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An Integrated Method of Subsurface Illumination Analysis for Shallow Gas Anomaly Data

A. Abdul Latiff, D.P. Ghosh, Universiti Teknologi PETRONAS; Z. Tuan Harith, Herriot-Watt University

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Abstract

In near surface anomaly region such as shallow gas accumulation and salt diapir, the acquired seismic data often suffer from poor quality image (shadow zones) due to low illumination coverage at subsurface reflector. Degraded signal information within these zones often been associated with multiple scattering of ray propagation or absorption of wave energy during seismic data acquisition stage. The distorted image underneath gas zones was caused by three factors: (i) properties of near surface anomaly; (ii) location of target reflector (both lateral and vertical position); and (iii) source-receiver configuration at surface level. Previously, the quality of subsurface data was determined by extrapolating source and receiver wave field, thus creating a pair of focal beams which can be used for evaluation of acquisition design. The highly successful focal beam method demonstrate the relationship between subsurface illumination and acquisition configuration by analyzing resolution and amplitude versus ray parameter (AVP) functions of target locations for a given geometry set-up. Another way to analyze subsurface illumination is through ray tracing method, where rays were propagated from source to target depth and reflected back towards the surface level. During reflection process, illumination will be measured by counting the number of rays hit the target reflector while taking into account incidence ray angle and travel-time measurement. Although both analyses will estimate the amplitude coverage of target reflector, confidence level of illumination quality is still lacking. With this view in mind, we are proposing an integrated method of illumination analysis known as Illummination Factor which based on focal beam and ray tracing methods for better subsurface illumination guidance. The Illumination Factor is formulated based on seismic attributes information from two forward modelling methods; amplitude distribution in spatial domain (focal beam analysis) and number of rays hit at target subsurface (ray interpolation). This new illumination indicator will be used for evaluating a near surface anomaly velocity model, in terms of its confidence level. Evaluation of Illumination Factor in this seismically complex region will set a basis for improving seismic acquisition design, enhance seismic data through better illumination while provide an insight for reservoir characterization.

Keywords – Subsurface Illumination, Shallow Gas Accumulation, Focal Beam, Ray Tracing, Illumination Factor

Introduction

In recent years, the task of finding new hydrocarbon reserve in shallow anomaly region such as shallow gas accumulation has becoming increasingly difficult due to poor seismic data quality. A couple of seismic section examples taken from a gas cloud affected field in Malay Basin (**Figure 1)** clearly indicate that our ability to image the true subsurface data remain limited even though with leading seismic data processing sequences and advance imaging algorithms. The weak seismic reflection signal underneath gas anomaly was caused by irregular ray path travel from surface to target reflector and vice versa. Another factor that contributes to poor illumination data comes from absorption effect as the wave propagating through shallow anomaly will experience internal losses as the part of wave energy was transformed into heat.

Therefore the shallow gas cloud data obtained after seismic acquisition stage requires travel-time error correction (ray scattering) as well as amplitude enhancement (attenuation effect). These two factors can be corrected in two common solutions: i) New seismic processing and imaging algorithms; and ii) Re-acquisition of survey area with different source-receiver configuration. For the last few years, several breakthroughs have been achieved in developing hybrid imaging algorithm to solve both travel-time error and absorption effect, such as Q-migration technique (J.M. Reilly et. al., 2012) and Reverse Time Migration (Schuster, 2002). On the other hand, innovative acquisition methods like coil shooting (Moldoveanu et. al., 2008) and blended acquisition with dispersed source arrays (Berkhout et. al., 2011) are also being widely used in acquisition industry by varying configuration of surface instrumentation. Latest research being pursue in acquisition design is by optimizing source-receiver location in near surface anomaly region (Abdul Latiff et. al., 2013).

