NORSAR Software Suite

A Case Study:
Ray based seismic modelling onshore with minimal subsurface data.

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The purpose of this synthetic example is to show how the NORSAR Software Suite (NSS) ray-based seismic modelling tool can assist in answering crucial survey geometry design questions even when there is limited available information about the area. To illustrate this we are simulating a land based scenario with an obstruction zone.

To illustrate the benefits of ray- based modelling in this scenario, we limited the project input. The only subsurface information used is a seismic time section along a 2D line, supplemented by detailed surface topography.

To prepare for a 3D analysis, the 2D line is placed into a 3D environment, based on the coordinates along the line (Figure 1).

Before the time section is digitized, the user must specify the mapping between pixels in the picture, and positions and travel times along the 2D line as shown in Figure 2.

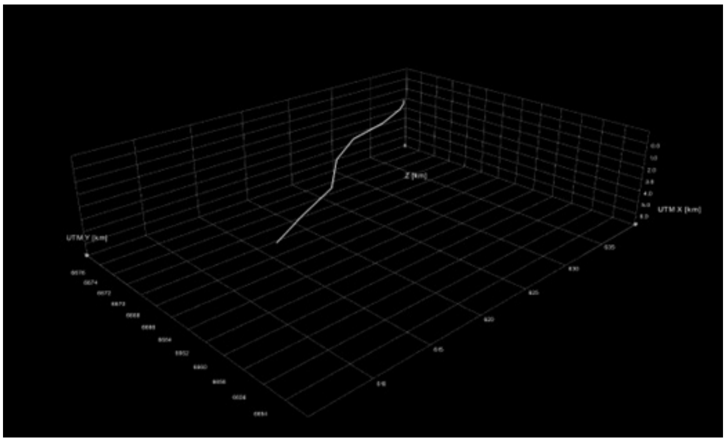

Figure 1 The 2D line in the 3D environment. The axes indicate the global coordinates in the area.

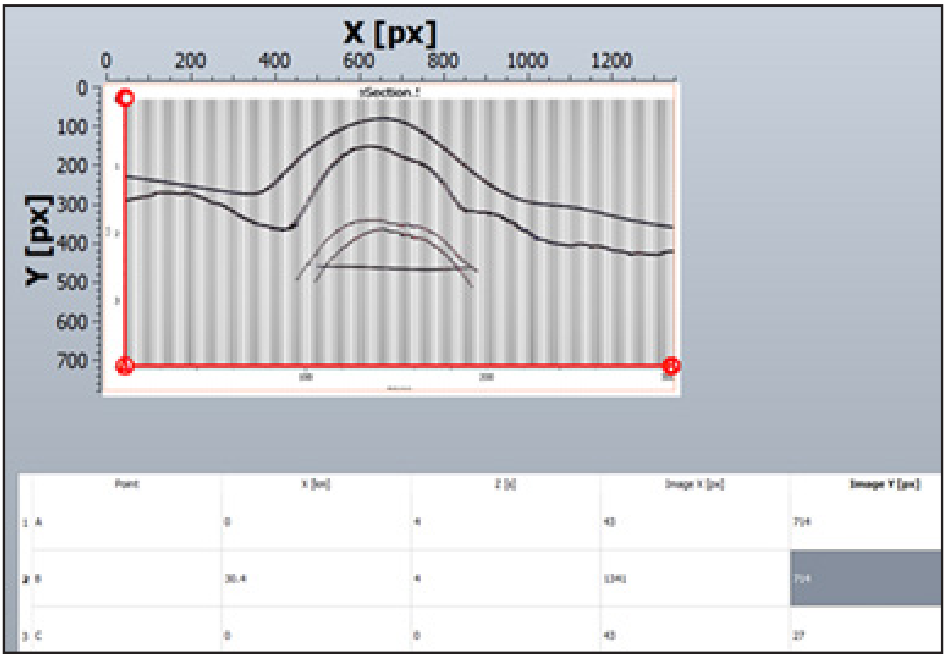

Figure 2 The time section and the specification of the mapping between picture and coordinates.

The horizons are picked by the user from the time section, and constant layer velocities are assumed. The structure is converted to depth by vertical stretching.

So far, the model has been two-dimensional. However, the topology varies crossline, therefore we want to combine the 2D line with the the 3D topology. As most subsurface features initially are only known along the 2D line it is expanded into 2.5D roughly orthogonal to the line, while the topography, that comes from a surface map, is truly 3D.

First the 2D model is expanded crossline to a ‘2.5D’model (Figure 3).

The 2D model started at zero two-way travel time. When the model was stretched to depth, zero time was mapped to zero depth. Since this is on land and zero travel time often corresponds to a specific, non-zero reference depth. In this example the reference level is 200 meters, thus all horizons in the cylindrical model must be vertically shifted by 200 meters.

