A ZERO-OFFSET PICKING APPROACH FOR PRE-STACK MULTIPLE ATTENUATION

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ABSTRACT

The main objective of seismic data processing is to obtain information about the subsurface structure and properties from the recorded data. Almost all imaging methods assume that the recorded seismograms contain only primary reflections. Consequently, identification and suppression of multiples is of high importance in data processing. In this paper, we present a zero-offset (ZO) traveltime picking approach for multiple prediction and attenuation, which is applicable to any type of multiple reflection including internal multiples. It includes picking of zero-offset traveltimes in a stacked section, which are then used to predict the pre-stack multiples with the help of the stacking velocity. The advantage of the proposed approach is that it performs stable for dipping reflectors and far offsets. Furthermore, it does not require high computational effort. Both synthetic and field data examples illustrate the potential of the method.

INTRODUCTION

Multiple attenuation is a challenging step in a seismic data processing workflow. Many methods are available for multiple identification and suppression, but every method uses different assumptions and thus has its advantages and drawbacks. In this paper, we present a rapid and robust approach based on a Common Reflection Surface (CRS) workflow for multiple attenuation of Dümmong and Gajewski (2008). Their method is an entirely data driven approach and includes two steps of prediction: first, zero-offset multiples in a CRS stacked section are predicted, and in the second step, the obtained result is used for pre-stack multiple prediction. They proposed multiple prediction in the CRS stacked sections using a series of convolutions. The idea of multiple prediction by convolution of stacked traces (i.e. poststack SRME) originates from the work of Verschuur et al. (1992) and Kelamis and Verschuur (1996). This workflow is restricted to 1D media; therefore, errors for dipping events are inevitable and it is necessary to correct the predicted data. This correction is not easy to determine. To resolve these issues, we propose to pick multiple events in the stacked section instead of predicting them by a convolution approach. Picking multiple events allows us to avoid the above described restrictions and to omit the correction. Another advantage is that, this method can be applied to surface related multiples as well as internal multiples. In contrast to the above mentioned data driven approaches this is a workflow relying on interpretation.
Since hyperbolic stacking operators are affected by spread length bias, we apply the workflow separately to near and far offsets. The method can be applied to CRS or Common Mid Point (CMP) processed data. Considering the fact that CRS stacking needs more computational efforts in comparison with CMP stacking, we decided to apply the method within a CMP workflow.

METHOD

Several multiple attenuation methods are based on periodicity of multiples or moveout discrimination between multiples and primaries. Our method is based on the fact that multiples, like primaries, are hyper-

bolic events. Thus, it is possible to estimate traveltimes of multiples in the pre-stack domain, if zero-offset traveltimes of multiples and stacking velocities are available.
As an initial step of the zero-offset traveltime picking approach, we apply a stacking operator to obtain a stacked section, a stacking velocity profile, and a coherency section. The stacking velocity and the coherency section are estimated by an automatic semblance optimization (Neidell and Taner, 1971) i.e., the standard data processing sequence. Since the stacking process should be steered such that multiple events are imaged, the velocity search interval is adjusted accordingly. For example, if we are aiming to predict surface related multiples, the velocity search interval should be set to a lower range. The velocity analysis step also provides a coherency section. This section is then used to differentiate between signal and noise. For this purpose, a threshold factor is used to cutoff the events with low coherency. In the next step, zero-offset traveltimes are picked in the obtained stacked section. Picking surface related multiples may be guided by the 1-D convolution prediction.
It is critical to recognize multiples in a stacked section. The following characteristics of multiples help us to distinguish multiples from primaries (Verschuur, 2006):
- Periodic repetition: If some reflections are replicated in a specific time interval and have amplitudes decreasing with time, they are likely to be multiples.
- Increasing dips: If primaries are dipping, the dip of multiples in every bounce increases by the same amount as the dip of primaries.
- Conflicting dips: Multiples may conflict with primary reflections from deeper interfaces.
- Focusing and defocusing events: Small fluctuations in primaries will be enhanced in high order multiples and will cause focusing and defocusing events.

