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Response Curves for Space-Frequency Domain of E_y Component of Electromagnetic Sources Field Propagated in Low Latitude after Interaction with 1-Dimensional 2-Layered Earth Model

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Abstract Different conductivity-depth variations for the response of the E_y component of non-uniform electromagnetic source field propagated in low latitude and prescribed in space-frequency domain after interaction of this component with 1-dimensional 2-layered earth model were presented. The low latitude is always referred to the equatorial region. The space-frequency domain of the source field was made possible by the use of a simple Fourier Transform and Cauchy Initial Boundary Values. The prescribed surface field was deduced from the total measured surface field by the separation of the fields into internal and external parts using surface integral. The response curves obtained for the conductivity-depth variation showed that in depth geo-physical structure can be ascertained with inducing field expressed in space-frequency domain.

Keywords: *response curves, 2-dimensional 2- layered earth structure, equatorial latitude, space-frequency domain, low latitude region*

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1. Introduction

Many studies have been carried out, to obtain the functional representation of the components of the electromagnetic source fields propagated in low latitude [1,2,4,5,7,9,10]. In each of these studies; the functional representations obtained are expressed in space-time domain. In addition, one important parameter used to completely specify these functional representations has always been the source field parameter [3,5]. No ideal source field parameter has ever been mentioned in literature. The only trace of such source field parameter in Oni and Agunloye [3,5] is in terms of a functional representation. For the reasons, this parameter cannot be quantified.

Realizing this shortcoming in their expressions for the electromagnetic waves, Oni [4] has suggested that a way of realizing the exact functional representation of the source field propagated in low latitude is to assume that the electromagnetic source field is a non-uniform wave and that this can be done by using an initial prescription.

With these noted defects in the earlier approach to obtain the functional representation of the components of the electromagnetic source fields propagated in low latitude devoid of source parameters and with the realization that the electromagnetic source fields are non-uniform waves, the main aim of this study is to modeled a non-uniform electromagnetic source field propagated at low latitude and thereafter generate response curves for such source fields prescribed in space-frequency domain after interaction with a one-dimensional two layered earth model.

We are prompted to embark on this present study because many of the studies cited in the literature, for example, Sogade and Oni [7] Onwumechili [8] are limited to waves prescribed in space-time domain in this region, and resulting response of these waves after interaction with the earth subsurface, have been found not to identify the various in-depth geophysical structures within the earth, Vestine [10].

2. Theory

The functional representation of a non-uniform electromagnetic source field propagated in the low latitude is given as $\psi(x,y,z,t)=0$. The partial differential equation to be satisfied by function is thus given as

$$\frac{\partial\psi}{\partial x^2}+\frac{\partial\psi}{\partial y^2}+\frac{\partial\psi}{\partial z^2}-\mu\sigma\frac{\partial\psi}{\partial t}-\mu\varepsilon\frac{\partial\psi}{\partial t^2}=0 \qquad (1)$$

where σ, μ and ε are respectively the conductivity, permeability and permittivity of either the free space or the earth layer. ψ represents any component of the electric field $\vec{E}$ or the magnetic field $\vec{H}$.

The general solution to equation (1) in the z-direction can be expressed as

$$\psi = \left(Ae^{i\gamma z} + Be^{-i\gamma z}\right) e^{-pt} \tag{2}$$

The relationship between γ and σ, μ, ρ is given as

$$p = \frac{\sigma}{2\varepsilon} \pm \sqrt{\frac{\sigma^2}{4\varepsilon^2} - \frac{\gamma^2}{\mu\varepsilon}} \tag{3}$$

γ and p are decay constants in equation (2).

If we set $q = \sqrt{\frac{\sigma^2}{4\varepsilon^2} - \frac{\gamma^2}{\mu\varepsilon}}$ and $b = \frac{\sigma}{2\varepsilon}$, then equation (2) can now be expressed as

$$\psi = \left(Ae^{i\gamma z} + Be^{-i\gamma z}\right) e^{-(b \pm iq)t} \tag{4}$$

Two independent general solutions of equation (1) are specified iv equation (4) and prescribed in space-time domain. These two solutions are

$$\psi = e^{-bt}\left(Ae^{i\gamma z} + Be^{-i\gamma z}\right)e^{-iqt} \tag{5}$$

and

$$\psi = e^{-bt}\left(Ae^{iqt} + Be^{-iqt}\right)e^{-i\gamma z} \tag{6}$$

For any of these electromagnetic waves components (E_x, E_y, E_z, H_x, H_z, H_y), represented for now as, ψ , interacting with any earth model, the waves pattern obtained at the interface of the earth sub-layer is given as

$$\begin{aligned} \psi = t_n &\left\{\tfrac{1}{2} g\ (z_n + a_n t) - \tfrac{1}{2} h\ (z_n - a_n t)\right\} \\ - r_n &\left\{\tfrac{1}{2} g (z_n - a_n t) - \tfrac{1}{2} h\ (z_n - a_n t)\right\} \end{aligned} \tag{7}$$

Where n is the n^{th} layer , z_n is the depth of the n^{th} layer, a_n is the speed of the waves in the n^{th} layer, t is the time foe the waves to tranverse n^{th} layer , t_n and r_n are respectively the transmission and reflection coefficients of the wave in the n^{th} layer.

In equation (7), two forms of waves are specified after incidence on the interface of the earth layer. The first is the transmitted wave in the negative z-direction and the second is the reflected wave in the positive z-direction. There are two ways of posing the initial boundary value problem so that a unique expression can be obtained to describe the exact functional representation of the electromagnetic waves in low latitude in equation (7). The two forms of the initial value problems are initial prescription in space and initial prescription in time. In this study, initial prescription in time is adopted. In this case, at initial time $t = 0$, ψ and $\frac{\partial \psi}{\partial z}$ are prescribed as functions of the space coordinate. Thus with the appropriate Cauchy initial boundary values from which the functional representation of $g(z,t)$ and $h\ (z,t)$ can be obtained are given as

$$g(z) = \psi_{(z,t)}\Big|_{t=0} \tag{8}$$

and

$$h(t) = -\frac{1}{a}\int_0^z G(z')dz' \tag{9}$$

where $G(z') = \left.\frac{\partial \psi_{(z,t)}}{\partial t}\right|_{t=0}$.

