Aspects of establishing a modern gravity control: case study Borowa Gora Observatory

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Abstract

The trend in the establishment of modern gravity control assumes using absolute gravity measurement as the primary measurement technique shifting relative gravity measurements to the secondary role of a supporting technique applied e.g. for gravity gradient determinations. Classic gravity control based on relative gravity measurements proves to be not as reliable as the one based on AG surveys .
Absolute gravity measurements requires higher standards for applying corrections to the measurements as well as monitoring the performance of the absolute gravimeter. This work presents results from absolute gravity measurements with the A10-020 gravimeter on the open field station at Borowa Gora Observatory. This station represents a typical open field station of a modern gravity control, susceptible to the full (local and non local) hydrological signal, hence is a valuable study object. Gravity surveys taken in 2015 and 2016 provide the unique time series of quasi-regular measurements on monthly basis. In the measurements evaluated with a standard set of corrections (IAG suggested models) remains a strong annual residual signal with a peak to peak variation of 200 nm/s^2, associated mainly with hydrology.
The use of selected correction models to elaborate AG measurements with special emphasis on hydrology will be discussed considering data from local hydrological sensors as well as from global hydrological models, e.g. GLDAS. These models will be used to evaluate the observed gravity variations with the A10-020 absolute gravimeter. Gravity changes due to hydrology for the area of Poland as well as recommendations for methodology of data elaboration will be presented.

Modernized Polish gravity control

The new and modernized gravity control in Poland was established in years 2012–2015 with the primary use of absolute methods (Krynski et al.,2012, Dykowski et al., 2015), i.e. at all stations gravity value was determined with an absolute gravimeter and no relative connections between stations were established. The gravity control consists of two separate classes of stations:
- fundamental stations – lab stations surveyed with the FG5-230 absolute gravimeter (owed by Warsaw University of Technology) – typically located in the basements of buildings;
- base stations – open field stations surveyed with the A10-020 absolute gravimeter (owed by IGiK)

This work focuses on the base stations (Fig. 1). The final number of established base stations in the modernized Polish gravity control is 168. At all of them gravity was determined with the A10-020 gravimeter (Fig. 2) using a standard and well tested measurement methodology consisting of two independent setups (Dykowski et al., 2014). At all stations precise vertical gravity gradient determinations were performed in order to reduce the obtained gravity value to the benchmark level. Total uncertainty of determined gravity value was evaluated for each station. The values of the calculated Total Uncertainties (Fig. 3) range from 60 to 110 nm/s^2 with the mean value of 75 nm/s^2.
One of the most important supplementary activities were absolute gravimeter comparison campaigns (ICAG2011, ECAG2013, ICAG2015). Participation in these campaigns was the primary way to assure proper level of the newly established gravity control as well as to link the periods before and after service of the A10-020 gravimeter in 2014.

Fig. 2. A10-020 absolute gravimeter on a base station

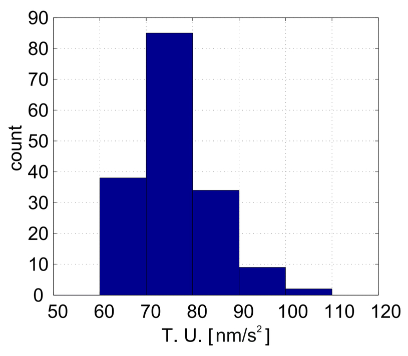

Fig. 3. Histogram of T.U. values on base stations

Hydrological Loading

Hydrological loading effects were evaluated for selected base stations with the support of EOST Loading Service (http://loading.u-strasbg.fr; Boy and Hinderer, 2006). The stations were selected to be representative for the whole territory of Poland, i.e. in a way to cover near Baltic Sea areas as well as flat open terrain and mountain areas. The period of hydrological loading presented is set from 2011 to 2016. The hydrological model considered is the GLDAS – Global Land Data Assimilation System. The GLDAS model provides a 0.25° × 0.25° spatial resolution and a 3 h temporal resolution.The provided loading effect consists of two components: local (calculated as a uniform Total Water Storage layer treated as a Bouguer plate) and non local (representing continental hydrological loading). The total effect is the sum of both effects mentioned above. The hydrological loading effects for selected stations is presented in Figure 1 (outside the map). The variability and seasonal amplitude of hydrological time series is not consistent from station to station. The smallest amplitude of the effect is at the stations nearest to the Baltic Sea coast (Rozewie, Karsibor) with peak to peak values visibly less than 100 nm/s^2. At other stations across Poland, e.g. Zubowice and Ustrzyki Gorne, the variability can even extend 200 nm/s^2 peak to peak within the presented period. For these two stations a verification was performed based upon repeated measurements with the A10-020 gravimeter nearly 2 years appart and performed in the maximum and minimum periods of hydrological loading. At Zubowice station the A10-020 gravity difference is -236 nm/s^2 and the hydrological loading difference is at -120 nm/s^2. At Ustrzyki Górne station the A10-020 gravity difference is -134 nm/s^2 and the hydrological difference is -128 nm/s^2. In both cases gravity value difference from the measurements with the A10-020 is consistent with hydrological loading difference within the estimated uncertainty values. In case of the location of the Borowa Gora Obsrvatory a more detailed analysis is possible as measurements with the A10-020 gravimeter are performed there regularly on monthly basis.

