Internal multiple attenuation to reduce the risk in quantitative interpretation A case study on Åsgard field Smørbukk

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Summary

When interpreting exploration and production datasets there can be uncertainty related to falsely identifying multiples as primaries. This can be experienced in exploration areas with limited well control and velocity information, and in more mature producing areas where we extract information from seismic data for drilling and production decisions. As a result, falsely interpreted multiples can affect both our structural and stratigraphic understanding as well as interfere with reservoir analysis, volume estimation and other relevant production decisions. This paper describes modeling of internal multiples using an inverse scattering series (ISS) algorithm and subsequent attenuation with an aim to improve data quality and quantitative understanding of Åsgard field Smørbukk.

Introduction

Generally, multiples can be subdivided into two main groups: free surface and internal multiples. In reflection seismic free surface multiples are events that experience at least one bounce at the free surface, while internal multiples have all their bounces within the subsurface, never experiencing reflection from the water surface boundary.
Conventional seismic processing has effective routines to attenuate free surface multiples. Various methods have been developed in the last 10-20 years. The more successful are based on data driven prediction of multiples which are followed by a sequence of adaptive subtraction. Although the quality of the predicted multiples and thus the final results depends on factors such as data sampling and acquisition configuration, conventional processing routines can mitigate some of these effects by adapted pre-processing, interpolation and regularization techniques. On the other hand, internal multiples have often been ignored in the conventional processing sequences. While there has been progress in development of tools to predict internal multiples, it is still challenging to apply these in practice. As a result, datasets presented to an interpreter can be contaminated by internal multiples and may pose a risk for structural interpretation and data analysis.

Method – zero offset

To predict internal multiples, we implemented a scheme based on Inverse Scattering Series (ISS) algorithm (Weglein et al. 2003). This algorithm is applied as a zero-offset prediction and is best adapted to work on stacked data migrated in time domain (Ramirez et al. 2017).
Formula (1) (Ramirez et al. 2017) describes implementation of ISS algorithm based modeling for zero-offset case:

$$b_3(k) = \frac{1}{2ik}\int_{-\infty}^{\infty} dz_1 e^{ikz_1} b_1(z_1) \int_{-\infty}^{z_1-\varepsilon} dz_2 e^{-ikz_2} b_1(z_2) \int_{z_2+\varepsilon}^{\infty} dz_3 e^{ikz_3} b_1(z_3), \quad (1)$$

where b_3 is the predicted internal multiple model; k is the vertical wavenumber; $b_1=-2ikD(k)$ is effective data *D*. ε is a positive parameter that defines the length of the source wavelet. The pseudodepths z_i, are defined with reference velocity c_0 to be $z=c_0t/2$. They are, in general, equivalent to vertical time. The limits of the integrals ensure that the nonlinear combinations of data have a *lower-higher-lower* relationship, thus predicting internal multiples only (Nita et al, 2007). Figure 1 shows a representation of an internal multiple. Reflection a-d can be represented as a combination of three subevents. S1 is a travel time between a and c, S2 is between b and c and S3 is between b and d.

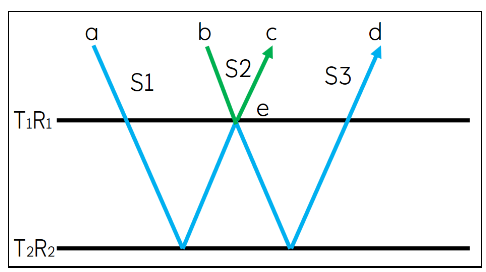

Figure 1 Internal multiple a-d can be represented as three subevents: S1, S2 and S3

Considering the expression in formula (1), we can represent an internal multiple's traveltime, Im, as:

$$Im = S1+S3-S2. \quad (2)$$

To predict internal multiples and avoid introducing artifacts in Im, subevent S2 shall not have contributions greater than subevents S1 and S3.

Applying this algorithm to a band limited dataset will effectively convolve three wavelets from the three subevents and thereafter modify the frequency range of the predicted model compared to the input data. This should be compensated for during the multiple modeling/subtraction processing sequence.

Key advantages of ISS based zero-offset internal multiple modeling implementation:

- Efficient and low cost.
- Prediction is purely data driven and as such does not require information on subsurface velocities, or multiple reflection generator interpretations.
- Applied in the post stack domain it can be used as a tool during interpretation where predicted models will guide interpreter to avoid following multiple events

Figure 2 shows a schematic workflow for modeling and subsequent adaptive subtraction.

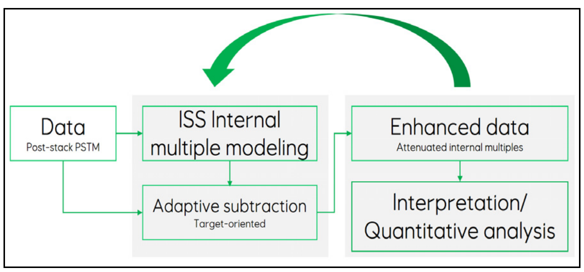

Figure 2 Schematic workflow for modeling and subtraction of internal multiples. Input stack data after preconditioning including noise attenuation/coherency/resolution improvements is used in modeling and adaptive subtraction workflow. Results are analyzed and workflow is iterated to optimized parametrization of modeling and subtraction.

