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About the need of modernization the Ukrainian height system

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SUMMARY

Nowadays work is underway to integrate the leveling network of Ukraine into the UELN (United European Leveling Network) to ensure the determination of the heights of geodetic points and terrain objects in the UELN/EVRS2000 height system. To fully coordination the height system of Ukraine with modern European GIS standards, it is necessary to have a high-precision reference surface of the height reference system (geoid surface), corresponding with the European geoid EGG07. The purpose of this work is to analyze the existing models of (quasi)geoid on the Ukraine area. It is investigated that the most accurate model is UQG2012. Despite this, the deviation of this model even at some points of State Geodetic Network (SGN) of I class can reach 8 cm, and at other points up to 23 cm. The model of the European geoid EGG07 is difficult to use from a practical point of view in Ukraine area because it is tied to the Amsterdam benchmark, and the average deviation, relative to the benchmarks in the Baltic Height System, reaches 25 cm. In order to fully coordination the height system of Ukraine with the modern European GIS standard according to the INSPIRE directive, it is necessary to build a high-precision model of the geoid surface, consistent with the European geoid EGG07, after the integration of Ukraine's leveling network into the European leveling network UELN.

Introduction

Any reference coordinate system consists of a datum and a coordinate system. The datum defines how the reference coordinate system is related to the Earth's body (center position, scale, coordinate axis direction), while the coordinate system is the mathematical part of the reference system and is a set of rules that determine the correspondence of points to coordinates. The datum can be geodetic, vertical or engineering (local).

The division of the datum into geodetic and vertical is due to the fact that to solve many problems of geodesy it is traditionally convenient to separate the plan and height component of the reference system (Fys et al., 2020; Savchuk et al., 2018). To set the vertical datum it is necessary to specify some conditional coordinate surface from which the vertical coordinates will be deducted. Such surfaces include geoid, quasigeoid and ellipsoid. For building leveling networks the most accurate are traditional leveling methods in combination with gravimetric measurements. This is due to the lack of sufficiently accurate (quasi)geoid models and entails high economic costs.

The Baltic Height System of 1977 has been functioned on the Ukraine area since the times of the USSR, the starting point of which is the zero of the Kronstadt benchmark. The implementation of this system is the leveling network of Ukraine. However, this network is morally obsolete primarily due to the large distance from the zero point of reference altitudes (about 2 thousand km) and the inability to adapt the use of GNSS-leveling methods. Therefore the leveling network of Ukraine today does not correspond to the level of development of modern geospatial technologies and it needs to be modernized.

To date work is underway to integrate the leveling network of Ukraine into the UELN (United European Leveling Network) (Adam et al., 1999) to ensure the determination of the heights of geodetic points and terrain objects in the UELN/EVRS2000 height system (Sacher et al., 2007). Introduction and distribution of this height system on the Ukraine area will ensure Ukraine's integration into the European economic system, participation in international research of global ecological and geodynamic processes, study of the Earth's shape and gravitational field and mapping of Ukraine using satellite technologies.

Following the introduction of the Spatial Information Infrastructure in the European Union (INSPIRE) in 2007, general rules were established for the creation of the EU Spatial Information Infrastructure for its environmental policy and the implementation of solutions related to environmental protection. The INSPIRE directive promotes the creation of a European GIS standard. Obviously, in order to fully coordination the height system of Ukraine with modern European GIS standard, it is necessary to analyze existing geoid models on the Ukraine area and create a high-precision reference surface of the height reference system (geoid surface), which would be consistent with the European geoid EGG07.

Method and Theory

The first quasigeoid of high resolution, constructed on the Ukraine area, is the quasigeoid EGG97 (Denker, Torge, 1998). However, its use was complicated not only by the difference of zero points of the respective height systems (for Eastern European countries it is assumed that the difference between the Baltic and Amsterdam height systems is about 15 cm, and such a connection in Ukraine is reflected only in the mountains Transcarpathia), but also because of its clearly unsuccessful definition in some regions. For example, despite a quite dense network of GPS-leveling points in the Crimea, the difference between the measured heights and the heights of the EGG97 quasigeoid model is on average 66 cm.

