Using A 3D PSDM Simulator to Facilitate Overburden and Survey Consistent Modelling of the 4D Seismic Response of the Norne Field

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Summary

In this paper we use an alternative approach to 3D and 4D elastic and seismic modeling based on a PSDM simulator technique introduced by Lecomte et al. (2003), Lecomte (2004), and presented in more detail in Lecomte (2008). The method is both computationally efficient (thus allowing quick, repeatable, multi-scenario desktop analysis) and allows the integration of constraints from the survey and overburden properties in terms of both illumination and resolution. The technique will be demonstrated on data from the Norne field offshore mid-Norway. An overview of a typical modeling workflow can be found in Gjøystdal et al. (2007). This paper will focus on the integration of survey data, overburden properties, rock properties and fluid simulator data into the 4D modeling scheme, and discuss their impact on the seismic responses. We refer to Osdal et al. (2006) for more information about the Norne field and how the 4D seismic data were applied to optimize production on Norne.

Introduction

Mapping the changes in the fluid and pressure distributions of a reservoir during production is a major objective in 4D seismic data analysis as seismic data is the primary source of information about the changes, in areas away from well control. Seismic modeling can be used as a guide for interpreting seismic changes during production, e.g. whether they are consistent with producing hydrocarbons or pressure changes, or a combination of both. However, in most 4D projects a simple 1D seismic modeling approach is used, disregarding the illumination and sampling characteristics imposed on the reservoir response as the seismic waves are transmitted by a pattern of sources, modified by the overburden structures, reflected in the reservoir and recorded by another pattern of receivers. It is documented that the combination of these influences will cause uneven sampling of the subsurface target and may in some situations cause "false" amplitudes in the seismic data (e.g. Laurain et al., 2004). Also the horizontal resolution characteristics are frequently ignored in the 1D approach. The complete 3D characteristics of the survey and overburden can be incorporated in FD approaches but the computing challenges for such methods in 3D and 4D field studies are prohibitively large to enable quick, repeatable, multi-scenario desktop analysis.

The PSDM simulator

A common technique within seismic time-lapse modeling is to create a vertical pseudo-well at the selected locations and perform the modeling by a simple convolution. By repeating the modeling over an area a 3D volume can be created, but the analysis is still 1D and there is no way of including survey-overburden constraints in terms of illumination and resolution. Through the use of a 3D PSDM simulator (SimPLI[1] – Simulated Prestack Local Imaging) we demonstrate the improvements that can be gained by extending routine seismic simulation from the local 1D approach to the 3D overburden-survey consistent SimPLI approach.

The SimPLI concept efficiently estimates PSDM seismic amplitudes without the need to predict and process synthetic seismic gathers. The method is a generalized 3D convolution technique working in the depth domain which enables the prediction of 2D / 3D illumination and resolution effects in pre-stack acquisition. As such, it is a cost efficient alternative for the simulation of seismic data which includes overburden and survey effects and goes beyond classic 1D trace modeling. The method combines a detailed reflectivity model of the target with an overburden-survey-wavelet filter (SimPLI filter) in the wavenumber domain, providing a direct prediction of the PSDM amplitude when being transformed back to the space domain. The method allows direct calculation of full stacks and partial offset and angle stacks. For more details about the method and the calculation of the SimPLI filter we refer to Lecomte (2008).

Effect of survey illumination

To demonstrate the importance of incorporating the survey characteristics in the seismic analysis we used five different survey templates in a homogeneous overburden and predicted the seismic response for a constant reflectivity surface. The only difference between the cases is the SimPLI filters used. These filters have been calculated for (and therefore represent) the following surveys.

- Marine 3D narrow azimuth multi-streamer survey.
- Ocean bottom (OBS) survey.
- Wide azimuth (WAZ) survey.
- Offset well seismic (VSP) survey.
- Ideal illumination survey (i.e. 1D approach).

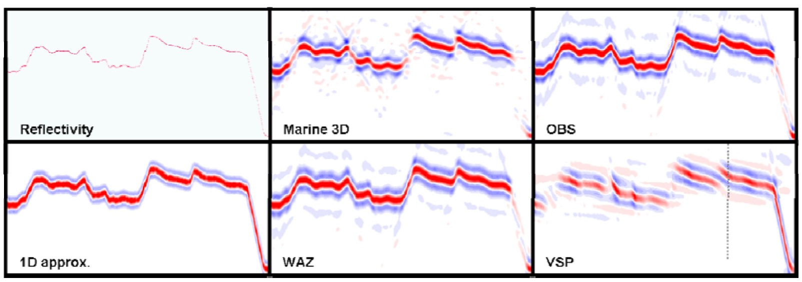

Figure 1. Reflectivity and the corresponding seismic responses for some seismic surveys as predicted by the PSDM simulator. Marked on the VSP section is the location of the well (dotted line).

The results of the exercise (Figure 1) show how the ability to map small-scale features within the interface clearly depends on the survey strategy implemented. Of primary importance is that a 1D approximation creates an image that mimics the structure shown in the reflectivity, though broadened by the seismic wavelet. However, the other survey types are all including the illumination constraints of the survey and therefore parts of the structure are rightfully absent from the image. Looking within these, note how the central fault is well mapped in the OBS and WAZ surveys, but is missing in the marine and VSP surveys. The VSP response is clearly influenced by the location of the well (as indicated by the dotted line).

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[1] Patented by NORSAR.

