GWR INSTRUMENTS, INC.

*i*Grav® Superconducting Gravity Meter

Superconducting persistent currents (*i*) produce the most stable relative gravity meter in existence

The iGrav SG provides continuous high-precision gravity data for studying a wide variety of geophysical phenomena

Super **stable**

Drift < 5 nm/s^2/month and constant
Scale factor constant to better than 0.01% for years

Super **precise**

1 nanoGal (10^{-2} nm/s^2) resolution in frequency domain
< 3 nm/s^2 resolution for 2 minute averaging

Super **low noise**

< 10 (nm/s^2)^2/Hz in seismic band (1 to 8 mHz)

PORTABLE, EASY, MORE AFFORDABLE

The *i***Grav**® Superconducting Gravity Meter is a more moveable and less expensive version of its predecessor, the Observatory Superconducting Gravimeter (OSG), used in the Global Geodynamics Project[1,2] and for more than 30 years worldwide.

Like the OSG, the ***i*****Grav** uses a superconducting shield, sphere, and coils[3]. Supercurrents flowing in the coils produce a magnetic field which levitates the sphere. The levitating sphere and magnetic field replace the function of the mass and mechanical spring found in other relative gravity meters. The perfect stability of the supercurrents produces a completely stable, non-mechanical, zero-mass, zero-length, non-degrading spring.

The *i***Grav**:

- **Requires minimal infrastructure**
  A small concrete pad, 1.5 kW power, and an Internet connection for remote access is sufficient.

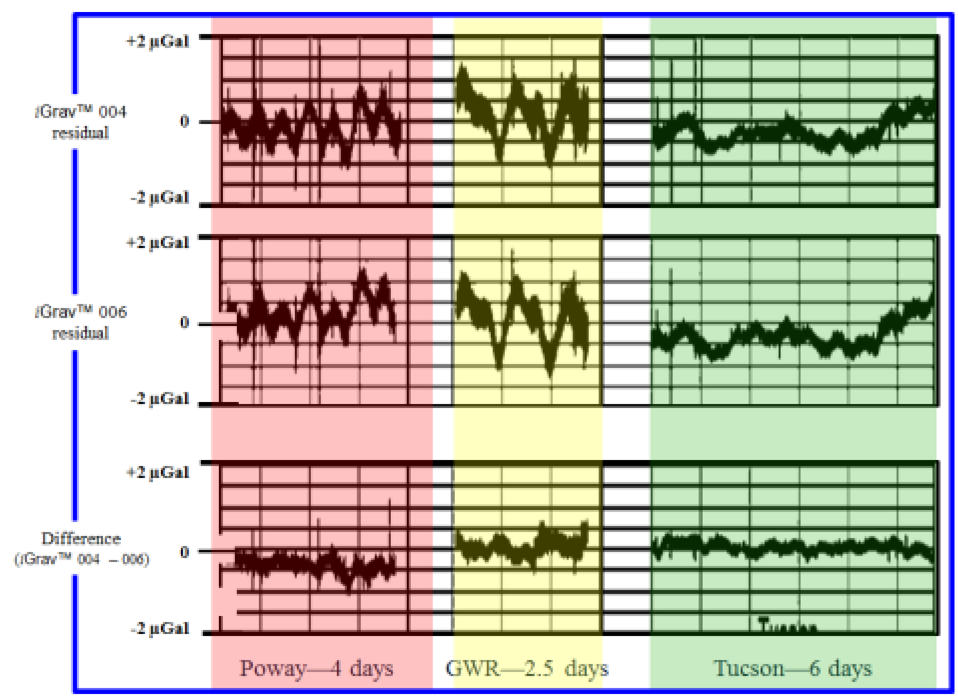
- **Requires minimal training**
  Sphere levitation is done in minutes with user-friendly control software
- **Consumes no liquid helium (LHe)**
  The refrigeration and Dewar system liquefies 16 L of liquid He from 9000 L (350 cu ft) He gas, transported in a standard gas cylinder
- **Has a simplified coldhead stand and frame**
  Coldhead insertion and alignment is straightforward
- **Is mobile**
  The *i***Grav** can be moved while the sphere is levitating, without a drift or change in scale factor (see Figure below).
- **Is less expensive**
  Approximately half the price of OSG
- **Is controlled remotely**
  System monitoring, control and data downloads via internet or other TCP/IP connection

Two *i*Grav SGs were moved from Poway, CA, to GWR (in San Diego), and then to Tucson, AZ.

