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Airborne Gravimetric Draped Survey with a Chekan-AM Gravimeter

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Abstract: The paper describes the methodology for carrying out airborne gravimetric surveys using the Chekan-AM gravimeter. The features of processing airborne gravimetric measurements obtained in the course of draped survey are discussed. The results of a detailed airborne gravimetric survey are presented.

Keywords: airborne gravimetry, gravitational field, gravity anomaly, Chekan-AM gravimeter, smoothing.

INTRODUCTION

Currently, airborne gravimetric surveys show great potential for gravity field studies and continue actively developing [1–3]. The advantage of this method is obvious: it allows effective exploration of specific areas, including remote, hard-to-reach regions of the Earth, where other methods have limited use or cannot be used at all.

Mobile Chekan-AM gravimeters are extensively used by Russian and foreign companies in marine geological exploration [4–7]. In 2005–2007, the Chekan-AM gravimeter software was upgraded, which made it possible to carry out airborne gravimetric measurements [8]. In the period from 2007 to 2011, Chekan-AM was used in five regional gravimetric surveys on the shelf of Greenland, and in 2015, in a gravimetric survey with a scale of 1:500 000 in the northern part of the East Siberian Sea [2, 9]. In addition, Chekan-AM gravimeters were used in a number of flight trials aimed to analyze the possibility of using different types of air vehicles for gravimetric surveys, including those at high latitudes [10, 11].

In 2024, JSC MAGE conducted the first airborne gravimetric survey over terrestrial areas in Yakutia with the Chekan-AM gravimeter for geological exploration. Due to the complex nature of airborne geophysical operations (gravimetric and magnetometric measurements), its key feature is draped surveying, this being a traditional requirement for the present-day geological exploration [12–14]. Additionally, the flight altitude should be the minimum permissible value above the earth's surface based on the conditions that ensure a safe flight.

The purpose of this work is to describe the possibilities of using the Chekan-AM gravimeter for airborne draped surveys and to evaluate the measurement accuracy achieved. The paper also analyzes the features and results of measurements obtained with the Chekan-AM gravimeter within the framework of the airborne gravimetric survey under consideration.

1. GENERAL CHARACTERISTICS OF THE SURVEY CONDITIONS

The Chekan-AM gravimeter sensitive element is built on the basis of a double quartz elastic system (DQES) developed jointly with specialists from the Institute of Physics of the Earth of the Russian Academy of Sciences. A schematic of the sensitive element is shown in Fig. 1.

A special feature of this type of the gravimetric sensor is liquid damping of its quartz sensitive element, which makes the processing of airborne gravimetric measurements significantly more complicated [15]. In addition, to compensate for the orbital effect inherent in all torsion-type measuring systems, the elastic system of the gravimeter comprises two identical systems made of ultra-pure quartz glass, installed in the horizontal plane at an angle of 180° relative to each other.

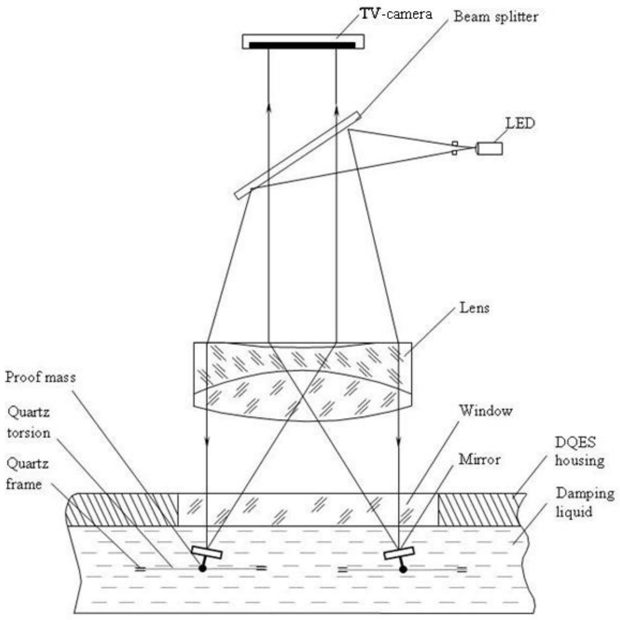

Fig. 1. Schematic of the gravimeter sensitive element.

