EOMAP residual statics: application to Marmousi model data with synthetic statics

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ABSTRACT

The equivalent offset mapping (EOMAP) residual statics method was used to estimate the synthetic static time-shifts added in the Marmousi model data, where most conventional methods fail to provide reliable statics estimations. The application results show that the EOMAP method can, in only one iteration and with satisfactory accuracy, estimate residual statics in data from area with complex subsurface velocity structure. In addition, the EOMAP method does not require accurate stacking or migration velocity information and can, in fact, be used without any velocity information at all.

INTRODUCTION

The EOMAP statics method includes two mappings (forward and inverse), called equivalent offset mappings or EOMAPs, between the source-receiver offset and the prestack migration equivalent offset (Bancroft et al, 1998). The forward mapping forms a partial migration process and the inverse mapping forms a pseudo-modelling process.

Seismic data with possible statics problems is first transformed to the equivalent-offset domain and prestack migration gathers (called common-scatter point (CSP) gathers) are formed. According to the original trace geometry of the seismic data, a set of “modelled” data is generated by inverse EOMAPs from the CSP gathers. As a result, every original seismic trace has its own unique model trace, which should have fewer traveltime errors due to the high fold superpositioning of both the forward and inverse EOMAPs.

The EOMAP method of generating model data for statics analysis can be graphically illustrated using the analogues of both Cheop’s pyramids and diffraction hyperbolas related to prestack migration concepts. As shown in Figure 1 (a), the diffraction energy from a certain scatterpoint in the subsurface can be approximated by a Cheop’s pyramid in the prestack data volume, and the seismic experiment can be represented as a relation between all subsurface scatterpoints and their corresponding Cheop’s pyramids. In this representation, modelling is a process that creates Cheop’s pyramids from the scatterpoints, while migration is a process recovering the scatterpoints from Cheop’s pyramids in the recorded seismic data.

The equivalent offset migration (EOM) method (Bancroft et al, 1998) introduces an intermediate product between scatterpoint and Cheop’s pyramid. This product is a hyperbola on the surface of the Cheop’s pyramid, which divides the whole migration process into two processes. The first process collapses Cheop’s pyramid into hyperbolas in the offset direction, which is the forward EOMAP (from Figure 1(a) to Figure 1(b)). The second process in turn collapses hyperbolas into scatterpoints (from Figure 1(b) to Figure 1(c)). From the forward EOMAP, its inverse can be kinematically defined as a process that creates Cheop's pyramid from hyperbolas (from Figure 1(b) to Figure 1(a)), which simulates a modelling process.

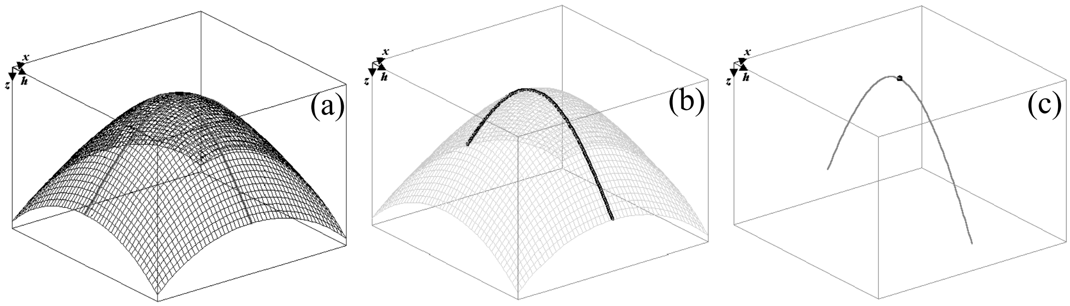

Figure 1: EOM collapses a Cheop's pyramid (a) to a hyperbola in the offset direction (b), which is then collapsed to the scatter point (c). The forward EOMAP is the process from (a) to (b) and the inverse EOMAP is the process from (b) to (a).

Equivalent offset concepts render the EOMAP statics method more efficient than some other migration-based methods, such as Tjan et al (1994) and Larner (1998), and make it much less velocity dependent.

For data obtained from areas with simpler subsurface structures, such as Blackfoot data, the EOMAP method can estimate residual statics with satisfactory accuracy without any velocity information. This paper will show some results of the EOMAP method from its applications to the Marmousi model data with synthetic statics added.

THE MARMOUSI MODEL DATA

The Marmousi model and seismic data were created at the Institut Français du Pétrole (IFP) in 1988. Its main structure elements are shown in Figure 2.

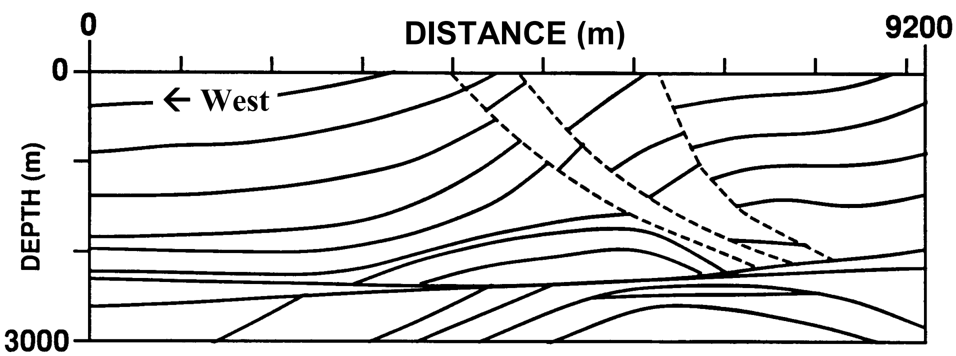

Figure 2: The structure elements of the Marmousi model. (after Versteeg, 1991)

The seismic data from the Marmousi model is generated numerically using typical marine acquisition geometry. As expected, given the subsurface structure shown in Figure 2, the CDP gathers located at relatively simpler structured area (within 3,000 m from the west) contain reflection events with traveltime moveout trajectories close to hyperbolic. However, the CDP gathers located in the middle of the line have nonhyperbolic reflection events. Figure 3 shows two CDP gathers located at 2,400 m and 5,400 m from the west, respectively.

