



## Target Oriented Illumination analysis as a comparative approach of PSPI and Finite Difference Methods

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### Abstract

The present work discusses an alternative approach for illumination studies using the commonly known Ray-tracing method. Previous papers have pointed out the effectiveness of the finite difference modeling, despite the fact of the high computational cost. Alves *et al.* (2009) proposed a technique of target orientating using Finite Difference (FD) which reduces significantly the computational efforts in comparison to the traditional approach based on modeling followed by migration. This work shows the first 2D results of a new approach to target oriented illumination using Phase Shift Plus Interpolation (PSPI) modeling. We make a comparison of illumination studies through FD and PSPI modeling utilizing several velocity models.

### Introduction

In the oil industry, the discovery of new reservoirs is a constant necessity and requires good seismic data interpretation. They have been investing heavily over migration techniques in order to gain more on image quality.

Migration, as all the other steps of seismic processing, depends on the quality of data acquired on field and cannot by itself overcome some of the data deficiencies. Illumination studies aims at the best acquisition geometry for a certain exploration target.

The choice of a geometry of acquisition is essential for a good subsurface imaging because it affects directly on the illumination quality of regions located below complex structures with discrepant acoustic impedance such as in the case of salt.

Studies of seismic illumination are usually made from ray-tracing modeling method due to its swiftness and efficiency in collecting a great amount of attributes to the respective traveltimes and amplitudes. However, according to Laurain *et al.* (2004), when the reflection and transmission coefficients vary abruptly along the interfaces, the method doesn't appear to achieve its

expectations and that way it creates artifacts such as shadowzones.

The main goal of this work is to make comparisons of the illumination energy curves calculated through modeling of two more robust methods: Finite Difference and Phase Shift Plus Interpolation which are described on the next section.

The chosen methods have two crucial differences in seismic modeling. The PSPI has a faster processing time and it propagates the one-way wave, while the finite difference method is slower and performs the same propagation as a two-way process which originates ascendants and descendants wavefields.

In the next section, the theory involving both methods is showed as each one's peculiarity. Then, the results due to calculation of illumination generated by the discussed modelings are displayed together with the advantages and disadvantages of PSPI and FD utilization. Finally, the conclusion section debates the work as a whole.

### Method

Both modeling methods are based on extrapolations of an initial wavefield related to the two-dimensional wave equation.

$$\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial z^2} = \frac{1}{c^2} \frac{\partial^2 u}{\partial t^2} \quad (1)$$

#### Finite Difference Modeling:

The FD approach consists of interpolating polynomials using Taylor series expansion between discrete points on the computational grid. We used the second order time derivative and the fourth order spatial derivative for the discretization of the wave equation as in Palermo (2002). This mathematical operation calculates the future wavefield using the values of the past ones for each point in the domain.

These approximations create some limitations to the method as instability and numerical dispersion that are related to the grid spacing, the source and the maximum local velocity which define the limits of the occurring phenomenon.

$$\bullet \quad \frac{v \times dt}{dh} \leq \sqrt{\frac{3}{8}} \quad (3)$$

- $V_{min} = 5 \times dh \times Freq_{max\_source}$  (4)

It is important to highlight that MDF solves the complete wave equation and for that one pays the price of propagating multiples. The reflection effect can be minimized by transforming the two-way modeling in one-way, as Alves *et al.* (2009) shows in his paper. Despite of that, the method becomes way too complex.

#### Phase Shift Plus Interpolation modeling:

The PSPI modeling method was adapted from PSPI migration algorithm accordingly to Cetale Santos *et al.* (2005), exhibiting some natural characteristics related to Fourier transforms applied to equation (1), and the interpolations which enables the method to accept lateral variations of velocity as seen in Gazdag and Sguazzero(1984).

$$P(k_x, z + \Delta z, \omega) = P(k_x, z, \omega) \exp(-ik_z \Delta z) \quad (5)$$

The extrapolation is due to multiplication of an exponential by the actual wavefield, as showed in equation (5), being  $\Delta z$  e  $k_z$  the grid spacing and wave number in z direction, respectively. In other words, one multiplies the amplitude in Fourier domain by a phase given by the parameters above.

$$k_z = \pm \frac{\omega}{v} \left[ 1 - \left( \frac{vk_x}{\omega} \right)^2 \right]^{1/2} \quad (6)$$

The wave number  $k_z$  is determined from the wave dispersion equation (equation 6),  $\omega$  e  $k_x$  being the frequencies on the other dimensions: time and horizontal offset. The sign of  $k_z$  is the responsible for fixing the direction of wave propagation. If it is equal to the sign of  $\omega$ , then the waves will be propagated to earlier times and vice-versa.

