Evaluation of Electric Field Components Response for Offshore Hydrocarbon Detection

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Abstract—This study is aimed to provide new insights on determining E field components for the sea bed logging application. In the scenario of increasing interest in CSEM since last two decades, it is desirable to evaluate the individual field component for the better hydrocarbon presence response. 1D forward modelling is carried out that have the capability to simulate offshore hydrocarbon detection using resistivity contrast analysis. Initially the study supports the proved Ex component of the in-line antenna with orientation along x direction as powerful response as compare to Ey and Ez field by providing a maximum of 93% difference with and without hydrocarbon. However the analysis of further results identifies that even with a weaker response, Ey component with same antenna orientation carries better information for hydrocarbon presence, a maximum of about 100% difference with and without hydrocarbon. Thus outcomes from this research have a clear potential for selecting the informative component of E-field to further the experiments for enhanced hydrocarbon detection.

Index Terms— Sea bed logging; Electromagnetics; 1D simulation; CST, Antenna geometry

1. Introduction

Seismic method has been the most useful approach to detect offshore hydrocarbon reservoir since past four decades. The technique typically uses sound waves released through the water. The reflected wave by rock underneath the sea floor is observed to determine the presence of potential hydrocarbon [1]. However a step from its abilities, the method is found incapable of distinguishing the water and oil reservoirs which may increase the risk factor for well drilling. The marine Controlled Source Electromagnetic (CSEM) method, which is introduced in the beginning of this century [2, 3], given the name seabed logging have gained intensive interest for the offshore hydrocarbon detection. Since then CSEM has evolved from a past significant technology to become a promising emerging tool for de-risking hydrocarbon exploration as witnessed by a number of the consequent successful surveys and result [4][5][6][7].

CSEM for sea bed logging method uses the powerful mobile horizontal electric dipole (HED) towed at a certain height of about 20-40m above the sea floor. HED emits the high alternating current, low voltage waveform typically in the low frequency range of about 0.1 to 10Hz [8]. The underlying principle of marine CSEM is that EM waves attenuate more in a conductive medium like water saturated rocks while less in a resistive medium like hydrocarbon saturated reservoirs due to skin effect. Moreover, some saturating fluids have varying conductivity levels too. Thus the generated EM waves while travelled down through several mediums are mainly refracted then received by the EM detectors [9], which measure the amplitude and phase relationship of the signal based on the resistivity contrast of the mediums. The received waves consist of mainly four kinds; direct waves, reflected and refracted waves (from subsurface), guided waves (through the hydrocarbon layer) and reflected and refracted waves (from sea air interface-Airwaves) as shown in the Figure 1 below. The most considerable is the guided waves, which carry the required data of hydrocarbon location. Therefore the guided wave must have enough energy to be received with reliable information of sub-surface.

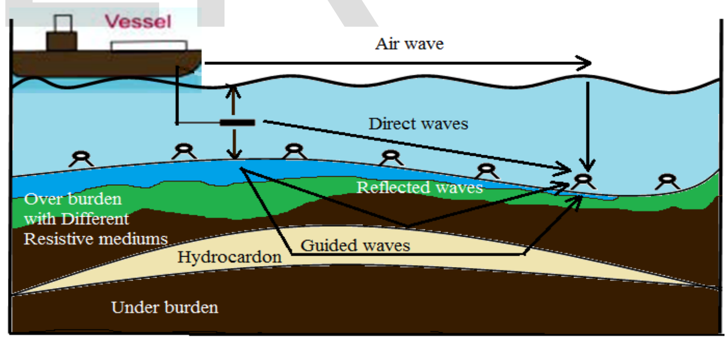

Figure 1: Types of waves received at EM detector. Usually hydrocarbon beneath sea bed is uneven in surface. Therefore effects of several types of waves can easily be received at EM detectors depends on transmitter towing orientation, water depth and target depth.

It is now well know that the main aspect of CSEM is the diffusive behavior of electromagnetic fields in the conductive medium. Therefore at certain offsets usually near or shallow water with deep target, the secondary fields like direct and airwaves dominates as compare to the primary field that carries the relevant information of the subsurface. In the presented condition, it is desirable to evaluate the field response in the paradigm having less effect of the secondary waves.