Difference in the signals remained <0.5 µGal. We can therefore conclude:

- **No drift caused by moving the *i*Gravs**
- **The calibration remains constant to within 0.01%**

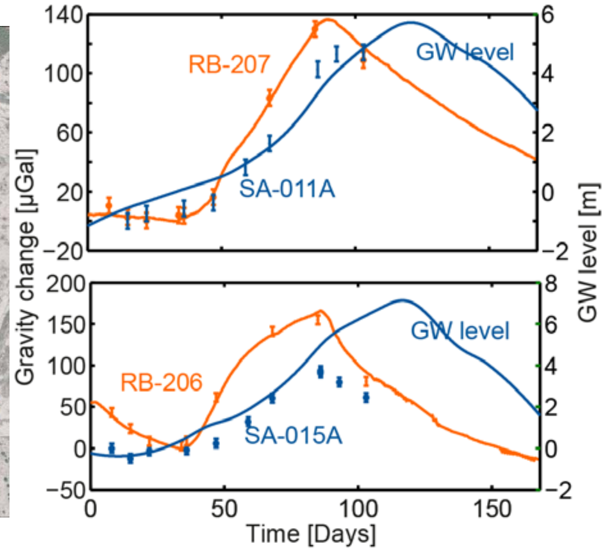
No drift is removed in the analysis at any of these sites!



APPLICATIONS

The *i***Grav** SG can be used as an ultra-high-precision **continuous** gravity reference for observatory measurements, short term deployment, or differential gravity measurements.

The figures to the right show an example of using gravity to measure water-storage change at a groundwater recharge facility in Tucson, Arizona (See Kennedy J *et al.* 2014; reference 4 below).



Orange lines show residual gravity from *i*Grav 004, operating at recharge pond RB 207, and *i*Grav 006, operating next to pond RB 206 500 m to the south. Extensive AG measurements (orange points with error bars) verify the drift-free operation of both *i***Grav** SGs. Blue lines show ground water level for wells SA-011A and SA-015A; blue points and error bars are co-located AG measurements. These data show how gravity variations can vary dramatically at an active hydrological site over short times and short spatial distances.

The *i*Grav SG provides continuous high-precision gravity data for studying a wide variety of geophysical phenomena, including:

- ✓ **Volcano monitoring**—both slow deformation and explosive activity
- ✓ **Hydrological**—e.g. non-invasive ground water monitoring
- ✓ **Geothermal**—mass movement dependence on injection and extraction
- ✓ **Subsidence** caused by oil, gas, or water extraction
- ✓ **Long-term tectonic effects**—either post-glacial uplift or subsidence
- ✓ **Active faults** and regions of active vertical displacement
- ✓ **Hazard-reduction geophysics**
- ✓ **Silent or slow-slip earthquakes**

PORTABLE

***i*Grav being transported by compact sports utility vehicle (SUV)**

The complete *i***Grav** SG can be moved in the back of a 2000 Honda CRV with a cargo space of 2 m^2 (72 ft^2). At a site prepared with a pier, electrical power, and an internet connection, the *i***Grav** SG can be up-and-running in 5 hours or less.

FEATURES

- **Consumes no liquid helium**
  Never buy or transport LHe again!
- **Cryogenic environment**
  Insensitive to local pressure, temperature, or relative humidity.
  Even moving the *i***Grav** does not affect its calibration factor or (negligible) drift rate.
- **Integrated data acquisition and control electronics**
  Microprocessor-integrated electronics reside in dewar head and control tilt and temperature. High resolution gravity data is logged in real time by 24 bit A/D that resides on gravity board in dewar head. Time stamp is provided directly from GPS signal.
- **Low-maintenance**
  10,000-hour recommended coldhead maintenance interval.
- **Simple power supply system**
  Electronics integrated with Dewar operate on 24 V DC supply. Uninterruptable power supply (UPS) is provided as an option.
- **Remote control**
  System monitoring, control, and data acquisition via an Internet or other TCP/IP connection.
- **Simplified initialization and operation**
  Minimally trained personnel can set up and operate the *i***Grav** in a day