Here, the multiples are inexistent caused by the fixed sign of  $k_z$  on the dispersion relation. This forces the phase shift of the amplitude only in one direction contradicting to what happens on the FD approach.

The extrapolation dictated by equation (5) is only valid for laterally homogeneous velocity models so the process is adapted for a model containing interpolation operations showed in the diagram of Fig. 01.

Hence, according to Alves *et al.* (2009), the assumption of image point coinciding with illumination point plus the Reciprocity Principle can be applied so that the position of the source match the area of interest in illumination matters, evaluating the upcoming and downgoing wavefields.

The illumination energy ( $I$ ) is attained by summation of square of amplitudes ( $p$ ) of wavefield which are recorded on the source-receiver positions localized on surface of the model.

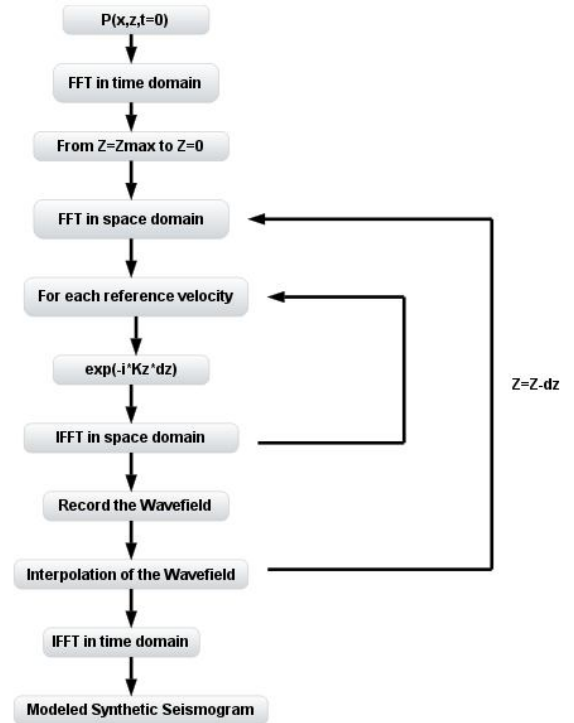


Fig. 01 - Diagram of Phase Shift Plus Interpolation modeling process

$$I(\vec{r}) = \sum_{surface} p^2(\vec{r}_i) \quad (7)$$

where  $\vec{r}_i$  is the position vector of the image point.

## Results

The velocity models utilized for generation and comparison of results were two very simple ones as the homogeneous and a slightly inclined parallel layer model and a more complex one revealing illumination issues on their geological contexts as shown in Fig. 02 e 03, respectively, with 5m of grid spacing. The colorbar besides the figures correspond to the velocity values within the model.

For both described methods, simulations of wave propagation were made in different geologic media so that the seismic source was positioned in a deep central point at approximately 390 samples depth, or in other words 1950m.

Therefore, the results are curves of energy intensity by the horizontal displacement generated from each modeling method assigning the velocity models mentioned.

The first curves are the ones shown in Fig. 04 and 05. They designate the energy calculated on surface of the homogeneous velocity model. Both figures show a central maximum energy peak at 200 samples corresponding to a horizontal displacement of 1000m. This location

matches the position of the source in subsurface. Due to spherical scattering culminating on energy loss, the general trend of these results were predictable assisting on an initial evaluation of similarity between the methods in simple media.

