Illumination studies with acquisition geometry and depth images comparison

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Abstract

This paper presents a way to perform qualitative and quantitative analyses for Seismic Illumination using Acoustic Wave Equation solved by Finite Difference Method.

A target-oriented methodology based on Alves *et al*. (2008, 2009) is employed to evaluate illumination values with the Energy Matrix that gives an estimative of the illumination energy for a specific point, chosen at the subsurface of the velocity model.

The proposed methodology is target-oriented, ideal for complex models such as the pre-salt and allows evaluation of different configurations of acquisition from a single wavefield extrapolation. Since it doesn't require successive migrations, the method has a lower computational cost than traditional methods based on generating a dataset followed by migration.

Numerical results are presented and analyzed in a modified version of the Hess velocity model.

Introduction

The growing interest in the exploration and exploitation of hydrocarbons reserves currently presents important challenges. Thus, it has increased the need to illuminate and image complex subsurface regions, especially involving salt domes.

It is known that, mainly, both the complexity of the velocity model and the acquisition geometry used can affect the quality of seismic data obtained during Seismic Data Acquisition. Thus, it becomes evident the importance of a previous planning for this step.

The seismic data can be considered the fundamental input for seismic migration schemes, so that if data does not possess the quality required, the studied subsurface will not be well imaged, compromising the achievement of goals involving the characterization of hydrocarbon reservoirs.

The goal of this methodology is to employ through the calculation of matrices and vectors of energy, an estimate of illumination for a given point of illumination in the subsurface, from which different acquisition geometries are evaluated by analyzing energy vector with the depth image.

The qualitative assessment of depth images can be obtained by seismic migration schemes and the target-oriented methodology of Illumination proposed by Alves *et al.* (2008, 2009), which is based on the Finite Difference Method for estimating the illumination of a given region of the velocity model, with modifications to calculate the Energy Matrix using the maximum amplitude of the wavefield.

Methodology

The concept of Seismic Illumination Studies was presented by Laurain *et al.* (2004). Basically, it is the effort involved in determining which regions have high amplitudes of propagated wavefields and which have shadow areas, considering a specific acquisition geometry. For this work, the Illumination Energy is defined as the energy of the wavefield propagated for a simulation time at points in the velocity model.

The methodology to perform qualitative illumination analysis is based on solutions for the Acoustic Wave Equation obtained by FDM (Finite Difference Method). The wavefield is extrapolated from the target illumination area applying the Reciprocity Principle, as in Alves *et al.* (2008). This allows for a lower computational cost when compared to conventional methods, which make two extrapolations, one for the source and another for the receiver.

An Energy Matrix is obtained from the wavefiield extrapolation. It represents the illumination energy associated with a target in the model for different source and receiver locations along the model. By selecting which of the points are sources and receivers, it is possible to simulate many different acquisition geometries. According to Alves *et al.* (2009) the value of illumination for different source and receiver positions can be expressed mathematically as:

$$I(\vec{r}) \cong \sum_{Sources} E_D(\vec{r},\vec{r}_S) \int_{\Omega_S} E_U(\vec{r},\vec{r}_R) d\Omega_S \qquad (1)$$

Where: I is the illumination energy at the investigated point $\vec{r}$; $\vec{r}_S$ and $\vec{r}_R$ are the source and receiver locations; Ω_S is formed by the receiver area considering a specific source location; E_D and E_U are, respectively, the energy matrices of downgoing and upcoming wavefields.

A problem with the implementation in the previous work (Alves *et al.,* 2009) is that the energy matrix contains information from the source signature, calculated by the auto-correlation of the wavefield, affecting the illumination estimates. The modification employed in the proposed methodology consists in calculating the maximum amplitude of the wavefield for each point at the velocity model to represent the energy matrix. This maximum amplitude represents an impulsive source, avoiding phases and amplitude changes in the seismic response caused by the source signature.

An energy vector is obtained from the energy matrix, and then analyses using different acquisition geometries are performed. A possible qualitative comparison consists to observe the depth image, obtained from Migration scheme, and the respective energy vector, both with the same acquisition geometry, analyzing the better configuration that contributes to illuminate the target point.

Evaluating the responses with the depth image quality for a chosen illumination point it is possible to choose the optimum acquisition configuration for the investigated target.

Other analyses can be performed without the need of a Migration scheme, since illumination studies are sufficient to investigate the response expected at the target point.

Results – Hess Model

The Hess Model was modified adding a reference reflector at the bottom of the model and extending it laterally. Figure 1 shows this model with one illumination point, chosen underneath the high velocity body in order to present the methodology and the influence of the overburden.

