Residual Statics using CSP gathers

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ABSTRACT

All the conventional methods for residual statics analysis require normal moveout (NMO) correction applied on the seismic data. The statics estimates from these methods are affected by the inaccurate velocity information and the NMO time variant effects. These can be easily demonstrated by experiments with different NMO velocity fields and with different horizon pickings.

We present a new method that is designed to estimate residual statics before NMO correction. This method is based on the concept that migration and its inverse operation (modeling) can provide reference correlating traces for the undesired time shift estimation.

Equivalent offset migration (EOM) technique introduces a new way to perform pre-stack Kirchhoff time migration. An intermediate step of this migration is to construct a new pre-stack data volume called CSP gathers. This construction process is a partial migration process that does not involve any time direction energy distribution. This no-time-shift partial migration and its inverse operation make up a faster and better way to create static model data by "migration-modeling" technique. And, the partial migration and its inverse operation are both insensitive to preliminary velocity information. In addition, an asymptotic solution for the CSP gather construction, which is basically related to post-stack migration, is totally velocity independent.

We present some results from synthetic and real seismic data. The statics estimated by our method are comparable to the results from conventional methods.

INTRODUTION

Methodology of automatic residual statics analysis

All the methods for analyzing residual statics utilize cross-correlation to estimate the assumed time anomalies on seismic traces, then honor the surface consistence assumption to decompose the estimated time shift into shot statics and receiver statics. One important step before these procedures is to find a trace (model trace) for each seismic trace to cross-correlate with. Some methods construct a new set of data which contains the model traces, such as Ronen-Claerbout maximum stack power method (1985). But most of the conventional methods usually just choose some specific traces in the seismic data itself. Our method differentiates from all other methods by using equivalent offset migration (EOM) technique to build a set of model data, which contains an individual model trace for each seismic trace.

The general methodology of computing residual statics can be illustrated by a simple systematic flow as in Figure 1. Some methods may have some differences, but they are usually not essential.

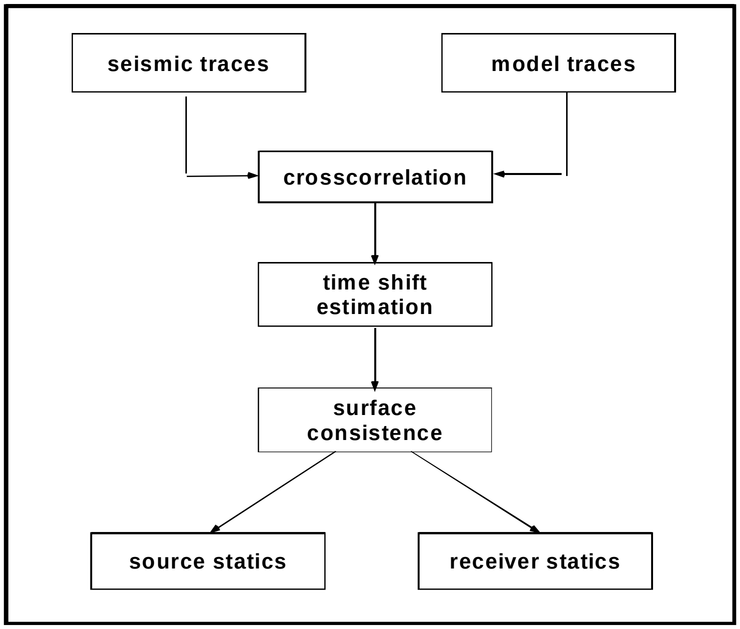

Figure 1: A general flow chart for computing residual statics. Some methods may have some differences about the order of the "cross-correlation" and the "surface consistence". There are many different ways to construct model traces, some methods just choose specific trace from seismic data itself.

Shortcomings of conventional methods

The main shortcomings of conventional methods are related to their dependence on NMO correction, and then on velocity information. Velocity errors cause mis-allignment of NMO corrected CDP events, and then causes different solutions of statics. NMO correction is a time variant operation applied on seismic traces, residual statics after NMO correction can only be regarded as "static" within very short time windows. This is why conventional methods always require horizon picking or time gate picking.