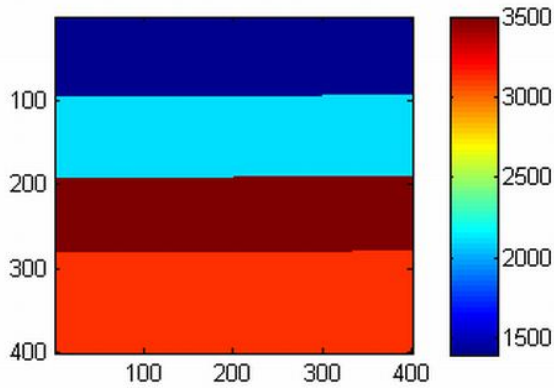


Fig. 02 - Slightly Inclined Parallel Layer Model with Layer of Higher Acoustic Impedance in the middle. The higher acoustic impedance layer is represented by the one in red colour.

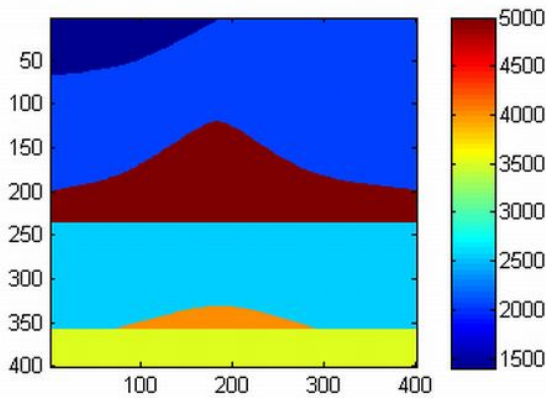


Fig. 03 - Thin Layer of Carbonate under a Salt Dome. The carbonate are displayed in orange colour.

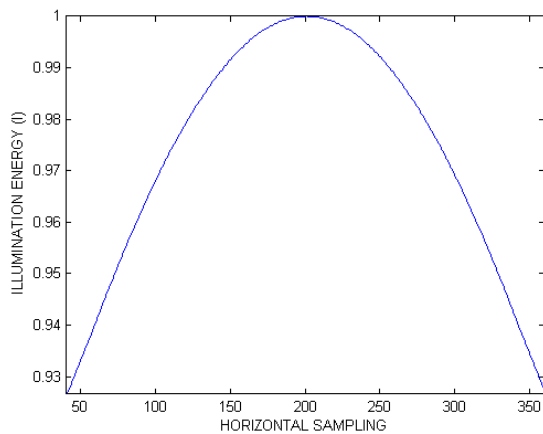


Fig. 04 - Illumination Energy Curve by FD in Homogeneous Medium

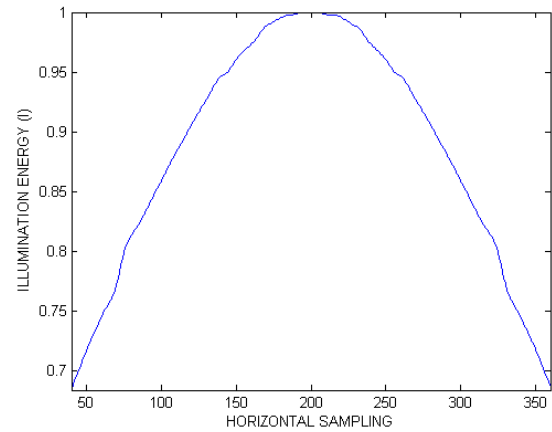


Fig. 05 - Illumination Energy Curve by PSPI in Homogeneous Medium

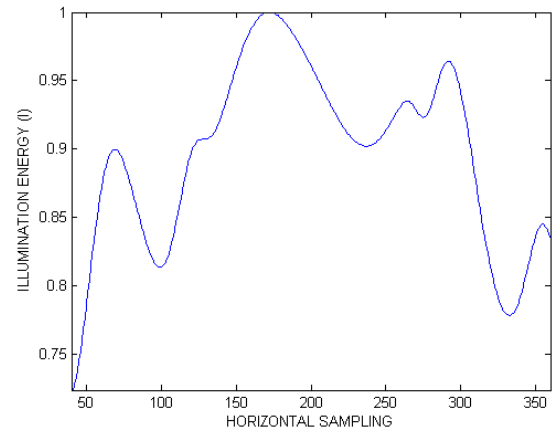


Fig. 06 - Illumination Energy Curve by FD in Parallel Layered Model with a layer in between having higher impedance

