On-going progress on the hybrid gravimetric monitoring of the Soultz-sous-Forêts and Rittershoffen geothermal sites

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Introduction

Time-lapse gravity is a monitoring tool to investigate underground mass redistributions and hence it finds a potential application to follow a geothermal reservoir both in its natural state or undergoing man-made stimulations.

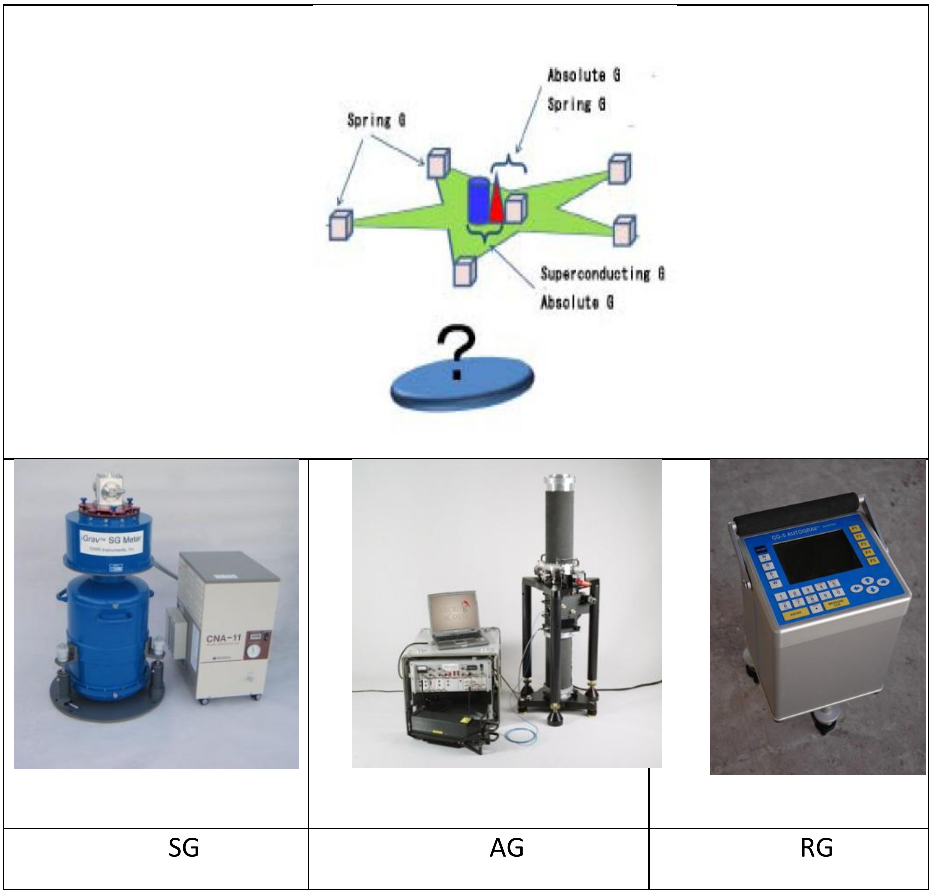

Fig. 1.The concept of hybrid gravimetry to investigate an underground reservoir with the combination of superconducting gravimeter (SG) absolute gravimeter (AG) and relative spring meter (RG) (adapted from Sugihara et al. 2013).

Several experiments have introduced the concept of hybrid gravimetry which is the optimal way to combine different types of instruments and techniques of measurement. In particular, hybrid gravimetry uses a reference station where gravity is continuously recorded with a relative gravimeter (either a spring meter or a superconducting gravimeter) and regularly checked with absolute gravity measurements, as well as repetitions of a micro-gravimetric network of several satellite stations in the vicinity of the reference one (see Fig. 1).

Modeling of surface and underground gravity changes due to geothermal activity

The first step was to compute surface and underground gravity changes that can be expected from mass redistribution related to the geothermal activity. Fig. 2 shows the gravity effects at the Earth's surface due to a mass perturbation of 0.17 MT located at 2 km depth (left) and the gravity effectsthat would be probed by means of borehole measurements according to the depth (right). This moderate mass perturbation is a typical value derived from what is known in terms of injection rate and duration that occurred in the past on the Soultzgeothermal site (Genter et al. 2010).