After zero-offset traveltime picking, pre-stack traveltimes of the multiples are predicted. The stacking velocity section, the picked traveltimes, the coherency section, and the selected threshold factor contribute to the prediction using the following well known equation:

$$t(h) = \sqrt{t_0 + \frac{4h^2}{v_0^2}} \tag{1}$$

where h is the half -offset, t_0 is the ZO traveltime and v_0 is stacking velocity.
After multiple prediction, we employ an adaptive filtering method to match the predicted multiples with the input data. A Wiener optimum filter (Wiener, 1964) is used to fit the input seismogram to the original data. After matching the predicted data with the input data, the multiples are subtracted from the data. This process is controlled by a window size and an operator length. The window size is the amount of traces that is used to determine the filter. A single trace, as well as several traces, are valid window sizes. The operator length is the length of the deconvolution operator applied to the data. The operator length is a critical parameter: If it is adjusted too large, the operator matches any predicted trace with the input data. Therefore, primaries in the vicinity of the multiples will be also subtracted. However, with a very short operator length, predicted data will not be matched to the input data properly. Consequently, multiples will not be subtracted from the data. The best result is obtained empirically, a window length matching the prevailing period of the data is a good choice in many cases. An example is provided in the next section.
It is shown that, the hyperbolic formula (equation 1) is limited to near offsets and is affected by spread length bias. To use this method for larger offsets, we apply the method twice, once to the near offsets and once only to larger offsets. In the next section the method is applied to synthetic data.

SYNTHETIC DATA EXAMPLE

To illustrate the method, we first applied it to the synthetic Sigsbee2B dataset. The minimum offset is 0 m, the maximum offset is 7932 m and the receiver spacing is 22.86 m.
For the processing, only CMPs in the range between 400 and 850 were chosen, since in this excerpt the 1D multiple prediction approach failed because of the strong dip of the ocean bottom. We applied adaptive subtraction in the common offset domain to investigate the result of our implementation at different offsets. As stated previously, the length of the operator in adaptive filtering should be chosen carefully to keep the primaries untouched while attenuating the multiples. To illustrate this, an example is provided. Figure 1(a) shows a common offset (CO) section at 4000 m after multiple attenuation with a short operator length.

The blue square specifies a part of a multiple event which is not attenuated properly and the red square specifies a part of a primary event which is untouched after the multiple attenuation. Figure 1(b) shows this section after multiple attenuation with a too long operator length, the blue square specifies a part of a multiple event which is strongly attenuated, and the red square specifies a part of a primary event in the vicinity of a multiple which is also suppressed after the multiple attenuation. Figure 1(c) shows this section after multiple attenuation with a suitable operator length, the blue square specifies a part of a multiple event which is attenuated properly while the event in the vicinity of a multiple is untouched in red square.
As mentioned before, the stacking operator is affected by spread length bias. This limitation is visualized in Figure 2. Figure 2(a) displays a common offset section at 500 m from Sigsbee2B dataset before multiple attenuation and Figure 2(b) displays this section after multiple attenuation. The first order multiple which is indicated by an arrow in Figure 2(a) is attenuated and not visible in Figure 2(b). Since a primary event crosses the multiple in the area which is specified by a square, it is attenuated as well. Considering that it is a pre-stack section and other offsets of this primary will compensate this effect and event will not be affected in the stacked section. Figure 2(c) shows a common offset section at 6000 m from Sigsbee2B dataset before multiple attenuation and Figure 2(d) shows this section after multiple attenuation. In Figure 2(d), you can still see the first order multiple, which is depicted with an arrow in Figure 2(c). In multiple prediction for both CO sections (500 m and 6000 m) stacking velocity and stacked section determined from near offsets data (shorter than 4500 m). To resolve this limitation, we applied the method to short and large offsets (larger than 4500 m) separately. Since we adjusted the velocity search interval and the apertures in a way that we could achieve the best possible result for imaging multiples, primaries maybe not be optimally imaged. Figure 3 shows the stacked section using only far offsets (4500-7000 m). In contrast to the multiples, primaries are not optimally imaged. Figure 4 displays the result of multiple attenuation in the CO section for the offset of 6000 m, Figure 4(a) shows the common offset section after multiple attenuation using the stacked section and velocity model from the data including only near offsets (0-4500 m), we can still see the multiple, which is indicated by an arrow. Figure 4(b) shows the common offset section after multiple attenuation using the stacked section and stacking velocities determined from the data including only far offsets (from 4500 m to 7000 m), the multiple energy is successfully removed from this section.
The Sigsbee2B data for CMP 400 to 850 were processed according to the above described procedure. The result is shown in Figure 5. In Figure 5(a), the stacked section including multiples is displayed and in Figure 5(b) the corresponding stacked section after multiple attenuation is shown. The energy from the first order multiple, which is indicated by an arrow in Figure 5(a), is removed and it is not recognizable in the stacked section in Figure 5(b), while the primaries in the vicinity of multiples are left untouched. Generally, the result is encouraging. For further investigation of the method we applied it to field data.