The information on the angular position of the elastic system pendulums is readout by an optoelectronic converter operating in autocollimation mode. A special 5-megapixel black-and-white CMOS matrix is used as a photodetector [2, 16].

The gravimeter is mounted in a small-sized two-axis digitally controlled gyrostabilizer. The hardware of the Chekan-AM gravimeter is identical in its shipborne and airborne modifications.

To perform the survey, the Chekan-AM gravimeter was placed in the central part of the Cessna 182 fuselage (Fig. 2). The navigation support for the survey included an onboard Novatel receiver of satellite navigation systems, which synchronizes the gravimeter readings and generates data for correction of the gravimeter gyroplatform, as well as two Novatel base stations located in the survey area. Taking into consideration the fact that the field season began in April and lasted until November 2024, special attention was given to temperature stabilization at the place around the gravimeter [17]. This task was successfully accomplished, so that the temperature range during the field work inside the aircraft was from +10 to +25°C.

The base airport was located within the survey area. The average flight speed during measurements on survey lines was 50 m/s with variations within ±5 m/s. The flight altitude, dictated by the terrain, varied from 200 to 450 m. It is important to note the high quality of the aircraft piloting owing to which it was made possible to ensure the draped survey when taking measurements. Thus, both when maintaining a constant barometric altitude and when conducting draped survey, as shown in Fig. 3, the vertical speeds did not exceed 2 m/s in absolute value, and the vertical accelerations were less than 200 Gal. It should be noted that it was for the first time that the Chekan-AM gravimeter was used in airborne gravimetric surveys with such a significant background of inertial accelerations [11].

Fig. 2. Cessna 182.

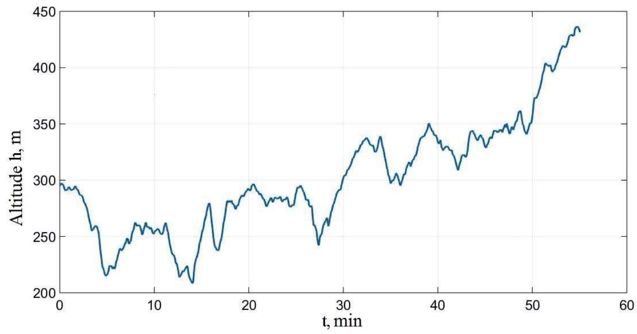

Fig. 3. Flight altitude when following a survey line.

Noteworthy also is the high dynamics of the Cessna 182 aircraft in the flight conditions close to the earth's surface. Despite the fact that the flights were carried out in the darkness, when there were no ascending thermal air currents, the aircraft roll and yaw angles varied within ±5° with periods of 15 s and 30 s, respectively.

The roll with the above parameters was compensated for in real time with the use of a gearless servo drive and an analytical system for generating the heading of the gravimeter gyroplatform. Variations in the yaw angle lead to changes in the Eötvös correction of ±25 mGal with the same period, which are taken into account during the combined processing of gravimeter readings and satellite navigation data [15].

2. METHODOLOGICAL FEATURES OF THE SURVEY AND DATA PROCESSING ALGORITHMS

On board the aircraft, the Chekan-AM gravimeter is serviced by one operator whose duties are preflight preparation of the gravimeter, as well as monitoring of specified parameters during the aircraft approaches to survey lines. Preflight preparation takes one hour. It is aimed to carry out reference observations and ensure that the gravimeter is ready for the survey. All operations are automated. During the flight, the operator switches the correction modes of the gravimeter stabilization system based on GNSS receiver data during approaches to survey lines. This is necessary to quickly bring the stabilization system to a steady-state mode after performing a maneuver along the heading.

After the flight, all gravimetric and navigation information, as well as the gravimeter stabilization system data recorded in real time are subject to quality control with regard to their suitability for postprocessing. All information acquired during the flight is combined and then automatically allocated to survey profiles to be further analyzed individually. About 20 parameters are evaluated, in particular, the level of stabilization errors on a survey line, the quality of the aircraft keeping on a given trajectory, the degree of turbulence, and others. Since the criteria are specifically developed for each of the parameters, the results of quality control are presented to the operator as ‘usable/unusable’ (Fig. 4). In the event of substandard data, the operator is able to identify the cause of the defect and exclude faulty sections from processing.

