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THE PHENOMENON OF TOPOLOGICAL INCONSISTENCIES OF FRAMES OF MAP SHEETS DURING THE CREATION OF THE MAIN STATE TOPOGRAPHIC MAP

The aim of this work – research of topological inconsistencies during adjustment and junction of adjacent map sheets of digital topographic maps of scale 1:50000 with the use of rigorous analytical geodetic methods on the reference ellipsoid in the geoinformation environment. The research analyzes the phenomenon of topological inconsistencies of frames of adjacent digital topographic maps of 1:50000 scale within the zones of Gauss–Krueger projections and the feasibility of transition to rigorous analytical geodetic methods in the geoinformation environment during the creation of the topographic database "The Main state topographic map" by determining the differences between the vertices of the frames of digital topographic maps at a scale of 1: 50000 at the boundaries of the projection zones. This phenomenon was discovered during work at the state enterprise "Research Institute of Geodesy and Cartography". The dependences are shown and analyzed, which show the changes in the distances between the vertices of the frames of adjacent map sheets of scale 1: 50000 in longitude and latitude. These values range from 1 mm to 8 mm, which leads to topological inconsistencies in the form of gaps and overlaps of adjacent map sheets. These gaps and overlaps complicate the process of adjustment of map sheets and make it impossible to automate the process of the junction of features into the topographic database. The scientific novelty of the research is to justify the use of rigorous analytical geodetic methods and tools instead of analog cartometric and standard methods of instrumental GIS; the use of a reference ellipsoid, not just cartographic projections, a spheroid or a sphere. The practical significance of research is the use of rigorous analytical geodetic methods that significantly minimize the values of gaps and overlaps, as the establishment of tolerances for these values does not automate the process of correct adjustment and junction of map sheets. The performed research can be used to create the topographic database "The Basic topographic map scale 1: 10000", during the creation and updating of geospatial data in the geoinformation environment and the implementation of geodetic methods to determine the cartometric characteristics of features using GIS. Given the results of research, we can conclude that the present stage of application of geographic information systems in topographic and geodetic activities requires increasing the level of data topology and accuracy of all cartometric methods, which leads to the transition to extremely rigorous analytical geodetic methods directly on the reference ellipsoid.

Key words: the reference ellipsoid, geodetic methods, gaps and overlaps, cartography, rigorous computer methods, the topographic database, cartometry, topology.

Introduction

Adoption of the Law of Ukraine "On National Geospatial Data Infrastructure" 13.04.2020 and approval of the resolution of the Cabinet of Ministers of Ukraine "On the functioning of the national infrastructure of geospatial data" 26.05.2021 promotes the comprehensive use of geographic information systems (hereinafter – GIS), geospatial database management systems, geoportals and other geographic information technologies in Ukraine. This, in turn, requires increasing the level of intellectualization of geospatial data, revision and introduction of new modern requirements for their creation and updating in the geographic information environment. These geospatial data form a unified digital coordinate-spatial basis for the production of the core reference dataset, the integration and implementation of other activities with different thematic geospatial datasets. The development of modern technologies and regulatory support of the state allows rethinking some issues of the digital coordinate-spatial basis for its further use and development, first of all, the issue of the mathematical basis of maps.

An example of the creation of the core reference dataset is the topographic database "Main State Topographic Map" (hereinafter – TDB) which was established in the state enterprise "Research Institute of Geodesy and Cartography" in the framework of the Ukrainian-Norwegian project "Maps for good land governance". This project began after the signing of the Agreement between the Cabinet of Ministers of Ukraine and the Government of the Kingdom of Norway on technical and financial cooperation on 18.10.2016 and the Agreement for the project concluded between the State Service of Ukraine for Geodesy, Cartography and Cadastre and the Norwegian Mapping Authority from 28.02.2018 [Lazorenko–Hevel et. al., 2021]. The geodetic basis of the TDB is the State Geodetic Reference Coordinate System USC-2000 (EPSG:5561), that is, the data of this topographic database are modelled on the reference ellipsoid. Publication of data on the national geoportal (https://nsdi.gov.ua/map50k) and determination of cartometric characteristics by geodetic methods of TDB features take place directly in USC-2000.