FIELD DATA EXAMPLE

In the next step, the method was applied to a Marin dataset. The data originated from the Levantine basin in the eastern Mediterranean Sea, and is provided by TGS-NOPEC. This data features a large offset of 7300 m with a maximum fold of 288.
At first, a stacked section, the corresponding coherency section, and stacking velocity profile were generated for near offsets (from 150 m to 3638 m). Since in this case our target was to image surface related multiples in marine data, we set the velocity search interval from 1450 m/s to 1550 m/s which includes the velocity of water. The ZO traveltimes were picked in the stacked section and pre-stack traveltimes of multiples were predicted using the stacking velocity profile and the coherency section. In order to predict multiples for far offsets, the method was applied once again, to far offsets (from 3638 m to 7338 m). Stacking velocity range were chosen in a way to enhance multiples. Figure 6 shows the stacked section of the far offset data. In Figure 7(a), the stacked section before multiple attenuation is presented, and in Figure 7(b) the corresponding stacked section after multiple attenuation is shown. Overall, we can see that most of the multiple energy, which is depicted with an arrow in Figure 7(a), is removed from the stacked section in Figure 7(b). Although there are some residuals of the multiples, the result is quite promising for future development of this approach.

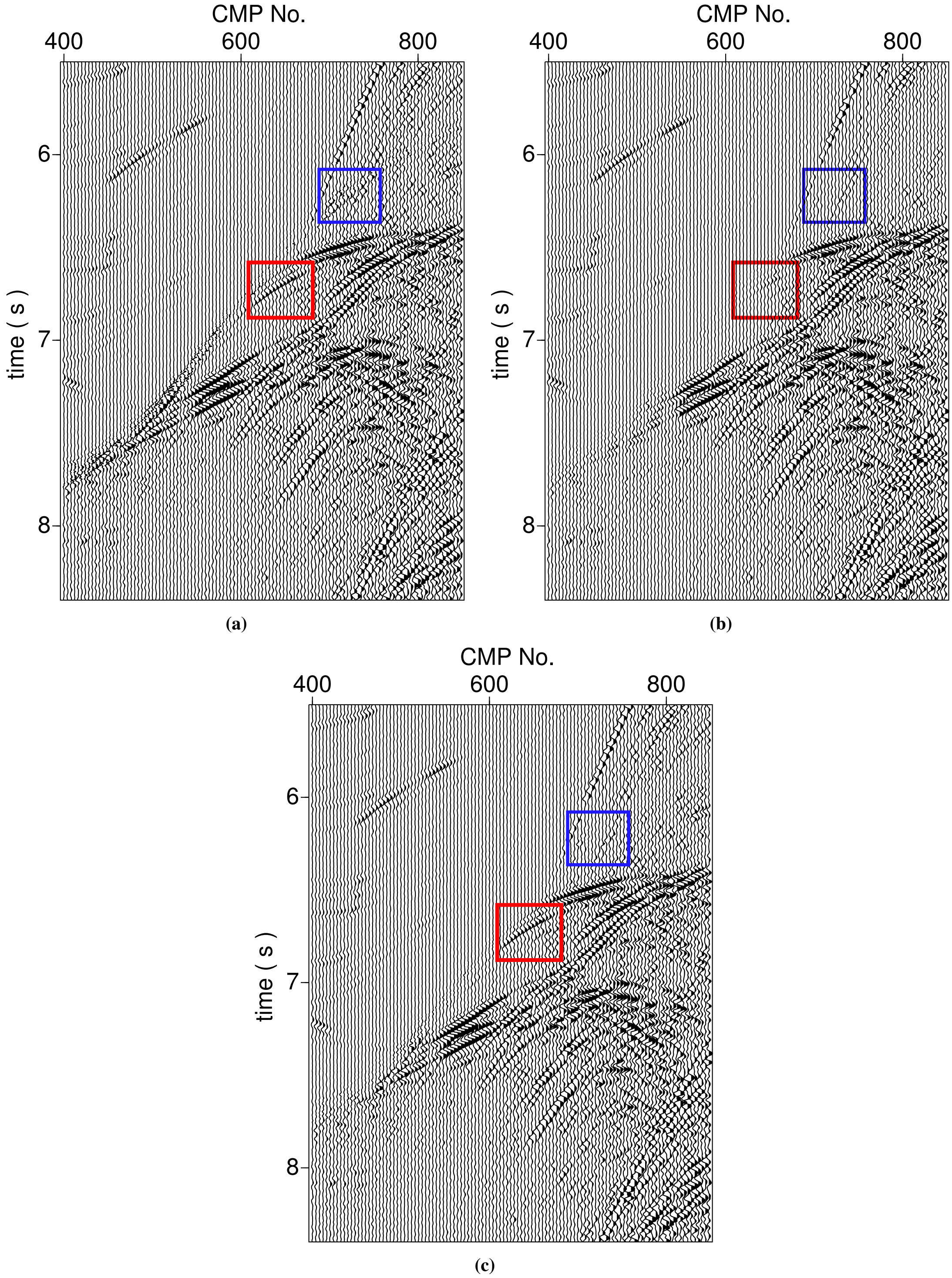


Figure 1: Sigsbee2B dataset common offset section at 4000 m after multiple attenuation . (a) shows a common offset section at 4000 m after multiple attenuation with a short operator length. The blue square specifies a part of a multiple event which is not attenuated properly and the red square specifies a part of a primary event which is untouched after the multiple attenuation. (b) shows this section after multiple attenuation with a too long operator length, the blue square specifies a part of a multiple event which is strongly attenuated, and the red square specifies a part of a primary event in the vicinity of a multiple which is also suppressed after the multiple attenuation. (c) shows this section after multiple attenuation with a suitable operator length, the blue square specifies a part of a multiple event which is attenuated properly and the red square specifies a part of a primary event in the vicinity of multiple which is untouched after the multiple attenuation.

