Modeling of wide-azimuth towed-streamer surveys with high performance computing

B. Kaelin (3DGeo Inc.), J. Higginbotham (3DGeo Inc.), C. A. Fernandez (3DGeo Inc.), F. Ortigosa (Repsol YPF), B. Fontecha (Repsol YPF) and J. M. Cela (Barcelona Supercomputing Center)*

Summary

Subsalt imaging in deepwater is still a challenging processes even with high quality data and sophisticated algorithms. The numerical modeling of wave propagation combined with the geological model build powerful tools to investigate proper imaging algorithms and survey acquisition geometries.

In this paper we show how the modeling parameters can be determined to optimize the computational costs and the image resolution. The presented geological model covers about 1,150 square kilometers and reaches 15 km in depth. To image the deepest geological structures the required trace length is 18 s. Each of the 4,047 modeled shot gathers covers about 240 square kilometers.

Introduction

Subsalt imaging in deepwater is still a challenging process even with high quality data and sophisticated algorithms. The reasons are usually poorly defined velocity models and illumination effects in general. Wide-azimuth data acquisition has proven to yield some of the required information (Regone, 2006; Herrmann et al., 2007). However, there is still more investigation required to find the proper survey acquisition geometry for different imaging algorithms.

Geological models combined with synthetic data build a common dataset which can be used to benchmark imaging algorithms, to evaluate processing workflow, to design multiple elimination strategies, to design field data acquisition including wide azimuth and rich azimuth alternatives. The combined dataset can even be used to compare the performance of computer architectures.

In this paper we will demonstrate the numerical modeling of shot gathers for a given geological model. We will show how we compromised the computational costs and the required resolution of the image. For the modeling we chose the wide-azimuth towed-streamer acquisition geometry (WATS).

Model

Geological model

Figure 1 shows the geological model used for this study. The geology behind the Repsol YPF model addresses both complex and common problems typically found in the subsalt exploration of the Gulf of Mexico. These problems include, imaging of salt feeders, steeply dipping subsalt reflectors, reflectivity changes in the subsalt section, faults and welds, rugose top of salt that originate multibranching and multipathing of seismic wavefronts and steep dips of the base of salt that cause illumination problems. In the near future, the model will be improved to benchmark anisotropy algorithms and reservoir characterization in full 3D.

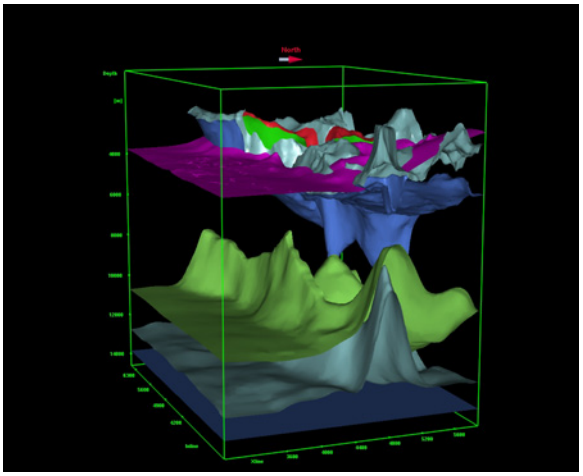

Figure 1: Geological Repsol YPF model with salt bodies (blue) and other structures.

Velocity model

Figure 2a shows the velocity model based on the geological model. Outside the pre-defined layers the velocity increases linearly with depth. Fine layers were added to the gridded velocity model, in seismic format, to simulate layered sediments (Figure 2b). The layering was added using a program that first interpolates, or extrapolates if necessary, the existing sediment layering through the salt. Once this is done the program then operates on one velocity trace at a time to insert a specified number of layers between existing layers. These layers vary randomly in thickness by 20 % of the average thickness with a velocity contrast of 3 % ± 0.6 %.

Modeling method

The two most common methods in modeling seismic wave propagation are the finite difference method (FD) (e.g., Dablain, 1986; Villarreal and Scales, 1997) and the pseudo-spectral method (e.g., Fornberg, 1987). The latter method has got the advantage to be stable for coarser grid sizes, but it is computationally more expensive than the FD method when the same grid size is chosen. Since we were focusing on detailed geological structures we required the best spatial resolution possible and we therefore chose the FD modeling.

