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Different Strategies Applied to 3D Inversion of MT Data from Los Humeros Superhot Geothermal Resource in Mexico

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ABSTRACT

Within the framework of the European-Mexican project GEMex, 122 Magnetotelluric (MT) and 120 Transient electromagnetic (TEM) soundings were acquired in Los Humeros volcanic complex (Mexico), which is considered a superhot geothermal system. Both datasets were collected at the same location, and the TEM data were used for static-shift correction of the MT data. Transient responses were measured from 0.1 to 90ms with a TerraTEM device and using a 100x100m^2 single-loop configuration. Whereas MT signals were recorded with Metronix systems in the period range from 0.001 to 1000s. The dimensionality analysis of MT data suggests a 1D and 3D subsurface structure. Three-dimensional inversion of MT data was performed with ModEM software. We applied different 3D inversion schemes to the MT data, and their results were appraised. Sensitivity studies were carried out to analyze whether or not the structures derived from the 3D MT inversion are reliable. This conference paper presents results of the GEMex Project, funded by the European Union's Horizon 2020 research and innovation programme under grant agreement No. 727550, and by the Mexican Energy Sustainability Fund CONACYT-SENER, Project 2015-04-268074. More information can be found on the GEMex Website: http://www.gemex-h2020.eu

1. INTRODUCTION

Super Hot Geothermal Systems (SHGS) are geothermal reservoirs with an extremely high geothermal gradient. In Mexico, Los Humeros geothermal field is considered a SHGS. It is located in the central-eastern part of Mexico (Fig. 1). In order to investigate the geometry of the SHGS at Los Humeros, a Magnetotelluric (MT) survey was carried out in 2017 and 2018. In addition, Transient Electromagnetic (TEM) data were acquired to correct the possible static shift effect on the MT data as described by Sternberg et al. (1988) & Pellerin and Hohmann (1990). This work is part of the GEMex Project, which involves a European and Mexican consortium for investigation of a SHGS and Enhanced Geothermal System (EGS) in Mexico.

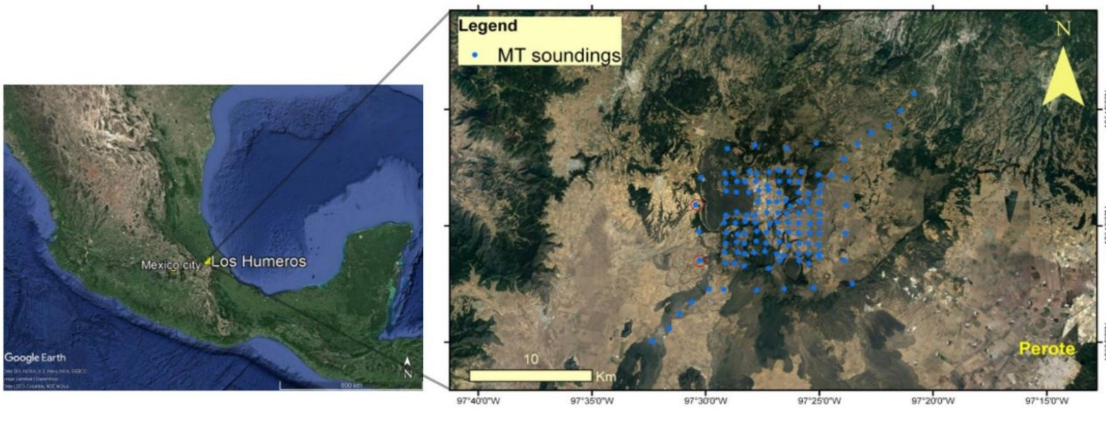

Figure 1: To the left, the location of the Los Humeros Super Hot Geothermal System is displayed. The image to the right shows the 122 MT sites. TEM measurements were deployed at the same MT locations, except for the two sites which are marked with red circles.