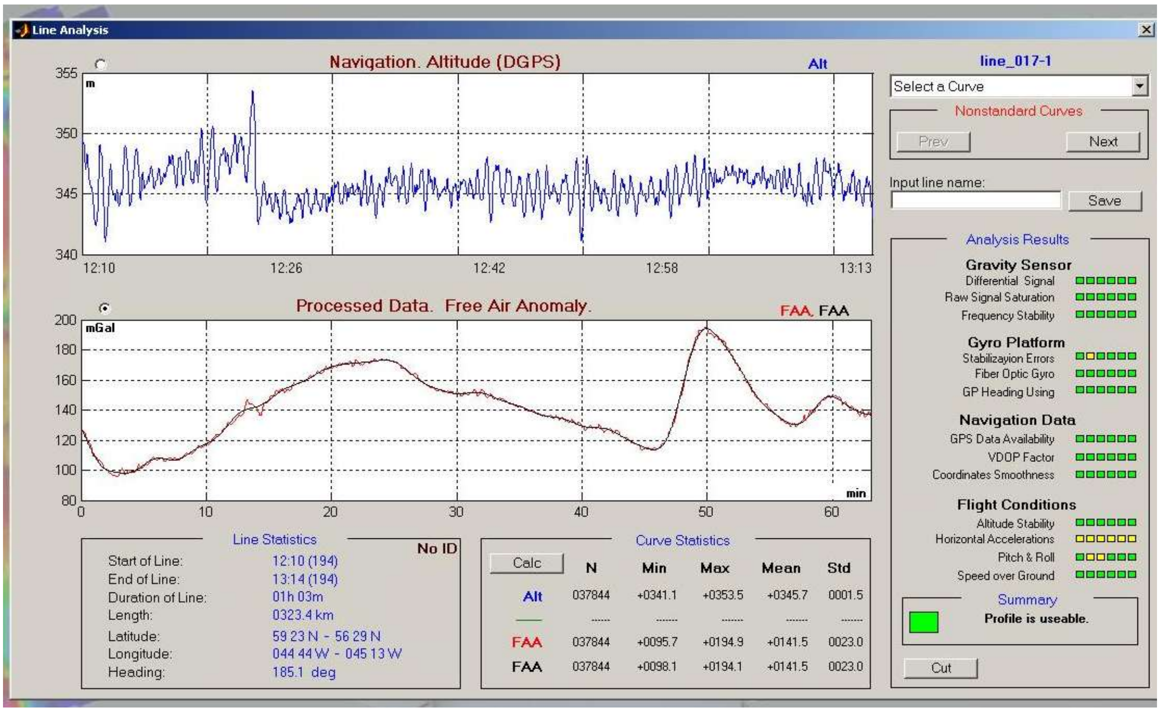

Fig. 4. Quality control display.

Postprocessing of gravimetric data is performed after compensation of residual errors of satellite navigation information in differential mode. This compensation was performed by JSC MAGE specialists using the Novatel software. The error in determining the vertical coordinate on the survey profiles in the postprocessing mode was less than 5 cm for 90% of the data.

Office processing of gravimetric data is performed with dedicated Chekan_QC software [18]. The program allows for calculation of all necessary corrections, calculation and smoothing of the free-air gravity anomaly. The data processing results are available in graphic and digital form. In addition, owing to this program, databases of reference observations and surveys with the evaluation of the intrinsic data convergence are formed. A flowchart of data processing implemented in the Chekan_QC program is shown in Fig. 5.

Though all the operations are performed automatically, the operator is able to display a certain plot and control the value of any parameter or signal at each stage of data processing.

