Addressing interferometric S-wave static corrections in the tau-p domain

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Summary

When velocity contrasts at the base of the near-surface layer are small, or when the base shows some degree of structural complexity, delay times of wavefronts transmitted through this layer may become raypath dependent. Due to the low velocity of S-waves this dependency is translated into significant non-stationary delays. In order to remove this effect we transform the data to a domain in which amplitudes are a function of the raypath angle. Processing the statics in the τ-p domain achieves this goal. The τ-p transform automatically scans the data and captures the intrinsic rayparameter values that represent the data. This idea was implemented and tested on the dataset from the Hussar experiment using an interferometric approach. Results showed that after removing the statics in the τ-p domain the stacking power and coherency of the events in the middle and deeper part of the section (1-3s) were improved. However, in the shallow part of the section (0-0.5s) we seem to lose vertical resolution. To improve these results, we need to address the artifacts and resolution of the τ-p transform. Trying a high resolution form of the τ-p transform will be the next step in this research.

Introduction

In processing multicomponent seismic data on land and on the ocean bottom, proper treatment of the effects of a complex near surface is a critical step. This is increasingly true as acquisition of broadband, wide-azimuth seismic data becomes the norm, and as the potential for full waveform inversion of land data becomes real, requiring both modelling of waves in the near surface and accurate accounting for surface wave modes. We seek an improvement in the converted wave statics solution not only to improve imaging, but also to extend the physical completeness of the earth model.

Within the context of seismic reflections, static time delays are the product of low-velocity sediments present near the surface. Changes in the velocity and thickness of these sediments introduce additional delays in the reflection traveltimes that may disturb the actual shape and alignment of the subsurface reflections. This problem is magnified in the case of converted-wave data due to the very low velocities of shear waves. In addition, the shear-wave velocity contrast at the base of the near surface may not be large enough to support the vertical raypath assumption that is conventionally used in the computation of static corrections. Cova (2013) showed how even if the velocity contrast at the base of the near surface is large, the presence of dip on this interface may cause raypath-dependent delays that may differ significantly from the vertical traveltimes in the near surface.

Henley (2012, 2014) showed how statics can be solved in the radial-trace domain by using the radial-trace (RT) and Snell-trace (ST) transforms. Both approaches solve the problem of raypath-dependent statics by moving the data to a domain where amplitudes are a function of raypath angle. However, both transforms make assumptions about the velocities controlling the changes in the rayparameter values. While the RT transform remaps amplitudes assuming an underlying constant velocity model the ST transform assumes a smooth velocity change with depth. Here we propose using the τ-p transform as a more complete way for moving the data to the rayparameter domain. In this study we will use the same interferometric approach presented by Henley (2012) but considering the τ-p transform as an alternative to move the data to a raypath-consistent framework. Results after processing the converted-

wave data from the Hussar experiment will be analyzed to show the pros and cons of computing shear-wave statics corrections in the τ-p domain.

The rayparameter domain

According to Snell's law the rayparameter "p" is a constant quantity when the propagation of the wavefield occurs in horizontally layered media. This principle of conservation of the horizontal slowness can be applied to the propagation of converted waves. This domain allows us to characterize the full raypath of a converted-wave by using a single rayparameter value despite the difference in velocity between the P- and S-wave legs.

When measured from data recorded with surface arrays, the rayparameter value is related to the emerging angle of the wavefield at the surface (Tatham, 1989). This feature makes the rayparameter domain a good candidate for understanding near surface effects. To transform the data to the rayparameter domain the "slant-stack" or τ-p transform can be used (Claerbout, 1975; Stoffa, 1989). The transform is achieved by stacking data along straight lines within a given range of slopes (p) and intercept times (τ).

Since seismic reflection data exhibit hyperbolic moveout, the τ-p transform amounts to scanning for all the possible tangents that define such hyperbolae. The "scanning" character of the transform means that no a-priori knowledge of the velocity model of the subsurface is required.

It is important to note that due to the limited aperture of the transform and limited bandwidth of the seismic data the transform process produces artifacts. This feature and the numerical incompleteness of its inverse transform are potential weaknesses when using the τ-p transform for solving statics problems.

