GeoConvention 2016
Calgary • Canada • March 7-11
OPTIMIZING RESOURCES

Time domain internal multiple prediction

Kris Innanen
CREWES-University of Calgary

Summary

Internal multiples are an ongoing challenge for seismic imaging, inversion and interpretation, with internal multiples in land environments being particularly problematic. The inverse scattering series internal multiple attenuation procedure is the high bar for multiple identification and suppression in circumstances where detailed structural and velocity information is absent, but on land its application is nontrivial. In this paper we discuss time and space-time versions of the algorithm, the consequent opportunities for selecting a time-nonstationary parameter ε, and the increasing ease with which artefact free predictions can be calculated as a result.

Introduction

Inverse scattering series internal multiple prediction and attenuation technology (Araujo et al., 1994; Weglein et al., 1997) is considered, with some of the specific challenges associated with land application in mind. On land, noise, poor coupling, thin bedding, in particular of coal (e.g., Wang et al., 2012), and generators in the near surface or well above the zone of interest (e.g., Luo et al., 2011) all contribute to increasing the challenge of internal multiple identification and removal. Frustratingly, land is just where precise internal multiple removal would be most welcome. This is especially true for unconventional plays, where inversions and interpretations are based on very subtle data variations (Iverson, 2014). Success stories have been published (e.g., de Melo et al., 2014; Luo et al., 2011), but fully robust implementations of the approach are still sought.

Inverse scattering prediction difficulties arise on land because of what the above factors do to the data *sub-events* (e.g., Weglein and Matson, 1998) combined in the algorithm. The characteristic separation of sub-events (mostly primaries) in time, a key attribute by which the algorithm parameter ε is selected, becomes highly variable in the presence of thin bedding and near-surface generators (e.g., Hernandez and Innanen, 2014). Amongst other difficulties, this makes the optimum ε, whose role is to limit the proximity of events being combined (Coates and Weglein, 1996), highly time-nonstationary. If ε is too small, artefacts correlated with primaries appear, and if ε is chosen too large, multiples are missed. With a nonstationary optimum ε, any single value will almost certainly lead to missed predictions or artefacts.

The standard form of the prediction algorithm is in the wavenumber-frequency domain, meaning the output is the spectrum of the prediction, and this limits our ability to include time-nonstationarity in any of the parameters. In this paper we consider a time-domain version and implementation of the algorithm, and examine the increase in precision a (now allowable) parameter schedule $\varepsilon(t)$ provides to prediction.

This work is part of an effort to systematically study the effect on prediction accuracy of (1) novel domains of output of the prediction, and (2) nonstationarity of ε relative to these output coordinates (Innanen and Pan, 2015). 1.5D versions of the algorithm, in the k_g-t and x_g-t domains (Innanen, 2015), and the τ-p domain (Sun and Innanen, 2015a), and a 2D version in the plane wave domain (Sun and Innanen, 2015b) have been framed.

Time domain formula and implementation

Within the 1D approximation it can be shown (Innanen, 2015) that the internal multiple prediction algorithm has the time-domain form

$$\mathrm{IM}(t) = \int_{-\infty}^{\infty} dt' s(t'-t) \int_{\alpha(t,t')}^{\beta(t)} dt'' s(t'-t'') s(t'')$$

for a seismic trace *s(t)*, with the interior integral limits

$$\alpha(t,t') = t' - (t-\epsilon)$$

and

$$\beta(t) = t - \epsilon$$

This formula has simple 1.5D extensions to IM(k_g,*t*) and IM(x_g,*t*), i.e., the wavenumber-time and offset-time domains (Innanen, 2015), both of which internally include the basic IM(*t*) form above. For instance, given a shot record s(x_g,t) the space-time prediction in 1.5D has the form

$$\mathrm{IM}(x_g,t) = \int dx' \int dt' s(x_g - x', t'-t) \int dx'' \int_{\alpha(t,t')}^{\beta(t)} dt'' s(x'-x'', t'-t'') s(x'', t'')$$

In Figure 1 a simple example of IM(x_g,t) is illustrated for a synthetic shot record over a two-interface model with a piecewise linear velocity model. The traveltimes were computed with a ray-tracing code; amplitudes are not computed and are set to unity. The prediction arrival times are within one sample of the multiple travel times, even with the source wavelet left intact, confirming that the formula is behaving as expected.

