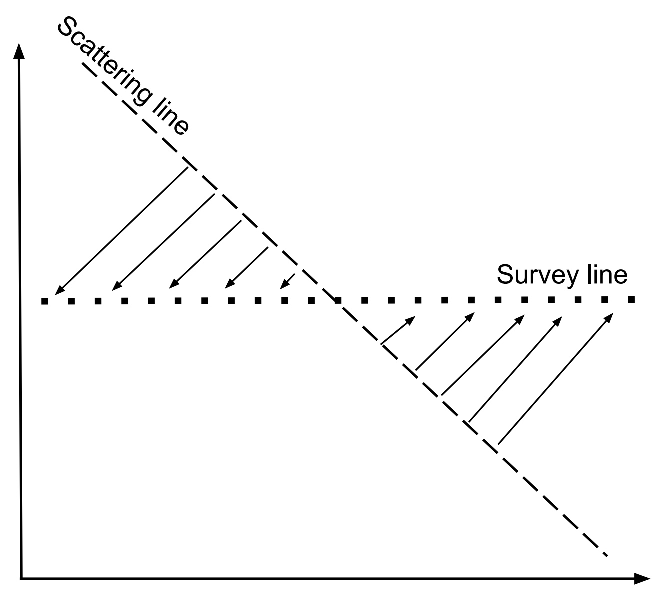

Figure 2: View of a surface plane containing a line scatterer. A vertically incident impulsive plane wave hits the scattering line. Travel time to the survey line is seen in the length of the rays (the arrows). The data (t, x) plane contains an impulse along the trajectory $v(t - t_0) = |x - x_0| \cos\theta$ where v is the surface wave velocity and x_0 is the location of the line crossing. [**NR**]

The simplest case to consider is deeply reflected waves emerging straight up. Figure 2 shows the rays propagating from the scattering line to the survey line. Travel time is the ray length, so the observations are again Vee patterns centered where the scattering line crosses the survey line. What differs from the elementary 2-D case is the angle of the Vees. The Vees now become faster, i.e. closer to the horizontal in

(t, x). (A special case is a scattering line parallel to the survey line.)

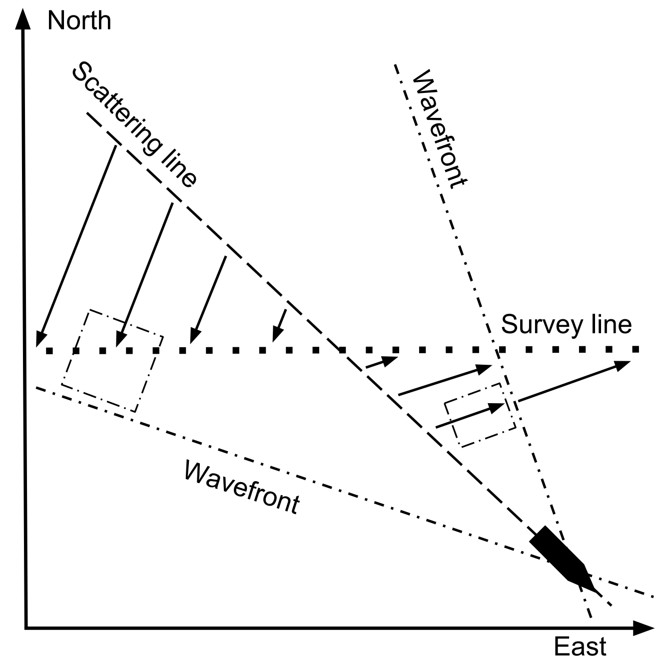

Figure 3: View of a surface plane containing a line scatterer. A non-vertically incident impulsive plane wave hits the scattering line. The impulse flies like a rocket along the scattering line. Wavefronts are no longer parallel to the scattering line. The arrows are perpendicular to the wavefront. Travel time to the survey line is again the length of the rays. The Vee pattern in (t, x) space is now a tilted Vee. [**NR**]

Figure 3 introduces the complication of a wavefront not emerging straight up, say an impulse emerging at an angle. Let it propagate along the scattering line from northwest to southeast. Wavefronts are no longer parallel to the scattering line. Rays are perpendicular to the wavefronts. Travel time is ray length from the scattering line to the survey line. The Vees are no longer symmetric in x. Minimum surface wave travel time remains at the Vee top where survey and scattering lines cross. The backscatter wavefront on the left races faster over the survey line than the forward scatter wavefront on the right. Thus, the Vee tilts pointing more to the right. Perhaps (I don't know.) the Vee is simply picking up the stepout of the upcoming wave.