One of the main sections of cartography is the use of geodetic and cartometric methods, which determine the conditions of all measurements on various cartographic materials: maps, topographic plans, profiles, orthophotos, satellites, etc [Kin & Karpinskyi, 2021].

It is possible to note three stages of the development of cartometric methods:

– analogue cartometric methods [Guidelines, 1973; Rechtzamer, 1974; Maling, 1989; Baranovskyi et. al., 2009a];

– standard methods of instrumental geographic information systems, which are not rigorous, but approximate, because the calculation uses a limited number of members in the Taylor series [Voser, 1999; Chamberlain & Duquette, 2007; Nishiyama, 2012; Panou et. al., 2013; Karpinskyi & Kin, 2018; Fisikopoulos & Oracle, 2019; Idrizi, 2020; Karpinskyi & Kin, 2020; Martínez–Llario et. al., 2021; Yildirim & Kadi, 2021];

– rigorous computer methods which determine the quantitative characteristics of features with high accuracy with a practically infinite sum of members in the Taylor series [Karney, 2011; Pędzich & Kuźma, 2012; Karney, 2013; Huang, 2017; Berk & Ferlan, 2018; Setiawan & Sediyono, 2020; Kin & Karpinskyi, 2020; Baselga & Olsen, 2021; Marx, 2021; Panou & Korakitis 2021].

The use of numerical methods to determine cartometric characteristics on a reference ellipsoid was considered in such articles [Rapp, 1993; Galo et. al., 2003; Turiño, 2008; Pędzich et. al., 2009; Sjöberg & Shirazian, 2012; Cazabal–Valencia et. al., 2016; Morgaś & Kopacz, 2016; Gojković et. al., 2017; Vermeer & Rasila, 2019; Morgaś & Kopacz, 2017; Fisikopoulos, 2019; Dong et. al., 2021].

This article focuses on the phenomenon of topological inconsistencies of frames of adjacent digital topographic map sheets at a scale of 1: 50000 at the Gauss–Krueger projection zones and solving this problem using the necessary data topology rules and rigorous analytical geodetic methods on a reference ellipsoid in the geographic information environment.

Aim

The aim of this work is the researching of topological inconsistencies during adjustment and junction of adjacent map sheets of digital topographic maps of scale 1:50000 with the use of rigorous analytical geodetic methods on the reference ellipsoid in the geoinformation environment.

Methodology

Traditionally, all existing characteristics of the accuracy of topographic maps in existing regulations are based on the limitations inherent in the paper, which has a resolution of 300 dpi. The maximum dimensions of features that can be distinguished on the analogue map are determined by the accuracy of the scale. The maximum dimensions of features that can be distinguished on the analogue map are determined by the accuracy of the scale [Baranovskyi et. al., 2009b]. Therefore, traditionally, the theoretical accuracy of the scale is taken as the distance on the ground, which corresponds to a given scale of 0.1 mm map. Modern geoinformatics allows us to work with a geospatial model at any scale and coordinate system, which affects the accuracy of determining the cartometric characteristics of the feature.

One of the main requirements for adjustment and junction sheets of adjacent topographic maps into the continuous seamless topographic database is the presence of multiple frames of topographic maps without gaps and overlaps. In this case, these multiple frames of map sheets are a continuous coverage.

The nature of the origin of the phenomenon of research is explained by the order of creation of a vector model of frames of map sheets of scale 1:50000 following the requirements of the map sheet of scale 1:50000 (Fig. 1), which consisted of such stages:

1) Based on the fixed values of the corners of the frames of the map sheets, which are indicated in geodetic coordinates in decimal degrees on the Krasovsky reference ellipsoid (EPSG:4284), polygonal map sheet frame objects were created.

2) Later, the geodetic coordinates of the corners of the frames of map sheets were transformed into plane rectangular coordinates of the zones of Gauss–

Krueger projections (EPSG: 5562, 5563, 5564, 5565) by standard tools of ArcGIS for Desktop 10.6.

3) Adjustment and junction features in the topographic database of the "Main State Topographic Map", the coordinates of the corners of the frame frames were transformed into geodetic coordinates by standard means QGIS 3.24 and ArcGIS for Desktop 10.6.

