GFZ Helmholtz-Zentrum POTSDAM

funvisis Fundación Venezolana de INVESTIGACIONES SISMOLÓGICAS

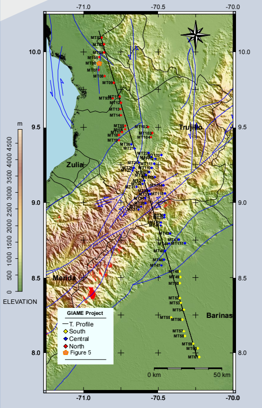
The Mérida Andes of Venezuela: Magnetotelluric forward modelling and comparison with real data

Cruces-Zabala, J.[1,2,3]**, Ritter, O.**[1,3]**, Weckmann, U.**[1,4]**, Tietze, K.**[1,3]**, Schmitz, M.**[2]

1 GeoForshungsZentrum Potsdam. 2 Venezuelan Foundation for Seismological Research. 3 Freie Universität Berlin. 4 Potsdam University

The Giame Project:

The interaction of the Caribbean and South American plates in the western part of Venezuela and its relationship with the Venezuelan Andes, is not well understood from a geophysical point of view. The aim of the project is to develop a geodynamic model of the Mérida Andes and Western Venezuela, employing a wide range of geophysical methods such as gravity, seismology, seismic, GPS, MT and others.



MT data acquisition and processing

Between March and April 2015 a total of 72 MT stations were acquired across the Venezuelan Andes

Acquisition settings:

- 5 – 3 km site spacing
- 5-component MT stations
- Sampling rates: 25 kHz (10 min/day) – 1250 Hz (10 min/2h) -50 Hz (continuous), using S.P.A.M. Mk IV.
- Recording time 3 days/site.
- Remote Reference Station approx. 300 km east of profile

Data processing

MT transfer functions were processed using single site and remote reference processing techniques (Ritter et al., 1998). Major improvements were achieved by using the Mahalanoubis statitistical approach (Platz et al., 2017, under review) and a frequency domain noise separation scheme (Weckmann et al., 2005).

Figure 1. MT survey map. Stations are grouped into three sections (south, center and north) indicated by yellow, blue and red dots on the map. Blue lines indicate fault systems.

Dimensionality and directionality analysis:

- Phase tensors (PT) (Caldwell et al., 2004) were used to describe the surface complexity of the area.
- PT beta values deviating from zero and variable orientation of PT ellipses indicate a 3D response for most of the sites towards medium/long periods
- A strike analysis using the algorithm of Becken & Burkhardt (2004) suggest a regional electrical strike of 55°NW.
- Data indicates that there is more than one strike direction varying from north to south along the profile.

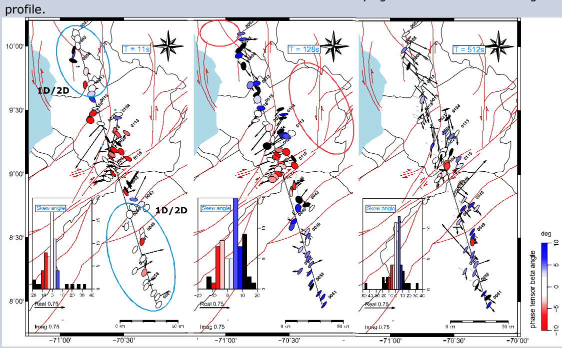


Figure 2. Phase tensor (PT) ellipses with real and imaginary induction arrows in Wiese convention, including Quaternary fault systems and histogram of skew angles. For longer periods, most PT major axis show a tendency of NE-SW strike direction but generally a 3D behaviour (high PT beta values idicated by dark colors). PT major axis in the South agree with the regional strike (Fig. 3).

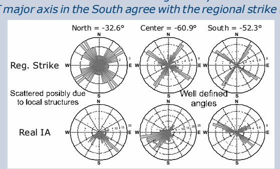


Figure 3. Rose diagrams showing the results of regional impedance strike analysis results and directions of the real part of induction arrows (IA) for periods of 10s-1000s. Dataset was divided into 3 subsets (Fig. 1). IA are used to solve 90° ambiguity of the strike.

Acknowledgements

This project was carried out with the funding of the Integrated Geosciences of the Mérida Andes Project (GIAME) (FONACIT 2012002202) and the specific agreement PDVSA – FUNVISIS (12/09/2012), as well as a cooperation agreement between GFZ-Potsdam – FUNVISIS (07/12/2014). Field work would have not been possible without all the hard work from the students and personal from USB, UCV, PDVSA, FUNVISIS and GFZ-Potsdam. The equipment for this campaign was supplied by the Geophysical Instrument Pool of Potsdam (GIPP) which was fundamental for the success of the measurements. JC is funded by DAAD

www.gfz-potsdam.de

Summary:

- Off-profile structures have strong influence on MT profile data: Inversion strategy based on 2D modelling with 3D control and 3D inversion with geological control.
- 3D forward modelling indicates that the Caribbean Sea has little influence (Fig. 5)
- Considering topography is important.

