How can gravimeters improve recordings of earthquakes?

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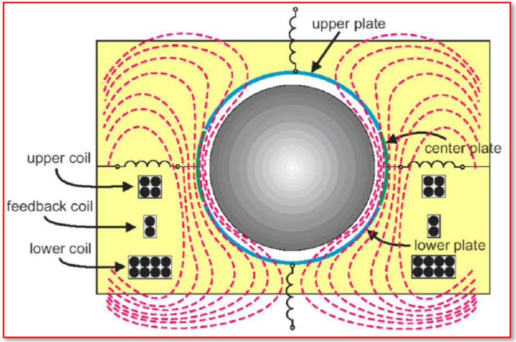
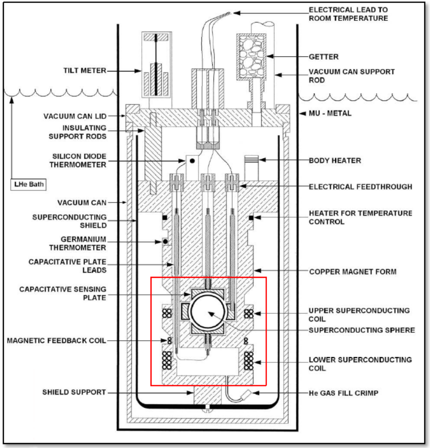
Photography encouraged

Superconducting gravimeter:

- niobium sphere levitates in an ultra-stable magnetic field
- sensor operates in liquid helium in a temperature of near 4K (superconducting effect in low temperatures)



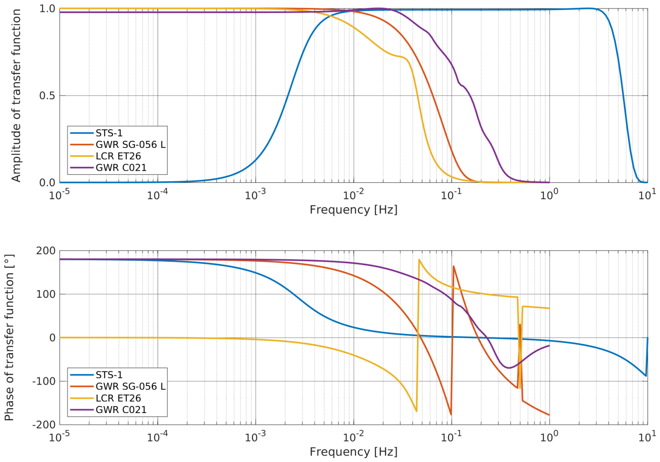
Conceptual drawing of flux lines, plates and Nb sphere



Sectional drawing of Gravity Sensing Unit (GSU)

Operating Principles of the Superconducting Gravity Meter (2011)

Introduction



Instrument responses from IRIS

Seismometer
responds to ground motions
Gravimeter
measures gravitational acceleration

Black Forest

- STS-1 – broadband seismometer
- GWR SG-056 L – superconducting gravimeter (low sphere)
- LCR ET 26 – spring gravimeter

Membach

- GWR C021 – superconducting gravimeter

Map of observatories and data resources

How to choose stations?

- gravimeter and seismometer are co-located
- available 1Hz gravimetric data

Observatories	Data resources
Borowa Góra, Poland	National pilot project
Józefosław, Poland	National pilot project
Lamkówko, Poland	National pilot project
Pecný, Czech Republic	IGETS[a] and IRIS[b]
Wettzell, Germany	IGETS and IRIS
Moxa, Germany	IRIS and courtesy of the observatory
Black Forest, Germany	IRIS
Membach, Belgium	IRIS
Rochefort, Belgium	IRIS
Onsala, Sweden	courtesy of the observatories
Sutherland, South Africa	IRIS, IGETS and courtesy of the observatory

[a] International Geodynamics and Earth Tide Service `http://isdc.gfz-potsdam.de/igets-data-base/`