2-D SPECTRUM

Various surface scattering lines introduce variously sloped Vee's. It might be that Normal Moveout Correction does a good job of symmetrizing the Vee patterns. To begin with we may address data with limited numbers of curved surface scattering lines. This situation is ripe for estimating 2-D PEFs from the 2-D spectrum of moved out data. Further, the PEFs may be spatially variable to account for curving surface scatterers.

Complications and generalizations

What if the earth really is more like point scatterers than like line scatterers? Then we will not see Vees. These Vees become nested identical hyperbolas. These are unlike the nested hyperbolas we see on the usual reflection gather. Each of these hyperbolas has the same asymptotic slope but not the same asymptote. These repeated hyperbolas all have the same $\tau = z/v$-value. They differ only in their time location (that being determined by the time to deep layer structures). So, the nature of the problem remains time convolutional although the 2-D filters are no longer simple Vee shapes. We can still readily estimate such filter inverses by familiar techniques.

What about statics? Does our approach require data with no statics on it? Good question. It happens that the data shown here has no apparent statics, but what if it did? We might find statics simply imposed upon the Vees and hyperbolas. The problem then amounts to deconvolution with an unstructured 2-D filter. The simple Vee structure is lost, but the method appears much the same. Perhaps this approach may be seen as a reformulation of the traditional statics problem.

CONCLUSION

On what important truth do very few people agree with you? —Peter Thiel

I feel this is a winner of a project for graduate students. It should produce interesting results on field data almost immediately. Intriguingly, there are many prospects for extensions: (1) what about midpoint-offset space? (2) what about 3-D coverage?

The traditional product that comes closest to these ideas is (f, k) steep dip rejection. But that process does not cope with spatial aliasing. Nor would it handle the hyperbola tops from point scatterers. Nor does it survive statics.

ANOTHER EXAMPLE

Years ago Sam Allen had a seismic recording company that could manage 600 channels of sign bit data. He had it strung out on a road about 200 miles from the Nevada nuclear test site. The military shot off some kilotons of explosive. Data shows the first 10 sec of the arrival. Essentially, we see a plane wave arriving. Fortuitously the recording line was perpendicular to the direction to the source (except for a bend in the road about 800m from the west end). The thing to notice is patterns of slow events, roughly 1.0 km/sec. And, the patterns have some resonance. (Sorry, I have very little densely sampled land data.)

