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FIELD SUPERCONDUCTING GRAVIMETER (FSG)

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Observatory Superconducting Gravimeter (OSG)

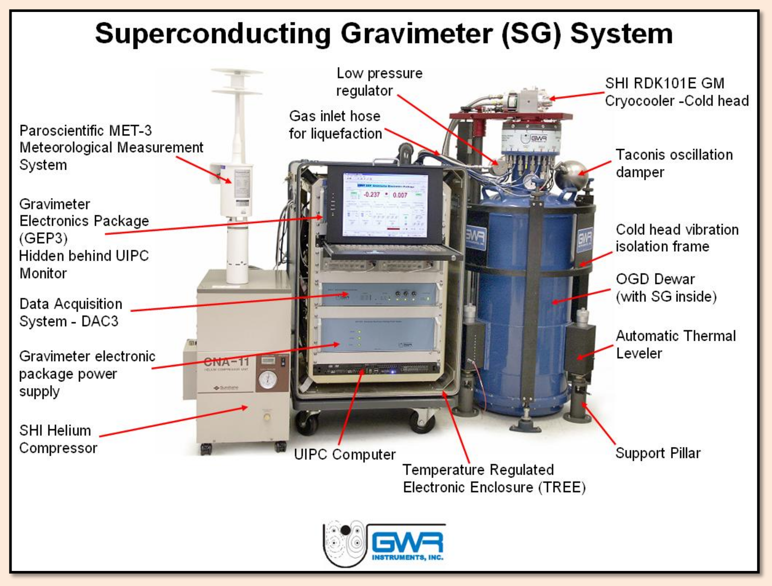
OSGs are designed for long term continuous measurements, operating for decades or more at one location. Therefore, GWR has designed the equipment to eliminate as many data interruptions as possible.

•The 4K Refrigeration system eliminates offsets or interruption from transfer of liquid helium that existed in previous TT70 and Compact SGs. Liquid helium is added to the inside of the Dewar by condensing helium gas supplied from external gas cylinders. This process eliminates offsets and produces a minimal increase in noise.

•Strict adherence to the specifications of the Global Geodynamics Project's guidelines for timing accuracy, analog data filtering, and barometer specifications.

•Features to ensure the quality of long term data include:

- Continuous display of a generated residual signal, so that disturbances as small as 0.1 microGal can be easily observed.
- A removable voltage standard
- Convenient user's and system logs to correlate any data interference with user or system descriptions and time stamp.
- Programmable alarm systems to automatically email user if any parameters exceed preset specifications.
- Coldhead frame is designed for easy removal and insertion of coldhead so that mechanical shocks are eliminated. This eliminates the source of offsets that was present in previous designs.



OSG Gravimeter Sensor Specifications

- **Precision:** 0.1 to 0.3 μGal/(Hz)$^{1/2}$
- 0.012 to 0.040 μGal for a one-minute averaging time
- **Drift:** Typically less than 6 μGal/year after 6 to 12 month stabilization period.
- After 2 to 3 years drift is between 1 to 3 μGal/year
- **Calibration**: Calibration done by users to a precision of better than 0.1%.
- **Scale factor (calibration) stability:** By comparing the OSG signal to models of the Earth Tides, several users have reported the scale **factor to be constant to** better than 0.01% over several years.

Customer Modified "Transportable" OSG

The Superconducting Gravimeter has been used for over 30 years and its history, development and many applications have been thoroughly documented (Hinderer, Crossley and Warburton, 2007). With very few exceptions, past measurements were made at fixed stations or observatories with the intent to measure gravity variations for decades. As a result of high interest in using SGs for hydrological measurements, several new users have requested SGs that can be moved to allow temporary installations to measure water storage properties of selected aquifers. One of the first to do so was Dr. Clark Wilson (Wilson, 2009) who has packaged the OSG into two large enclosures with dimensions of 1.5 x 0.8 x 1 m and mass of about 250 kg. As can be seen by the pictures, the size of the Dewar and electronics; and the complexity of the coldhead frame make for a very complex assembly inside the enclosures. This has encouraged GWR to proceed with a simple Field SG design that is much easier to move and operate at remote locations.