In contrast to the previous airborne gravimetric surveys, because of terrain following, we had to additionally compensate for the orbital effect, which was done for the first time using formula [19]

$$\Delta g_{ORB} = k(m_2 - m_1)W_X ,$$

where k = $3.15 \cdot 10^{-5}$ rad/px is the coefficient of conversion from pixels to the angle of rotation of the gravimeter elastic system pendulum; m_1, m_2 are current readings of the gravimeter elastic system pendulums in pixels; W_X is longitudinal horizontal acceleration recorded from the gravimeter gyroplatform accelerometer readings.

This correction allowed us to increase the final accuracy of the airborne gravimetric measurements and ensure the required cutoff frequency of the smoothing filter, which made the survey on a scale of 1:100 000 possible.

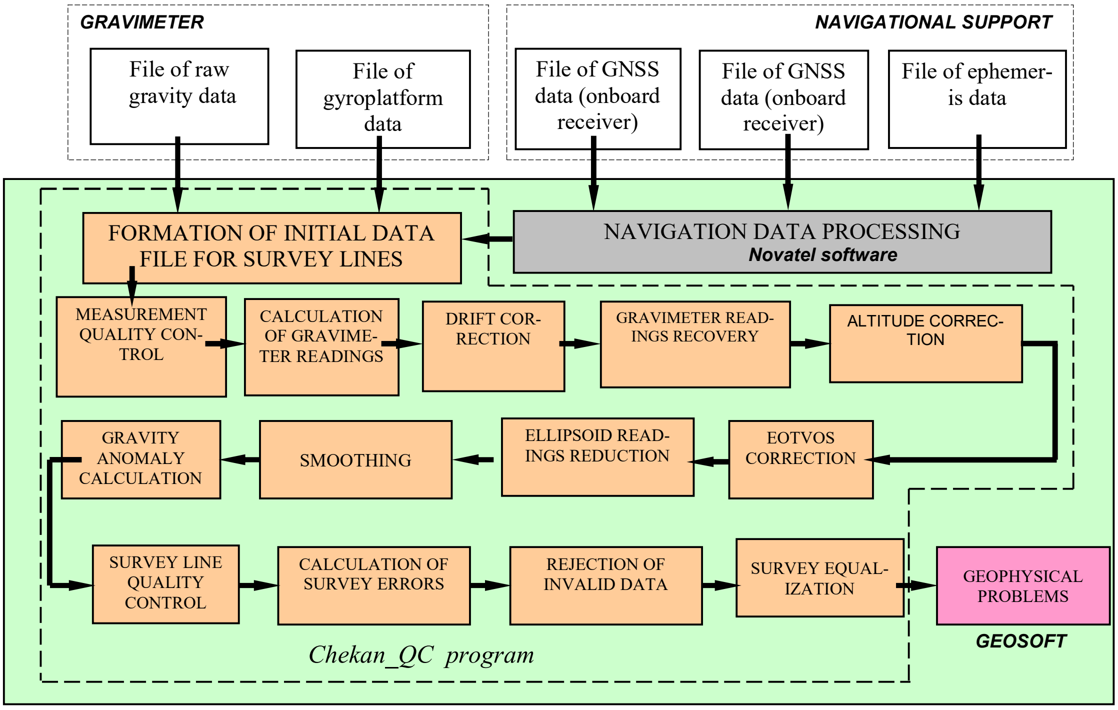

Fig. 5. Flowchart of data processing in Chekan QC.

3. RESULTS OF THE AIRBORNE GRAVIMETRIC SURVEY AND ACCURACY ESTIMATION

In accordance with the methodology of the airborne gravimetric survey, before each flight, we made reference measurements with the Chekan-AM gravimeter for one hour. Figure 6 shows a part of the database which presents the results of one-month reference observations. The statistical estimates of reference observations for the whole period of the field survey are as follows: the gravimeter drift was 0.94 mGal/day, with its standard deviation not exceeding 0.1 mGal/day. This made it possible to process the survey results without additional correction for the gravimeter drift.

Because of weather conditions and forest fires, the airborne gravimetric survey operations were not unevenly distributed:

- March–August – 8000 km;
- September – 19 000 km;
- October – 9000 km;
- November – 9000 km.

In total, measurements were made on 319 main coverage survey lines and 10 control lines, with a total length of 45 000 km, and an average work productivity of 250 km/day. However, the actual productivity per flight, including take-offs, approaches to survey lines and returns to the base, was 100 km/h.