It should be noted that the gaps and overlaps between adjacent sheets of topographic maps at the boundaries of the Gauss–Krueger projection zones were formed due to the use of approximate standard GIS tools and rounding of coordinate values during their coordinate transformations. This, in turn, affected the topological consistency of the vertices and edges of the polygonal frames of adjacent map sheets, the edges of which must be common, do not overlap and do not form gaps between them.

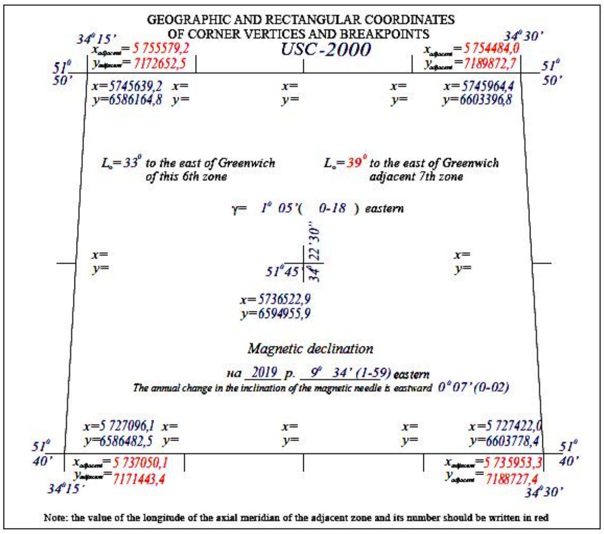

Fig. 1. Example of map sheet's scope page of the scale 1:50 000 M-36-9-G

In terms of the Digital Geographical Information Standard (DIGEST) such data organization corresponds to the 0th level of topology – models of vector data known as spaghetti data. Each individual frame of a topographic map sheet exists on its own: without taking into account topological relations with adjacent frames of topographic map sheets.

Results

Possibilities of standard tools of modern geographic information systems and computer technologies have been considered and analyzed in the previous work to solve the problem with the necessary and sufficient accuracy and reliability for geodetic and land management tasks, namely the determination of cartometric characteristics in geographic information environment [Karpinskyi & Kin, 2020, Kin & Karpinskyi, 2020]. The current regulatory status of cartometric methods is defined by the application of the "Guidelines for determining the calculated hydrological characteristics", 1973 [Guidelines, 1973].

Research results of the accuracy of the application of the cartometric and geodetic method indicate that outdated analogue cartometric operations and standard tools in existing geographic information systems are approximate, so it necessitates the transition to the use of rigorous mathematical methods [Karpinskyi & Kin, 2018].

Previously, the relative error of the measured lengths of geodetic instruments, such as light rangefinders could be 1/500 000 (1 cm / 5 km). The influence of the Earth's curvature must be taken into account, regardless of the relative errors of the measured lengths by geodetic instruments.

The influence of the Earth's curvature is present in all topographic products and does not depend on its scale. The construction of the model of the earth's surface and its reflection should be carried out on a reference ellipsoid. In this case, the rigorous analytical geodetic methods should be used in the geoinformation environment.

Today, the processing of geodetic measurements is performed in modern software with the use of computer technology. Solving systems of equations with three or more unknowns, decomposing functions into a Taylor series with almost no limit on the number of members, calculating the integral of a function and other mathematical analysis operations used in modern geodesy and geoinformatics are performed quite quickly and with the peculiarity: use of double-precision or long double data format, which takes up 64 bits or 16 bytes of memory according to the IEEE 754 standard.

This peculiarity indicates that the value of a solution is a number of a certain order after the comma, which is rounded depending on the required value. The IEEE 754 standard defines five rounding rules:

1) rounding to the nearest number (rounding to an even number). If the nearest two double-precision numbers are equally close, the number with the lowest even number must be obtained (recommended by default for decimal numbers);

2) rounding to the nearest number (rounding away from infinity). If the nearest two double-precision numbers are equally close, a number with a larger modulus must be obtained;

3) rounding to 0 – rounding toward zero;

4) rounding to (+ ∞) – rounding toward positive infinity (also known as round up);

5) rounding to (– ∞) – rounding toward negative infinity (also known as round down).