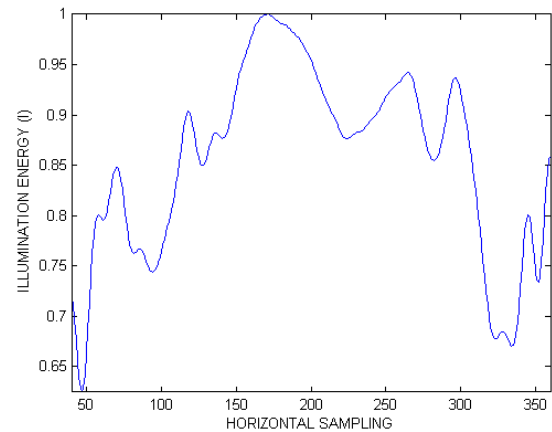


Fig. 07 - Illumination Energy Curve by PSPI in Parallel Layered Model with a layer in between having higher impedance

The curves referred to Fig. 06 and 07 demonstrate energy calculated on a parallel layered velocity model in which

similarities still occur between methods. Both happen to have a maximum peak shifted to the left at 125 samples, or 625m due to the layers being slightly inclined to the left as is showed by Fig. 02.

Analyzing Fig. 08 and 09 one can notice again a compatibility between the energies calculated on the model of Fig. 03. This illustration displays a geologic model representing a carbonate reservoir located under the salt region whose geometry provided a energy loss in central portions of the grid as if it was imprisoned inside the salt layer. Thus, a little amount of energy was registered from this area on the surface while a higher intensity was acquired on the left and right edges, mostly from the right edge, of the grid where the salt layer are thinner.

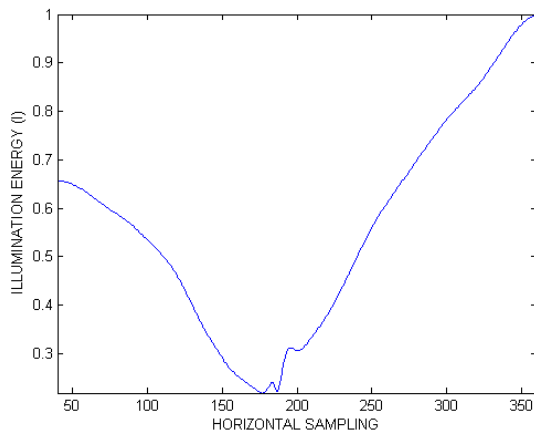


Fig. 08 - Illumination Energy Curve by FD in Carbonates under a Huge Salt Layer

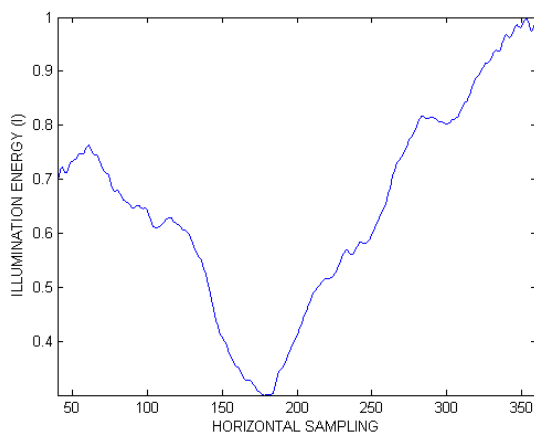


Fig. 09 - Illumination Energy Curve by PSPI in Carbonates under a Huge Salt Layer

Despite the few visually differences exposed when comparing the energy curves given by FD and the ones given by PSPI approaches, the illumination distribution remains the same.

## Conclusions

From the plots seen in the previous section, we can make some comparative observations between both methods of modeling, PSPI and Finite Difference due to some first 2D target oriented illumination results. The source used in PSPI and FD approaches were the unit impulse and the ricker, respectively. For comparison criteria, we had to make adjustments on the PSPI modeling source changing its cutoff frequency values for the curves of both PSPI and FD to be compatible. This could have created the few deviations observed on the PSPI curves.

We presented the illumination studies for PSPI approach. Although its higher cost comparing to ray-tracing methods, the results acquired are similar to the FD ones. Moreover, the PSPI is extremely faster than FD and although FDM models solving the complete wave equation, the PSPI is more versatile to be applied to a great amount of data.

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