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Field Geophysical Complex for Creating Maps of the Parameters of the Earth's Gravitational and Magnetic Fields

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Abstract: The article discusses a field geophysical complex that includes the Earth's gravity and magnetic fields parameters meters — an digital zenith camera (DZC), a relative gravimeter, onboard quantum magnetometer and ground magnetovariation station. This complex allows determining such parameters of the Earth's gravity field as acceleration and anomalies of gravity, plumb line deviations, horizontal components of the acceleration of gravity and gravitational gradients, and parameters of the Earth's magnetic field — absolute and anomalous values of induction. Maps of the Earth's gravity and magnetic fields can be used in various fields, in particular, in the creation and testing of integrated autonomous navigation systems using the parameters of these fields. The paper presents examples of parameter maps created using this complex. The measurement error of acceleration and gravity anomaly is 10 µGal, plumb line deviation is ≈ 0.2″, horizontal components of gravity acceleration are ≈ 1 mGal, gravitational gradients are 10 Eötvös at a distance between calculation points of ≈ 1.4 km, and the parameters of the Earth's magnetic field are 1 nT.

Keywords: Earth's gravity field, Earth's magnetic field, digital zenith camera, gravimeter, magnetometer, navigation charts.

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Research Article

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1. Introduction

Today, the highest navigation accuracy is achieved by systems based on the use of global satellite systems (GNSS) signals. However, to ensure "seamless" navigation in conditions of interference and unavailability of GNSS signals, it is necessary to develop an integrated navigation system. The integration of GNSS consumer navigation equipment and a strapdown inertial navigation system (SINS) has become widespread, which improves accuracy and noise immunity. However, as is known, in the case of a prolonged absence of GNSS signals, the error in determining the location using the SINS accumulates and its readings must be corrected. In such cases, it is possible to use the parameters of the Earth's gravity and magnetic fields (EGF and EMF) to correct SINS readings [*Canciani et al.*, 2017; *Denisenko et al.*, 2020; *Sazonova*, 2020; *Stepanov et al.*, 2020].

One of the components of such an integrated system is a reference navigation map of the parameters of the EGF and EMF, which is used to determine the current location based on the results of comparison with the measurement data of the onboard measuring device. It should be noted separately that, as noted in works [*Peshekhonov*, 2020; *Popadyev et al.*, 2015], EGF maps are also needed as a source of correction information for SINS. These works note that for promising SINS, the error in determining the EGF parameters will make a significant contribution to the accuracy of the navigation solution.

The paper presents a field geophysical complex that will allow the creation of EGF and EMF maps, with previously unattainable accuracy and discreteness, which can be used in the creation and testing of integrated navigation systems.

2. Field gravity complex

2.1. EGF measuring instruments

To measure the EGF parameters, it is proposed to use together the DZC to measure the deflection of vertical (DoV) developed by the FSUE "VNIIFTRI" [*Murzabekov et al.*, 2020] and the relative gravimeter of the Scintrex CG-5 (Figure 1).

Figure 1. DZC and relative gravimeter.

The combined use of these devices allows measuring the components ξ, η of the DoV and the acceleration of gravity g (AGG) at a single point. Both devices are field devices, relocatable and allow measurements to be taken with any specified discreteness. The measurement error of DoV is 0.2″, and of AGG is no more than 10 µGal.

With known values of DoV and AGG, the horizontal components of AGG g_x and g_y are calculated at the same point [*Ogorodova*, 2010]:

$$g_x \approx -g \cdot \xi; \; g_y \approx -g \cdot \eta.$$

With known g_x and g_y values between measurement points, the gravity gradients T_{ij} (second derivatives of the anomalous potential) are calculated as their change along the corresponding axis, divided by the distance between them. For example, the T_{xx} component of the gravity gradient between points 1 and 2, lying along the meridian (OX axis) at a distance of $\Delta x = x_2 - x_1$, is calculated as:

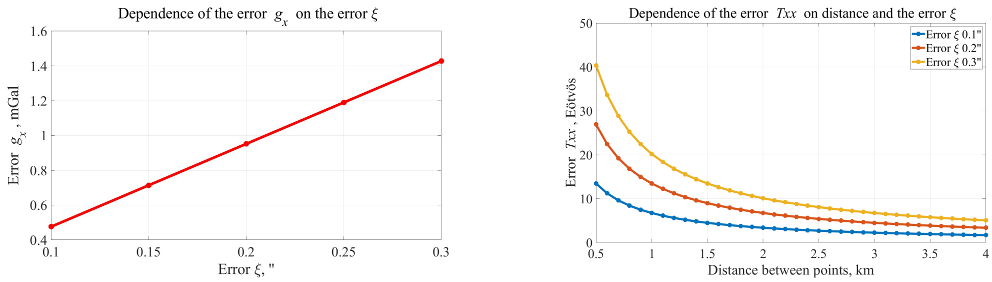
$$T_{xx} = \frac{g_{x_2} - g_{x_1}}{x_2 - x_1} = \frac{\Delta g_x}{\Delta x}.$$

Similarly, the expressions for calculating T_{yy} and T_{xy} are:

$$T_{yy} = \frac{\Delta g_y}{\Delta y}; \; T_{xy} = \frac{\Delta g_x}{\Delta y},$$

where Δg_x and Δg_y are the changes in g_x and g_y between the measurement points along the meridian (OX axis) and parallel (OY axis); Δy is the distance between the points along the OY axis.