The accuracy of airborne gravimetric measurements was estimated by the differences of the main and control survey lines at their cross points, as well as on the repeat lines. Because of the small number of control lines, the number of cross points was 355, the RMS error in determining gravity anomalies was 1.94 mGal.

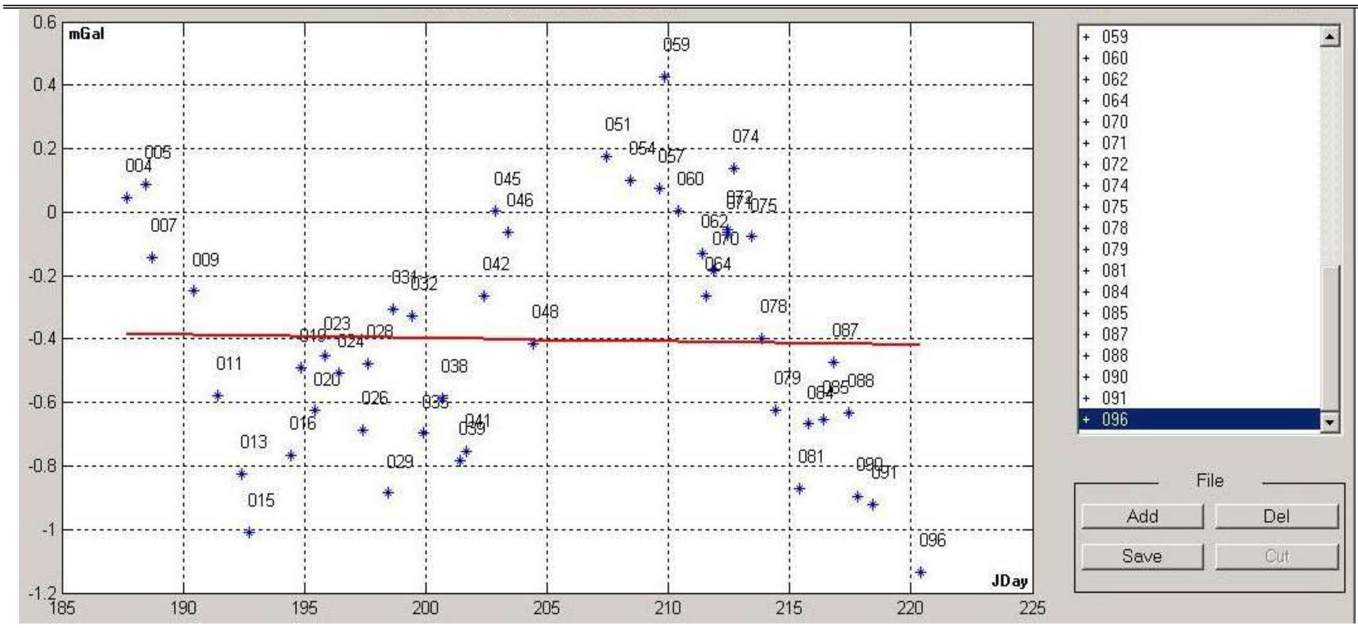

Fig. 6. Reference observation database.

Figure 7 shows the gravity anomalies obtained from the measurements on the 125 km repeated survey line made during the flights on May 19 and June 7, 2024.

The standard deviation of the measurements on the repeated survey line was 0.83 mGal with 422 repeated points. The average value of the measurement difference is 0.35 mGal. The data processing was performed with a low-pass filter with a 0.01 Hz cutoff frequency [15]. Taking into account the flight speed of 50 m/s, the spatial resolution of the measurements is 2.5 km [20].