We use some real data example to demonstrate these shortcomings. The data used here is from a 2-D line with 200 receiver arrays placed in the middle of the line. The shooting began from one end to the other.

Figure 2 shows the results of statics estimation using three different NMO velocity fields. The differences between the statics results are evident. The offset is larger at the ends of the line. That is why the largest statics differences happened there. The results were obtained by the Max-Stack Power Auto-statics module in ProMAX.

Figure 3 shows the residual statics results from same NMO corrected data, but with different time horizons. This demonstrates that the residual statics are not really “static” after NMO correction, even when the NMO velocity is accurate.

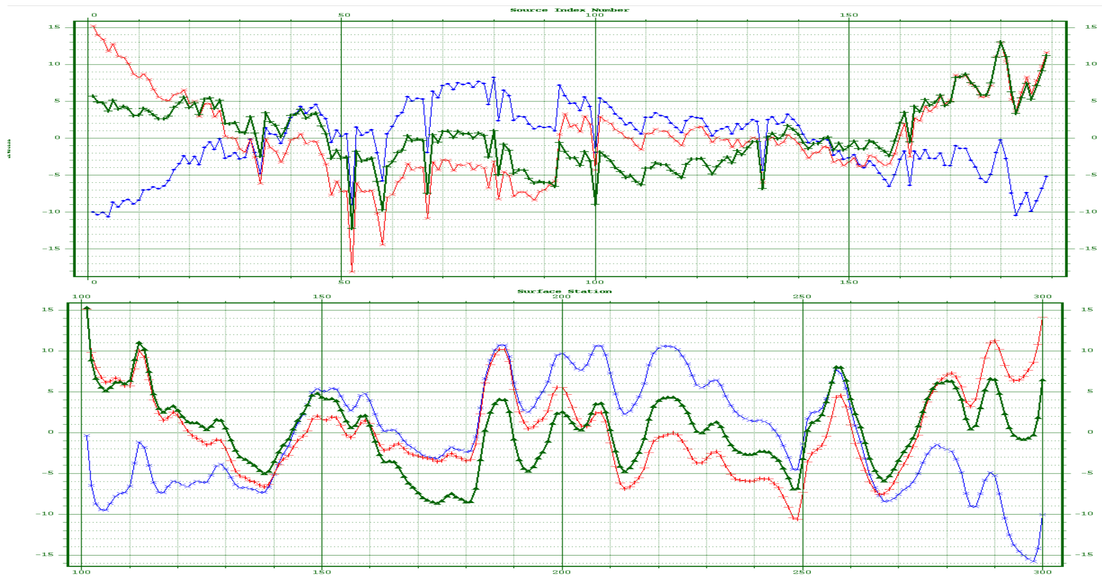

Figure 2: Residual statics estimates from datasets NMO corrected by three different velocity fields based on a same set of data. The upper picture shows the three different source statics, while the lower one shows the receiver statics estimates. One of the three velocity fields was picked on the CMP gathers, while the other two velocity fields are respectively 90% and 110% of the picked velocity

