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Comparison of various dimensionality methods on the Sabalan magnetotelluric data

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ABSTRACT

Dimensionality of MT data is a powerful tool that selects which type of approach is more suitable to accomplish the modeling, or interpretation: one dimensionality, two dimensionality or three dimensionality. Moreover, dimensionality analysis can be a tool to determine whether data are affected or not by local heterogeneities. In this paper, a part of the Sabalan geothermal field in the NW of Iran was selected as a test area to determine the dimensionality models. Different methods were used to assess the structural dimensionality of the electrical conductivity of the earth and identify distortions from observed data. A comparison has been made between the results of the methods and the main limitations existing in dimensionality characterization were discussed. The analysis of all sites in the Sabalan area using various methods indicates the electrical conductivity structure is less complex at the shallowest depths, with mixed 1D and 2D cases that are affected by galvanic distortion, whereas at middle and lower depths, dimensionality is mainly 3D. The dimensionality of the underlying conductivity distribution coincide with the known geological evaluations in the study area.

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1. Introduction

The spatial distribution of the electrical conductivity known as geoelectrical dimensionality, which can be organized as 1D, 2D and 3D structures. In a 1D Earth, the conductivity varies only with depth. In a 2D Earth, the conductivity is fixed along one horizontal direction (this direction is strike) while altering along the other horizontal directions and the vertical direction and in a 3D Earth, the conductivity distribution differs along all directions (Marti, 2006). The common representation of the magnetotelluric impedance tensor (z) is denoted as follows (Cantwell, 1960):

\[
z = \begin{pmatrix} z_{xx} & z_{xy} \\ z_{yx} & z_{yy} \end{pmatrix}
\]  

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The diagonal components of the impedance contain the information on lateral conductivity while its off-diagonal components indicate mainly the vertical conductivity effects (Berdichevsky, 1999). For all horizontal rotations of the coordinate system, in a 1D Earth the diagonal components of impedance tensor are zero, while the non-diagonal components are equal in modulus but with opposite signs. When one of the measurement axes coincides with the strike direction of structure, in a 2D Earth, the diagonal components of impedance vanish to zero, while the non-diagonal components differ. There is no strike direction for a 3D Earth, Nevertheless it has become customary to assess the direction that minimizes the diagonal components and maximizes the non-diagonal components of impedance tensor. In a 3D Earth, all the components of impedance tensor never vanish for any direction (Caldwell and Savit, 1988). In nature, because of distortions or 3D induction, diagonal components of impedance tensor are not zero. Thus, it is not possible to discriminate the type of the regional structure and to determine whether data are affected by galvanic distortion or not. The dimensionality analysis should be carried out to obtain such information (Naidu, 2012).

Most of the dimensionality methods are based on the rotational invariants of impedance tensor and different collections of rotational invariants have been introduced to assert specific categories of the dimensionality (Martí, 2006). Many authors have used the rotational invariants of impedance tensor to obtain information about the geoelectrical structures (Swift, 1967; Bahr, 1991; Szarka and Menvielle, 1997; Weaver et al., 2000). Other authors have introduced the graphical representations of function of components for a dimensionality interpretation (Berdichevsky, 1968; Sims and Bostic, 1969, Lilley, 1976). In some methods, the geomagnetic transfer function was utilized to characterize the dimensionality of the Earth (Parkinson, 1962; Romo et al., 1999) and more recently, Caldwell et al. (2004) suggested the phase tensor to acquire information about the dimensionality of the regional structures, because it is unaffected by local heterogeneities.

In this paper we applied different methods for dimensionality analysis of the Sabalan area in NW of Iran. The choice of the several methods is due to the fact that they use all the information from the MT data and provide a dimensionality description not limited to a particular model. Examples from four sites of the Sabalan area (sites 111, 203, 210 and 211) is presented (Fig. 1) and discussed.