Seismic illumination analysis

Before modeling the 4D response an illumination analysis was performed to investigate for the seismic sampling characteristics, the offset-angle dependencies and whether “false amplitudes” generated through the survey-overburden interaction are significant. The major 4D surveys on Norne are Q-on-Q surveys using a layout with 6 streamers with length of 3.2 km and separation of 50 meters. The Simulated migration amplitude (SMA) concept described by Laurain et al. (2004) can be used to provide an indication of “false amplitudes”. Looking at the results of this approach (Figure 2), it appears that the main reservoir plateau shows few of these amplitude anomalies whereas they become stronger in the more faulted parts towards the north. Similar observations are also valid for both hit map and aperture. Also note the no-hit areas on the horst flank since the survey is a conventional 3D marine survey.

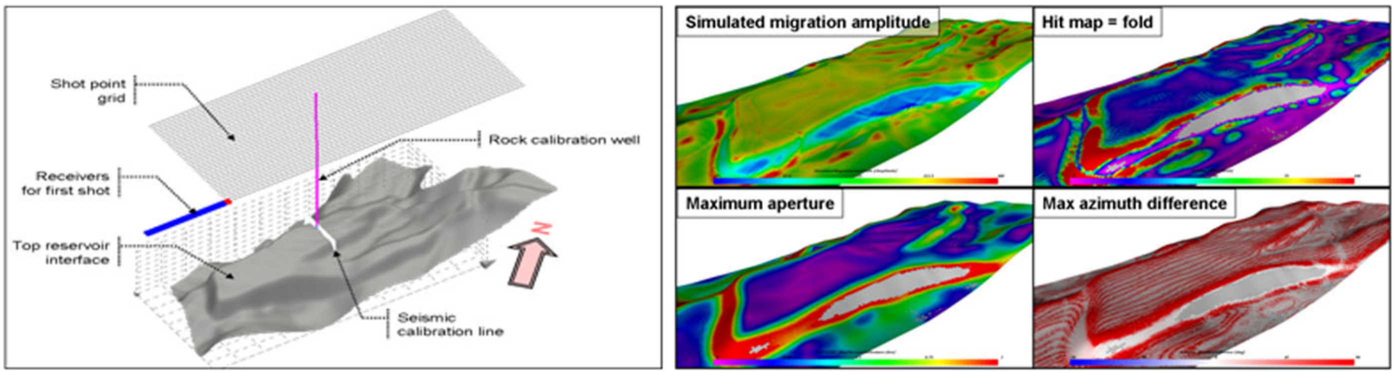

Figure 2. Overview of nominal survey layout, top reservoir horizon, location of well for rock properties calibration and location of line for evaluating the seismic tie (left) and illumination maps of top reservoir horizon from the nominal 3D survey (right).

Seismic 4D modelling results

The elastic and seismic 4D modeling was based on fluid simulator data provided by StatoilHydro and shows a spatial distribution of static parameters that do not change with production, like porosity (PORO) and net-to-gros (VSAND), and dynamic parameters that change with the production, like water saturation (SWAT), gas saturation (SGAS) and pore pressure (PRESSURE). The first step is to convert these into elastic parameters, like P-wave velocity (VP), S-wave velocity (VS) and density (RHO). We present the elastic properties by the P-impedance (VP*RHO) and the VP/VS ratio together with snapshots of some geological and elastic parameters from the model and a comparison between the observed and modeled seismic response (Figure 3). Note the difference in how the fault zones are modelled in the two approaches.

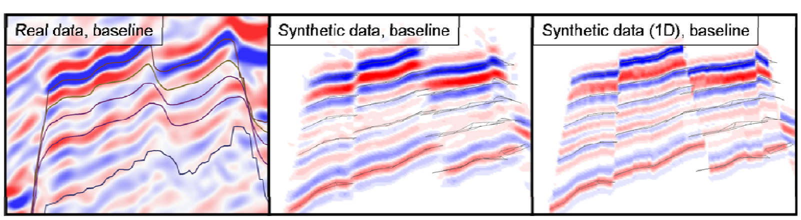

Figure 3. Comparison between the observed baseline seismics and the modelled seismic responses using the PSDM simulator and the 1D approximation along line shown in **Error! Reference source not found.**. Importantly, the PSDM simulator includes a more realistic lack of resolution imposed by the design of the seismic survey.

To compliment this, we show and discuss the predicted changes in geological and elastic parameters together with the predicted seismic changes, comparing them with the observed changes.

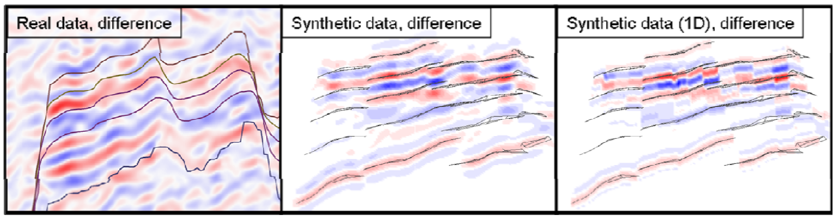

Figure 4. Comparison between the observed seismic differences and the modelled differences along the line shown in Fig.1 The differences generated using the PSDM simulator and the 1D approximation are both shown for comparison.

Conclusions

An overburden and survey consistent PSDM simulator is proven to be a valuable tool for calculating the synthetic seismic response from complex reservoir geometries. Using real data taken from the Norne field we have shown that the SimPLI approach, where PSDM seismic amplitudes that include 2D / 3D illumination and resolution effects are used, is superior to a 1D approach where illumination and resolution constraints are ignored. What is more, the methodology behind SimPLI and the implementation of the technology means that the rapid evaluation of different survey configurations can be easily achieved.

The workflow presented here has shown that more realistic 4D signals are obtained from the PSDM simulator compared to the 1D approximation. This is so even in the Norne case with its geologically simple overburden. It is right to assume that as the overburden increases in complexity, the value of a survey and overburden consistent modeling technique also increases. As the SimPLI method includes the resolution and illumination of the overburden it can provide more accurate seismic simulations thus leading to the generation of a better history match within the reservoir model.

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