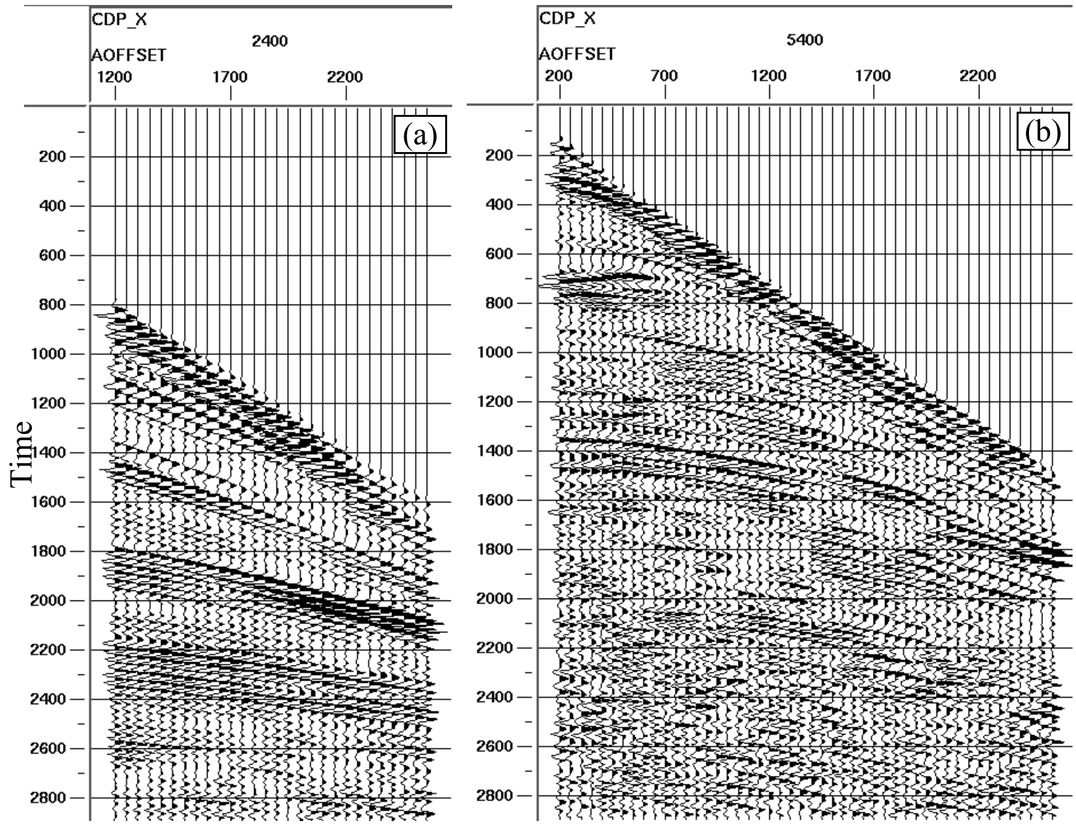

Figure 3: (a) A CDP gather at 2,400 m where the traveltime moveout is close “to normal” and (b) a CDP gather located at 5,400 m where the subsurface is complex and the reflection traveltime moveout deviates from hyperbolic trajectories.

FAILURE OF CONVENTIONAL METHODS

The Marmousi seismic dataset does not contain any static problems. This static-free data was used to demonstrate how conventional residual static methods fail to provide reliable statics solutions. Two methods (the stack-power maximization method and the correlation autostatics method) have been applied to the Marmousi data with some preliminarily observed NMO velocities.

Figure 4 shows a set of statics estimated by the correlation autostatics method, where the maximum allowed static time shift was set to 24 ms. The estimated statics at locations where the subsurface structure is not very complex are closer to the correct value of zero. However, the statics estimated at the locations where the subsurface structure is complex are very large and their maximum values are bounded only by the maximum static shift allowed. The receiver statics were not estimated at the two ends of the line because the fold is too low and only far-offset traces are contained.

