Modelling-based survey and processing design

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Abstract for FORCE seminar, Valhall, 11 April 2019.
1: CGG Norge

A marine seismic survey consists of a number of sources close to the sea surface and seismic streamers sitting in the water column near to the sea surface or, in the case of ocean bottom nodes (OBN) at the water bottom. Simple heuristic methods based on surface fold and azimuth coverage have traditionally been used (and is still used) to determine the sampling and lateral extension of the sources and receivers. In addition, several forms of modelling-based survey design have been used; see e.g. Laurain et al. (2004) for an overview of ray-based methods or Zhu et al. (2013) for an example of a survey planning based on finite difference (FD) modelling. In this paper, we bring the modelling based approach to a new level of complexity by including more advanced diffraction modelling and state-of-the-art processing, imaging and inversion tools.

A successful acquisition project depends on clearly defined goals. When planning a marine seismic survey, we need to be more specific than just stating that we want "better information of the subsurface". We need to know up-front what the specific exploration- and production related targets are. For instance, do we have a shallow or a deep target? Are we looking for high-resolution structural details or are we more concerned with accurate AVO to drive inversion for reservoir parameters. Is it more important to reveal complex faulting and other dipping structures, or thin, horizontal bedding? In addition, we also need to know the timing and cost constraints of the survey.

The aim of survey design is to choose optimum survey parameters to reach the goals mentioned above. Parameters include type and size of sources, the lateral distribution and sampling of sources and receivers, depth of receivers, waiting time between shots, the time sampling of the traces (1, 2 or 4 ms), sail line direction etc. We start by choosing a number of survey configurations based on the time/cost constraints and simple rule-of-thumb considerations, taking into account the geophysical goals. We then compare the performance of these surveys using the generic approach shown in Figure *1*.

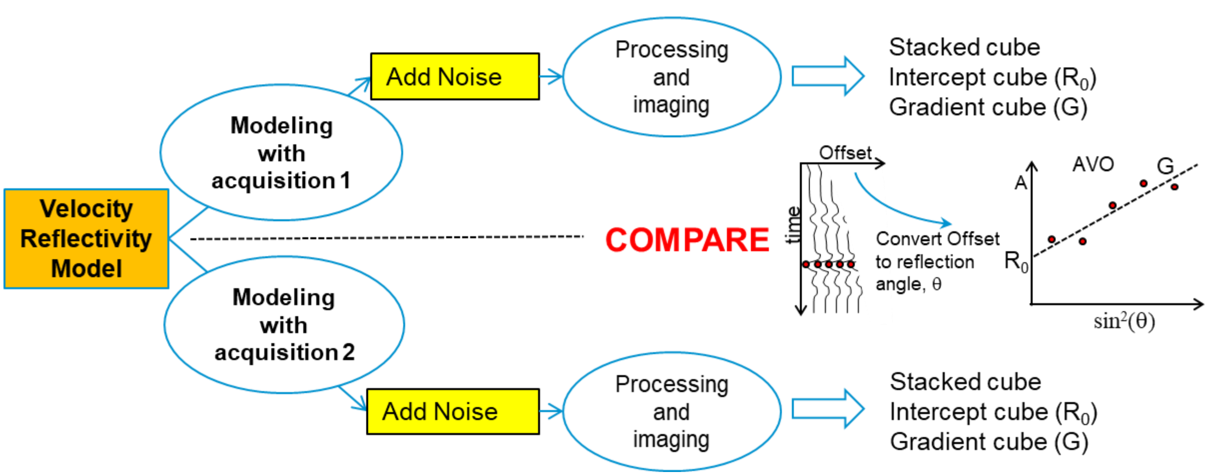

Figure 1: *Schematic view of evaluation of seismic surveys based on modelling and processing/imaging*

We use a best-guess model of the subsurface (velocities, reflectivity, anisotropic parameters, attenuation etc.) for modelling of the wave field of the different survey configurations. In this best-guess model we can also insert additional geological structures which we expect to find in the area. We then add real recorded noise or alternatively modulated Gaussian noise model to the synthetic data sets and feed it into a processing and imaging workflow to create stacked images and AVO products, which we then compare. This approach is dependent on both the survey configuration as well as the processing and imaging algorithms. We may, for instance, find that a least-squares migration is less sensitive to poor sampling of the data than a conventional migration, or that a particular demultiple algorithm is more sensitive to the streamer separation than another one. In this way, we will be able to test all the key processing steps like source designature, receiver deghosting and demultiple for a given survey configuration and we can adjust both the survey design as well as the processing workflow accordingly.

We use to types of modelling algorithms; diffraction modelling (e.g. Zhang et al 2002) and FD modelling of the 2D or 3D (acoustic or elastic) wave equation. If we need to model the whole wavefield, including diving/guided waves and internal multiples, we use FD modelling. In 3D, it is computationally heavy to model higher frequencies, so FD modelling is not suited for studying imaging and its resolution, but is well suited for evaluating Full Waveform Inversion which is an algorithm working in the low frequency part of the spectrum (up to e.g. 15-20 Hz). If we restrict the study to 2D models, however, we can do FD modelling of the full seismic bandwidth and evaluate processing, imaging and inversion algorithms.

For high-resolution 3D surveys within the full seismic bandwidth (2-200 Hz), we have found that the only practical applicable modelling tool is diffraction modelling which computes the summed seismic response of the subsurface reflectivity represented by a large number (millions) of diffraction points making up the reflectors, faults, and diffractive edges in the model. Since diffraction modelling only computes the reflections/diffractions, it is primarily suited for studying imaging and AVO quality. An example of a reflector and a shot gather from diffraction modelling is shown in Figure 2.