Figure 2a shows a graph of the dependence of the calculation error g_x on the latitude error of the DoV, and Figure 2b shows a graph of the dependence of the error T_{xx} on the distance between measurement points with an DoV error 0.1″÷0.3″.



(**a**) (**b**)

Figure 2. g_x and T_{xx} calculation error.

2.2. Measuring instruments for EMF parameters

To measure the EMF parameters, the complex uses an onboard quantum magnetometer from *Geoscan* and a magnetovariation station from *Radar MMS Research and Production Enterprise* (Figure 3). In this case, to increase the efficiency of measurements, a quadcopter is used, to which an onboard magnetometer is attached on a 10 m long non-magnetic cable. A distance of 10 m is sufficient to completely eliminate the influence of interference from the quadcopter on the magnetometer readings.

(**a**) (**b**)

Figure 3. Measuring instruments for EMF parameters.

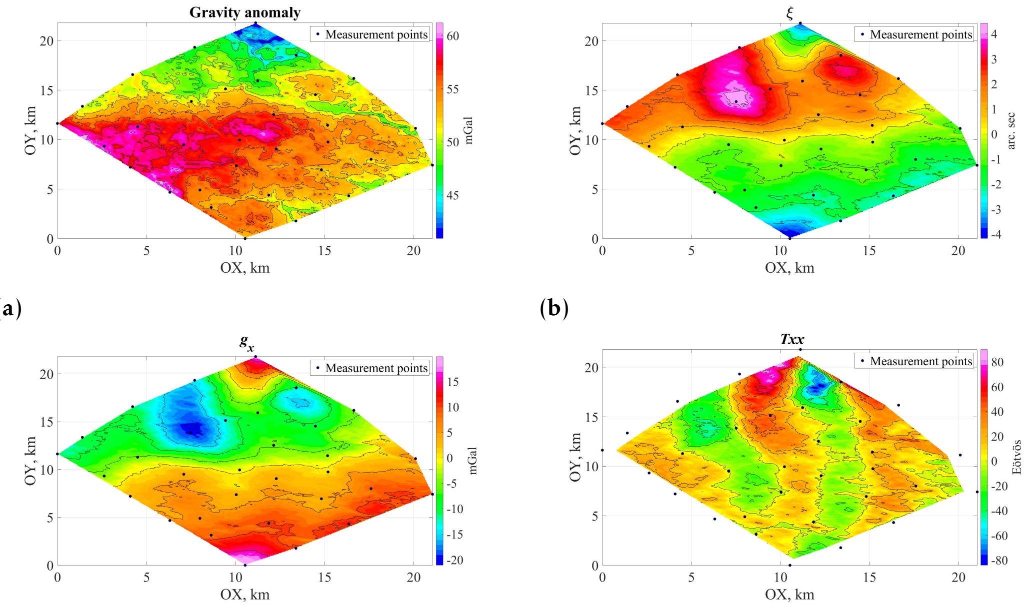
3. Map creation results

3.1. EGF maps

Joint measurements of the DoV and AGG components using an DZC and gravimeter were performed in the Moscow region at a test site with linear dimensions of approximately 20×20 km. The test site includes 32 measurement points with an average distance of approximately 4 km from each other. The measurement time at a single point using the complex does not exceed 1 hour.

To create DoV and AGG maps, a uniform grid with a step of 100 m was created, including measurement points. Interpolation DoV and AGG values into points of the uniform grid was performed using the well-known "remove-restore" method, which allows taking into account the influence of topographic masses and increases the accuracy of map creation [*Yang et al.*, 2020].

At each point of the uniform grid, first the calculation of g_x and g_y was performed, and then the gravity gradients were calculated at a distance of 1.4 km between the calculation points. Figure 4 shows examples of the created maps of some parameters of the EGF.



(a) (b) (c) (d)

Figure 4. Examples of created EGF maps.

3.2. EMF maps

When creating the EMF maps, measurements were performed by tacks at a flight altitude of 150 m with a distance between tacks of 200 m. A magnetovariation station was located in the measurement area. The map of the EMF anomalous induction component, created based on the results of these measurements, is shown in Figure 5.

