A floating transient electromagnetic system to acquire dense data on volcanic lakes

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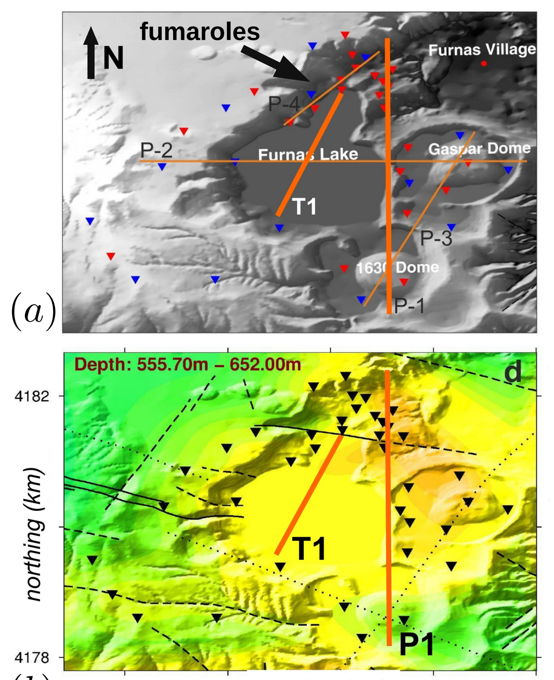
I. Introduction

Often geophysical surveys leave out water covered areas due to inaccessibility, leading to a lack of resolution in derived subsurface images and consequently leading to interpretation uncertainty. For measurements on volcanic lakes a floating transient electromagnetic system (FloatTEM) was developed. The FloatTEM system was successfully used to image the hydrothermal system and CO2 outgassing areas of the Furnas volcanic lake on the Azores islands down to 180 m depth [1,3]. Recent Audio-magnetotelluric (AMT) geophysical data revealed a conductor in 500m depth which is interpreted as related to hot fluids near the boiling point [2]. However, as no data was measured on the lake directly, the spatial dimension of the conductor (C3) is not known precisely. Due to the latter and due to the limited depth resolution of the current FloatTEM system, we propose a modified TEM setup to image the Furnas volcanic system. The modified system combines large fixed loop TEM and grounded dipole transmitter configurations with floating and anchored receivers. Modeling studies show that the proposed configuration is capable of resolving the deep conductor. The original floating and modified semi-floating TEM system, are a new approach to look “into the depth of a volcano”.

II. Furnas volcanic lake - AMT and FloatTEM result



- 3D AMT results [2]: good conductor in 500 m depth (C3) and shallow conductor C1 near the fumaroles; Interpreted as related to hot fluids near the boiling point; very consistent image but no data on Furnas lake
- FloatTEM results [3]: very dense data set around fumaroles (500 soundings)
  - shallow conductor near the fumaroles (CT)
  - CT extends below the Furnas lake (CT)
    → structure not present in AMT results
  - very good correlation with CO2 outgassing maps [3]
    → shallow hydrothermal system is well imaged
  - deep structure below Furnas lake uncertain, due to lack of AMT data on lake