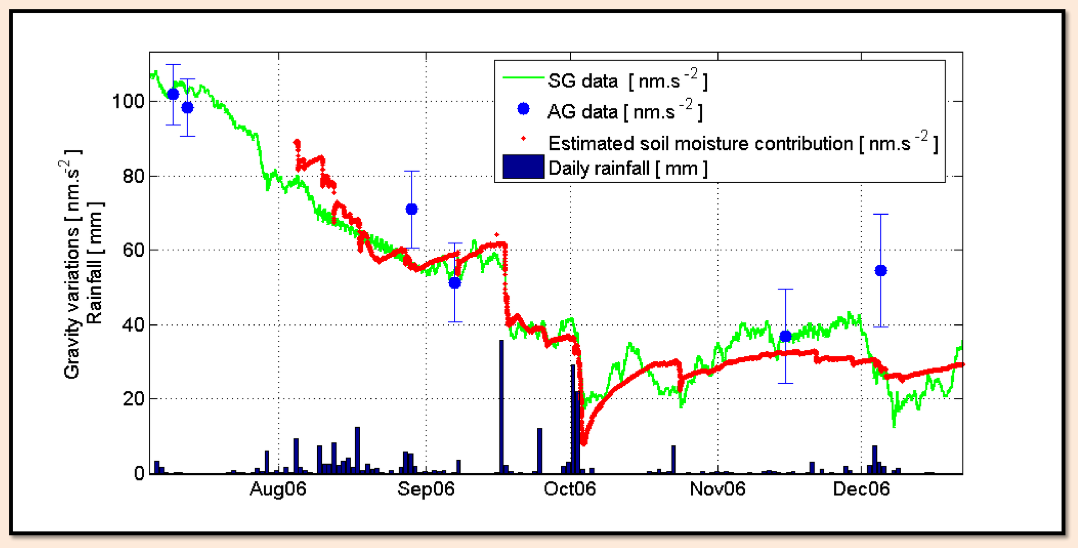
Although Wilson did not measure significant changes in hydrology because of prevailing drought conditions, his experiment did demonstrate the feasibility of operating an OSG in a remote location unattended for periods of many months.

Interior of enclosure E2
E2 contains the helium dewar, coldhead and coldhead frame with rack mounting of most of electronics at upper right. In the lower right are the computer and current supply for sphere levitation.

Interior of enclosure E1
E1 contains UPS and refrigerator. Lightning Surge protector and thermostatic control for the top-mounted cooling fan are located at mid-level.

Hydrological Measurements – An old nemesis turns into a signal of high importance and interest :

For many years, hydrological signals were considered a nuisance and as noise interfering with other gravity signals of choice. However, deployment of the GRACE satellites ignited interest not only in regional and global hydrology; but also in local hydrology. Accurate hydrological models needed to be developed and tested in order to remove local hydrological effects from SG records. Removal of local effects would enable using the SG's measure of regional hydrological signals as a test of satellite measurements. As a by-product, researchers realized that the SG could be a powerful tool for studying local hydrology – in particular water storage and discharge in regional aquifers that are crucial to both agriculture and cities water supply.



Gravity variations (SG in Green; AG in Blue) versus Rainfall and estimated soil moisture.
An example of temporal variations of the gravity field caused by water infiltration within the ground (Longuevergne, L., 2008).

Local hydrological contributions to gravity

Since the SG responds to and records all gravity signals from DC to 1 second, it provides a continuous measure of all hydrological signals. These include: accumulation of moisture in clouds overhead, rainfall, percolation of rainwater through the soil, changing soil moisture, and underground water storage. Therefore, the SG provides the continuous data needed to correlate with land surface hydrological models that use meteorological data, in situ soil measurements, water run-off, and various parameterizations of the soil-vegetation-atmosphere continuum. The Figure below shows a comparison of the Catchment Land Surface Model (CLSM) set up and forced by high resolution meteorological data at the scale of the hill where the SG is located in Strasbourg, France

