# Improving the Quality of Tidal Gravimetric Recordings

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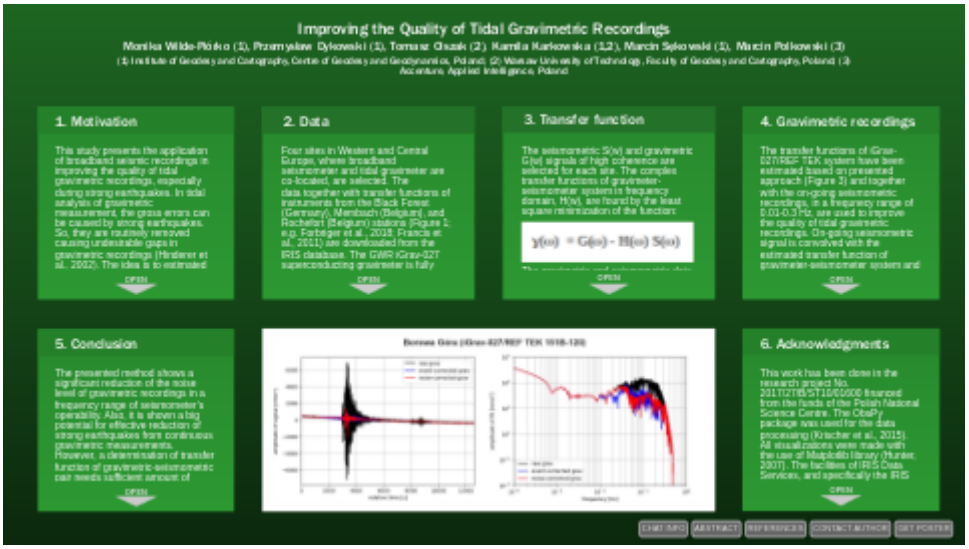
**Abstract**

This study presents the application of broadband seismic recordings in improving the quality of tidal gravimetric recordings, especially during strong earthquakes. Four sites in Western and Central Europe, where broadband seismometer and tidal gravimeter are collocated, are selected. The data together with transfer functions of instruments from the Black Forest (Germany), Membach (Belgium), and Rochfort (Belgium) are downloaded from the IRIS database. The GWR iGrav-027 superconducting gravimeter is fully operational at the Borowa Gora Geodetic-Geophysical Observatory of the Institute of Geodesy and Cartography (Poland) since late April 2016. Later, the REF-TEK broadband seismometer was installed in the cooperation with the University of Warsaw. The Observatory, also temporally hosts a spring gravimeter, LCR ET-26 (owned by the Warsaw University of Technology). The seismometric and gravimetric signals of high coherence are selected for each site. The complex transfer functions in frequency domain are found by the least square minimization of the seismometric and seismic-corrected gravimetric signal. The transfer functions are calculated when the coherence is significant for two cases: with and without observed earthquake recordings. Next, the estimated transfer functions and the ongoing seismometric recordings are used to improve the quality of tidal gravimetric recordings. The presented method shows a significant reduction of the noise level of gravimetric recordings in a frequency range of seismometer's operability. In order to obtain reliable models of the Earth's structure based on analysis of surface waves recorded by tidal gravimeters, the careful estimation of gravimeters' transfer functions in the seismic frequency range is necessary. The transfer functions of iGrav-027 and ET-26 were determined by the step response method during the experiments in 2018-2019. Now, thanks to the presented research, their quality can be verified. The limitation of this verification can be tested on recordings of Black Forest, Membach and Rochfort with very well-determined and documented transfer functions of tidal gravimeters. This work has been done in the research project No. 2017/27/B/ST10/01600 financed from the funds of the Polish National Science Centre.

# Improving the Quality of Tidal Gravimetric Recordings

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**PRESENTED AT:**

# 1. MOTIVATION

This study presents the application of broadband seismic recordings in improving the quality of tidal gravimetric recordings, especially during strong earthquakes. In tidal analysis of gravimetric measurement, the gross errors can be caused by strong earthquakes. So, they are routinely removed causing undesirable gaps in gravimetric recordings (Hinderer et al., 2002). The idea is to estimated the transfer function between the gravimeter and seismometer (located in the same site) to use it later for on-going gravimeter and seismometer recordings.