These initial boundary value problems provide a platform for the integration of the general solutions for equations (5, 6) into equation (7).

The two forms of the initial value problems are initial prescription in space and initial prescription in time.

Applying these initial boundary values, we have that

$$g(z) = \psi_{(z,0)}\Big|_{t=0} = (A+B)\ e^{i\gamma z} \tag{10}$$

$(A+B)$ represents the amplitude of the wave denoted by $e^{i\gamma z}$ .Since this wave shows an increasing exponential function with increase in z, we want to consider a model where $(A+B)$ is used as a modulating factor. Unless this factor is properly chosen we shall end up with the conclusion that the values of the waves at the edges of the low latitude region are infinite. One of the important conditions is the choice of the coordinate axes. In this study the coordinate axes are modeled such that the x-axis runs across the width of region while the y-axis runs along the AB length of the region and the z-axis is vertical axis to the region. All these descriptions are shown in Figure (A1). With this, $(A+B)$ modulates a plane wave propagating along the z-axis with its direction specified along the Z0 and of length z. Thus $(A+B)$ can functionally be represented as e^{-z/a_o} . Where a_o is the speed of electromagnetic waves in air. Figure A2 shows a one directional two earth layer model).

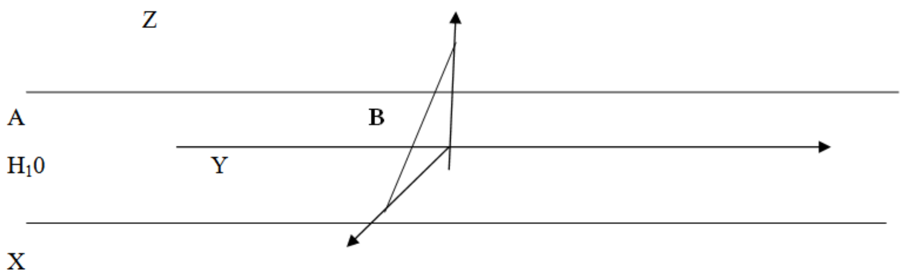

Figure A1. Schematic model of the low latitude region

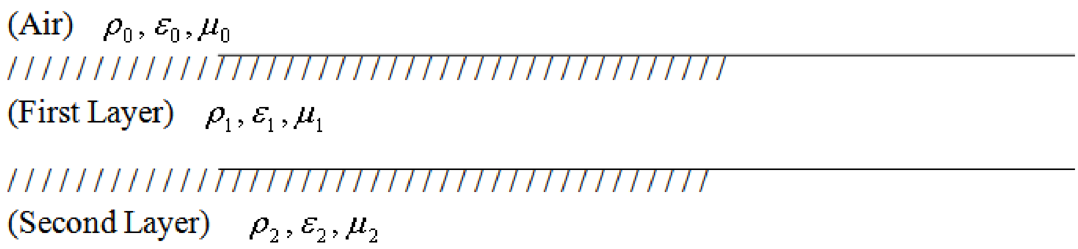

Figure A2. Schematic of a 2-earth layer

Equation (10) can fully be written as

$$g(z) = \psi_{(z,0)}\Big|_{t=0} = e^{-z/a_o} \text{ x } e^{i\gamma z} = e^{-(1/a_o - i\gamma)z} \quad (12)$$

From equation (12) the functional representation for $g(z+at)$, at a later time t becomes

$$g(z+at) = e^{-(1/a_o - i\gamma)(z+a_o t)} \quad (13)$$

while the functional representation for $g(z-at)$ at a later time t becomes

$$g(z-at) = e^{-(1/a_o - i\gamma)(z-a_o t)} \quad (14)$$

In addition the initial boundary condition, at time $t = 0$ is given as

$$\frac{\partial \psi_{(z,\ o)}}{\partial t}\Bigg|_{t=o} \quad G(z) = \{-b(A+B) + iq(A-B)\} e^{i\gamma z} \quad (15)$$

Again the factor $\{-b(A+B)+iq(A-B)\}$ whichis the amplitudeof function $e^{i\gamma z}$ is also taken as the modulating factor of the function $e^{i\gamma z}$. This modulating factor is made up of two terms, the real part and the complex part. In this study we have taken the real part of this factor, so that in equation (15) only the term $\{-b(A+B)\}$ is sufficient so that equation (15) becomes

$$\frac{\partial \psi_{(z,\ o)}}{\partial t}\Bigg|_{t=o} \quad G(z) = \{-b(A+B\} e^{i\gamma z} \\ = -b\psi_o e^{-(1/a_o - i\gamma)z} \quad (16)$$

Thus

$$h(z) = \frac{-1}{a_o}\int_0^z G(z')dz' = \frac{-1}{a_o}\int_0^z -b\psi_o e^{-(1/a_o - i\gamma)z} dz' \quad (17)$$

Integrating within these limits and finding the functional representation for $h(z+a_o t)$ and $h(z-a_o t)$ at later time t, we have that

$$h(z+a_o t) = -\frac{b\psi_o}{a_o(1-i\gamma a_o)}\left[e^{-(1/a_o - i\gamma)(z+a_o t)} - 1\right] \quad (18)$$

and

$$h(z-a_o t) = -\frac{b\psi_o}{a_o(1-i\gamma a_o)}\left[e^{-(1/a_o - i\gamma)(z-a_o t)} - 1\right] \quad (19)$$

Substitute equations (13), (14), (18) and (19) into equation (7) to have

$$\psi_{(z,\ t)} = \frac{\psi_o e^{-(1/a_o - i\gamma)(z+a_o t)}}{2} - \frac{\psi_o e^{-(1/a_o - i\gamma)(z-a_o t)}}{2} \\ - \frac{\psi_o e^{-(1/a_o - i\gamma)(z-a_o t)}}{2(1-ia_o\gamma)} + \frac{\psi_o e^{-(1/a_o - i\gamma)(z-a_o t)}}{2(1-ia_o\gamma)} \quad (20)$$