FD modeling becomes computationally intensive for the deepwater salt structure investigated in this paper. To avoid numerical dispersion the grid size is confined by the maximum frequency and the slowest velocity in the model. Dependent on the order chosen to approximate the spatial derivatives, the number of grid points per smallest wavelength lies usually between three and four. On the other hand, the required time step in the modeling decreases linearly with the grid size, which increases the computational cost. Hence, to optimize the computational cost and to guarantee numerical stable condition grid size and time step have to be compromised.

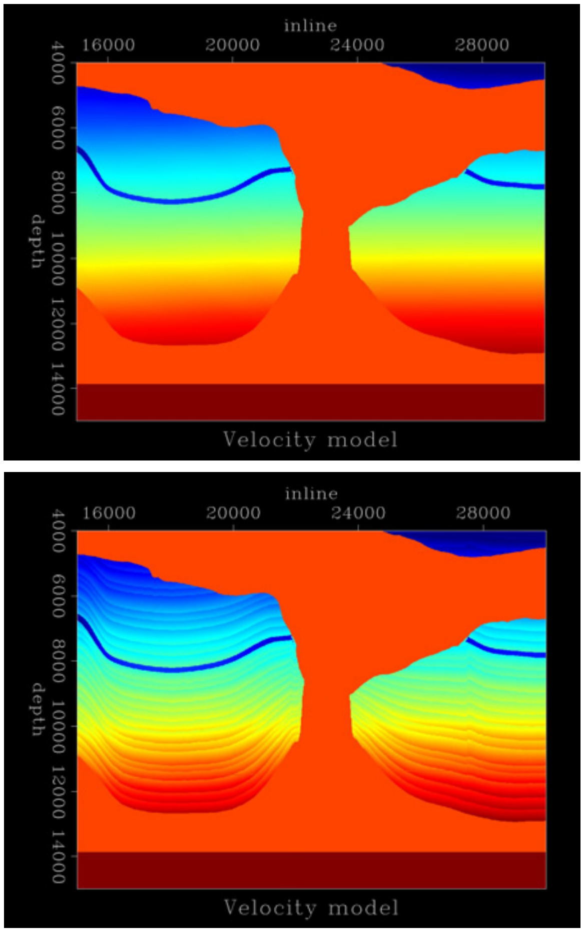

Figure 2: (a) 2D cross-section through the velocity model derived from the geological model shown in Figure 1, (b) additional fine layering in the sediments.

Modeling of a wide-azimuth towed-streamer survey

Modeling Parameters

Before starting the modeling in 3D the grid size, the maximum frequency, the trace length and the source spacing had to be determined. We chose a 2D cross-section through the center of our subsurface model to determine the required trace length and the source spacing (Figure 3 and Figure 4). Figure 3a shows the reverse time migration (RTM) with 14 s trace length. Figure 3b shows the same part of the model with 18 s trace length and Figure 3c shows the difference between the two images. The difference shows clearly that the steep structures in the deeper part of the model require 18 s trace length to be resolved. Figure 3 also shows that the chosen maximum frequency of 18.5 Hz is sufficient to resolve the geological features.

Next, the minimum number of source locations had to be determined. Figure 4a shows the 2D velocity model, Figure 4b shows the reverse time migration (RTM) with 75 m source spacing. Figure 4c shows the same cross-section with 536 m source spacing. Compared to Figure 4b there are artifacts in the shallow part of the image in Figure 4c, but the deeper part the image is not significantly different. Hence, we chose 536 m source spacing both in the in-line and in the cross-line direction for the 3D modeling..

Modeling with high performance computing

The geological model has the dimensions 30 km x 38.4 km and it is 15 km deep (Table 1). For the modeling we chose 57 shots per line with 71 lines in total, which results in 4,047 shot gathers. The dimensions of each shot gather are 20 km x 12 km.

The computation was performed on MareNostrum at the Barcelona Supercomputer Center. MareNostrum consists of 2,560 nodes with 4 processors and 8 GB of memory on each node. We were able to use a maximum of 2,000 processors in parallel, which made the computation highly efficient.

Figure 5 shows the first results of the migrated data with limited aperture (Guitton et al., 2007). The data is now available for more studies with different imaging algorithms and variable survey geometries.

Table 1: Dimensions of the model and the shot gathers.

