

# Taking the Superconducting Gravimeter to the Field - A new tool for Hydrologic and Other Investigations

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## ABSTRACT

A Superconducting Gravimeter (SG) provides the best precision available, in the 10-nanogal range, with sampling as frequent as once per second. Although the SG has been available for over three decades, it has been restricted to laboratory and vault environments. We have adapted a GWR SG to a transportable configuration for field studies in support of hydrologic and other investigations. Initial application will be hydrologic studies in karst and desert alluvial aquifers. The system is designed to observe hydrologic variations in gravity with a precision of  $\sim 1 \mu\text{gal}$ , equivalent to the attraction of a layer of water  $\sim 2 \text{ cm}$  thickness. Companion weather and well observations will be used to observe and interpret the gravity signals in terms of infiltration and storage changes, and GRACE satellite gravity data will allow separation of regional and local influences.

## Enclosure Configuration



Fig 1. Left image: superconducting gravimeter, its electronics and user interface computer (within one enclosure), refrigerator and UPS (within another enclosure), and hand-lift in lab.



Figure 1 Bottom row of images shows our superconducting gravimeter (SG) system. The gravimeter and associated instruments are contained within two enclosures, which have cooling systems and waterproof aluminum boxes. The hand-lift helps to transport and install the system in the field. By making the instrument transportable, one may choose sites where better-defined hydrologic problems can be investigated, and consider tectonic, volcanic, and other applications, such as deep slow earthquakes (Crossley D. et. al., 1999). The lower row of images shows from left to right: Power Supply and 4 Kelvin refrigerator in one enclosure; 35 liter helium dewar containing sensor in the gravimeter enclosure, with instrument rack on right; and right, the instrument rack showing GWR data logger, volt meter, barometer, electronics, and at the right side, the enclosure heating / cooling system.

## GRACE vs. SG

Compared with GRACE satellites, the SG makes local but much more precise and frequent measurements at Earth's surface. We expect to be able to interpret SG signals at the 1 microgal level, comparable to GRACE.

	GRACE	SG
Gravity resolution ( $\mu\text{Gal}$ )	$\sim 1$	$< 0.01$
Spatial resolution ( $\lambda/2$ )	$\sim 500 \text{ km}$	Point
Temporal resolution	1 month	1 second
Long-term stability (drift)	No drift	$\sim 1 \mu\text{Gal}/\text{month}$

Fig 2. Comparison of GRACE and superconducting gravimeter measurements.

Technical advances have reduced the size of the SG helium dewar and solved the helium replenishment requirement via a compact refrigeration system. With the ability to cool to 4 K, it is possible maintain a full dewar indefinitely. With support of NSF EAR Instrumentation and Facilities, we procured a GWR gravimeter and developed the system to be transportable, self-contained within two enclosures, and accessible via cell-phone internet service. A bracket system allows the helium dewar containing the gravity sensor to be locked to the frame and transported without disassembly.

## System Configuration

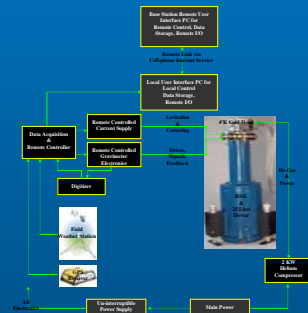


Fig 3. Schematic diagram of field superconducting gravimeter system.

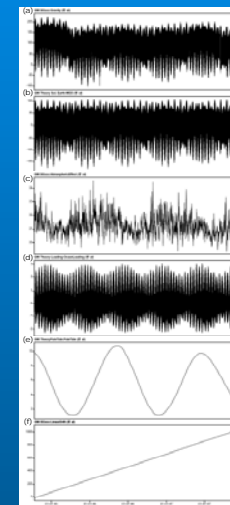
Figure 3 shows the configuration of the system. Besides the superconducting gravimeter, the system includes a GPS receiver (to measure atmospheric water vapor, and provide a time standard), and a field weather station (to get barometric pressure, temperature, rainfall data etc.). The on-site user interface computer (UIPC) is used to store and transfer data that collected from all devices. An uninterruptible power supply (UPS) is provided to maintain proper system operation during power failures. The system can be accessed and controlled through wireless Internet. When deployed in the field, it is possible that well observation and moisture content measurements will also be available.

## Measurement

Temporal gravity variations include solar and lunar tides, solid Earth tide, selected secular variations, pole-tide, atmospheric and oceanic effects and terrestrial water storage variations. Figure 4 shows typical amplitudes. Because SG's accuracy is about 10 nanoGal, all these signals can be seen in the records. Coupled to Earth's surface, the SG is sensitive to the gravity effect due to elastic loading deformation (unlike GRACE).

Solar and lunar tides - Including Direct Attraction and Solid Earth Tide (Earth's elastic response to solar and lunar tides)	$\sim 200 \mu\text{Gal}$
Pole-tide	$\sim 10 \mu\text{Gal}$
Atmospheric mass (pressure) attraction change	$\sim 20 \mu\text{Gal}$
Oceanic loading effect	0.3-3 $\mu\text{Gal}$
Terrestrial water storage variation	$\sim 20\text{-}50 \mu\text{Gal}$

Fig 4. Sources and amplitudes for various sources of temporal gravity variation.



## Data processing

Figure 5 shows a typical data processing procedure for SG data. The raw data was collected by a GWR compact style superconducting gravimeter C024, which is installed at Table Mountain Gravity Observatory (TMGO) near Boulder, Colorado (Van Dam et. al., 1998). In order to retrieve terrestrial water storage variation, other gravity effects must be modeled and removed from SG data. From top to bottom are (a) raw gravity data, (b) Earth tides due to Wahr-Dehant model, (c) atmospheric effect due to local air pressure, (d) ocean loading effect due to NOA99-model, (e) pole-tide effect due to IERS data, (f) linear instrumental shift. The gravity residual mainly reflects terrestrial water storage variation, which consists of changes in surface water, soil moisture and groundwater.

Fig 5. Processing of SG data (Table Mountain Gravity Observatory, Boulder, Colorado)

## Conclusions & Acknowledgments

1. Superconducting gravimetry (SG) has been adapted to field studies in support of hydrologic and other investigations.
2. SG recordings are accurate and frequent enough to detect local groundwater signals at cm level and variations within a day.

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## References

- Crossley, D. et. al., Network of Superconducting gravimeters benefits a number of disciplines, E.O.S. 80(11), 1999
- Van Dam, et. al., Two years of continuous measurements of tidal and nontidal variations of gravity in Boulder, Colorado, Geophys. Res. Lett. 25(3), 1998