Surface-consistent amplitude simultaneous joint inversion for PP and PS data

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Summary

Surface-consistent amplitude corrections are commonly used to correct for the amplitude variations due to near-surface conditions in land processing. Usually, the corrections for PP and PS datasets are computed separately. There are, however, sound geophysical reasons why a subset of these scalars should be common or shared between PP and PS data. The simultaneous joint estimation of the source and receiver correction scalars for PP and PS datasets that we propose is a way to ensure the consistency of the surface-consistent corrections for both datasets. It also enables a better estimation of the source term which must be identical for PP and PS traces originating from the same shot to be in accordance with the surface-consistent model. When performing surface consistent amplitude corrections of PS datasets, only the radial projection is usually used for the estimation of surface-consistent scalars. As regards the simultaneous joint inversion we also investigated the use of the transverse projection in addition to the radial projection for completeness.

Introduction

Surface-consistent amplitude corrections are commonly used in seismic processing to correct for amplitude perturbations due to near-surface conditions ranging from coastal salt areas, sabkhas in north Africa and Arabia, dunes in desert areas, foothills and Artic or swamp soils. The typical approach to tackle this issue is to decompose the RMS amplitude of each seismic trace from a dataset into the combination of a source term A_s, a receiver term A_r and a mean amplitude term A_m (Taner and Koelher, 1981) as $A = A_m . A_s . A_r$. To refine this model, other terms can also be added. A bin term A_b can, for instance be used to incorporate mid and long wavelength structural variations. An offset term may also be inserted in order to compensate strong attenuation due to complex wave propagations.

In the log-frequency domain, Taner's surface-consistent assumptions become a linear system of equations which can be inverted using one of the many techniques available for the resolutions of linear systems of equations. Garceran and Le Meur (2012) used a Gauss-Seidel inversion scheme.

Due to the slower velocities of shear waves, PP and PS data are characterized by different time scales and seismic events are not at the same time location. To enable comparisons between datasets, PS data can be squeezed to PP time using an estimation of the P-velocity to S-velocity (gamma) ratio. Several techniques are available to estimate this key value, based on optimal correlation between opposite azimuth stacks or derived from transit times as explained by Garotta et al. (2003). In this paper we describe how we can take advantage of the correspondences between PP and PS datasets, enabled by a first estimate of the gamma ratio to build a method for a simultaneous joint inversion of surface-consistent corrections for PP and PS datasets.

Method

Starting from a first estimate of the gamma ratio, the radial projections of PS traces are first squeezed to PP time to relocate the energy of converted waves in a similar way to the PP events. A first correction of the shear wave splitting effects in the PS dataset, due to the near-surface layer, prior to surface-consistent amplitude correction is recommended to transfer most of the PS energy on the radial component and increase the similarity between PP and PS datasets after the PS squeezing. The critical pre-processing step is the de-noising, especially on the PS data, in order to avoid computing RMS amplitude scalars on data dominated by only noise. Moreover, existing PP and PS velocity fields as well as statics could help to assure that both PP/PS RMS amplitudes are related to the same geology.

The absence of sensitivity to fluids presented by shear waves, and more generally, the different sensitivities of compressional and shear waves to the lithology, make it difficult to obtain fully comparable datasets in terms of short wavelength amplitude variations, even after PS squeezing. However, to isolate amplitude effects related to the near-surface, we compute and apply a global amplitude equalization term prior to our joint inversion.

To catch only the effects of the near-surface conditions on the trace amplitudes and to take into account short wavelengths directly linked to the geology, the window used for the amplitude computation has to be relatively large. After the pre-processing step and the PP /PS amplitude computation, a joint inversion process is done. This inversion computes: a common source scalar, each individual PP and PS receiver and offset scalars in a surface-consistent manner. More precisely, Taner and Koehler (1981) surface-consistent equations can be written in this case as:

$$\forall (i,j,k) \in B \text{ x } C \text{ x } D,\ A_{i,j} = A_m A_{si} A_{rj} A_{ok} \quad (1)$$

DOI http://dx.doi.org/10.1190/segam2014-0518.1

where **i** is the index of the shot-point (common to PP and PS datasets), j is the index of the receiver (the same receiver has a different index for PP and PS traces) and k is the index of the offset class (different indexes for PP and PS traces)