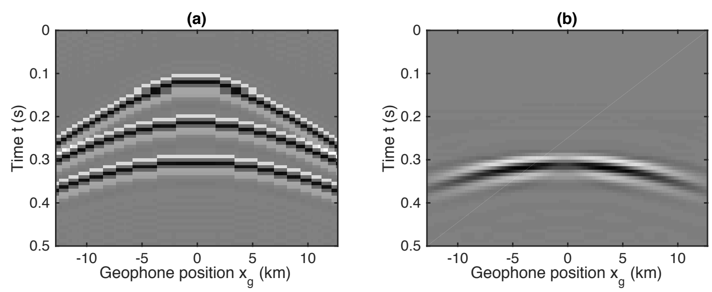

Figure 1: (a) Simple shot record with over a piecewise linear v(z) with two interfaces; amplitudes are not modelled. (b) Output of IM(x_g,t); input data have had a cosine taper applied horizontally, i.e., across offset.

The 1D time domain formula produces the same output as the standard frequency domain form,

$$\mathrm{IM}(\omega) = \int dt e^{i\omega t} s(t) \int_{-\infty}^{t-\epsilon} dt' e^{-i\omega t'} s(t') \int_{t'+\epsilon}^{\infty} dt'' e^{i\omega t''} s(t'')$$

after an inverse Fourier transform over frequency. However, there is a significant difference between the two, because ε must remain fixed relative to the integrations on the right hand sides of both formulas. So, it can at most be set to vary with frequency in the IM(ω) case. It can, however, be set to vary with time in the IM(t) formula, and x_g and t in the IM(x_g,t) formula.

1D time domain prediction examples

We will consider nonstationary $\varepsilon = \varepsilon(t)$ in the context of the 1D time domain formula. To simulate a trace the Ganley algorithm for layered media (as implemented by Margrave, 2015) is used; amongst its useful features multiples can be turned on and off and so comparison of predictions to exact calculations of multiples is possible. In Figure 2a a simple velocity model is illustrated, involving a relatively shallow generator above a reflector from a deeper zone of interest. The associated trace (source and receiver collocated at z=0m) is plotted in Figure 2b. There are three visible sets of multiples of various orders, indicated with arrows. The set near 0.2s are the result of reverberations within the generator; those near 0.5s are pegleg events with only one interaction with the deeper reflector, and those near 0.8s are long path multiples which have traversed the full distance between the shallow and deep structures four times.

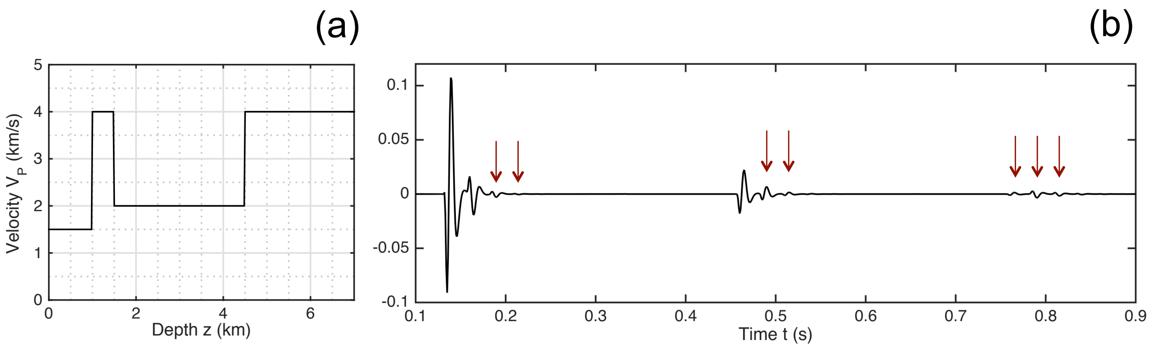

Figure 2: (a) Velocity model representing a shallow generating layer and a deeper reflector. (b) Seismic trace with multiples indicated by arrows.

