Investigation of the hydrothermal system below Lagoa das Furnas (São Miguel, Azores) using a Floating TEM system: Measurements and first results

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Introduction and Measurement area

São Miguel is the largest island of the Azores archipelago, which is located in the North Atlantic Ocean, where the American, Eurasian and African plates meet at a triple junction (see Fig. 1).
The geology of São Miguel is dominated by three central volcanoes: Sete Cidades, Fogo and Furnas. The measurements were conducted on Furnas Lake, located inside the caldera of Furnas volcano.

Fig. 1: Left: Location of azores archipelago: Furnas Volcano marked with red frame (modified from [1] and [2]); right: Lagoa das Furnas (view in south-east direction)

One of the most important fumarolic fields at Furnas volcano is located in the northern margin of the Furnas lake[3], CO_2 being the most significant gas emitted. The fumarolic field aquifers are proposed to be supplied with gas from volcanic bodies cooling at greater depths[5].
The resistivity of the lake water was estimated to be 63-70 Ωm[3] and the maximum depth of the water column is about 12 m[6], known from sonar and seismic measurements.
As there were no previous geophysical measurements on the lake, the structures below the lake (as the extend of the hydrothermal system) were unknown.

FloatTEM

For measurements on lakes a Floating TEM set up was developed[4], consisting of a frame of plastic drain pipes, composing an in-loop configuration with transmitter and receiver sizes of 18.36 m and 12.24 m, respectively. As receiver and transmitter the GDP32II and NT-20 from Zonge Engineering were used. While on water the pipe construction is pulled by a boat also containing the measurement equipment (see Fig. 2).
During the field survey 52 stations were measured while the boat and the pipe construction were anchored on the lake. As the anchor process is time consuming and only possible with good wind conditions, additionally on 16 profile lines in the northern part and on 6 in the southern part continuous measurements were conducted in the Nano-TEM modus while the boat was slowly pulling the device across the lake (see Fig. 2). A Comparison of transients from anchored and mobile stations can be seen in Fig. 4 c).

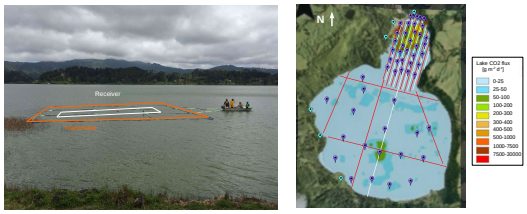

Fig. 2: Left: Floating TEM set up, transmitter loop marked in orange, receiver loop in white; right: Location of anchored stations, land stations, continuous profiles as solid lines and lake CO2 flux (modified from [3])

The profiles in the northern part are 25 m apart with a lengh of approximately 600 m, while in the main lake 2 North-South profiles (each about 2 km long) and 2 East-West profiles (1.5 km long) were surveyed with a station spacing of 20 to 30 m.

It was achieved to collect a large and very dense data set during the survey, consisting of more than 650 TEM stations on the lake and 6 land side reference stations.

References

[1] Wallenstein et al. (2007): Fogo volcano (São Miguel, Azores): a hazardous edifice
[2] Guest et al. (1999): Volcanic geology of Furnas Volcano
[3] Andrade et al. (2014): CO2 emission in Furnas lake (São Miguel, Azores): preliminary results
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[5] Viveiros et al. (2010): Soil CO2 emissions at Furnas volcano, São Miguel Island, Azores archipelago
[6] Anderson et al.. (2016): Bottom characterization of Lagoa das Furnas on São Miguel, Azores archipelago
[7] Hogg et al. (2017): Three-Dimensional interpretation of short period magnetotelluric data at Furnas Volcano, Azores Islands (under review).

Preliminary Inversion results

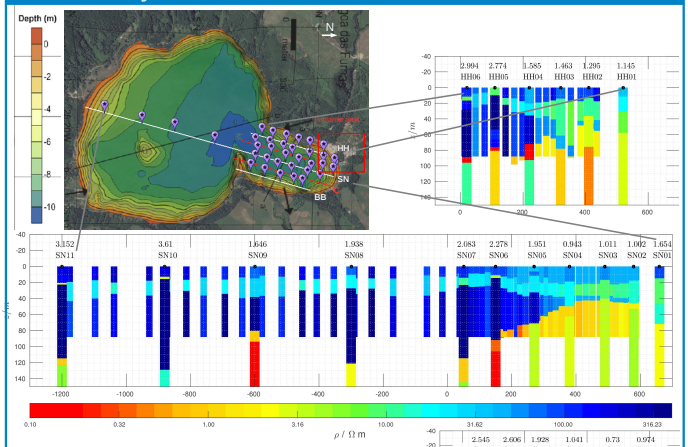

Fig. 3: Marquardt inversion results along four profiles; three 600 m profiles in the northern part of the lake and a 2 km profile crossing the whole lake from south to north. Profiles and locations of anchored stations can be seen in the Google Earth image in the upper left with lake bathymetry (modified from [6]) in the background.
Inversion results from anchored stations are plotted with station number and model error above station name. Results from continuous lines driven by boat plotted in the background. Continuous measurements have a shallower depth of investigation than anchored stations as only Nano-TEM was used.

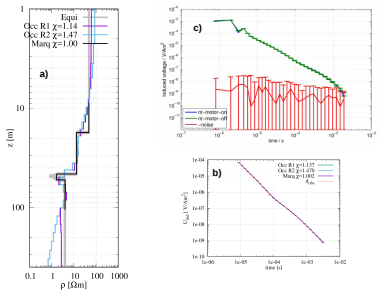

Fig. 4: a) 1D inversion model and **b)** data fit from station SN02; **c)** Comparison of transients of anchored station and continiuous measurement at a station in the northern bay of Furnas lake

If the well conducting structure correlates with the hydrothermal system, it appears to be near the surface at the fumarole area and dips downwards to greater depth towards the main lake.

Outlook

- Spatial visualization:
  - visualize the continuous dense data set as resistivity maps (xy-slice plane views) in three dimensions

  → correlation to hydrothermal system and outgassing anomalies
- Comparison of inversion results for reference land side stations with ERT-data (ISTerre) and AMT- data (DIAS, Fig. 5)

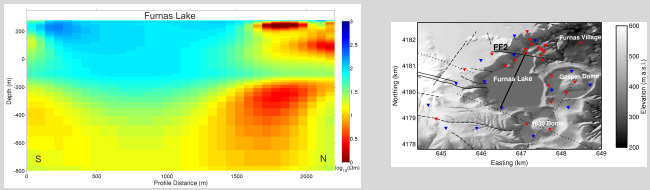

Fig. 5: 2D profile extracted from a 3D AMT resistivity model. Locations of the MT stations around the Furnas Volcano. The red inverted triangles represent AMT only sites, while the blue ones represent combined AMT and BBMT sites, from [7].

- Spatially constrained inversion of the lake stations