In this conference paper, we only present results of the 3D inversion modeling of MT data using ModEM software (Egbert and Kelbert, 2012; Kelbert et al., 2014). MT transfer functions were estimated with BIRRP (Bounded Influence Remote-Reference Processing; Chave and Thomson, 2004), a robust processing algorithm. Dimensionality analysis of MT data was performed with the phase tensors (Caldwell et al., 2004), which suggested a 1D and 3D subsurface resistivity structure. The robust processing scheme applied to the recorded MT time series, the 1D joint inversion of the TEM/MT data and 3D inversion of static shift corrected MT data using the WSINV3DMT code is discussed by Benediktsdóttir et al. (2020), whereas the phase tensor analysis will be discussed by Held et al. (2020)

2. DATA ACQUISITION

A resistivity survey was carried out in 2017 and 2018, consisting of Magnetotellurics (MT) and Transient Electromagnetic (TEM) measurements. In total, 122 spatially distributed MT soundings were carried out (Fig. 1). Additionally, 120 co-located TEM soundings were acquired in order to correct the static shift effect in MT data. The stations distribution was decided considering the locations of the geothermal surface manifestations and orientation of the geological structure. The distance between neighboring MT sites ranges from 500m to 1.5km.

The MT soundings were recorded with Metronix/ADU-07 devices. Metronix induction coils and non-polarizable Pb/$PbCl_2$ with horizontal dipole lengths of 100m were deployed. The sampling frequency was 4096Hz for 30 minutes and 128Hz for at least 20 hours. An additional MT site was deployed ~80km away from the survey area to apply remote reference processing technique (Gamble et al., 1979). TEM measurements were done with a TerraTEM device from Monex Geoscope Ltd. Transient responses were measured between a range from 0.1 to 90ms. A single loop configuration was used, where the same wire works as a receiver (Rx) while the transmitter (Tx) is off (Nabighian and Macnae, 1991). The effective area of Tx and Rx was of 100 x 100m^2.

3. THREE-DIMENSIONAL INVERSION MODELING

After robust processing the acquired MT time series and analyzing the estimated Transfer Functions, a three-dimensional inversion modeling scheme was applied using ModEM software. Prior to inversion, MT data affected by static shift were corrected using the acquired TEM data. At the current stage of our 3D inversion working flow, Vertical Magnetic Transfer Functions (VTF's) and topography have not been included yet.

3.1 Off-diagonal elements inversion

As a first approach, 3D inversion of MT data from Los Humeros was carried out only using the off-diagonal elements of the impedance tensor in order to identify which parts of the inverse model are constrained by such elements. The selection of a suitable prior or background resistivity model is important in 3D inversion of MT data scheme because it is the starting point for the optimization and defines the penalty functional. In this regard, inversion runs with different starting models were firstly performed to select the most appropriate one for further interpretations. The starting models consisted of a homogeneous half-space with 10, 30, 50, and 100Ωm. The Gulf of Mexico was included in all models. The 3D finite-difference grid contains 91 x 91 x 53 nodes in the x, y and z directions, respectively. Based on previous modeling studies, a mesh with cells of 400m length within the data coverage area was found to be the most suitable for the 3D inversion of Los Humeros MT dataset. The first vertical layer has a thickness of 15m, and the subsequent layers were increased by a factor of 1.2. Thus, inversion runs were carried out for the off-diagonal dataset and using the four different background conductivity models as the starting point. All the runs were performed with the same inversion input parameters.