From the point of view of the prediction procedure, the difference between these three groups of multiples is that their sub-events are separated by very different vertical traveltimes; because ε determines the minimum allowable separation, it follows that the optimum ε for the shallowest group might be different from that for the deepest. In Figure 3a, a prediction with a relatively cautious ε of 30 sample points, or roughly $\varepsilon \sim 3/f_{dom}$ is plotted. Comparing the prediction, in blue, to the exact multiple, in black, we see that the deeper multiples are predicted satisfactorily, while some energy is missed in the mid-depth prediction, and almost none of the multiple energy is predicted up shallow. In Figure 3b, we attempt to fix the problem by moving to a more aggressive $\varepsilon \sim 1/f_{dom}$. Again the first order internal multiples at the later times near 0.8s are satisfactorily predicted, and this time the mid-range multiples at 0.5s are very close to optimally predicted as well. But, now, artifacts appear near 0.2s, correlated with the shallow primaries; such a ε is too aggressive for this output time.

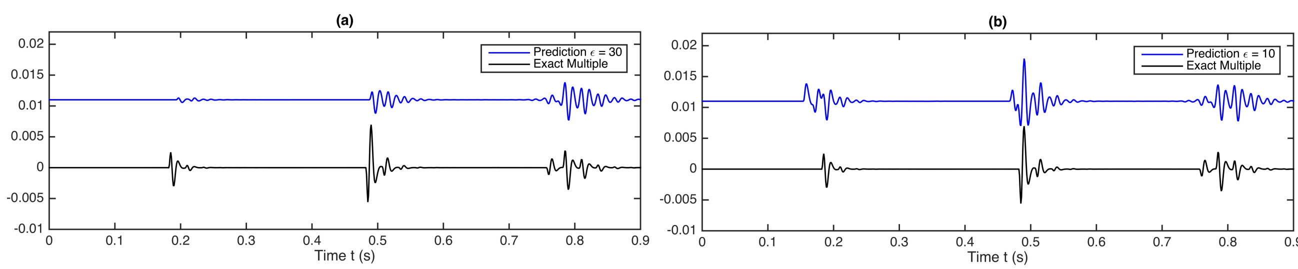

Figure 3: (a) Prediction vs exact multiple traces for a fixed, "cautious" ε value of 30 sample points; (b) for fixed, "aggressive" ε value of 10 sample points.

Neither of these ε values as fixed constants of the prediction are optimal, however if these two values are distributed across the range of output values, a much better result can be obtained. In Figure 4a, the input trace is plotted with ε(t) overlain as a dashed line: the high value being 30 sample points and the lower value being 10. In Figure 4b, we plot the prediction generated using the time-domain formula and the nonstationary ε(t) plotted above; we note that ε(t) that transitions towards cautious values in regions containing identifiable primary energy, produces something much closer to an optimal prediction.

Conclusions

Next steps include formulating the full 2D/3D versions of the algorithm in the time domain; in a separate communication we discuss strategies for selection of ε(t) which, absent other special knowledge of regions needing cautious or aggressive values, may be employed.