The disadvantage of rounding the values of the plane rectangular coordinates of points during the transition from geodetic coordinates to standard GIS tools is the occurrence of topological inconsistencies within the zones of Gauss–Krueger projections.

This phenomenon was discovered during the creation of the seamless topographic database "Main State Topographic Map". One of the main initial data was updated map sheets of digital topographic maps at a scale of 1:50000 in 4th, 5th, 6th and 7th zones of Gauss–Krueger projection (Figs. 2–4). As a result of the request to the TDB, the user must receive data on a specific seamless feature, such as a highway M-06, (Kyiv–Chop), which is 900.9 km long and crosses 55 topographic maps of a scale of 1:50000. Such seamless features were segmented by frames of digital topographic maps, and they should be adjusted and form a cover in the coordinate system in the TDB. This coverage corresponds to the 2nd level of topology – models of vector data such as "Planar Graph" [Karpinskyi, 2015].

For processing with features longer than 500 km, it is advisable to use a reference ellipsoid. The calculation of cartometric characteristics and performance of geoinformation modelling and analysis should be carried out taking into account the influence of the Earth's curvature. This will ensure the transition to rigorous computer methods that allow quantitative characteristics to be determined with ultra-high accuracy.

The phenomenon of topological inconsistencies of the frames of adjacent topographic maps at the scale 1:50000 at the boundaries of the Gauss–Krueger projection zones was detected in ArcGIS for Desktop 10.6. The detailed research of this phenomenon was performed in QGIS 3.24 by standard tools for determining distances on the reference ellipsoid USC-2000. For this purpose, 10 pairs of frames of topographic maps at the scale 1:50 000 were chosen along the meridians 24°, 30°, 36° in the 4th, 5th, 6th and 7th Gauss–Krueger projections.

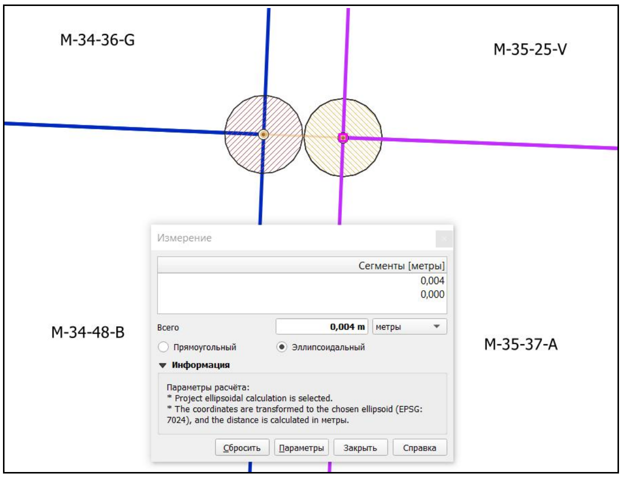

Fig. 2. The distance between the vertices of the frames of map sheets at the scale 1:50 000 in the 4th and 5th zones of the Gauss–Krueger projection (example of gaps)

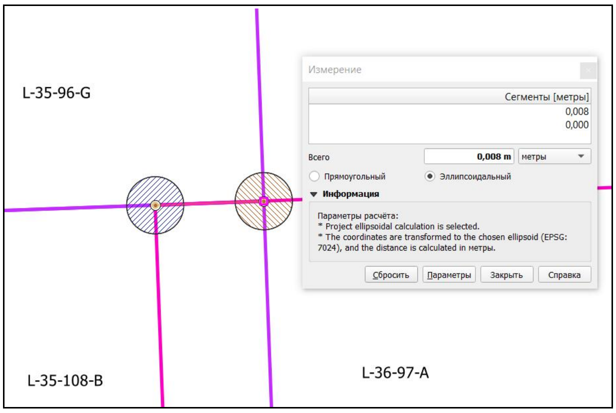

Fig. 3. The distance between the vertices of the frames of map sheets at the scale 1:50 000 in the 5th and 6th zones of the Gauss–Krueger projection (example of overlap)