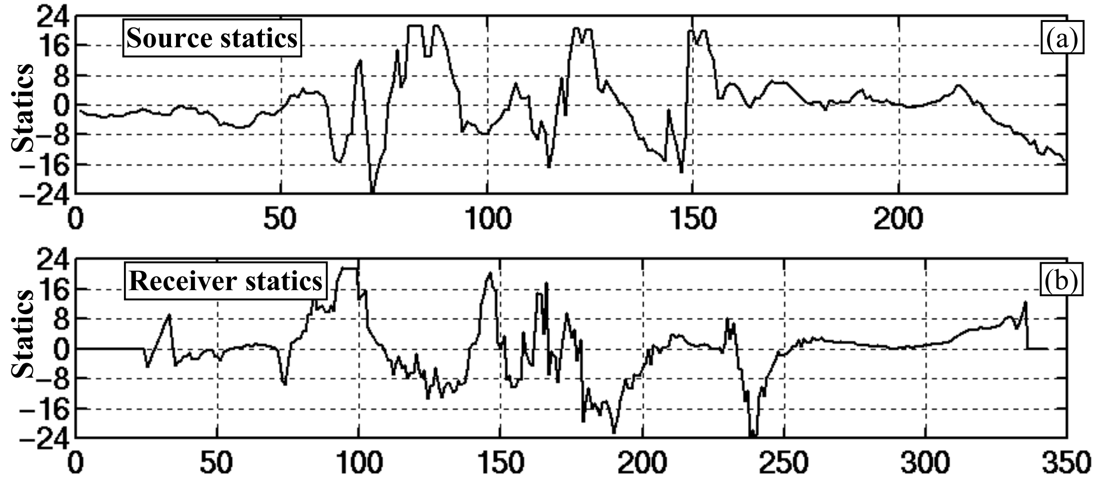

Figure 4: Source statics (a) and receiver statics (b) estimated by the correlation autostatics method from the Marmousi seismic data where no statics are present.

The statics estimated by the EOMAP method from the static-free Marmousi data are shown in Figure 5. The estimation errors are mostly below 4 ms, which is the sample rate.

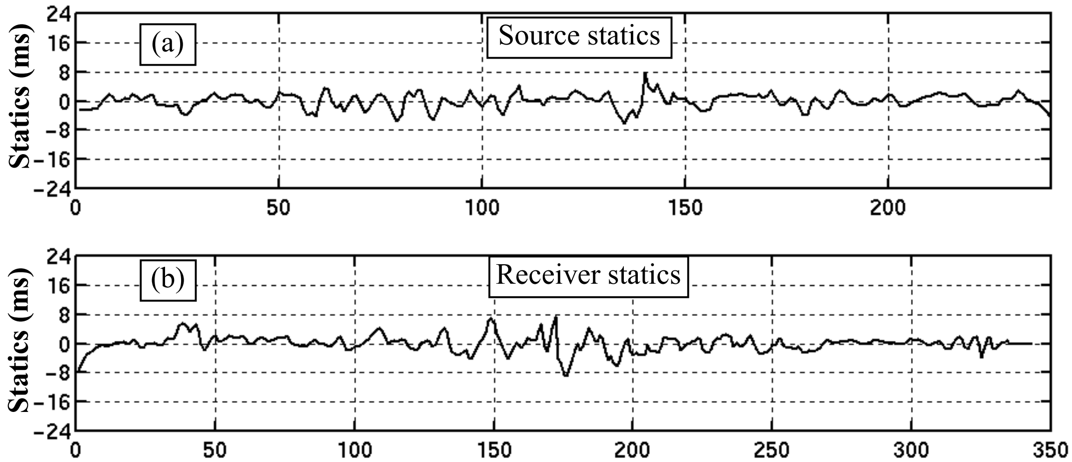

Figure 5: Source statics (a) and receiver statics (b) estimated by the EOMAP statics method from the Marmousi seismic data where no statics are present.

SYNTHETIC STATIC SHIFTS AND EOM REFERENCE MODEL DATA

Two arrays of random numbers were independently created for the time-shifts at the shot and receiver locations. The time shifts for both these shot and receiver locations range from –20 ms to 20 ms. Traces of the original Marmousi data are then time-shifted in a surface consistent manner. The Marmousi data contaminated with these synthetic static time-shifts will be used to test the EOMAP statics method.

The forward and inverse EOMAPs are applied to time-shifted Marmousi data and a set of reference data for residual statics analysis is formed. Both the forward and inverse EOMAPs use a migration velocity that was estimated using the CSP gathers created by preliminary stacking velocity. Figure 6 shows three CMP gathers at one location above the relatively simple structure: (a) a CMP gather from the original static-free Marmousi data; (b) the same CMP gather but from the contaminated Marmousi data; and (c) the CMP gather from the reference model data created by the EOMAP method. The traveltime discontinuity caused by static time-shifts is attenuated by the EOMAPs, although they could not perfectly reconstruct the original static-free data.

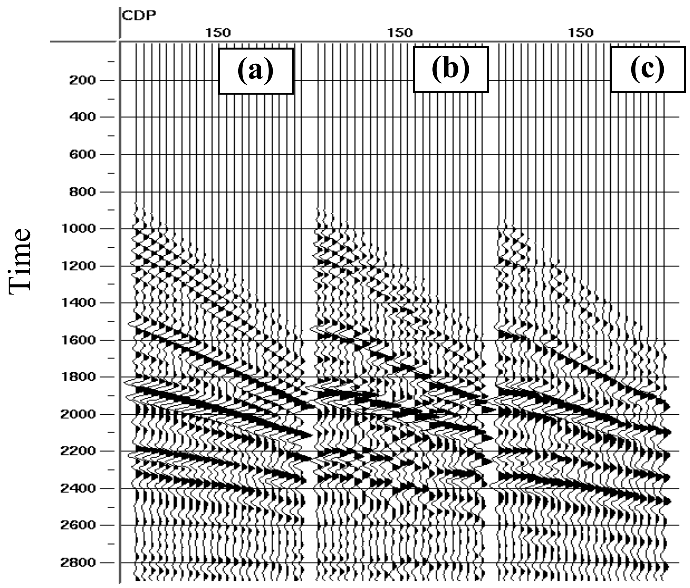

Figure 6: Three CMP gathers from the same location above the simple-structure area of the Marmousi model, where (a) is from the original traveltime-error-free data, (b) is from the data with traces time-shifted and (c) is from the reference model data created by the EOMAP method.