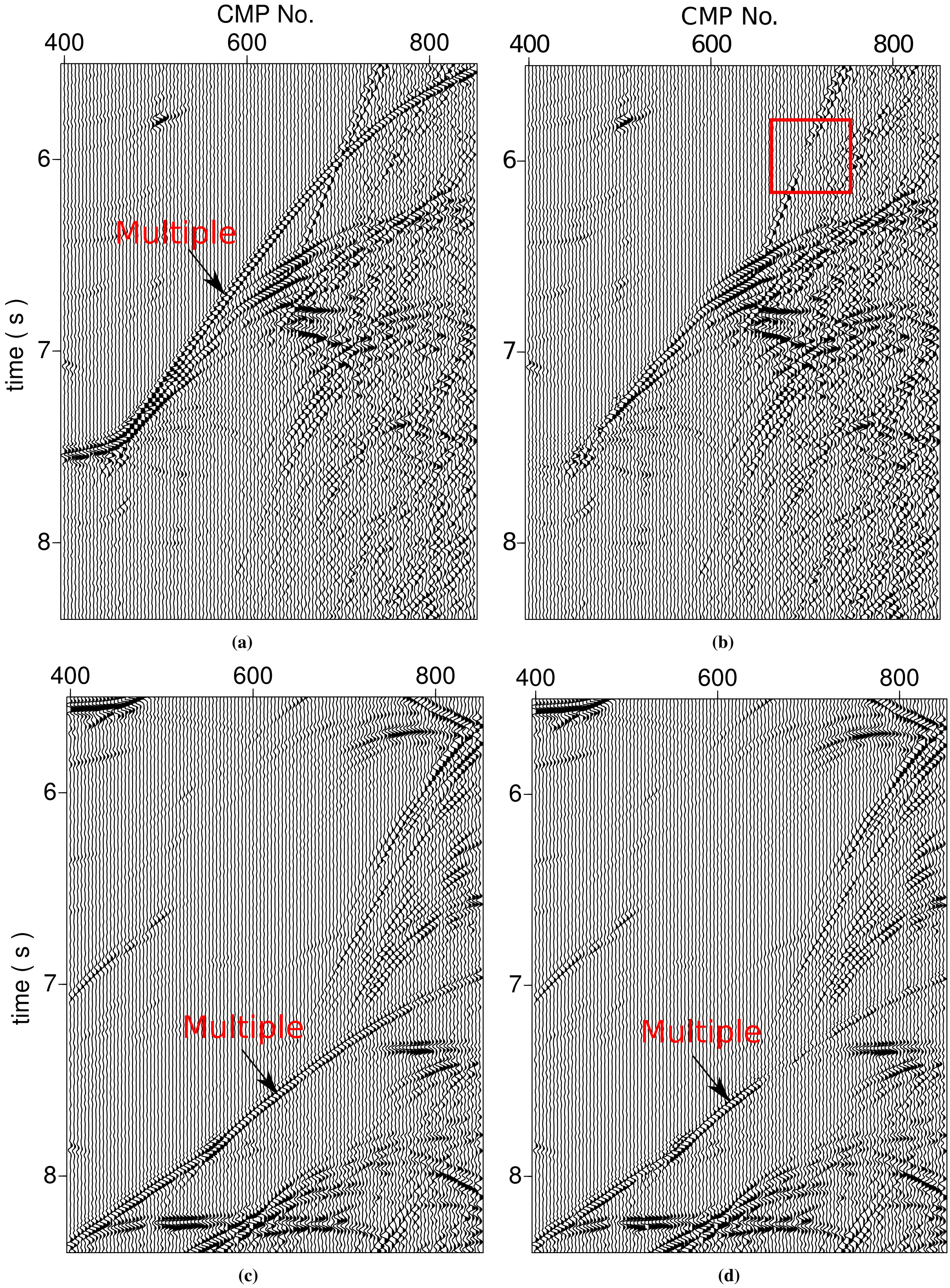


Figure 2: (a) displays a common offset section at 500 m from Sigsbee2B dataset before multiple attenuation. (b) displays this section after multiple attenuation, the first order multiple which is indicated by an arrow in (a) is attenuated and not visible in (b). Since a primary event conflict with multiple in the area which is specified by a square, it is attenuated as well. considering that it is a pre-stack section other primaries offsets of this primaries will compensate this and there will be no effect in the stacked section. (c) shows a common offset section at 6000 m from Sigsbee2B dataset before multiple attenuation and (d) shows this section after multiple attenuation. In (d), you can still see the first order multiple, which is depicted with an arrow.