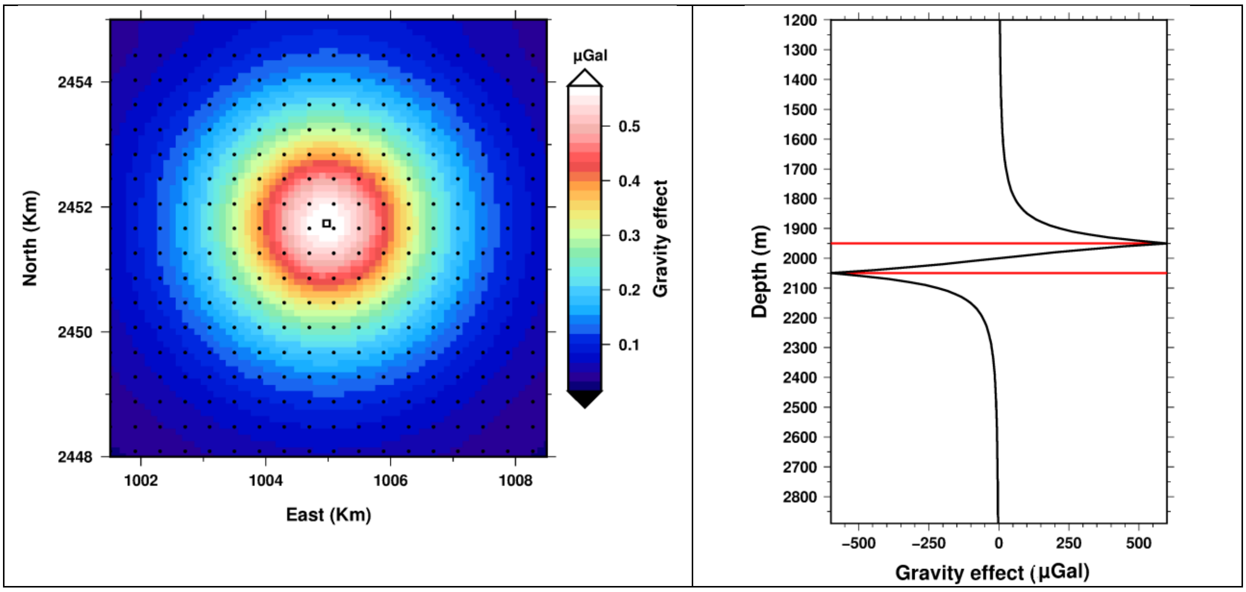

Fig. 2.Modelled surface gravity effect (in µGal) due to a mass perturbation of 0.173 MT located at 2 km depth within a prism of dimension 100 m x 100 m x 100 m (left).Modelled borehole gravity effect as a function of the depth due to a mass perturbation of 0.173 MT located at 2 km depth (right). The two horizontal red lines show the top and bottom of the layer (100 m thick) where the source anomaly occurs.

One can immediately see that the expected surface gravity effects are very small (less than one µGal) and hence undetectable by gravity surveys. On the contrary, gravity changes increase with depth when becoming closer to the source and they can easily reach several hundreds of µGal close to the source pointing out the interest of borehole gravimetry.

Gravity observations on the Soultz and Rittershoffen sites in Northern Alsace

Previous results (2013-2014)

We establishedaround the Soultz-sous-Forêts geothermal site a repetition network of 11 relative stations linked in 5 separate loops around GPK1 station (Fig. 3). The survey was routinely done with a RG (Scintrex CG5 microgravimeter) on a weekly basis during four months in July and August 2013 and again in July and August 2014. Initially only two stations were established around the ECOGI site near Rittershoffen.