By making use of Fourier and Inverse Fourier Transformation in harmonic analysis, solutions were found for equation (20) in space-frequency domain after integrating between the limits $0 \geq t \geq H1/a_0$. The derived solution by the authors for any field components in dimension in space-frequency domain is given as

$$\psi_{(z,\ w)} = \frac{\psi_o}{M_8}\begin{bmatrix} \{M_6 - M_9\} e^{-z/a_o} \\ -M_{11} e^{-(z+H1)/a_o} \\ -M_{13} e^{-(z-H1)/a_o} \end{bmatrix} \quad (21)$$

The expressions for M_6, M_9, M_{11} and M_{13} are given in appendix 1C. In this study, the expression represented in equation (21), is chosen to represent for H_x component of the source fields. Thus

$$H_{(z,\ w)} = \frac{\psi_o}{M_8}\begin{bmatrix} \{M_6 - M_9\} e^{-z/a_o} \\ -M_{11} e^{-(z+H1)/a_o} \\ -M_{13} e^{-(z-H1)/a_o} \end{bmatrix} \quad (21a)$$

Following the same method above the other components of the source field could be obtained by appropriate choice of Maxwell equations and the constitutive relations as expressed in equations (22)- (28).

$$\nabla x\vec{H} = \frac{\partial D}{\partial t} + \vec{J} \quad (22)$$

$$\nabla x\vec{E} = \frac{\partial \vec{B}}{\partial t} \quad (23)$$

$$\nabla . D = \rho \quad (24)$$

$$\nabla .\ B = 0 \quad (25)$$

The constitutive relations to be used along with these equations are

$$J = \sigma\vec{E} \quad (26)$$

$$\vec{B} = \vec{\mu}H \quad (27)$$

$$\vec{D} = \varepsilon\vec{E} \quad (28)$$

Substitute the constitutive relations in equations (16) and (18) into equation (12) and thereafter expand the result, we have for each of the electrical components of the source fields

$$E_x = \left(\varepsilon \frac{\partial}{\partial t} + \sigma\right)^{-1} \left(\frac{\partial H_z}{\partial y} - \frac{\partial H_y}{\partial z}\right) \quad (29)$$

$$E_y = \left(\varepsilon \frac{\partial}{\partial t} + \sigma\right)^{-1} \left(\frac{\partial H_z}{\partial x} - \frac{\partial H_x}{\partial z}\right) \quad (30)$$

$$E_z = \left(\varepsilon \frac{\partial}{\partial t} + \sigma\right)^{-1} \left(\frac{\partial H_y}{\partial x} - \frac{\partial H_x}{\partial y}\right) \quad (31)$$

Also substitute the constitutive relation in equation (22) into equation (28) and thereafter expand the result, also the magnetic components of the source fields are obtained. Also adopting the same procedure specified above, the H_z component in the space-frequency domain is given as

$$\begin{aligned} H_{z(z,\ w)} &= \frac{\psi_o}{S_6}\begin{bmatrix} T\{S_{17}+S_{16}\}e^{-(z+H1)/a_o} \\ -NS_{18}e^{-H1/a_o} + NS_{11} + TS_{21}e^{-z/a_o} \end{bmatrix} \\ &-\frac{\psi_o T}{S_5}\left[S_{161} - \{S_{19}+S_{20}\}e^{-(z-H1)/a_o}\right] \\ &+\frac{\psi_o N}{S_7}\left[S_{14} - \{S_{22}+S_{23}\}e^{H1/a_o}\right] \\ &-\frac{\psi_o}{q_7}\begin{bmatrix} \{P_1+P_2\}+e^{H1/a_o}+(q_3+q_5) \\ +-\{P_3-P_4\}+e^{-H1/a_o} \end{bmatrix} \end{aligned} \quad (32)$$

Where T= $\psi_o \rho \mu a_o 2\sqrt{z}$, N= $\rho\mu a_o 2H_1$, $P_1 = q_3\cos(\gamma H_1 + wH_1/a_o)$, $P_2 = q_4 \sin(\gamma H_1 + wH_1/a_o)$, $P_3 = q_5\cos(\gamma H_1 - wH_1/a_o)$ and $P_4 = q_6\sin(\gamma H_1 - wH_1/a_o)$. Expressions for other parameters are shown in appendix 2A. For Lack of space, we have not shown the expressions for E_y, $\frac{\partial H_y}{\partial x}$, $\frac{\partial H_x}{\partial z}$ and $\frac{\partial H_z}{\partial x}$. These expressions are obtained following the procedure used for the expression for $H_{x(z,\ w)}$.

Interaction of the Non-Uniform Fields with 1-dimesional (1-D) 2-Layered Earth Structure

The boundary conditions to be met at each of the interfaces are (1) continuity of tangential components of the electrical and magnetic fields (2) continuity of the normal component of the current (σE) and magnetic induction $B = (\mu H)$. By using the magnetic and the electric fields in the following forms

$$H_{nx} = T_{nx}H_{-nx} + R_{nx}H_{+nx};\ H_{nz} = T_{nz}H_{-nz} + R_{nz}H_{+nz}$$

where n represents the n^{th} layer of the earth and the $-$ or $+$ respectively denotes the negative or the positive direction of the axes involved in prescribing the components of the source field.