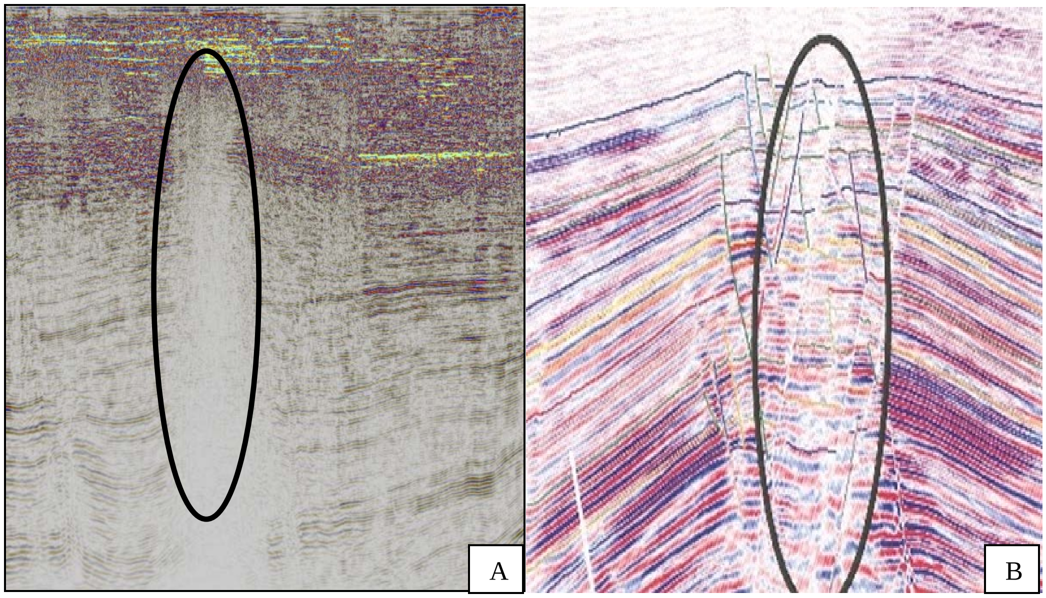

Figure 1: Figure A and B show the adverse effect of shallow gas accumulation on the seismic signal. It can be seen here that reflectors (circled) located directly underneath the gas suffer from data wipe-out. Both seismic sections were obtained after applying standard processing and imaging procedures.

The acquired seismic data sometime need a tool to explain the shadow zones which were detected after processing stage was completed. Hence seismic exploration geophysicists introduce various illumination studies in order to understand subsurface amplitude distribution. All existing methods were reviewed by Laurain et.al., 2003 and they categorized existing illumination methods into two major categories: i) Global method, i.e. amplitude distribution over whole reflector horizon; and ii) Local method, i.e. locating information at a specific area. Global illumination technique is commonly used in exploration industry due to faster implementation of ray tracing technique which enables subsurface illumination evaluation carried out instantly during acquisition stage. Contradict to global solution, local methods such as focal beam (Van Veldhuizen et. al., 2008) have the ability to estimate amplitude at particular point while incorporate wave field propagation through inhomogeneous layers albeit of extensive computing needed.

Throughout the years, both ray interpolation and wave propagation were implemented separately, due to conflict in interest zones. The difference led to various ways of measuring subsurface illumination, for example, ray tracing technique used hit count and angle distribution to measure illumination density of target reflector, while focal beam used resolution and amplitude versus ray parameter (AVP) to determine the amplitude distribution. Without integrating outcome analyses from both global and local methods, it is difficult to understand the true illumination value as both represent different way of subsurface attributes. Therefore, this work will propose a method that integrates ray and wave combinations, by development of new illumination value, known as illumination factor.

Methodology

Development of integrated illumination analysis requires a combination of two parallel workflows; focal beam method and ray tracer implementation. Base concept of focal beam method was originated from WRW wave propagation concept which the formulation contains all aspect of travelling wave field from sources to series of receiver locations. The wave field at target reflector position, $P(z_m,z_m)$ can be represented in matrices as:

$$P(z_m, z_m) = D(z_o)W_u(z_o, z_m)R(z_m, z_m)W_d(z_m, z_o)S(z_o) \quad (1)$$

where $D(z_o)$ is detector matrix, $W_u(z_o,z_m)$ is upward wave matrix, $R(z_m,z_m)$ is reflection coefficient, $W_d(z_m,z_o)$ is downward wave matrix and $S(z_o)$ is source matrix. Next, by adding two focal functions to the front and rear side of equation (1), the wave field representation become:

$$P(z_m, z_m) = F_d(z_m, z_o)D(z_o)W_u(z_o, z_m)R(z_m, z_m)W_d(z_m, z_o)S(z_o)F_s(z_o, z_m) \text{ ---------------------- } (2)$$