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The response of the resistivity contrast effect depends on the HED excitation mood either galvanic or inductive [2]. Both modes are specifically the function of the HED geometry. The HED orientation can be defined in terms of the source receiver azimuth, the angle between the dipole axis and the line joining the source and receiver. At an azimuth of 90° (broadside geometry) inductive effects dominates due to skin depth whereas at azimuth of 0° (in-line geometry) galvanic effects are much stronger. Thus a study carried out to evaluate the response of a 1-dimensional model comprising of 100 m thick layer of the hydrocarbon bearing reservoir, overburden of 1000 m and overlain by an 800-m thick seawater layer. The outcomes mentioned that source at 0.5 Hz HED at the seafloor; the radial amplitudes are 20 times more sensitive to the presence of the thin resistive layer as compared to the azimuthal component. The obvious reason is that the radial dipole geometry carries a vertical component of electric current, which is guided back by the thin resistor, whereas the azimuthal dipole fields are largely horizontal and perturbed little [7].

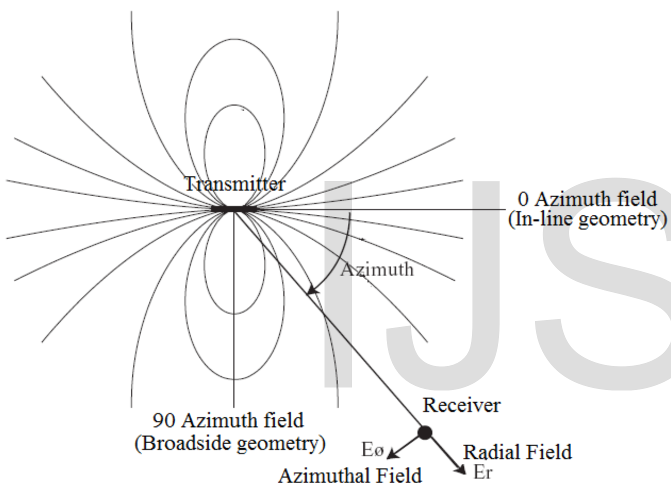

Figure 2: Transmitter orientation; Azimuthal and Radial field for the transmitter geometry evaluation as in-line or broadside.

Increasing scope of 3D forward modelling is well documented for the sea bed logging data interpretation [10, 11, 12] because of extended target oil reservoir bearing is needed. However the experimental design considering merely frequency range, offsets and oil detection can be easily addressed by 1D modelling [7, 13]. Thus the sufficient works on evaluating field response with respect to the offsets and water depths encouraged this research to examine the components of the merely E field for the suitable selection among them for further the experiments. Simulation based modelling using CST uses Maxwell equations to solve the EM propagation with respect to the provided medium like air, hydrocarbon and sea water in the x, y and z plane as shown in Figure 3. In this study, the fix inline geometry of the dipole antenna along x direction is chosen. Therefore, the Maxwell equation below can be used to predict the propagation of EM waves (Electric Field Strength) in seawater (lossy dielectric) [14].

$$E_x = E_0 \exp^{(j\omega t - \gamma y)} \quad (1)$$

$$E_y = E_0 \exp^{(j\omega t - \gamma x)} \quad (2)$$

Where j is the current density (A/m2) and γ is the propagation constant (m-1) in the time domain which can further be expressed in terms of α, the attenuation constant in Np/m and β, the phase constant in rad/m.

$$\gamma = \alpha + j\beta \quad (3)$$

Even though the transmitter in-line orientation along x direction proved Ex and Hz components as the better choice [15, 16], however this simulation study identifies that the Ex component of E-field is not adequate enough for the better resistivity contrast information. Simulations based on 1D forward modelling are carried out using a conventional straight antenna. The results mention that although Ex field shows strong response however Ey component have the better capabilities as compared to Ex related to the hydrocarbon presence at far offset..