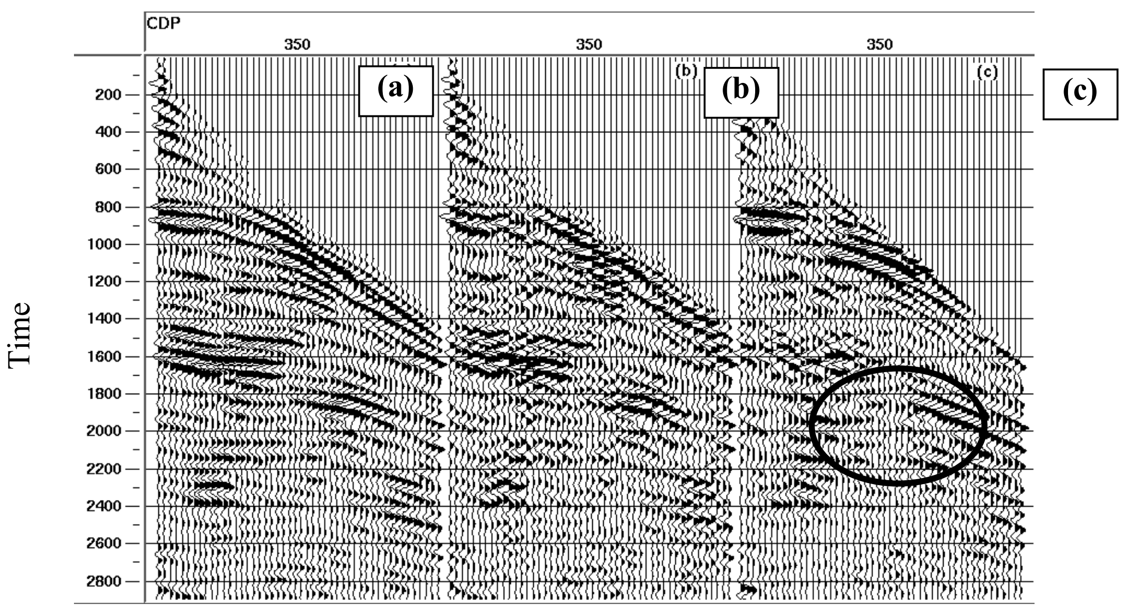

Figure 7: Three CDP gathers from the same location above the complex-structure area of the Marmousi model, where (a) is from the original static-free data, (b) from the data with traces time-shifted and (c) from the reference model data created by EOMAP method.

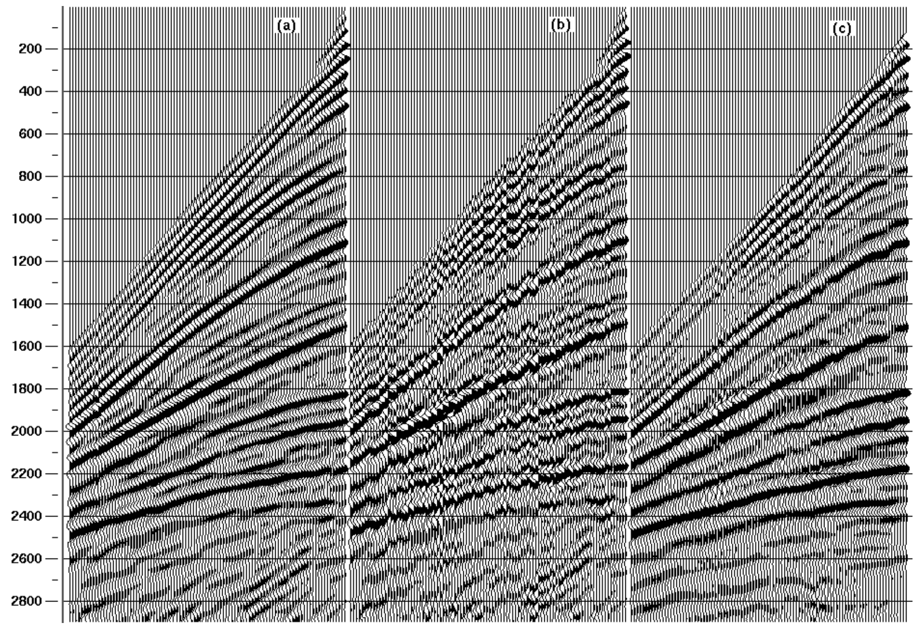

Figure 8: Three shot gathers from the same location above the simple-structure area of the Marmousi model, where (a) is from the static-free data, (b) is from the data with traces time-shifted and (c) is from the reference model data created by the EOMAP method.