Focal beam equation of $P(z_m,z_m)$ now contains $F_d(z_m,z_m)$ as receiver focal function, and $F_s(z_o,z_m)$ as source focal function. When implementing equation (2) in focal beam analysis, wave propagate from target location on reflector horizon towards surface level and vice versa hence creating a dual beams of upward and downward waves. Throughout the upward propagation, the wave field will convolve with several inhomogeneous layers including shallow gas anomaly, thus caused wave distortion before it could reach source and receivers. The surface instruments inability to pick up strong seismic signal will further degrade amplitude signal for back propagation to reflector level, subsequently produced the non-illuminated zones at target subsurface. Illumination result obtained from focal beam analysis will be measured in term of resolution and amplitude versus ray parameter (AVP) functions.

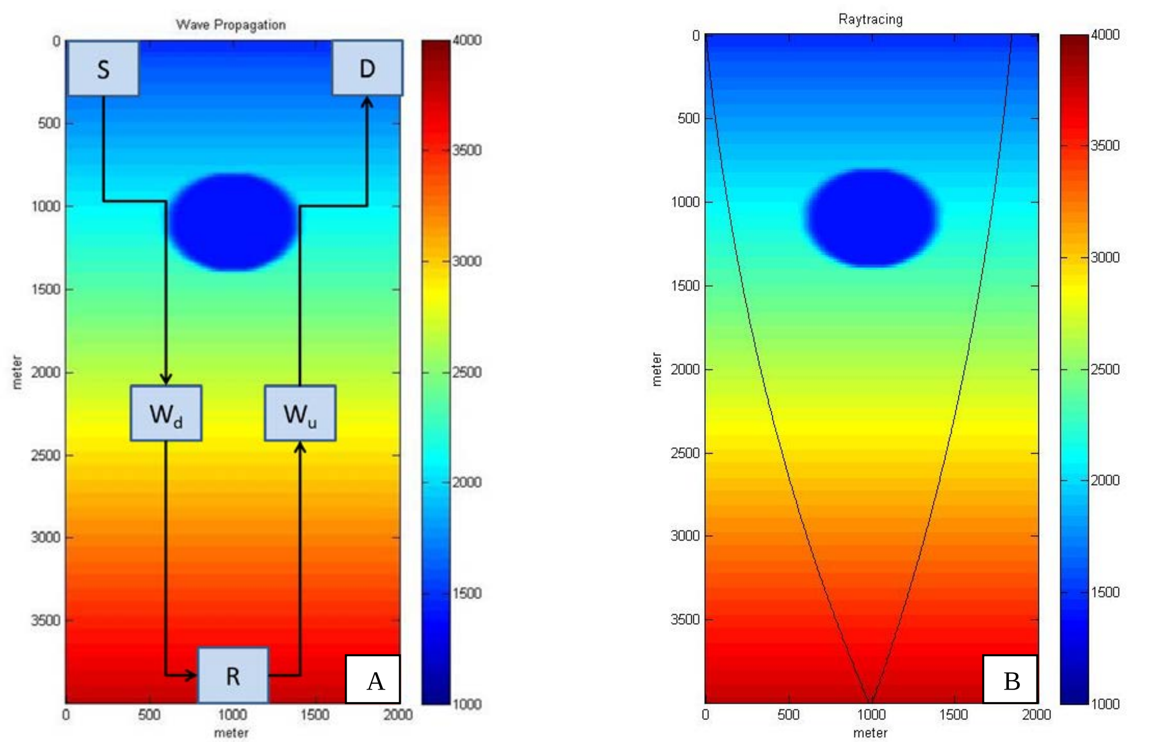

Figure 2: Figure A represent focal beam method analysis using WRW concept. The model represent the total wave fields incorporate in formulation from sources on surface level till receivers detected back on surface. Figure B shows the example of ray tracing implementation in this inhomogeneous model. By shooting rays from source directed to subsurface, only the reflected rays will be propagated back towards surface and detected at receivers.

In ray tracing workflow, ray interpolations throughout the layers will be determined by fourth order Runge-Kutta (RK4) method, which gives approximate solution to ordinary differential equation. For consistency, ray tracer implementations through shallow gas cloud velocity model follow focal beam applications, i.e. a fan of rays were interpolated using RK4 method from target location on subsurface, until reach surface level. Once source or receiver detected any rays passing through, rays will be propagated back toward reflector level, passing through the velocity models. The measurement attribute proposed for this ray tracing method is hit count method with number of hit will be counted once it falls within $\lambda/4$ radius of target point.