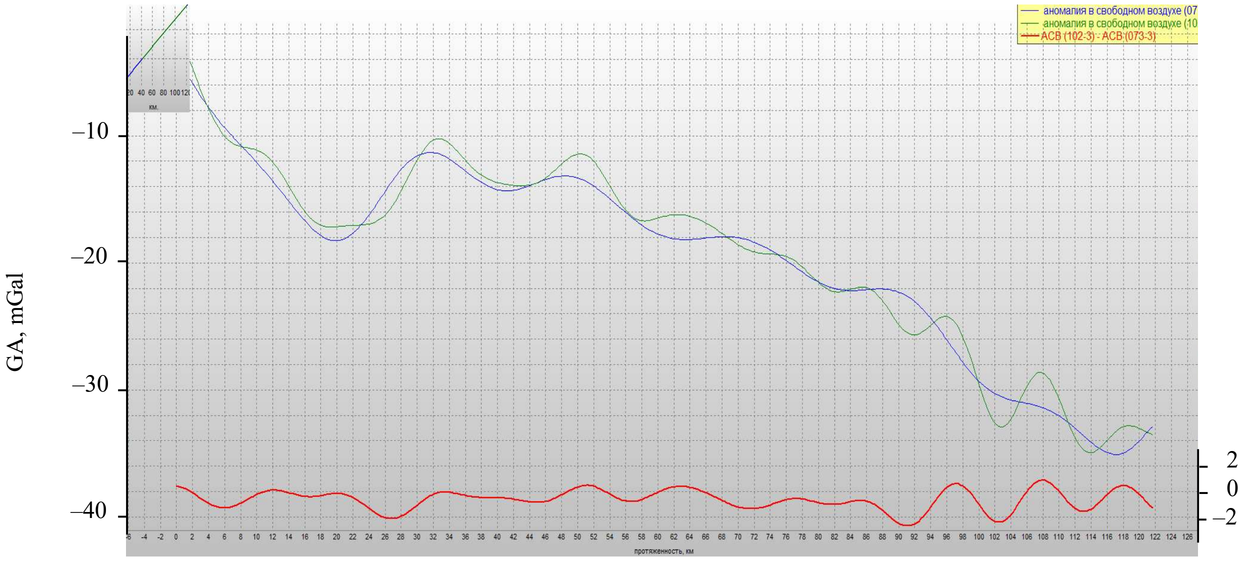

Fig. 7. Gravity anomaly curves based on measurements on a repeated survey lines (blue and green, scale on the left) and their difference (red, scale on the right).

Additionally, Fig. 8 shows the orbital motion effect on the gravimeter data. It is obvious that the proposed correction has changed the estimates of gravity increments by up to 10 mGal.

The airborne gravimetric information obtained in this survey served as a basis for the construction of a 1:100 000-scale gravity anomaly map at a conventional level (Fig. 9). The anomaly gravity difference in the survey area was 40 mGal. At the same time, the survey area has different spatial variability of the gravitational field: from tenths of a mGal/km in the northern part of the area to 10 mGal/km in the southern part.

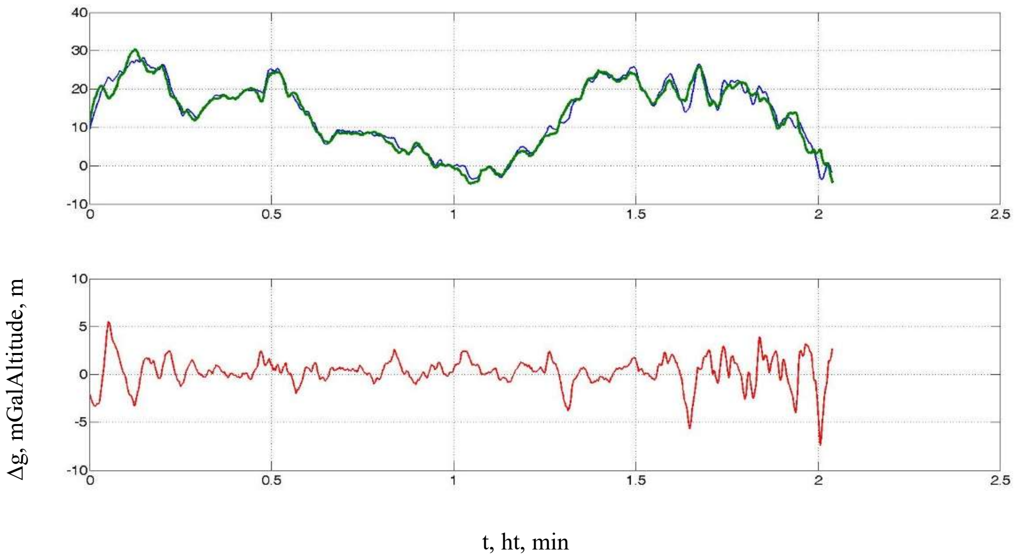

Fig. 8. Gravity anomaly curves without correction for the orbital effect (blue) and with correction (green), and their difference (red).