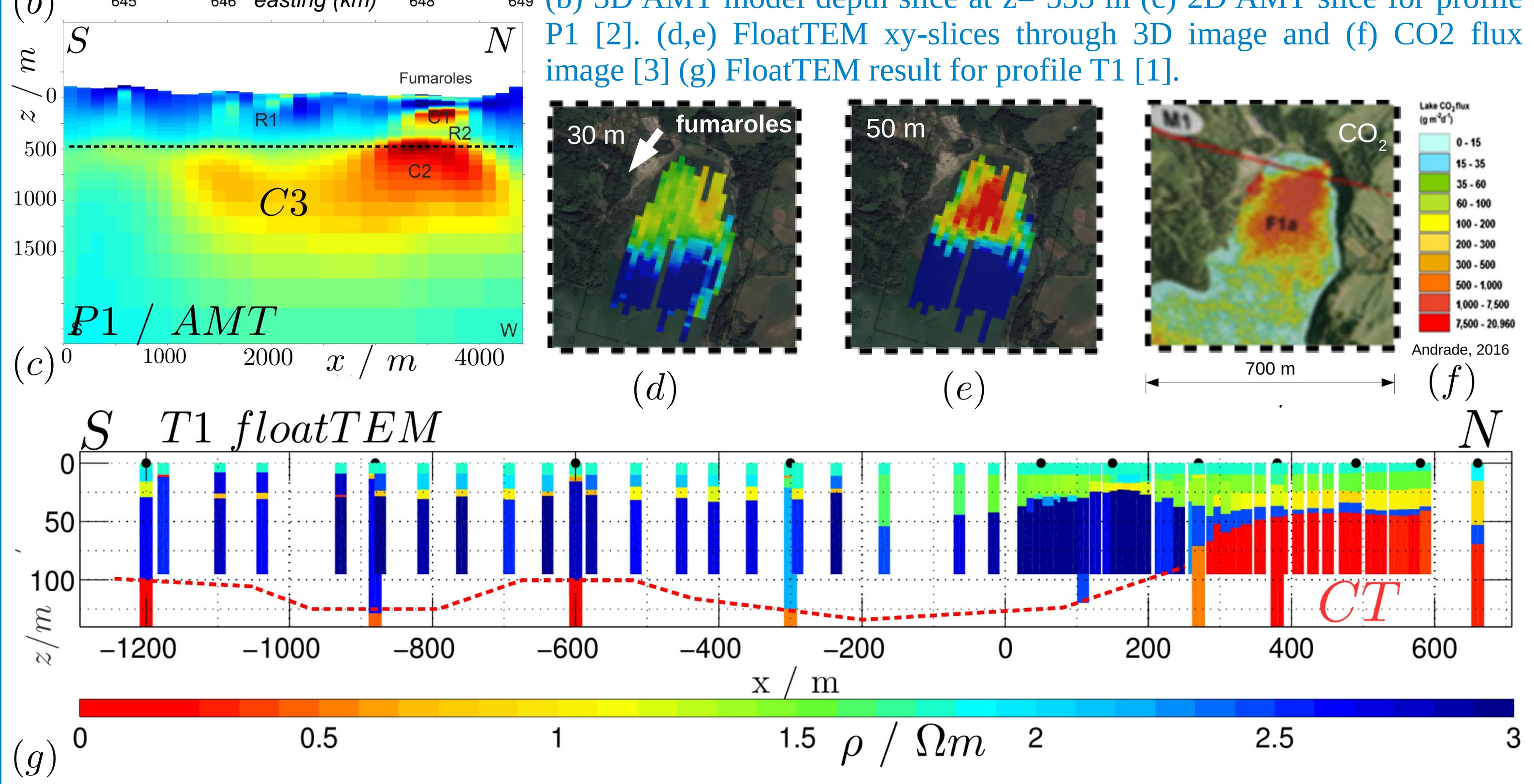


Fig. 1: (a) Furnas lake area with AMT soundings and FloatTEM profile. (b) 3D AMT model depth slice at z= 555 m (c) 2D AMT slice for profile P1 [2]. (d,e) FloatTEM xy-slices through 3D image and (f) CO2 flux image [3] (g) FloatTEM result for profile T1 [1].