Output from both focal beam and ray tracing analyses will be used when formulating illumination factor. To ensure fair illumination comparison between focal beam, ray tracing and the illumination factor, all three analyses were conducted in identical velocity model, a fix target location [1000,1000,4000] and using constant frequency content, 35 Hz. The factor will be calculated by selecting the target point amplitude distribution from focal beam analysis, hit count along with travel-time computation from ray tracing method, before integrating both values using simple multiplication. Calculated values then will be used exclusively for analysis of the selected target point. Workflow in **Figure 3** explains the integrated illumination analysis in diagrammatic way.

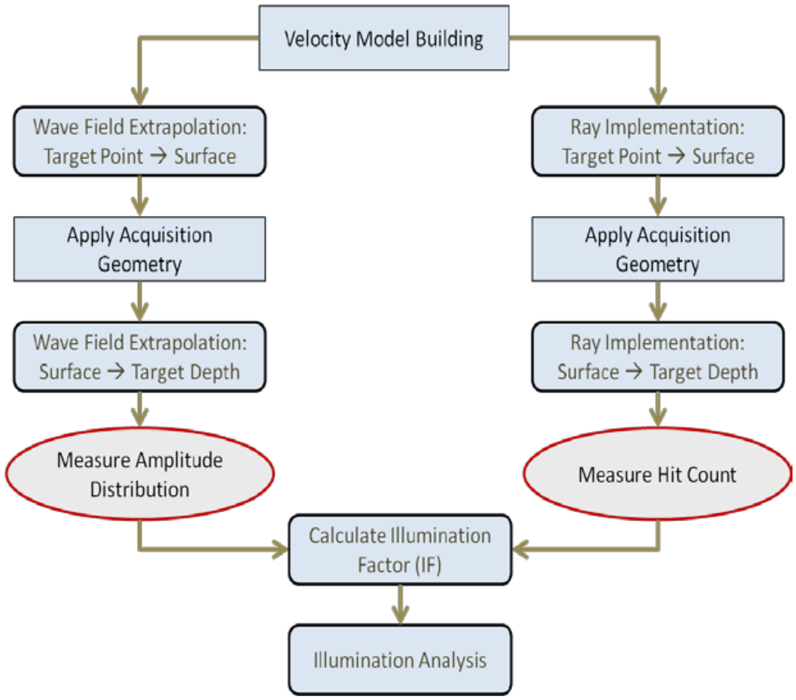

Figure 3: Integrated workflow used throughout the research work. Implementation of ray tracing (right sequences) and focal beam (left sequences) were conducted simultaneously, thus each outcomes from single implementation will not affect another illumination analysis

Illumination Analysis

i. Initialization

The first step of illumination study was to build a velocity model that resembles a shallow gas cloud field. This was done by introducing a near surface anomaly with slower velocity content compare to surrounding sediments velocity. In addition, the 3D velocity model (**Figure 4**) was built with constant velocity gradient from surface level (with velocity of water layer at $1500ms^{-1}$) till depth of 4000m (velocity up to 3990 ms^{-1}). The shallow anomaly was situated at depth range from 700m to 1200m with velocity of 1400 ms^{-1}. The reflection point chosen for analysis is situated underneath the gas cloud, where the seismic data generally has lowest recorded amplitude.

In focal beam analysis, we will obtain amplitude distribution at surface level after first leg of wave extrapolation from target subsurface. At the same instance, ray interpolations arrived at 0m depth level will be measured in number of detected hit rays. Contrary to previous work where the detected amplitude will be convolved with pre-design acquisition configuration, this work will use existing amplitude and rays location at surface level as the starting point for second leg of wave and ray propagation. It should be note that during ray tracing implementation, it can only be done in 2D structure, thus the ray detected on surface and used for initializing downward ray are within a single inline / crossline. To achieve a 3D ray tracing illumination, higher computational power will be needed as RK4 ray tracer implementation will be carried out for every single inline / crossline data.