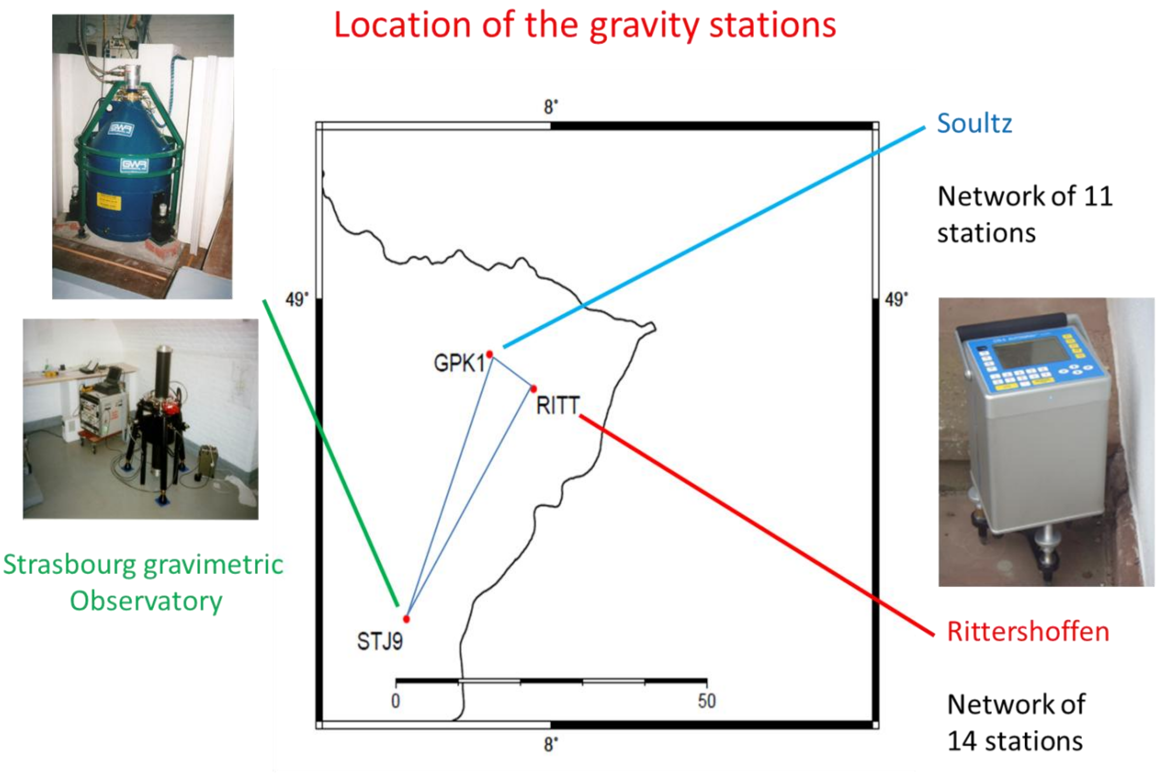

Fig. 3. The three main locations of our hybrid gravity approach. STJ9 is the Strasbourg Gravimetry Observatory where both a superconducting gravimeter (GWR C026) and an absolute gravimeter (Micro-g Solutions FG5#206) are available. There are 11 micro-gravity stations in the Soultz network (GEIE) established in 2013 and 14 stations in the Rittershoffen (ECOGI) network since 2015.

The first results of the hybrid gravimetry concept applied to the Soultz sitecan be found in Hinderer et al. (2015). Wereportedin this paper on the stability of the reference point (GPK1) from a series of absolute gravity measurements done with EOST ballistic AG (FG5 model of Micro-g Solutions). We also showed the preliminary temporal gravity variations derived from these repetitions, after removal of the instrumental drift and applying precise tidal corrections (Fig. 4). These gravity changes are presented as double differences, which are differences with respect to the base station and to a single epoch (here the first 2014 survey date). It turns out that the 2014 micro-gravimetric measurements are much better than the 2013 ones mostly because of the use of a more stable RG instrument, reducing the average loop error by almost a factor 10.

We hence inferred a threshold for detecting any gravity signal of geothermal origin in the frame of our local network. The 1 σ uncertainty taking into account all error sources in the measurements and processing is found to be close to 5 µGal. This means that almost no changes canbe observed in the ± 2 σ uncertainty band as shown on Fig. 4.

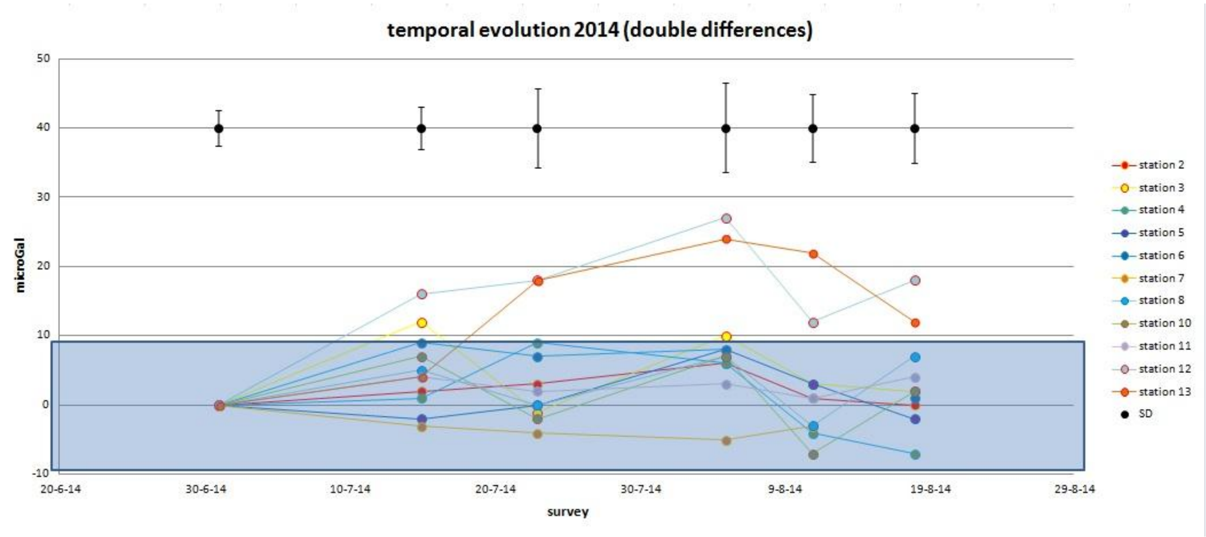

Fig. 4.Gravity double differences in 2014. The blue area is the ± 2 σ uncertainty band computed from the uncertainties in the measurements and processing of all surveys. All stations refer to the Soultz site except stations 12 and 13 which are close to ECOGI.

The only changes above this threshold concerned stations 12 and 13, close to the ECOGI site, at a time where some production tests were indeed done. However no conclusion could be drawn on the basis of this isolated observation.

New results (2015)

This led us to establish a new gravity network in 2015 around the Rittershoffen geothermal site with 14 stations (4 being common to the Soultz network). Both Soultz and Rittershoffen networks were repeated in summer 2015, together with the survey of the leveling network connecting the gravimetric sites. We also acquired during the whole repetition period a continuous gravity time series at GPK1 with a second Scintrex CG5. Moreover two new absolute gravity measurements were done at GPK1 at the beginning and at the end of the 2015 observing period.All these new hybrid gravity data have been processed and we will show the new results that can be inferred.

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