Monte-Carlo Statics on P-P or P-Sv Wide-Azimuth data
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Summary

Estimation of surface consistent residual statics on 3D wide-azimuth P-P or P-Sv data using a Monte-Carlo approach is a challenge. This non-linear method that uses Simulated Annealing is known for its efficiency to compute large magnitude statics but is also characterized by a high computation cost. However, by using advanced methods like High Performance Computing (HPC), the computation cost of this not “embarrassingly parallel” algorithm can be drastically reduced. This paper demonstrates that a non-linear approach to estimate large magnitude Monte Carlo statics either on P-P or P-Sv data is now possible with a reasonable turn-around. Moreover, this can be done without splitting or chunking the statics computation into several swaths.

Introduction

Conventional approaches in evaluation of residual statics on P-P or P-Sv data are mostly based on a linear inversion scheme that uses cross-correlation functions (Ronen, 1985, Jin et al. 2004) or the trace-to-trace coherence of Common Receiver Stack section (Cary and Eaton, 1993). Rothman (1985) and Vasudevan et al. (1991) showed that the estimation of large magnitude statics is better handled with a non-linear scheme based on a Monte-Carlo method coupled with a Simulated Annealing approach. This non-linear method shows promising results on 2D and 3D narrow/wide-azimuth P-P surveys (Le Meur and Poulain, 2011).

Nevertheless in converted waves processing, shear wave receiver statics are characterized by a large magnitude which can be two to ten times greater than P-P static values as well as by a noisier input data than the P-P data. In this paper, we propose to overcome the issues described above by computing large magnitude residual statics with a non-linear approach at a reasonable cost using advanced High Performance Computing methods. The efficiency of such an approach is presented on a 3D P-P and a P-Sv wide-azimuth land datasets.

Description of the Method

Different methods are used in computing surface-consistent residual statics on P-P data and receiver statics on P-Sv data (Marsden, 1993). Most of these methods are based on the use of the cross-correlation functions and solution of linear system of equations which very frequently give a local minimum solution. A non-linear approach, however, that uses the Simulated Annealing concept (Kirkpatrick et al., 1983) coupled with a Monte-Carlo technique (Metropolis et al. 1953) allows computing residual statics at the global minimum. In this technique, the cost function usually increases (called the crystallization step) when a certain set of statics and an ad-hoc temperature is achieved (cooling schedule). Different kinds of cost functions can be used; they are based on either the stack power (Rothman, 1986) or the coherence of the neighboring pre-stack gathers to optimize the reflections on the final stack (Vasudevan et al., 1991).

The Monte-Carlo approach we chose to implement to compute surface-consistent residual statics on P-P or P-Sv data uses a cost function that is based on the coherence of the stack accompanied by some robust criteria to stabilize the results (Le Meur and Merrer, 2006). The cooling schedule is computed as a function of the number of iterations and the initial temperature $T_0$. This temperature is determined during a pre-processing step of tens of iterations that precede the non-linear inversion. The whole process contains hundreds of simulations, each of which is randomly explored for all the shot points and receivers stations to avoid bias and cycle-skipping (Dahl-Jensen, 1989). For each selected shot point and receiver station, a random static value is chosen and applied to the prestack data. The cost function variation reflects then the influence of this random static shift through the neighboring CMP gather (Common Mid Point for P-P data) or ACP gather (Asymptotic Conversion Point for P-Sv data); if the variation is positive the static shift is accepted, otherwise the static acceptance depends on the metropolis criterion that uses the Simulated Annealing concept. In this technique, the cost function usually increases (called the crystallization step) when a certain set of statics and an ad-hoc temperature is achieved (cooling schedule). Different kinds of cost functions can be used; they are based on either the stack power (Rothman, 1986) or the coherence of the neighboring pre-stack gathers to optimize the reflections on the final stack (Vasudevan et al., 1991).