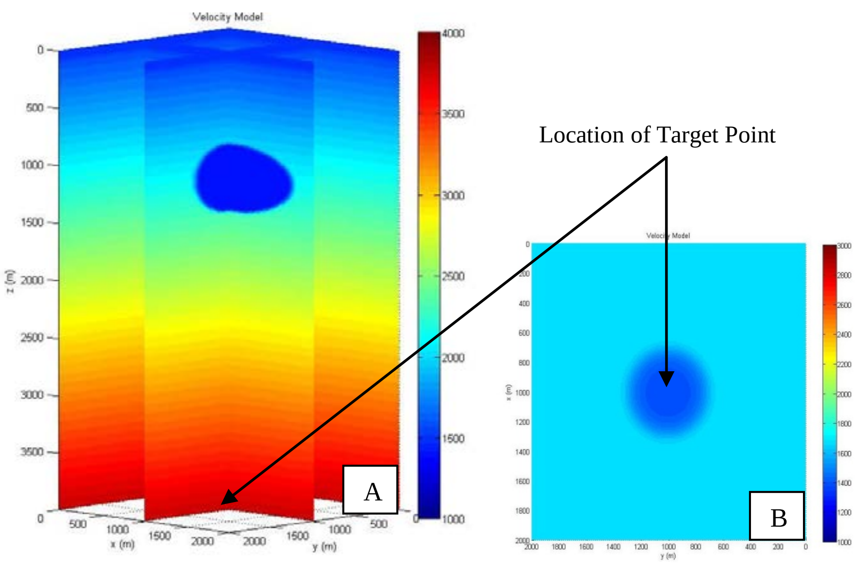

Figure 4: Figure A shows shallow gas accumulation velocity model used for illumination analysis. The low velocity region located between 700m to 1200m. Figure B represent a time slice of velocity model, cutting through the gas zone. Although the gas value was fixed at 1400 ms^{-1}, the edge of gas zone was smoothed to prevent abrupt wavefield propagation.

ii. Amplitude Distribution

The recorded amplitude distribution will be converted into secondary source for downward propagation. Again the wave field will travel through inhomogeneous velocity model by convolving velocity information with wave equation. Once the wave field reached the target subsurface, we determined the quality of subsurface illumination through focal beam function in two domains, spatial and radon domains. Each domain give different ways of interpreting the quality of the data, for example, the focal function in spatial will give details of resolution characteristic of subsurface. On the other hand, transforming the data into radon domain will guide us into amplitude versus ray-parameter (AVP) attribute.

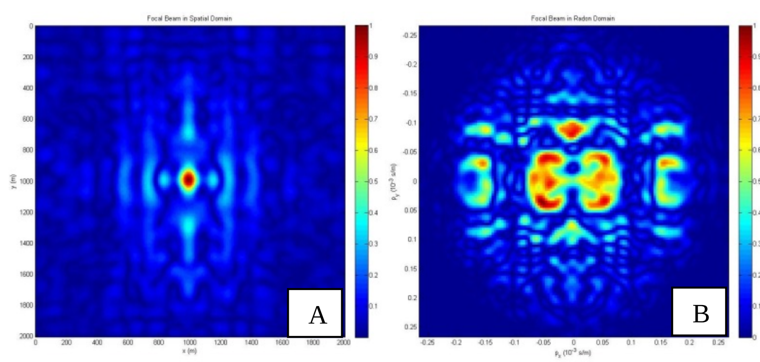

Figure 5: Focal beam results obtained for target location at [1000,1000,4000]. Figure A shows resolution function while figure B indicates AVP amplitude distribution

Figure 5A represents illumination in spatial domains while **Figure 5B** shows the result obtained in radon domain for target reflector at 4km depth. From spatial focal function result, although it is not a highly focus result, the fact that illumination value of 1 in the middle of area show that acceptable illumination range is achievable at this depth position and within this velocity anomaly. The presence of spatial aliasing can also be seen due to insufficient sampling when placing source and receiver configuration. Meanwhile, radon domain analysis indicates amplitude distribution at target point is sufficient for producing good seismic image.

iii. Hit Count

Starting points for ray tracing during downward propagation are based on rays' location on the surface after upward ray implementation. Due to irregularity of ray trace caused by shallow anomaly, the downward starting points are also scattered at surface level. During downward ray shooting, a fan of rays will be considered instead of single ray travel to ensure the outcome contains all travelling rays' possiblities. From **Figure 6A**, there are seven ray fans considered for implementation from surface towards target reflector. When the ray approached target point, number of rays that hit the reflector within its Fresnel zone will be counted which approximately 4m around the target point.

