Some Experience in Gravity Time Variation Studies

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Key words: gravity, variation

ABSTRACT

Geodetic frame developed with modern technologies and means requires integration of practically all the types of high-precision geodetic constructions. To establish a precise correlation between geodetic and normal heights, the values of precise quasi-geoid heights should be available, this being a rather sophisticated research task and requiring thorough investigations of the Earth gravity field and its time variation.

At present the most precise and objective information on gravity variation could be obtained with not only high-precision tidal relative gravimeters but with absolute ballistic gravimeters as well. The precision of absolute gravity determinations with the gravimeters of this type is supposed to vary between 3 and 10 micro Gal depending on the level of local interferences. Such precisions could be already compared with current precisions of normal and geodetic heights determinations since a change in a gravity value by 1 micro Gal is equivalent to a change of a height by 3 mm.

On the territory of Russia a network of points of Fundamental Astronomic-Geodetic Network, including those ever operating, is being developed. The world experience in permanent GPS determinations on such points reveals that the precision of geodetic heights determinations is not below 1 cm, and that of their time variation speeds is not below the first mm. On some world base gravimetric points high-precision determinations of gravity acceleration have been carried out for many decades already. A most prolonged series of determinations of the kind with ballistic gravimeters is the series carried out on the Main Gravimetric Point of Russia located in Moscow. Despite gravity determinations not having been performed routinely enough, a total number of repeated high-precision determinations comes to more than 200. Such amount of measuring allows arriving at some conclusions on the approaches and conditions in the researches of gravity time variation patterns.

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1. INTRODUCTION

On the Main Gravimetric Point of Russia absolute and relative gravity acceleration determinations have been carried out since 1989 with the most possible precision at the moment. Determinations were performed with the gravimeters GBL-1, GBL-2, GBL-3, GBL-4, GBL-P and GABL. In 2003 this work was continued with the gravimeters GBL-3 and GBL-П. On the 11th of June 2003 one determination was made with the gravimeter GABL-E that belonged to the Institute of Automatics and Electrometry of the Russian Academy of Science (Siberian Division).

To carry out metrological check up of the gravimeters and their operation as well as to determine actual measuring precision, in June 2003 on the international fundamental gravimetric point of Ledovo (Moscow region) a comparison of the Russian ballistic gravimeters was made. The mean square error of determinations with the gravimeters GBL-3 and GBL-P basically did not exceed 5 micro Gal by inner repeatability and by the repeatability of instruments. The mean values of the gravity acceleration of GBL-3 and GBL-P differed from the general mean value on the point not more than by 5 micro Gal. The difference in the indications of GBL-3 and GBL-P and of the ballistic gravimeter GABL-E that has been repeatedly compared to the best gravimeters of other countries in Sevres (France) does not exceed 3,2 micro Gal. Thus, the ballistic gravimeters GBL-3 and GBL-P applied in the determinations on the Main Gravimetric Point rank with the best instruments of this kind.

Results of all the determinations made with all the instruments during all the years are shown on the plot (diagram 1). Determinations were carried out approximately on a monthly basis, both in the daytime and at night. By present time 251 determinations have been made. Spread of all the determinations does not exceed 50 micro Gal. Mean square error of all the isolated determinations by the inner repeatability equals approximately 5 micro Gal. Total error of a single determination does not exceed 10 micro Gal.

The results of the determinations carried out in 2003 are given in table 1 and shown in plot 2.

The determination results were processed to get both the mean value and mean weight value. The determination results explicitly reveal the repeatability of the mean values in series of determinations and mean weight values. The mean weight value is considered as a final result. The maximum spread in the determination results equals 20 micro Gal for GBL-3 and 30 micro Gal – for GBL-P. As a result, the mean annual values of gravity acceleration equal 718,5 micro Gal for GBL-3, and 714,6 micro Gal for GBL-P. The gravity acceleration determined in June with GABL-E equals 716,0 micro Gal. Obviously, it lies between the values obtained with GBL-3 and GBL-P.