Thus using the usual physical considerations we have that the boundary conditions give rise to the following equations, $H_{ox} = H_{1x}|_{z=o}$; $H_{1x} = H_{2x}|_{z=1}$; $E_{oy} = E_{1y}|_{z=o}$; $E_{1y} = E_{2y}|_{z=1}$; $E_{oz} = E_{1z}|_{z=o}$; $E_{1z} = E_{2z}|_{z=1}$; $\mu_o H_{oz} = \mu_1 H_{1z}|_{z=o}$; $\mu H_{1z} = \mu H_{2z}|_{z=1}$

By making use of appropriate physical constraints on the fields within each layer, and expressing the partial differential in equation (30) as $H^z_{-ox} \equiv \partial H_{-ox}/\partial z,\ \ H^x_{-oz} \equiv \partial H_{-oz}/\partial x,\ \ etc$, with the usual physical properties in the form $\rho_o \equiv \left(\sigma_o + \varepsilon_o \frac{\partial}{\partial t}\right) \approx \varepsilon\frac{\partial}{\partial t},\ \rho_n \equiv \left(\sigma_n + \varepsilon_n\frac{\partial}{\partial t}\right) \approx \sigma_n$, the above boundary conditions can be put in a matrix form represented by equation (33).

$$\begin{bmatrix} \sigma_1^{-1}H^x_{-1z} & \sigma_1^{-1}H^x_{1z} & -\rho_o^{-1}H^x_{+oz} & -\rho_o^{-1}H^z_{+ox} & 0 & 0 & -\sigma_1^{-1}H^z_{-1x} & -\sigma_1^{-1}H^z_{+1x} \\ 0 & 0 & 0 & \sigma_1^{-1}H^y_{+ox} & 0 & 0 & -\sigma_1^{-1}H^y_{-1x} & -\sigma_1^{-1}H^y_{+1x} \\ 0 & 0 & 0 & H_{+ox} & 0 & 0 & -H_{-1x} & -H_{+1x} \\ -\mu_1 H_{-1z} & -\mu_1 H_{+1z} & \mu_o H_{+0z} & 0 & 0 & 0 & 0 & 0 \\ -\sigma_1^{-1}H^x_{-1z} & -\sigma_1^{-1}H^x_{+1z} & 0 & 0 & -\sigma_2^{-1}H^z_{-2x} & \sigma_2^{-1}H^x_{-2z} & \sigma_1^{-1}H^z_{-1x} & \sigma_1^{-1}H^z_{+1x} \\ 0 & 0 & 0 & 0 & -H_{-2x} & 0 & H_{-1x} & H_{+1x} \\ \mu_1 H_{-1z} & \mu_1 H_{+1z} & 0 & 0 & 0 & -\mu_2 H_{-2z} & 0 & 0 \\ 0 & 0 & 0 & 0 & -\sigma_2^{-1}H^y_{-2x} & 0 & \sigma_1^{-1}H^y_{-1x} & \sigma_1^{-1}H^y_{+1x} \end{bmatrix}$$

$$x \begin{bmatrix} T_{1z} \\ R_{1z} \\ R_{oz} \\ R_{ox} \\ T_{2x} \\ T_{2z} \\ T_{1x} \\ R_{1x} \end{bmatrix} = \begin{bmatrix} \rho_o^{-1}\left(H^x_{-oz} - H^z_{-ox}\right) \\ -\rho_o^{-1}H^y_{-ox} \\ -H_{-ox} \\ -\mu_o H_{-oz} \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \quad (33)$$

The response waves required at the surface after interaction with the earth layers is given as [7],

$$R = \left.\frac{E_{oy}}{H_{ox}}\right|_{z=0} = \frac{\rho_o^{-1}\begin{pmatrix} H_{-ox}^{z} + R_{ox}H_{+oz} \\ -H_{-oz}^{x} - R_{oz}H_{+oz}^{x} \end{pmatrix}}{\left(H_{-ox} + R_{ox}H_{+ox}\right)} \qquad (34)$$

Equation (34) is fully specified only when the expressions for R_{ox} and R_{oz} are known. These terms are obtained using a combination of LU-decomposition techniques for finding the inverse of matrices and back-substitution method to solve the simultaneous equations. The expressions for R_{ox} and R_{oz} are respectively given as

$$R_{oz} = 0, \qquad (35),$$

$$R_{ox} = \frac{\rho_0^{-1}\mu_1 H_{-1z}\left(H_{-oz}^{x} - H_{-ox}^{z}\right) - \rho_1^{-1}\mu_o H_{-oz} + Q}{\mu_1 H_{+ox}^{z} H_{-1z}} \qquad (36)$$

The expression for Q is shown in appendix 3C.

3. Results and Discussion

The main aim of this study is to investigate the geo-physical structure that may be detected using the E_y component of electromagnetic source field propagated in low latitude and expressed in space frequency domain. This is made possible by obtaining the response of the interactions of this component after interactions with the modeled earth layers on the earth surface. The response curves were completely specified by substituting the values of the usual earth electrical and magnetic parameters, ρ_o, ρ_1, ρ_2, σ_1, σ_2, ε_o, ε_1, ε_2, μ_o, μ_1 and μ_2, for both space and for each of the earth layer. Table 1 contains the values of these parameters, Oni (2002).

Table 1. Values for electric and magnetic parameters for space and for each of the layers.

Layers	Values for the Physical Parameters for each of the Layers					
	ρ [mhos/m]	σ [mhos/m]	μ [A/m]	a [m/sec]	ε [Farad/m]	γ
Air	0.2	-------------	12.56x10^{-7}	3x10^{8}	8.85x10^{-12}	7000/a$_0$
First Layer	--------------	10^{-4}-10^{-0},1	12.56x10^{-10}	3x10^{4}	8.85x10^{-15}	7000/a$_1$
Second Layer	--------------	10^{-8}	12.56x10^{-15}	3x10^{3}	8.85x10^{-20}	7000/a$_2$

4. Distribution of Daily Range of the H_x Component of the Electromagnetic Waves

The functional fits obtained from equation 21b and 32, for the propagation of the component H_x in space at frequencies 0.0015 Hz and 50 Hz are showing in Figures 1 and 2 respectively. It is observed here that at the edges of the equatorial region the waves have finite values, represented by the amplitude of the wave at these edges, negating the ideal of infinite value at the edges of the equatorial region, as earlier speculated, (Oni 1973). One important feature of the curve fit is the depression of the waves at the mid-points of the field at frequencies 0.0015H$_z$ and 50H$_z$. This feature is more prominent at frequency 50H$_z$.