Additionally, in order to obtain reliable models of the Earth's structure based on analysis of surface waves recorded by tidal gravimeters, the careful estimation of gravimeters' transfer functions in the seismic frequency range is necessary. The transfer functions of superconducting gravimeter GWR iGrav-027 (Borowa Góra, Poland) and LCR ET-26 (Jozefoslaw, Poland) were determined by the step response method (Van Camp et al., 2000) during the experiments in 2018-2019 (Wilde-Piorko et al., 2019). Now, thanks to the presented research, a quality of estiamted transfer fuction can be verified. The limitation of presented apporach can be tested on gravimetric and seismometric recordings from the Black Forest, Membach and Rochfort sites, with very well-determined and documented transfer functions of tidal gravimeters.

# 2. DATA

Four sites in Western and Central Europe, where broadband seismometer and tidal gravimeter are co-located, are selected. The data together with transfer functions of instruments from the Black Forest (Germany), Membach (Belgium), and Rochefort (Belgium) stations (Figure 1; e.g. Forbriger et al., 2018; Francis et al., 2011) are downloaded from the IRIS database. The GWR iGrav-027 superconducting gravimeter is fully operational at the Borowa Góra Geodetic-Geophysical Observatory of the Institute of Geodesy and Cartography (Poland) since late April 2016 (Sekowski et al., 2016). Later, the REF-TEK broadband seismometer was installed in the cooperation with the University of Warsaw (Faculty of Physics, Institute of Geophysics). The Observatory, also temporally hosts a spring gravimeter, LCR ET-26, owned by the Warsaw University of Technology, Faculty of Geodesy and Cartography (Bogusz, 2008). All instruments used in this study are listed in Table 1.

Table 1. List of gravimeters and seismometers used in the study.

| Observatory | Latitude [degrees] | Longitude [degrees] | Data resources | Analysed data | Gravimeter | Seismometer |
|---|---|---|---|---|---|---|
| Black Forest | 48.3301 | 8.3296 | IRIS | 12.2016-12.2019 | GWR SG-056 U | STS-1 |
| Membach | 50.6092 | 6.0067 | IRIS | 12.2016-12.2019 | GWR C021 | CMG3T (30 s) |
| Rochefort | 50.155 | 5.2260 | IRIS | 12.2016-12.2019 | GWR iGrav-019 | Trillium Compact 120 s |
| Borowa Góra | 52.4755 | 21.0359 | Operator | 12.2016-12.2019 | GWR iGrav-027 | REF TEK 151B-120 |
| Józefosław | 52.0978 | 21.0323 | Operator | 12.2016 – 09.2017 | LCR ET-26 | REF TEK 151B-120 |