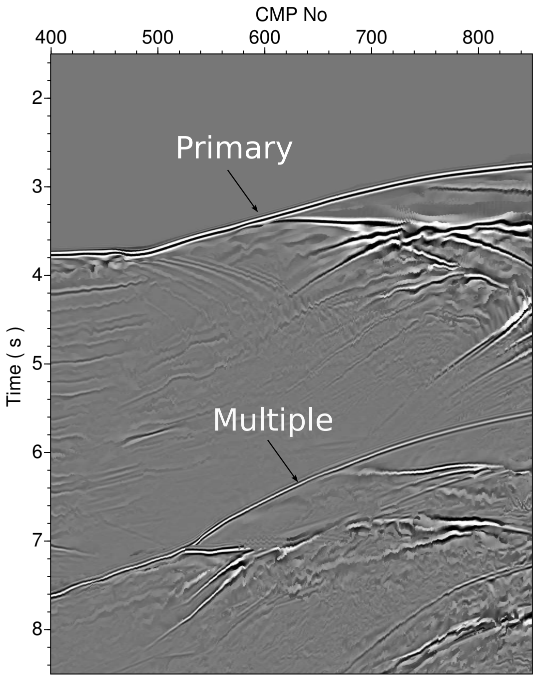
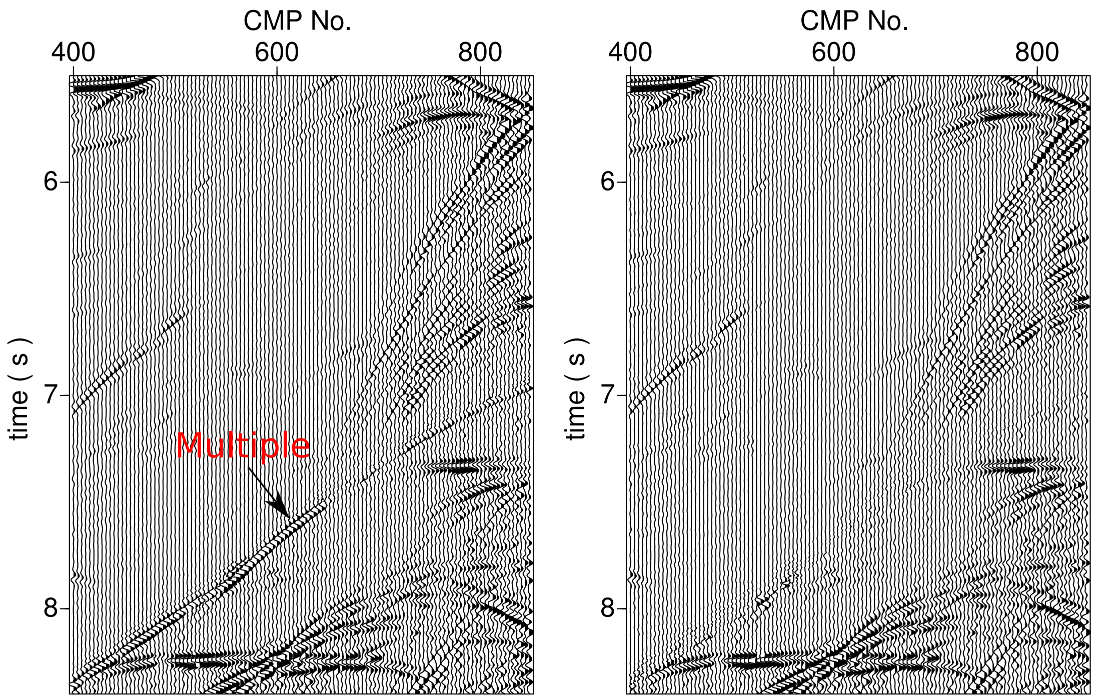


Figure 3: The stacked section of far offsets (4500-7000 m) in the Sigsbee2B dataset. The stacking process is done, such that multiples are optimally imaged.



(a)

(b)

Figure 4: Figure 4 compares the result of multiple attenuation at offset of 6000m. (a) using the stacked section and velocity model from the data including only near offsets (0-4500 m). We can still see the multiple, which is shown by an arrow, in the section. (b) using the stacked section and velocity model from the data including only far offsets (4500-7000 m), multiple energy is removed from this section.