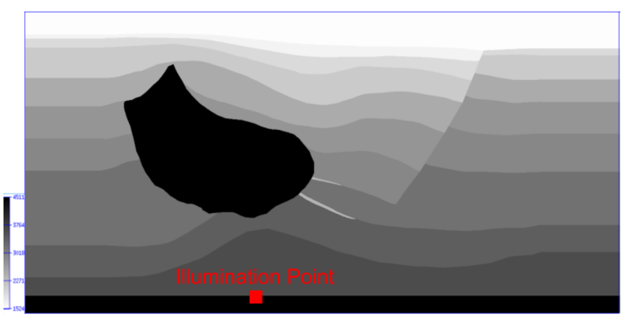


Figure 1: A Hess velocity model with the chosen illumination point.

The illumination results were divided in two analyses: the first one qualitative, comparing the energy vector with the depth image, and the second one quantitative, which is useful to evaluate the illumination results obtained using different acquisition parameters.

For the selected point, energy matrices were obtained for different acquisition times over the entire velocity model.

Figure 2 shows the complexity associated to the illumination at the double time 9.0 s. This figure illustrates that, when applying the Reciprocity Principle, the energy remains trapped underneath the salt body.

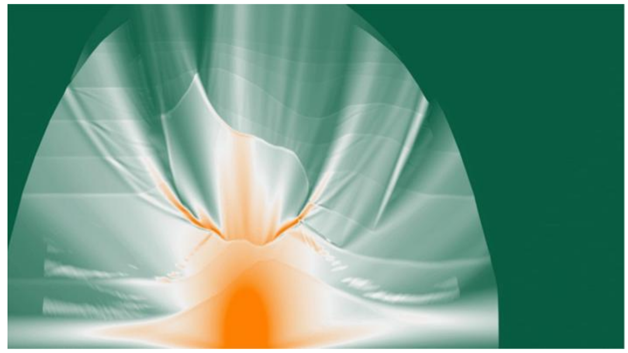


Figure 2: Energy Matrix for the Hess model considering the double time 9.0 s.

Qualitative and quantitative analyses can be performed employing the energy matrix, providing the possibility to test many acquisition geometries and parameters.

First a qualitative analysis was performed comparing the energy matrix with the correspondent migrated depth image, considering a single shot gather. With this kind of analysis is possible to estimate the quality of the depth image based on the energy matrix and the acquisition parameters.

Results for the qualitative case are shown in Figures 3 and 4. With the energy vector for the illumination point, two different shot positions were investigated. In the first shot position (Figure 3), the streamer is on a lower energy area and the source is located in a worse region in energy terms. Consequently, a bad image quality was observed at the illumination point and a low illumination value was expected, based on the position of the source and receivers.

However, Figure 4 illustrates results for a better source point location, in which the streamer is in a high energy area. The depth image confirms this result, showing the high amplitude around the illumination point.

A zoom in around the illumination point in both depth images can be observed in Figure 5. A lack of image quality can be seen in 5(A), due to the low illumination by the selected source location. However, 5(B) shows a much better image for the same target, because a different source location was selected, this one at a high amplitude of the energy vector.

This type of analysis allows the comparison and a better understanding of depth image quality for a specific acquisition geometry using the energy vectors. This provides the opportunity to choose a more suitable acquisition geometry to illuminate the selected target in the velocity model.

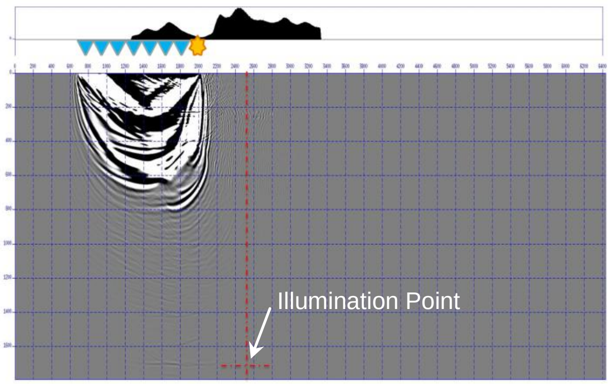


Figure 3: Qualitative comparison between the depth image amplitude with the respective energy vector for a specific illumination point, with the source on a low illumination area.

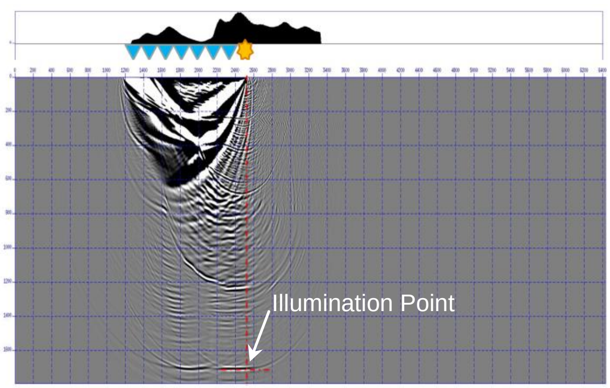
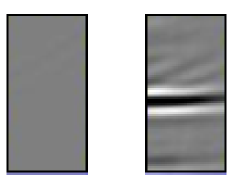


Figure 4: Qualitative comparison between the depth image amplitude with the respective energy vector for a specific illumination point, with the source on a high illumination area.