- $\mathbf{A_m}$ is the average amplitude of a trace of the two datasets (a single value for the two datasets after application of an equalization gain),
- $\mathbf{A_{si}}$ is the correction scalar for the source i,
- $\mathbf{A_{rj}}$ is the correction scalar for the receiver j
- $\mathbf{A_{ok}}$ is the correction scalar for the offset class k,
- **B** is the set of all shot-point indexes,
- **C** is the set of all PP and PS receivers indexes,
- **D** is the set of indexes of the chosen PP and PS offset classes (geometry dependent choice)

We can linearize system (1) using the log:

$$\forall(i,j,k) \in B \times C \times D,$$

$$\log A_{i,j} = \log A_m + \log A_{si} + \log A_{rj} + \log A_{ok} \quad (2)$$

Removing the constant term $\log A_m$, identical for PP and PS datasets because of the equalization performed in the preliminary steps, we can rewrite the system (2) in matrix notation as Ax = b (3), where

- **A** is a sparse matrix containing only zero, one and two values,
- **x** is a vector of size card (B) + card (C) + card (D) containing the source, receiver and offset terms,
- **b** is a vector containing the log-amplitudes of all the PP and PS traces

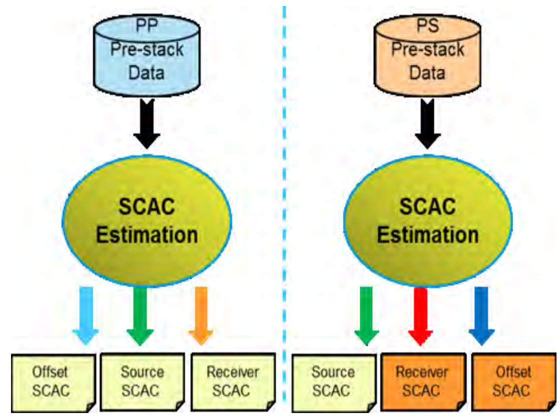
To solve this over-determined linear system, we can use the least squares solution

$$x = (A^tA)^{-1} A^t b \quad (4)$$

This is equivalent to solve the system

$$A^tA\, x = A^t b \quad (5)$$

A Gauss-Seidel iterative process is then used to solve (5) for all source, receiver and offset scalars simultaneously.



b)

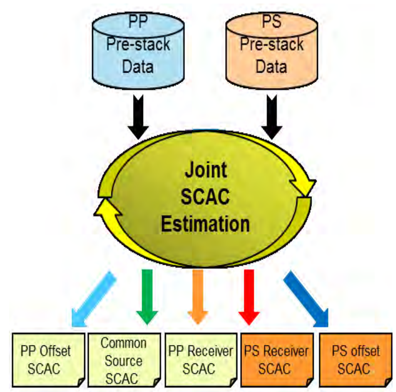


Figure **1**: **a)** description of the conventional parallel SCAC flow; **b)** description of the simultaneous joint SCAC flow.

Results

Here, on a 3D/3C wide-azimuth land data, we compared the results obtained with the conventional parallel flow and the simultaneous joint flow for the determination of the PP and PS surface-consistent amplitude corrections (SCAC).

Three scalars are usually computed in the conventional flow (offset, source, and receiver) for PP and PS dataset respectively (Figure 1-a). For the simultaneous joint flow, five scalars are computed, which are: the common source term, each individual PP and PS receiver and PP and PS offset terms (Figure 1-b).

The source (Figure 2) and receiver (Figure 3) scalars obtained with the conventional and the joint flows have a similar trend with similar patterns representing near-surface amplitude anomalies. Due to the large range of offsets involved (~4000m), the insertion of an offset term

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a)
b)
c)