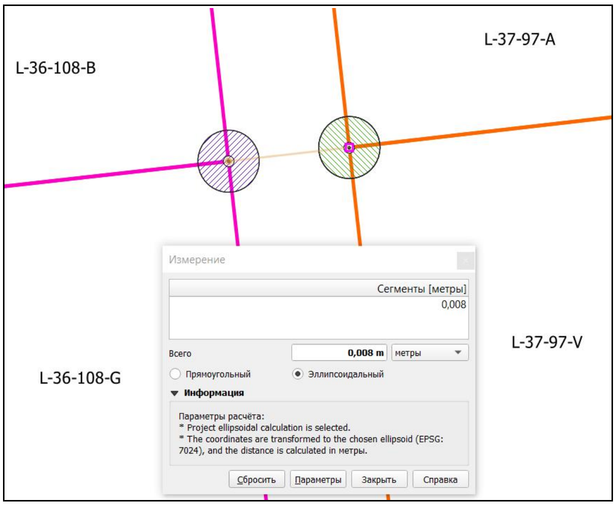

Fig. 4. The distance between the vertices of the frames of map sheets at the scale 1:50 000 in the 6th and 7th zones of the Gauss–Krueger projection (example of gaps)

Table 1

No.	B,°	L,°	The distance between the vertices of the frames of map sheets at the scale 1:50 000 (d, m)
1	47°50′00″	24°00′00″	0,002
2	48°00′00″	24°00′00″	0,001
3	48°11′00″	24°00′00″	0,002
4	48°42′30″	24°00′00″	0,001
5	49°09′30″	24°00′00″	0,004
6	49°41′00″	24°00′00″	0,003
7	50°21′00″	24°00′00″	0,004
8	50°31′00″	24°00′00″	0,002
9	50°57′30″	24°00′00″	0,004
10	51°23′30″	24°00′00″	0,005

Table 2

No.	B, °	L, °	The distance between the vertices of the frames of map sheets at the scale 1:50 000 (d, m)
1	45°21′00″	30°00′00″	0.08
2	45°41′00″	30°00′00″	0.002
3	45°59′00″	30°00′00″	0.003
4	46°54′30″	30°00′00″	0.002
5	47°48′30″	30°00′00″	0.002
6	48°41′30″	30°00′00″	0.001
7	49°36′30″	30°00′00″	0.003
8	50°30′30″	30°00′00″	0.002
9	51°23′30″	30°00′00″	0.005
10	51°50′30″	30°00′00″	0.004

Table 3

No.	B, °	L, °	The distance between the vertices of the frames of map sheets at the scale 1:50 000 (d, m)
1	45°11′00″	36°00′00′	0.008
2	45°31′00″	36°00′00′	0.005
3	46°30′00″	36°00′00′	0.004
4	47°31′00″	36°00′00′	0.004
5	47°57′00″	36°00′00′	0.001
6	48°23′30″	36°00′00′	0.006
7	48°51′00″	36°00′00′	0.003
8	49°18′00″	36°00′00′	0.001
9	49°41′30″	36°00′00′	0.007
10	50°31′30″	36°00′00′	0.002

Tables 1, 2 and 3 show the values of the distances between some vertices of the frames of map sheets at the scale 1: 50000 depending on the latitude and longitude. Analyzing the obtained results, we can conclude that the available distances are up to 8 mm at the northern and southern boundaries of the zones of Gauss–Krueger projections.

Standard GIS tools allow the user to measure, for example, the length of a route, the area of a certain area directly on a mobile device or on a personal computer. It should be noted that these cartometric methods are performed in the GIS environment without the ability to specify the accuracy of the input data to determine the cartometric characteristics. This is being replaced by rigorous computer methods that allow user-defined accuracy to determine the metric properties of a feature.

Figs. 5–8 show the changes in the distances between the vertices of the frames of map sheets at a scale of 1: 50000. These values are in the range from 1 mm to 8 mm and represent the phenomenon itself: gaps and overlaps.

Graphs of the dependences of the gaps and overlaps distances on latitude and longitude show the absence of correlation between these two values, as their correlation coefficients range from 0.0261 to 0.75 with a tolerance of 0.8–0,9.

This suggests that topological inconsistency errors are random rather than systematic.