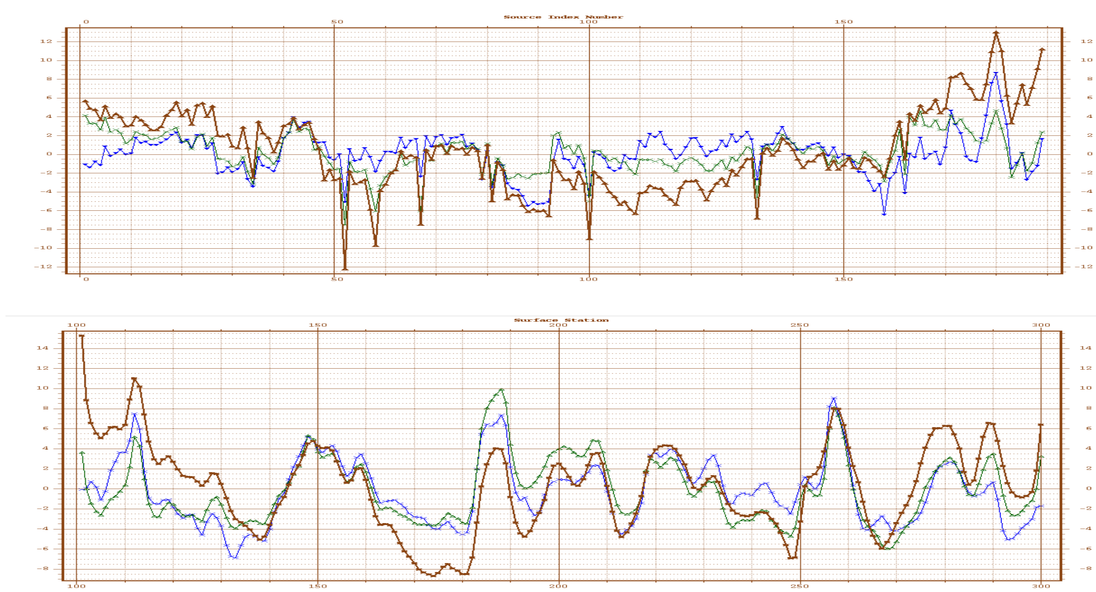

Figure 3: Residual statics estimates from the same set of NMO corrected data, but using three different horizons, and the time window widths around the horizons are the same. These three horizons were picked at deep (1.5 seconds), middle (1.1 seconds) and shallow (0.6 seconds) time locations. The upper plot shows the source statics estimates and the lower plot shows the receiver statics. The deep horizon is along the strongest event on the whole stacked section.

Integration with migration

Depth migration and modeling are a pair of forward and inverse transformations. We can also construct an inverse operation for time migration and still call it "modeling".

It is the energy destructive and constructive property of migration that makes the effects from residual statics become weaker. The inverse operation, modeling, is also a process with destructive and constructive behavior, this again reduces the effects from the residual statics.

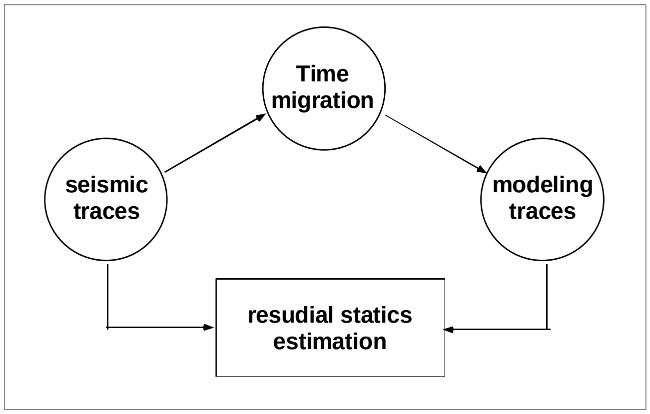

Figure 4: Time migration and its inverse operation create a set of data that is proper to use as model for statics analysis.

EQUIVALENT OFFSET MIGRATION (EOM)

Basic Kinematics

Equivalent offset migration (EOM) splits the conventional Kirchhoff pre-stack time migration process into two steps. The first step is to define a different offset value at a different migration distance for any given input sample. The new offset is called equivalent offset, and it is defined as

$$h_e^2 = x^2 + h^2 - \frac{4x^2h^2}{V^2T^2}, \tag{1}$$

where x and h are the migration distance and the half source-receiver offset of the sample, T is the time location of this sample. CSP location and equivalent offset make up a convenient coordinate grid structure to sort the intermediate data volume. They are called CSP gathers. The second step consists of NMO and CDP stacking applied on the CSP gathers.

Some important properties of CSP gathers are as following:

(1) The construction of these CSP gathers does not involve any energy distribution in time direction. (2) The size of the data volume is determined by the number of CSP

locations and the number of equivalent offset bins. (3) Equivalent offsets of a sample are always larger than its source-receiver offset. The possible equivalent offset range of a sample is determined by the velocity distribution around its own CMP location and its own source-receiver offset. (4) For constant velocity case, the maximum equivalent offset remains the same for a given time-slice.