2. Modelling Methodology

The Marine CSEM method requires modelling tools for the characterizing, mapping and detection of hydrocarbon reservoir. 1D forward modelling have potential to investigate the effect of electromagnetic fields (E, D, B and H) with respect to several transmitting frequencies and current, distance between the source and the seabed, sea water depth, thickness of overburden, hydrocarbon and under-burden layer etc. In this research, Computer simulation technology (CST) is selected for modelling of the real seabed environment by using a conventional straight EM antenna for deep target hydrocarbon detection. CST uses a pattern to discritize Maxwell's equations at low frequency to investigate the resistivity contrast.

Certain steps are involved in order to generate the CST simulated mode. This investigation uses the parameters for 1D modelling inspired by recent studies. Arranging background parameters is considered as the first step that consist of setting model area 50 x 50 km to replicate the real seabed environment with fixed target position, air thickness at 500 m, sea water depth 2000 m, overburden thickness 1000 m, hydrocarbon thickness 100 m and under burden 900 m. All the layers are allotted with their specific conductivities and permeability values. Second step is to set parameters for aluminum antenna. In the case, length of 270 m, frequency of 0.125 Hz and a current of 1250 A, along with x direction is used as shown in Figure 2. Subsequently electric boundary conditions are applied then run low frequency full wave solver to initiate simulation for sea bed model [14].

It is evident from a number of the successful surveys that hydrocarbon usually exists as the thin-bed layer, approximately parallel to the sea floor [3, 4, 7]. In this simulation study, towing the transmitter over the conduction and resistive mediums is represented by the absences and the presence of hydrocarbon respectively. Since the amplitude and phase response of the resistive medium (presence of hydrocarbon) increases in the measured electric and magnetic field, thus it is taken as reference for the comparison in order to have a clear hydrocarbon presence response. Figure 3 shows a 3-dimensional sea bed model to perform the simulations.

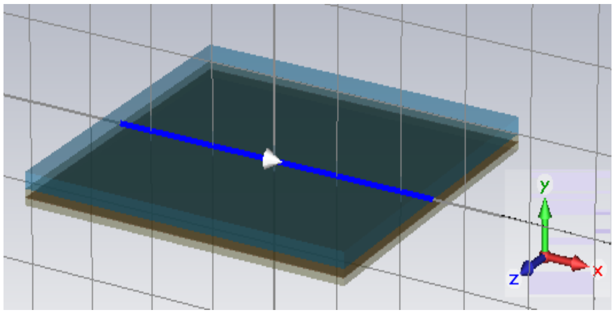

Figure 3: Sea bed logging model showing different resistive mediums in 3D. Transmitter with current path (white arrow direction) is placed 30m above the sea bed while receivers are placed all along the axis, shown in blue line to measure field response at every offset.

3. Simulation Results

Since 1D modelling has the ability to evaluate the behavior of the CSEM method as the function of its individual electric field components. This research simulates each of them as per described in the modelling methodology. Figure 4 shows the plot for Ex, Ey and Ez component including the presence of hydrocarbon. All three components of electric field response are measured with conventional HED antenna within the proposed area (50 km x 50 km) having deep water (2000 m) where no airwaves effect takes place. The comparison of amplitude response clearly mentions that using the in-line geometry of the transmitter, Ex proves to be the strongest among other two. The same behavior is observed while eliminating the hydrocarbon layer. From the Figure 3, it verifies that strength of E field in x direction due to well guided by some critical angle and less attenuation.

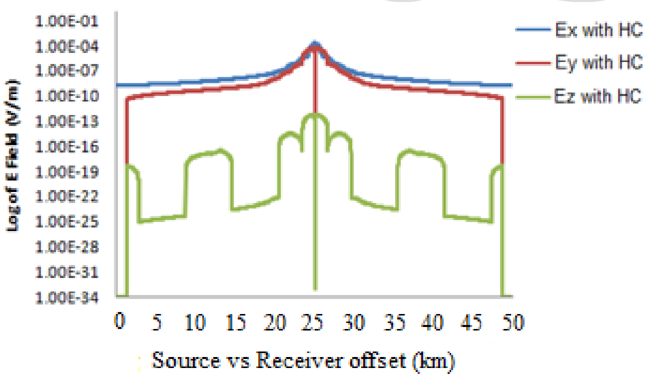

Figure 4: E field component response with hydrocarbon. Ex and Ey shows a customary behaviour of response while Ez shows abnormal due to broadside transmission against the receiver across the water level surface.