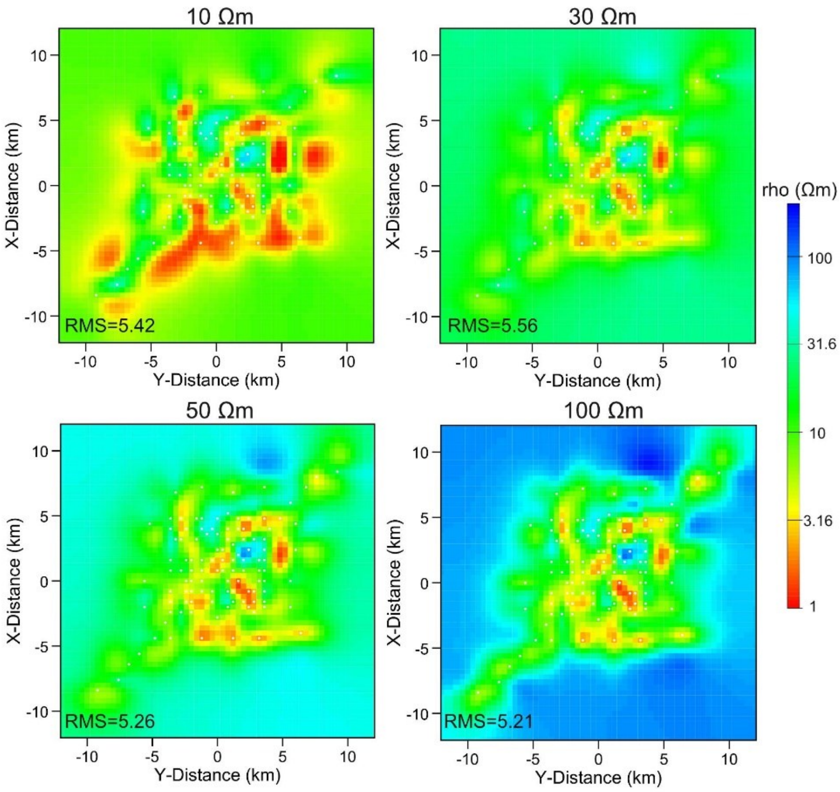

Figure 2: Results of 3D inversion using only off-diagonal elements. Resistivity slices obtained at ~660m depth, inversion with four different starting models. The MT stations are marked with white dots.

The results of the four different inversion trials are displayed in Fig. 2 as resistivity slices at a depth of ~660m. The Figure shows that conductors are derived with greater dimensions at the inversion run with a 10Ωm starting model. Despite the resistive bodies located within the data coverage are imaged at the four inversion models, they show shorter dimensions for the inversion trial with a 10Ωm starting model. In general, the inversion results show that resistivities of the used starting model remain in areas where data coverage is insufficient.

Table 2: Initial and final RMS values of the off-diagonal inversion trials using different starting models.

Starting model	Initial RMS	Final RMS
10Ωm	13.68	5.42
30Ωm	14.86	5.56
50Ωm	20.08	5.26
100Ωm	32.8	5.21

Table 1 indicates that all inversion trials reached comparable RMS (Root Mean Square) values. We chose the most suitable starting model based on the lowest initial RMS value. In this sense, the 10Ωm starting model showed the lowest RMS at the iteration 0 (i.e., forward modeling) of the inversion run and therefore, it was taken as the prior model for the subsequent inversion routines.

3.2 Full impedance tensor inversion

After selecting the most suitable starting model based on the inversion of the off-diagonal components, we included the main diagonal elements of the impedance tensor for inversion. Since the 3D MT inversion is a strongly ill-posed problem, we analyzed the outputs of inversion trials with different input parameters, such as the regularization parameter, model covariance, and data errors. In this regard, the most reasonable inversion results were obtained with an initial regularization parameter value of 1, an isotropic model covariance of 0.3, and data errors were set to 3% of abs(Zij) for the off-diagonal elements, whereas for the main diagonal components, data errors were set to 10% of abs(Zij).

The results of the 3D inversion of the full impedance tensors are shown in Fig. 3, as resistivity slices at four different depths. At shallow depths (~130m), resistive bodies are imaged in almost all the survey area. A conductor is derived at the central part of the data coverage. At a depth of ~660m, conductive bodies can be mainly distinguished within and outside the data coverage. Two resistive bodies are imaged at the central area. At a depth of ~1750m, a conductor and three resistive bodies are derived. Finally, at a depth of ~4480m, a resistive structure is imaged at the central part of the survey area.