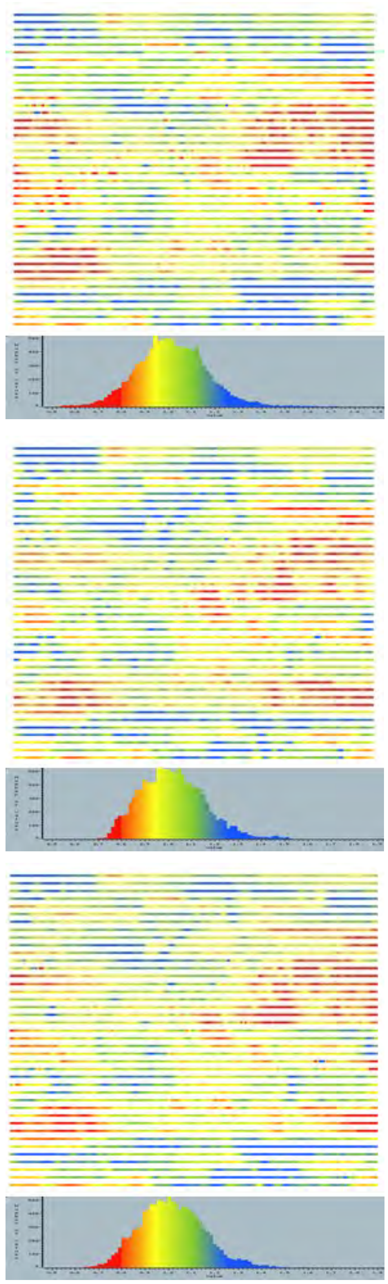

Figure 2: Shot point scalars a) for the PP dataset, computed with the conventional parallel SCAC flow; b) for the PS dataset, computed with the conventional parallel SCAC flow; c) computed with the simultaneous joint SCAC flow.

was clearly needed to correct for strong amplitude variations with offsets (Figure 4-a, 4-d, 5-a and 5-d).

a)
b)
c)
d)

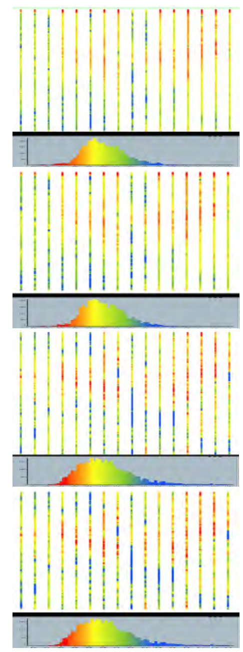

Figure 3: Receiver scalars a) for the PP dataset, computed with conventional parallel SCAC flow; b) for the PP dataset, computed with the simultaneous joint SCAC flow; c) for the PS dataset computed, with the conventional parallel SCAC flow; d) for the PS dataset, computed with the simultaneous joint SCAC flow.

The source and receiver lines (Figures 4-b-c, 4-e-f, 5-b-c and 5-e-f) are slightly better balanced in terms of amplitude for the whole offset range after the joint flow. These results illustrate the validity of the simultaneous joint approach for both PP and PS surface-consistent amplitude corrections.

Use of the transverse for the joint PP-PS SCAC flow

The computation of the PS RMS amplitude using the radial projection only is sufficient and even recommended in most cases because of the low signal to noise ratio of the transverse projection of the PS data. However, for datasets with significant shear wave splitting effects, the L2 norm of the horizontal components can be used for the PS RMS amplitude computation in order to recover the energy of the signal present on the transverse projection (not shown).This variable is completely independent of orientation and mainly reflects the amount of shear wave energy arriving at the given time at a receiver station.

As the signal to noise ratio of the transverse projection is generally poor compared to the radial, benefit from the use

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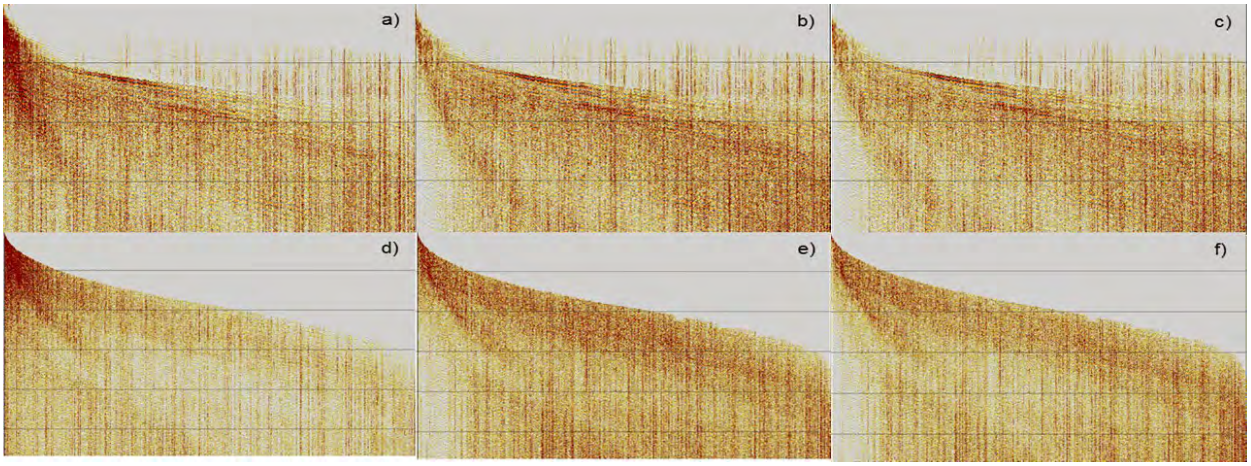

