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Short Note

Coherent noise in the passive imaging experiment

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INTRODUCTION

Inherent in the passive seismic imaging experiment is the troublesome coexistence of the direct source phase and its excited ghost reflections that image the subsurface. Akin to the multiple problem in conventional seismic, I propose to attack the direct waves as noise in the framework outlined by Guitton et al. (2001). Whereas his methodology is effective at separation of signal and noise models, building an appropriate noise model is often the most limiting aspect of the technique. I propose a method to reconstruct the parameters of the impinging direct wave that is responsible for the image point in the reflection in order to build the noise model. Alternatively, it is possible to separate the recorded wave field into its up-going and down-going constituents if one has all three components of the displacement recorded at the surface. Both of these methodologies will be discussed herein. The concepts are not mutually exclusive.

DATA=SIGNAL + NOISE

Figure 1 shows the simple model of a plane wave emergent on the the surface layer and then exciting what we will call a source wavelet that can be used to image reflectors at depth. As the correlated traces in panel **(c)** show however, the output traces will have correlation peaks at lags corresponding to the arrival of the direct wave and the reflection. For the purpose of subsurface imaging then, we will refer to the direct wave correlation as noise, n, and the reflection correlation as signal, s. The signal will have hyperbolic move out while the noise will exhibit linear move out.

Because of this fact, reflection energy will have parabolic shape in the $\tau - p$ domain while the linear incident waves will coalesce to a point, that may be buried within reflection parabolas that will prevent a simple mute. However, if we were able to find the points corresponding to the direct waves for every event, we could make a noise model to use in an adaptive subtraction scheme.

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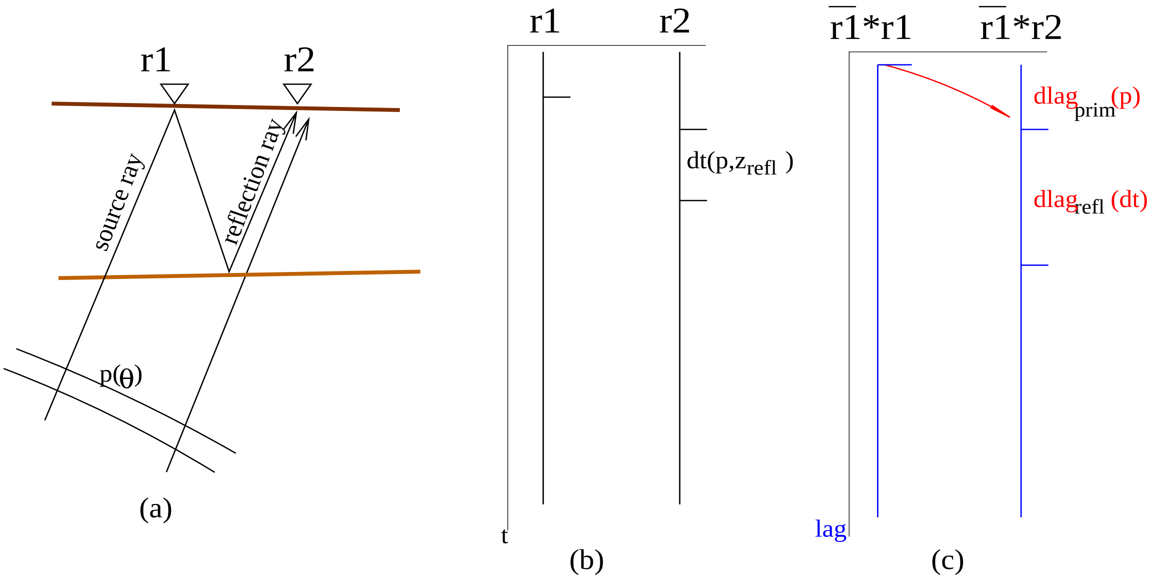

(a) (b) (c)

Figure 1: In correlation traces, there is a “noise peak” due to the direct arrival, and a “signal peak” from the reflection of the direct wave. brad3-noise [NR]

From Figure 1 one can see that every distinct incidence plane wave of ray-parameter p_i will contribute to the imaging of a reflector with the offset shown. If the incident wave is less vertical, the reflection ray will emerge past the second receiver. This leads us to the conclusion that all energy due to reflections has uniquely parameterized direct rays that excited it. Figure 2 shows the geometry of a single incoming plane wave, defined by its ray’s angle to the vertical, θ, reflecting at the surface and then again on a subsurface reflector to emerge at an angle θ_e. The following development is for constant velocity.

Therefore, we would like an expression for the angle of the direct wave as a function of the emergence angle of the reflected wave, $\theta_i(\theta_e)$. By inspection of the of the geometry, that relation is:

$$\theta_i = \theta_e + 2\phi \, . \tag{1}$$

So by transforming the correlation volume into $\tau - p$ space, parabolic summations that would correspond to an event should be mappable back to its source plane wave. This kinematic mapping can then act as the training model for a PEF estimation that is the operator N^{-1} for the coherent noise attenuation exercise outlined as the subtraction method in Guitton et al. (2001). Implementation of this methodology will follow presently.

Rays traveling close to 90^o from the azimuth of a recording line will not result in a recorded reflection along the same line. However, because it will arrive at all the receivers in the line at nearly the same time, these events should be easy to separate with a simple velocity dependent mute.