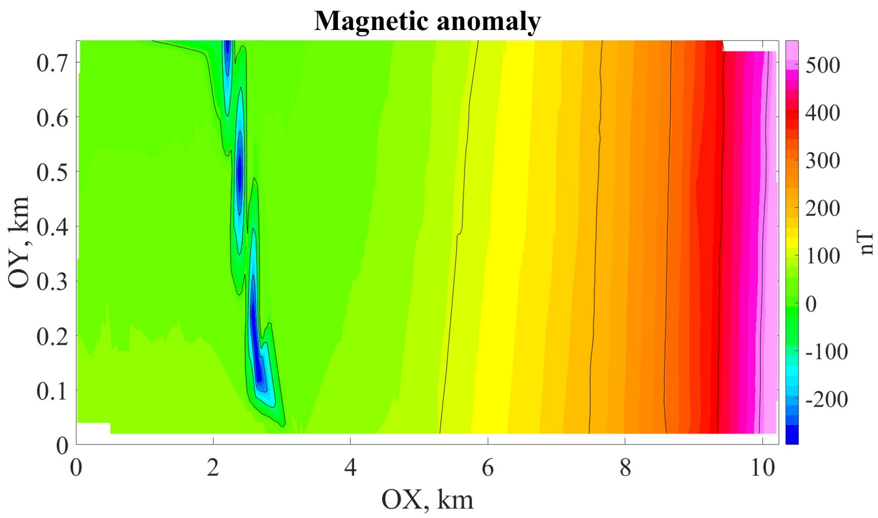


Figure 5. Anomalous EMF map.

The created anomalous EMF map is planned to be used in testing the experimental sample of the EMF navigation system, which is being created at the FSUE "VNIIFTRI". The experimental sample of the EMF navigation system will include the above-mentioned magnetometers and a quadcopter, as well as a SINS on MEMS sensors.

4. Conclusion

The paper presents a geophysical complex that includes meters for the parameters of the EGF and EMF. This complex allows creating maps of the AGG, DoV, gravity gradients, as well as a map of the anomalous EMF. These maps can be used, in particular, in the creation and testing of integrated navigation systems for the EGF and EMF.

Using the complex, examples of maps of the EGF and EMF parameters were created at a local test site. In this case, the measurement error of the AGG is 10 μGal, DoV ≈ 0.2″, horizontal components of the AGG ≈ 1 mGal, gravity gradients — 10 Eötvös at a distance between calculation points of ≈ 1.4 km, EMF parameters — 1 nT.

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References

Canciani A., *Raquet J.* Airborne Magnetic Anomaly Navigation // IEEE Transactions on Aerospace and Electronic Systems. — 2017. — Vol. 53, no. 1. — P. 67–80. — DOI: 10.1109/taes.2017.2649238.

Denisenko O. V., *Pustovoit V. I.*, *Silvestrov I. S.*, *et al.* Problems of development of seamless assistive navigation technology in GNSS GLONASS based on measurements of parameters of geophysical fields // Almanac of modern metrology. — 2020. — 4 (24). — P. 127–160. — (In Russian).

Murzabekov M. M., *Fateev V. F.*, *Yuzefovich P. A.* Measuring Plumb-Line Deviations with a Digital Astrometer at the Moscow Gravitational Attraction // Astronomy Reports. — 2020. — Vol. 64, issue 10, no. 10. — P. 876–882. — DOI: 10.1134/s1063772920100042.

Ogorodova L. V. Normal field and definition of anomalous potential. — Moscow : MIIGAiK, 2010. — P. 105. — (In Russian).

Peshekhonov V. G. Problem of the Vertical Deflection in High-Precision Inertial Navigation // Giroskopiya i Navigatsiya. — 2020. — Vol. 28, no. 4. — P. 3–15. — DOI: 10.17285/0869-7035.0046. — (In Russian).

Popadyev V. V., *Soroka A. I.*, *Polubekhin A. I.* The possibilities of correction parameters of onboard inertial navigation systems for aircraft based on gravimetric maps of the Earth // Civil Aviation High Technologies. — 2015. — No. 222. — P. 90–97. — (In Russian).

Sazonova T. V. Experimental studies of the accuracy characteristics of correlation-extreme navigation systems based on the Earth's magnetic field // Almanac of modern metrology. — 2020. — 4(24). — P. 86–96. — (In Russian).

Stepanov O. A., *Nosov A. S.* A Map-Aided Navigation Algorithm without Preprocessing of Field Measurements // Giroskopiya i Navigatsiya. — 2020. — Vol. 28, no. 2. — P. 70–90. — DOI: 10.17285/0869-7035.0029. — (In Russian).

Yang M., *Hirt C.*, *Pail R.* TGF: A New MATLAB-based Software for Terrain-related Gravity Field Calculations // Remote Sensing. — 2020. — Vol. 12, no. 7. — P. 1063. — DOI: 10.3390/rs12071063.