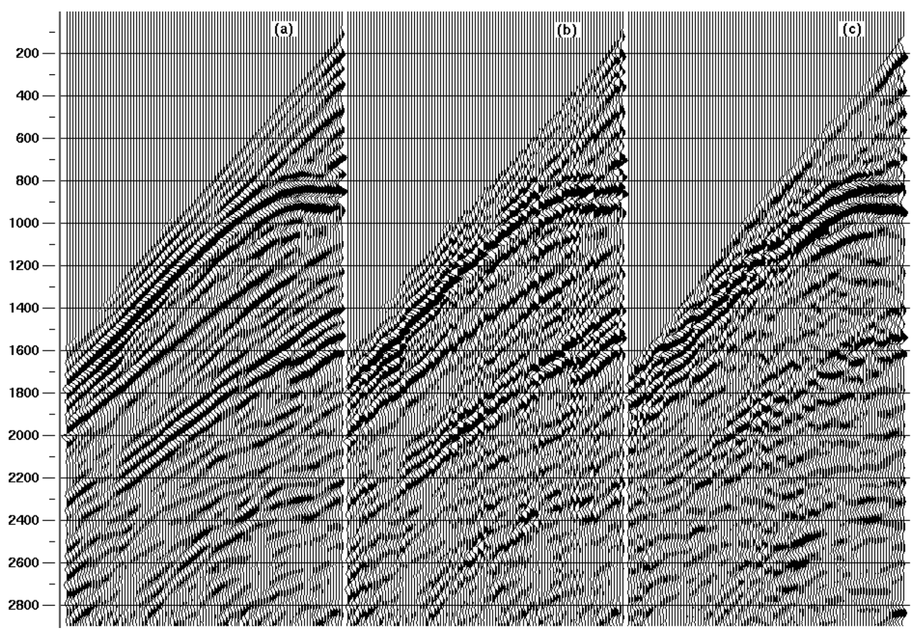

Figure 9: Three shot gathers from the same location above the complex-structure area of the Marmousi model, where (a) is from the static-free data, (b) from the data with traces time-shifted, and (c) from the reference model data created by the EOMAP method.

Figure 7 shows three CMP gathers at one location above the complex structure in the Marmousi model. The EOMAP model gather (c) shows better traveltime continuity than the contaminated gather (b), although some reflections in gather (c) (as circled) could not be recovered at all. This signal loss is partly because of the statics; partly because the Marmousi model contains too strong lateral velocity variations for a prestack time migration algorithm. Fortunately, all that is needed here is the static reference model.

Figures 8 and 9 show two groups of shot gathers, with each group containing three gathers from the error-free Marmousi data, time-shifted Marmousi data and the EOMAP reference model, respectively. Conclusions similar to those from Figures 6 and 7 can be drawn here.

STATIC ESTIMATIONS

Figure 10 shows the source and receiver synthetic statics and the corresponding EOMAP static estimations. In this figure, part (a) shows the synthetic and the estimated source statics at all the source locations. The black line shows the synthetic statics and the light grey line indicates the EOMAP estimations. Part (b) is the source statics estimation errors, i.e., the difference between the estimations and the synthetics. Similarly, (c) shows the synthetic receiver statics (black line) and their EOMAP estimations (grey line) and (d) is the estimation errors of the receiver statics.

From Figure 10, it can be seen that:

the short wavelength (about two shot or receiver intervals, which is 40 m for this data) source and receiver statics are very well estimated by the EOMAP statics method. The estimation errors are of mid-wavelength, which is about 10 to 20 shot intervals, i.e., 200 to 400 m.;

the estimation errors are much smaller than the original static shifts added. The source statics estimation errors have an average less than 4 ms, and the receiver statics estimation errors have an average less than 8 ms.;

source statics estimations have better accuracy than the receiver statics estimations. This is mainly because the source fold (uniformly 96) is larger than the receiver fold.;

there is no recognisable long-wavelength (over 100 shot intervals, e.g.) trend in the static estimations, although the decomposition does not take into account the geology (structure) terms.

Figure 11 (a) and (b) show the zoomed source statics from source numbers 115 to 240 and the zoomed receiver statics from receiver numbers 175 to 305, respectively. The black lines are the synthetic statics and the grey lines are the EOMAP estimations.