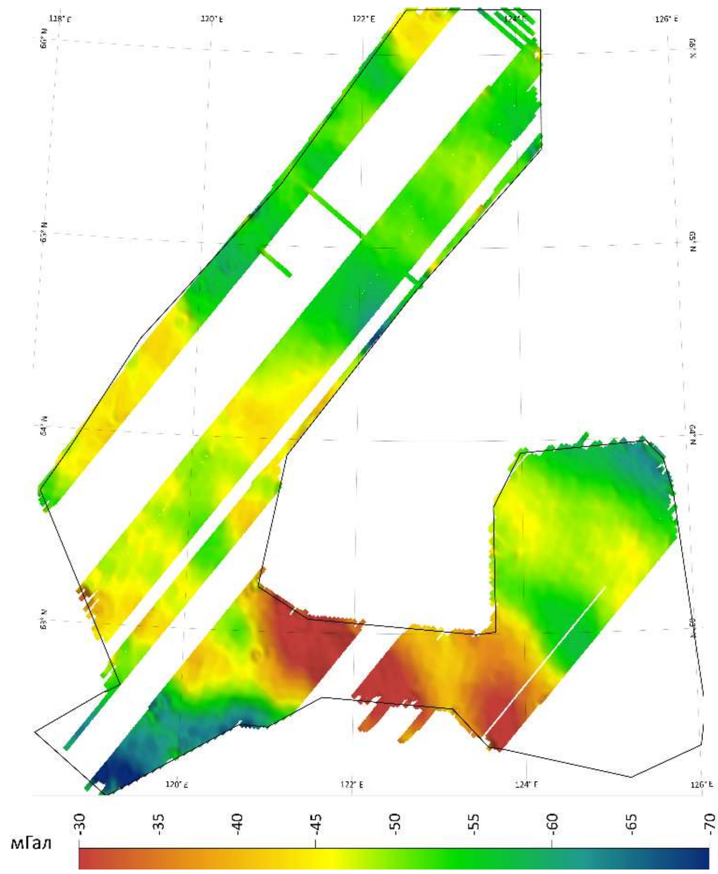

Fig. 9. Gravity anomaly map based on the results of the first field season survey.

4. COMPARISON OF MEASUREMENT RESULTS WITH THE GLOBAL MODEL

Figure 10 shows a fragment of the gravity anomaly field measured in this airborne gravimetric survey and the gravity anomaly field for this area according to the EGM2008 global model data.

From the difference between the measured and model GA fields (Fig. 11), it is evident that for weakly anomalous areas, the model and measurements coincide to within a few milligals. In areas with a GA gradient of more than 2 mGal/km, the deviation of the model GA values from the measurement results in absolute value can reach 10 mGal, which confirms the insufficient detail of modern models of the Earth's gravity field and the prospects for high-precision airborne gravimetric surveys [21].

