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# Preliminary Magnetotelluric monitoring results at Rittershoffen

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## INTRODUCTION

Changes in fluid pathways in the subsurface of a geothermal project during stimulation and operation are typically inferred from micro-seismic monitoring. Micro-seismicity can provide information about where fractures shear and open, but neither on fracture connectivity nor on the fluid content. Electromagnetic methods are sensitive to conductivity contrasts and are typically employed as a supplementary tool to delineate reservoir boundaries (e.g. Geiermann et al., 2010). In this respect, in July, 2011, an injection test for a 3.6~km deep EGS at Paralana, South Australia, was continuously monitored by both micro-seismic and magnetotellurics (Peacock et al., 2012). First results from continuous magnetotelluric (MT) measurements suggesting transient variations in subsurface conductivity structure generated from the introduction of fluids at depth. Furthermore, phase tensor representation of the time dependent MT response suggests fluids migrated in a NE direction from the injection well. Results from this experiment support the extension of MT to a monitoring tool for not only EGS but other hydraulic stimulations.

## MONITORING USING MAGNETOTELLURIC

Physical principles of MT monitoring include the following relations between the electric and magnetic field components defining the phase tensor and phase tensor difference. The classical impedance tensor Z is defined as the solution to following linear relationship between horizontal components H of the magnetic field and that of the electric field E

$$E = ZH$$

Each component of Z is represented by a complex value with real and imaginary parts, i.e. $Z = X + iY$. From modulus and phase of each component of Z the apparent resistivity and phase are determined. Since phase terms have a number of drawbacks, we use the the phase tensor (Caldwell et al. 2004):

$$\phi = Y^{-1}X$$

This phase tensor has been shown to be independent of distortion. For monitoring applications that aim on observing transient effects, e.g. prior and after stimulation or pumping/fluid injection, Thiel and Peakock (2011) introduced the relative phase difference tensor defined from the phase tensor at two different dates

$$\Delta\phi_{1,2} = I_d - \phi_1^{-1}\phi_2$$

The relative phase difference tensor at a given frequency can be represented by an ellipse. In this way, a simple scalar can be used to represent the relative phase difference. Thiel and Peakock (2011) defined the average radius of the phase difference tensor with respect to the main axis (other properties such as the direction of the main axis are useful but are not discussed here)

$$\delta\phi_{1,2} = \sqrt{\Delta\phi_{1,2}^{max}\Delta\phi_{1,2}^{min}}$$

While Thiel and Peakock (2011) performed time lapse MT by comparing two measurement campaigns before and after injection at several locations around the stimulated area. In this study, we consider the possibility of continuous monitoring, in which phase difference is a time functional that can be defined relatively to the initial state (or any other date or reference model).

Against this background, first MT measurements over time were acquired during the chemical and hydraulic stimulation of GRT-1 in 2013 in the Rittershoffen area in frame of ECOGI geothermal project (Sailhac et al., 2013). A second set of data is currently acquired before, during and after the circulation experiment carried out at the site. It allows for improving MT measurements with respect to data coverage in time and thus, increasing data accuracy.

The aim of this paper is to introduce the fieldwork achieved in 2014, the methodology and discuss the preliminary results obtained from observed data and probably from sensitivity analysis.

## DATA ACQUISITION

In 2013, MT-setup included three MT stations (Metronix-Cooper Tools). One station was installed at Welschbruch observatory (about 85 km South from Rittershoffen) as a remote reference (with MFS06 soft-coils magnetic sensors). A second one was installed at Rittershoffen at the RITT seismic station (about 1 km to the East from the well, Fig. 1), it using MFS06 soft-coils for the two horizontal components and MFS07e for vertical component. A third one was installed at OPS4 seismic observation station of the Soultz project (5 km to the West of the well) using MFS07e soft-coils magnetic sensors. MT sample frequency for all stations is 512 Hz.

In 2014, a total of six MT stations (one permanent and five temporary) were installed from May 2014. The permanent station is located at RITT and is synchronized with reference remote station located at Welschbruch observatory, there are still in operation.. The temporary MT sites are located around Rittershoffen well (Fig. 1), three stations had been installed South in the Betschdorf forest and two outside of it (Fig. 1). Temporary sites recorded continuously for at least four days at each site before circulation operation started. We will repeat measurements at the temporary stations after termination of the circulation experiment.