Asymptotic solution

The computation of equivalent offset has a simplified solution by obtaining an asymptotic definition of the equivalent offset:

$$h_e^2 = x^2 + h^2. \tag{2}$$

This asymptotic solution has advantages:

(1) It is totally velocity independent; (2) the equivalent offset is time invariant on a given input trace; (3) it is a faster algorithm than the accurate one; and (4) for our residual statics analysis purpose, this asymptotic solution and its inverse operation will provide very good static model data.

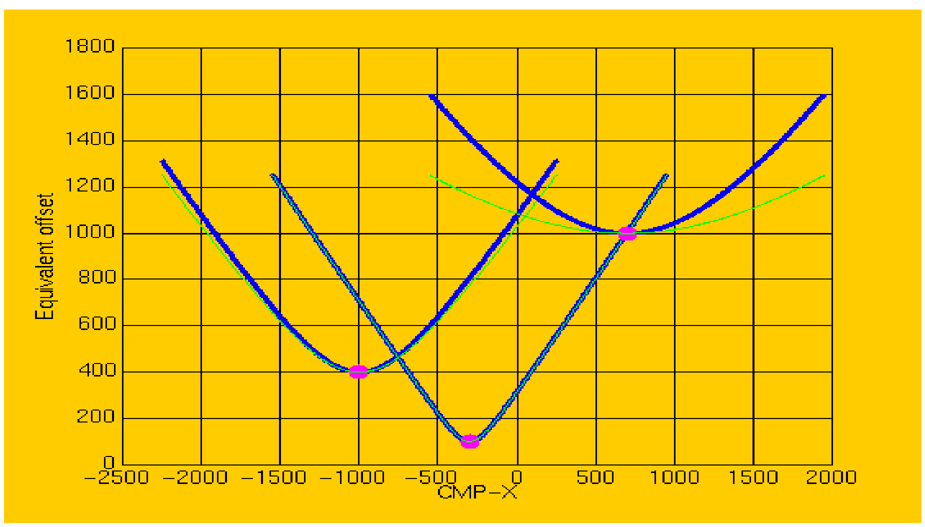

Figure 5: The comparison of the accurate solution (thicker curves) and the asymptotic solution (thinner curves) of EOM. The accuracy of the approximation is good when the offset or the migration distance is small.

CSP STATIC MODEL

Constructing CSP gathers is to distribute the sample energy to a hyperbola in space-offset domain, while its inverse operation is to collect the energy along the same hyperbola and put it at the original sample location. Constructing the model data from CSP gathers (we call it inverse CSP) is exactly the opposite operation of the CSP gather construction (we call it forward CSP). The energy distributed during the forward CSP will be collected within the inverse CSP procedure. The destructive and constructive behavior of the two operations will largely reduce the effects caused by the residual statics of the input data.

During the forward operation and its inverse operation, we do not need any time domain displacement. This property is essential for residual statics analysis because no time variant stretch is involved.

Figure 6 shows a example of our CSP static model shot gather.