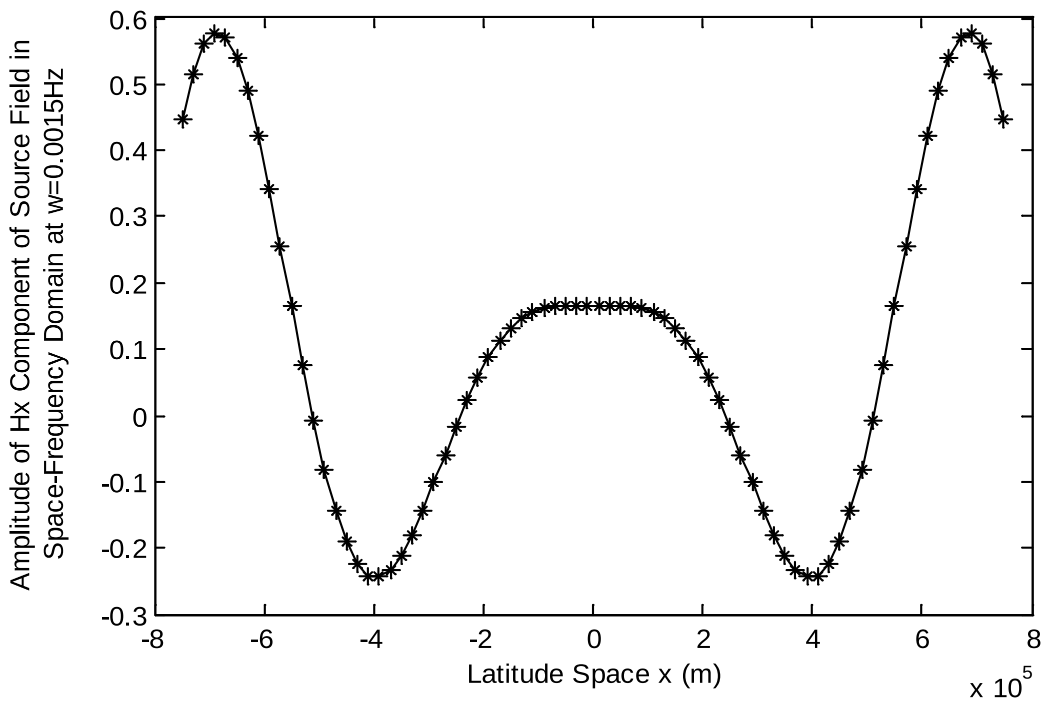

Figure 1. The distribution of the daily range of the horizontal component of the eletrojet magnetic field Hx with latitude x at w=0.0015Hz

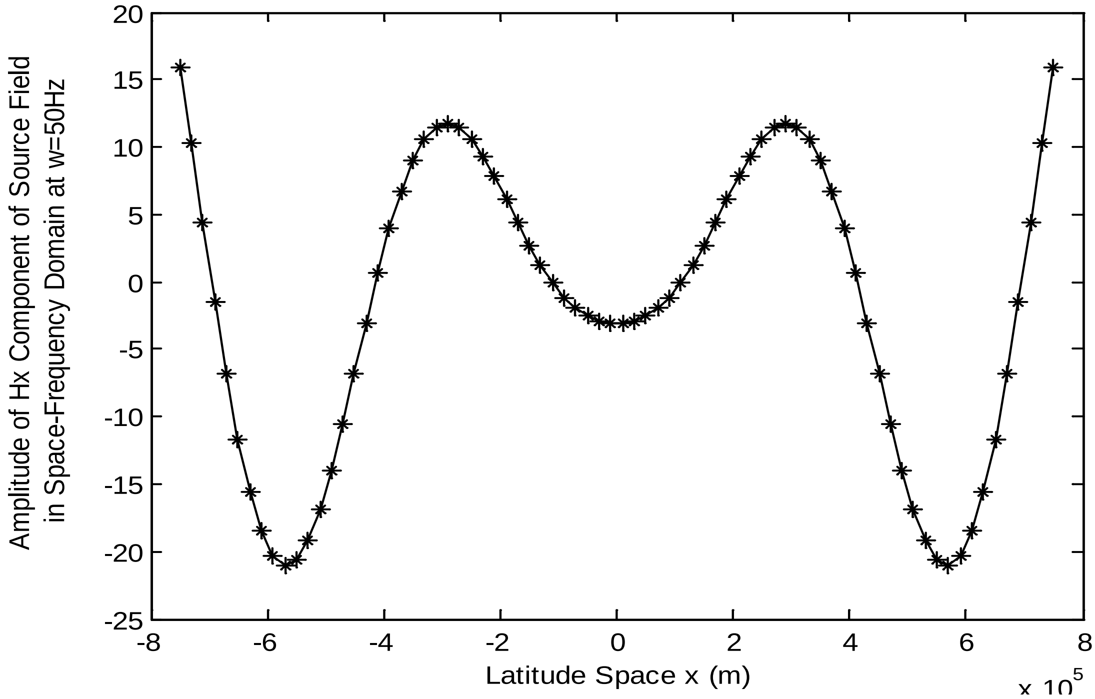

Figure 2. The distribution of the Ampliture of the horizontal component of the eletrojet magnetic field Hx with latitude x at w=0.0015Hz

Figure 3 represents the functional fits for the E_y component of the source fields at frequencies ranging from 750 H_z to 0.0015 H_z. This frequency range is considered to be within the low frequency range. These curves show normal wave propagation within the latitude. There is phase shift of the wave obtained for 0.0H_z.