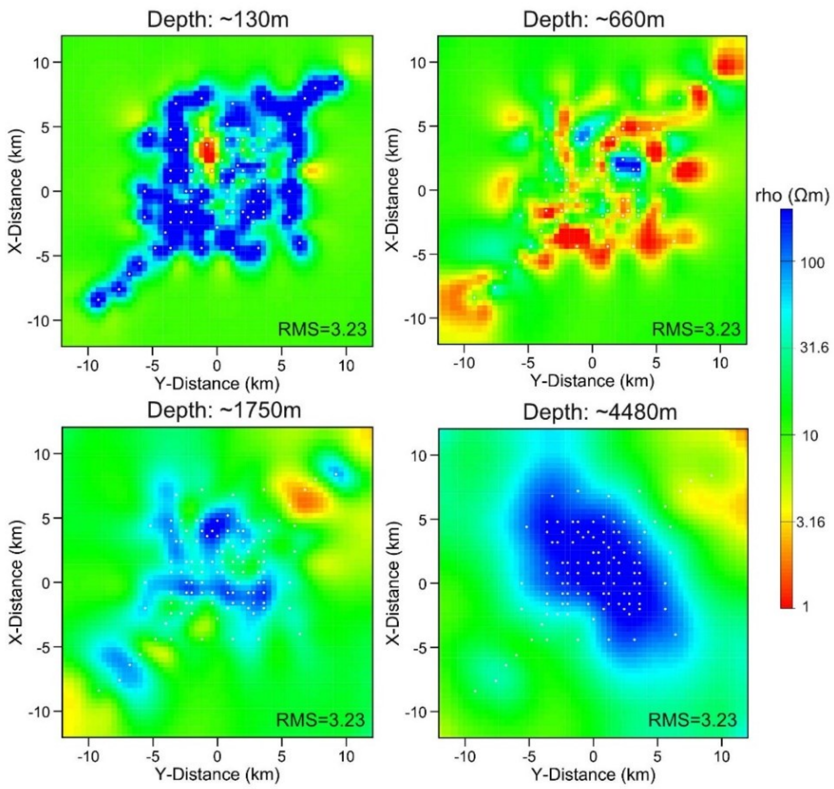

Figure 3: Resistivity slices resulting of the full impedance tensor inversion. The MT stations are marked with white dots.

3.3 Model assessment

Sensitivity studies were carried out to test artifacts generated from the 3D inversion of MT data. A synthetic model was constructed containing the main features that were identified on the inverse model. The images in the left column of Fig. 4 are resistivity slices at selected depths extracted from the synthetic model. A 3D forward modeling was applied to this model, and the calculated data were used for inversion. The images in the right column in Fig. 4 are the corresponding slices extracted from the inverse model. In general, all the conductive bodies located within the data coverage were successfully derived by the inversion routine. At a depth of ~800m, the resistor was not retrieved by the inversion, which is reasonable because MT is not sensitive to resistive bodies as it is to conductors. On the other hand, the northeastern and southwestern conductors were not recovered. An explanation might be the lack of data coverage in these areas and therefore there are not sufficient data that can effectively constrain those conductive bodies.

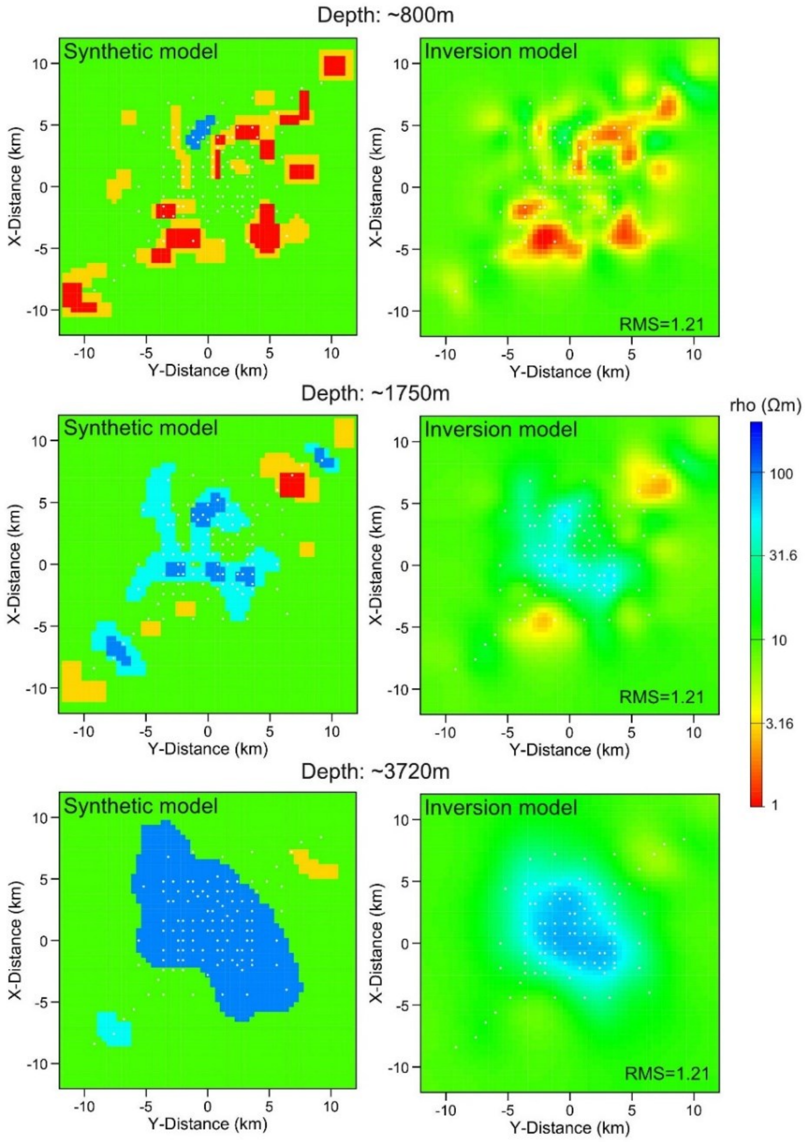

Figure 4: Left column: resistivity slices extracted from the 3D synthetic model containing the main features derived from the inversion of field data. Right column: results of the inversion of data calculated from the synthetic model. MT sites are marked with white dots.