[b] Incorporated Research Institutions for Seismology `https://www.iris.edu/hq/`

Data processing

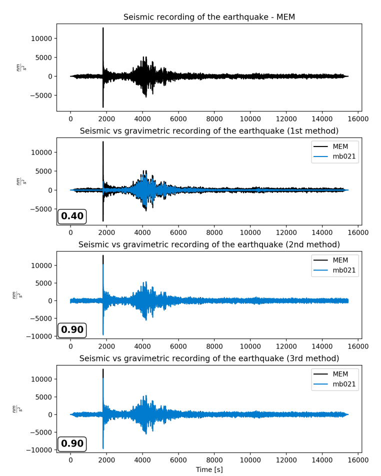
GRAVIMETRIC DATA			SEISMIC DATA
1st method	2nd method	3rd method	
	instrument response + prefiltr (with detrend)	instrument response	
Earth tide ocean loading polar motion atmospheric pressure		Earth tide ocean loading polar motion atmospheric pressure	
gravimetric recordings of earthquakes	gravimetric recordings of earthquakes	gravimetric recordings of earthquakes	seismic recordings of earthquakes
detrend | taper | filter		detrend | taper | filter	detrend | taper filter | resample
			instrument response + differentiation

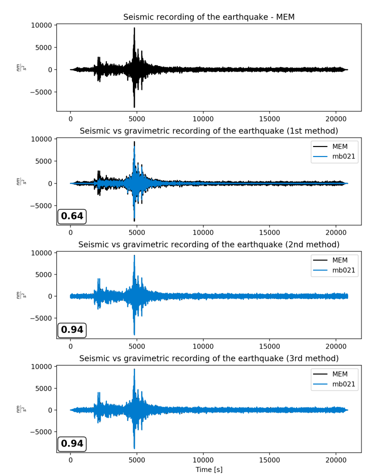
Gravimetric vs. seismic recording of the earthquake

Membach
MEM seimsmometer CMG3T
mb021 gravimeter GWR C021

NEAR EAST COAST OF KAMCHATKA[1]
magnitude 6.6
depth 20km
2017-03-29
04:09:24.0
distance 7890km

MINDANAO, PHILIPPINES[1]
magnitude 6.8
depth 42km
2017-04-28
20:23:18.8
distance 11516km



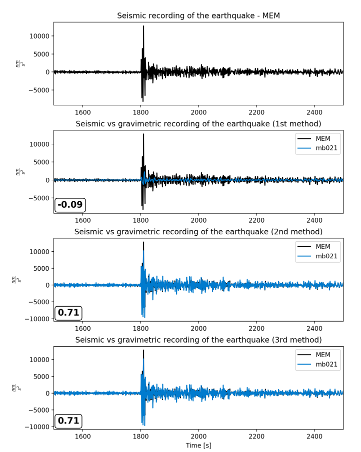


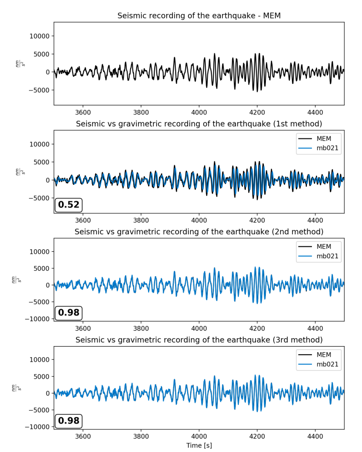
[1] according to European Mediterranean Seismological Centre `https://www.emsc-csem.org/Earthquake`

Gravimetric vs. seismic recording of the earthquake (2)

Membach
MEM seismometer CMG3T
mb021 gravimeter GWR C021

NEAR EAST COAST OF KAMCHATKA[1]
magnitude 6.6
depth 20km
2017-03-29
04:09:24.0
distance 7890km





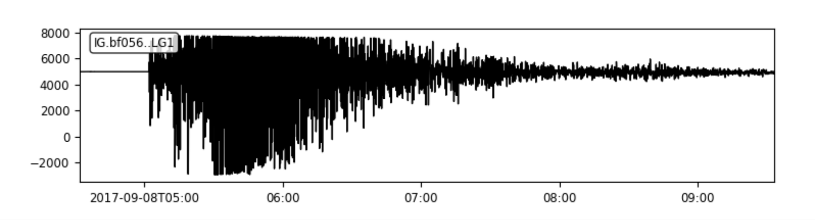
[1] according to European Mediterranean Seismological Centre `https://www.emsc-csem.org/Earthquake`