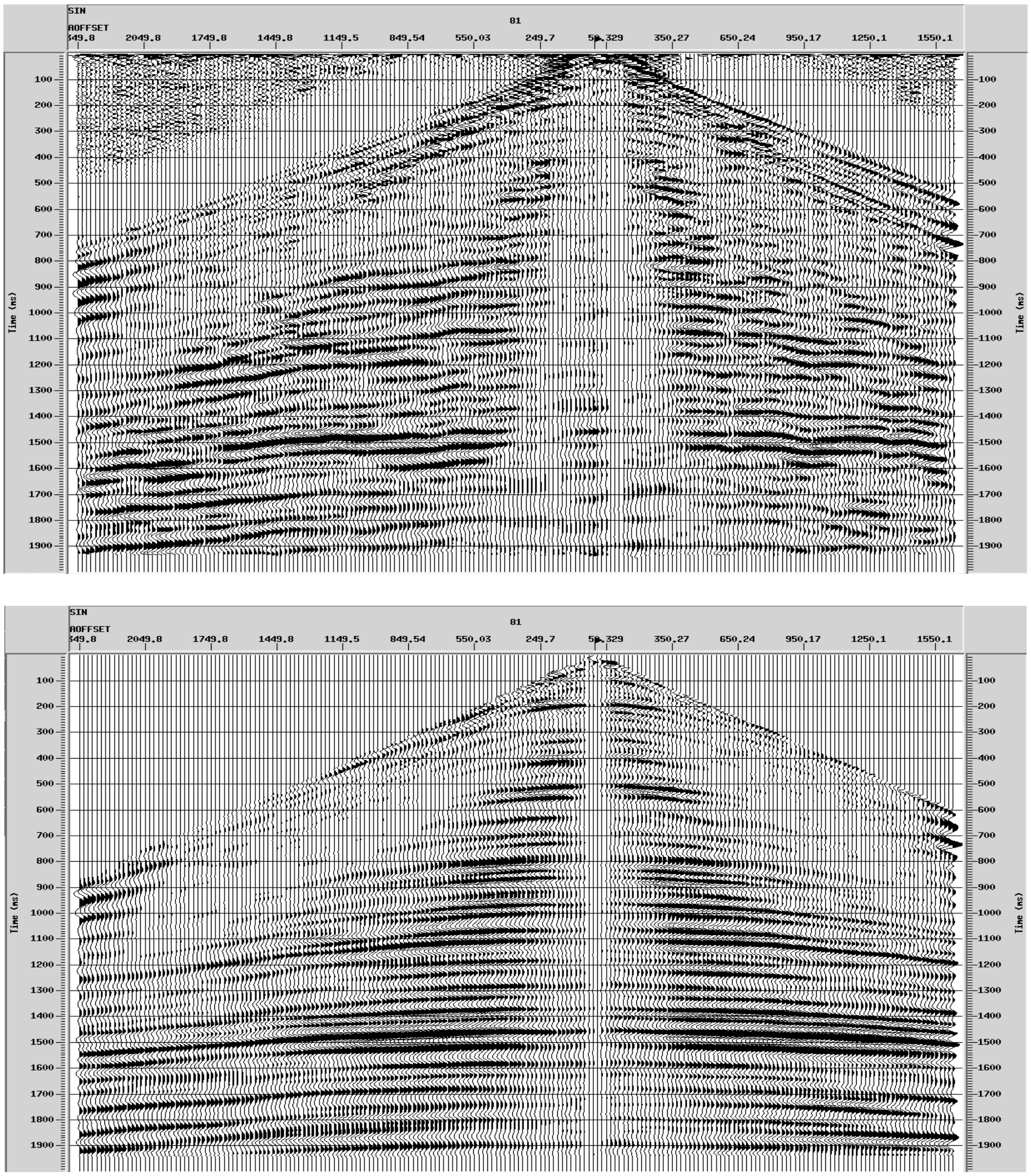

Figure 6: A shot gather (the upper one) from some real data and its CSP static model (the lower one). The residual statics on the original shot gather are evident, but the model gather has almost perfect hyperbolas. The very near offset and very far offset traces are not as good as the traces in the middle range of the offsets, this is because the destructive and constructive property has better coverage at the middle offset range.

We applied the asymptotic solution with limited migration aperture, smaller maximum equivalent offset and a CSP spacing twice the CMP spacing, these make the CSP model construction around 10 times faster than using the normal parameters for migration purpose.

PRACTICAL CONSIDERATIONS

There are many considerations based on our new algorithm.

Computation cost: To make this method efficient, we can make the size of partially migrated data volume as small as possible. That is:

- less CSP gathers by using larger CSP spacing than normal CMP spacing;
- less traces in a CSP gather by using smaller equivalent offset range and larger equivalent offset bin size;
- less samples on each trace by using larger sample rate and shorter trace length.

We can also use more efficient way to construct the CSP gathers, that includes:

- using asymptotic solution;
- limiting the migration aperture to reduce the migration distance;
- limiting migration dip;
- simplifying the amplitude scaling factor.

Reliability of model traces: Traces at different offset ranges have very different CSP fold. Usually, the middle offset range traces have much higher fold than very near or very far offset traces.

Correlating trace re-processing: We can apply any kind of the processing on the model data and the original data if necessary, such as bandpass filter which is a very efficient way to reduce "cycle skipping" effects.