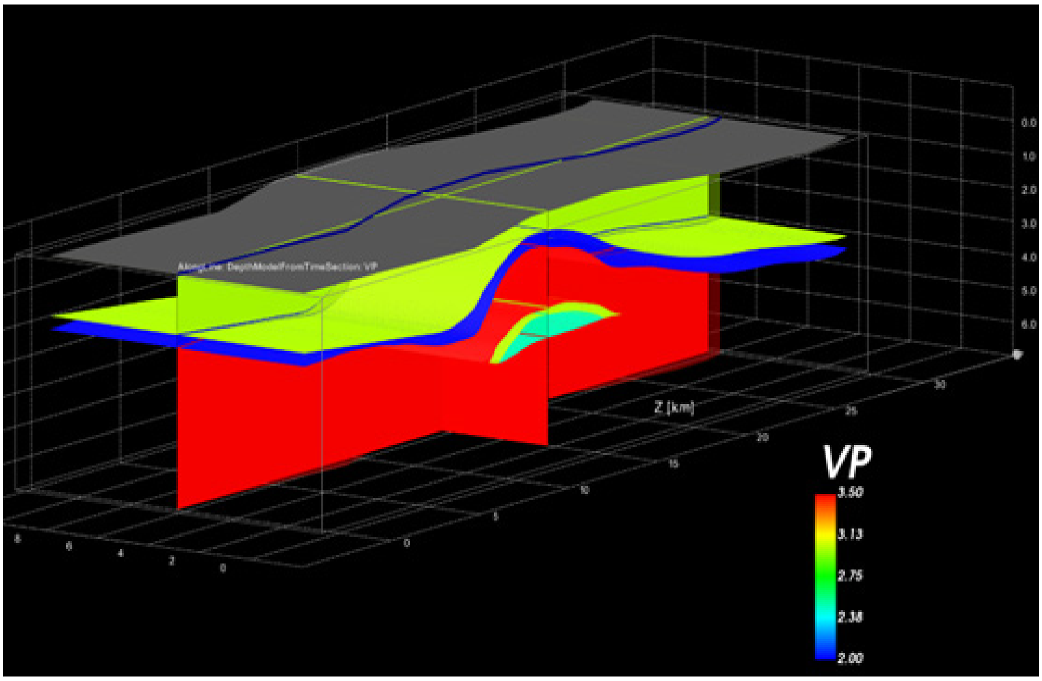

Figure 3 The cylindrical, ’2.5D’ model.

Now the topography is added on top of the model. There is a river through the area, and Its boundaries are given as a polygon (Figure 4). Only shots and receivers outside of the river area are used in the illumination analysis.

We also introduce an Area Of Interest (AOI) on the target, such that only reflections inside the AOI are of importance.

The purpose is to investigate and compare some nominal survey geometries. The term ‘nominal’ emphasizes that these are regular acquisition geometries. More irregular survey geometries can be utilized in NSS through dedicated survey design tools. Geometries from these tools can be imprted through one of our many direct links with our partnered survey design providers, or they may be imported into NSS from an SPS file.

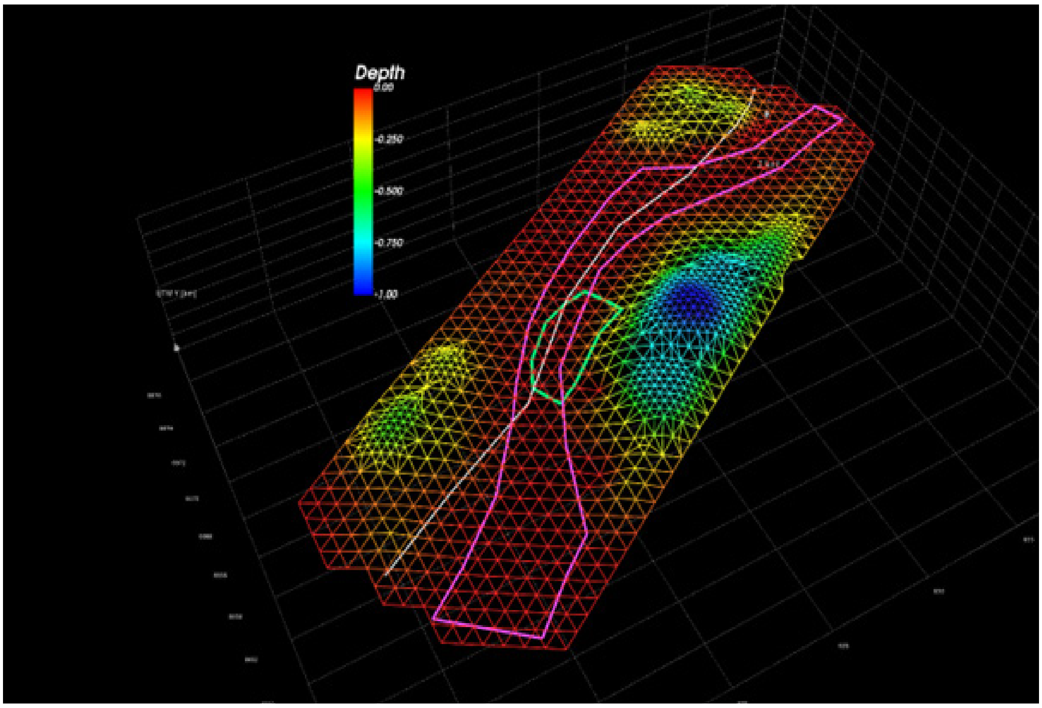

Figure 4 The topography. Depth values for the topography are negative, as the positive z-axis in NSS points down. The 2D line is shown in white. The pink polygon encloses the river area, and the green polygon is the primary AOI.

Two basic types of land survey geometries are used here: Parallel and Orthogonal. In the Parallel Survey the receiver and shot lines are roughly parallel with and on both sides of the river (Figure 5 and Figure 6).