SPECIFICATIONS

***i*Grav® Gravity Sensor** (single-sphere Niobium-based transducer)**:**

Noise:	3 nm/s²/(Hz)$^{1/2}$
Frequency domain:	Sub-nanoGal (< 10^{-2} nm/s2) signals observed
Time domain:	1 to 3 nm/s² signals observed, 1-minute filtering
Scale factor:	Stable to better than 1 part in 10^4 for decades
Linearity:	Linear to 1 part in 10^7
Insensitivity:	Cryogenic environment insensitive to temperature, pressure and humidity

System Electronics:

Gravity control electronics:	Sphere position controlled to < ±1 Å
Cryogenic temperature control:	Sensor body controlled to < ±2 μK
Barometer:	Setra Model 270
Data acquisition:	24-bit ΔΣ ADC; gravity oversampled 8x/sec
GPS timing:	SEL-2401 Satellite Synchronized Clock

System Software:

Remote system access and control:	Via Internet or other TCP/IP connection
Operating system:	Windows 7
*i*Grav® Monitor:	Data acquisition, FTP data transfer Sensor control panel and data plotting Email alarm and warning messages
Data compression and storage:	User-selected variables Easy concatenation into continuous time series Lossless data compression Data saved in TSoft-compatible format

Cryogenic Orthogonal Tilt Meters and TCS-6 Tilt Compensation System:

Sensitivity / dynamic range:	0.1 μRadians / 60 mRadians
Controlled alignment with set vertical:	0.1 μRadians
Dynamic range of controlled system :	2.5 μRadians

Dewar:

Height (including cold head)/ Diameter:	102 cm (40 inch) / 36 cm (14 inch)
Weight (including sensor and electronics):	30 kg (65 lbs)
Volume:	16 L liquefied from 9000 L (350 cu ft) gas
Base plate & thermal levelers:	55 cm (21.5 inch) diameter / 7 kg (16 lbs)

Refrigeration:

Coldhead:	Sumitomo SRDK-101D
First stage:	3.0/5.0 W at 60 K (50 Hz)
Second stage:	0.1 W at 4.2 K (50/60 Hz)
Ambient operating temp.:	5 to 28° C recommended (10% capacity loss from 28 to 35° C)
Dimensions / Weight:	Width-10 cm x length-23 cm x height-44 cm / 7.2 kg
Coldhead service:	Mandatory factory reconditioning at 10,000-hour interval
Compressor:	Sumitomo CNA-11C, Indoor, air-cooled
Operating temperature:	4 to 28 ° C recommended (10% capacity loss from 28 to 35° C)
Operating pressure:	2.2 to 2.3 MPa
Dimensions / Weight:	39 cm (width) x 450 cm (length) x 61 cm (height) / 75 kg
AC power: phase / voltage/ frequency:	single phase / 100, 120, 220-230, 240 VAC / 50, 60 Hz
Current @ 100VAC:	Max. 13.9 A / steady state 12.4 A at 50 Hz Max. 15.1 A/ steady state 13.3 A at 60 Hz
Compressor service:	Mandatory adsorber replacement at 30,000-hour interval

Options:

Uninterruptible power supply (UPS):	Solar-Craft DC-UPS 24-100 for backing up ***i*Grav electronics only**

Specifications subject to change without notice – 12/02/2014

References:

1. Global Geodynamics Project (http://www.eas.slu.edu/GGP/ggphome.html)
2. Hinderer J and Crossley D (2004) Scientific achievements from the first phase (1997-2003) of the Global Geodynamics Project using a worldwide network of superconducting gravimeters. *J. Geodyn.* **38**:237-262.
3. Goodkind J M (1999) The superconducting gravimeter. *Rev. Sci. Instrum.* **70**(11): 4131-4152
4. Kennedy J, Ferré T P A, Güntner A, Abe M, and Creutzfeldt B (2014) Direct measurement of subsurface mass change using the variable baseline gravity gradient method. *Geophys. Res. Lett.* **41**, doi:10.1002/2014GL059673.

And more than 100 additional references listed at: http://www.gwrinstruments.com/published-papers.html

PRICES AND OPTIONS Contact GWR INSTRUMENTS, INC. for prices and options

GWR INSTRUMENTS, INC.

5985 Pacific Center Blvd., San Diego CA 92121, USA

Tel: (858)425-7655 Fax: (858) 452-6965 Email: information@gwrinstruments.com

http://www.gwrinstruments.com