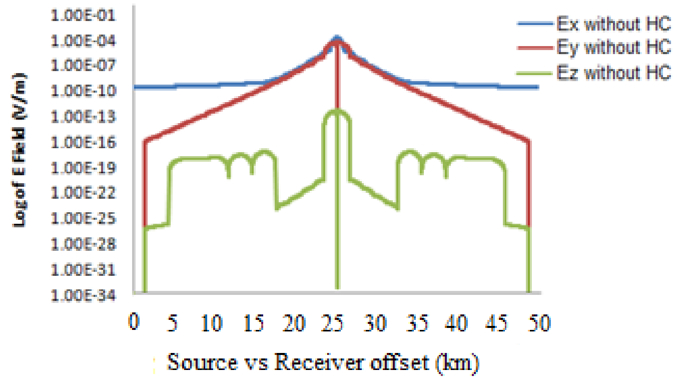

Figure 5: E field component's response without hydrocarbon. Ex, Ey and Ez with apparently same response behavior in contrast with presence of hydrocarbon.

From above Figures 4 and 5, E field in x direction qualified as the most dominant with strong response for further the experiments related to seabed logging environment. Now this study will analyze the individual component of E-field with and without hydrocarbon with the percentage difference obtained between them. The differences in the response have the clear potential to finalize the informative signal in terms of hydrocarbon presence instead of strong amplitude response elements.

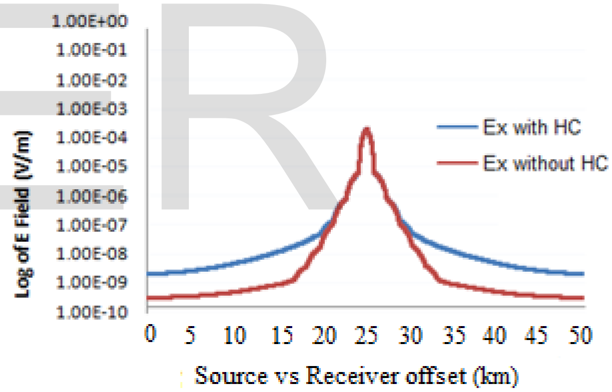

Figure 6: Ex field strength with and without hydrocarbon received at the detectors along the surface of subsurface

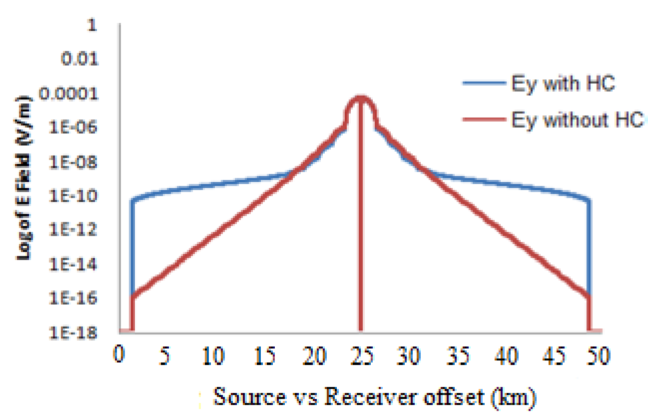

Figure 7: Ey Ex field strength with and without hydrocarbon received at the detectors along the surface of subsurface

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Figures 6 and 7 show the evaluation of Ex and Ey field component in the presence and absence of hydrocarbon. Specifically Figure 7 demonstrates the effect of down going vertical component of E Field. The steep attenuation of Ey field without high resistive layer led to a broader difference when the hydrocarbon is placed as resistive medium. Table 1 and 2 shows the maximum difference with and without hydrocarbon cast by Ex and Ey component of E field.