Application of target oriented adaptive subtraction can improve data quality for subsequent quantitative data analysis. Rapid implementation in zero-offset domain provides an effective platform for integration between processor and interpreter where several iterations of modeling and subtraction are performed to optimize the results. There are several assumptions and points to consider when applying ISS algorithm for internal multiple prediction:

- Input data is considered as free of free-surface multiples.
- Because modeling algorithm is fully data driven, resolution of predicted multiples and their coherency will be affected by input data quality. Thus, necessary data preconditioning such as overburden coherency/resolution enhancement and noise attenuation should be performed prior to modeling application.
- Internal multiples can be partly attenuated as part of application of typical processing steps such as velocity discrimination techniques, migration, stacking and other steps. Therefore, not all modeled internal multiples will be present in the input stack data and adaptive subtraction techniques will be required to obtain optimal multiple attenuation.

Adaptive subtraction

To fully utilize the potential of predicted models we apply adaptive subtraction techniques to attenuate predicted multiples from the input data. Adaptation is aimed to compensate for differences between the input and the model and adaptively subtract the two. In typical scenarios of free-surface multiples, predicted models are more energetic than the underlying input data. In such cases least-squares type of adaptation is very effective and is typically applied in a pre-stack domain. Internal multiples with all downward reflections within the subsurface do not show such a strong discrimination from the input data. Additionally, in the domain we are applying this workflow there can very little structural discrimination between primaries and multiples. Due the polarity differences the primary signal amplitude can experience local reduction or amplification through interference with the internal multiples. Such cases will require a more complicated and uncertain adaptive subtraction. Utilization of L1 norm can be beneficial to preserve the underlying signal (Guitton et al, 2004) along with combination of frequency and dip discrimination techniques. Even though the current workflow is implemented as a zero-offset technique through application of adaptive subtraction we have experienced good results on both near, mid and full angle volumes.

Identification and QC

Given a strong reflectivity in the overburden we should expect to see internal multiples in our data. However, it can be challenging to identify them, especially at the target level. In the process of imaging primaries and attenuating all multiples we will subsequently reduce internal multiples in the final stack data and as such predicted models may not fully correlate to residual internal multiple energy left in the data. Various techniques can be used as support to identify the presence of internal multiples and guide the

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quality of adaptive subtraction. Comparing signal amplitude extracted over a target interval to multiple model can potentially show possible interference of internal multiple and primaries (Sigernes et al. 2017). Cross-correlating multiple model with stack before and after adaptive subtraction we can quantify multiple prediction and subtraction results. Plotting such an attribute laterally can provide areas where we can experience higher risk of interference between multiples and primaries and provide valuable information for interpreters. Figure 3 shows an example of a cross-correlation produced before and after internal multiple removal. The peak at zero lag within the green rectangle shows a correlation between the multiple model and stack data with residual internal multiples. This peak is reduced after adaptive subtraction of the internal multiples in the stack data, as shown on figure 3b. Such QC should be used with caution and combined with a lateral examination, as there could be a correlation between the multiple model and genuine dips in the data.

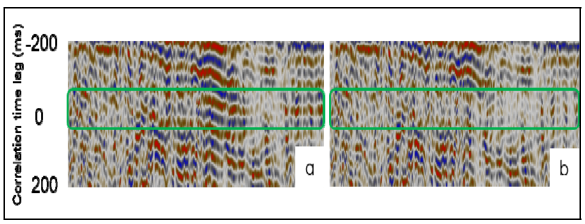

Figure 3 Cross-correlation calculated in the target interval, before (a) internal multiple attenuation and (b) after internal multiple attenuation. On the (b) plane we can observe reduced pick of cross-correlation within the green rectangle

Case study – Åsgard field Smørbukk

Zero-offset domain internal multiple prediction and subtraction was applied to the Åsgard field Smørbukk (Sigernes et al. 2017). Åsgard field is located on the Halten Terrace and includes several fields; one of them is Smørbukk. Hydrocarbons in this field are present in the middle and lower Jurassic. Top reservoir is located at depth mostly below 4 km. Water bottom in the area is roughly 320 m deep. Streamer data which was used for internal multiple modeling was acquired in 2013. There are more than 50 wells drilled. This provides a good stratigraphic understanding of the subsurface. There are several strong reflective layers in the shallow overburden that are potential internal multiple generators which can cause interference with primary signal at the target level.
Applying zero-offset modeling algorithm we were able to:

- Identify internal multiples in the stacked data
- Provide value though adapted subtraction of identified multiples from the stacked data.