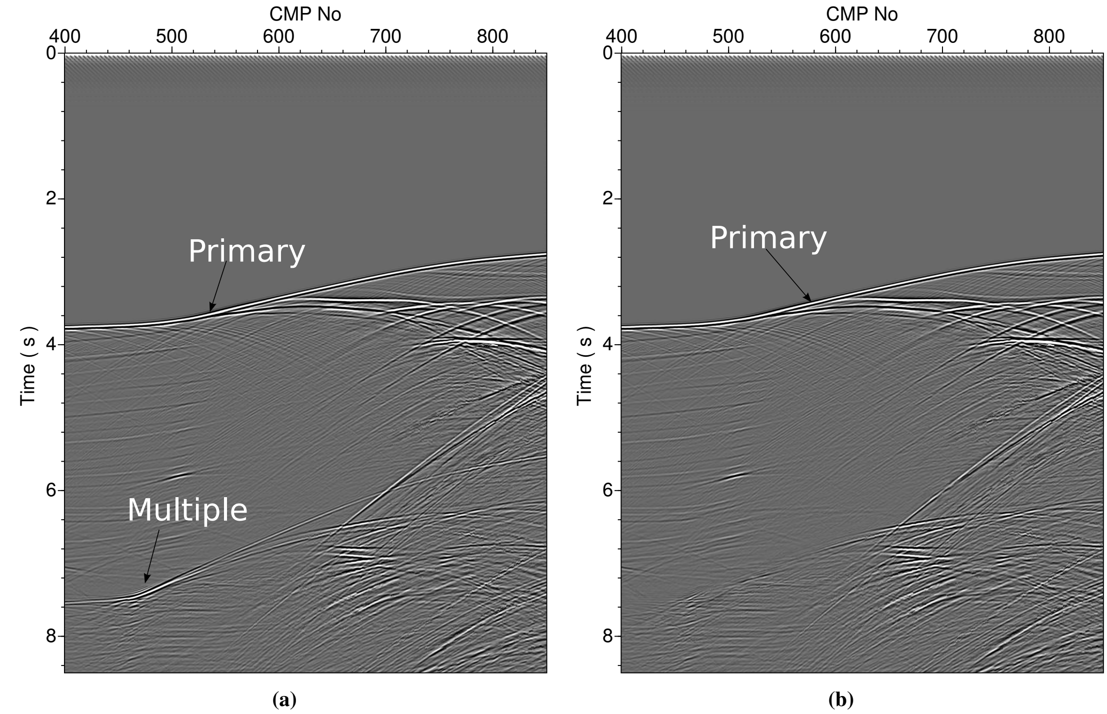


Figure 5: Sigsbee2B dataset CMPs form 400 to 850 with strong dip in sea bottom. In (a) the stacked section including multiples is displayed. In (b) the corresponding stacked section after multiple attenuation is shown. The first order multiple (indicated by an arrow in (a)) is removed and it is not recognizable in the stacked section in (b), while the primaries in the vicinity of multiples are left untouched.