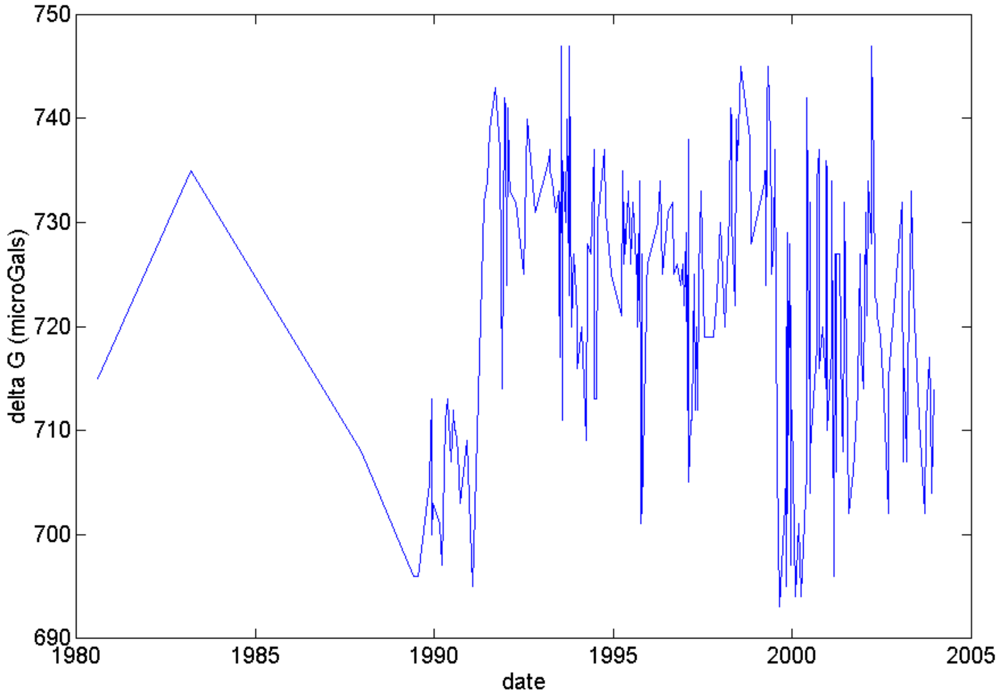

Diagram 1. A trend of the gravity value changes determined on the Main Gravimetric Point of Russia with different ballistic gravimeters

The plot shows some increase at ≈ 5–10 micro Gal in the gravity acceleration in April-May. Probably, this is connected with a man-caused activity.

Table 1: Results of determinations made on the Main Gravimetric Point in 2003.

№№	Observation date	Instrument	Mean value and its error in micro Gals	Mean weight value and its error in micro Gals	Subsoil water level in cm
1	23.01	GBL-3	730,2± 7,0	731,9± 5,8	906
2	31.01	GBL-P	709,1± 6,8	706,7± 6,7	908
3	11.02	GBL-3	713,3± 4,5	712,8± 4,0	908
4	19.02	GBL-P	716,0± 4,5	716,5± 4,5	908
5	13.03	GBL-P	707,2± 4,4	706,8± 4,1	
6	27.03	GBL-3	716,7±7,1	715,7± 6,1	
7	11.04	GBL-P	723,2± 4,9	726,2± 6,2	
8	22.04	GBL-3	735,5±7,4	731,8± 6,2	892
9	29.04	GBL-P	734,0± 5,0	733,0± 5,0	890
10	15.05	GBL-P	724,4± 6,1	722,6± 4,8	893
11	11.06	GABL-E	716,1± 2,7	715,9± 2,7	
12	14.07	GBL-P	710,1± 4,8	711,4± 4,6	
13	17.09	GBL-P	708,3± 5,3	702,4± 4,3	859

№№	Observation date	Instrument	Mean value and its error in micro Gals	Mean weight value and its error in micro Gals	Subsoil water level in cm
14	23.09	GBL-3	710,2± 9,4	710,6± 9,2	862
15	30.10	GBL-P	718,0± 5,6	717,4± 5,3	865
16	12.11	GBL-3	711,5± 5,8	712,7± 5,9	870
17	27.11	GBL-P	705,9±4,8	703,5± 4,4	873
18	10.12	GBL-3	712,5± 7,6	714,2± 7,3	868

One of the tasks pursued by the regular determinations on the Main Gravimetric Point is to further develop the technology of determinations carried with ballistic gravimeters. While the precision provided by these instruments being high, determination results are impacted by various effects both instrumental and external. Micro seismological impacts have the strongest bearing on measuring process, especially at the frequencies with the periods that are multiples of the free falling body fall ≈ 0,3 s.

This impact could be partially (high frequencies) reduced by suspending a referent corner reflector in the center of low frequency seismometer rocking. Non-compensated portion of micro seismological impacts is reduced by averaging an array of determination results.
Micro seismological vibrations of a basement differently impact the indications of different instruments.

Micro seismological impacts and vibrations on the Point before June 1994 had been considerably lower than the background common to the given area. However, later they increased even at nighttime. The urban transport (metro, tram, auto) interferes with observations. This causes a need to look for a new spot with lower vibration level to carry out such observations.

Determination results are impacted by changes in hydro-geological conditions in the area where an observation point is located. The change in subsoil water by 1 meter corresponds to the change in gravity acceleration by 10–20 micro Gal.