Table 1: Percentage difference of Ex field with and without hydrocarbon vs source receiver offset

Offset	Ex-Field (With HC)	Ex-Field (Without HC	Percentage Difference
0	2.01E-09	2.98E-10	85%
5009	2.49E-09	3.32E-10	87%
10003	4.59E-09	4.70E-10	90%
15012	1.16E-08	8.51E-10	93%
20006	6.44E-08	3.16E-08	51%
25000	1.97E-04	1.97E-04	0%
30009	6.35E-08	3.08E-08	52%
35003	1.15E-08	8.49E-10	93%
40012	4.58E-09	4.70E-10	90%
45006	2.49E-09	3.32E-10	87%
50000	2.01E-09	2.98E-10	85%

Table 2: Percentage difference of Ey field with and without hydrocarbon vs source receiver offset

Length	Ey-Field, (With HC)	Ey-Field, (Without HC)	Percentage Difference
5009	1.71E-10	4.25E-15	100%
10003	4.32E-10	5.32E-13	100%
15012	1.03E-09	8.40E-11	92%
20006	1.13E-08	1.92E-08	-70%
25000	1.54E-18	1.55E-18	-1%
30009	1.12E-08	1.89E-08	-69%
35003	1.03E-09	8.24E-11	92%
40012	4.31E-10	5.27E-13	100%
45006	1.70E-10	4.18E-15	100%

4. RESULTS VALIDATION

The validation of the Ey component selection is supported by further simulations carried out with varying water depths from 2000m until 500m. The results strengthen the claim of Ey selection followed by deep until potential shallow water depth. The outcomes in terms of the percentage difference with and without hydrocarbon with respect to E field, Ey proved to be the most stable choice, as Ex showed a nearly undetectable difference in the presence of hydrocarbon while lowering water depth. The validation of the results as shown in Figure 8 until 11 which describes that the Ex field while lowering down the water depth, have severely affected by air waves. In the contrast, the vertical component of E field, Ey while having low magnitude response provided better delineation in terms of percentage difference for hydrocarbon presence.