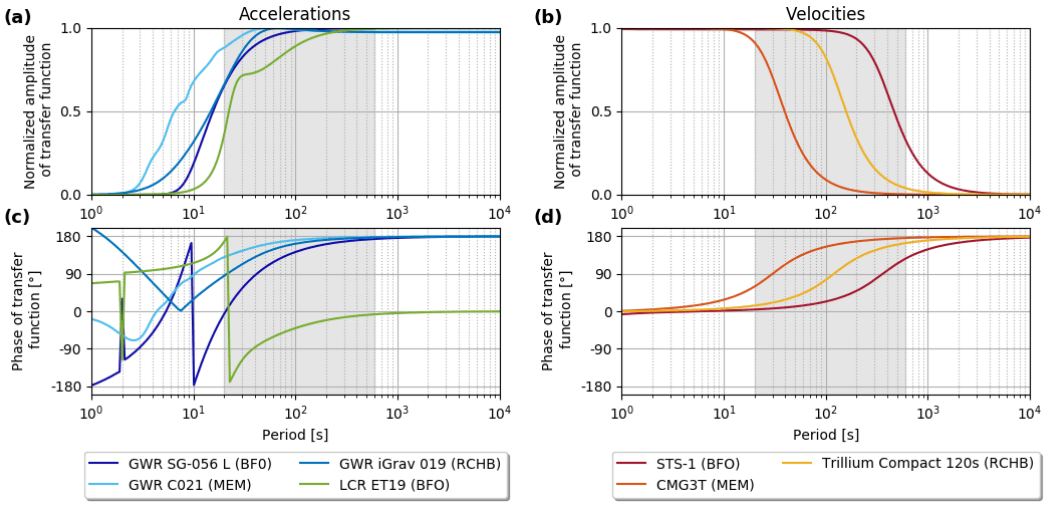



Fig. 1 Normalized amplitude and phase of the transfer function of instruments from the Black Forest, Membach and Rochefort stations: ground accelaration for superconducting gravimeters (a, c - lines in shades of blue) and ground velocities for broadband seismometers (b,d – lines in shades of orange).

# 3. TRANSFER FUNCTION

The seismometric S(w) and gravimetric G(w) signals of high coherence are selected for each site. The complex transfer functions of gravimeter-seismometer system in frequency domain, H(w), are found by the least square minimization of the function:

$$\gamma(\omega) = G(\omega) - H(\omega)\, S(\omega)$$

The gravimetric and seismometric data are prelimninary detrended, tappered and filtered in a frequency range of 0.002-0.4 Hz. Additionally, the seismometric data are differentiated and resampling to 1 Hz. The transfer functions are calculated in 1 hour windows with 25% overlap. The transfer function of gravimeter-seismometer system is estimated as a mean value of indivitual calculations. The transfer function of each gravimeter-seismometer system is calculated for two cases based on recordings of (1) days with observed earthquake (marked as “based on events”) and (2) days without observed earthquake (marked as “based on noise”). The theoretical gain and phase of transfer function of gravimeter-seismometer system have been marked as “grav/seis” (Figure 2a nd 2b).

