Large magnitude residual static corrections

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Summary

The goal of this paper is to present a new algorithm that solves large magnitude statics without falling prey to cycle-skipping problems. No pilot trace is needed. In a defined window around the target, the cross-correlations of all traces participating in a bin are calculated. Shot and receiver static corrections are obtained through an inversion scheme using conjugate gradients. Unlike many linear inversion methods, this algorithm is able to provide residual statics much larger than the length of the embedded seismic wavelet. The efficiency of this approach has been improved by replacing the cross-correlation function by its envelope. The robustness of the method will be demonstrated on real 3D data examples. These tests will show that Surface Consistent residual static corrections up to 100ms (shot + receiver) can be resolved.

Introduction

In conventional seismic data time processing, the key assumption is that raypaths through the near-surface are approximately vertical. This implies that a simple constant time shift of the seismic trace is enough to compensate for the traveltime through the near-surface low velocity layers; hence the term “static correction”. Usually, this correction is carried out in two steps:

Firstly, using the traveltimes of the first arrivals, a smooth near-surface velocity model is estimated. Refraction static corrections are computed replacing tens or hundreds of meters of laterally and vertically varying velocity layers by a single constant velocity layer.

Secondly, the short-wavelength component of the statics is computed (reflection statics). These residual statics are surface consistent (S. C.), the analyses can be decomposed in three components: a shot-point static, a receiver static and a residual NMO correction (Wiggins et al., 1976).

Conventional methods for S. C. residual statics use a pilot trace obtained from a preliminary stack. These methods assume that a first guess solution, picked from the data, is close enough to the optimum statics. However, the pilot trace could itself be questionable due to noise contamination and/or NMO errors. These potential pitfalls limit the span of the search for large statics, and generate “cycle-skipping” (Marsden, 1993). Moreover, most of the linear inversion methods fail to resolve statics larger than the length of the embedded seismic wavelet, mainly due to the poor quality of the cross-correlations. In this paper, we will present a robust method able to resolve large magnitude S. C. residual statics based on a conjugate gradient scheme rather than a pilot trace approach.

Technical overview

The first step of the method is to apply an approximate NMO correction in order to obtain somewhat flat gathers. However, the choice of this correction is not a critical issue; it is used just as an initial guess and will be refined latter through the inversion.

The cross-correlations of all traces participating in each CMP gather are then calculated and their maximum values are stored to be the input of the inversion scheme. To understand better why cross-correlations are used to calculate static corrections, let’s take a CMP bin containing n traces. Assuming that NMO has been applied, the energy of the stack is represented by:

$$E = (t_1 + t_2 \ldots t_i)^2 \qquad (1)$$

In this expression t_i is a vector containing all the samples of the trace i. When the expression (1) is expanded, we find terms like t_i^2 unaffected by source or receiver shifts and terms like 2 $t_i t_j$ are critically dependent on them. These sensitive terms are included in a cross correlation space for all combinations of traces within each bin. Given such a couple ij, with corrections s_i and r_i (source and receiver) for the trace i, and s_j and r_j for the trace j, the time shift between two traces is given by:

$$\tau = s_i + r_i - s_j - r_j$$

Then, as suggested by Stork and Kusuma (1992) a function involving the sum of all these cross correlations (Φij) is optimized:

$$E' = \Sigma \, \Phi ij$$

As the number of local maxima plagues this objective function, cross-correlation functions are replaced by their envelope computed from the maxima of these functions as proposed in Deng et al. (1996). The advantage of this substitution is double: first, reduce the number of local extrema by reformulating the problem in a lower frequency frame; second, reduce the storage of the cross correlation functions.

In the third step, the linear inverse problem is solved by a standard hill-climbing conjugate gradient approach using the maxima of the envelops as described in the following function:

$$\delta E' / \delta s_i = \Sigma (\delta \Phi_{ij} / \delta \tau).(\delta \tau / \delta s_i) .$$

Finally, the S. C. residual source and receiver static corrections as well as residual NMO are computed and refined after several iterations.

Data examples

Real data 3D seismic data from Northern Alberta are used to calibrate this new static tool. Preprocessing based on S.C. deconvolution and a denoising to remove various noises has been firstly applied to the whole data set. The goal of the tests will be to calibrate the tool in different geological situations where large magnitude static values are present. Two different scenarios are simulated: large magnitude with random statics and box-car type statics, respectively. In both cases the corresponding statics will be calculated, applied to the data and the tool will be used to correct the data and find the original section.