Direction	**Model size**	**Shot gather**
In-line	30,000 m	19,725 m
Cross-line	38,400 m	12,060 m
Depth	15,000 m	15,000 m

Conclusions

The 3D FD modeling of a 1,150 square kilometer deepwater model can be performed very efficiently with the proper algorithm and high performance computing. The computed data provides a great opportunity to study various imaging algorithms and survey acquisition geometries.

Acknowledgement

The modeling has been performed in the supercomputer MareNostrum at Barcelona Supercomputing Center – Centro Nacional de Supercomputacion (The Spanish National Supercomputing Center). We acknowledge Mark Gordon for his help. We thank 3DGeo Inc. and Repsol YPF for permission to publish this work.

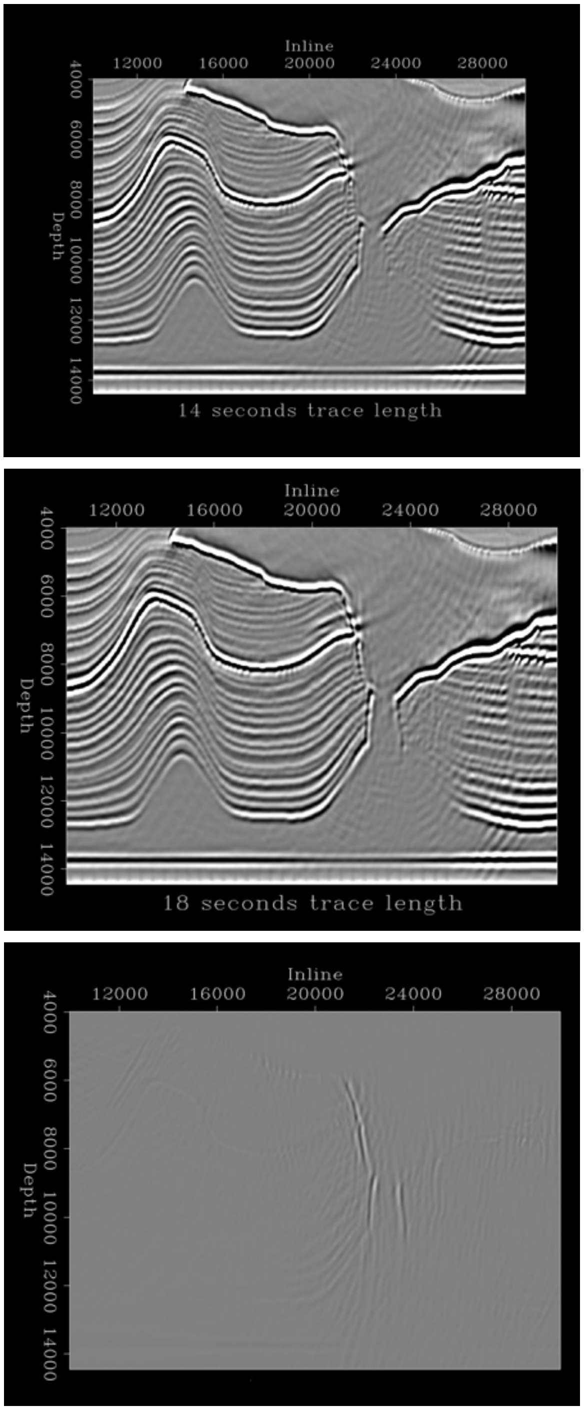

Figure 3: (a) Image centered at the salt feeder with RTM and 14 s trace length, (b) RTM and 18 s trace length and (c) difference between two images.