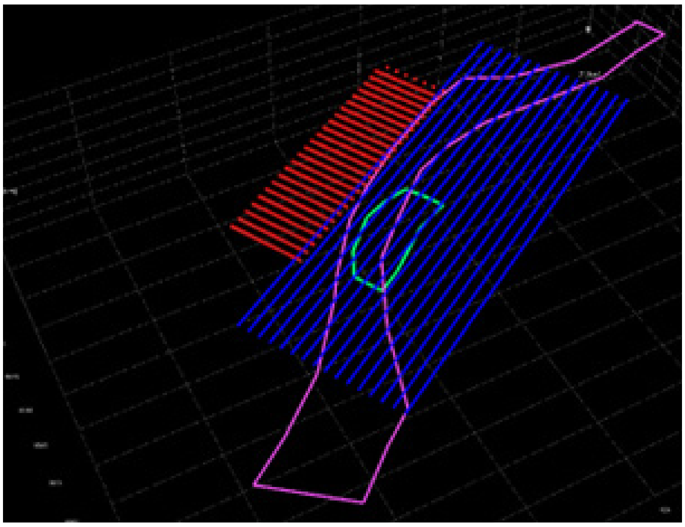

Figure 5 The acquisition geometry with shots (red) and receivers (blue) on either side of the river. Shots and receivers in the river are not used in the illumination analysis.

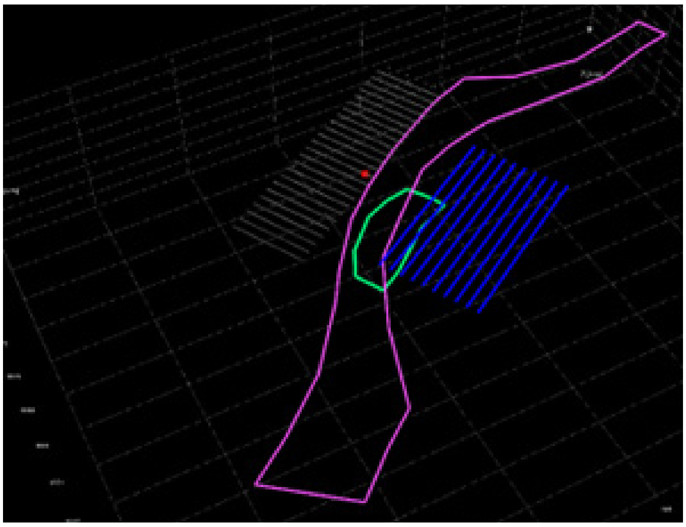

Figure 6 The template of active receivers (blue) for one shot (red) in the geometry in Figure 5.

An example of rays with the parallel survey is shown in Figure 7. Possible reflections of importance are included.

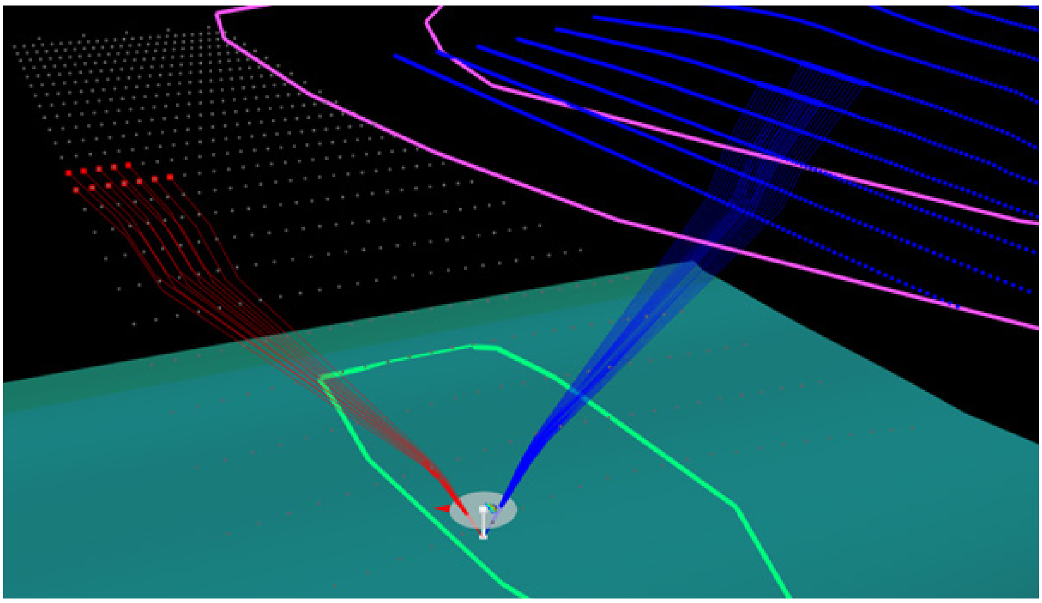

Figure 7 Example of rays. Some selected rays from shot locations (grey) via a point on the target horizon, and up to receivers (blue). River area is in pink, and the AOI is in green.

In the Orthogonal Survey the shots are placed along the river, while the receivers are placed across the river (Figure 8 and Figure 9).

