A method for converted wave receiver statics correction in the CRG domain
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Summary

A method for receiver statics correction of converted waves (PS-waves) is proposed here. It is based on the observation that the static time delay on PS-wave events between two adjacent receivers, after the source statics correction has been applied, should correspond mostly to the differential receiver statics. The surface consistent statics model provides the theoretical framework. Adjacent Common Receiver Gathers (CRG) are crosscorrelated to obtain their time delay, namely their differential receiver statics. Stacking of PS-waves is not required, therefore the method does not depend on Vc (stacking velocity for converted wave), neither does it assume a simplified PS-wave stacking model. Application of receiver statics computed using this method on both synthetic and real data yielded encouraging results.

Introduction

The statics correction aims to overcome the delay caused by the near surface layer (NSL) on seismic data reflected from deeper layers. Since S-waves propagate more slowly than P-waves and are more affected by the NSL heterogeneity, their statics correction becomes more critical and difficult to obtain. S-waves correspond to the receiver statics correction in converted wave (PS-wave).

Several methods have been proposed for the PS-wave receiver statics correction, which can be grouped into two main approaches (Cox,1999): methods that require a NSL velocity model (datum statics) and methods based on the surface consistent model, analogous to the P-wave residual statics. The methods based on the NSL velocity model appear less accurate than what is required and the picking of events is frequently challenging (Schafer, 1993; Al-Dulaian and Stewart, 2010). The methods based on the surface consistent model are more popular (Harrison 1992, Cary and Eaton 1992) since they show the capability for short wavelength statics resolution. They require PS-wave reflections to be stacked and the calculation is frequently cumbersome and laborious.

An alternative approach to obtain the receiver statics correction for PS data is proposed in this paper. It is carried out on surface receiver gathers using data without NMO correction, based on the principle that all the PS-wave events of a common receiver gather are affected by the same S-wave static delay. Related techniques for conventional seismic data statics using prestack data in the surface domains Common Receiver Gather (CRG) and Common Shot Gather (CSG) can be found in Disher and Naquin (1970) and Cox (1999). The method’s principles and tests with synthetic and real data are presented in the following sections.

Theoretical background

The statics correction can be described by the surface consistent model, established by the following equation (Taner et al., 1974):

\[ T_{ijk} = R_{ij} + S_{ij} + G_{kj} + M_{ij} h_{ij}^2 \]

where

- \( R_{ij} \) = receiver statics at the \( i^{th} \) receiver position.
- \( S_{ij} \) = Source statics at \( j^{th} \) source position.
- \( G_{kj} \) = arbitrary time shift for \( k^{th} \) CDP gather (“geology”).
- \( M_{ij} \) = residual NMO component at \( k^{th} \) CDP gather, and \( h_{ij} \) = source to receiver distance.

The method proposed is based on the assumption that all the PS-wave events of a common receiver gather are affected by the same S-wave statics. Then, in principle, it would be possible to obtain the differential delay time between receivers from the delay time of each trace with the corresponding trace of the adjacent receiver. Thus we require traces organized into Common Receiver Gathers (CRG), namely traces recorded at the same receiver, generated by all sources.

The PS-wave events involved are illustrated in the sketch of Figure 1. Two adjacent receivers have a different near surface delay, which is common to all the traces of the same pair of CRGs, irrespective of the source. This delay should be detected by a method such as crosscorrelation (e.g. Li, 1999) applied to PS-wave reflections. We assume that the source statics (obtained from the PP-wave processing) have been already applied. Let us assume that \( G_{kj} \) (“geology” delay) is small, since the distance between reflections is small.

We could also assume that the NMO effect (\( M_{ij} h_{ij}^2 \) in Eq. 1) is negligible, taking into account the short distance between the reflections. However, the numerical experiments showed a meaningful effect related to the NMO. It can be considered a pervasive issue, taking into account that the distance between sources is usually larger and more irregular than the distance between receivers. An interpolation method to obtain the corresponding offsets, applying the \( \tau-p \) transform (see e. g. Margrave, 2007), was used to overcome this NMO delay. The raypath of these traces with the same offset to the adjacent CRG is illustrated by the dashed lines in Figure 1.
The differential delay time corresponding to two traces from adjacent receivers with the same offset can be found from the crosscorrelation:

\[
C_{h,j+1}^h(\tau) = \sum_i \frac{D_j^h(t)D_{j+1}^h(t+\tau)}{\sqrt{\sum_i D_j^h(t)^2 \sum_i D_{j+1}^h(t)^2}}
\]  

(2)

Where \(D_j^h\) is the trace with offset \(h\), and receiver location \(j\), and \(\tau\) is the time delay.

