Monte-Carlo Residual Statics – Seismic Processor’s Dream


kumar_gvr@ongc.co.in

Keywords
Residual statics, Monte Carlo, Simulated Annealing, Non linear inversion

Summary
Most Surface-Consistent (SC) residual statics estimations are based on the results of cross-correlation functions and use an inversion with a linear system that can produce solutions trapped in a local minimum. In order to find the solution at the global minimum, a nonlinear approach based on the Monte-Carlo method with a Simulated Annealing (SA) scheme using prestack data is presented. The efficacy and the robustness of this method to compute SC residual statics will be demonstrated on a real 3D data from Krishna-Godavari basin, India.

Introduction
The idea behind the Monte-Carlo method is old, but its actual application to the solution of scientific problems is closely connected to the advent of modern computers. An interesting approach to the solution of large statics anomalies has been proposed by Daniel Rothman (1985, 1986). The algorithm which he proposed called Simulated Annealing uses a Monte-Carlo optimization technique which solves the statics problem in a way that is similar to sudden crystallization in a melt. Keeping up with this physical analogy, the statics are like molecules, and the algorithm allows the temperature of the system to change while keeping the molecules in thermal equilibrium. Although this method is nonlinear, it preserves the surface consistent approach. Rothman also uses the concept of stack power, introduced by Ronen and Claerbout (1985), to measure the effectiveness of his method. Stack power is a power estimate based on the sum of the squared amplitudes of the CMP section. The best estimate of the statics is thus the solution which maximizes stack power. This method utilizes the stack power concept by first randomly generating sets of statics. After the random statics have been generated, they are applied to the data, and a stack is generated. If the stack power is plotted as a function of iteration, a point is reached at which the true statics suddenly crystallize. Rothman (1985) applied Monte-Carlo method on field data from Wyoming over thrust belt and shown that this method yields better estimates of residual statics than the conventional method. Le Meur and Merrer Sophie (2006) applied Monte-Carlo technique on 2D and 3D seismic data from Canadian Foot hills and Northern Alberta and achieved successful results than that of methods using linear approach. Conventional residual statics programs for mode converted data often create “cycle-jumps” due to large magnitude of the shear wave statics. Methods like cross-correlation function (Jin et.al 2004), and trace-to-trace coherence of the common receiver stack (Cary and Eaton, 1993) using linear inversion failed to produce good results. Chapman et.al (2013) demonstrated that Monte-Carlo approach using Simulated Annealing is effective in resolving PSv statics when applied on a real data which is noisy, having large residuals and complex structure from North West Territories of Canada. In his approach the conventional linear scheme estimated the statics up to 100 ms and still having areas with poor reflection continuity. The non linear Monte-Carlo technique using Simulated Annealing allowed the resolution of receiver statics up to 220 ms creating stacks with much better continuity.

In this paper, the authors have used Monte-Carlo method using Simulated Annealing technique for computing the residual static correction for a 3D dataset from Krishna-Godavari basin and applied. It is found that the method is very powerful and can deal with large statics. When compared with standard method of residual estimation, Monte-Carlo method has provided stupendous result. The advantages of this method are discussed.

*Processing Centre, GPS, Chennai
Monte-Carlo Residual Statics – Seismic Processor’s Dream

Theory and Method

Conventional methods of residual statics estimation obtain solutions by performing linear inversion of observed travel time deviations. A vertical component of the procedures is the packing of time delays. Gross errors in these picks are known as “cycle skips” and are the bane of linear travel time inversion scheme. Rothman (1985) demonstrated that the estimation of large statics in noise contaminated data is posed better as a nonlinear, rather than as linear, inverse problem. Cycle skips then appear as local minima of the resulting nonlinear optimization problem. To perform global optimization, Rothman (1985) adopted a Monte Carlo technique that originated in statistical mechanics and applied this technique to synthetic data as well as to field data from the Wyoming overthrust belt.

Most surface consistent residual statics estimations are based on the results of cross-correlation functions and use an inversion with a linear system that can produce solutions trapped in a local minimum. In order to find the solution at the global minimum, a nonlinear approach based on the Monte-Carlo method with a SA scheme using prestack data is presented. The efficacy and the robustness of this method to compute SC residual statics will be demonstrated on a real 3D data from Krishna-Godavari basin, India. M/s CGG’s standard surface consistent residual statics has been rather unique and provide the near accurate static solutions using linear inversion but fails to work for large static anomalies or long wavelength statics.