Detected gaps and overlaps are obstacles to automated methods of the adjustment of digital topographic map sheets and junction features in the TDB. Such changes in distances affect not only the creation of seamless features of road infrastructures and railways but also hydrography, settlements, political and administrative boundaries, etc., that is, for the entire feature composition of the topographic database.

During the creation of the topographic database “Basic topographic map scale 1:10000” problems with the use of the frames of map sheets of digital topographic maps scale 1:10000 will also arise, both at the stage of updating and compiling digital topographic maps and at the stage of junction the TDB, so to avoid this it is necessary to provide two stages:

1) transition to more accurate methods of determining the coordinates of the corners of the frames of map sheets;

2) fixing the values of the coordinates of the corners of the frames of map sheets during the creation of the reference frames of the map sheets at scales 1: 10000 and 1: 50000.

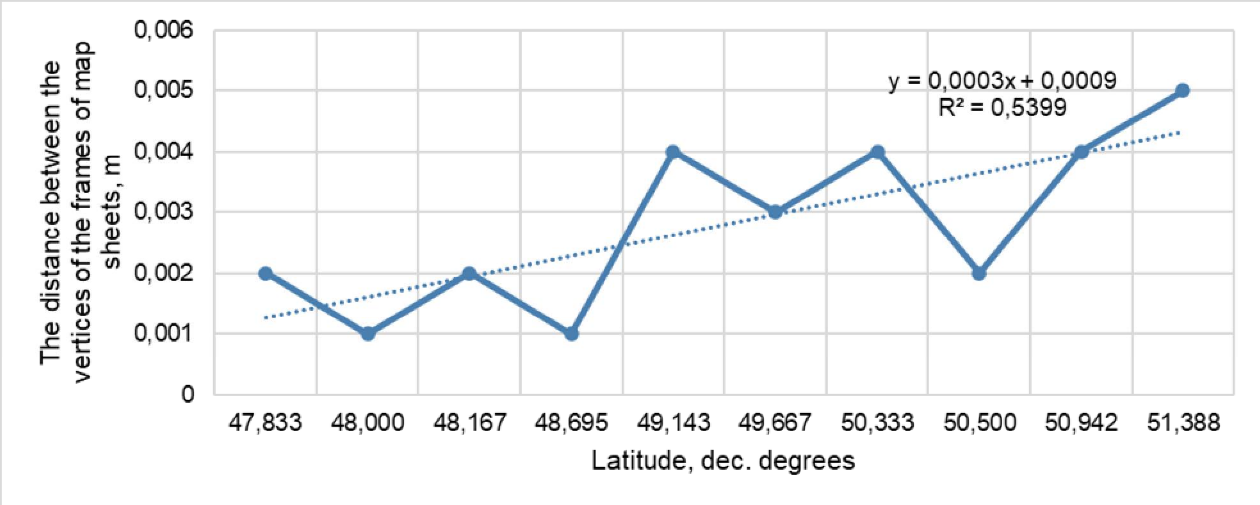

Fig. 5. Change the distances between the vertices of the nomenclature frames of map sheets at the scale 1:50 000 in the 4th and 5th zones of the Gauss–Krueger projection