3D forward modelling:

3D forward models were developed to better understand the influence of far away structures and the effect of topography.

- Models were created on 3D grid (version 2.1.4) and ModEM (Egbert & Kelbert 2012, Meqbel 2009, Kelbert et al. 2014) with varying structural and topographic complexity.
- Topography in the survey area varies from 0 m to 3600 m asl.

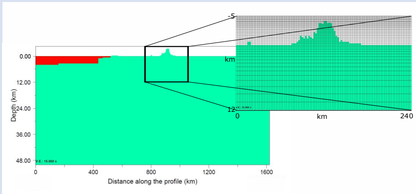


Figure 4. Profile taken from the 3D model used to produce the synthetic data on Fig. 5 (right) following the same direction as in Fig. 1 (black line). Two models were compared with and without the Caribbean Sea. The variable grid particularly on Z direction (zoomed area) was developed to compensate for the effect of topography.

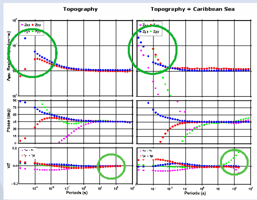


Figure 5. Apparent resistivity, phase and VTF for station MT06 (orange mark, fig. 1) for a model with only topography (left) and with topography and bathymetry (right), green circles denote the topographic and oceanic effects respectively.

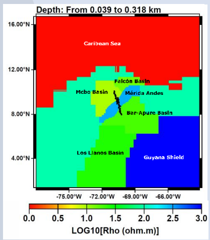


Figure 6. Model used to evaluate the effect of 3D structures on 2D inversions and to compare with real data. It consists of 122, 92 and 65 cells for X, Y and Z directions and dimensions of X=1711 km, Y=1633 and Z=301 km. Cells size grows gradually from 2600 m horizontal to 120 km at the edges of the model. Z ranges from 50 metres at the most shallow layer to 56 km for the deepest slice. Topographic and bathymetric data are taken from the NOAA open database. Background resistivity is 100 Ωm. Based on geological data from several sources 4 sedimentary basins, the Mérida Andes and the Guyana Shield were major features included in the model. Data noise were set to 5%.

2D Inversions:

2D inversions were run with the MARE2DEM (Key & Ovall, 2011)

- Data sets were rotated into profile direction (-17°, black line fig. 1) for better comparisson with the 3D forward modelling (FM)
- RMS values are 6.26 for FM data after 36 iterations, and 7.27 for real data after 17 iterations

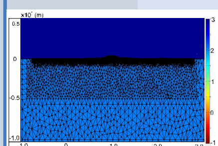


Figure 7. Grid definition and initial model for 2D inversions. Topography was taken from the NOAA webservice.The grid varies from 300 m triangles at the surface to 1000 m triangles to 100 Km depth

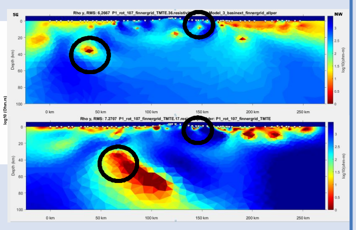


Figure 8. Comparison between 2D inversions of (top) 3D forward modelling responses with (bottom) real data inversion. Black circles denote possible off profile 3D effects.

References

- Becken, M. & Burkhardt, H. 2004. An ellipticity Criterion in magnetotelluric tensor analysis. Geophys. J. Int., 159, 69-82.
- Caldwell, G.,Bibby, H., & Brown, C. 2004. The magnetotelluric phase tensor, Geophys. J. int., 158, 457-469.
- Egbert, G. D. & A. Kelbert, 2012. Computational Recipes for Electromagnetic Inverse Problems. Geophys. J. Int. 189, 251–267.
- Kelbert, A.; Meqbel, N.; Egbert, G. D. & Tandon, K., 2014. ModEM: A modular system for inversion of electromagnetic geophysical data Computers & Geosciences, 66, 40 - 53
- Key, K., and Ovall, J. (2011). A parallel goal-oriented adaptive finite element method for 2.5-D electromagnetic modelling Geophysical Journal International, 186(1), 137–154.
- Meqbel, N., 2009. The electrical conductivity structure of the Dead Sea Basin derived from 2D and 3D inversion of magnetotelluric data, PhD thesis, Free University of Berlin, Berlin, Germany.
- Platz, A.; Weckmann, U. 2017. The Mahalanobis distance: A new measure to detect outliers in Magnetotelluric data. In Preparation.
- Ritter, O., Junge, A., & Dawes, G.J.K. 1998. New equipment and processing for magnetotelluric remote reference observations, Geophys. J. Int., 132, 535-548
- Weckmann, U., Maguinia, A., & Ritter, O., 2005. Effective noise separation for magnetotelluric single site data processing using a frequency domain selection scheme, Geophys. J. Int., 161,635-652.

HELMHOLTZ GEMEINSCHAFT