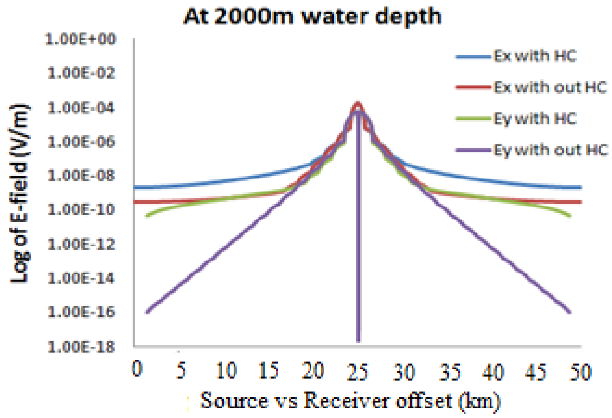

Figure 8: Ex and Ey comparison with and without hydrocarbon at water depth 2000m

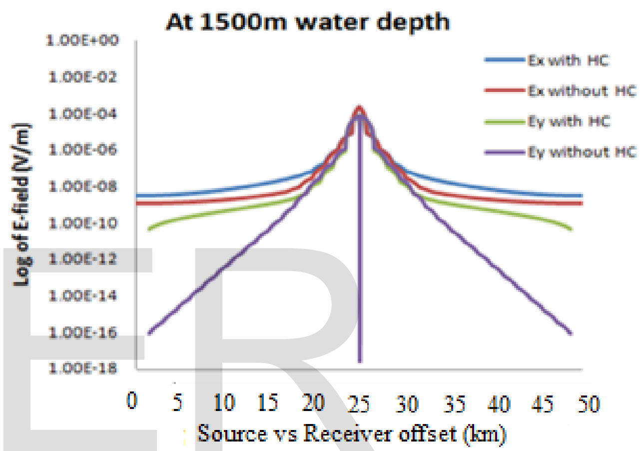

Figure 9: Ex and Ey comparison with and without hydrocarbon at water depth 1500m

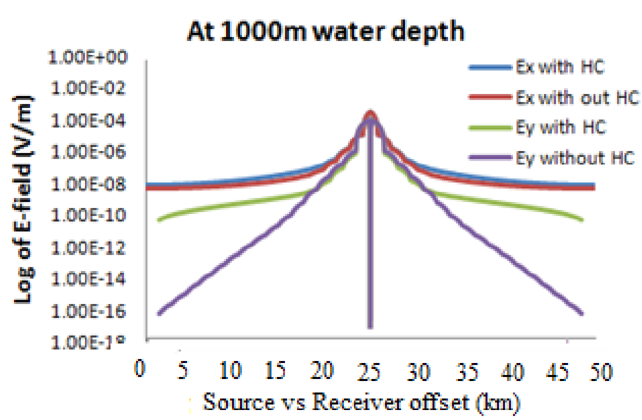

Figure 10: Ex and Ey comparison with and without hydrocarbon at water depth 1000m

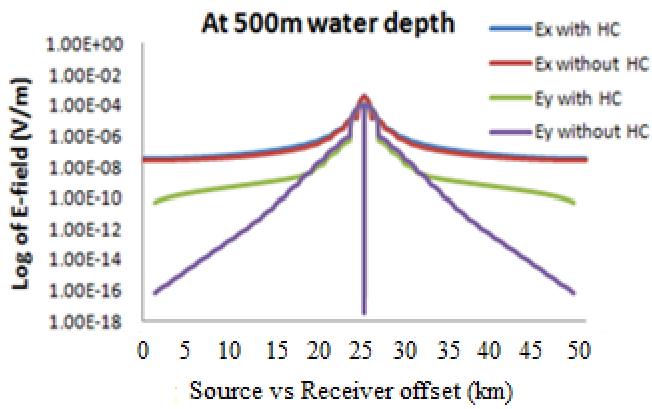

Figure 11: Ex and Ey comparison with and without hydrocarbon at water depth 500m

5. Discussion

In shallow water depth, the possibility of the airwaves to produces an unwanted response is high. Thus for the investigation, initially deep water is focused to avoid air wave effects. The results are generated using 1D forward modelling that exhibits a realistic distribution of individual E field response. Figure 4 and 5 describe the E field components comparison as the function of offset, distance between transmitter and receiver. This 1D simulation supports the proved strength of Ex field over Ey and Ez component with and without hydrocarbon. The clear reason for x field domination is its diffusion pattern in the subsurface. Ex component enters in the subsurface with critical angle. This entering pattern helps the component to be guided well back from higher resistive layer and show up with strongest response. The x components of downward moving EM waves have less possibility to decay or attenuate thus can show a considerable value of the percentage difference between with and without hydrocarbon as shown in Figure 6 and Table 1.

In the contrast, the distinguishing results are shown in Figure 7 and Table 2. Although the y components of downward moving EM waves showed weak response, however the enhanced percentage difference between with and without hydrocarbon is observed as compared with Ex. The reason is the rate of attenuation of Ey field due to Eddy current in the conductive medium. Since Ey is purely a vertical component thus when the EM waves cross deeper into the medium without hydrocarbon, the eddy current turned incrementally weaker which lead the field response weaker as compare to the x field in a conductive medium. While in the presence of hydrocarbon, the direct waves dominate vigorously at near offsets. Therefore while neglecting the response at near offsets, a potentially promising wider percentage difference is observed at far offset. Eventually the enhanced percentage difference with and without the presence of hydrocarbon with y component of E-field showed a clear potential to lead the future research considering it as more better replacement of evaluating E field in x direction.

6. Conclusion

In CSEM, it is desirable to evaluate the individual electric field component for enhanced hydrocarbon detection in seabed logging application. This study focused on evaluating x, y and z component of specifically E field. The 1D simulation results identify that with the in-line geometry of the transmitter, Ex proved to be the strongest among other field component in the presence and absence of hydrocarbon. However in the comparative analysis between Ex and Ey component for better percentage difference with and without hydrocarbon, Ey proved to be the better choice with approximately 100% difference as far offset. The observed reason is due to its distinguishing trait as the vertical component of the E field while transmitter geometry along x direction, skin effect and steep attenuation in conductive medium which lead to bring up with a wider percentage difference in the presence of high resistive medium like hydrocarbon. While the stronger Ex field is found capable of distinguishing hydrocarbon up to maximum 93%.

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