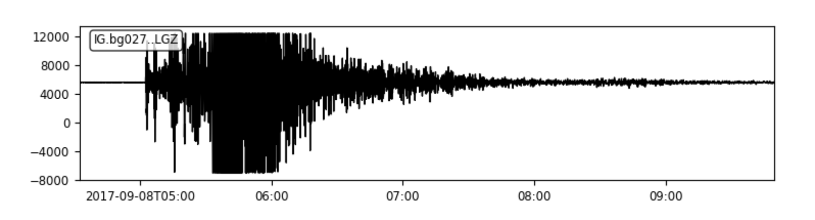
Saturation signal

Black Forest
bfo056 gravimeter GWR SG-056
Borowa Góra
bg027 gravimeter GWR iGrav 027

OFFSHORE CHIAPAS, MEXICO[1]
magnitude 8.1
depth 72km
2017-09-08 04:49:21.2

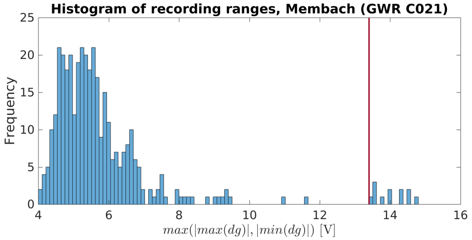
Black Forest	9647km
Borowa Góra	10286km

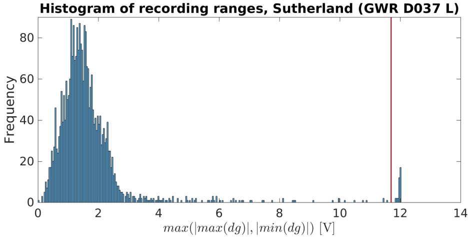


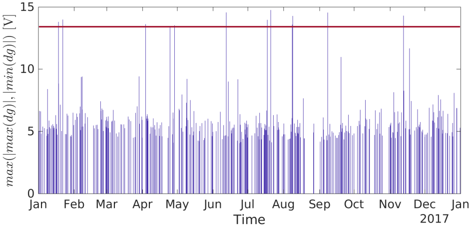


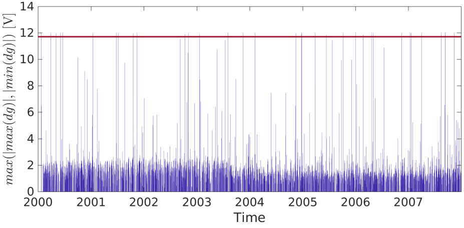
[1] according to European Mediterranean Seismological Centre `https://www.emsc-csem.org/Earthquake`

Saturation signal (2)

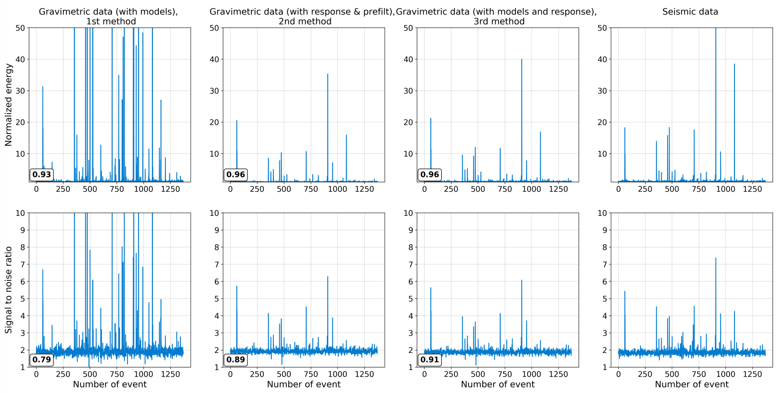








Earthquake energy and signal to noise ratio



Membach, Belgium (Jan-Dec 2017)