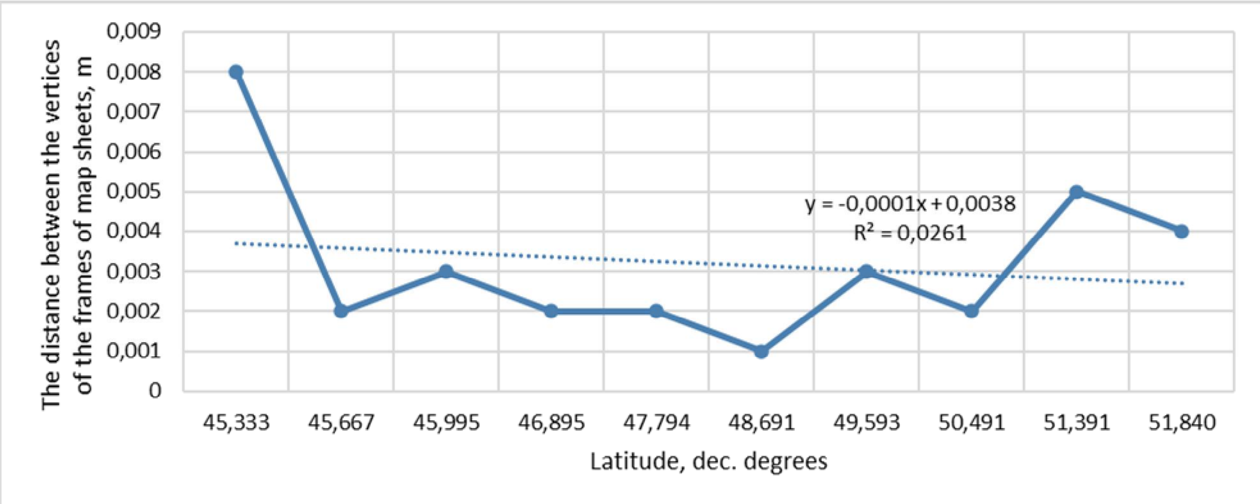

Fig. 6. Change the distances between the vertices of the nomenclature frames of map sheets at the scale 1:50 000 in the 5th and 6th zones of the Gauss–Krueger projection

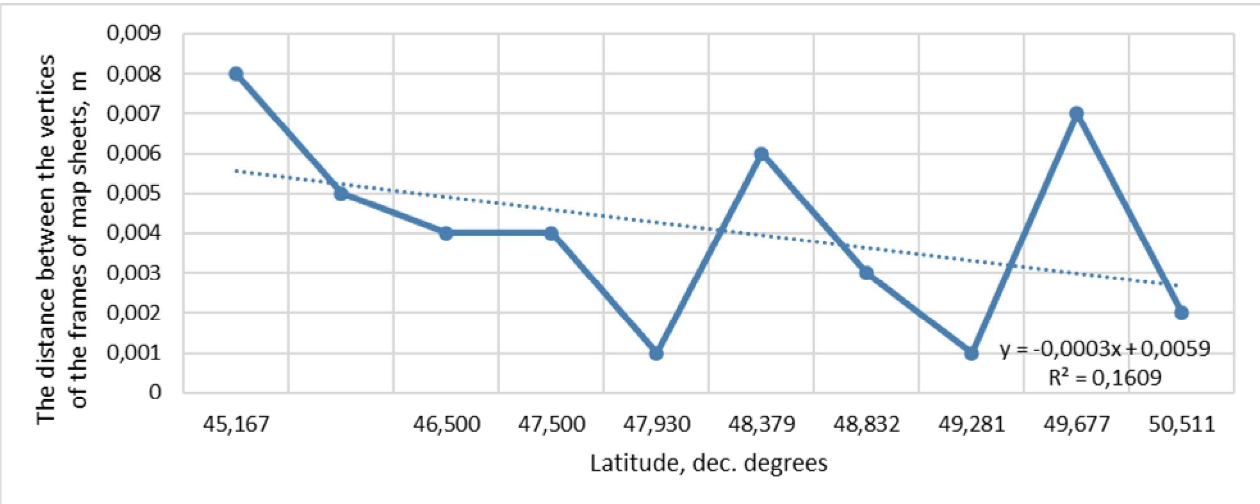

Fig.7. Change the distances between the vertices of the nomenclature frames of map sheets at the scale 1:50 000 in the 6th and 7th zones of the Gauss–Krueger projection