III. Original FloatTEM system for shallow imaging

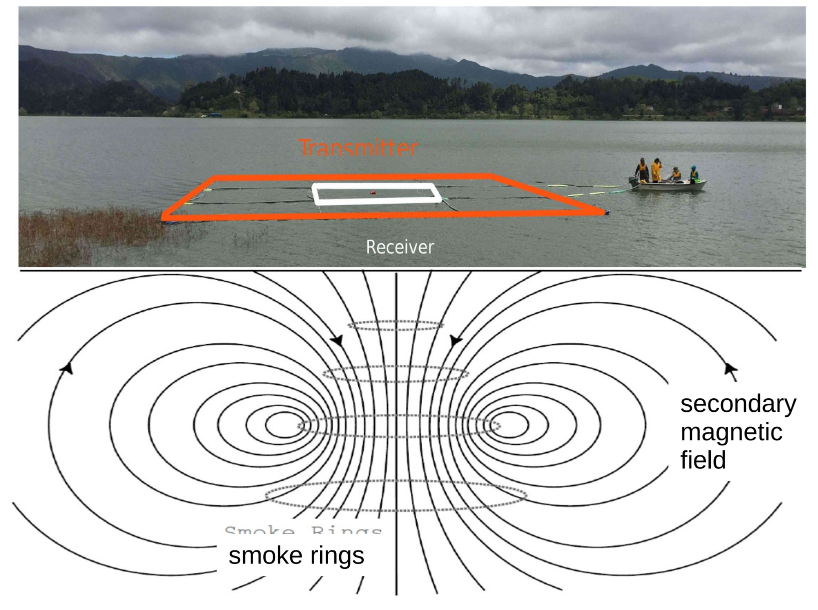


Fig. 2: FloatTEM system with tube frame and boat and the diffusion pattern of the signal in the subsurface

- **Transient EM:** → current switch-off in transmitter → diffusion of EM fields in subsurface with time → record secondary magnetic field (transient) in receiver coil.
- outer 18 m x 18 m square frame holds transmitter cable, inner 6 m x 6 m frame holds receiver cable
- built of conventional plastic drain pipes
- stable frame using several tow ropes and tensions belts; fenders and floats used for sufficient buoyancy
- continuously pulled by boat containing the TEM logger system (speed v=0.2 m/s) → fast and dense data
- anchored measurements → improve S/N