Earthquake energy

$$E = \frac{\sum(A_i^2)}{n} \quad (1)$$

$$E_{norm} = \frac{E_s}{E_n} \quad (2)$$

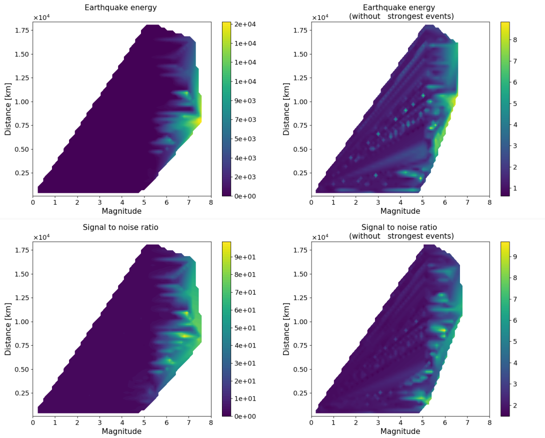
Signal to noise ratio

$$SNR = \frac{\mu}{\sigma} \quad (3)$$

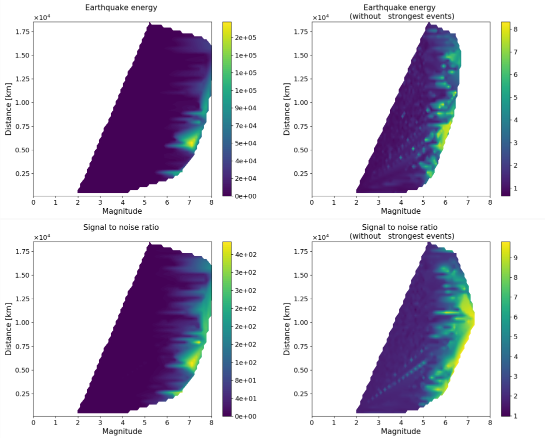
A_i – amplitude of signal
n – number of samples
μ – mean of envelope (signal)
σ – standard deviation of envelope (noise)

Earthquake energy and signal to noise ratio (2)