High Performance Computing implementation

Data access is the main bottleneck when non-linear methods based on Simulated Annealing are used on 3D wide-azimuth surveys. At each simulation step, stations must be visited in a random order. For each station, two associated collections (shots or receivers and CMP or ACP gathers) are used to compute the cost function (Figure 1). As several hundreds of simulations are necessary for convergence, this means that the input prestack dataset has to be read several hundred times in a random order! Moreover, the algorithm is not “embarrassingly parallel”. Indeed, for a given simulation step, residual static
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corrections cannot be computed independently because stations overlap each other in the CMP or ACP stack domain, i.e., the algorithm cannot be massively parallelized in stations domain. Processing 3D surveys in a reasonable turn-around time was a real challenge for that method.

We succeeded in running our implementation on a 3D P-P/P-Sv survey in a very similar turn-around time to the ones obtainable with linear inversion methods. The algorithm’s implementation can process a 3D survey efficiently without chunking the input data by swaths thanks to a careful fine-grained multi-core parallelism as well as some software optimization. These High Performance Computing techniques allow us to minimize the data access time and therefore to improve the efficiency of the non-linear inversion.

Examples

Two examples demonstrate the efficiency of our Monte-Carlo approach on a 3D P-P and a P-Sv land survey. These successful results have been obtained in a reasonable turn-around time before compared to a conventional linear approach.

The first example is a 3D P-P wide-azimuth survey of several tens of terabytes of input prestack data containing more than 100,000 shot and receiver stations and an offset range up to 3000 m in both inline and broadside directions. The input data was previously corrected with an isotropic velocity field to flatten the gathers as much as possible. The benefit of such surface-consistent Monte-Carlo statics can be observed on the stack section. On the raw data, the shallowest reflectors show a lack of continuity (Figure 2a) that has been restored after application of the Monte-Carlo surface-consistent residual statics (Figure 2b). Moreover, the continuity of the reflectors in the deeper part is enhanced and sharper fault delineations are now apparent (Figure 2b).

The second example is a 3D P-Sv wide-azimuth survey. Here, the pre-stack input volume is more than several tens of gigabytes containing around 1500 shot points and 4000 receiver stations. The shot and receiver distribution is very irregular due to field constraints and consequently introduced a high variability of the fold coverage inside each ACP gathers. A computation of receiver statics has been done using our non-linear Monte-Carlo approach and compared with a conventional approach based on Cross-Correlation Functions. Both receiver statics solutions were applied on the pre-stack data before performing the ACP stacks. The benefit of the Monte-Carlo static can be observed on the stack section below. On the left hand side part of the raw ACP stack, reflectors show a lack of continuity in the very shallow and very deep part of the section (Figure 3a). The continuity has been partially restored after the application of the receiver statics computed with a linear approach (Figure 3b). Moreover, this continuity of reflectors in the shallow and in the deeper part has been enhanced after the application of the Monte-Carlo receiver statics (Figure 3c). The magnitude of the Monte-Carlo receiver statics were as high as 80 ms on some part of the section which is difficult to recover with a linear approach.

Conclusions

The Monte-Carlo method coupled with a Simulated Annealing process is a very powerful approach to compute large magnitude residual statics on P-P or P-Sv waves. The real challenge is to perform it on a 3D wide-azimuth survey in a reasonable time schedule. This result was made possible by using advanced High Performance Computing methods. Such non-linear approach offers a new alternative to compute large magnitude surface-consistent residual statics on very noisy data acquired on difficult environments for 3D P-P or P-Sv wide-azimuth data.

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Figure 1 - HPC processing flow implementation

Figure 2 - (a) Stack without s.-c. residual statics, (b) Stack after the application of s.-c. Monte-Carlo statics solution
Figure 3 - (a) ACP Stack without receiver statics, (b) ACP Stack with conventional receiver statics solution, (c) Stack with Monte-Carlo receiver statics solution.
EDITED REFERENCES
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