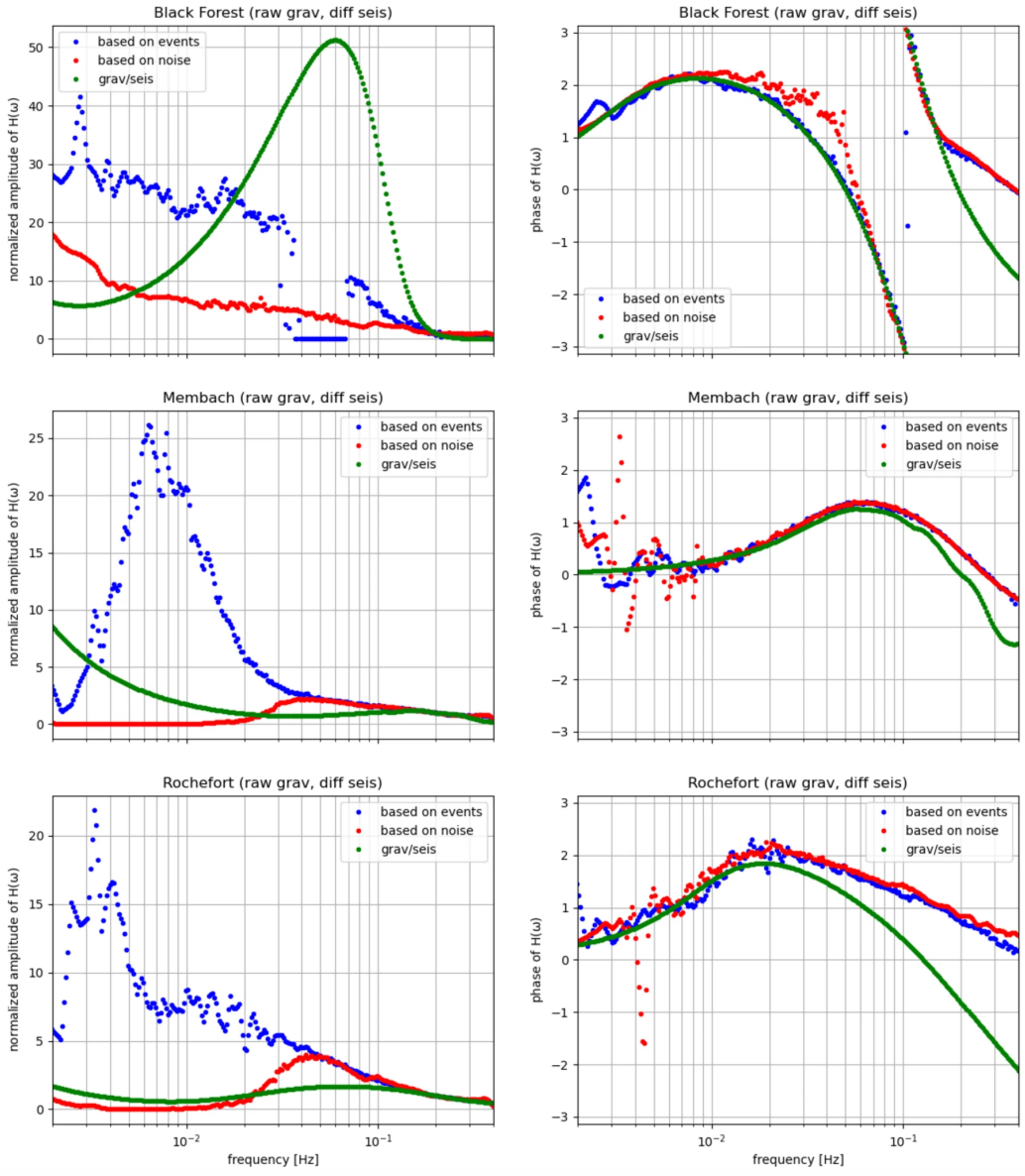



Figure 2a. Estimated (blue and red dots) and theoretical (green dots) amplitude and phase of transfer function of

gravimeter-seismometer system for the Black Forest, Membach and Rochefort stations.