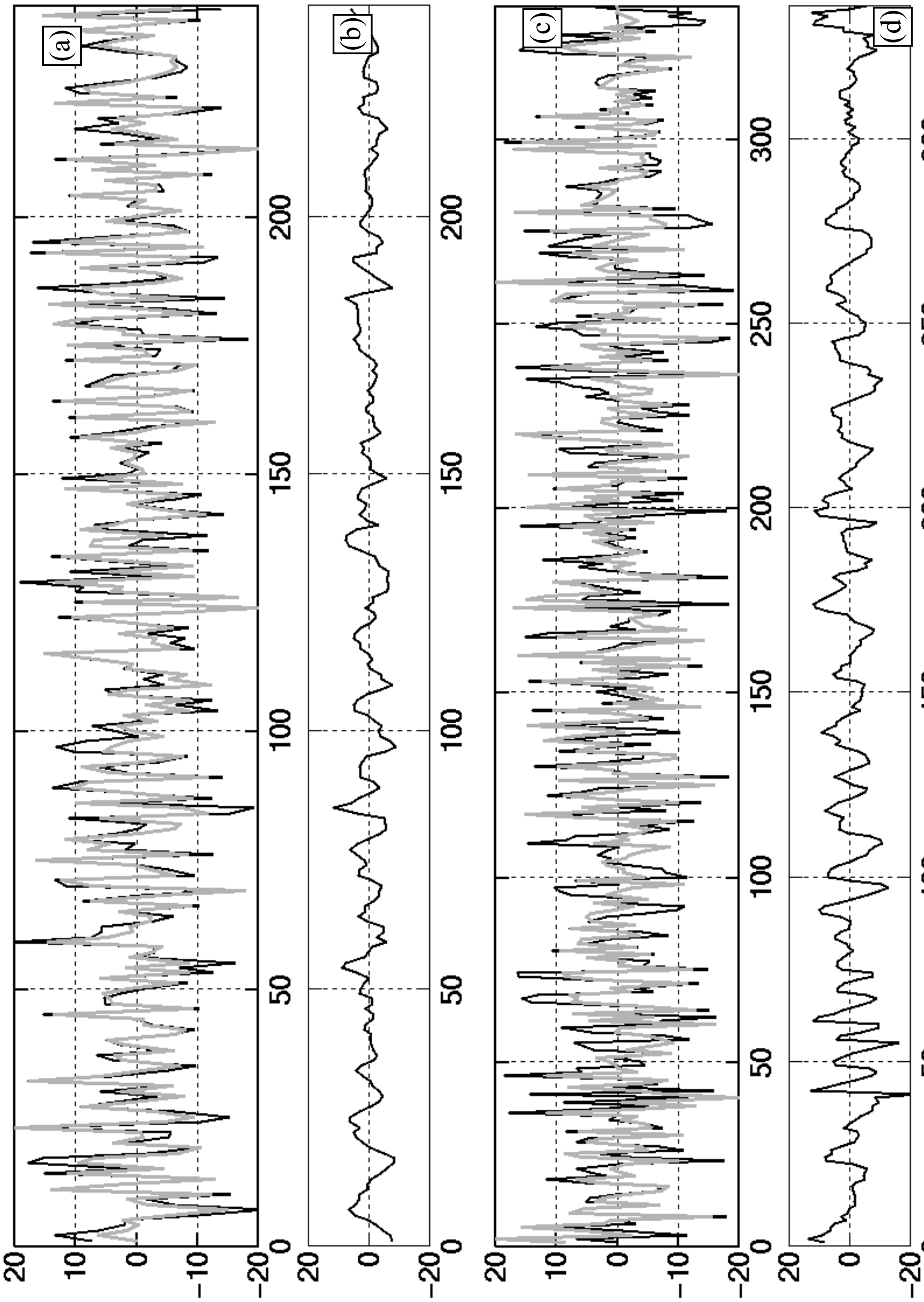

Figure 10: Statics estimated by the EOMAP method. Where (a) shows the added (dark colour) and estimated (light colour) source statics with their differences showing in (b), and (c) shows the added (dark colour) and estimated (light colour) receiver statics with (d) showing their differences.

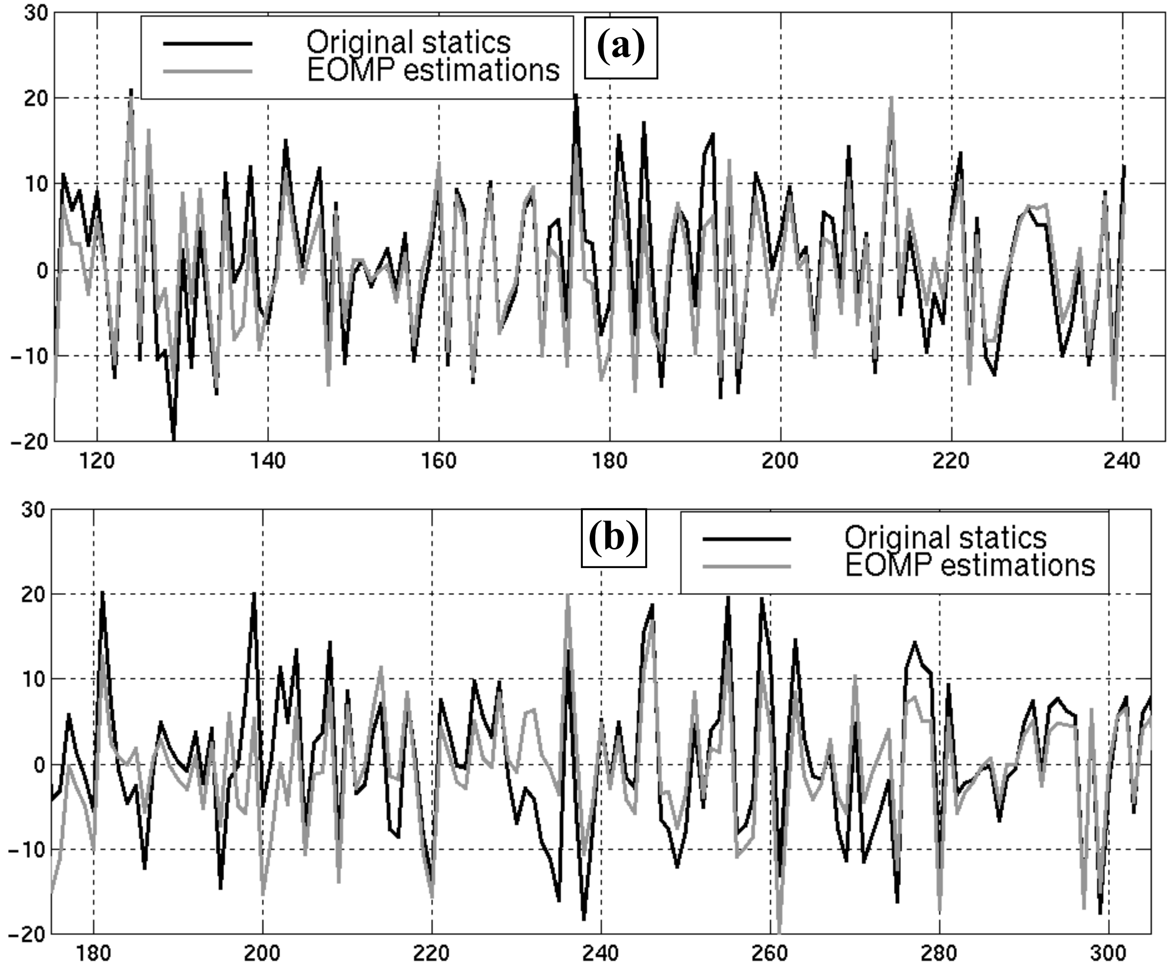

Figure 11: Zoomed details of the EOMAP estimations of the source statics (a) and the receiver statics (b).