(A) (B)

Figure 5: A zoom in on the depth images showing the amplitude difference at the illumination point region when the acquisition geometry is positioned on a low illumination area (A) and on a high illumination area (B).

The energy vector allows performing a quantitative analysis with the illumination value calculated considering different acquisition parameters and geometries, besides a qualitative analysis as presented previously.

To illustrate some possibilities of such application, equation 1 was employed using the illumination point and different acquisition types. Figure 6 shows results for a conventional streamer acquisition and figure 7 shows results using a split spread configuration, both considering three different acquisition times (4.0, 4.5 and 5.0 s).

Quantitative analyses consist in evaluating the illumination value and comparing this result for different acquisition types. According to figures 6 and 7, the longer the cable configuration, the higher the illumination value. However this analysis does not take into account the associated costs for the seismic surveys.

Since the number of sources can vary significantly, this was employed as a normalization factor to make a comparison between different acquisition types. Figure 8 presents the normalized illumination value at time 5 seconds, showing that split spread is the most effective configuration to illuminate the selected target in this case.

A 3D evaluation may bring advantages, especially to compare distinct acquisition directions that influence the illumination responses.

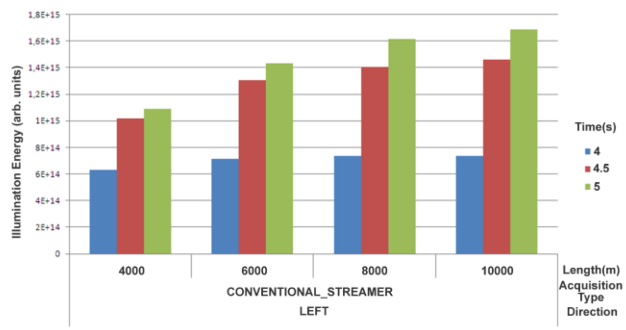


Figure 6: Illumination energy for conventional streamer, considering left direction of acquisition and source spacing 100 meters.

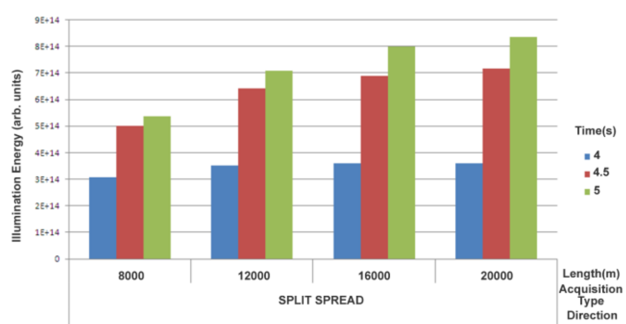


Figure 7: Illumination energy for split spread with source spacing 400 meters.

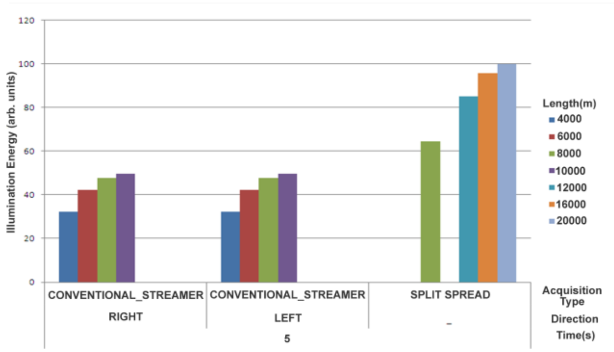


Figure 8: Normalized illumination energy with respect to source number for distinct acquisition type, varying the device length and considering 5.0 s of acquisition time.

Conclusions

The gain of the illumination methodology employed consists in a less expensive computational cost when compared with traditional methods since these techniques require successive modeling and migrations. Moreover, due to the Reciprocity Principle, different acquisition strategies can be compared without many wavefield extrapolations.

Another gain is that this methodology is a target-oriented tool, useful for illumination studies of specific areas, unlike global methods, which need to evaluate the illumination values for the whole velocity model, making the process considerably more expensive.

The main motivation was to perform qualitative and quantitative analyses for seismic illumination using the complete acoustic two-way wave equation discretized by Finite Difference Method. The energy matrix employed in this methodology was similar to that one used in the excitation time imaging condition, obtained by the maximum amplitude of the wavefield.

The use of this amplitude matrix as an input for the illumination methodology avoids the phase and amplitude changes in the seismic responses, that occurred in the previous work presented by Alves *et al* (2009) that used the auto correlation of the wavefield.

Results also show that the proposed illumination studies are useful to understand how an acquisition strategy can influences the depth image in resolution terms. The illumination value obtained can be used for quantitative evaluations and the methodology is also effective for qualitative analyses. In fact, using the energy vector, a broad range of acquisition parameters can be evaluated for the illumination values for a chosen target.

Acknowledgments

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