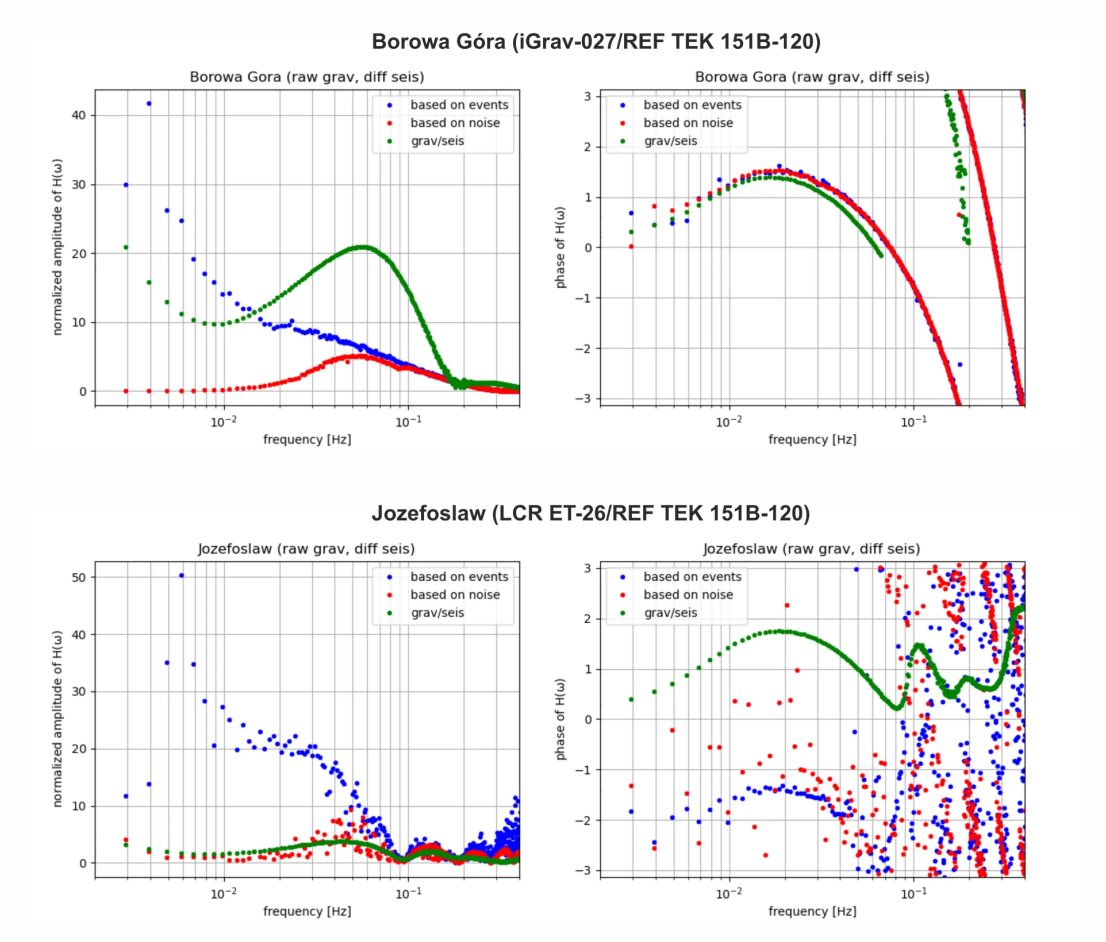



Figure 2b. Estimated (blue and red dots) and theoretical (green dots) amplitude and phase of transfer function of gravimeter-seismometer system for the Borowa Gora and Jozefoslaw stations

# 4. GRAVIMETRIC RECORDINGS

The transfer functions of iGrav-027/REF TEK system have been estimated based on presented approach (Figure 3) and together with the on-going seismometric recordings, in a frequnecy range of 0.01-0.3 Hz, are used to improve the quality of tidal gravimetric recordings. On-going seismometric signal is convolved with the estimated transfer function of gravimeter-seismometer system and subtraced from the on-going gravimetric recordings (Figure 4).

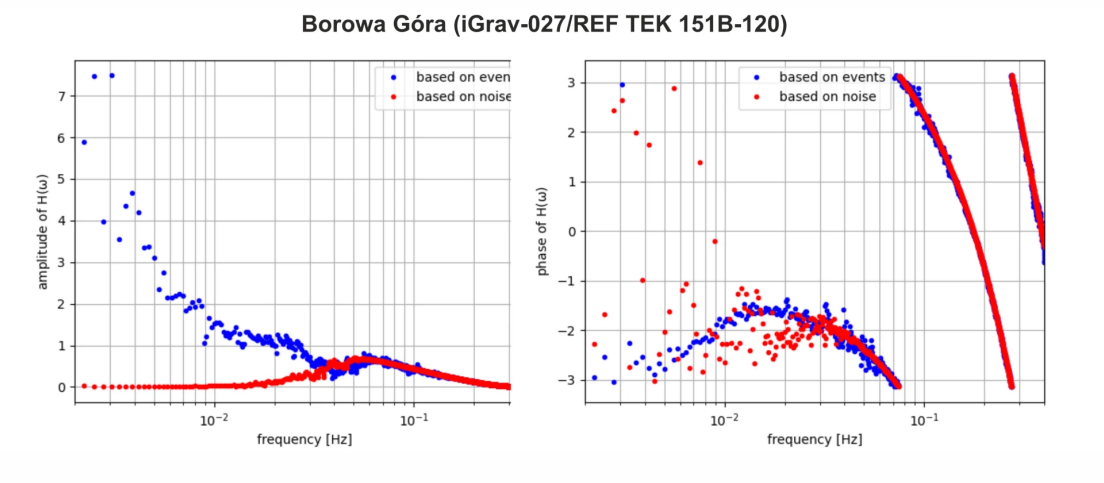



Figure 3. Estimated amplitude and phase of transfer function of gravimeter-seismometer system for the Borowa Góra instruments (blue dots - based on events recordings, red dots – based on noise recordings).