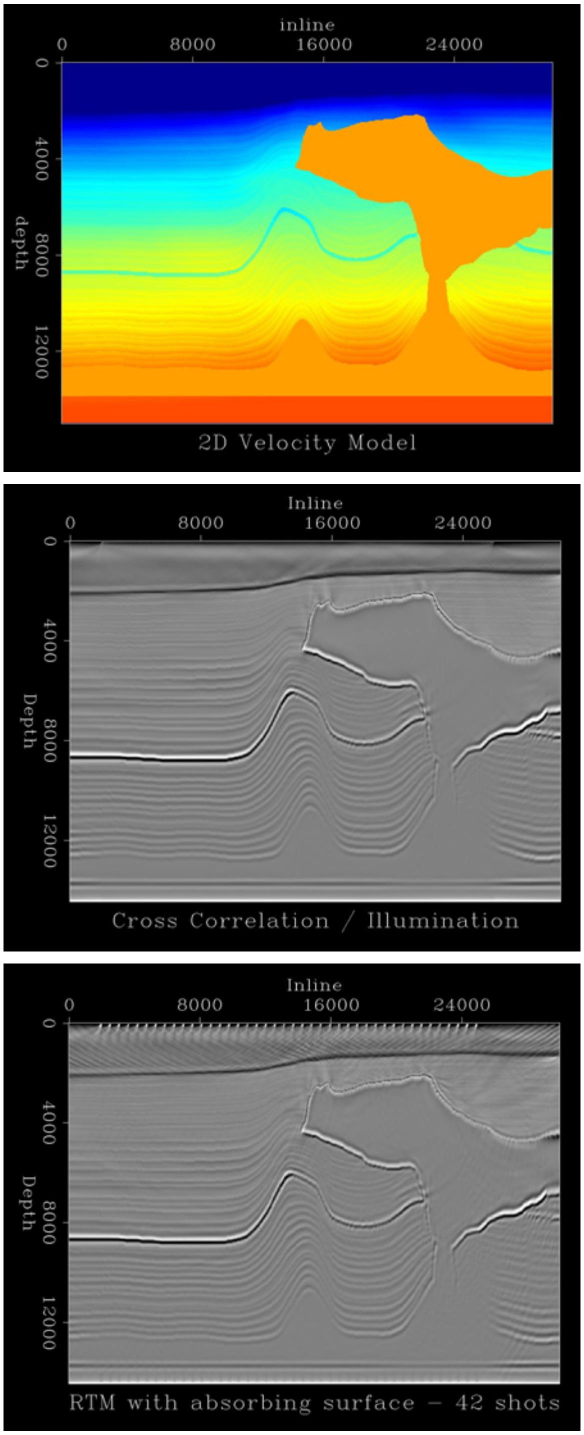

Figure 4: (a) 2D velocity model, (b) RTM with split-spread data from 300 shots and (c) RTM with split-spread data from 42 shots.

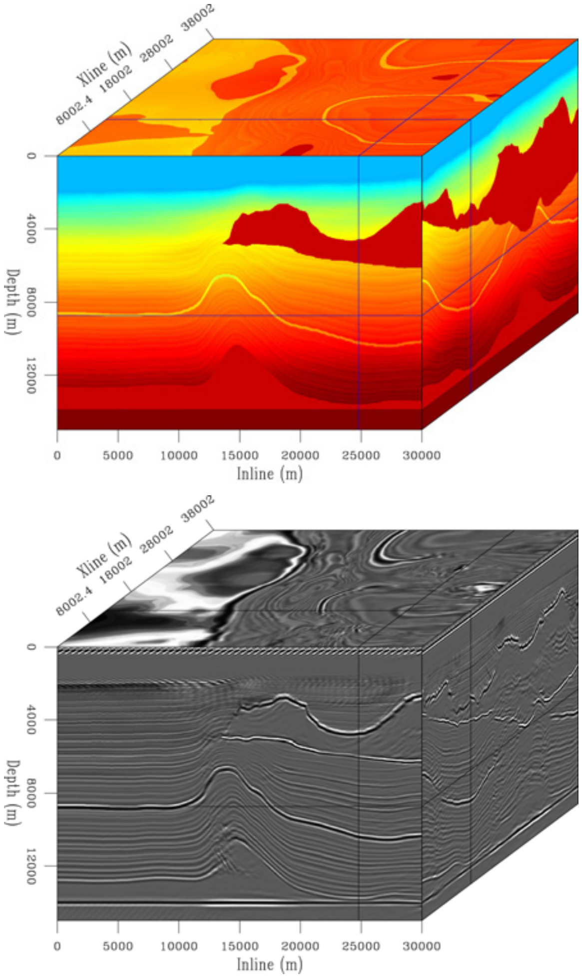

Figure 5: (a) 3D velocity model, (b) Shot-Profile Migration (SPM) of the modeled data with 4,047 shot gathers and limited cross-line aperture. AGC has been applied to the image.