In 1990 a correlation between the change in gravity acceleration and the change in subsoil water level at a phase shift in time was revealed. The data on subsoil water level were taken for the borehole located at 800 m from the observation point.

In 1993 a borehole was drilled at 20 m from the observation point to determine a level of subsoil water, the fluctuations of which did not exceed 2 m. Therefore, the change in gravity acceleration could reach ≈ 30 micro Gal. The measured gravity acceleration and subsoil water level data did not bring out any explicit correlation. All the more, the water level happened to suddenly lower by ≈ 4 m and then it reached the former level again. Usually the change in subsoil water level in this borehole was within 1 m range for several years. Apparently, under urban conditions, and especially near the metro such investigations are difficult to carry out since subsoil water level is changing at random not considerably changing the mass that

governs the gravity value. Several of such levels are available here. The plot, diagram 2, does not either display any impact caused by subsoil water level changes.
A full set of determination results allowed establishing a ratio of the correlation between the changes in subsoil water level and gravity acceleration. To solve this task there is about a hundred of pairs of appropriate values. The obtained ratio of the correlation between immediate results of gravity determinations and the water depth in the borehole equals r=0.31. The estimation of its statistic significance is m=0.07. These results prove an important correlative connection as the value of correlation ratio exceeds its mean square error by more than three times. Evidently, the study of correlation between changes in subsoil water level and gravity should be continued to account and detail the results of gravity determination.

The plot, diagram 3, shows the results of determinations of an absolute value of gravity acceleration on the Main Gravimetric Point averaged over years and instruments. The smoothed curve is drawn there to display a trend in gravity acceleration variation, with the GABL measurements being marked with the circle.

Occasional errors of determinations are considerably lowered here. The curve specifies both instrumental errors and possible gravity acceleration changes that cannot be split.

In the city, with large constructions being built nearby the determination point, such changes in gravity acceleration are highly possible. In this case they do not exceed 10 micro Gal. This plot allows obtaining the most smoothed absolute value of gravity acceleration on the Main Gravimetric Point for this very time period and using these values as reference ones in various gravimetric activities. It also allows determining instrumental errors for each instrument.

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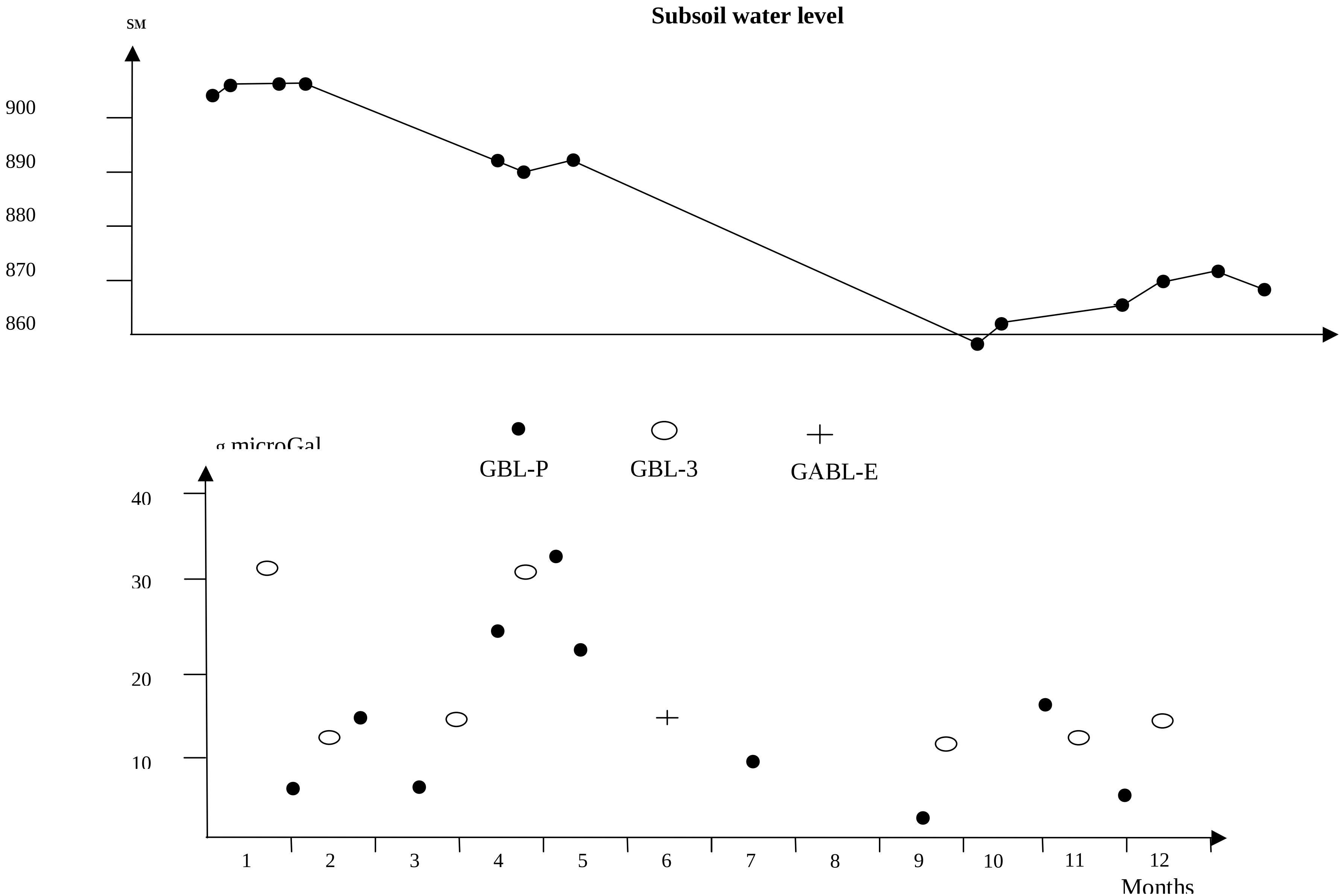