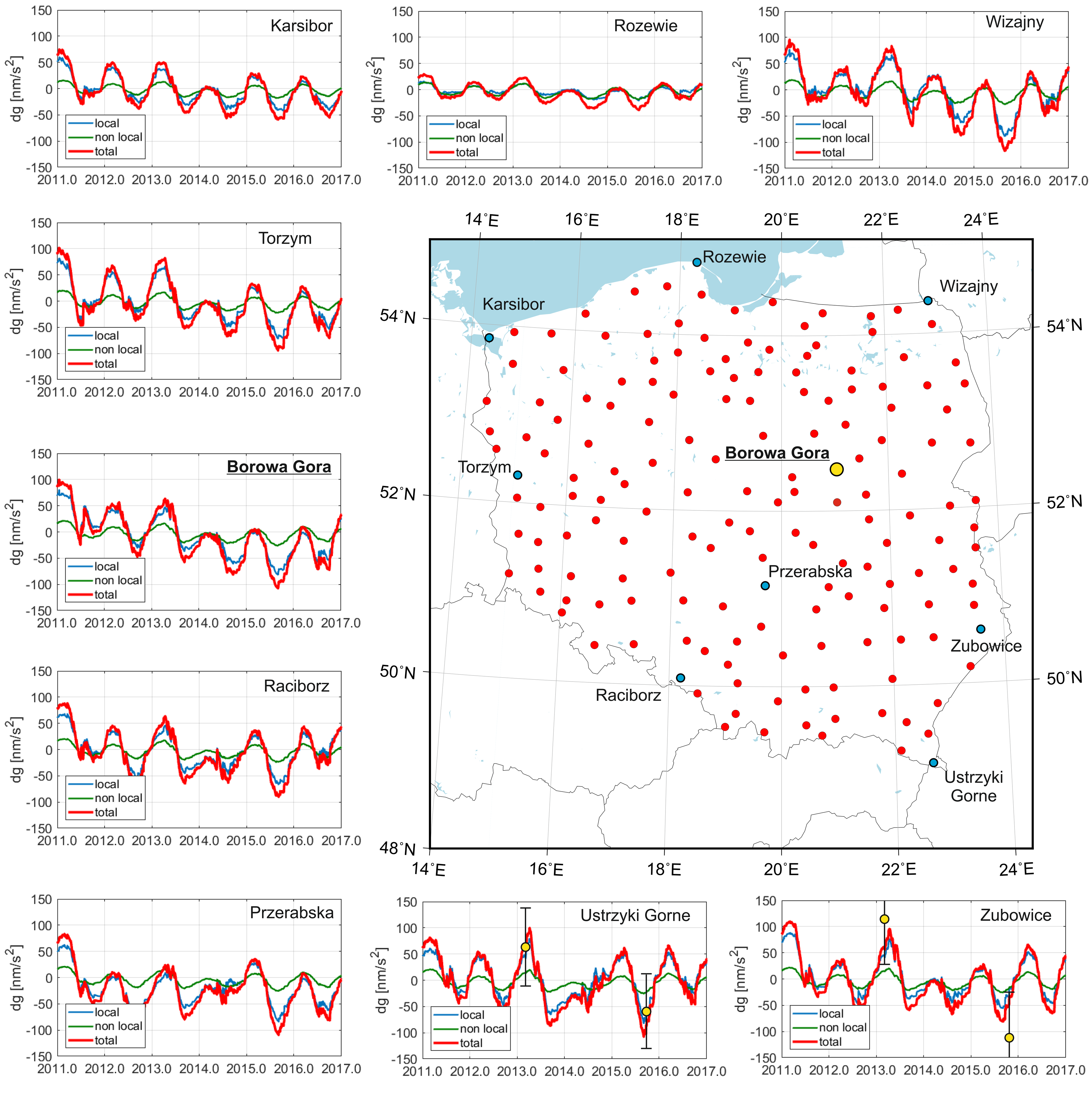

Fig.1. Base station of the modernized gravity control in Poland (the map); gravity variations from hydrological loading on selected base stations (surrounding graphs)

