STATUS REPORT
to the Global Geodynamics Project

Superconducting gravimeter station at the Onsala Space Observatory, The National Facility for Radio Astronomy in Sweden

Hans-Georg Scherneck

Department of Radio and Space Science
Chalmers University of Technology
Göteborg, Sweden

September 11, 2008

Summary

We describe the current status of establishing a superconducting gravimeter station and absolute gravimetry platform at the Onsala Space Observatory, Sweden. As of writing the instrument has been delivered, but site construction work has not yet commenced. The site will be housed in a hut above ground and rest on crystalline bedrock. We detail the plans and various instances of precautions that have been taken prior to building. First we present the organisations involved.

Onsala Space Observatory

Onsala Space Observatory (OSO) is the centre of Radio Astronomy in Sweden. It has the status of a National Facility with direct support from the Swedish Research Council (VR). It carries out observations for an international scope of researchers using single-dish and VLBI techniques. OSO is a partner in large international projects in radio astronomy (e.g. ALMA, LOFAR, satellites like ODIN). Geodetic activities comprise geodetic VLBI and GNSS. OSO maintains an IGS station and a platform for absolute gravimetry. Additional long-term observation programs are carried out with OSO support like remote sensing and radiometry of atmospheric gasses, of which water vapour plays an important role for space geodetic measurements.

At present we look forward to the establishment of a tide gauge station that the Swedish Meteorological and Hydrological Institute (SMHI) is willing to contribute. Further plans exist to host a broad-band seismological station as one observing site of the Swedish National Seismic Network (SNSN).

Radio and Space Science at Chalmers

The Department for Radio and Space Science at Chalmers employs several groups which utilise the OSO facilities, ranging from atmospheric remote sensing and space geodesy to radio astronomy and astrophysics.

In 2006 the space geodesy group suggested to upgrade the geodetic observation program to include continuous observation of gravity at the OSO site, making OSO a fundamental geodetic station (albeit SLR will not be represented because of large average cloud cover). The proposal, forcefully backed up by the National Facility, was successful and earned support from VR. The new instrument will be a GWR Superconducting Gravimeter (SG).

Purpose

By virtue of the collocation of VLBI, GNSS, and an absolute gravimetry site with ancillary observations of atmospheric water vapour, weather, and with the prospect of collocated tide gauge and seismometers, OSO is looking forward to play a key role in international research and observation programs, most notably under the GGOS umbrella. Starting in March 1993, absolute gravimetry teams have carried out measurements at 29 occasions, on average once per year with increasing activity from 2003 on. In 2004 and 2006, two additional AG groups obtained their own instruments (UMB at Ås, Norway, and NLS at Gävle, Sweden). The absolute gravity platform can support two FG5 instruments side-by-side. The common denominator of the AG projects is to determine solid earth and oceanic mass redistribution as part of the Glacial Isostatic Adjustment (GIA) process related to the Fennoscandian ice sheet of the Pleistocene.

The main purpose for the SG station will be monitoring of gravity variations for the reduction of systematic perturbations of the campaign-style AG measurements. Together with the space-geodetic instrumentation OSO qualifies to become a **fundamental geodetic station.**

Apart from the plain monitoring and reference purpose the space geodesy group will devote research to study the gravity perturbations as plenty are expected. There is the Kattegat sea basin with coast at a distance of less than 1 km. This basin has tides at the decimetre scale but also dynamic atmosphere response to pressure and wind. At closer range there is a wetland that is flooded in spring and drained in late summer every year. The hydrological situation of the site within a distance range of 100 m may be more favourable than at many other SG stations. However, we still may expect an impact of ground water and soil moisture and also ground temperature variations despite a number of countermeasures taken prior to and during the construction of the station. More on these issues follows below.

The site

The Onsala Space Observatory is situated near the coast of Kattegat about 40 km south of the city of Göteborg, Sweden. In Figure 1 we zoom in on the OSO area. In frame 1.c the wetland and the beach are outlined. Both lie at sea level while the height of the gravity points (O the existing AG-point and X, the place of the SG and new AG points) are at about 6 m above the sea. The wetland may be flooded to on average 1 m water depth; however, soil moisture may be influenced to some unknown depth. The beach uses to run dry during weather periods of high-pressure about to the ends of the blue line. Except for farmland and meadows the surface near the observatory is made up of bedrock outcrop, eventually with thin soil and organic layers carrying brush and tree vegetation.