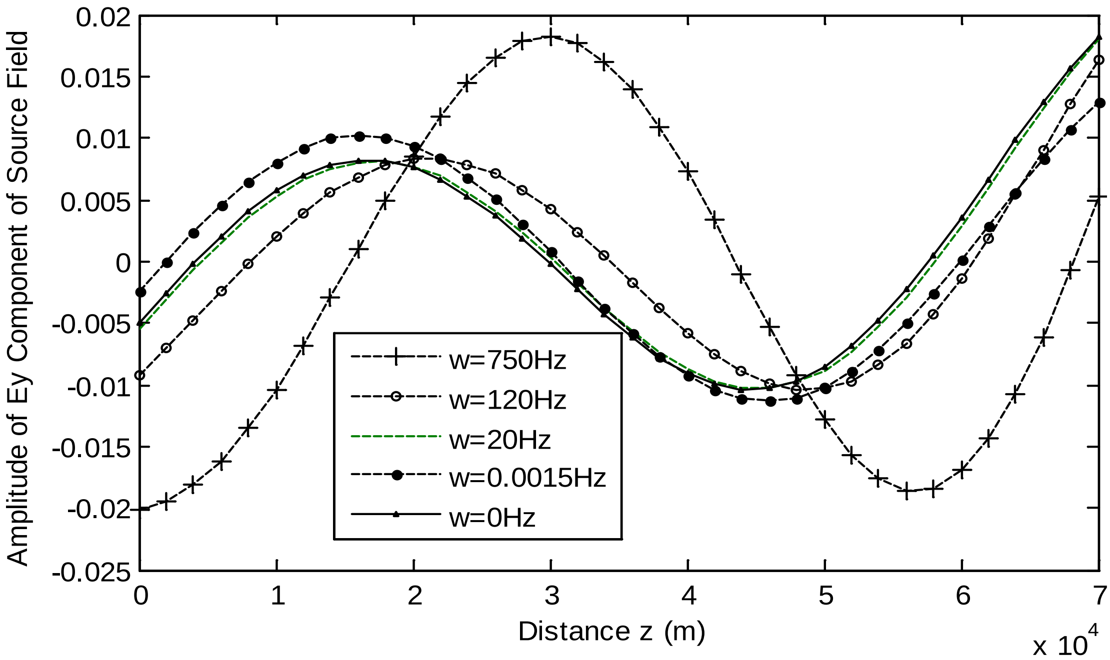

Figure 3. Graph of Amplitude of Ey Component of source Field in Space-Frequency Domain vs Distance at w=750,150,20,0.0015 (Hz)

4.1. The Response Curves

The response R in equation (34) was computed for 5 different conductivities of $\sigma_1(10^{-4}, 10^{-3}, 10^{-2}, 10^{-1}\text{mhos/m})$ and 3 conductivities $\sigma_2(10^{-8}, 10^{-4}$ and $1 \text{ mhos/m})$ for depth of 0-10,000 m respectively. We resolved to have the value of γ as indicated in table 1 so that appreciable amplitude of the waves in each of the earth layers can be obtained. Figure 4 shows the response at the surface for conductivity $\sigma_1(10^{-2}\text{mhos/m})$, conductivity $\sigma_2(10^{-4})$ and depth 7500 meters for the first layer and 8000 meters for the second layer. Again, this is measured across the low latitude region. This curve is symmetrical about the center mark zero.

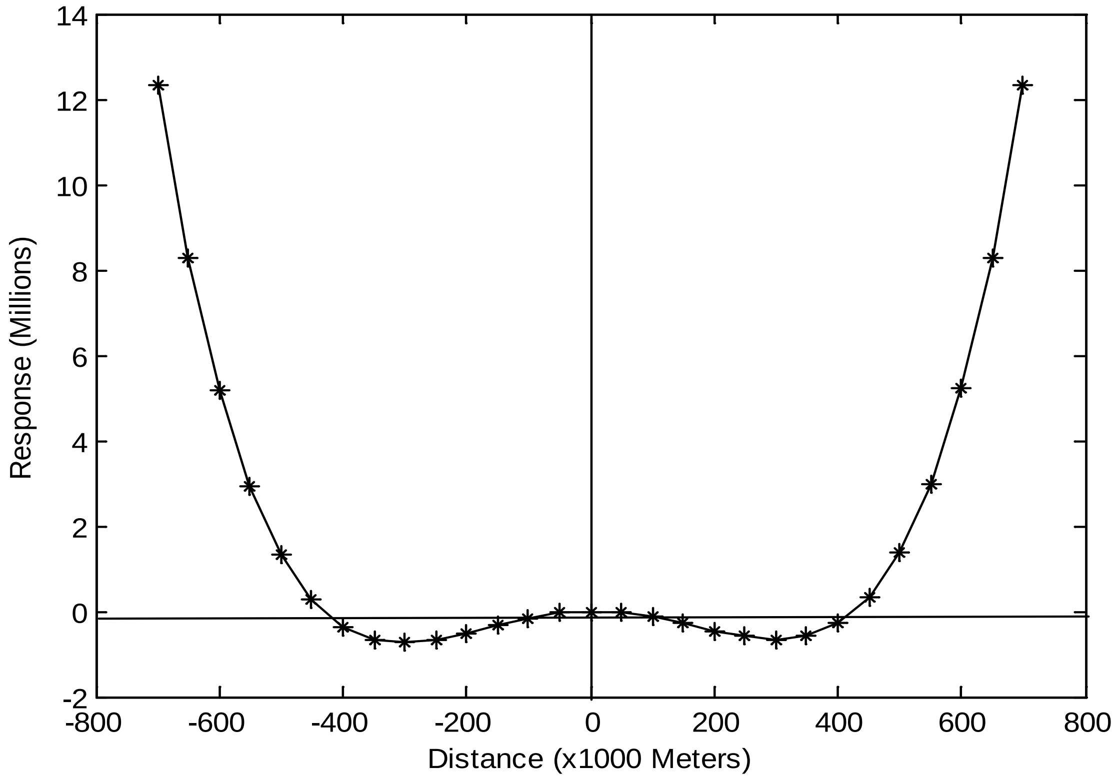

Figure 4. Variation of Response with Dostance

Figure 5 shows two the functional fits, for the response curves of E_y component. The first response curve marked A is the response curve obtained at three conductivity values, $\sigma_1 = 10^{-4}$, $\sigma_1 = 10^{-1}$ and 1 mhos/m. and at two different frequencies (0.0015 H_z and 550 H_z) for a depth of $z = 100\ m$. The three curves are plotted differently but assume this same form. Also, the response curve for this same component, at frequencies (0.0015 Hz and 550 Hz), for a depth of $z = 100\ m$ and conductivity $\sigma_1 = 10^{-4}$ is presented as curve B. The two curves (A and B) do not show any appreciable difference in shape. Curve B shows that a geo-physical structure could be predicted at about a depth of 800 meters because of the sudden change in direction of the curve.