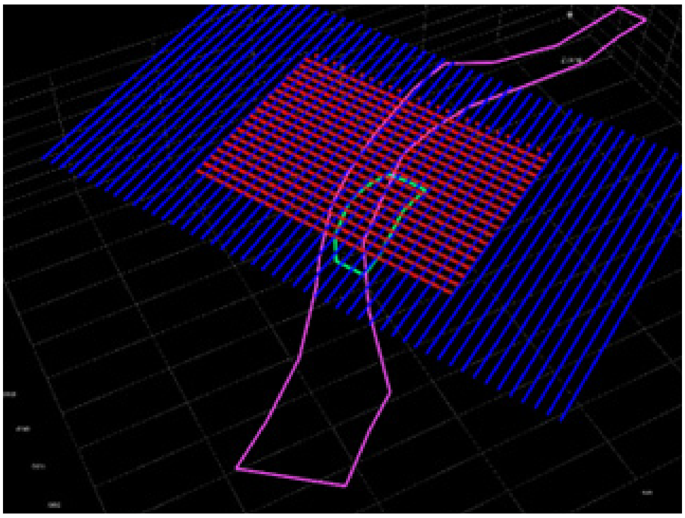

Figure 8 All shots (red) and all receivers (blue) in the orthogonal geometry. Shots and receivers in the river are not used in the illumination analysis.

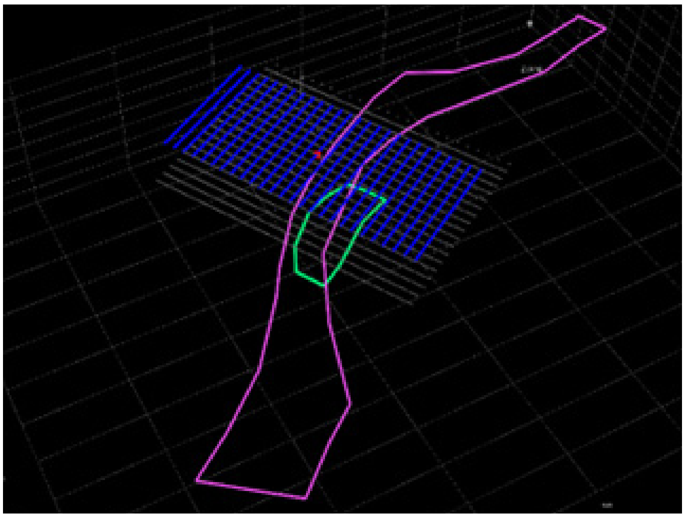

Figure 9 The template of active receivers (blue) for one shot (red) in the geometry in Figure 8.

The regular survey designs initially include the obstruction zone, but utilizing the river polygon as an areal filter, the shots and receivers inside the river zone are easily excluded from the illumination analysis. The nominal surveys also cover much larger areas than just right above the AOI, to make sure that all possible reflections of importance are included.

The basic map is the target domain hit map. It shows how many rays have reflected in the different areas (Figure 10 and Figure 11).

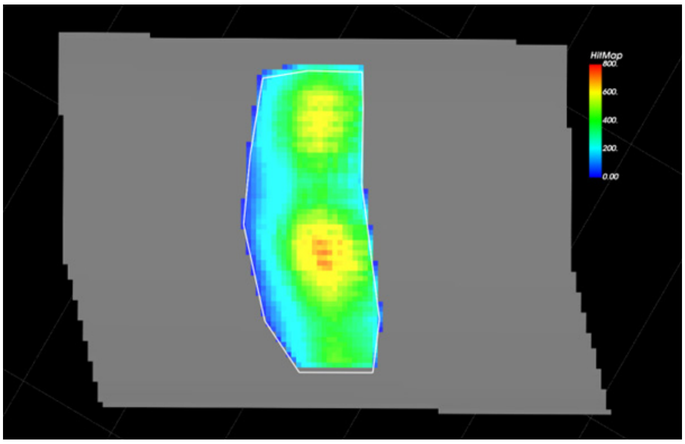

Figure 10 Hit count on the middle reservoir horizon for the parallel geometry.

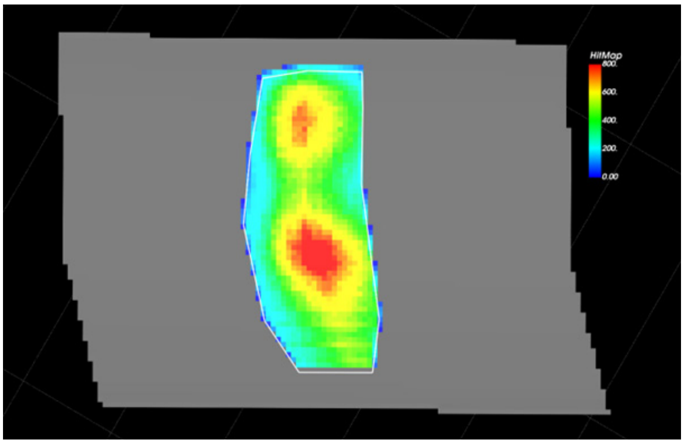

Figure 11 Hit count on the middle reservoir horizon for the orthogonal geometry.

The orthogonal survey has more hits in some areas than the parallel one because it has more shots and receivers. On the other hand, the orthogonal geometry is more complex and expensive, as shots and receivers must be placed on both sides of the river.