In frame 1.d a piece of land covered with a 2-5 m sediment pack is delineated in orange. A large part is covered with asphalt. The administration building is located on top of it. Part of the pack has been added in 1980 before the building was made. The pink polygon encircles the near surrounding of the planned gravimetry facility. It has been cleared of vegetation and sediment in the spring of 2008. In the course of that the bank of the outcrop was denudated, and a pit of 3 m depth capable of holding a volume of 100 m^3 water was uncovered. The pit fills slowly from the sediment pack and quickly from rain showers by draining 50% of the outcrop area. The distance between X and the 20 $m^{ø}$ radio telescope is 60 m.

Bedrock

The rock in the outcrop is composed of low-metamorphic gneiss with about 25% quartz content, eventually crossed by veins of amphibolite carrying orthopyroxene and plagioclase. The outcrop is in unit with the bedrock.

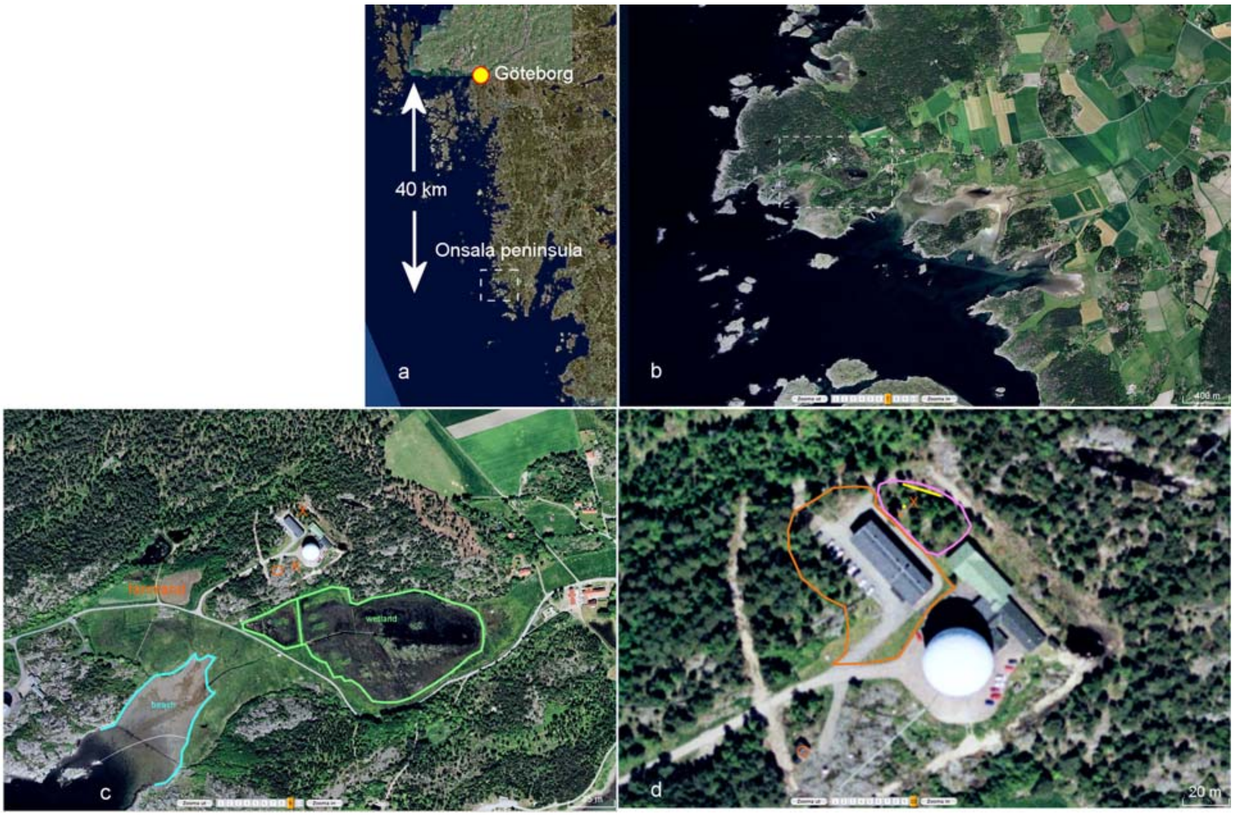

Fig 1 Zooming in on the Onsala Space Observatory on the Swedish West Coast. The coordinates of point X, the gravimeter site under construction, are approximately N 57° 23' 45", E 11° 55' 36"