Due to the practical impossibility of using the EGG97 quasigeoid model for the Ukraine area, a gravimetric quasigeoid UQG2006 was created for the region of Ukraine in 2006, and a combined quasigeoid UQG2007 was built in 2007 (Kucher et al., 2012). These were, in fact, the first quasigeoid solutions exclusively on Ukraine area, and they improved the quasigeoid definition compared to other regional and global models of that time (such as EGG97 or EGM96).

The next solution of the quasigeoid on the Ukraine area was the solution of UQG2011, built in 2011, and its redefinition with additional conditions UQG2012, obtained in 2012. This quasigeoid was constructed using gravitational anomalies in free air Δg for the Ukraine area, data from various altimetric missions as well as GPS-leveling data at 4070 points of the State Geodetic Network (SGN) of different classes (Fig. 1).

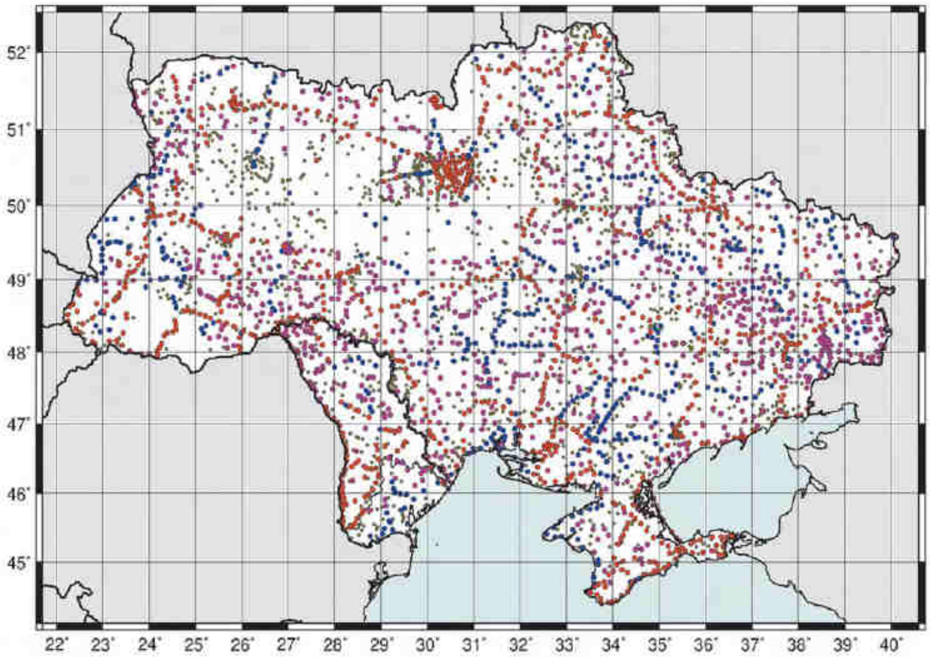

***Figure 1**. Distribution of GPS-leveling points of*
I ( ), II ( ), III ( ) and IV ( ) classes (Kucher et al., 2012)

The quasigeoid UKG2011 was constructed using the method of least square collocation. To assess its accuracy, the obtained solution was compared with the values obtained by GPS-leveling at SGN points of different classes: Class I - 827 points, Class II - 556 points, Class III - 878 points, Class IV - 1809 points. The minimum and maximum deviations as well as the mean and standard deviations were determined. The values of the relevant statistics are shown in table 1 (Marchenko et al., 2013).

***Table 1**. Statistics of differences in the measured heights of the quasigeoid and the solution of UQG2011*

Statistics, sm	GPS-leveling classes				
	I	II	III	IV	All points
Minimum deviation	-10.5	-18.9	-19.5	-20.6	-20.6
Maximum deviation	13.2	17.5	21.0	25.2	25.2
Mean deviation	0.7	1.4	2.2	0.8	1.1
Standard deviation	2.4	3.8	5.8	6.6	5.5

As we can seen from table 1, the standard deviation, depending on the leveling class, ranges from 2.4 cm to 6.6 cm. However, a differentiated approach shows that even in points of class I deviations can reach 10 cm, and the maximum deviations of the quasigeoid UQG2011 on leveling of IV class reaches about 25 cm. It can be argued that at other points, data from which were not used in the construction of this quasigeoid model and which are not included in the SGN, the deviation of UKG2011 may be even greater.