2. Sabalan geothermal field

The area of study lies at the NW of Mt. Sabalan in Ardabil province at the NorthWest of Iran. The Sabalan area is the most interesting location of Iran for Geothermal activities due to occurrence of hot spring. The area has been extensively studied since 1978. Fig. 1 shows the geological map of the Northwest of Sabalan and the location of selected MT sites. Mt. Sabalan is underlain mostly by intrusive and effusive volcanic rocks. In relation to the original geological evolution, the Northwest of Sabalan has been divided into four major units: Lacustrine, fan and terrace deposits related to Quaternary age, post-caldera trachy-andesitic flows related to Pleistocene age, Pleistocene syn-caldera trachy-dacitic to trachy-andesitic domes and Pliocene pre-caldera trachy-andesitic pyroclastic, tuffs and lavas (SKM, 2005; Noorollahi et al., 2008; Ghaedrahmati et al., 2013).

MT survey was carried out by the EDC at 78 sites in 2007 and 2009 to identify probable center of the resource and to determine drilling targets for the development of geothermal energy purposes. Final analysis of MT data sets shows a hot zone, east of Well Pad D (Fig. 1), postulated to be the heat source for the Northwest of the Sabalan area (Ghaedrahmati et al., 2013).

3. Traditional parameters

Different Sets of dimensionality parameters can be defined as a function of traditional parameters of impedance tensor. Traditional parameters in terms of trace, determinant and non-diagonal components of impedance can be obtained (Vozoff, 1991; Szarka and Menvielle, 1997):

\[ z_1 = \frac{z_{xy} - z_{yx}}{2} = \frac{z_{xx}(\theta) - z_{yy}(\theta)}{2} \quad (1) \]

Fig. 1. A geological map of the NW of Sabalan geothermal field in Iran. Station numbers are shown for selected sites.
\[ z_2 = \frac{z_{xx} + z_{yy}}{2} = \frac{z_{xx}(\theta) + z_{yy}(\theta)}{2} \]  
\[ \text{det}(z) = z_{xx}z_{yy} - z_{xy}z_{yx} \]  
\[ z_3 = \frac{z_{xy}(\theta) + z_{yx}(\theta)}{2} \]  
\[ z_4 = \frac{z_{xx}(\theta) - z_{yy}(\theta)}{2} \]  

As these definitions emphasize, \( z_1, z_2 \) and \( \text{det}(z) \) are rotational invariant whereas \( z_3 \) and \( z_4 \) are not. (Fischer and Masero, 1994). The applications of these parameters has been shown in next sections.

3.1. Skew and Ellipticity

Skew and Ellipticity are defined as the ratio of the diagonal components to non-diagonal components of impedance tensor. Skew is obtained by the expression (Swift, 1967; Sims and Bostic, 1969):

\[ S = \left| \frac{z_{xx} + z_{yy}}{z_{xy} - z_{yx}} \right| = \frac{|z_2|}{|z_1|} \]  

and Ellipticity is expressed as:

\[ E = \left| \frac{z_{xx} - z_{yy}}{z_{xy} + z_{yx}} \right| = \frac{|z_4|}{|z_3|} \]  

Since any function of the invariants is rotational invariant, so Skew will be rotational invariant but Ellipticity will be changed with rotation (Caldwell et al., 2004). Skew and Ellipticity are zero, where electrical conductivity structure is 1D or 2D (in noise-free data) and they will be greater than zero (usually greater than 0.3) for 3D structures. However small values of Skew and Ellipticity can also be observed in 3D structures which means that the values of Skew and Ellipticity are not unique. Another problem of the Skew and Ellipticity is that they do not account for the influence of local heterogeneities (Kao and Orr, 1982).

Fig. 2 shows variation of the Skew and Ellipticity for sites 111, 203, 210 and 211. Selected sites have Skew and Ellipticity values below 0.3 for frequencies above 1 Hz. This behavior is consistent with 1D or 2D structures.

The values of Skew and Ellipticity within the range \( 1\times10^{-3} \) Hz are generally greater than 0.3 at selected sites except at some frequencies below 1 Hz. Great value of Skew and Ellipticity (greater than 0.3) indicates the structures are approximately 3D at corresponding frequencies.