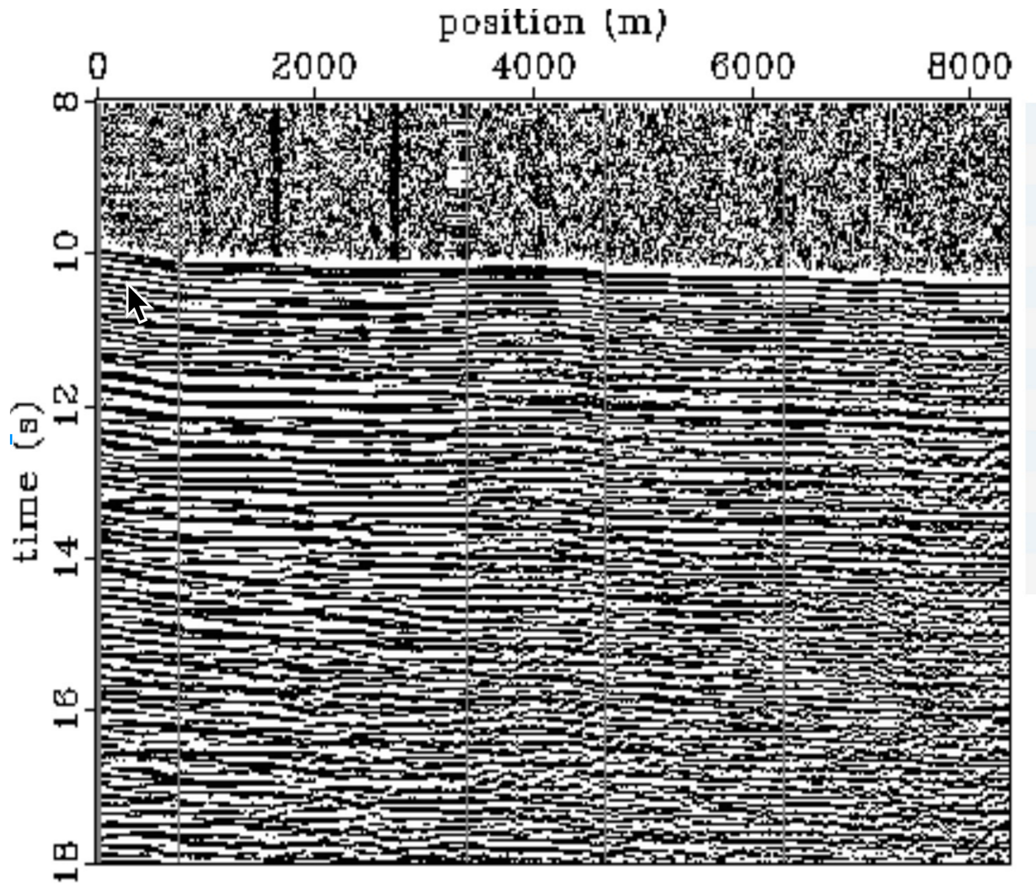

Figure 4: Multiple tons of old military explosives were detonated at the Nevada nuclear test site. Here see first arrivals at a couple hundred kilometers distance. Observe the "plane wave" is soon followed by cross-hatching slow waves, roughly 1 km/sec. [**NR**]

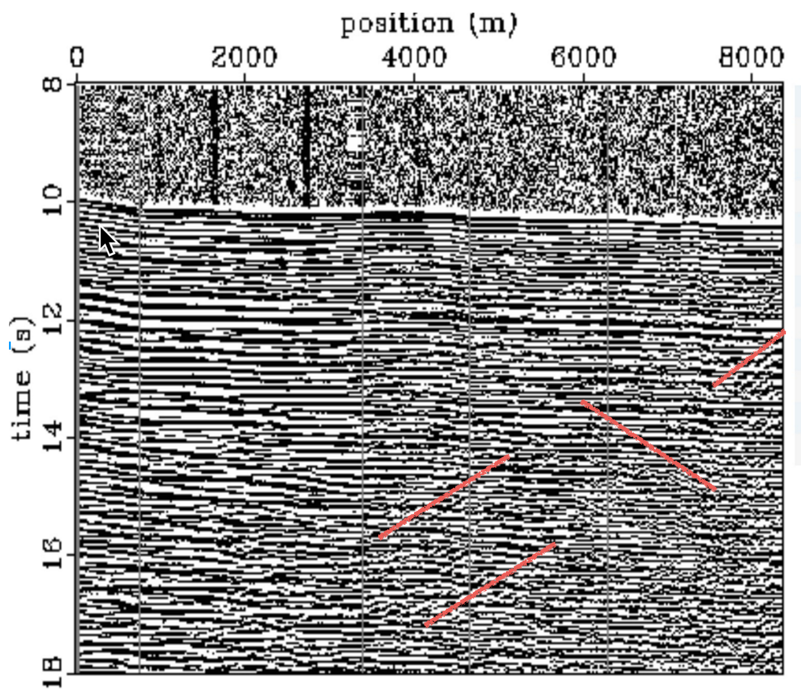

Figure 5: Multiple tons of old military explosives were detonated at the Nevada nuclear test site. Here see first arrivals at a couple hundred kilometers distance. Observe the “plane wave” is soon followed by cross-hatching slow waves, roughly 1 km/sec. [**NR**]