Hit count is a good indication of illumination, but weak reflections count just as much as strong ones. For a more reliable estimate, we use the Simulated Migration Amplitude (SMA) map, showing how the amplitudes are expected to vary across the target.

In the SMA calculation only reflections inside the AOI are used. However, as the SMA is computed with a migration-like summation process, there will also be values outside the AOI. The SMA map mainly indicates the relative variations in that map.

The SMA maps for the two geometries are shown in Figure 12 and Figure 13. They show the general amplitude trends across the target, and as expected they are quite similar.

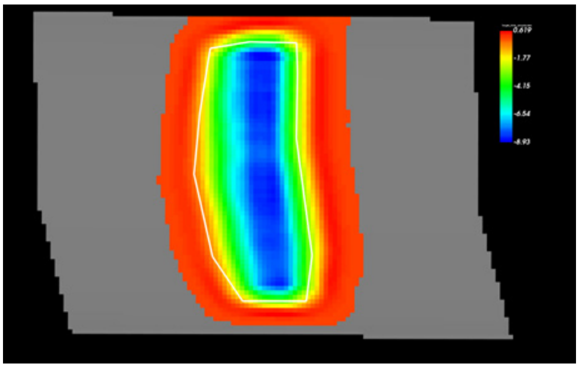

Figure 12 Simulated Migration Amplitude for the middle reservoir horizon for the parallel geometry. Compare with the hit count in Figure 10.

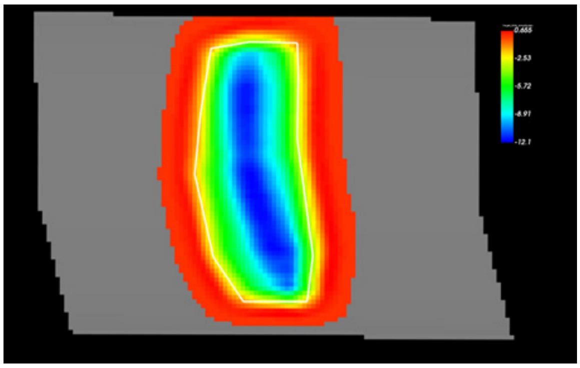

Figure 13 Simulated Migration Amplitude for the middle reservoir horizon for the orthogonal geometry. Compare with the hit count in Figure 11 and the Simulated Migration Amplitude for parallel geometry in Figure 12.

In the modelling, the two acquisition geometries have been very large, so that in practice all possible reflections on the target inside the AOI are included. However, a real survey should be as small and efficient as possible, but still with no loss of significant information. A key tool to this end is the illumination map in the survey domain: It shows how much the different shots and receivers contribute to the illumination.

Figure 14 is the shot domain illumination map for the parallel acquisition geometry. Most reflections are created by the shots in the quite limited red area. Figure 15 is for the receivers on the other side of the river. The receivers that contribute are more widespread, but still there are some outer areas that probably can be dropped.

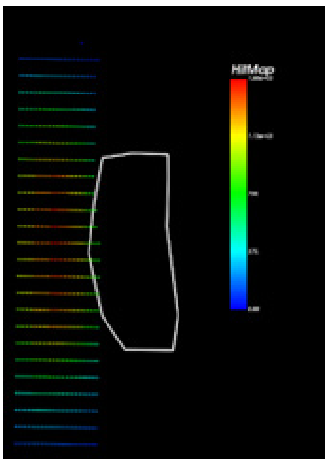

Figure 14 The shot domain illumination map for the parallel geometry.

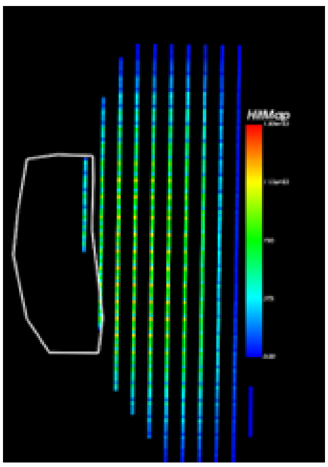

Figure 15 The receiver domain illumination map for the parallel geometry.

To check the illumination with only the remaining shots and receivers, the less important shots and receivers are excluded by some additional areal filters and new target domain maps are made.

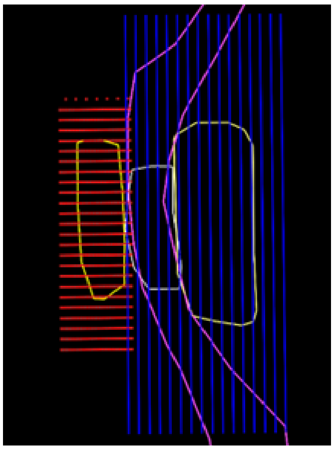

Figure 16 Selection of shots and receivers for optimizing the survey based on Figure 14 and Figure 15. Only shots inside the yellow polygon to the left and receivers inside the yellow polygon to the right are used.

Figure 16 shows how the shot and receiver areas can be limited based on the shot and receiver domain illumination maps. The effect on the target illumination is shown in Figure 18, to be compared with Figure 17.

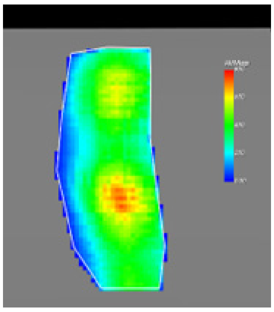

Figure 17 Hit count for the full parallel survey. This is the same map as in Figure 11 and is shown for comparison with Figure 18.