Figure 6 shows the response variation with depth, z=1000m and respectively at frequencies 550 H_z. The conductivity used at this instance was $\sigma = 10^{-1}$. One geo-physical feature which is obtainable from Figure 6 is a fault at about 7000 m.

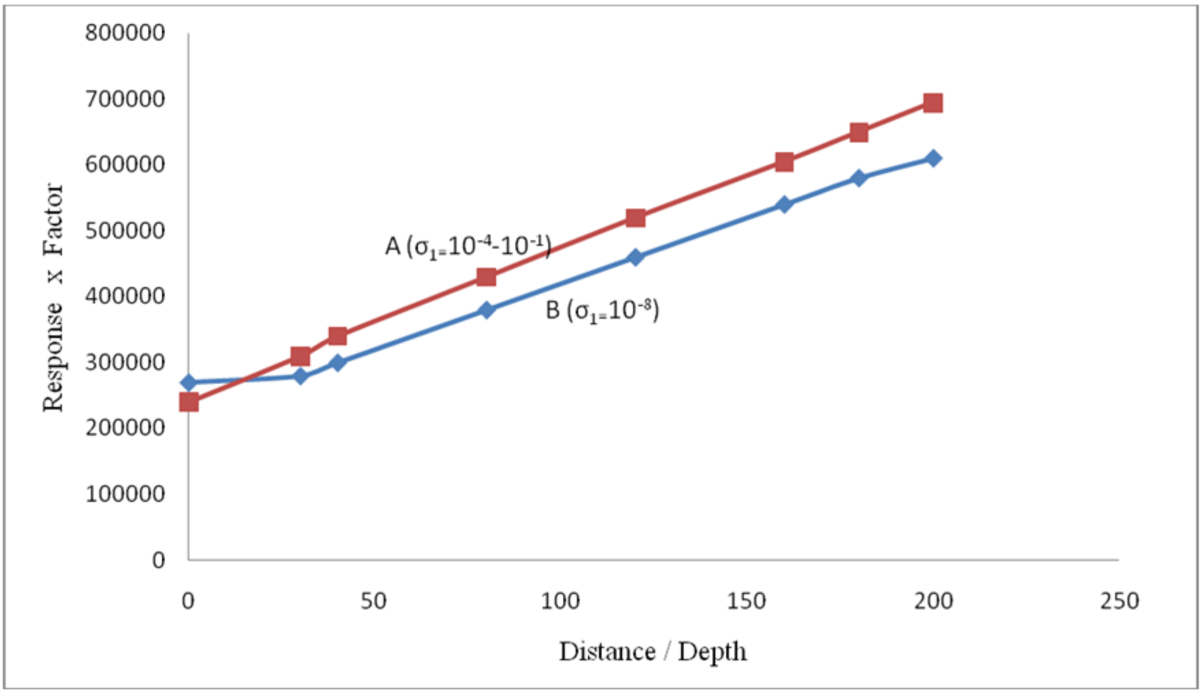

Figure 5. Variation of Response with Distance

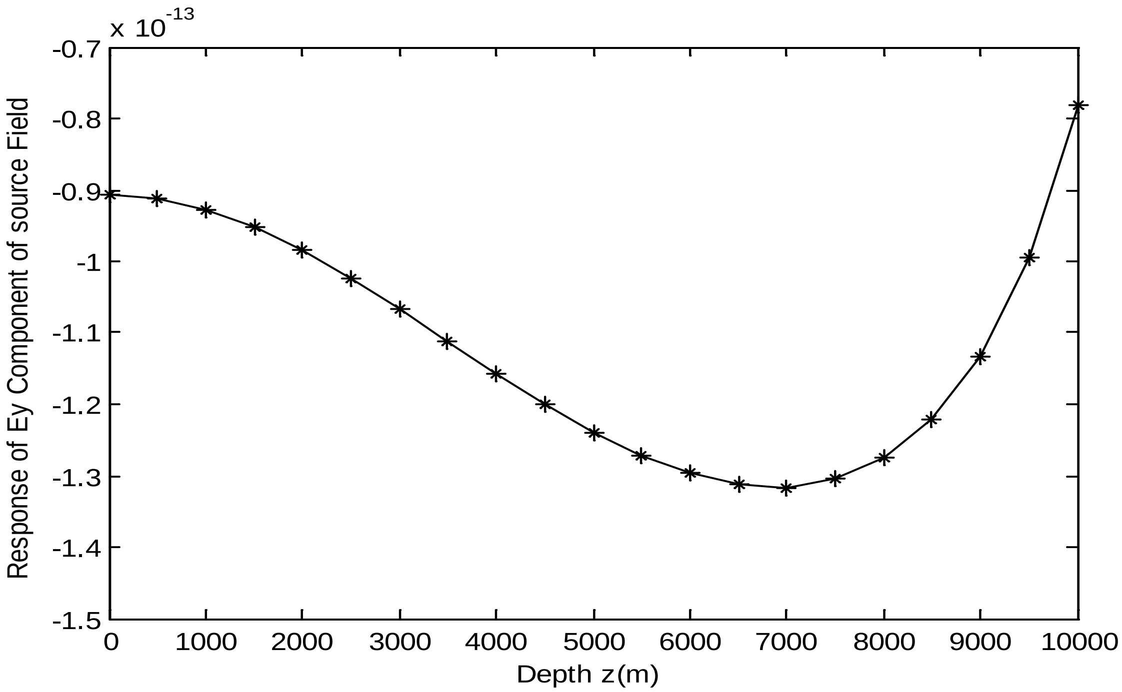

Figure 6. Graph of Response of Ey Component of source Field in Space-Frequency Domain vs Depth z(km) at w=550 Hz

5. Conclusion

We have set out to find out major geo-physical features that may be obtained when the inducing electromagnetic field is expressed in space frequency-domain. Our investigations have shown that one prominent geo-physical feature which may be obtained is a fault. The results obtained within the fundamental concept of the inducing electromagnetic field in low latitude as developed in this study indicate that the source field here when expressed in space-frequency domain approach can exposed more geo-physical features at a very great depth within the earth.