Processing the Hussar data

Data from the Hussar experiment were used to test the performance of the proposed τ-p *solution*. Details about the acquisition of these data can be found in Margrave et al. (2011).

The interferometric approach used to solve the statics is very similar to the one introduced by Henley (2012). Figure 1 shows the processing workflow used in this research.
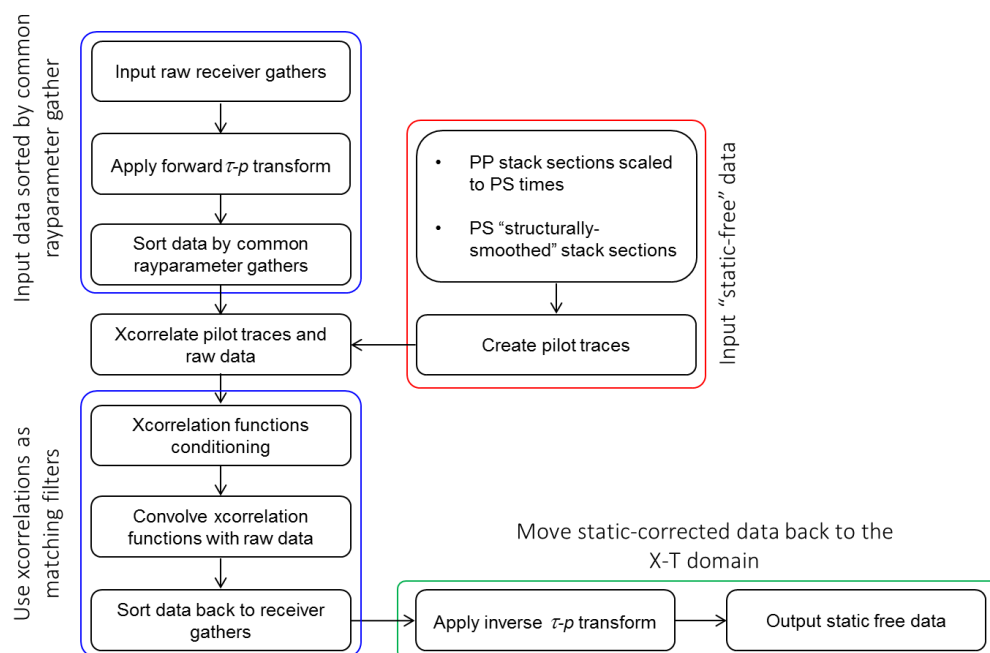

Figure 1: Interferometric static correction workflow.

The general idea is to retrieve the delay times caused by the near surface by cross correlating the raw data with a set of pilot traces. One difference with the work of Henley (2012) is that transformation to the rayparameter domain is done without applying a NMO correction. In this way any residual NMO present in the data is preserved and anisotropic analysis can be performed later.

Figure 2 (left) shows a raw radial-component shot gather. Static problems are evident between the offsets 1500m and 2000m. The event at 1.6s is being pulled down due to low velocities in the near surface.

The same shot gather after applying raypath-consistent static corrections is shown in Figure 2 (right). There we can see how the pull down of the events around 1.6s is removed. Furthermore, better coherency for the events below 0.5s and at large offsets can be observed.

Figure 3 shows the ACP stack before static corrections. There we can see how the static problems are clearly affecting the continuity of the events. This lack of continuity could be missinterpreted as faulting. However, the PP stack of the same line and general geological knowledge of the area indicate that significant faults are not expected to be found in this area.

The ACP stack after removing the statics in the τ-p domain is shown in Figure 4. There we can see how all the false structures displayed on the raw stack were removed and the data now show a very flat and coherent character. This is in agreement with the character of the events observed in the PP-stack.

The improvement in the coherence of the events may be caused, not only by the removal of the static problems, but at least partially by the filtering effect of the τ-p transform. Since only a finite range of p values can be used in the transform p values outside that range are thus automatically muted.