The construction of the quasigeoid UQG2012 was similarly to UQG2011 with the additional condition that for points of I and II classes the accuracy must be maintained <2 cm (Marchenko et al., 2013). Fig. 2 shows a map of the heights of the quasigeoid UKG2012 relative to the normal field GRS80. The obtained solution of UKG2012 was compared with the same values of GPS-leveling at SGN points of different classes. Relevant statistics are shown in table 2 (Marchenko et al., 2015).

Table 2. *Statistics of differences in the measured heights of the quasigeoid and the solution of UQG2012*

Statistics, sm	GPS-leveling classes				
	I	II	III	IV	All points
Minimum deviation	-8.1	-6.7	-17.9	-22.9	-22.9
Maximum deviation	6.2	6.8	17.6	23.6	23.6
Mean deviation	-0.3	-0.1	0.9	0.0	0.1
Standard deviation	1.4	1.6	5.5	7.0	5.4

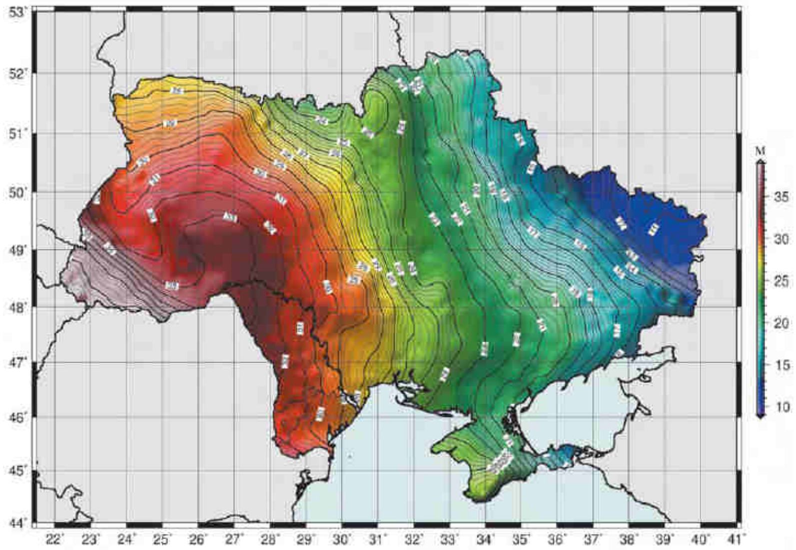

Figure 2. *Map of the heights of the quasigeoid UQG2012 (Marchenko et al., 2013)*

As we can see from table 2, the UQG2012 model is much more accurate than the UKG2011 model. Despite this, the deviation of this model even at some points of I class can reach 8 cm, and at other points up to 23 cm.

It should also be noted another regional quasigeoid, which covered the Ukraine area, named EGG07 (Denker et al., 2009). By analogy with EGG97, it is difficult to use from a practical point of view in Ukraine area due to the fact that it is tied to the Amsterdam benchmark, and therefore the average deviation relative to the benchmarks set in the Baltic height system reaches 25 cm. Statistics comparing the heights of EGG07 quasigeoid with measured values are shown in table 3.

Table 3. *Statistics of differences in the measured heights of the quasigeoid and the solution of* EGG07

Statistics, sm	GPS-leveling classes				
	I	II	III	IV	All points
Minimum deviation	-4.7	-0.6	-3.7	-7.9	-7.9
Maximum deviation	54.3	51.8	55.7	54.4	55.7
Mean deviation	25.6	26.0	26.8	24.6	25.5
Standard deviation	7.9	7.6	9.3	9.0	8.7

Conclusions

1. This paper analyzes the accuracy of different solutions of (quasi)geoid models on the Ukraine area. It is established that the UQG2012 model has the best accuracy in comparison with the obtained geoid heights from GNSS-observations at SGN points. Despite this, even at some points of I class the deviation of the quasigeoid UQG2012 can reach 8 cm, and at other points up to 23 cm.

2. The European geoid EGG07 is difficult to use from a practical point of view in Ukraine area due to the fact that it is tied to the Amsterdam benchmarks and therefore the average deviation relative to the benchmarks set in the Baltic height system reaches 25 cm.

3. In order to fully coordination the height system of Ukraine with the modern European GIS-standard according to the INSPIRE directive, it is necessary to build a high-precision model of the geoid surface in accordance with the European geoid EGG07 after the integration of the leveling network of Ukraine into the European leveling network UELN.

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