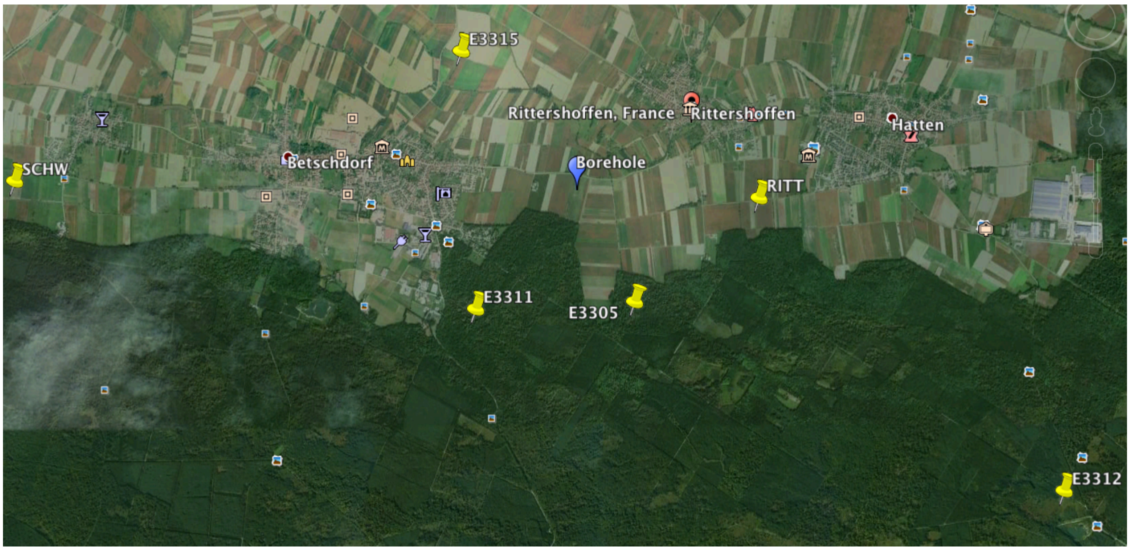


**Figure 1: Location of the Rittershoffen wells, the permanent MT station RITT and the temporary stations of SCHW, E3315, E3311, E3305, E3312 (source of image: Google Earth)**

## PROCESSING AND PRELIMINARY RESULTS

To handle natural transient effects in the electromagnetic sources such as variable intensity, polarities and frequencies, data processing to estimate Z tensor was carried out using the well-known, robust Chave's code (Chave and Thomson, 2004). Error bars were obtained using the error tensor of Wawrzyniak et al. (2013). Furthermore, uncertainties on the impedance were used to estimate uncertainties on the phase differences (Tartrat, 2014).

Representative MT data recorded at Rittershoffen (local site) and at Welschbruch observatory (remote site) is shown in Fig. 2. Resistivity and phase variation are obtained for the measured frequencies (Fig. 3).

Preliminary results of the phase difference tensors obtained from the time series recorded in Rittershoffen between August 10$^{th}$ and 12$^{th}$ 2014 are shown in Fig. 4. Phase difference tensors have been determined stepwise from one day to the next resulting in phase difference tensors between 08/10 and 08/11 (Fig. 4a) and between 08/11 and 08/12 (Fig. 4c). An overall phase difference tensor has been obtained for the period between 08/10 and 08/12 (Fig. 4b). The preliminary results obtained in these periods show negligible variation. So far, this is in agreement with the fact that no circulation took place in the Rittershoffen geothermal well during this period. This is the ideal case where the physical conditions of the underground remain unchanged. However, once these underground conditions change by modification of the natural flow path, the phase difference tensor should indicate those variation.