Figure 4 shows a seismic section (a) before subtraction, (b) after subtraction of internal multiples and (c) the difference before-after subtraction. We can observe reduction of internal multiple energy in the data and improvement in continuity of events in the green circled area at the target level. These observations are also confirmed by a cross-correlation QC as shown on figure 3.

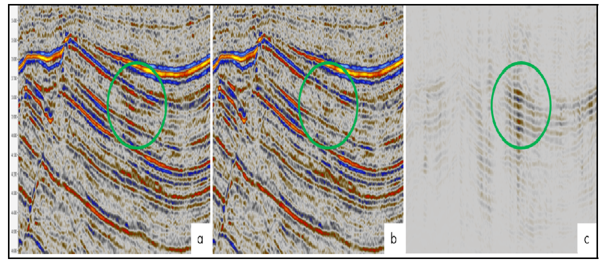

Figure 4 (a) seismic section before internal multiple attenuation, (b) after and (c) the difference. Reduction in internal multiple energy and improved coherency at the target level can be observed.

The main goal of internal multiple attenuation workflow is to improve data quality and extract value through better reservoir management decisions. Improved seismic data quality on Smørbukk allowed interpreters to extract more accurate porosity information as shown on figure 5. The black curve shows acoustic impedance (AI) calculated from the well information (figure 5b). AI is used as an approximate for porosity value. The red curve (figure 5b) is AI inverted on data before and the green curve is after attenuation of internal multiples. AI inverted on the data after internal multiple attenuation shows a better match to the values calculated from well logs. Observed improvement in the porosity is approximately 2%. This is not a large value but given the initial porosity values, it was enough to convince the interpreter to adjust planned well location to an area with a better predicted porosity as shown on figure 5a.

Method – extension to multiD

Described zero-offset workflow for internal multiple prediction is adapted to stack data in time migrated domain. Further extension of internal multiple modeling to pre-stack domain before imaging should allow for a more optimal prediction, with potentially more genuine amplitude information provided for AVO analysis. More data domains should allow for a more optimal adaptive subtraction considering for example moveout information. Such an extension to pre-stack domain is considered as a challenging task, given computational and input data requirements.

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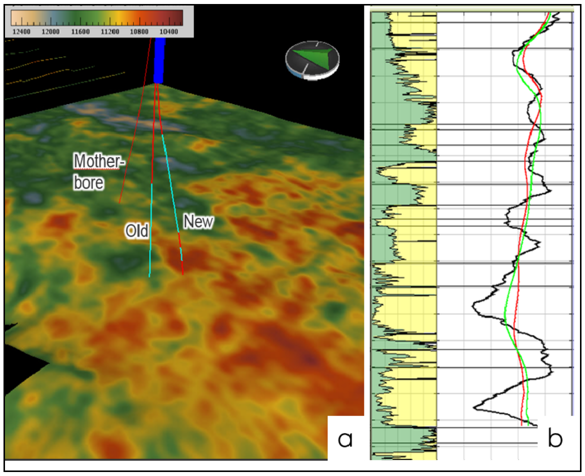

Figure 5 (a) porosity difference map shows an area with a planned well location (old) and the adjusted (new). Adjusted well location is planned in an area with higher porosity estimated on the data after internal multiple attenuation. (b) AI curves which is an approximate for porosity, extracted from the well in black, and inverted from seismic data before internal multiple attenuation in red and after in green.

We are in the process of developing a workflow for multiple prediction applied in coupled plane wave domain. The figure 6a shows data generated with FD modeling for the velocity displayed in figure 6d. Figure 6b shows the data after adaptive subtraction and figure 6c shows predicted internal multiple model. Predicted multiple model can be adaptively subtracted from the input data either before or after migration. The benefit of working in either domain is being investigated and will be reported in future publications.

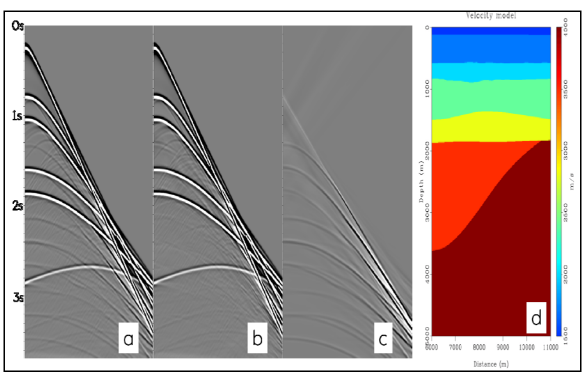

Figure 6 (a) synthetic data generated using FD modeling; (b) synthetic data after adaptive subtraction of predicted model in (c). (d) velocity model for FD forward modeling

Conclusions

Internal multiple prediction method based on Inverse Scattering Series applied in the zero-offset domain is a powerful tool to predict multiple energy in the data. It is fully data driven and an easy to use tool. Predicted models can be used as a direct input during interpretation. Additional application of adaptive subtraction can further improve data quality for reservoir characterization. Further improvement of the workflow by extending it to pre-stack domain is in progress. Extended workflow can allow for more optimal modeling and subtraction of internal multiples.

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