The numbers of rays that hit the area around target reflector were counted and corresponding travel time values were measured. Since the analysis in ray tracing is being carried out in 2D manner, the rays from other inline (y-spacing) are not being considered. From **Figure 6B**, there is only single ray that pass through the target point reflector thus indicates low probability of having high illuminated subsurface zone.

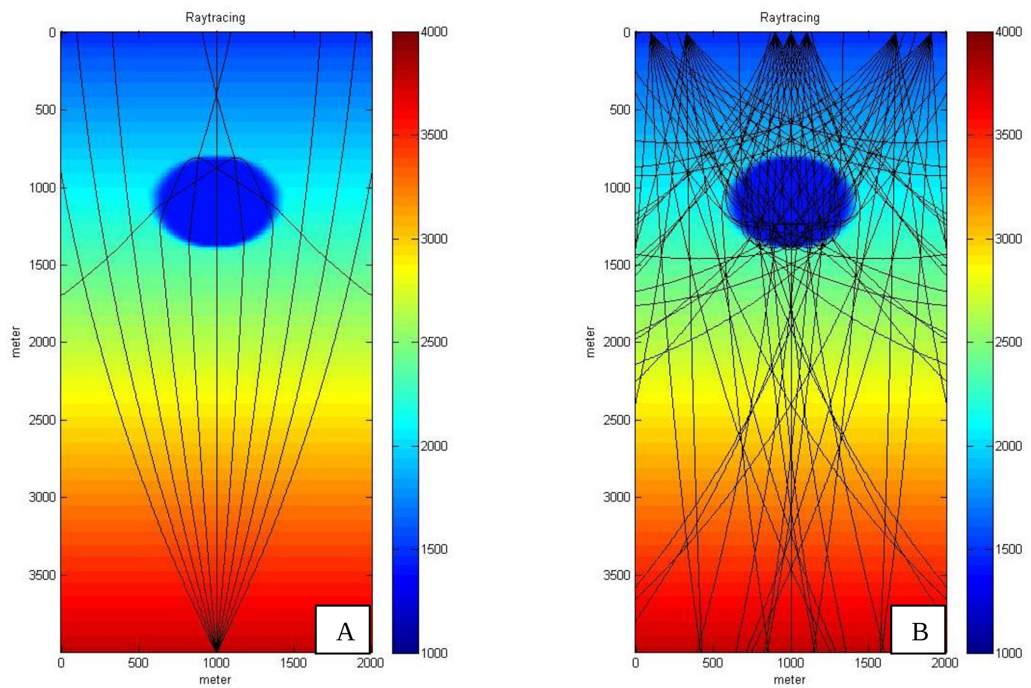

Figure 6: Figure A demonstrated upward rays interpolation from target depth point towards surface level. In figure B, multiple fans of rays were shot downwards. The starting points for downward ray propagation were chosen at the location of rays - surface level crossing.

iv. Illumination Factor (IF)

From focal beam and ray tracing results, the illumination factor was determined by multiplying amplitude distribution with number of hit counts recorded. Since the ray tracing is determined in a particular target position, focal beam measurement at target reflector requires some alteration for changing from whole target reflector coefficient to specific target point. The range of values determined for illumination factors was set from 0 to 10, where 0 indicate low confidence of illumination level of target subsurface while 10 shows extreme confidence towards obtaining good images.

Initially, number of rays propagated in a rayfan was varied from single ray per shot up to 1000 rays per shot. As a result, different hit counts values was detected, ranging from single ray hit up towards more than 100 ray hits. As describe in **Figure 7**, various numbers of rays' hits will indicate different target's illumination confidence level. During ray tracing implementation on shallow gas anomaly model using 100 rays per shot, the number of hit count recorded at point [1000,1000,4000] was 13, which is sufficient for getting moderate quality data compare to ray tracing result in section (iii). The illumination factor obtained in the analysis was represented in **Figure 7B** thus verify the results produced from focal beam and ray tracing analysis, as target point image produce reasonably good illumination quality. If we have 100 hit count on reflector as shown in **Figure 7C,** the illumination factor obtained indicate a very good illumination can be achieved. However if only single ray trace was detected, the illumination confidence value is very poor as indicate in **Figure 7A.**