Diagram 2: Results of determinations made on the Main Gravimetric Point in 2003

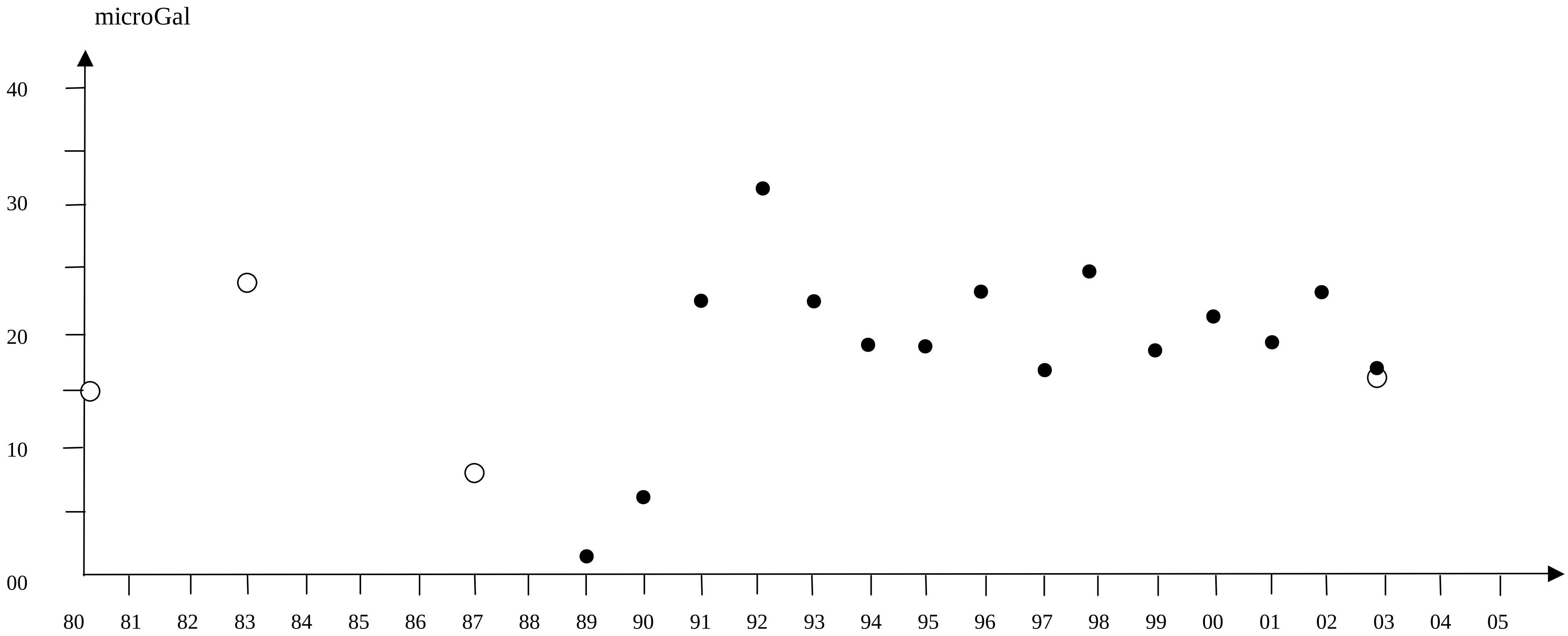

Diagram 3: The plot of gravity acceleration on the Main Gravimetric Point