Methodology

In this study, the Monte-Carlo method used within the simulated annealing approach is an updated version of the objective function published in Vasudevan et. al. (1991), which gives more stable and robust results.

\[
\sum_{i \neq j} \sum_{k} \sum_{l} \sum_{m} \sum_{n} \sum_{p} \sum_{q} \left( \left( \sum_{r} f_{r} \right) + \sum_{s} f_{s} \right) + \sum_{t} f_{t} + \sum_{u} f_{u} + \sum_{v} f_{v} + \sum_{w} f_{w}
\]

The cooling schedule (2) is computed as a function of the iterations (t) and initial temperature \( T_0 \) where \( T_0 \) is a function of the initial RMS energy (RMS0).

\[
T(t) = a^t \beta \cdot \text{RMS}_0
\]

Each iteration processes every shot and receiver randomly to avoid bias or cycle-skipping (Dahl-Jensen, 1989). For each selected shot or receiver, a random value is chosen in a pre-defined static range and applied to the pre-stack data. The difference in the energy function between the new and old state is computed \( \Delta E = E_{\text{new}} - E_{\text{old}} \) which reflects the fluctuation of the coherence in the CDPs. If \( \Delta E \) is negative the static shift is automatically accepted. If \( \Delta E \) is positive, the decision to keep it or not is made using the Metropolis criteria (3):

\[
p = \exp\left(\frac{-\Delta E}{T}\right)
\]

Each iteration is completed when every shot and receiver has been processed once. Maintaining the cooling schedule, hundred iterations are necessary to obtain a jump in the energy function, which characterizes the crystallization stage. The process continues with additional iterations until minor changes in shot and receiver statics are observed.

Case study

A 3D seismic dataset from Krishna-Godavari basin is taken up for calculating residual statics using Monte Carlo method within the Simulated Annealing approach. For this dataset before starting of the computation of the surface consistent residual statics process, a random perturbation was applied to each shot and receiver between a range of +/- 40 ms. The dataset consisted of 12620 shotpoints and 32322 receivers. The calculation window is set from 500 ms to 3000 ms. The maximum static correction allowed during computation is +/- 40 ms. The initial temperature is fixed up at 7.84 X 10^{10}.

At the end of first iteration the energy growth is -12.05 percent. At the end of iteration 116 the energy growth was 8.89 percent. During cooling process the temperature was set at 9.98 X 10^{10}. The change in the stack power through the iterative process is underlined by the energy function.
versus number of iterations. Until 116 iterations, the energy level stayed low providing nonoptimal surface consistent residual static values and defocused the CMP stack. The crystallization stage started at initial temperature $9.98 \times 10^{10}$ and after 123 iterations maximum stack power was achieved.

Residual static corrections are also computed and applied for the same data using conventional method which uses linear inversion with the same parameters as above. The maximum and minimum residual static correction estimated from the conventional method are -22.96 to 22.99 ms for source and -23 to 23 ms for receiver. The maximum and minimum residual static correction estimated from Monte-Carlo technique are -24.7 to 35.3 ms for source and -33.2 to 34.0 ms for receiver.

Fig.1(a) Source statics from conventional residual statics calculation.

Fig.1(b) Source statics from Monte-Carlo method.

Fig.1(c) Receiver statics from conventional residual statics calculation.

Fig.1(d) Receiver statics from Monte-Carlo method.
Monte-Carlo Residual Statics – Seismic Processor’s Dream

Fig. 4. (a) Stack without residual statics (b) residual statics applied from a conventional approach (c) residual statics computed using Monte-Carlo approach.

Fig. 5. Zoomed image of Fig. 4 showing (a) residual statics applied from a conventional approach (b) residual statics computed using Monte-Carlo approach.

Fig. 6. (a) Stack without residual statics (b) residual statics computed using Monte-Carlo approach.

Fig. 7. (a) Stack without residual statics (b) residual statics computed using Monte-Carlo approach.

Fig. 8. Zoomed image of Fig. 7 showing improvement in the shallow part.

Fig. 9. (a) Stack without residual statics (b) residual statics computed using Monte-Carlo approach.
Monte-Carlo Residual Statics – Seismic Processor’s Dream

Fig.10. Zoomed image of Fig.9 showing improvement in the shallow part.

Conclusions

The Monte-Carlo method within Simulated Annealing process is a very effective approach to compute surface consistent residual static corrections for seismic data. This non-linear approach is the tool to obtain a set of surface consistent residual statics at the global minimum instead of at local minimum as other linear approaches do. Examples demonstrate significant benefits of this technique to obtain high resolution images for a 3D land seismic dataset. The other advantages of this method are:

a) the data need not be sorted
b) can be used for data sets requiring large static corrections up to 100 ms like foot hills and other fold belt areas
c) static corrections can be computed swath-wise even for over-lapping swaths
d) the method needs to be implemented in multi-threading environment to speed up computation.

References

Alice Chapman, Steve Zamfires and Guillaume Poulain, 2013, Monte-Carlo Statics on PSv data, Integration, Geoconvention.

Acknowledgment

Thanks are due to Director (E), ONGC, for according permission to publish/present this paper. The views expressed in this paper are solely of the authors and do not necessarily endorse by ONGC.
Authors are indebted to Sh. T. Rajendran, GGM (Geology), Basin Manager, Cauvery basin and Sh. S.K. Kaplesh, GM (GP), HGS, Chennai for their constant encouragement and support throughout this study.