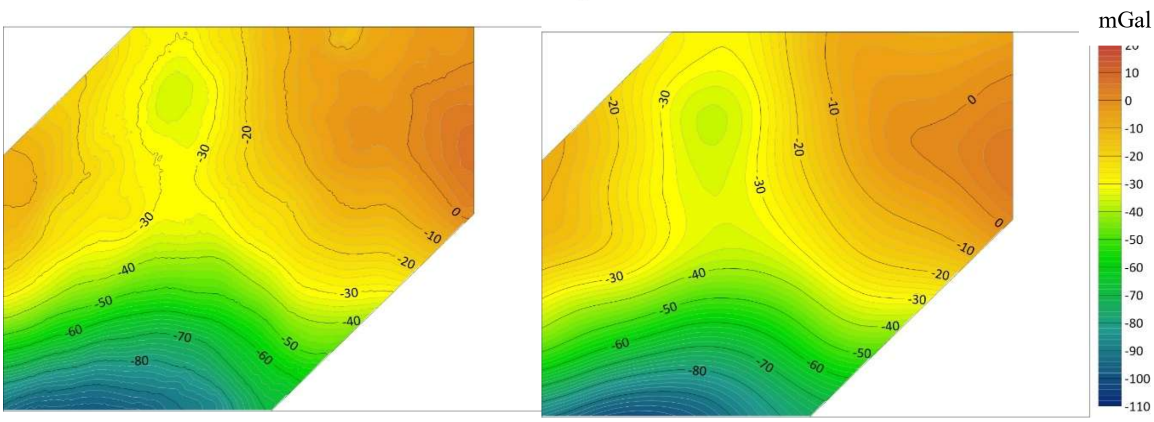

Fig. 10. A fragment of the gravity anomaly (GA) map constructed in this airborne gravimetric survey (on the left) and the global model data (on the right).

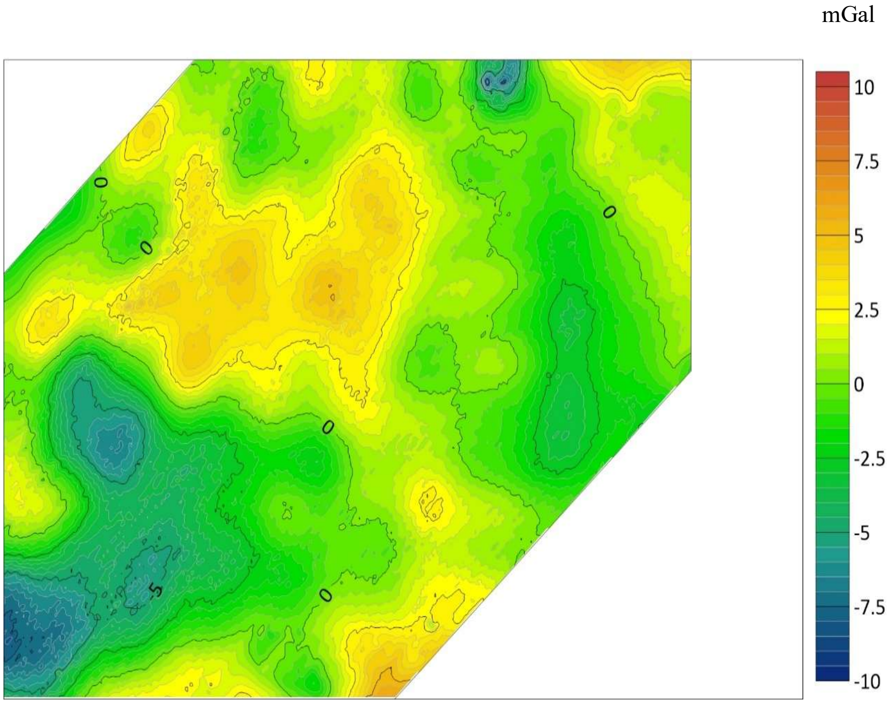

Fig. 11. Map of the differences between the measured and model Gas.

CONCLUSIONS

The analysis of the airborne gravimetric survey data has confirmed the possibility of using the Chekan-AM gravimeter (model Shelf-E) to perform surveys at a scale of 1:100 000. The terrain following during the draped survey reduces the accuracy of measurements to a certain extent, but it is not a limiting factor for airborne gravimetric measurements. It was for the first time that the draped survey was carried out with a gyrostabilized gravimeter.

The airborne gravimetric survey conducted in 2024 by JSC MAGE has shown that the Chekan-AM gravimeter can be used not only to accomplish the previously formulated objectives of studying the Earth's shape [22–29] and exploring hydrocarbons on the shelf [2–7], but also to search for oil and gas structures on land, which opens up new prospects for damped gravimeters of this type. Currently, Concern CSRI Elektropribor, JSC, is conducting a research aimed to improve the accuracy of airborne gravimetric measurements using algorithms of Kalman filtering and smoothing [20].

CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

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