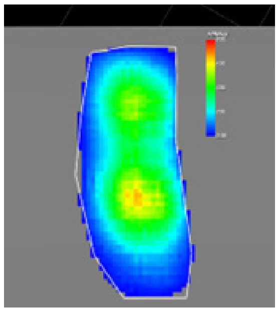

Figure 18 Hit count for the parallel survey when shots and receivers are optimized as shown in Figure 16.

With the orthogonal geometry (Figure 19 and Figure 20), the differences between favourable and unfavourable shot and receiver areas seem less pronounced, but still there are some peripheral shots and receivers that may be dropped (Figure 21).

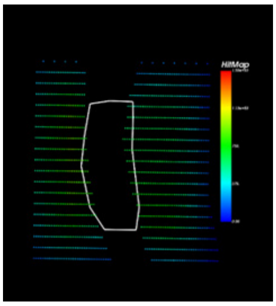

Figure 19 The shot domain illumination map for the orthogonal geometry.

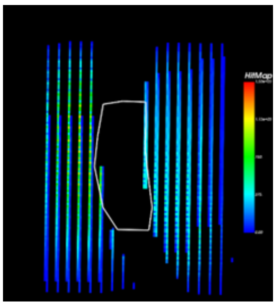

Figure 20 The receiver domain illumination map for the orthogonal geometry.

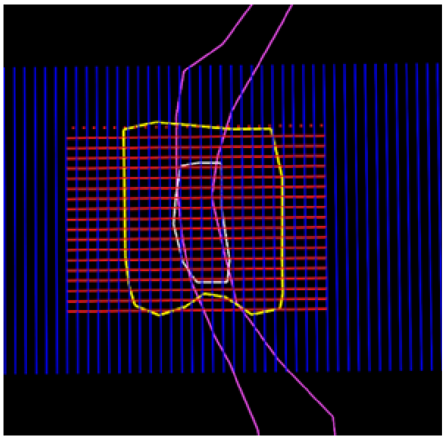

Figure 21 Limitation of shots and receivers based on the maps in Figure 19 and Figure 20. Only shots and receivers inside the yellow polygon, but outside the pink river polygon are used.

The effect on the target illumination is shown in Figure 23, to be compared with Figure 22.

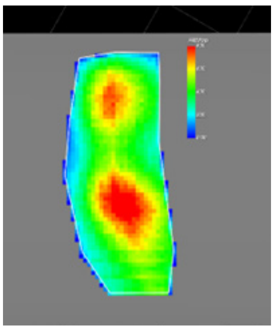

Figure 22 Hit count for the full orthogonal survey. Same map as in Figure 11 shown for comparison.

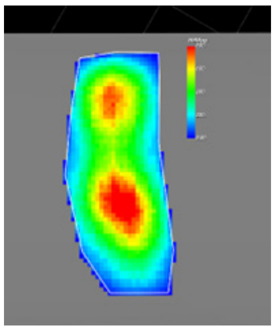

Figure 23 Hit count for the orthogonal survey where shots and receivers are optimized as in Figure 21.

So far we have looked at a quite simple, mainly 2.5D model based on a 2D section (Figure 24), but what are the consequences if the model is more complex? This can easily be tested, and is certainly worthwhile, as the survey acquisition geometry shouldn't be tailored too strictly to a largely unknown subsurface geology. We assume that a more realistic, and complex model is as shown in Figure 25.

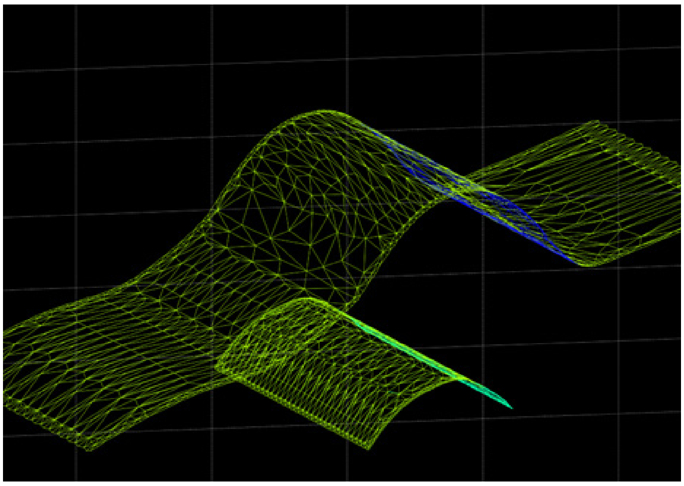

Figure 24 This figure shows an anticline and a reservoir horizon in the 2.5D model used so far. Vertical exaggeration is 3.