The differential delay time between two receivers then would be the summation of the delay between same offset traces, according to:

\[
\delta R_j = \max \sum_h C_{h,j+1}^h(\tau)
\]  

(3)

Finally the statics correction relative to a datum defined by the receiver \(m\) is

\[
R_i = \sum_{j=m} \delta R_j
\]  

(4)

Figure 1: The PS-wave events that arrive at two adjacent receivers (G1 and G2) with a differential time delay \(\delta R\) (statics) between them, illustrated by raypaths. The events generated by different sources (S1 and S4) should have the same differential delay \(\delta R\). However there is an additional delay generated by the different offset \(h\). The dashed rays illustrate the appropriate offset traces, which are obtained by interpolation.

**Application to synthetic data**

A test of this method on a synthetic model is shown in the following. The data were generated using Finite Difference elastic modeling. Figure 2 illustrates the S-wave velocity model. The surface, where sources and receivers are located, is assumed to be flat and 75 m deep. Receivers are separated by 5 m and sources are spaced at 20 m intervals. Besides the near surface layer, there are five layers each one characterized by its own velocity (Figure 2(a)). The S-wave velocity in the near-surface layer is made up of five lateral zones as shown in the close-up of Figure 2(b), and each one of them has an increasing gradient with depth.

Figure 3 shows the crosscorrelation results for each receiver location, namely the summation along all the offsets. The differential receiver statics (the maximum of Figure 3 for each receiver, which corresponds to the right hand side of Eqn. 3) is shown in Figure 4 (red crosses). Notice that the picks can be nicely related to the lateral velocity variations of the near surface in Figure 2(b). Figure 4 also shows the receiver statics calculation according to Eqn. 4 using the blue line composed by dots, assuming the datum at the first receiver of the left hand side (\(m=1\) in Eqn. 4). Figure 5 shows the application of the receiver statics correction to shot gathers. Notice that the continuity of the events has been improved after the application of the receiver statics (Figure 5(b)).

Figure 2. Synthetic model: (a) S-wave velocity model. The free surface is at \(z=75\) m. (b) A close-up of the near surface. Notice the lateral velocity variation in five zones and a velocity gradient in \(z\).

Figure 3: Stacked crosscorrelations for each receiver. Notice the time delay at the limit between the lateral zones of Figure 2.

Figure 4: Differential delay \(\delta R\), shown by red crosses, after the result of Figure 3(a) according to Eqn. 3. The blue line (dots) corresponds to the receiver statics correction, calculated from the differential delay according to Eqn. (4).
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Figure 5: Shot gathers after the application of the receiver statics correction of Fig. 3(b). (a) Before statics, (b) after receiver statics application. Notice the improved continuity of the events.

Application to real data: Spring Coulee, Alberta

We tested this method on a real 3C data set, the Spring Coulee 2008 survey. This is an experimental 2D3C seismic survey acquired by the CREWES project with the support of some sponsor companies at the Spring Coulee field in Alberta, Canada. Details have been published by the CREWES project (e.g. Lu and Hall, 2008; Al-Dulaian and Stewart, 2010). The seismic line selected for testing the method is 6500 m long, and is composed of 652 3C sensors separated 10 m from each other and uses 192 energy sources separated nominally at 30 m.

The result of the receiver statics correction test is illustrated in Figure 6, with PS-wave stacks before (Figure 6(a)) and after (Figure 6(b)) the receiver statics application. The data correspond to the radial component, after preprocessing that includes noise attenuation and deconvolution. The vertical component was processed previously to obtain a P-wave section, as usual in conventional multicomponent data processing (e.g. Harrison, 1992). The PS stacking velocity (Vc) is a preliminary approximation, obtained from P-wave stacking velocity assuming a Vp/Vs ratio of 2. The source statics correction had been applied previously, corresponding to the source statics of the P-wave. Asymptotic binning was applied to generate the gathers for converted wave stacking.

The only difference between the stack of Figure 6(a) and Figure 6(b) is the receiver statics correction. The events after the statics application are more coherent and correspond better to more advanced processing of the same data (e.g. Lu and Hall, 2008). The improved coherence would be a better basis for the PS-wave velocity analysis.

Conclusions

- We propose a method for PS-wave receiver statics correction based on CRGs without stacking PS-wave reflections.
- The method yielded promising results when applied to synthetic and real data.
- These test results also confirm the working assumptions, namely that there are coherent PS-waves in CRG data which yield meaningful information about the receiver statics time delay.
- The method can provide short wavelength receiver statics, is automatic and does not require a Vc (stacking velocity) model. These characteristics increase its potential for application to challenging issues, e.g. to relatively complex geological settings.

Figure 6: PS-wave receiver statics test on real seismic data from Spring Coulee. (a) PS-wave stack with elevation statics. (b) PS-wave stack with receiver statics according to the method proposed. Notice increased coherence of the events in (b) (an example shown by the arrow).

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