Reconnaissance

As a first prospecting effort we conducted a **ground-penetrating radar** survey. Two places were investigated, X and another candidate site labelled K in Fig. 1c-d. The radar survey was able to detect fractures in the rock down to about 10 m depth. A major subhorizontal fracture was detected near X. It was decided to stay clear of this fracture utilising that it cuts the surface at the yellow line (Fig. 1d) from where it continues to the NNW. Thus, the highest elevation part of the outcrop will not be used. The surface near point X forms a stair-step shape at a level 1 m above the surrounding pavement of the administration building.

A **borehole of 20 m length was cored** in spring 2008 (yellow dot). Together with a pre-existing borehole (brown dot) we have the opportunity to install water level sensors close to the gravimeter platforms. See the photo in Fig. 2.

The results of the core examination and rock quality inference are summarised in short as follows:

The average hydraulic yield in **drainage tests** of the bedrock is 0.2-0.3 m^3/h. At the site there are three families of **fractures** characterised by their orientation angles. One family has shallow dip (20°) and two families steep dip (70° resp. 85°). The latter intersect at almost right angle as their strike angles are 80° resp. 285°. All fracture surfaces are plane or slightly bulging with little roughness. The frequency of the steep fractures is low, mean distance being 1 m. A subhorizontal fracture zone is located at 2.05 to 2.3 m depth. Drainage measurements showed little flow, which suggests that it is filled with clay. Open cracks with high water conductivity appear to exist in another fracture zone between 5.81 and 6.23 m depth. This depth is meters below the average ground water surface. The surfaces of thinner fractures at greater depth show some effect of extended contact with ground water.

The question has been raised whether tightening of the fractures by injection with fine cement would be needed in order to lower ground water flow. The findings that the upper fracture zone seems almost water-tight and the lower being well below the ground water surface suggest that this measure would not be necessary. The water mass inside the rock would be small and sufficiently constant, and injection would have little effect to mitigate the mass redistribution.

Piers and pillars

Two pillars will be cast in concrete using a recommend recipe (T. Lambert, pers. comm.). Magnetically neutral arming will be used. The pillars will be high, 1.5 m, with a 1.2 x 2.0 m cross-section. The tops will be honed to level and smoothness. The AG pier is wide enough to be occupied by two FG5 instruments simultaneously. The SG pier is wide enough for placing a portable gravimeter or other movable instruments next to the SG meter.

Cabin design and construction

The **bearing walls and foundation** of the cabin can be erected on the bare rock surface without blasting or hammering. For drainage of rain water, some blasting is necessary. Only the outer walls of the cabin will carry the weight of the floor, roof etc. No part of the cabin will touch the pillars except for soft, air tightening gaskets around the top of the piers.

The SG-AG station is divided into an **inner cabin** for the SG and an **outer cabin** housing the AG pier. The entrance of the building has an air sluice. Windows have been avoided. The inner cabin is only passively connected by outlets at ceiling height to the air of the outer cabin, where temperature and humidity are controlled by a air conditioner device. Heat exchange between the cabins occurs thus predominantly by conduction through pier, floor, ceiling and walls. A blueprint of the hut is shown in the Appendix.

The inner cabin will house only the SG sensor assembly. Control and data acquisition units and compressor/refrigerator are placed in the outer cabin.

