Leveling and hybrid gravimetry monitoring applied to geothermal sites of Soultz-sous-Forêts and Rittershoffen, Rhine Graben, France

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Abstract. Here we report on some case histories of geodetic and gravity surveys for monitoring of geothermal sites. The monitoring of a geothermal reservoir by hybrid gravimetry combining different types of instruments (permanent superconducting gravimeter, absolute ballistic gravimeter and micro-gravimeters) is presented. A relative gravimetric network equipped with levelling benchmarks was designed and surveyed at annual frequencies (2013, 2014 and 2015 for gravity measurements, 2014 and 2015 for the levelling). Repetition of high precision relative gravity measurements on a network developed around a reference station, which is regularly measured with both relative and absolute gravimeters, leads to the knowledge of the time and space changes in surface gravity. The observed gravity changes can be linked to the natural or anthropic activities of the reservoir. A feasibility study using this methodology is applied to two geothermal sites of Soultz-sous-Forêts and Rittershoffen in the Alsace region (France) in the Rhine graben (Hinderer et al. 2015).

Keywords. Leveling, hybrid gravimetry, geothermy, deformation monitoring

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1 Introduction

Time-lapse gravimetry can then be a monitoring tool of any underground or surface mass redistribution and has many applications in volcanology (magmatic chamber evolution), hydrology (water storage changes in the critical zone), and geothermics

The surface at a geothermal site can be monitored by different techniques, i.e. GPS/GNSS, InSAR, leveling to name only a few. To get in-deep monitoring, repetitions of gravimetric measures can be performed.

Several studies have introduced the concept of hybrid (resp. super-hybrid) gravimetry (Okubo et al. 2002; Sugihara and Ishido 2008; Hector et al. 2015) that is the optimal combination of two (resp. three) types of gravimeters (absolute AG, supra-conducting SG or relative gravimeters RG). By using different types of gravimeters, we take advantage of each instrument: i.e. transportable for a RG and precise and absolute measurement for an AG (see Table 1 of Hinderer et al. 2015).

This paper reports an experiment of monitoring using hybrid gravimetry (SG+RG) and leveling at two geothermal sites in the Rhine graben, France.

2 Hybrid gravimetry

Two geothermal sites are monitored in the northeast of France (Figures 1 and 2): the Soultz site and the Rittershoffen site (also called ECOGI).

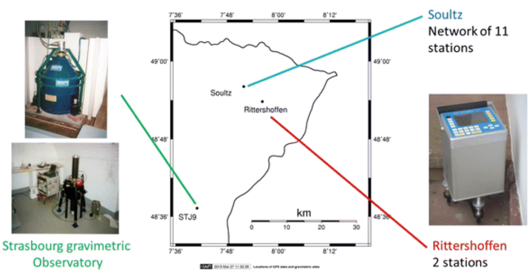

Fig. 1 The three main locations of our hybrid gravity approach. STJ9 is the Strasbourg Gravimetry Observatory where both a superconducting gravimeter (GWR C026) and an absolute gravimeter (Micro-g Solutions FG5#206) are available. There are 11 micro-gravity stations in the Soultz network (GEIE) and 2 stations close to Rittershoffen (ECOGI) (after Hinderer et al. 2015).

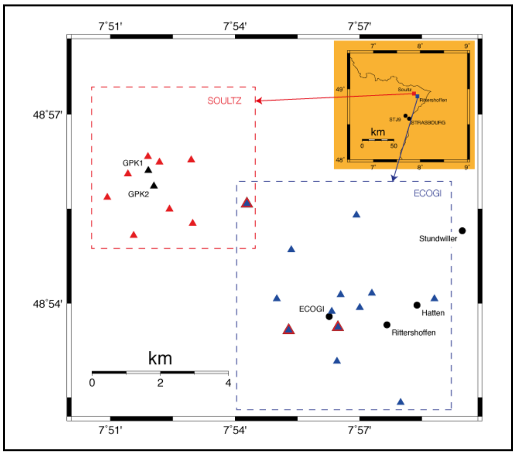

Fig. 2 Location of the relative gravimetric measurement site (red or black triangles): 11 surrounding Soultz-sous-Forêts (GPK1 and GPK2) and 2 sites close to Rittershoffen (ECOGI site). Permanent GPS stations are indicated by black triangles or black circles. Blue triangles are the newly monumented sites in 2015 around ECOGI.

To perform hybrid gravimetry, we use a SG located at the gravimetric Observatory of STJ9 (see location on Figure 1) which records daily the gravity variations. To establish absolute gravity measurements at STJ9 and at the reference benchmark of the Soultz network (reference called GPK1 on Figure 2), we measure the gravity with an AG. The Soultz network was measured in 2013, 2014 and 2015. We report only here results of 2014 gravimetric survey. For a complete description of measurement procedure and processing see Hinderer et al. (2015).