Case study: Borowa Gora Geodetic-Geophysical Observatory

One of the base stations (noted as BOG8) of the modernized gravity control in Poland is located in Borowa Gora Geodetic-Geophysical Observatory (layout of the relevant Observatory infrastructure is presented in Fig. 4). There is another open field station (noted as 156) at the Observatory which is a part of the Borowa Gora gravimetric test network. Since 2008 regular monthly gravity measurements with the A10-020 are performed at this station. In 2015 the infrastructure of the Observatory has been supplemented with a variety of hydrological sensors allowing to evaluate local hydrological modelling and compare it with a larger scale hydrological modelling. The hydrological sensors locations along with absolute gravity stations are presented in Figure 4.
Gravity measurements on an open field station 156 were corrected for the standard set of corrections, i.e. earth tides ocean loading, atmospheric pressure (Fig. 5). The remaining signal shows a visible annual variation reaching peak to peak 200 nm/s^2. In Figure 5 two additional gravity variation time series are presented; the GLDAS hydrological model and a local hydrological effect estimate based on soil moisture sensors and water table level sensor supplemented with GLDAS continental water storage loading effect. Both hydrological estimates are strongly correlated; correlation coefficient is at 0.85. Figure 6 presents time series of gravity determination with the A10-020 corrected for GLDAS and local hydrological model. Standard deviations of gravity determinations with the A10-020 corrected using both hydrological models are visibly reduced after removing 3 epochs of gravity determinations that were considered as outliers. Table 1 presents the basic statistics of gravity determinations with the A10-020 as well as their correlations with the hydrological models. Values presented in Table 1 assume the use of complete A10-020 datasets well as removal of apparent outliers. The removal of outliers visibly improves the presented notions on the correlation of gravity results obtained with the A10-020 and hydrological signals.

	full A10-020 timeseries			reduced A10-020 timeseries (outliers)		
	std [nm/s^2]	max-min	corr. A10-020	std [nm/s^2]	max-min	corr. A10-020
A10-020	62.6	217	-	52	172	-
A10-020 - GLDAS corrected	51.6	195	0.493	**32**	**113**	**0.742**
A10-020 - local model corrected	54.8	244	0.569	**33**	**114**	**0.775**

Table 1. Data statistics of comparison of gravity variations from the measurements with the A10-020 and from the hydrological model

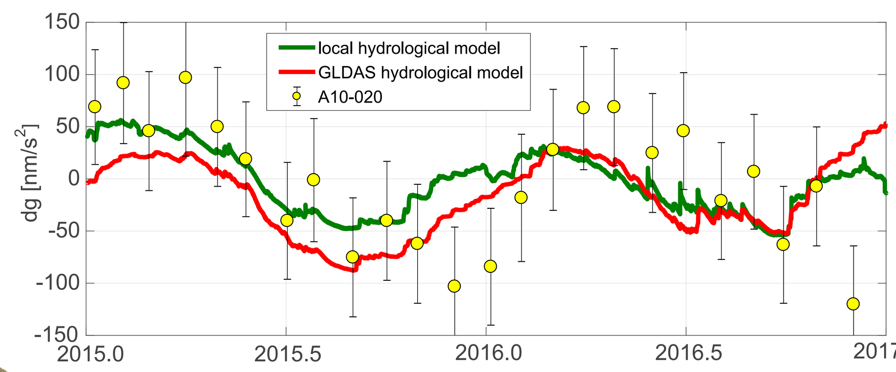

Fig.5. Monthly gravity determinations with the A10-020 along with GLDAS and local hydrological models

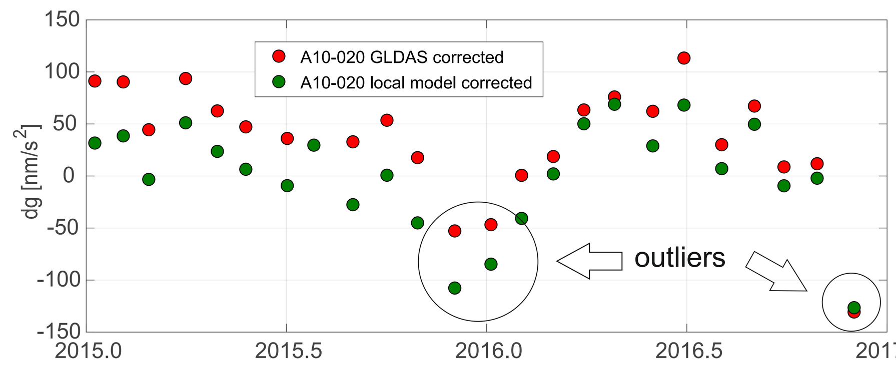

Fig.6. Monthly gravity determinations with the A10-020 reduced using GLDAS and local hydrological models; outliers indicated

Summary and conclusions

- Seasonal gravity variations due to hydrological loading significantly exceed uncertainty of gravity determination in a modern gravity control. Besides gravity, the epoch of its determination should be recorded. Gravity control should thus be considered as a dynamic reference for relative gravity survey.
- Available hydrological models can be calculated for any given location allowing evaluation of hydrological gravity variations
- The correction of absolute gravity determinations for hydrological effects determined using hydrological models results in a substantial improvement in the consistency of the obtained gravity values.
- Further studies considering other available hydrological models are required.

Reccomendations for gravity control establishment and evaluation

- Perform absolute gravity determinations on all designed stationswithin a possible shortest time frame.
- Consider gravity variations from hydrological loading when analyzing and interpreting gravity determinations.
- Reduce measured absolute gravity values to a „zero value" epoch of the hydrological variation for any given station - way to obtain a more consistent gravity reference throughout a given country

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