For the first test a zero average random perturbation on shot and receivers is applied on the pre-stack data set. The range of the perturbation varied from – 50ms to + 50 ms on both shots and receivers (see Figure 4a). The application of these large magnitude statics on both shots and receivers destroys all the coherency of the flat events visible on the reference stack (Figure 1 and 2). The static solution calculated using our new tool is presented on Fig 4b. To better evaluate the accuracy of the method, both input (red curve) and calculated (blue curve) statics are presented on the same picture (Figure 4b): the match is excellent. In fact, over the entire survey, the standard deviation between the input and calculated values is close to the sample rate (here, 2 ms). The application of these new output values on the perturbated pre-stack data allows recovering the reference section (Figure 3). Positions in time of the reflection events (kinematics) as well as the amplitudes of the main reflectors (dynamics) have been well restituted.

For the second test, a 50 ms box-car perturbation on shot and receivers is applied on the pre-stack data producing an upward shift on a portion of the data (Figure 5). It is important to note that this box-car perturbation just shifts the reflections without destroying their coherency (Fig. 6). Conventional methods usually fail to solve for this type of perturbation and cannot converge to the exact solution (see black arrows on Figure 6). The accuracy of our methods is well illustrated in Figure 8b where a comparison between the input box-car perturbation (red curve) and the calculated values (blue curve) is presented. Excluding some small edge effects (less than the sample rate value), the input box-car shape is well restituted. The application of these statics completely recovers the original stacking section (Figure 7), the kinematics as well as the dynamics of the original section is well restituted without any cycle skipping (see black arrows on Figure 5 and Figure 7)

Conclusions

In this paper a robust linear inversion method based on the conjugate gradient scheme is presented to solve large magnitude S.C. residual statics without falling into the cycle-skipping problem. The efficiency of this kind of approach is demonstrated with two calibration tests on a real 3D data set.

References

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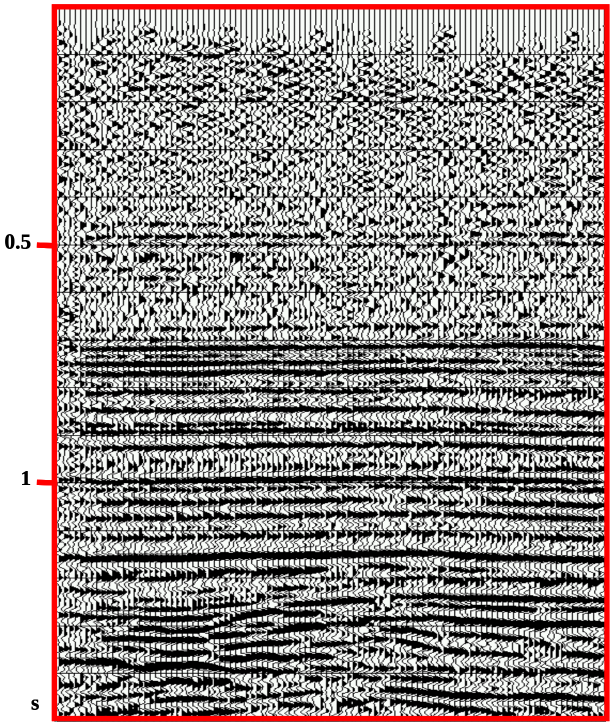


Figure 1: Reference stack

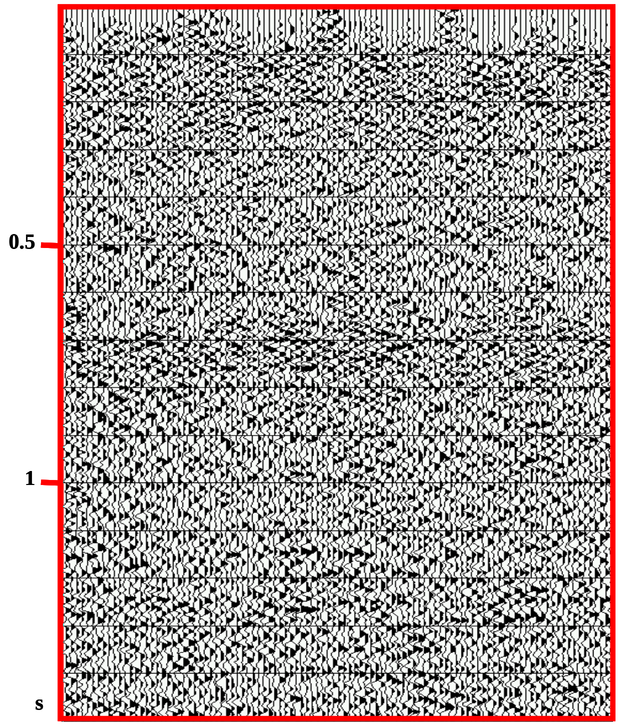


Figure 2: Stack after the application of a random perturbation on shot and receiver statics (from –50 ms to +50 ms).