Although these estimations are not perfect, they succeed in highlighting the ability of the EOMAP statics method to estimate the residual statics in data from complex areas, where the normal moveout assumption is no longer valid. The results shown in the next section demonstrate how the data quality is very much improved by the static corrections using EOMAP estimations.

RESULTS AFTER APPLYING THE EOMAP STATICS

After applying the statics estimated by the EOMAP method, the quality of the Marmousi data is improved. Figure 12 shows the near-offset sections before and after the EOMAP static correction. The lateral consistency of the reflection events is enhanced. For example, some weak diffractions, which are very important for the final migration imaging, lost their recognizable continuity by the static time shifts. Many of them reappear after the EOMAP statics are applied.

Figure 13 shows two stacked sections before and after applying the EOMAP statics. Both the signal-to-noise ratio and the resolution are very much enhanced.

VELOCITY DEPENDENCE

Velocity dependence is always a concern when more accurate statics estimations are to be obtained without introducing too many artefacts to the seismic data, especially for data from areas with complex subsurface structure. The EOMAP method has the advantage of being able to estimate reliable statics without the requirement of accurate velocity information. This does not mean, however, that the EOMAP processes are independent of velocity information, although the following suggestions may be applied to reduce the dependence of the velocity information:

using the asymptotic EOMAP method, which is velocity independent;

using smaller migration aperture, but keeping in mind that apertures that are too small may reduce the traveltime-error attenuation ability;

using a later time window because of the weaker velocity dependence of both EOMAPs at later times.

CONCLUSIONS AND POSSIBLE EXTENSIONS

For data with very complex structures, such as Marmousi model data, conventional methods cannot usually be applied because their hyperbolic normal moveout assumption is no longer valid. In these cases, the EOMAP method can still estimate residual statics with plausible accuracy. Some velocity information may be needed but is not essential.

The first iteration of the EOMAP method usually provides satisfactory statics estimations.

The EOMAP method is not only much faster but also less velocity sensitive compared to the depth migration method presented by Tjan, et al (1994) and Larner (1998).

Practically, the efficiency of the EOMAP method can be enhanced by choosing appropriate parameters.

The EOMAP statics method not only works for 2D PP data, it can also be extended to residual statics analysis for 3D or even converted wave data, because the EOM concept has been successfully applied to different types of data as a prestack migration algorithm.

The current implementation of the EOMAP method may not yet have been optimised. Some algorithm improvements related to both the equivalents offset mapping (migration part) and the surface consistent statics decomposition (statics part) are still possible. For example, the amplitude-scaling factor during both forward and inverse equivalent offset mappings can be more accurate.