At a depth of ~1750m, only the conductors within the data coverage were retrieved, whereas the resistive structure was only derived in the central part of the survey area. Finally, at a depth of ~3720m, the resistive structure was retrieved but with shorter dimensions.

4. CONCLUSION & OUTLOOK

The update presented in this conference paper is an intermediate step for further integration. At the current stage of our working flow, it is already possible to identify the conductive clay cap and a high resistive core. For instance, in Fig. 5, two selected profiles extracted from the 3D inversion model are displayed, where the typical high enthalpy geothermal anomaly can be distinguished (i.e., a conductive clay cap over a more resistive core; Pellerin et al., 1996).

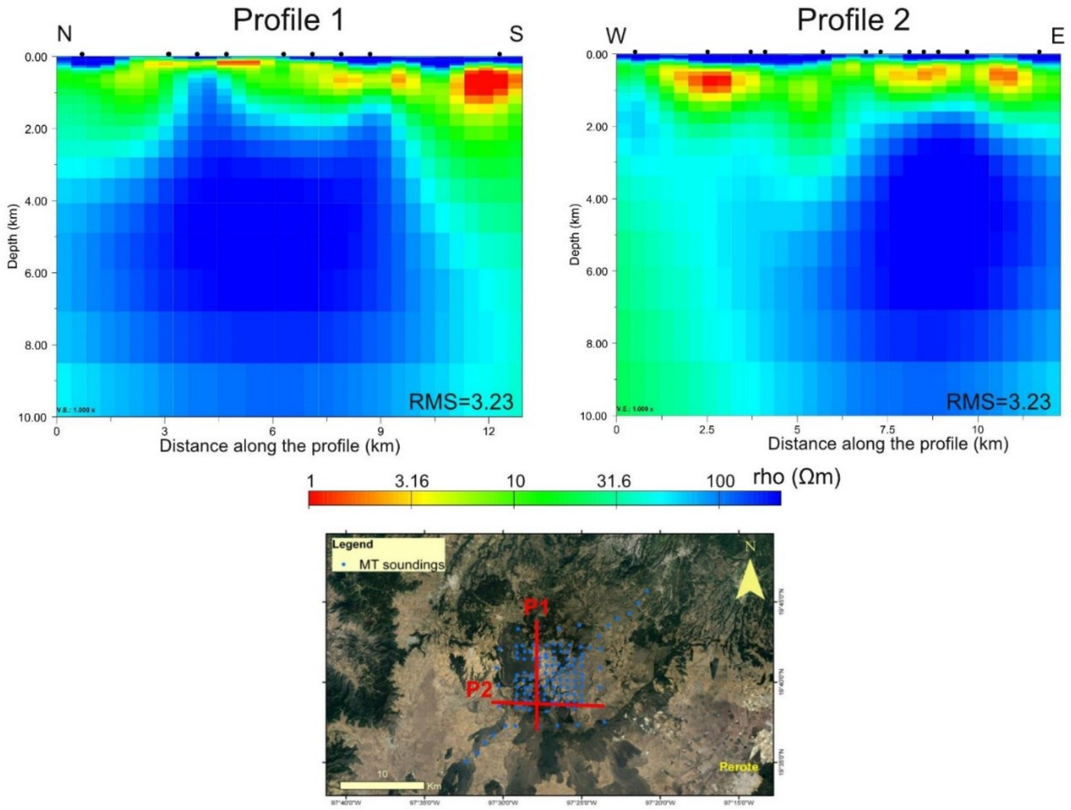

Figure 5: Profiles extracted from the full impedance inversion model. Locations of the profiles can be distinguished on the map.

The model assessment was fundamental to identify artifacts derived by the 3D inversion (e.g., two conductive bodies located at the northeastern and southwestern zones). As the next step of our 3D inversion modeling working flow, we will include the topography from the survey area. Thus, a comparison between inversion models with and without topography will be made. Furthermore, these 3D MT inversion results will be compared with the 3D inversion model obtained by Benediktsdóttir et al. (2020) using a different inversion code.

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