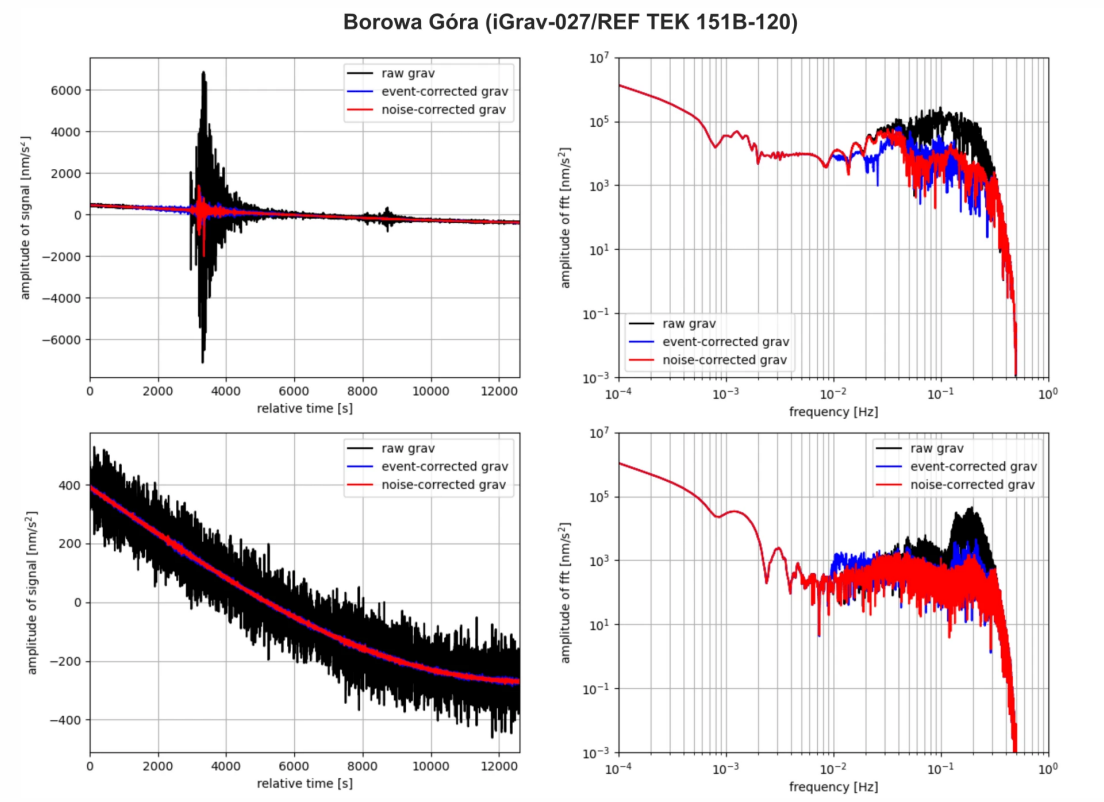
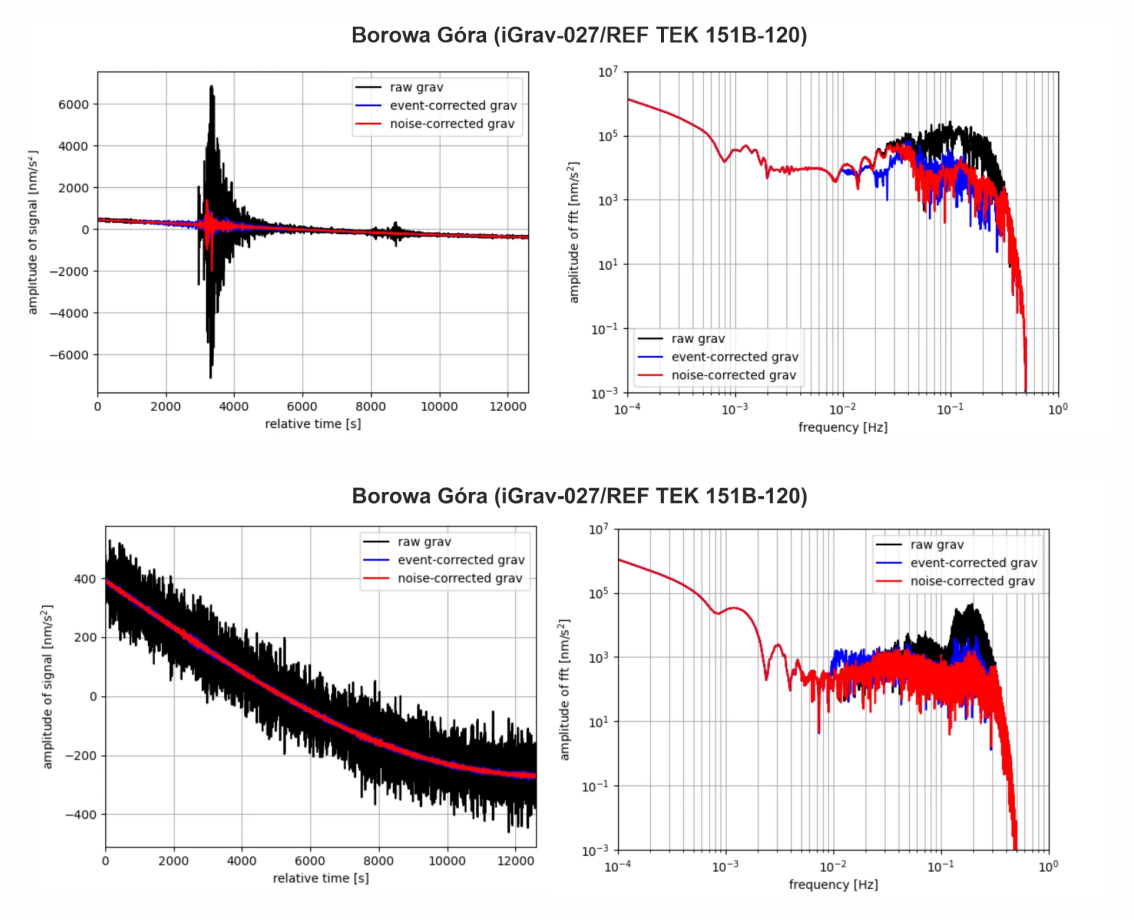