Cross-correlation methods: After we obtain the model traces, we are free to use any method to perform cross-correlation and honor the surface consistence assumption.

Time gate: Choosing time gate for our method is only for avoiding strong noise such as refraction waves at the earlier part of traces.

Iterative technique: Our method can also be applied iteratively if really necessary. The iterative approach can be considered as a process to maximize the "power" of CSP gathers, as well as the final imaging sections.

A SYNTHETIC DATA EXAMPLE

We created a set of synthetic data with changing velocity structure, then artificially applied surface consistent source and receiver statics on the traces. The statics for sources and receivers have random distribution, their ranges are both from -20ms to 20ms. In this way, the possible relative time shift between two traces can be as large as 80ms.

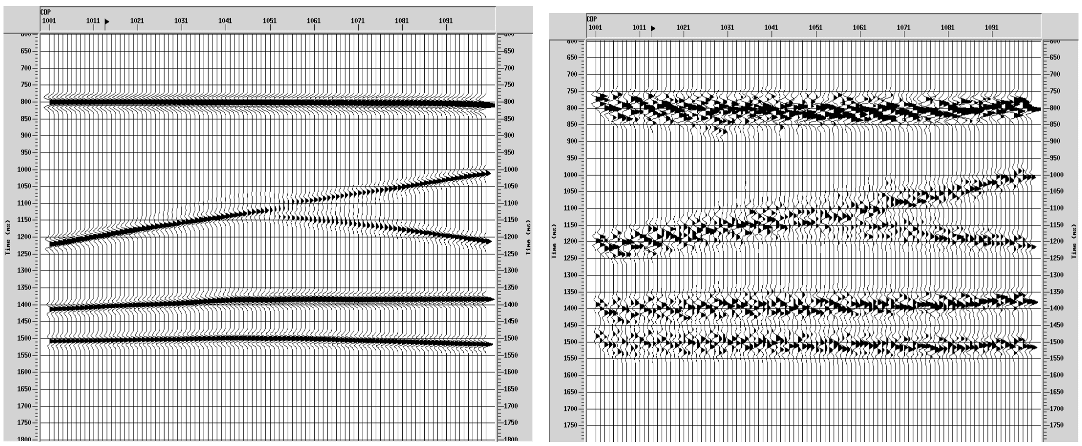

Figure 7: The left is the stacked section directly from the synthetic data without statics effected. The right one is the stacked section from the data with synthetic time shifts applied. The NMO velocity is picked on this static shifted data. The statics make every event smeared.