IV. Modified FloatTEM → imaging deep conductor

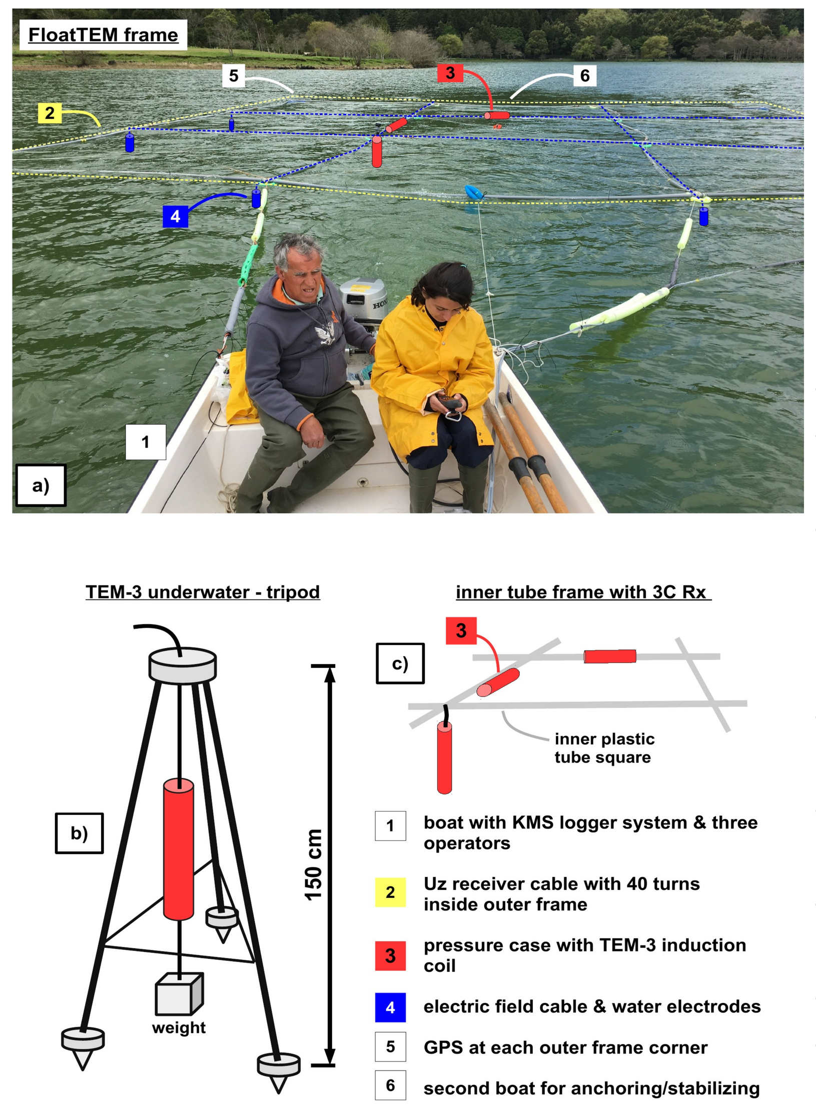


Fig. 3: (a) modified FloatTEM system with tube frame and boat. (b) underwater tripod (c) 3C-Uz-receiver.

We propose a modified FloatTEM system combining large sources and multi-receiver sites in order to investigate the spatial extent of the deep hydrothermal system (conductor C3) below lake Furnas

Modified FloatTEM receiver system

- depth of exploration ~ 1000 m
- fixed large loop and dipole transmitters around lake
- use FloatTEM frame as mobile receiver with 3-component induction coil receivers (Ux,Uy,Uz) in water-proof pressure cases mounted on inner tube frame
- additional electric field receivers (Ex, Ey) mounted along tube frame
- GPS at frame corners → fast/dense data acquisition
- additional underwater tripods for anchored soundings → improved S/N
- 2 -3 operators and logger unit inside boat
- second boat for taxi and stabilizing system

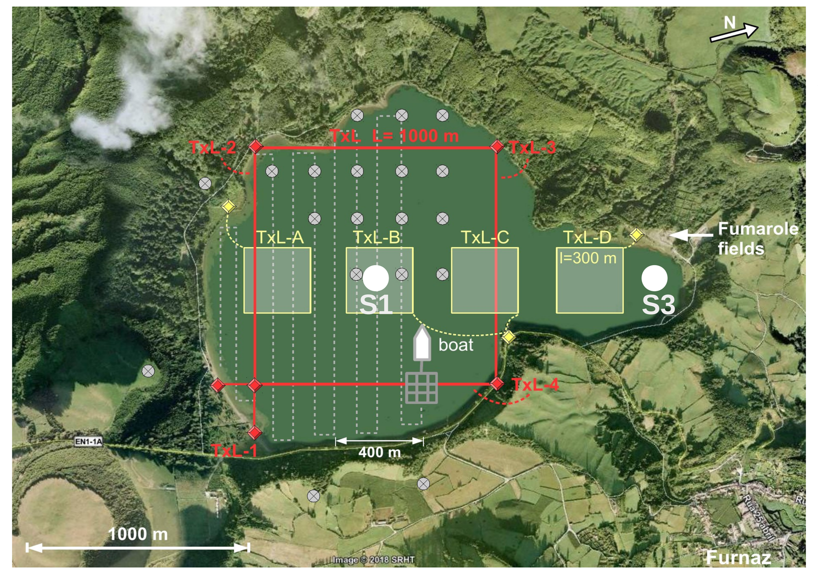


Fig. 4: Furnas lake survey design with transmitters (red, yellow) and receivers as gray dots and dashed lines

Survey design and procedure

A) install large loop transmitter (TxL)
B) move FloatTEM frame with receiver boat continuously along grid
C) additional anchored soundings
  → deploy underwater tripods
  → anchor floatTEM
  → improved S/N
D) open large loop use 1 km dipole (TxL)
  → partly repeat step B) - C)
E) install small loops (e.g. TxL-A)
  → partly repeat B) - C)
  → improved spatial resolution