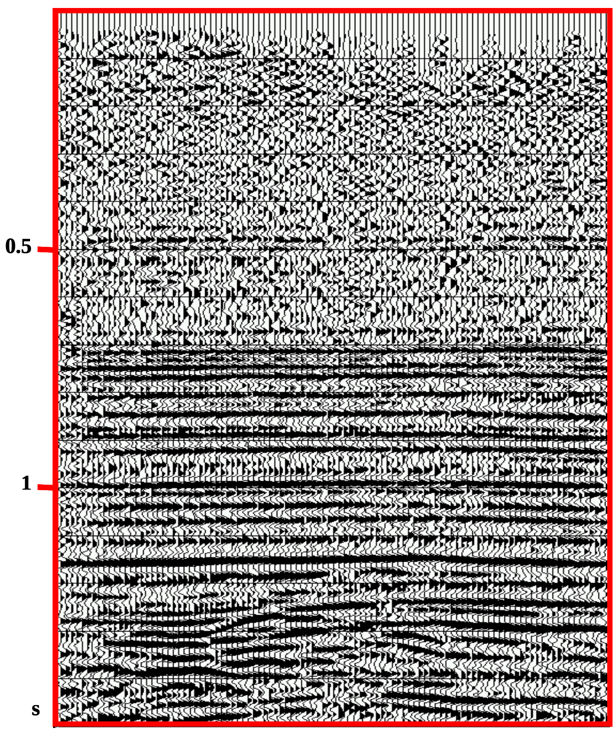


Figure 3: Stack after the estimation of the random perturbation on shots and receivers .

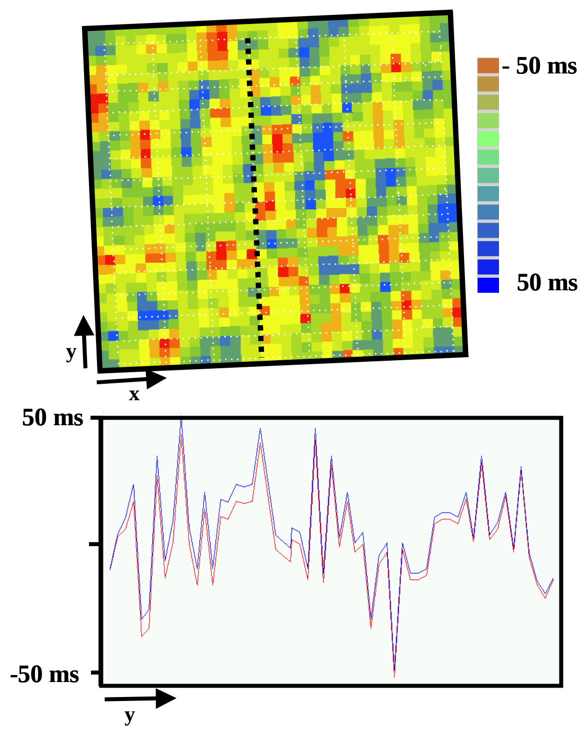


Figure 4a: location of the input random shot and receiver statics.
Figure 4b: Shot line (dashed line on Fig 4a):
the blue line corresponds to the input perturbation (see Fig.4a).
the red line is the estimation of the perturbation with the new tool.