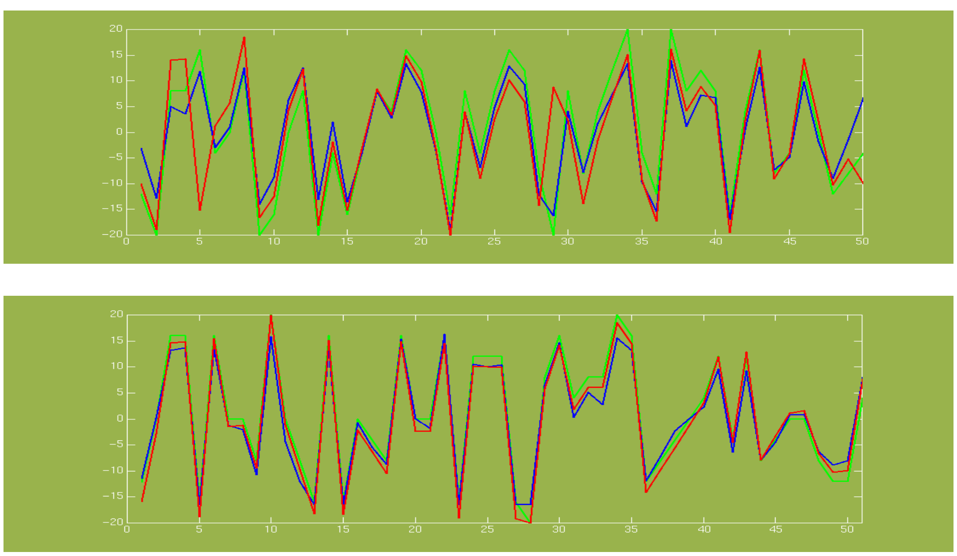

Figure 8: The upper picture shows the synthetic shot statics (GREEN), the shot statics estimated by Max Stack Power method (RED) and the shot statics estimated by our EOM method (BLUE). The estimates from two different methods are both very good. But the Max Stack Power method has mis-estimates at two shot locations, the errors may be caused by cycle skipping effects, but even when we limited the frequency band-width of the data to 3-5-15-20Hz, the mis-estimations were still there. The lower picture shows the synthetic receiver statics (GREEN), the receiver statics estimated by Max Stack Power method (RED) and the receiver statics estimated by our new method (BLUE). Both methods have excellent results.

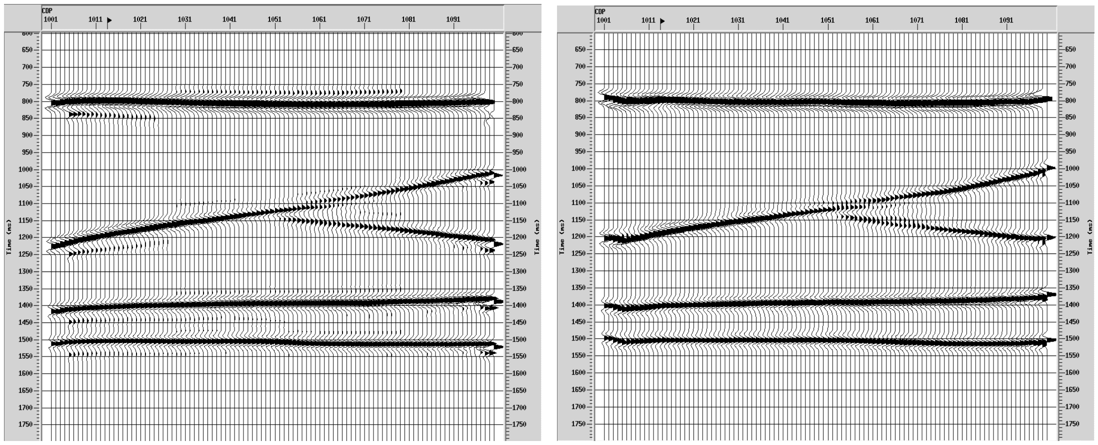

Figure 9: The left is the stacked section from data where statics are corrected with the estimates by Max Stack Power method, as shown in Figure 8. We can see some effects caused by the mis-estimates of the shot statics. The right one is the stacked section from data where statics are corrected with the estimates by our EOM method, which are shown in Figure 8

BLACKFOOT DATA EXPERIENCE

Blackfoot data has very good quality, the residual statics are generally less than 10ms. On stacked sections we could not find obvious difference between different methods. Here we choose the strongest event and enlarge it to show the detail improvements by different methods.

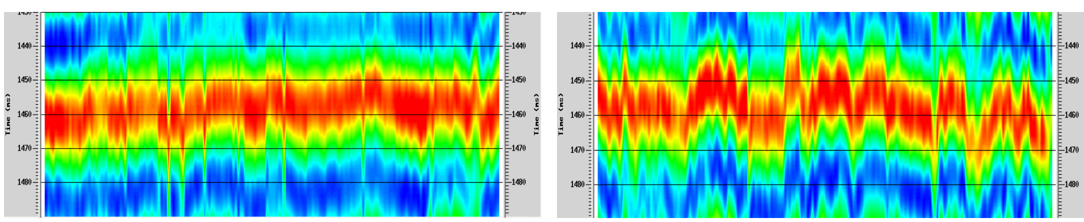

Figure 10: The left one is an event on the common shot stack section. The right one shows the same event on the common receiver stack section. The NMO corrections used for both are exactly the same.