Figure 4. Improving of the iGrav-027 gravimetric recordings based on co-located seismometric measurements at the Borowa Góra in the case of earthquake recordings (top) and noise recordings (bottom). The signal (left) and amplitude of its Fourier tranform (right) are shown for raw data (black line) and for data corrected with the transfer function of the gravimeter-seismometer system estimated based on days with earthquake (blue line) and days without earthquake (red line).

# 5. CONCLUSION

The presented method shows a significant reduction of the noise level of gravimetric recordings in a frequency range of seismometer's operability. Also, it is shown a big potential for effective reduction of strong earthquakes from continuous gravimetric measurements. However, a determination of transfer function of gravimetric-seismometric pair needs sufficient amount of recordings and further research, e.g. with using a more advanced approach proposed by Beauduin et. al (1996).



# 6. ACKNOWLEDGMENTS

This work has been done in the research project No. 2017/27/B/ST10/01600 financed from the funds of the Polish National Science Centre. The ObsPy package was used for the data processing (Krischer et al., 2015). All visualizations were made with the use of Matplotlib library (Hunter, 2007). The facilities of IRIS Data Services, and specifically the IRIS Data Management Center, were used for access to waveforms (seismic data and gravimetric data from the Black Forest, Membach and Rochefort stations), related metadata, and/or derived products used in this study. IRIS Data Services are funded through the Seismological Facilities for the Advancement of Geoscience and EarthScope (SAGE) Proposal of the National Science Foundation under Cooperative Agreement EAR-1261681.

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This study presents the application of broadband seismic recordings in improving the quality of tidal gravimetric recordings, especially during strong earthquakes. Four sites in Western and Central Europe, where broadband seismometer and tidal gravimeter are collocated, are selected. The data together with transfer functions of instruments from the Black Forest (Germany), Membach (Belgium), and Rochfort (Belgium) are downloaded from the IRIS database. The GWR iGrav-027 superconducting gravimeter is fully operational at the Borowa Gora Geodetic-Geophysical Observatory of the Institute of Geodesy and Cartography (Poland) since late April 2016. Later, the REF-TEK broadband seismometer was installed in the cooperation with the University of Warsaw. The Observatory, also temporally hosts a spring gravimeter, LCR ET-26 (owned by the Warsaw University of Technology).

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In order to obtain reliable models of the Earth's structure based on analysis of surface waves recorded by tidal gravimeters, the careful estimation of gravimeters’ transfer functions in the seismic frequency range is necessary. The transfer function of iGrav-027 and LCR ET-26 were determined by the step response method during the experiments in 2018-2019. Now, thanks to the presented research, their quality can be verified. The limitation of this verification can be tested on recordings of Black Forest, Membach and Rochfort with very well-determined and documented transfer functions of tidal gravimeters.

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