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Appendix C 1

b= $\rho / 2\varepsilon$, $m_{11} = m_6 \cos(\gamma H_1 + wH_1 / a_0) - m_7 \sin(\gamma H_1 + wH_1 / a_0)$, $m_1 1 = +b + \gamma z$

$m_2 = \gamma(1+b) - \gamma a_0$, $m_3 = 1 + (\gamma a_0)^2$, $m_{12} = m_7 \cos(\gamma H_1 + wH_1 / a_0) + m_6 \sin(\gamma H_1 + wH_1 / a_0)$

$m_4 = m_1 \cos\gamma z + m_2 \sin\gamma z$, $m_5 = m_2 \cos\gamma z + m_1 \sin\gamma z$, $m_6 = m_4 - m_5(\gamma a_0 + w)$

$m_7 = m_5 - m_4(\gamma a_0 + w)$, $m_8 = m_3(1 + (\gamma a_0 + w)^2)$, $m_9 = m_4 + m_5(\gamma a_0 - w)$

$m_{10} = m_5 - m_4(\gamma a_0 + w)$, $m_{13} = m_9 \cos(\gamma H_1 - wH_1 / a_0) - m_{10} \sin(\gamma H_1 - wH_1 / a_0)$

$m_{14} = m_{10} \cos(\gamma H_1 - wH_1 / a_0) + m_9 \sin(\gamma H_1 - wH_1 / a_0)$

Appendix C 2

$c_1 = a_0\gamma$; $c_2 = 1 - b$; $c_3 = 1 + b$; $c_4 = c_1 - c_2 a_0 \gamma$; $c_5 = c_2 + c_1 a_0 \gamma$; $c_6 = c_3 - c_1 a_0 \gamma$; $c_7 = c_3 a_0 \gamma + c_1$;

$c_8 = (1+(a_0\gamma + w)^2)$; $q_1 = 1-b+(a_0\gamma)^2$; $q_2 = (1-b)a_0\gamma - a_0\gamma$; $q_3 = (1-b)-(a_0\gamma + w)a_0\gamma$; $q_4 = (1-b)(a_0\gamma + w) + a_0\gamma$;
$q_5 = (1-b)+(a_0\gamma - w)a_0\gamma$;
$q_6 = (1+b)(a_0\gamma + w) - a_0\gamma$; $q_7 = (1+(a_0\gamma + w)^2)$; $s_1 = 1-(a_0\gamma + w)a_0\gamma$; $s_2 = 2a_0\gamma - w)$;
$s_3 = 1+(a_0\gamma - w)a_0\gamma$; $s_4 = 2a_0\gamma + w)$; $s_5 = c_8(s_3{}^2 + s_4{}^2)\sqrt{(H_1{}^2 - z^2)/a_0}$; $s_8 = c_4 s_1 - c_5 s_2$; $s_6 = c_8(1+(a_0\gamma - w)^2)$;
$s_7 = c_8(1+(a_0\gamma + w)^2)$; $s_9 = c_4 s_2 - c_5 s_1$; $s_{10} = c_4 + c_5(\gamma a_0 - w)$;
$s_{11} = c_5 + c_4(\gamma a_0 - w)$; $s_{12} = c_6 s_3 - c_7 s_4$; $s_{13} = c_7 s_3 - c_6 s_4$; $s_{14} = c_6 - c_7(\gamma a_0 + w)$;
$s_{15} = c_7 + c_6(\gamma a_0 + w)$; $s_{16} = (s_9 \cos\gamma z + s_8 \sin\gamma z)\cos(\gamma H_1 - wH_1/a_0)$; $s_{161} = (s_8 \cos\gamma z + s_9 \sin\gamma z)$;
$s_{17} = (s_8 \cos\gamma z - s_9 \sin\gamma z)\sin(\gamma H_1 - wH_1/a_0)$;
$s_{18} = s_{10}\sin(\gamma z - wH_1/a_0) + s_{12}\cos(\gamma z - wH_1/a_0)$; $s_{21} = s_{13}\cos\gamma z + s_{12}\sin\gamma z$; ;
$s_{19} = (s_{12}\cos\gamma z + s_{13}\sin\gamma z)\cos(\gamma H_1 + wH_1/a_0)$; $s_{22} = s_{14}\cos(\gamma H_1 + H_1 w/a_0)$
$s_{20} = (s_{12}\sin\gamma z + s_{13}\cos\gamma z)\sin(\gamma H_1 + wH_1/a_0)$; $s_{23} = s_{15}\sin(\gamma H_1 + H_1 w/a_0)$

Appendix C 3

$Q_1 = \sigma_2\sigma_1\rho_0\varepsilon_1\varepsilon_2 H_{-1z}H_{+0x}H^z_{-1x}(1+\sigma_2)$; $Q_2 = \sigma_1\rho_0\varepsilon_0\varepsilon_1 H_{-1z}H^z_{-1x}(H^z_{-0x} - H^x_{-0z})$;
$Q_3 = H_{-0z}\sigma_2\sigma_1\varepsilon_1\varepsilon_0 H_{-0x}H_{-1z}H^z_{+0x}$; $Q_4 = \sigma_1\rho_0\varepsilon_1 H_{+0x}H_{-1z}H_{-1x}H^x_{-1z}(\varepsilon_1 H_{-1z}H^x_{P0z} - \varepsilon_1 H_{-1z}H^z_{-ox} + \sigma_1\varepsilon_0 H_{-0z})$;
$Q_5 = \sigma_2\sigma_1\varepsilon_2 H^x_{-1z}\sigma_2 H_{-1x}H^z_{-2x} - H_{-2x}H^z_{-0x} + 2H_{-2x}H^z_{-1x}$; $Q = (Q_1 + Q_2 + Q_3 + Q_4)/Q_5$