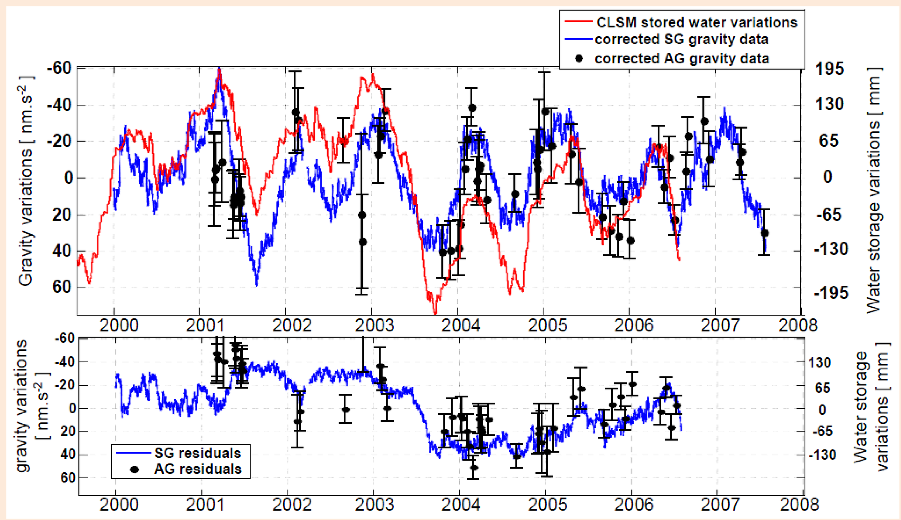


Figure: Top, comparison between modeled and observed gravity variations. The modeled variations are deduced from the variation of stored water simulated by the CLSM (including canopy interception, snow pack and total ground water) and the observed variations (both SG and AG) corrected from atmospheric and global hydrological contributions.
Figure: Bottom, residuals between modeled and observed gravity effects. The right vertical axis translated gravity effect in terms of equivalent water layer using the -0.3 nm.s^{-2}.mm^{-1} coefficient. (Longuevergne, L., et al., (2009))

The Field Superconducting Gravimeter (FSG)

The Need for a Field SG

Many new applications need a less expensive SG to be used in local, regional or national networks. For example measuring subsidence or crustal uplift over large areas; hydrology; oil and gas reservoir monitoring. However, a less expensive version must retain two fundamental properties of previous SGs – the extremely low drift and low noise of less than 1 μGal.

In addition, the Field SG must be simplified for easier installation; moving; and operating. GWR Instruments is presently building the first prototype Field SGs for distribution in 2010. The FSGs will have the following characteristics:

New Modular Design

This allows separation of SG into 4 parts, each of which can be moved easily. Major improvements include a lighter Dewar and sensor and reduction of both the physical size and power consumption of the electronics. The electronics now reside in the head of the Dewar. The five modular parts are:

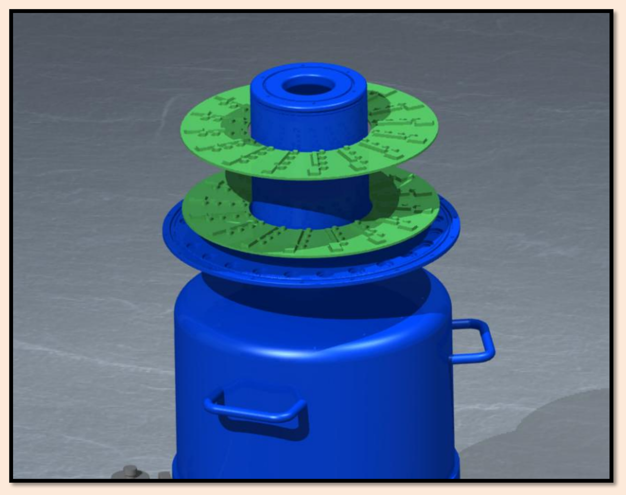
- Base plate/thermal leveler (18 lbs). This can be set on the floor or bolted down.
- Lightweight Dewar – this contains both the sensor and electronics (70 lbs).
- Coldhead (18 lbs)
- Compressor (165 lbs)
- Data System and Control Box (15 lbs) – remote access by Ethernet
- User friendly software

Simplified Initialization and Operation

- Magnetic gradient set at GWR
- Field SG can be moved without lowering the sphere
- Separate coils for re-centering the sphere after the Field SG is moved
- Much smaller UPS required to backup low powered electronics

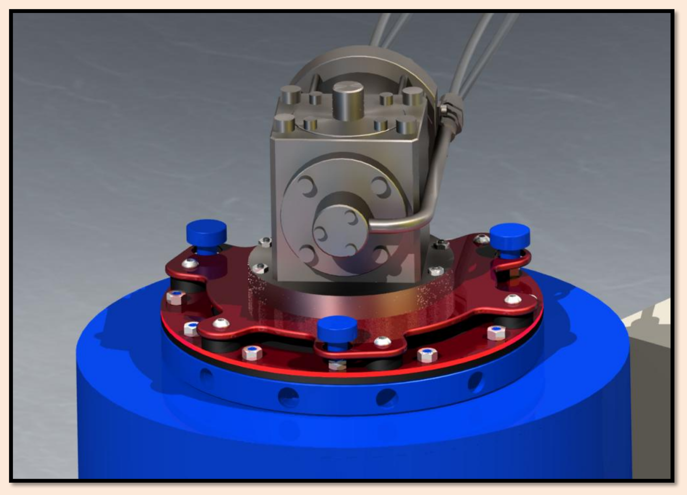
New Electronics

Small low powered electronics now fit inside the head of the Dewar. This eliminates the extensive cabling required for the OSG and the need for a separate electronics enclosure. This is shown in the figure below:



Elimination of Coldhead Stand

Four bolts are used to attach the coldhead into the head of the Dewar. A vibration damper is placed between the coldhead and Dewar to minimize noise and to seal the Dewar.