Perturbations

Candidate site K was ruled out for two reasons: frequent car traffic at a 10 m range and a 30 m range to the radio telescope. The weight of the instrument, roughly resembling a mass dipole of 2 x 4500 kg on a 10 m arm 10 m above the eventual gravimeter would exert a maximum attraction effect on the order of 1 nm/s^2 during slewing of the telescope by 90°. As the effect decreases with the distance cubed, at site X 0.1 nm/s^2 effects is expected. It is possible to log all telescope motions and model the effect by regression with respect to antenna azimuth and elevation. **Wind load** may be a problem since the site faces Kattegat to the west with almost no wind shelter effect. Although site X is more or less in the shadow of the administration building, and the latter rests on a sediment pack, we nevertheless have to expect ground shaking from the wind load on the administration building, as well as on the planned hut itself. In order to attenuate **seasonal temperature cycles** the gravimetry hut will be surrounded by an insulating layer of polystyrene foam 1 to 2 m wide. The air temperature in the outer cabin of the hut will be kept constant using an air conditioning device. Air from the height of the ceiling will be circulated by fans and directed to under the floor, thus transferring heat to the rock surface. The gravimeter pier will be enclosed by thin walls in order to prevent the air from blowing against it and eventually escape back to the cabin near the instruments. We expect to reach steady temperature gradients during one month. What will be left is the annual temperature cycle. A finite-difference model was used to predict ground and pier temperature depending on solar irradiation, surface back-radiation, and thermal conductivity in the rock. The calculations show that the annual variation will be strongest at depths between 2 and 4 m below the pier; its amplitude is predicted at 2 °C (see Fig. 3). The height of the pillars was determined to minimise effects of **mass variations**

Fig. 2 Civil engineering geologists Sarah Mell and Bengt Ludvig standing on the ground level of the future gravimetry building. In the front the cap on top of the 20 m core borehole is visible. The puddle, a result of rain and surface water collection, will be adverted by means of a drainage canal. After one week of existence of the puddle while the weather had been dry, its water level was still about 1 m higher than the ground water surface in the borehole, suggesting negligible flow through the rock.

around the site. The height at which the SG sensor will be located is approximately at the level of ground water in the **forested area** to the north and east. The level also coincides with the height of the bottom floor of the administration building. With tongue in cheek the chosen height level is also a perfect trade-off of downward pulling gravity exerted by the **cars** parked to the SW of the administration building and the upward pulling effect of their drivers, i.e. **observatory personnel**, if (and only if) they are in the office on the top floor of the building. The effect we speak of is at the 0.01 nm/s^2 level, but nevertheless an S_1 **human tide** following the UT-synchronous office hours, widened by weekend free-time (thus biasing the observable NDFW effect) could be minimised this way.