3.2. Normalized Dimensionality Weights

Past parameters appears to be simply contaminated by noise and as noise is unavoidable in the observed data it makes unsure parameters with which to assess the dimensionality of the structures. For this reason, normalized dimensionality weights have been introduced to estimate the dimensionality of the Earth. This technique uses the amplitude of \( z_1, z_2, z_3 \) and \( z_4 \) to represent the relative weights of the geoelectric dimensionality and \( D_1, D_2, D_3 \) show the weights of 1D, 2D and 3D structures respectively (Kao and Orr, 1982):

\[ D_1 = |z_1|/\gamma \]
Component and the horizontal magnetic components. The linear combination are described as follows (Parkinson, 1962):

\[ T = (T_{zx}^2 + T_{zy}^2)^{\frac{1}{2}} \]

Induction arrows are a graphical representation of the geomagnetic transfer functions (Parkinson, 1962; Lezaeta, 2001):

\[ T = T_{zx}\hat{x} + T_{zy}\hat{y} \]

Which is separated into its real and imaginary parts. The length (\(L\)) and direction (\(\lambda\)) of the induction arrows are expressed as follows (Lezaeta, 2001):

\[ L = \sqrt{\text{Re} T_{zx}^2 + \text{Im} T_{zy}^2} \]

\[ \lambda = \tan^{-1} \left( \frac{\text{Re} T_{zy}}{\text{Re} T_{zx}} \right) \]

In the Parkinson conventional, the real parts of induction arrows point away from areas of low conductivity and towards areas of higher conductivity at sufficiently low frequencies (Berdichevsky and Dmitriev, 2008). In a 2D Earth the induction arrows are oriented perpendicular to the regional strike. Tipper and induction arrows can be affected by galvanic distortion like past parameters (Lezaeta, 2001).

Fig. 3. The variation of \(D_1\), \(D_2\) and \(D_3\) dimensional factors with frequency for measurement sites. A. Site 111; B. Site 203; C. Site 210; D. Site 211.
The shape and configuration of polar diagrams can be associated with the dimensionality of geological structures. Upon rotation of measuring axes clockwise by angle \( \alpha \), the new components are introduced (Eggers, 1982):

\[
\begin{align*}
z'_{xx} &= z_2 + z_1 \sin(2\alpha) + z_4 \cos(2\alpha) \\
z'_{xy} &= z_1 + z_3 \cos(2\alpha) - z_4 \sin(2\alpha)
\end{align*}
\]

As \( \alpha \) changes between 0 and \( 2\pi \), plotting the amplitude of \( z'_x \) and the amplitude of \( z'_y \) on new x axis defines closed curves known as impedance polar diagrams (Berdichevsky, 1968; Berdichevsky and Dmitriev, 2008).

For a 1D Earth the diagrams of the amplitude of \( z_{x0} \) degenerate into a point while the diagrams of amplitude of \( z_{x0} \) are circles. In a 2D Earth the diagrams of \( |z_{x0}| \) are similar to a flower with four petals and the diagram of \( |z_{x0}| \) has the form of a regular oval. For 3D resistivity structures, diagrams of \( |z_{x0}| \) and \( |z_{y0}| \) look like oblique eight figure and \( |z_{x0}| \) becomes comparable to \( |z_{y0}| \). There is not the limitation of threshold value in polar diagrams but they are perturbed by the errors in data responses (Green, 2003).

Polar diagrams, Induction arrows and Tipper strike from just two of the sites (111 and 211) are shown in Figs. 4 and 5, as examples. In Figs. 4 and 5, at frequencies above 1 Hz, \( |z_{x0}| \) has been elongated in a parallel or perpendicular direction to strike and \( |z_{y0}| \) has attained the shape of a flower, indicating that the data are closely 2D. Small magnitude of induction arrows and also no significant variation of their directions show an agreement with polar diagrams for this rang of frequency. Eight figure of \( |z_{x0}| \) and \( |z_{y0}| \) at frequencies lower than 1 Hz, and big amplitude of \( z_{x0} \) suggest either the influence of 3D effects or noise in data. At low frequencies, the variety in the directions of the induction arrows confirms the complexity of underground structures.