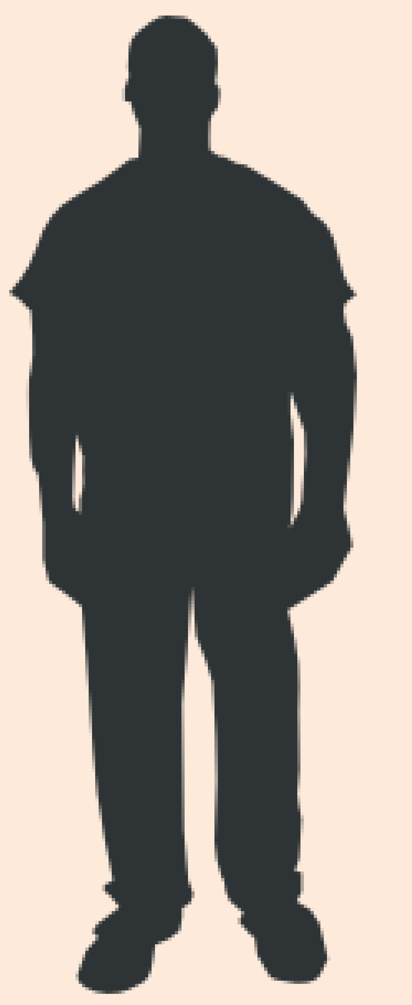


Field SG Specifications:

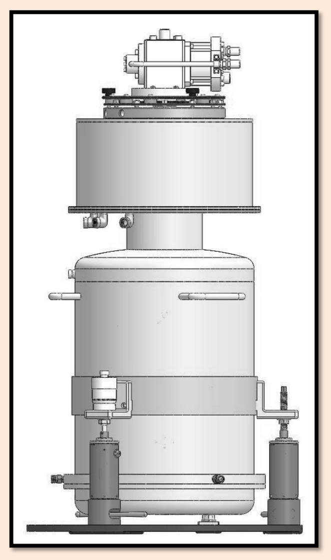
Maintains similar characteristics to Observatory SG
Drift less than 6 μGal/year
Noise of order 0.1 μGal
Electronics insensitive to temperature – less than 0.1 μGal /10 C
Insensitive to humidity
Automatic leveling of gravimeter

Under Development

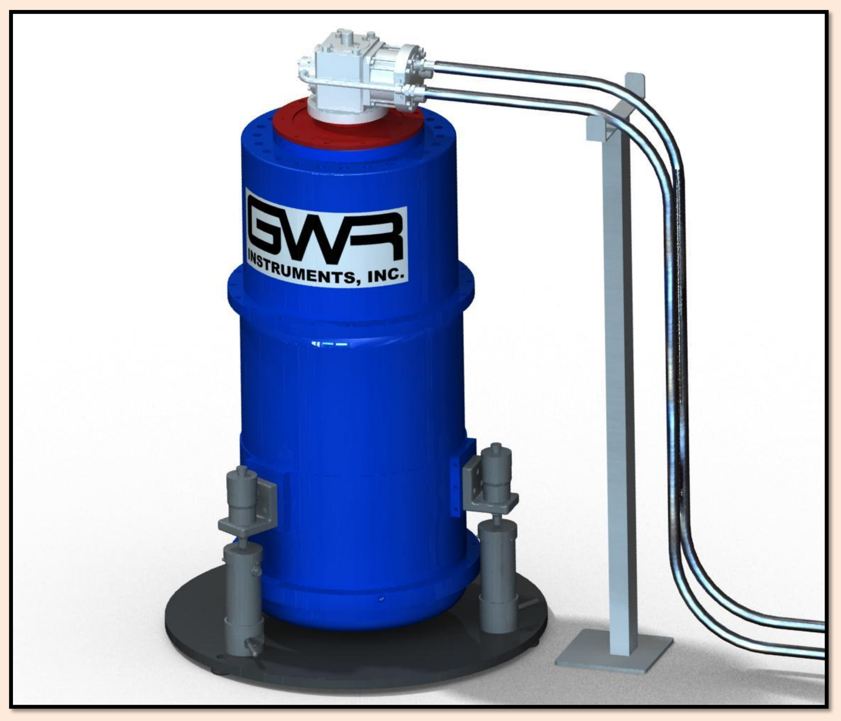
- Automatic sphere levitation
- Refrigerator capable of cooling the Dewar/sensor from room temperature to 4 K without needing any liquid helium.
- Extended high temperature range for Compressor
- Temp regulation enclosure for FSG operating indoors
- Portable outdoor enclosures for FSG operating outdoors