Figure 4: PP receiver gather in PP time, a) Input data, b) After the conventional parallel SCAC flow, c) After the simultaneous joint SCAC flow. - PS receiver gather in PS time, d) Input data, e) After the conventional parallel SCAC flow, f) After the simultaneous joint SCAC flow.

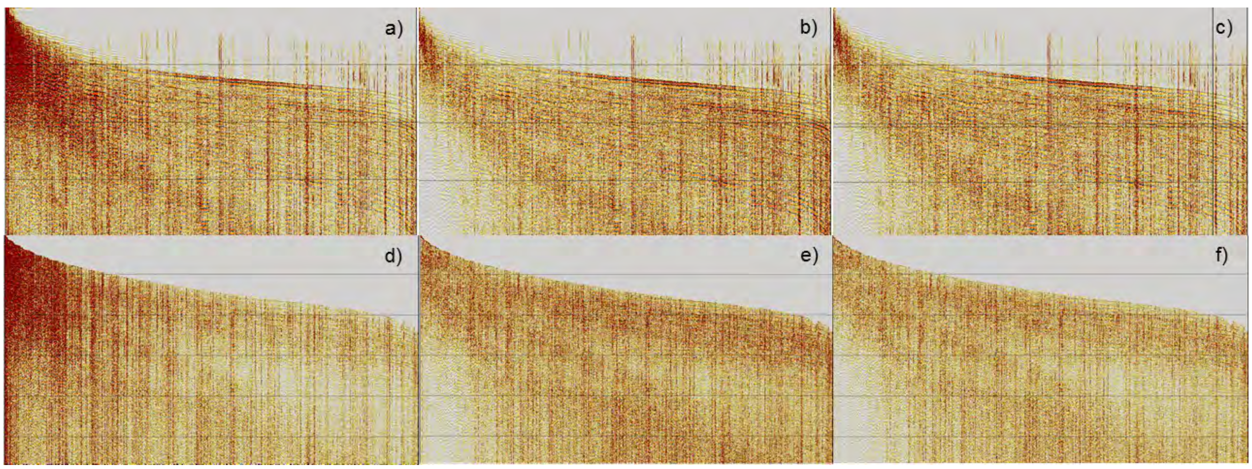

Figure 5: PP shot point gather in PP time, a) Input data, b) After the conventional parallel SCAC flow, c) After the simultaneous joint SCAC flow. - PS shot point gather in PS time, d) Input data, e) After the conventional parallel SCAC flow, f) After the simultaneous joint SCAC flow.

of the transverse projection for the scalar computation is very data dependent.

Tests of PP-PS Radial-Transverse SCAC don't reveal much change of the surface consistent scalars compared to the joint PP-PS Radial SCAC. It can be explained by the small amount of coherent energy observable on the transverse projection of the dataset used for the tests (not shown).

Conclusions

In this paper, we propose to estimate the surface-consistent amplitude correction scalars for PP and PS datasets simultaneously. This simultaneous estimation enables us to obtain comparable results to those obtained with the conventional parallel workflow. A slightly better amplitude balancing for source and receiver lines have been observed with the joint flow.

This simultaneous joint approach has the advantage to offer a way to simplify PP and PS processing projects with the guarantee to offer coherent results for both PP and PS data which is crucial for AVO analysis. We also investigated the possibility to include the transverse projection of PS within the datasets used for the joint simultaneous inversion. Our joint inversion scheme is able to handle it, but this possibility has to be kept for special datasets which contain a large amount of coherent energy on the transverse.

Acknowledgements

We thank all our colleagues from CGG which helped us in this project and CGG to allow us to publish this paper.

DOI http://dx.doi.org/10.1190/segam2014-0518.1

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EDITED REFERENCES

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