### 3.4. Mohr diagrams

Mohr diagrams originally used in the analysis of shear stress, normal stress and strain in a body (Lilley, 1993a). This technique is of general application in describing tensor information by diagrams and was initially introduced for the magnetotelluric data in Lilley (1976). Upon rotation of the measuring axes by angle \( \theta' \), the new components of impedance tensor are related to the first, by the following equations (Lilley, 1998):

\[
\begin{align*}
z'_{xx} &= \frac{(z_{xx} + z_{xy})}{2} + C \sin(2\theta' + \beta) \\
z'_{xy} &= \frac{(z_{xy} + z_{yx})}{2} + C \sin(2\theta' + \beta) \\
z'_{yx} &= \frac{(z_{yx} + z_{xy})}{2} - C \sin(2\theta' + \beta) \\
z'_{yy} &= \frac{(z_{yy} + z_{yx})}{2} + C \sin(2\theta' + \beta)
\end{align*}
\]

Where \( \beta \) is defined by:

\[
\tan \beta = \frac{z_{xx} - z_{yy}}{z_{xy} + z_{yx}}
\]

![Fig. 4. Impedance polar diagrams, Tipper strike and induction arrows for site 111 in the Sabalan area. Thick lines show \( z_{xx} \) element and thin lines show \( z_{yy} \) element. Intersected lines are Tipper strike and induction arrows. Notably the length of tipper strike is longer than induction arrows in figure.](image)

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Fig. 6. Real part of Mohr circles for four sites of the Sabalan magnetotelluric data set. Each tensor component has been scaled by multiplication by the square root of period, to produce the plot of compact circles. The radial arms is indicated for each circle. A. Site 111; B. Site 203; C. Site 210; D. Site 211.

Fig. 5. Impedance polar diagrams, Tipper strike and induction arrows for site 211 in the Sabalan area. Thick lines show $z_{xx}$ element and thin lines show $z_{xy}$ element. Intersected lines are Tipper strike and induction arrows. Notably the length of tipper strike is longer than induction arrows in figure.
At first all components should be normalized by multiplication by 
the square root of period. Plotting \( z_{xx} \) against \( z_{xy} \) as the axes are rotated 
(by angle \( \theta \)) generates circles known as Mohr diagrams. The center of 
Mohr circles is at the point (Lilley, 1993b):

\[
\begin{align*}
Z'_{xy} & = \frac{1}{2} (Z_{xy} - Z_{yx}) \\
Z'_{xx} & = \frac{1}{2} (Z_{xx} + Z_{yy})
\end{align*}
\]

And the radius of Mohr circles is given by:

\[
\begin{align*}
C & = \frac{1}{2} \left[ (Z_{xx} - Z_{yy})^2 + (Z_{xy} + Z_{yx})^2 \right]^{\frac{1}{2}}
\end{align*}
\]

Where the subscript \( r \) denotes the real part of impedance components. Circles similar to the real part of impedance tensor can be drawn for the imaginary part of components. The radial arm drawn from the center of circle to the observed point can be traced for evidence of strike direction. For one dimensionality, Mohr diagram is a point on the horizontal axis. For 2D structures Mohr circles are centered on the horizontal axis but have a certain radius. In a 3D Earth, the center of Mohr circles does not lie on the horizontal axis (Lilley, 1993b). The weakness of the Mohr circles is that the real and imaginary parts of impedance tensor can lead toward different interpretation in some cases (Fischer and Masero, 1994).

Figs. 6 and 7 shows Mohr circles for sites 111, 203, 210 and 211 at frequency ranges (0.0011–0.0092, 0.107–0.860, 1.02–9.4, 11.2–97, 115–320 Hz). At high and middle frequencies the center of circles are near the horizontal axes and non-zero radius of circles, indicating that the data are approximately 2D in both real and imaginary sets of circles.

At low frequencies, the data set exhibits 3D behavior of the Earth or noise in the observed data, with circle centers above or below the horizontal axes. Radial arms clearly show the variation of strike direction in different frequencies.