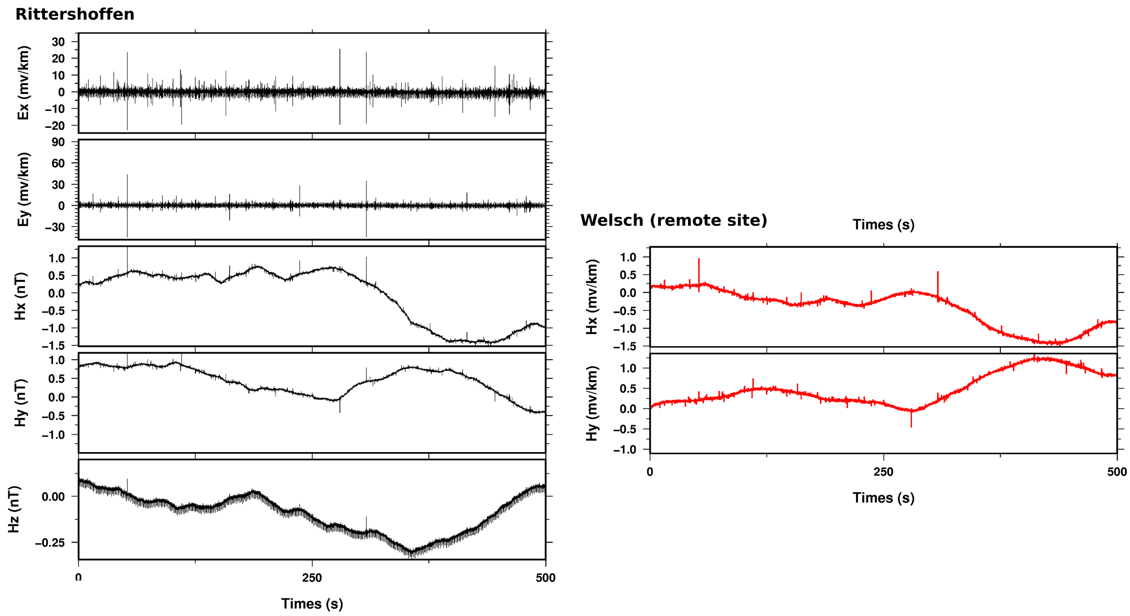


**Figure 2: Representative MT data recorded at Rittershoffen and Welschbruch (August 10th 2014).**

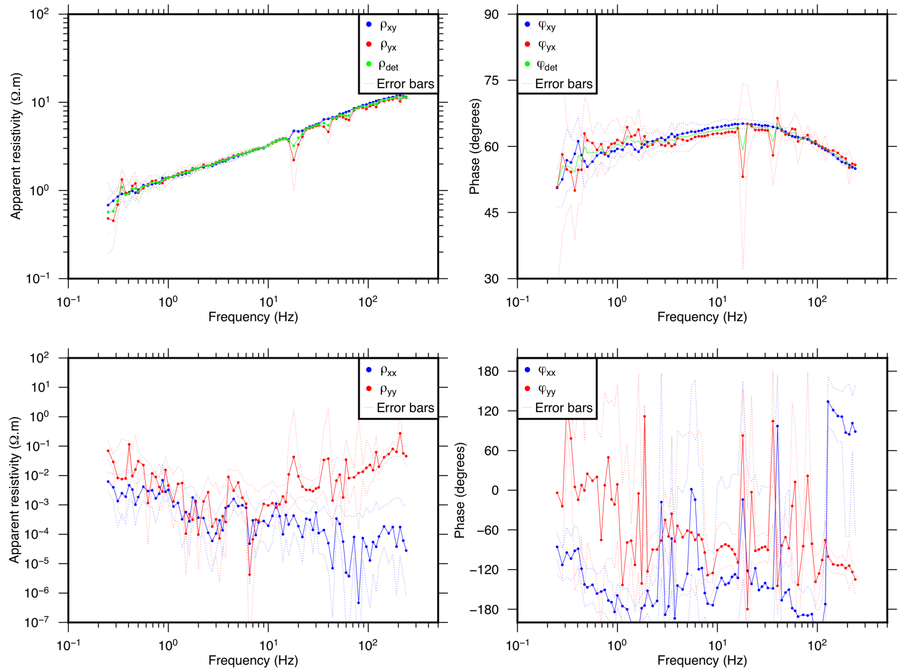


**Figure 3: Apparent resistivity and phase obtained for Rittershoffen MT site. This is the result of the robust processing applied for data recorded in August 10th 2014, using the remote site, Welschbruch observatory.**

## CONCLUSION

In this study, preliminary results obtained for monitoring of Rittershoffen geothermal site using magnetotelluric method are presented and discussed. We are mainly interested for the frequency range between 0.1 to 10 Hz to record a significant signal, which may occur at the pumping and injection depths. The phase difference tensor obtained from measurements acquired between August 10th and 12th 2014 reveal small variation about 1-2 % at 10 Hz and 10-20 % at 0.1 Hz. This is in agreement with the fact that no hydraulic modification occurred during this period in the Rittershoffen subsurface.