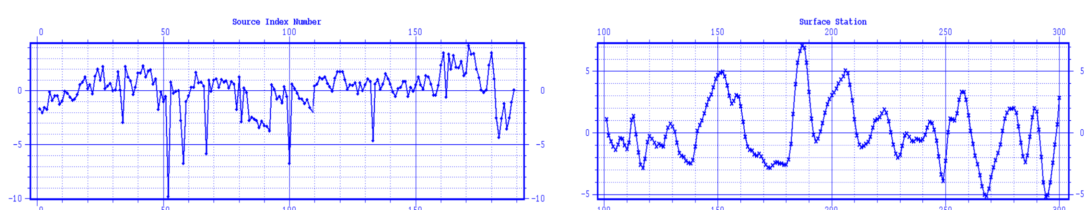

Figure 11: (left) The shot statics estimated by our EOM method. (right) The receiver statics estimated by EOM method. We show this result together with Figure 10 to make their similarity clearer.

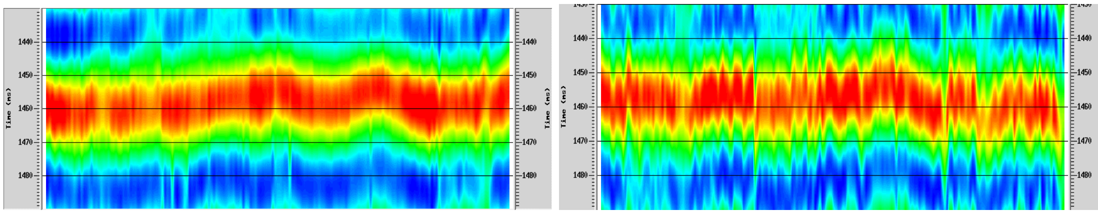

Figure 12: (left) The same event on the common shot stack section and (right) the event on the common receiver stack after the EOM residual statics shown in Figure 11 are applied. The events here have better continuity and are straighter than those in Figure 10, but there are still residual statics left.

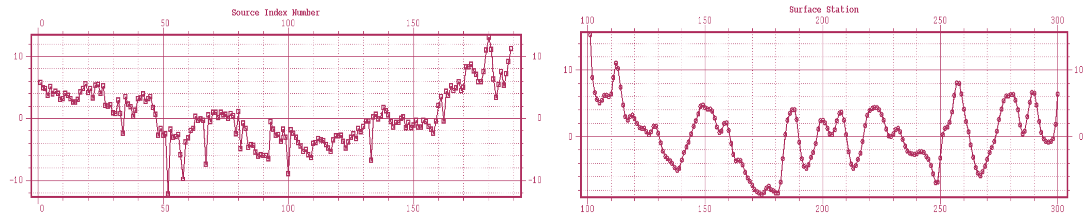

Figure 13: The shot statics (left) and the receiver statics (right) estimated by Maximum Stack Power method.

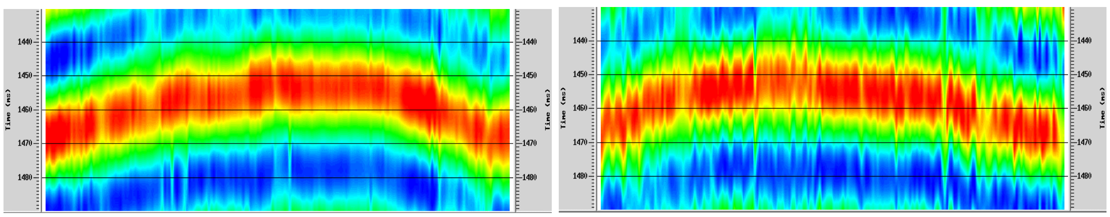

Figure 14: The event on the common shot stack (left) and the event on the common receiver stack (right) after the residual statics shown in Figure 13 are applied. These events are much smoother than in Figure 10. This means Max Stack Power method has very good high frequency estimates. But, compare to Figure 12, these events are affected badly by the low frequency trend in the static estimates.

CONCLUSIONS

Our EOM statics method has following advantages:

- Residual statics analysis before NMO;
- Independent to preliminary velocities;
- It can be used for data with only one fold;
- It has better low frequency estimation;
- It can be used iteratively;
- It directly benefit pre-stack migration.

The computation cost of this method is still a significant consideration.

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