V. Modeling study of a deep conductor below Furnas lake

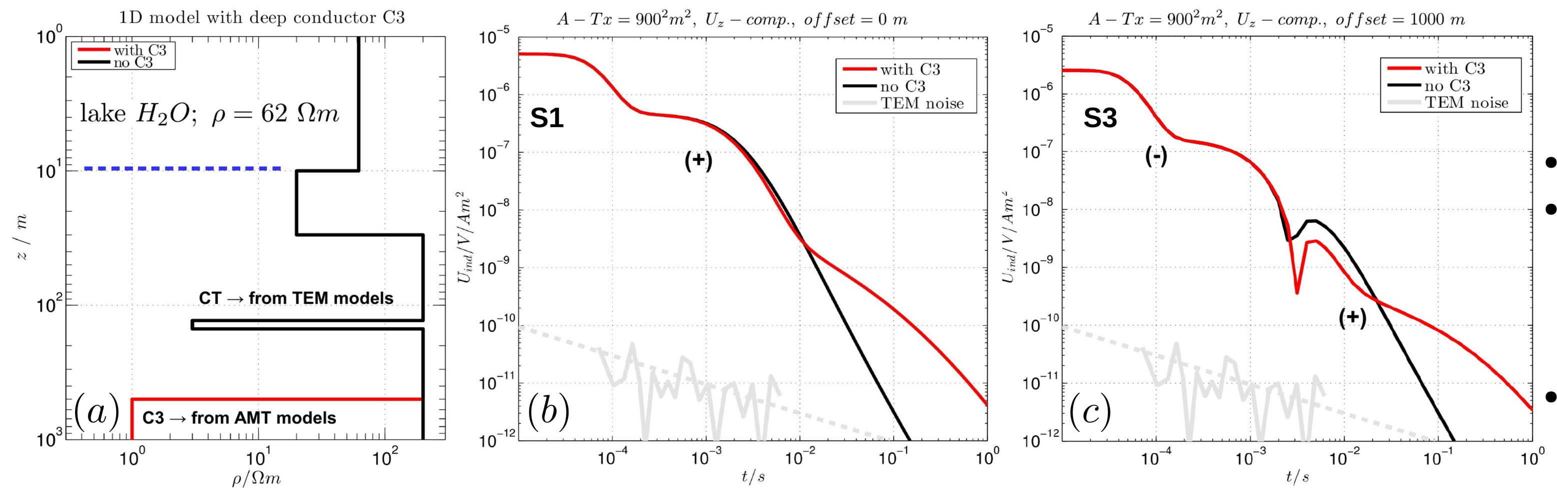


Fig. 5: (a) 1D model derived from AMT and FloatTEM results with and without C3 (b) secondary magnetic field in the center of the loop TxL (c) electric field at 1000 m offset for a dipole TxL-1

1D modeling study with and without conductive layer (C3) at 500 m depth

- assume the 1D model in Fig. 5(a)
- the secondary magnetic field in the center of a large transmitter loop (TxL, location S1) indicates a strong response stronger than the measured Furnas noise level (cf. Fig. 5(b))
- the response outside the loop for location S3 is also strong enough to detect the conductor C3 (cf. Fig. 5(c))