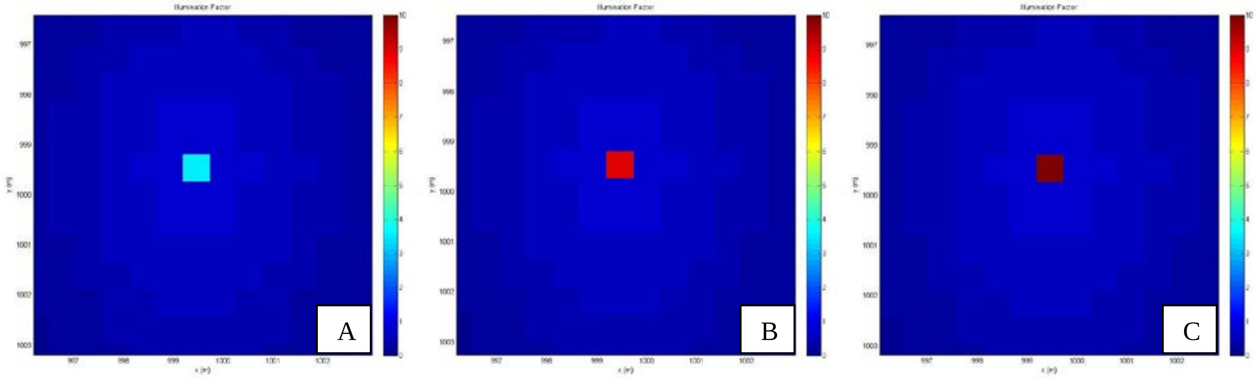

Figure 7: Three illumination factors were produced with various number of hit counts received at target depth point. Illumination factor value in figure A was obtained if only a single hit count was detected, while in figure B is obtained after 13 hit count, which is equivalent to number of hit counts determined in shallow gas anomaly model. Figure C has highest illumination factor value and can only be obtained if the number of hit counts achieve 100 marks.

Conclusion

From the extensive simulation, it can be concluded that illumination at our chosen point [1000,1000,4000] give a promising result in illuminating the seismic image underneath gas cloud. This is shown by illumination factors calculation which was formulated by combining both focal beam and ray tracing methods. Focal beams method, represent the subsurface in term of amplitude distribution suggest that target subsurface is experiencing good resolution function with uniform AVP value. At the same time, ray tracing implementation through shallow anomaly velocity model give a decent result with 13 hit counts recorded which indicate plenty of rays able to propagate through shallow gas anomaly and detected at target subsurface. By integrating both analyses, the outcome from this work can be used to determine the quality of subsurface illumination.

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References

Abdul Latiff, A.H., Ghosh, D.P., Tuan Harith, Z.Z., 2013. Seismic illumination analysis of different shallow gas cloud velocities by focal beam method, Sains Malaysiana (In Review)

Abdul Latiff, A.H., Ghosh, D.P., Tuan Harith, Z.Z., 2013. Advance acquisition design in presence of near surface anomaly using particle swarm optimization, Journal of Seismic Exploration (In Review)

Berkhout, A.J., Ongkiehong, L., Volker, A.W.F., Blacquière, G., 2001. Comprehensive assessment of seismic acquisition geometries by focal beams—Part I: Theoretical considerations. Geophysics, Vol. 66, p 911–p917.

Laurain, R., Gelius, L.J., Vinje, V., Lecomte, I., 2003. Review of 3D illumination studies, Journal of Seismic Exploration, Vol. 13, p17-p37.

Reilly, J.M., Montelli, R., Curry, W., Bear, L., 2012. Unmasking the crest, imaging below shallow gas using prestack Q depth migration. Petroleum Geoscience Conference & Exhibition 2013 Short Course.

Schuster G.T., 2002. Reverse-time migration = Generalized diffraction stack migration. SEG International Exposition and 72nd Annual Meeting

Van Veldhuizen, E.J., Blacquière, G., Berkhout, A.J., 2008. Acquisition geometry analysis in complex 3D media. Geophysics, Vol. 73, p43–p58.

Volker, A.W.F., Blacquière, G., Berkhout, A.J., Ongkiehong, L., 2001. Comprehensive assessment of seismic acquisition geometries by focal beams—Part II: Practical aspects and examples. Geophysics, Vol. 66, p918–p931.