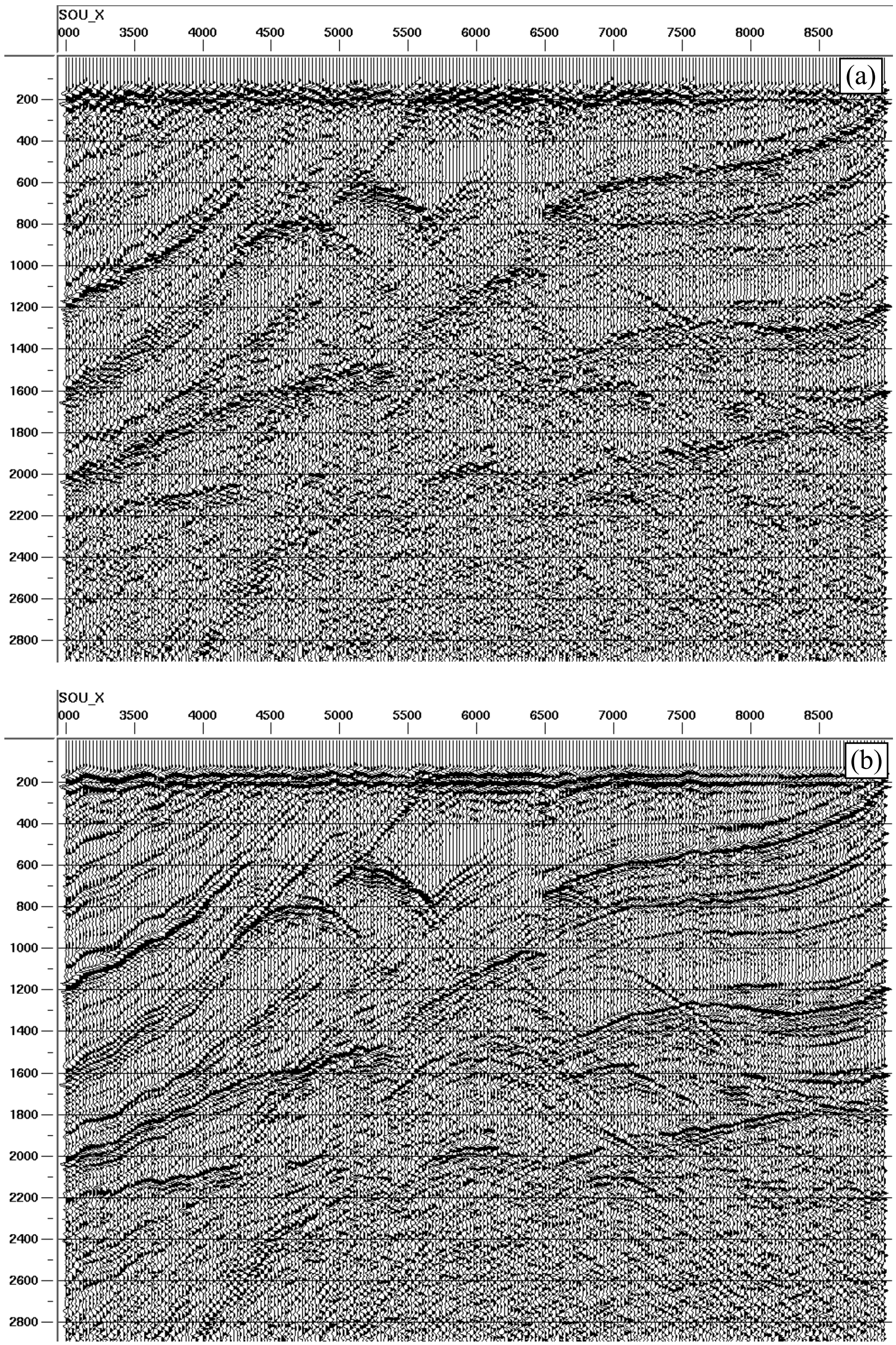

Figure 12: The near-offset sections before (a) and after (b) applying the residual statics estimated by the EOMAP statics method.

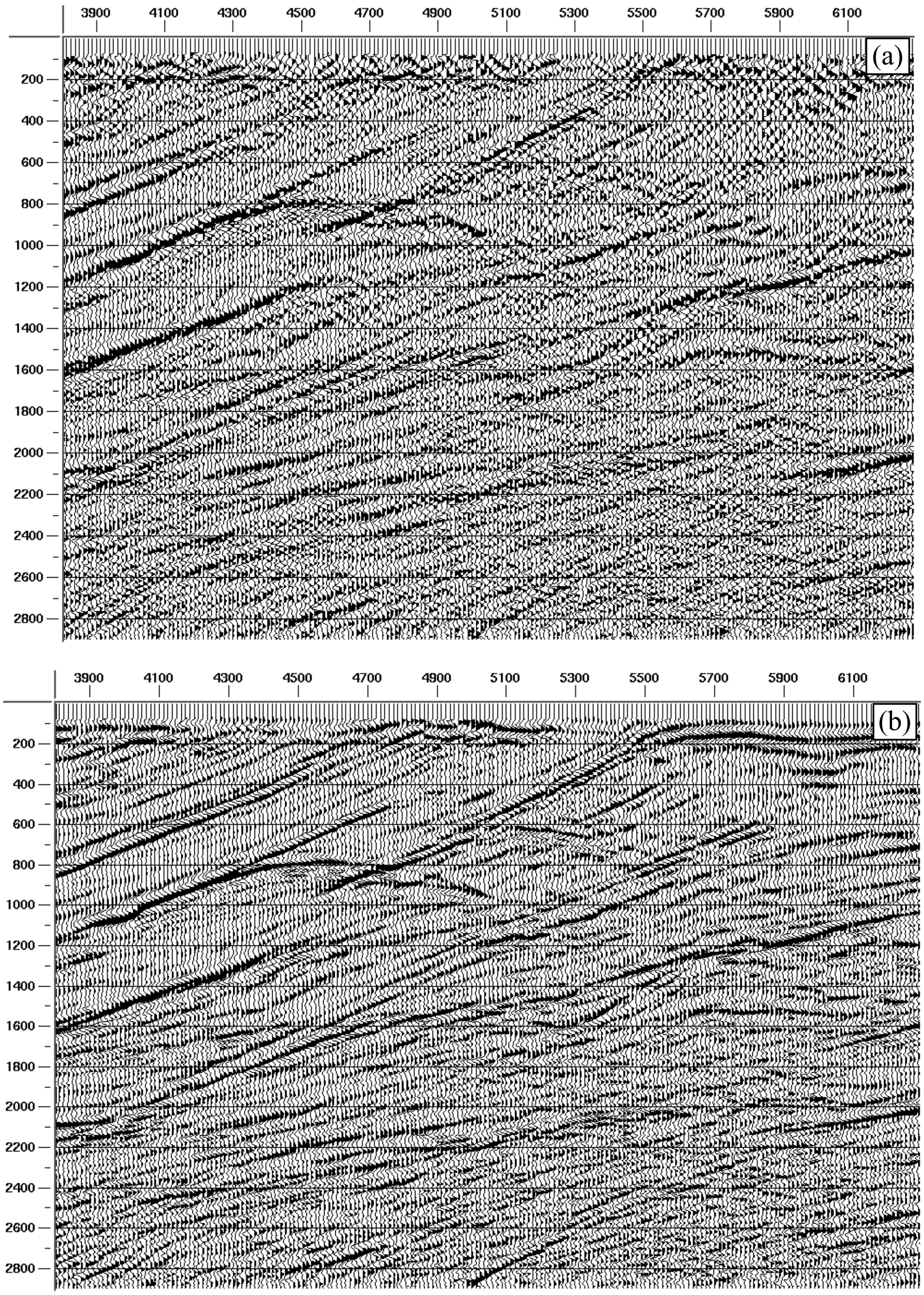

Figure 13: The stacked sections (portions) before (a) and after (b) applying the residual statics estimated by the EOMAP statics method. The same stacking velocity was used for the NMO correction of both datasets.

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