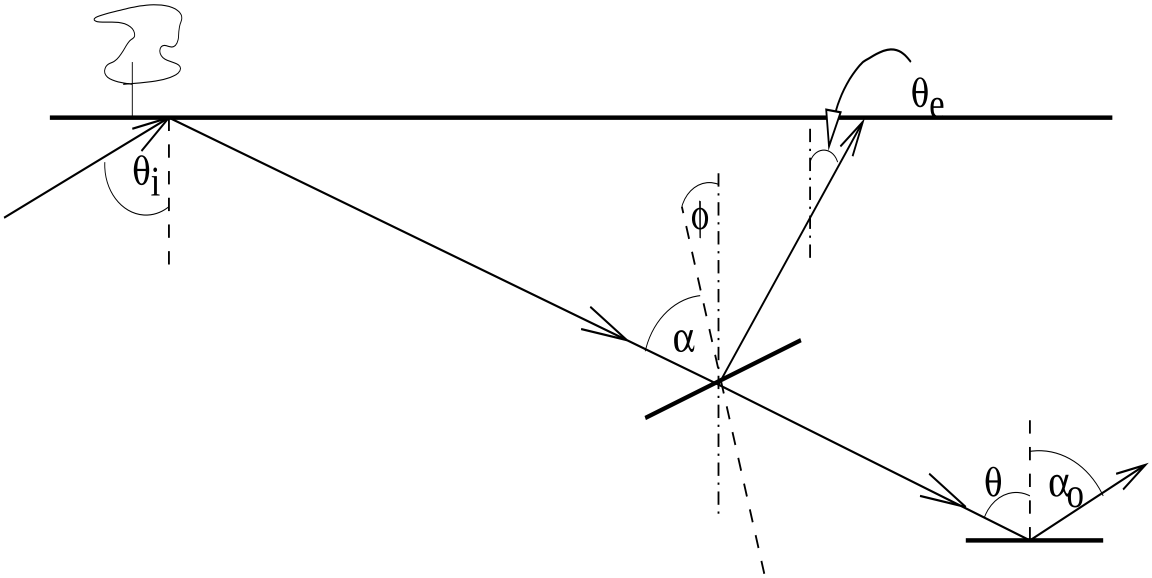

Figure 2: Thick lines are reflectors. Dashed lines define the normal to a reflector. Solid lines are rays. Dot-dashed lines are vertical references. Tree-like items are trees. θ_i corresponds to the incident plane wave. α is the incidence angle from the normal of the reflector plane. ϕ is geologic dip. θ_e is the emergence angle that will define the ray-parameter of the signal. α_o shows that for $\phi = 0$, $\theta_e = \theta_i$ in constant velocity. brad3-angles [NR]

WAVE FIELD = WAVES UP + WAVES DOWN

One could also attempt to separate the data into two wave fields in a pre-processing step rather than the signal/noise framework described above. Seismologists face this problem when analyzing so called “receiver-function” data. Kennet (1991) explains using three-component receivers to remove the free surface interaction. We know that the displacements at the surface (**u**) are caused by a wavefield (**w_o**) that is the sum of both up-going ($\mathbf{w_u}$) and down-going ($\mathbf{w_d}$) component fields. Thus the $\mathbf{w_u}$ will be a combination of the direct and the reflected event, but $\mathbf{w_d}$ will contain only the “source” wave field that propagates down to excite subsurface reflectors.

We know that the wave field will give rise to displacements at any boundary. So we can construct a relation between the displacements and the wave field such as

$$\mathbf{u_o} = \mathbf{E}\,\mathbf{L}\,\mathbf{w_u} \tag{2}$$

where: **E** is the eigenvector matrix that relates the Fourier components of the wave fields to physical parameters; **L** is composed of reflection and transmission matrices within the layer just below the surface; $\mathbf{u_o}$ is the column vector composed of the compressional and two shear propagation modes (each a function of frequency and ray parameter).

Thus, if we consider a very thin layer just below the surface the all energy is transmitted through, and no energy is reflected from, **L** becomes identity, and we only need a form for $\mathbf{E^{-1}}$

to solve (estimate) the up-going wave field. Because **E** arises through solving the ODE's that relate displacement and tractions to a wave field, we can find expressions for it and evaluate them at the special case of the free surface.

The utility in this argument outlined above is in the ability to estimate the down-going wave field from the free surface that is the actual source wave form to convolve our traces with. Unfortunately, this process has analogous features to a rotation aligning recieiver axes with the angle and azimuth of the incoming energy source. Thus we may not be successful in generalizing this sufficiently when we hope to utilize truly random incident energies.

This treatment highlights our fortune in having three-component data available to us in our test data sets (outlined in Artman (2002)), as well as the need for three component acquisition in the future.

CONCLUSION

To attack the coexistence of the reflection wave field and the direct waves in the correlation space of a passive seismic data set, I propose two methods to attempt their separation. One is from a standpoint of the data consisting of signal and noise components. The other is by extracting up-going and down-going components from the recorded wave field if we have three-component receivers. Both methodologies will be pursued in an effort to fully understand minimum design parameters for a successful passive seismic imaging experiment.

REFERENCES

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