Conclusions

The solution of the shear-wave static problem in a raypath-consistent framework provides important improvements in coherency and resolution on the stacked sections. The τ-p domain solution demonstrated here achieved the goal of removing the reflection distortions caused by the near surface. One important feature of the interferometric approach is that no first break picking is needed, and no velocity model for the near surface was required in order to remove the statics. Nevertheless, the information about structure and velocities in the near-surface is contained in the crosscorrelation functions used to remove the statics, and can be used to construct a near-surface model for use in other processing.

The most important concern with the τ-p transform resides in its invertibility. Due to the band-limited character and finite aperture of the data the inverse transform from the τ-p to the x-t domain loses resolution. For this reason the use of a high resolution τ-p transformation must be tested in future work.
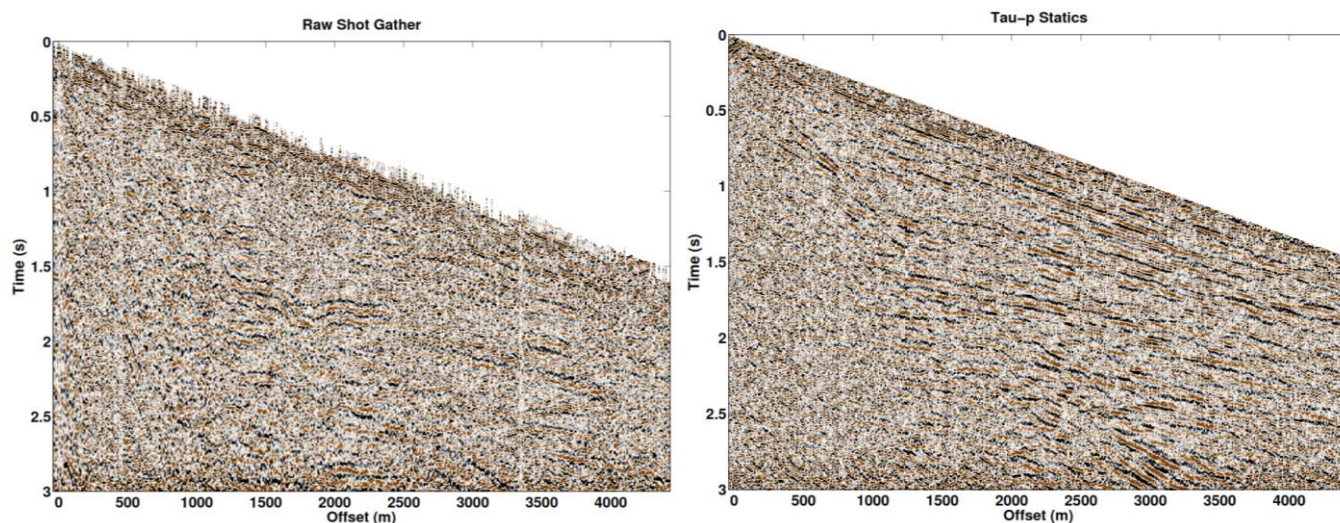