→ the large loop setup is well suitable to detect the depth of the conductor C3

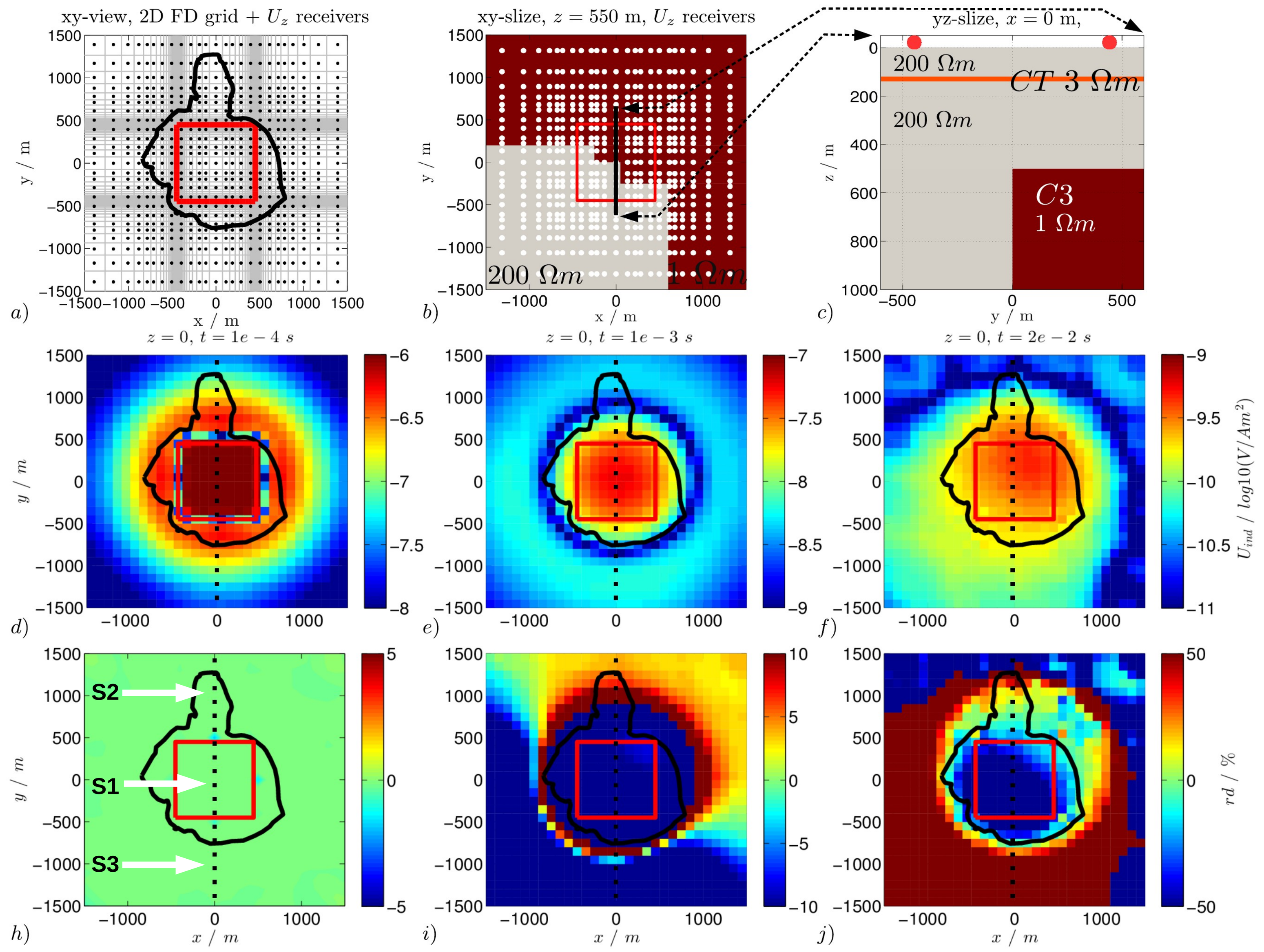


Fig. 6: (a) 3D survey setup for a large loop TxL and multiple receivers as dots (b,c) xy- and yz-slice with conductor C3 interrupted below the lake (d,e,f) xy-slice of the received secondary magnetic field for three transient times (h,i,j) relative difference of secondary magnetic field to response with a continuous C3.