6 foot man (1.82 m)



Side view of FSG compared to scale of man at right



Rendering of Field SG showing base plate with leveler, Dewar and coldhead

Synergy Between AG and SG Measurements

Several groups (Including Van Camp, M., et al. (2005), Wziontek, H., et al. (2007) and Longuevergne, L., et al. (2009)) use a combination of concurrent sets of SG and AG gravity measurements. Typically the AG is used to calibrate the SG and to measure and remove its drift. Since the AG's noise level (300 to 480 nm.s^{-2}.Hz$^{-1/2}$) is typically 100 times higher than the SG's noise level of 1 to 3 nm.s^{-2}.Hz$^{-1/2}$ (Van Camp, M., et al. (2005)), the SG is then used to provide a continuous and precise measure of all gravity changes at a single location. Historically, the AG has also been used to eliminate DC offset that may occur in the SG record. However, the real advantage of the AG is its ability of make repeated temporal measurements over a large geographical area.

More recently Wziontek, H., et al. (2007) have shown that the AG may also suffer from offsets. Despite their absolute characteristics, changes caused by maintenance of equipment, mechanical wear or misalignment may result in small offsets with respect to previous observations. Generally AG offsets are within the AG instrumental accuracy of +/- 20 nm/s^2 , which demonstrates the stability of the AG over a time span of several years. Nonetheless, correcting the AG using SG records decreases the standard deviation of AG measurement from 22 to 14 nm/s^2 as shown in the figure below. This result supports many groups that out of personal experience already regularly check their AGs versus local SGs to verify proper operation.

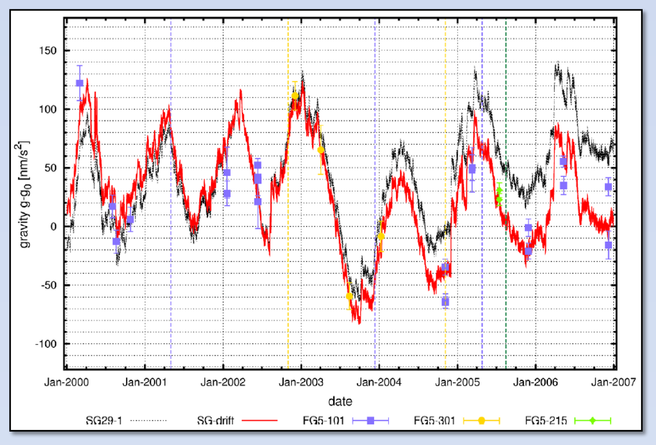


Figure 1, lower (Wziontek, H., et al. (2007)): Gravity values after removal of main parts of the time dependent gravity signal for Wetzell, Germany based on results of simultaneous adjustments to AG measurements at both Bad Homburg and Wetzell. The black and red curves show the residual time series for the lower sphere of SG 029 before and after the drift correction (drift about 1.4 +/- 0.2 nm.s^{-2}/year). Symbols indicate mean absolute gravity values for the observation epochs after offset correction. Vertical lines designate significant offset periods in AGs.

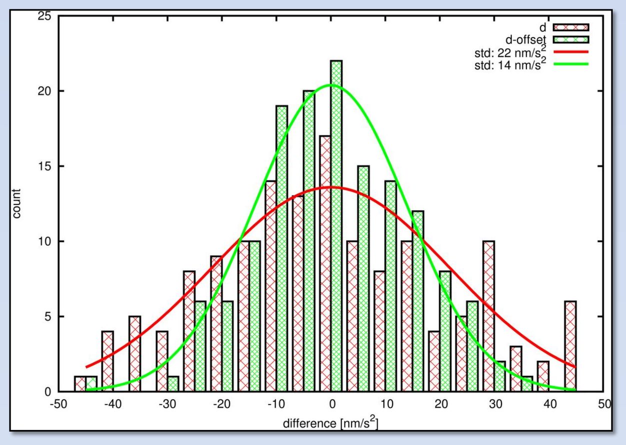


Figure 3 (Wziontek, H., et al. (2007)): Histogram of difference between AG measurements and SG 030 lower sphere before (red pattern) and after (green pattern) apply offset corrections to AGs. The standard deviation reduces rom 22 to 14 nm/s^2.

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