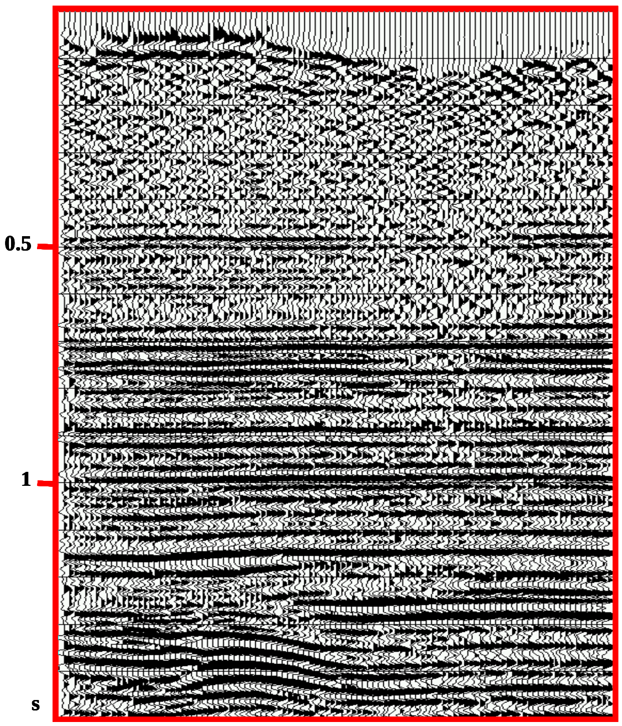


Figure 5: Reference stack

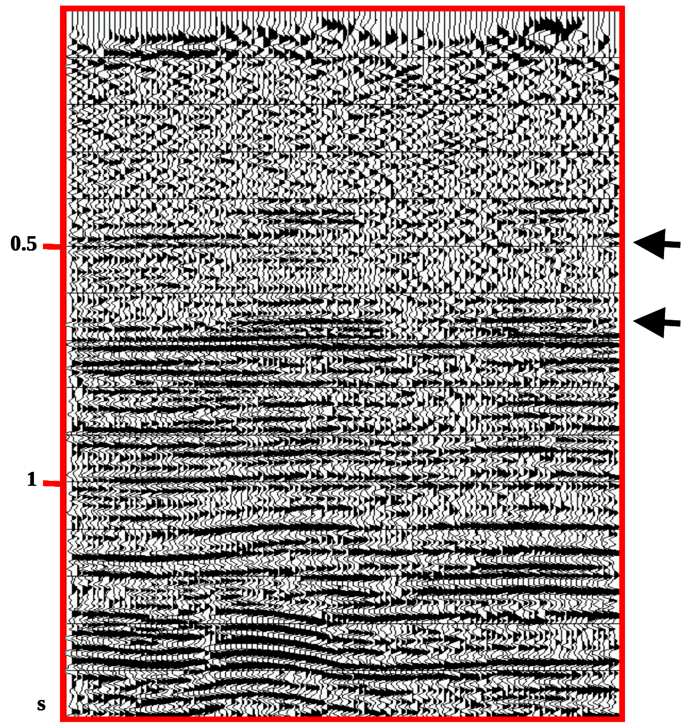


Figure 6: Stack after the application of a box-car perturbation on selected shots and receivers (50 ms).

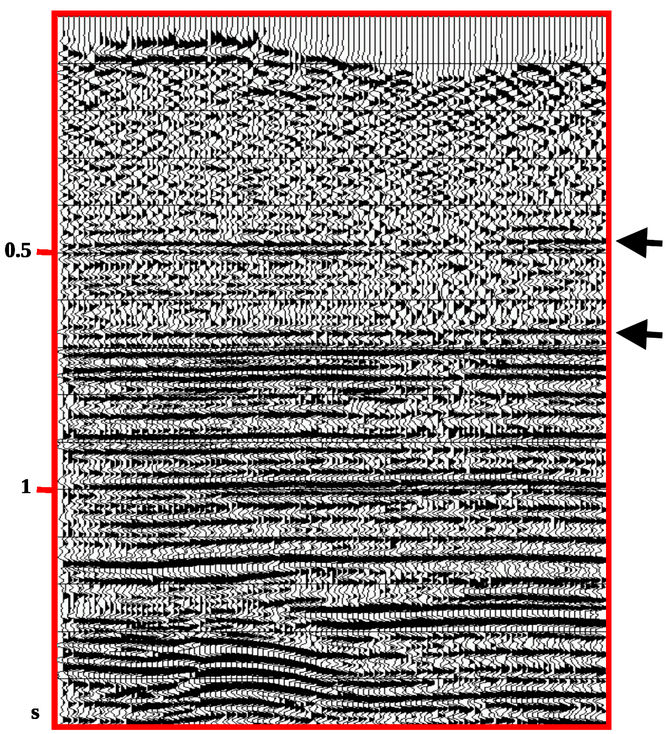
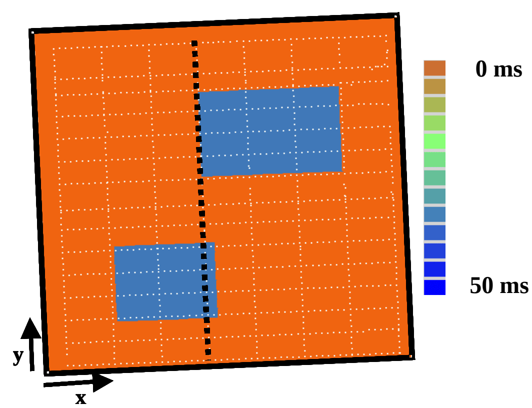


Figure 7: Stack after the estimation of the box-card perturbation on shots and receivers.



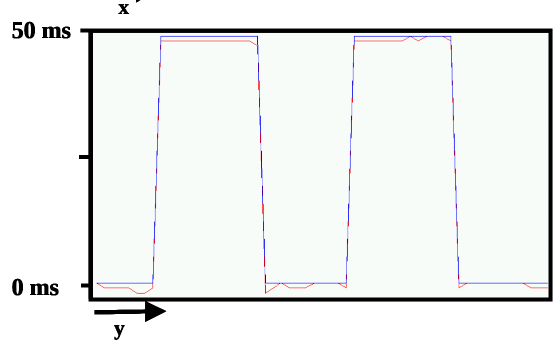


Figure 8a: location of the input box-car perturbation.
Figure 8b: Shot line (dashed line on Fig 8a):
the blue line corresponds to the input perturbation.
the red line is the estimation of the perturbation with the new tool.