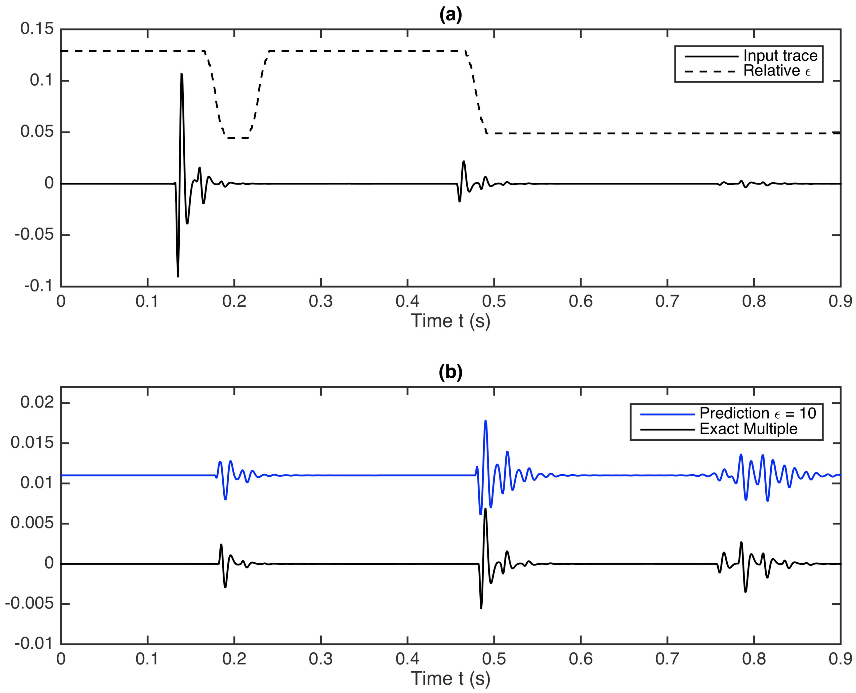

Figure 4: (a) Input trace containing primaries and multiples, overlain by the ε(t) curve (dashed line); (b) prediction vs. exact multiple.

Acknowledgements

This work was funded by CREWES industrial sponsors and NSERC (Natural Science and Engineering Research Council of Canada) through the grant CRDPJ 461179-13.

References

Araujo, F. V., A. B. Weglein, P. M. Carvalho, and R. H. Stolt, 1994, Inverse scattering series for multiple attenuation: an example with surface and internal multiples, in SEG Expanded Abstracts, 1039–1041, Society of Exploration Geophysicists.

de Melo, F., Idris, M., Wu, J., and Kostov, C., 2014, Cascaded internal multiple attenuation with inverse scattering series: Western Canada case study: SEG Expanded Abstracts.

Hernandez, M. J., and Innanen, K. A., 2014, Identifying internal multiples using 1d prediction: physical modelling and land data examples: Canadian Journal of Geophysical Exploration, 39, No. 1, 37–47.

Innanen, K. A. and P. Pan, Large dip artifacts in 1.5D multiple prediction and their mitigation, 2015, CSEG Expanded Abstracts.

Innanen, K. A., Time domain internal multiple prediction, 2015, CREWES Technical Report.

Iverson, A., 2014, The impact of interbed multiples on the inversion of pre-stack data: CSEG Recorder 39, 1, January.

Luo, Y., P. G. Kelamis, Q. Fu, S. Huo, G. Sindi, S. Hsu and A. B. Weglein, 2011, Elimination of land internal multiples based on the inverse scattering series: The Leading Edge 30, 8, 884-889.

Margrave, G. F., 2015, Stratigraphic filtering and Q estimation, CSEG Geoconvention Expanded Abstracts.

Sun, J. and K. A. Innanen, 1.5D internal multiple prediction in the plane wave domain, 2015, CSEG Geoconvention Expanded Abstracts.

Sun, J. and K. A. Innanen, 2D multiple prediction in the coupled plane wave domain, 2015, CREWES Technical Report.

Wang, M., B. Hung and K. Xin, 2012, Application of inverse scattering series method for internal multiple attenuation – a case study: ASEG Expanded Abstracts.

Weglein, A. B., Gasparotto, F. A., Carvalho, P. M., and Stolt, R. H., 1997, An inverse-scattering series method for attenuating multiples in seismic reflection data: Geophysics, 62, No. 6, 1975–1989.

Weglein, A. B. and K. H. Matson, 1998, Inverse scattering internal multiple attenuation: an analytic example and subevent interpretation: SPIE Conference on Mathematical Methods in Geophysical Imaging, 108–117.