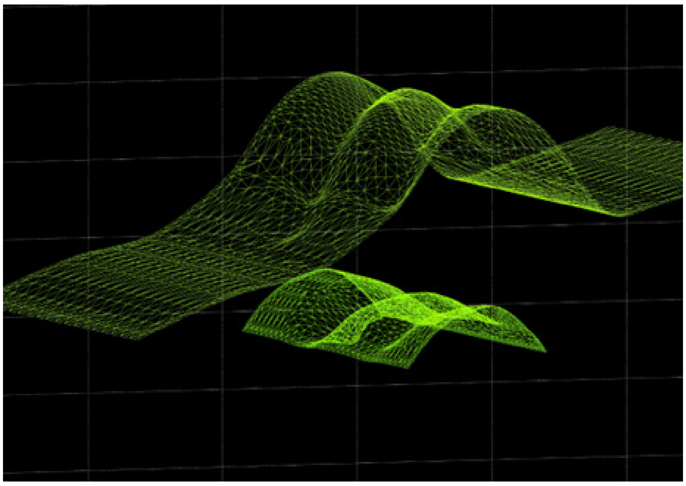

Figure 25 True 3D model derived from the model in Figure 24.

As expected, the hit count as well as the Simulated Migration Amplitude are quite different, shown for the parallel geometry in Figure 26 and Figure 27.

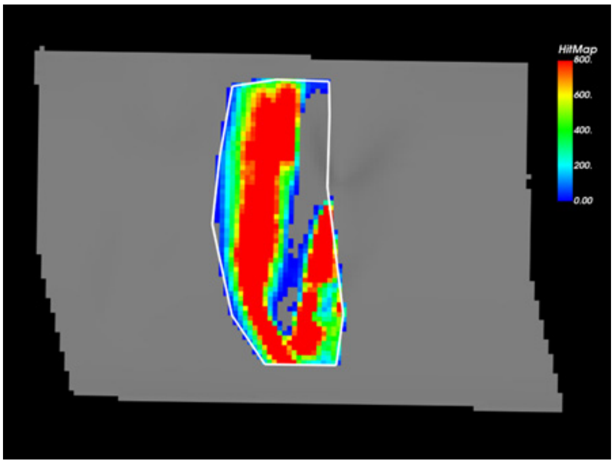

Figure 26 With the changes in the subsurface model, the illumination is quite different. Parallel survey geometry. Compare with Figure 10.

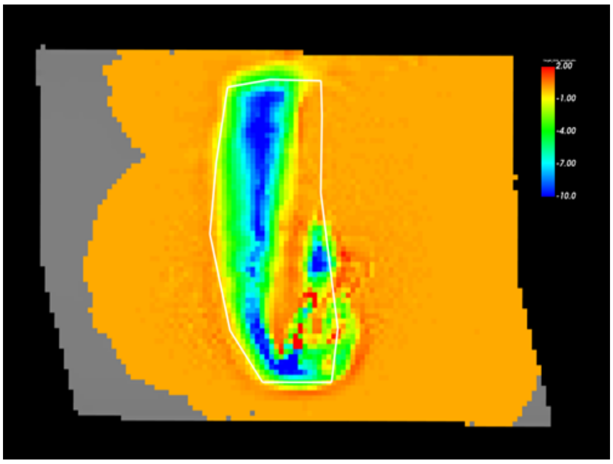

Figure 27 Simulated Migration Amplitudes for the modified model and parallel survey geometry, to be compared with Figure 12.

The main contributions to illumination in this case are from shots and receivers in smaller areas than observed in the previous example, thus more restricted shot and receiver areas should be sufficient for this model as well (Figure 28 and Figure 29).

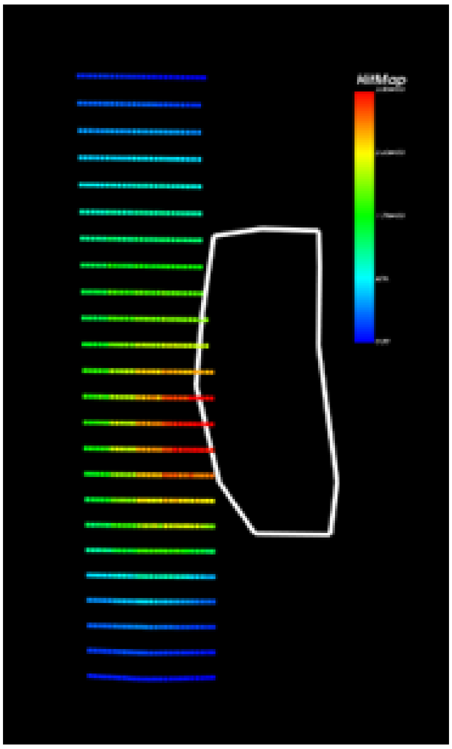

Figure 28 The contribution of the shots in the parallel survey to the illumination of the model in Figure 25. A smaller cluster of shots dominates the illumination than in the more regular model, see Figure 14.