In the next step, we plan to process longer periods (> 1 day) to increase the skin depth. This is essential to characterize the phase difference tensors for deeper geological structures. Besides, we are still carrying sensitivity analyses using forward numerical modeling.

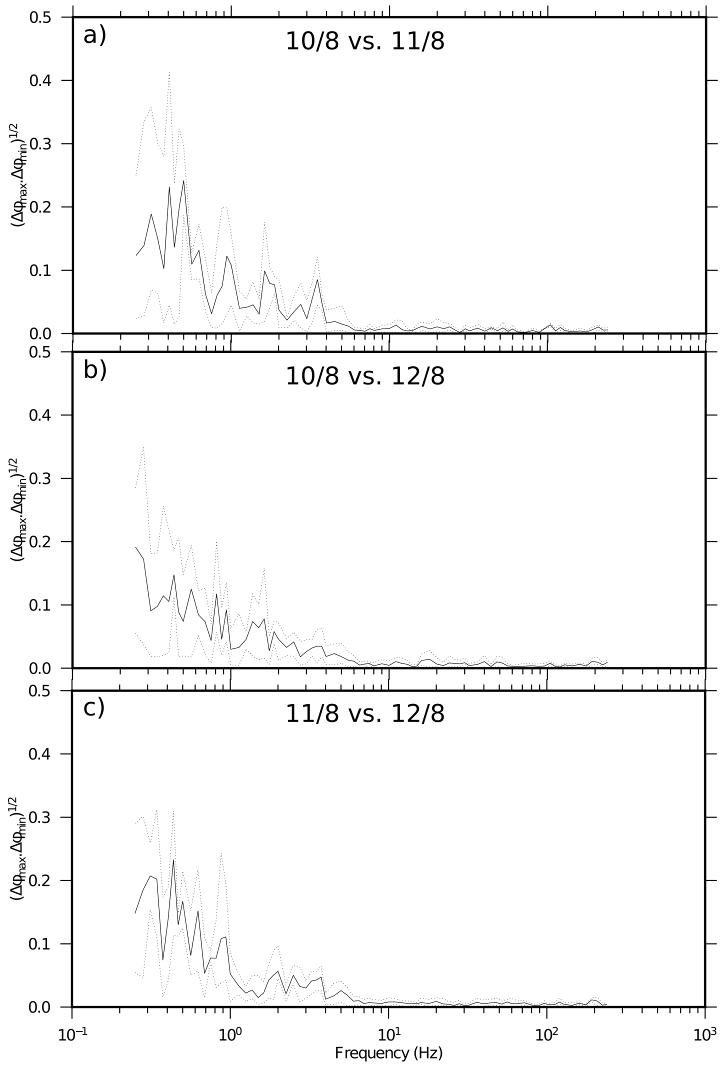


**Figure 4: Preliminary results of the difference phase tensor at Rittershoffen obtained from August 10th to 12th 2014.**

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## REFERENCES

Caldwell T.G., H.M. bibby, C. Brown, The magnetotelluric phase tensor, Geophys. J. Int. 158, 457- 469, (2004).

Geierman J., E. Schill, 2-D magnetotellurics at the geothermal site Soultz-sous-Forêts: Resistivity distribution to about 3000 m depth, C.R. Geoscience 342, 587-599, (2010).

Peakock J.R., S Thiel, G.S. Heinson, P. Ried, Time-lapse magnetotelluric monitoring of an enhanced geothermal system, Geophysics 78, B121-130, (2013).

Sailhac, P., Larnier, H., Matthey, P.-D., Schill, E., and Chambodut, A., Testing geothermal monitoring using MT and SP at Rittershoffen. 2nd European Geothermal Workshop, October, 4p (2014).

Tartrat, T., Monitoring d’un site géothermique à l’aide de données magnétotelluriques, Rapport de stage de Master 2, Ecole et Observatoire des Sciences de la Terre, Université de Starsbourg, 30p (2014)

Thiel S., Peakock J.R., G.S Heinson, P. Ried, M. Messeiller, First results of monitoring fluid injection in EGS reservoirs using Magnetotellurics, Australian Geothermal Conference. Extended Abstract, 4p (2011).

Wawrzyniak P., P. Sailhac, G. Marquis, Robust error on Magneto-Telluric impedance estimates. Geophys. Prospect. 61 533-546. (2013).