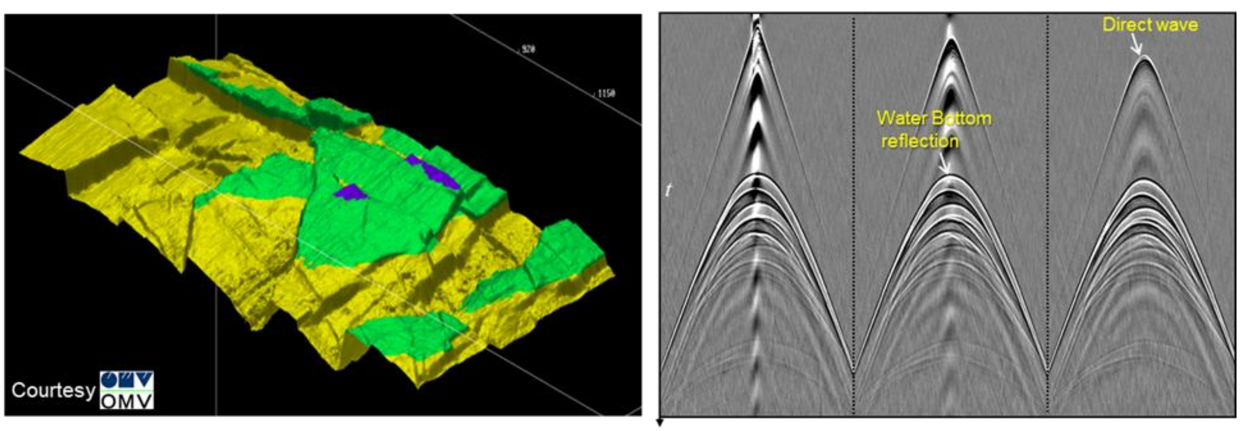

Figure 2: *Example of diffraction modelling: Top Reservoir with reflectivity (left) and synthetic shot gather in three streamers with noise (right)*

The gas, oil and water accumulations under this reflector create variations in the reflectivity as color coded on the reflector. Our implementation of diffraction modelling has the ability to include source signatures, anelastic attenuation (amplitude and phase), receiver ghosts, receiver array effects, simple peg leg multiples and AVO response of the reflectors. In most previously published modelling-based survey design studies, the modelling has been done without these features includes.

We used this modelling to develop and evaluate the TopSeis concept (Vinje et al. 2017) in which we locate the seismic sources on top of the seismic streamer spread. The split-spread shot gather on the right in Figure *2* is from a TopSeis modelling. TopSeis was successfully applied by Lundin and CGG in the Barents Sea in a large-scale acquisition in the summer of 2017, (Dhelie et al. 2018).

In Figure *3* we show an example of fully migrated stacks (crossline view) and depth slices of AVO volumes of a conventional (dual source) survey and a dual-vessel, triple source TopSeis survey. Both the stacked images and the AVO gradient show clear improvements from a conventional solution to a TopSeis solution in this shallow area.

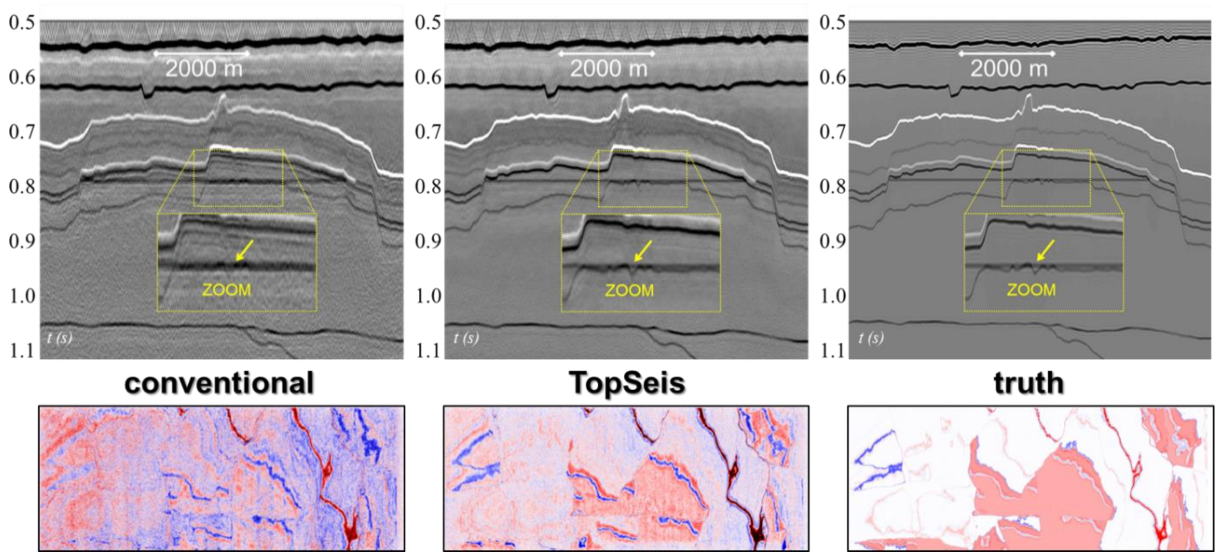

Figure 3: *Migrated stacked images with zooms on the oil-water contact (top row) and extracted AVO gradient (G) parameter along the oil water contact (bottom row) for a conventional marine survey (left column), a TopSeis solution (middle column) and the true reflectivity/AVO model (right column).*

The TopSeis survey configuration in Figure *3* is one of many that we modelled in this comprehensive modelling project, which was pivotal in the development of TopSeis acquisition and the special solutions in processing and imaging required. The development of TopSeis is one of several examples of a successful implementation of our modelling-based survey and processing design approach.

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