3.5. Bahr parameters

Bahr method categorizes the types of dimensionality and distortion types that can influence it. Bahr rotational invariants are derived from the traditional parameters (Bahr, 1991):

\[
\begin{align*}
s & = \frac{Z_2}{Z_1} \\
\Sigma & = \frac{(Z_2^2 + Z_1^2)}{Z_1^2} \\
\mu & = \frac{(Z_4 Z_3 + Z_2 Z_1)^{\frac{1}{2}}}{|Z_1|} \\
\eta & = \frac{(Z_4 Z_3 - Z_2 Z_1)^{\frac{1}{2}}}{|Z_1|}
\end{align*}
\]

\( s \) is the skew parameter and \( \Sigma \) is related to the dimensionality of 2D structures. \( \eta \) or regional skew shows the distortions and determines the 3D structures. \( \mu \) is a quantity of the phase difference between the components of impedance tensor (Bahr, 1991). Threshold values of Bahr parameters are summarized in Table 1. The use of only 4 parameters in Bahr method is a significant problem in specifying...
dimensionality and the method may fail in some cases (Ledo et al., 2002; Marti et al., 2005). Plots of Bahr parameters for sites 111, 203, 210 and 211 are shown in Fig. 8. Invariant $s$ shows values near zero at frequencies greater than 1 Hz, a clear indication of 1D or 2D structures in observed data. Further, $\Sigma$ also shows values smaller than 0.1 at frequencies greater than 1 Hz, indicating absence of 2D structures. At frequencies lower than 1 Hz, $s > 0.1$ and $\eta > 0.3$. Therefore, the regional conductivity distribution is
approximately 3D. A value above 0.1 and zero value of $\mu$ depict galvanic distortions over 1D structures for some medium frequencies.

3.6. Phase tensor

Phase tensor maintains the regional phase information where galvanic effects made by localized heterogeneities distort the regional responses. Impedance tensor can be separated into a real and imaginary part:

$$\mathbf{Z} = \begin{pmatrix} Z_{xx} & Z_{xy} \\ Z_{yx} & Z_{yy} \end{pmatrix} = \begin{pmatrix} \text{Re}Z_{xx} & \text{Re}Z_{xy} \\ \text{Re}Z_{yx} & \text{Re}Z_{yy} \end{pmatrix} + i\begin{pmatrix} \text{Im}Z_{xx} & \text{Im}Z_{xy} \\ \text{Im}Z_{yx} & \text{Im}Z_{yy} \end{pmatrix}$$

Fig. 9. Phase tensor plotted as function of frequency for sites 111, 203, 210 and 211 (A) arctangents of singular values of phase tensor onto a plot of the TM and TE mode phases. (B) phase tensor Skew angle $\beta$. 

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Table 1

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Dimensionality/distortion type</th>
</tr>
</thead>
<tbody>
<tr>
<td>S &lt; 0.1</td>
<td>1D</td>
</tr>
<tr>
<td>S &gt; 0.1</td>
<td>2D</td>
</tr>
<tr>
<td>µ &lt; 0.05</td>
<td>3D/1D</td>
</tr>
<tr>
<td>µ &gt; 0.05</td>
<td>3D/2D</td>
</tr>
<tr>
<td>η &gt; 0.3</td>
<td>3D</td>
</tr>
</tbody>
</table>

Written in terms of the real and imaginary part of impedance tensor the phase tensor can be written as the matrix (Caldwell et al., 2004):

\[
\Phi = \begin{bmatrix}
\psi_{xx} & \psi_{xy} & \Re z_{xy} & \Im z_{xx} \\
\psi_{yx} & \psi_{yy} & \Re z_{yy} & \Im z_{yx} \\
\Re z_{xy} & \Re z_{yy} & \Re z_{xx} & \Re z_{yy} \\
\Im z_{xx} & \Im z_{yx} & \Im z_{xy} & \Im z_{yy}
\end{bmatrix}
\]

(33)

In phase tensor we will use three rotational invariants to obtain a description of the dimensionality (\(\psi_{\text{max}}, \psi_{\text{min}}\) and \(\beta_p\)). By using singular value decomposition of phase tensor, dimensionality parameters are given by the expressions (Caldwell et al., 2004):

\[
\beta_p = \frac{1}{2} \tan^{-1} \left( \frac{\psi_{xy} - \psi_{yx}}{\psi_{xx} + \psi_{yy}} \right)
\]