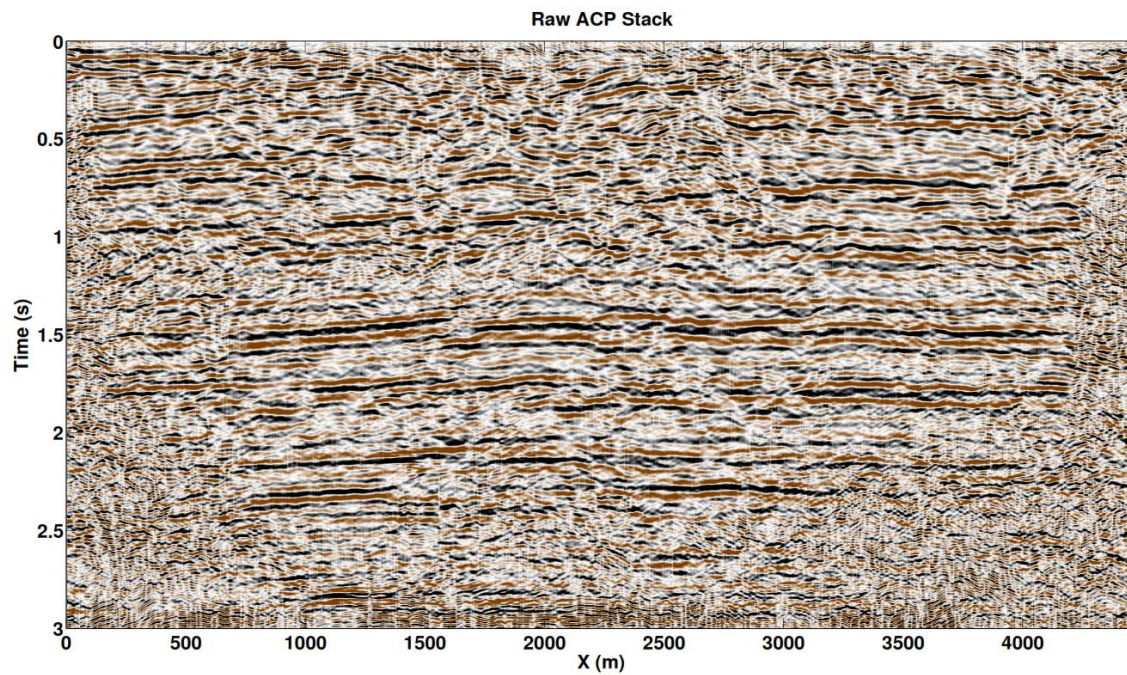Figure 2: Shot gather before (left) and after (rigth) receiver static corrections

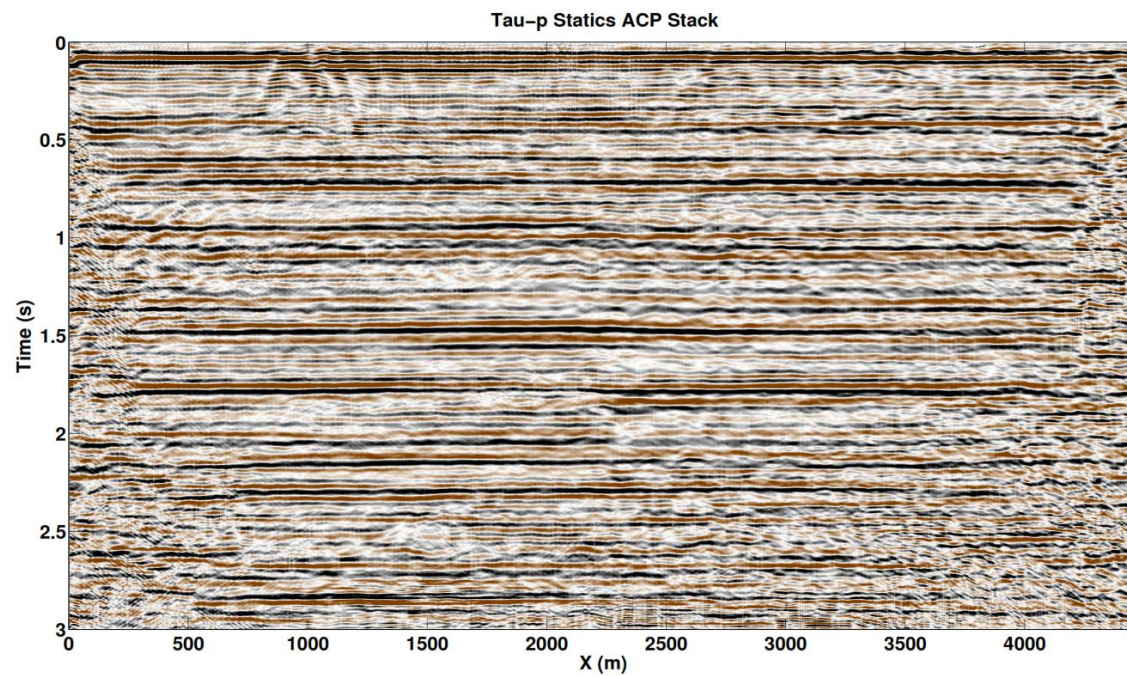**Raw ACP Stack**

Figure 3: ACP stack before static corrections.

Tau−p Statics ACP Stack

Figure 4: ACP stack after S-wave static corrections.

Acknowledgements

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