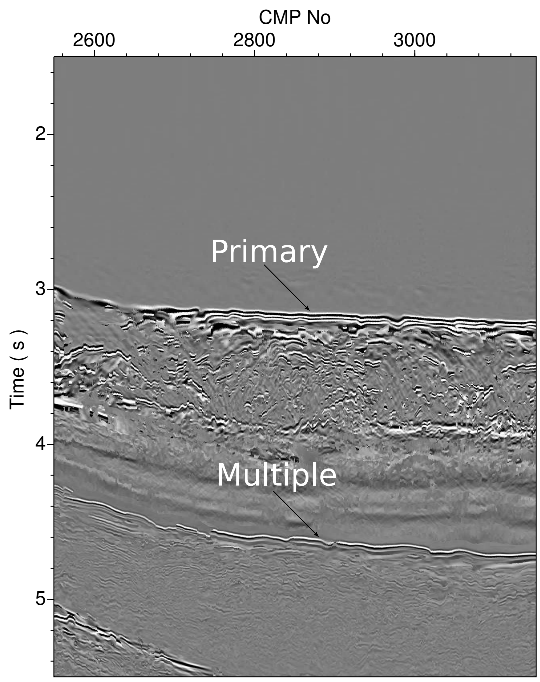
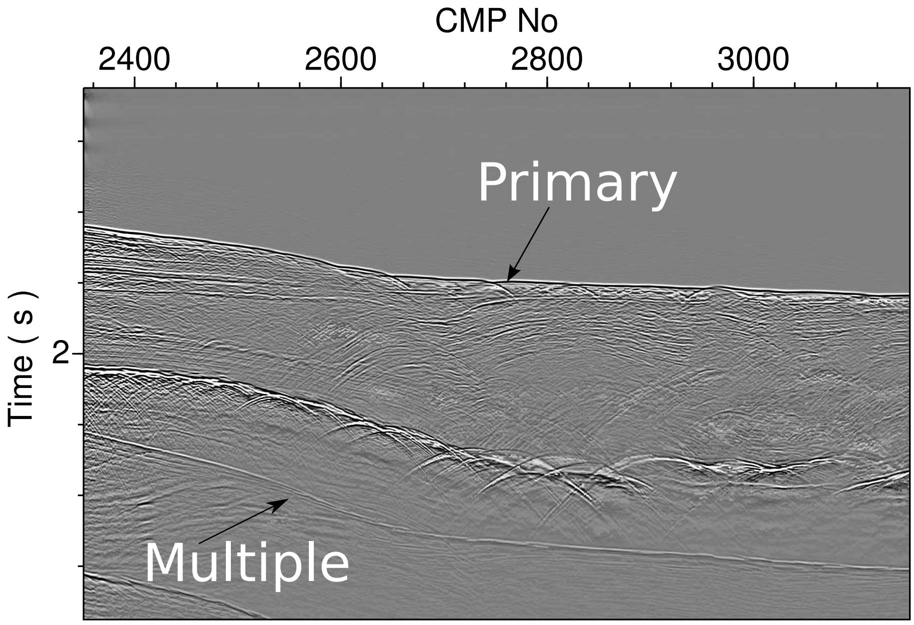
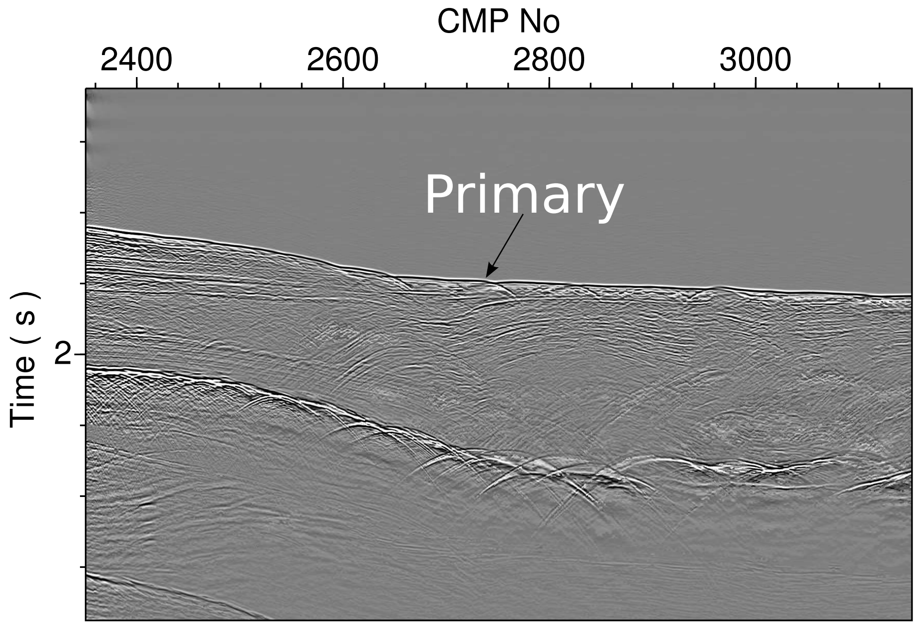


Figure 6: The stacked section of far offsets (3638-7338 m) in the TGS data. The stacking process is done, such that multiples are optimally imaged.



(a)



(b)

Figure 7: Marine data example. In (a) the stacked section including multiples is displayed. In (b) the corresponding stacked section after multiple attenuation is shown. we can see that most of the multiple energy (indicated by an arrow in (a)) is removed from the stacked section in (b).

CONCLUSIONS

Initial results on a marine dataset and a synthetic dataset show the prospect of the presented multiple attenuation method. The main advantage of the approach is its speed and robustness. The methodology can be applied to any hyperbolic event, including internal multiples and surface related multiples.
We have presented an approach for multiple attenuation within the stacking approach. Any kind of stacking operator can be used including the CRS operator. In that case, it is possible to use CRS pre-stack data enhancement (Baykulov and Gajewski, 2009) to obtain a stacked section with high S/N ratio. Automatic picking is an alternative for manual picking, but might be challenged by triplications and conflicting dips. Multiple identification in the stacked section is an interpretational step and should be done carefully in order to avoid picking primaries instead of multiples. Picking events in area with triplications and diffractions is a very challenging task. To ease this step, we can apply the method in the Common Scatter Point (CSP) domain (Dell et al., 2010). Extending the method to 3D is a straight forward step.

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