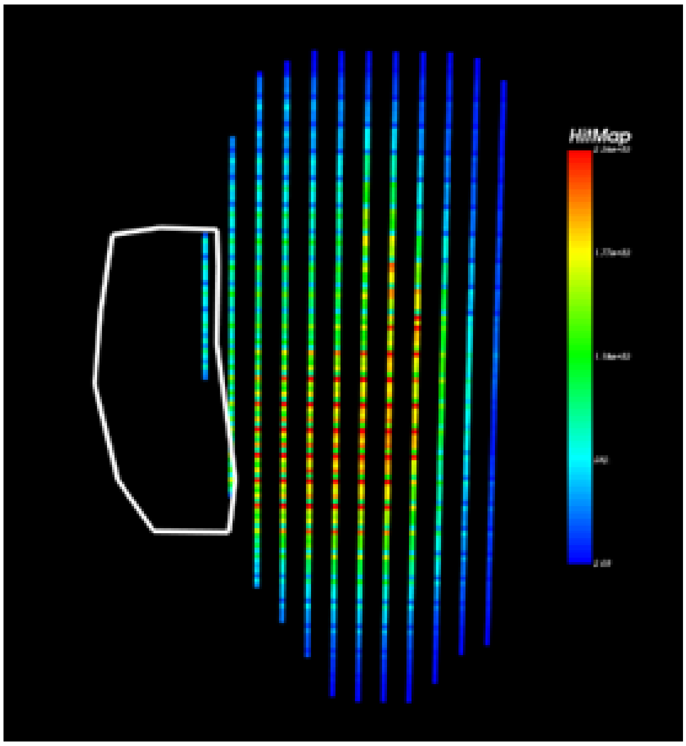

Figure 29 The contribution of the receivers in the parallel survey to the illumination of the model in Figure 25. Also, the contributing receivers are more clustered, compare to Figure 15.

It is important to note that, to make sure that the entire AOI is well illuminated, a reduction of the shot and receiver areas should always be followed a final target horizon illumination analysis with the reduced survey for quality controll, as was done in the first example in Figure 18 and in Figure 23.

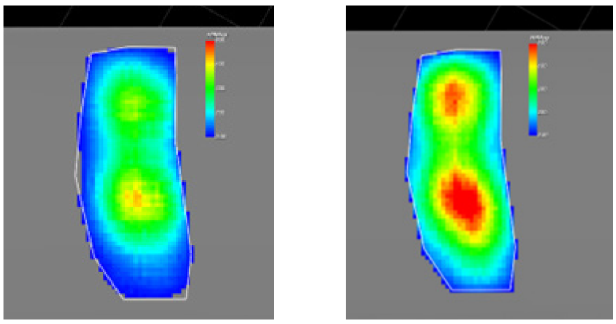

Figure 18 and 23 as examples of QC to ensure hit count when shots and receivers are limited.

Illumination maps are computed for many different attributes. Examples are minimum and maximum reflection angle (Figure 30 and Figure 31), and maximum required migration aperture for the different parts of the target (Figure 32).

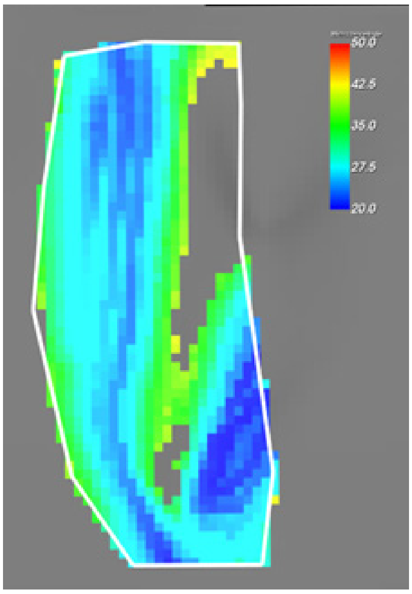

Figure 30 Minimum reflection angle on the target horizon shown in Figure 25 for the parallel survey.

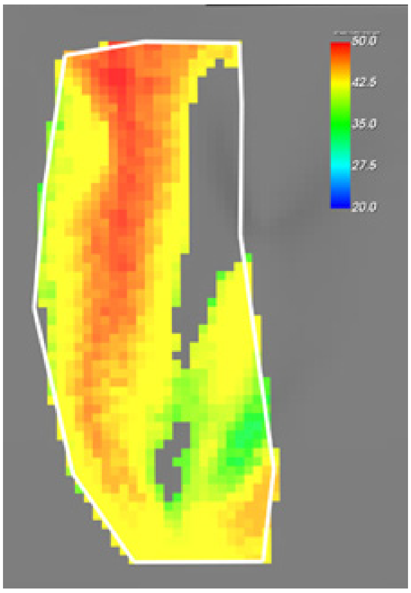

Figure 31 Maximum reflection angle on the target horizon shown in Figure 25 for the parallel survey.

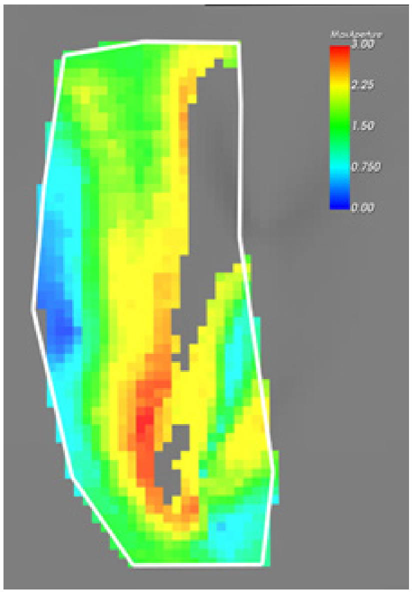

Figure 32 Maximum required migration for the target horizon shown in Figure 25 for the parallel survey.

Concluding remarks

This synthetic study demonstrates how the NORSAR Software Suite can be used for an onshore illumination analysis even when available data is very limited. 2D and 3D information were combined, and different acquisition geometries was tested giving valuable information about the project. A seismic survey is always inherently uncertain before it is acquired, but judicious use of seismic modelling can reduce cost and risk by ensuring increased efficiency and optimizing quality of the acquired seismic.