(34)

\[
\psi_1 = \frac{\psi_{xx} + \psi_{yy}}{2}
\]

(35)

\[
\psi_2 = \psi_{xx} - \psi_{yy}
\]

(36)

\[
\psi_3 = \frac{\psi_{xy} - \psi_{yx}}{2}
\]

(37)

\[
\psi_{\text{min}} = (\psi_1 + \psi_2)^{\frac{1}{2}} - (\psi_1 - \psi_2)^{\frac{1}{2}}
\]

(38)

\[
\psi_{\text{max}} = (\psi_1 + \psi_2)^{\frac{1}{2}} + (\psi_1 - \psi_2)^{\frac{1}{2}}
\]

(39)

Where \(\beta_p\) (phase tensor skew) is zero and \(\psi_{\text{max}}\) and \(\psi_{\text{min}}\) have same values, conductivity distribution is 1D. For 2D structures, \(\beta_p = 0\) and \(\psi_{\text{max}}\) and \(\psi_{\text{min}}\) are different, it is notable \(\beta_p = 0\) is a necessary condition but not sufficient. Only where analysis illustrates that \(\beta_p\) is unimportant for all frequencies greater than some minimum value can we deduce that conductivity distribution is 2D, and thus that observed data have been distorted by local heterogeneities. Moreover for 1D and 2D structures, singular values are calculated by the tangents of conventional TM and TE mode phases. In a 3D Earth, \(\beta_p\) will have a non-zero value. It should be noted difference between singular values and TM and TE mode phases depict presence of 3D structures (Caldwell et al., 2004). Disadvantage of phase tensor is that under noise effects and extreme distortions the parameters of phase tensor become unstable and the distortion-invariance feature is not true (Marti, 2006).

In Fig. 9, we have plotted the phase tensor features as function of frequency for 4 of the sites shown in Fig. 1. As shown in Fig. 9, \(\psi_{\text{max}}\) and \(\psi_{\text{min}}\) are generally equal to each other at frequencies > 10\(^2\), so we deal with 1D structures at high frequencies of the selected sites. For sites 111 and 211 at frequencies between 10\(^1\) and 10\(^3\) Hz and for sites 203 and 210 from 10\(^2\) to 10\(^3\) Hz, the differences between the singular values and TE and TM mode phases are small, indicating that the conductivity distribution is approximately 2D. Significant Differences between singular values and the TM and TE mode phases implying that regional conductivity structure is 3D in neighborhood of these 4 stations. The values of \(\beta_p\) verify this inference.

3.7. WALDIM code

Weaver et al. (2000) presented a dimensionality study based on the eight invariants of the MT tensor (WAL hereafter). WALDIM program automatically obtain the dimensionality analysis from a set of MT data, based on WAL criteria while considering the level of noises in data. By replacing magnetic field instead of magnetic intensity in Eq. (1) and using traditional parameters, WAL parameters are defined as follows (Weaver et al., 2000):

\[
I_1 = \left( (\Re z_1) + (\Re z_2) \right)^2
\]

(40)

\[
I_2 = \left( (\Im z_1) + (\Im z_2) \right)^2
\]

(41)

\[
I_3 = \frac{(\Re z_1)^2 + (\Re z_2)^2}{I_1}
\]

(42)

\[
I_4 = \frac{(\Im z_1)^2 + (\Im z_2)^2}{I_2}
\]

(43)

\[
I_5 = \frac{(\Re z_1)(\Re z_2) + (\Im z_1)(\Im z_2)}{I_1 I_2}
\]

(44)

\[
I_6 = \frac{(\Re z_1)(\Re z_2) - (\Im z_1)(\Im z_2)}{I_1 I_2}
\]

(45)

\[
I_7 = \frac{(I_6 - I_5)}{Q}
\]

(46)

\[
Q = \left[ (I_6 - I_5)^2 + (I_5 + I_6)^2 \right]^{\frac{1}{2}}
\]

(47)