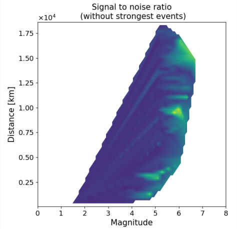
Moxa | 2 years | CD034 U



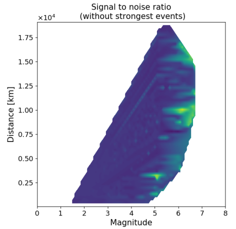
Sutherland | 12 years | GWR D037 U



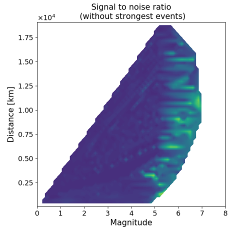
Signal to noise ratio



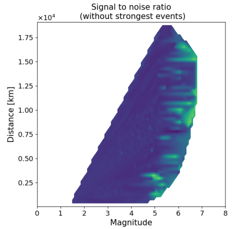
Black Forest | GWR SG-056 L



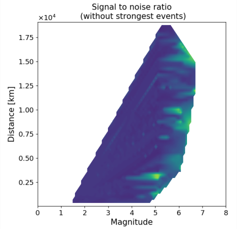
Józefosław | LCR ET26



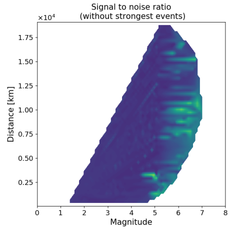
Pecny | GWR OSG-050



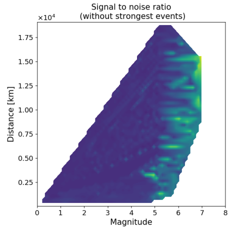
Membach | GWR C021



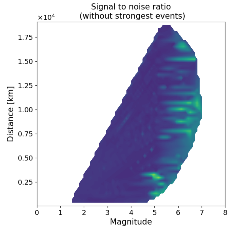
Borowa Góra | GWR iGrav 027



Onsala | GWR OSG 054



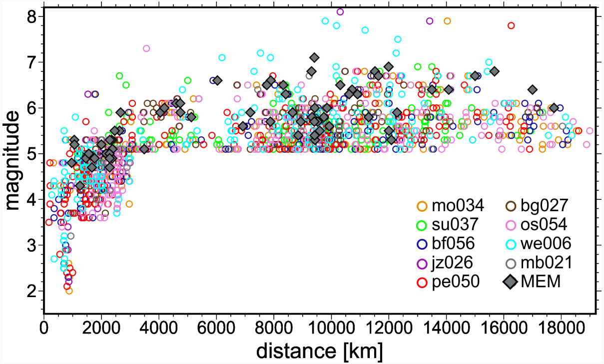
Wettzell | iGrav 006



Membach | CMG3T

Analysis was carried out for one year of observations.

Parameters of earthquakes recorded by the gravimeters

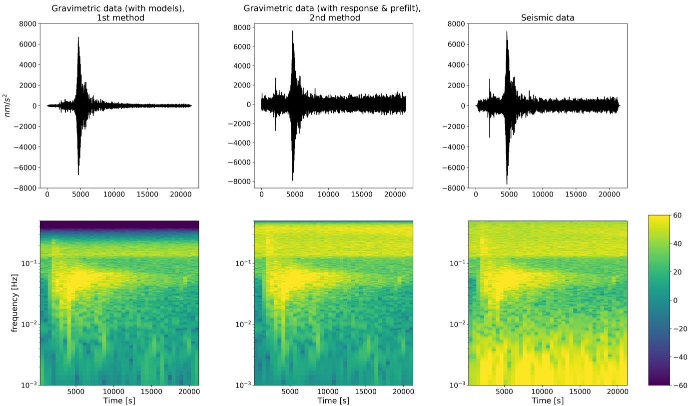


$d \leqslant 870km$	$m \geqslant 2.0$
$870km < d \leqslant 970km$	$m \geqslant 0.0184 * d - 14.1$
$970km < d \leqslant 2500km$	$m \geqslant 3.6$
$2500km < d \leqslant 3100km$	$m \geqslant 0.0025 * d + 3.6$
$3100km < d \leqslant 17500km$	$m \geqslant 5.1$
$17500km < d \leqslant 18800km$	$m \geqslant 0.0004 * d - 1.9$

d – distance
m – magnitude

Relation of distance and magnitude for events with visible energy (one year, without strongest events)

Conclusion



Membach | **MEM** seismometer CMG3T | **mb021** gravimeter GWR C021
OFFSHORE VALPARAISO, CHILE | magnitude 6.9 | depth 10km
2017-04-24 21:38:27 | distance 11991km

- seismic body waves can only be analysed on gravimeter data when gravimeter's transfer function is applied to correct the signal
- seismic surface waves can be analysed even when gravimeter's transfer function is not applied, but phase shifts must be considered; when gravimeter's transfer function is applied a correlations of gravimetric and seismic signals is excellent
- the same procedure of signal preprocessing, as for seismic data, can be used if gravimetric transfer function is known; if gravimeter's transfer function is unknown, the correction of signal due to major gravity effects must be applied
- there is no possibility to properly record by superconducting gravimeters the strongest earthquakes due to saturation of signal
- superconducting gravimeters can record seismic signals with very good signal-to-noise ratio up to periods of 1000 s

Resources & Acknowledgements

Data source:

1. Förste, Ch., et all (2016): Superconducting Gravimeter Data from **Sutherland** - Level 1. V. 001. GFZ Data Services.
2. Güntner, A., et all (2017): Superconducting gravimeter data of iGrav006 and auxiliary hydro-meteorological data from **Wettzell**.
3. Palinkas V.: Superconducting gravimeter data from Pecny, Level 1, IGETS database
4. The facilities of IRIS Data Services, and specifically the IRIS Data Management Center, were used for access to waveforms (**seismic data and gravimetric from Black Forest, Membach, Rochefort**), related metadata, and/or derived products used in this study.

Programs:

1. Krischer, L., et all (2015). ObsPy: A bridge for seismology into the scientific Python ecosystem. Computational Science & Discovery.

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- Thomas Jahr from Geodynamic Observatory Moxa (ata from Moxa)
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