3D modeling study with spatially continuous and interrupted conductor C3

- assume the TEM setup in Fig. 6(a) with a large loop (TxL) and multiple receivers at the surface (black dots). The 3D model is displayed as xy- and yz-slices in Fig. 6(b,c).
- the received secondary magnetic field at the surface is symmetric for an early transient recording time t=1e-4 s. At later times the secondary magnetic field distribution becomes very asymmetric with respect to the transmitter loop
- the relative difference of the received signal at the surface with and without continuous conductor C3 in Fig. 6(h,i,j) is larger than the typical error floor for secondary magnetic field transients at late times.
- the response curves and the relative differences are shown in Fig. 7(a – b) for two locations, S1 and S3. We can clearly distinguish the situation with continuous C3, interrupted C3 and complete removal of C3.
- the asymmetric behavior of the response in Fig. 7(b) indicates that the proposed setup can resolve the spatial shape of C3 below lake Furnas

→ the spatial geometry of the conductor at 500 m depth can be detected with the setup

→ a 1D interpretation of such distorted 3D data is not adequate and would lead to wrong subsurface models. And consequently to mis-interpretations. Therefore, a 3D interpretation is required

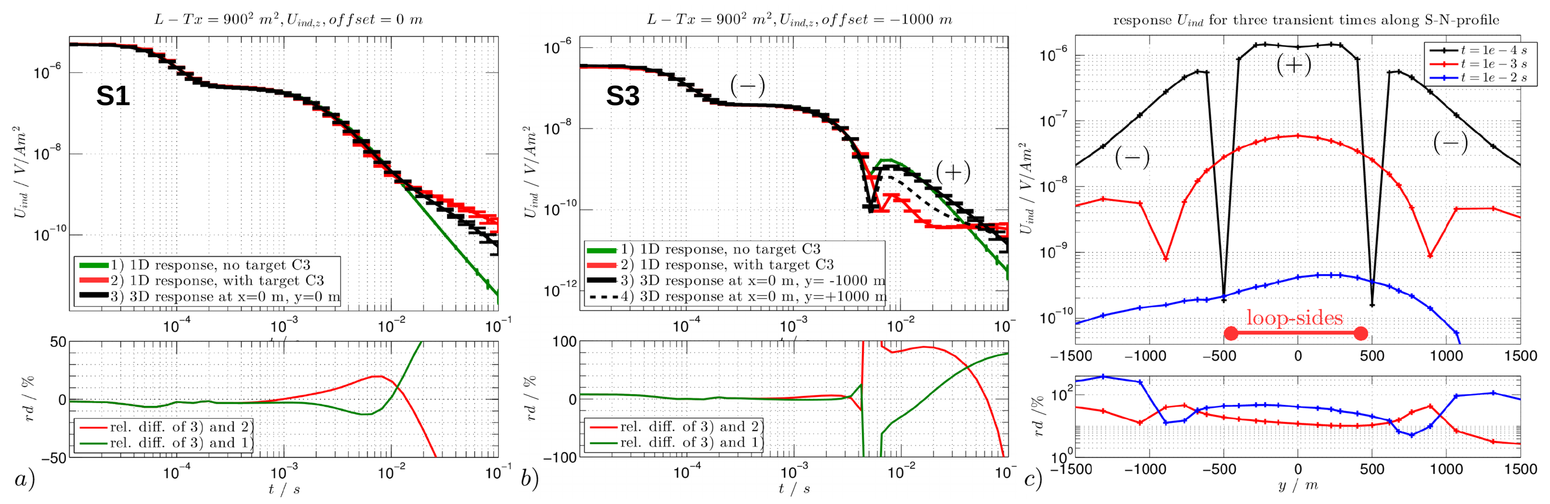


Fig. 7: (a) received signal for sounding location S1 for a continuous and interrupted conductor C3 and for a complete removal of C3 (b) similar as a) for sounding S3 + response for sounding location S2 (c)response plotted for three transient times and all receiver location along the dotted line in Fig. 6 (d – j). The relative difference is plotted in the lower panel.

VI. Conclusion & Outlook

- FloatTEM can image the shallow Furnas hydrothermal system down to 200 m depth.
- modified FloatTEM systems image the conductivity structure of a volcanic lake down to ~1000 m depth with sufficient resolution to image a deep conductor below Furnas lake
- both approaches are new and can be easily adopted to different cases/lakes

Outlook:

- apply modified FloatTEM system at Furnas
- derive 3D model of the deep subsurface structure below lake Furnas

References

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