The dimensionality information given by WAL parameters and the threshold values are summarized in Table 2. The main problem of WAL parameters is that the invariants are rarely zero. This problem was solved by introducing the threshold value (0.1), the threshold value was checked using a synthetic model with 2% noise. Since, real data have a higher value of error it was necessary to express a new threshold value. The new threshold value is between 0.1 and 0.2 for I3-17 and 0.1 for Q, dimensionality analysis will be well determined with new threshold value when relative errors in off-diagonal components are lower than 30%. For high error levels (but lower than 30%) and low values of the threshold related to \(I_7\), the dimensionality will be underdetermined in some cases. (Marti et al., 2009).

Table 3 shows the results of WALDIM code for representative sites for a pattern of 6 frequency bands. The Results of WALDIM code indicate that geomorphological dimensionality is commonly 3D for low frequencies up to 0.86 Hz; and 1D or 2D with some local 3D heterogeneities in high frequencies down to 11.2 Hz. Underdetermined dimensionality in some low frequencies depict high percentage of data errors.

4. Comparison

Skew, Ellipticity, Tipper and normalized dimensionality parameters do not present an absolute measure of dimensionality. Furthermore, they can be affected by distortions and the threshold value of them has not been clearly defined. The results of Polar diagrams and Mohr circles are dependent upon the values of the impedance components and their errors which can lead to incorrect hypothesis in interpretation of the observed data. In spite of Caldwell’s criteria, the effects of noise...
and extreme galvanic distortions lead to significant difference with respect to the regional structures. Among of used dimensionality methods only Bahr parameters and WALDIM method can discriminate between 3D induction and small scale 3D galvanic distortion (2D regional structures) nevertheless Bahr parameters is failed in some special cases. It is notable WALDIM code not only computes distortions parameters but also considers the percentage of data errors. In the light of our studies, WALDIM method seems to be more informative than any other dimensionality techniques.

5. Conclusion

This paper has used different methods to characterize the geoelectric dimensionality of 4 MT sites in the Sabalan geothermal field. The complete analysis for the full range of Sabalan sites shows the subsurface structures are 1D or 2D mixed with some near surface 3D effects at the shallowest depths, whereas at middle and lower depths, they are commonly 3D. Thus, it should be applied static shift corrections to remove the effect of distortions. The dimensionality results point at 3D inversion as the best choice to reproduce subsurface structures of the Sabalan, although some 2D models can also be built form the observed data, which may show a preview of the geoelectric structures. Comparison between the observed electrical conductivity and the geological structure of the Sabalan represents a good correlation to the geoelectric structures. Comparing with the regional structures, WALDIM method seems to be more informative than any other dimensionality techniques.

Table 2

<table>
<thead>
<tr>
<th>Case</th>
<th>WAL Values</th>
<th>Dimensionality Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$l_1 = l_2 = l_3 = 0$</td>
<td>1D</td>
</tr>
<tr>
<td>2</td>
<td>$l_1 = 0$ or $l_2 = 0$ or $l_3 = 0$</td>
<td>2D</td>
</tr>
<tr>
<td>3</td>
<td>$l_1 = 0$ or $l_2 = 0$ or $l_3 = 0$ and $\text{Im}(z_2) = 0$</td>
<td>3D/1D2D diag Galvanic distortion over 1D or 2D Earth in diagonal tensor</td>
</tr>
<tr>
<td>4</td>
<td>$l_1 = 0$ or $l_2 = 0$ or $l_3 = 0$ or $l_4 = 0$</td>
<td>3D/1D2D twist Galvanic distortion over 1D or 2D Earth (only twist)</td>
</tr>
<tr>
<td>5</td>
<td>$l_1 = 0$ or $l_2 = 0$ or $l_3 = 0$ or $l_4 = 0$</td>
<td>3D/2D Galvanic distortion over 2D Earth</td>
</tr>
<tr>
<td>6</td>
<td>$l_1 = 0$ or $l_2 = 0$ or $l_3 = 0$ or $l_4 = 0$</td>
<td>3D Galvanic distortion over 2D Earth</td>
</tr>
</tbody>
</table>

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References


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