3 Data processing

The repetition of a micro-gravimetric network, where x0 and t0 are the reference point and time, leads to the following formula for the gravity double differences at point x and time t:

$$Dg_{x-x0}^{t-t0} = (g_x - g_{x0})_t - (g_x - g_{x0})_{t0} \qquad (1)$$

Since any change in elevation modifies the gravity measurement, it is crucial to perform a vertical control, all gravimetric sites are equipped with a leveling benchmark.

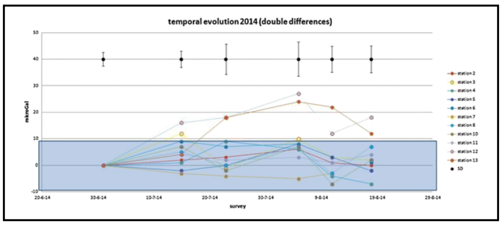

Fig. 2 Gravity double differences in 2014. The blue area is the ±2 σ uncertainty band computed from the uncertainties in the measurements and processing of all surveys (after Hinderer et al. 2015)

During May 2014, a large leveling network (~40 km long) connecting the 13 gravimetric sites was observed in 4 main loops and a small loop around ECOGI site (Ferhat et al. 2014). The closure loops show an equivalent precision of 1.5 mm/km for the main loops and 0.5 mm/km for the small loops (Ferhat et al. 2014). This accuracy is large enough to guarantee a vertical precision better than a few millimeter required for gravimetric variation interpretation.

3 Leveling network

The leveling network is made of five loops (figure 4). Each loop was observed using a digital level (Leica DNA03) and standard leveling staff. The leveling lines include some National leveling benchmarks installed by the French Mapping Agency (IGN, *Institut National de l'Information Géographique et Forestière*) in order to tie the altitudes to the national reference.

The loop 5 was observed several times using the same digital level, but this time using invar staffs. By fixing the altitudes of three leveling benchmarks BM at IGN values, we computed the altitudes of all other benchmarks (Ferhat et al. 2014). Uncertainties on these altitudes are about 2 to 5 mm. This leveling network has been surveyed in May 2014 and May 2015 and will be re-measured in May 2016.

Differences in elevation between consecutive BM have been computed and are less than few mm (Ferhat et al. 2015).

In order to evaluate the effect of the network geometry, we fixed the altitude of the GPK1 benchmark (Figure 5) and compute the error transmission for all benchmark using 2014 and 2015 leveling observations (Figure 5).

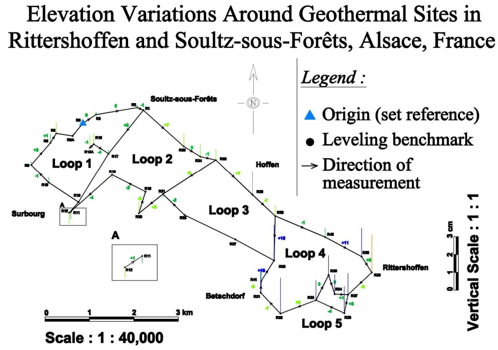

Fig. 4 Elevation error variations between the two epochs of 2014 and 2015. GPK1(blue triangle) is supposed to be fixed.

Leveling data processing has been performed using a Matlab program and also Geolab program developed by Bitewise company.

Figure 4 shows that sites close to GPK1, vertical errors are a few mm and reach 1 or 2 cm at the more distant points. Only one leveling benchmark exhibits a value of 2.1 cm. Moreover, several GPS antennas were installed at specific site of the survey network (GPK1, GPK2, ECOGI) or in the surrounding area (Figure 5).

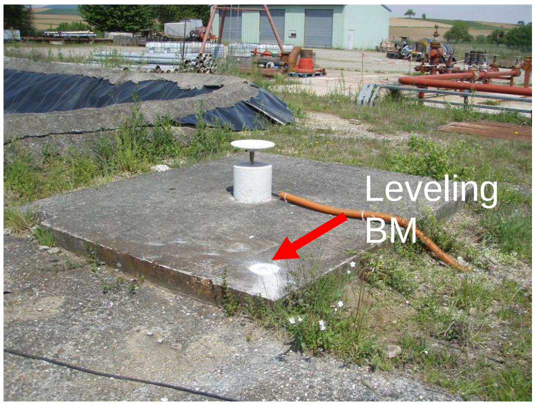

Fig. 5 Permanent GPS antenna at GPK1 site also equipped with several leveling benchmark BM.

5 Conclusion

The monitoring of the two geothermal sites did not detect any vertical or deep deformation during the 2013-2014 period or 2014-2015. Future gravimetric and leveling surveys are planned in 2016 to continue the monitoring of the area. GPS measurements in the area not described here will be also analyzed in the future.

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