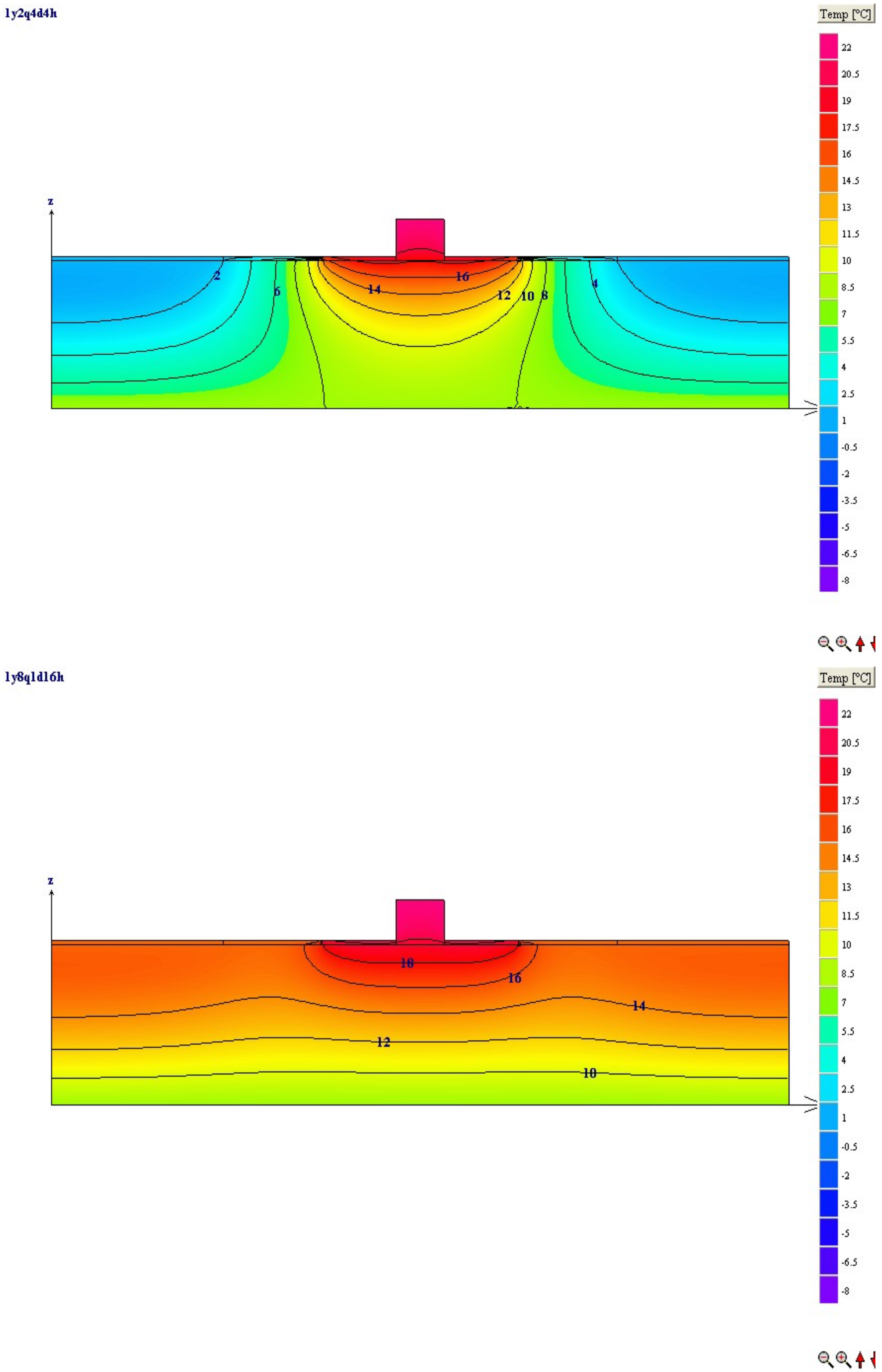

Fig. 3 Heat flow model, estimated temperatures below the gravity pillar in February (top) and August (bottom). The model takes into account the presence of the hut and its estimated heat generation, and the seasonal climate variations characteristic for the area. The model covers a length of 40 m and a depth of 8 m.

Supporting equipment and installations
In order to monitor the vertical motion due to thermal expansion, eventually amplified by rock heterogeneities and fracturing, a borehole drilled to 4 m depth near the SG pier will house an invar rod. By this we will be able to monitor the height of the top of the pier with respect to the rock at 4 m depth continuously at a µm resolution.
Additionally, the following sensors will be installed:

- Thermistors in different locations in the pillars and in the bedrock below the pillar.
- Borehole sensors to monitor ground water level and temperature.
- Water level sensors in the well in the wetland.
- A tide gauge instrument in the sea at the observatory
- Rain meter
- A 3-component broadband seismometer (hopefully)

GGP participation and data management
The gravimeter facility promotes us to become a fully cooperative partner in GGP. At OSO we will archive the gravimeter data along with the environmental parameters and records from the sensors (water levels, ground temperatures, meteorology) except from the tide gauge (for which SMHI will be responsible) and the eventual seismometer (for which Uppsala University will be responsible). We will adhere to the agreements and standards of GGP as laid out in http://www.eas.slu.edu/GGP/ggpas.html .

GGP-name of the site and location
The official name of the station in the context of GGP is suggested as
Onsala Space Observatory, Sweden.
Short name: **On**
Location: N 57° 23' 45", E 11° 55' 36" (prelim.)

Current status as of September 2008.
The instrument has arrived. The first building stage will occur during September 2008. The site will be ready for installation and acceptance test earliest by mid December 2008.

Acknowledgements
Thanks to Christer Ahlinder for the thermal model calculations. Thanks also to Tony Lambert, Ludger Timmen, Walter Zürn, Jürgen Neumeyer and David Crossley for helpful comments and advice.