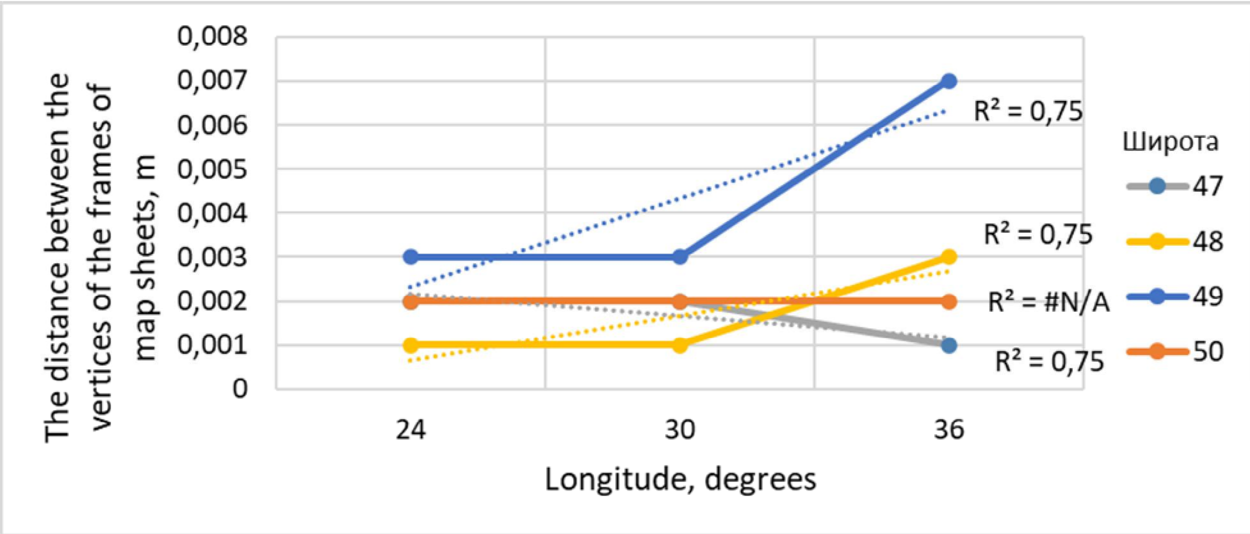

Fig. 8. Change the distances between the vertices of the frames of map sheets at the scale 1:50 000 depending on longitude

Scientific novelty and practical significance

The scientific novelty of the research is to justify the use of rigorous analytical geodetic methods and tools instead of analog cartometric and standard methods of instrumental GIS; the use of a reference ellipsoid, not just cartographic projections, a spheroid or a sphere.

The practical significance of research is the use of rigorous analytical geodetic methods that significantly minimize the values of gaps and overlaps, as the establishment of tolerances for these values does not automate the process of correct adjustment and junction of map sheets.

Conclusions

During the adjustment and junction of adjacent sheets of digital topographic maps at a scale of 1:50000 by using standard methods of cartometric operations in ArcGIS revealed the phenomenon of topological inconsistencies: the peculiarity of the formation of gaps and overlaps up to 8 mm. This allegedly insignificant amount of topological inconsistency has become a certain obstacle to the automation of these processes.

Overlay analysis, from the point of view of geoinformation modelling, at the stage of the automated adjustment and junction of features within adjacent map sheets, at the stage of quality control of digital topographic maps identifies this phenomenon as an error. So, it does not allow for the creation of continuous seamless features. The value of gaps and overlaps for such cases does not matter. It is obvious that delineation of topographic map sheets should create a continuous topological coverage of polygons without gaps and overlaps, that is, the rules must be followed:

1) must Not Have Gaps – requires that there be no gaps in the middle of the polygons or between adjacent polygons; all polygons must form a continuous cover;

2) must Not Overlap – requires that the internal parts of polygons do not overlap; polygons can have common edges or vertices.

Solving this problem and many others [Karpinskyi & Kin, 2018; Lazorenko–Hevel & Kin, 2019; Kin & Karpinskyi, 2020] is based on the use of computer methods in modern geographic information systems.

In the future, research will be conducted to develop new techniques for cartometric operations, which would have virtually no restrictions to achieve the required accuracy, including for long distances.

These proposals will justify changes in regulatory documents regarding the creation and updating of geospatial data and the implementation of geodetic, cartometric and morphometric methods in the geoinformation environment.

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ФЕНОМЕН ВИНИКНЕННЯ ТОПОЛОГІЧНИХ НЕУЗГОДЖЕНОСТЕЙ РАМОК КАРТ ПРИ СТВОРЕННІ ОСНОВНОЇ ДЕРЖАВНОЇ ТОПОГРАФІЧНОЇ КАРТИ

Мета цієї роботи – дослідження топологічної неузгодженості під час зшивання та зведення рамок суміжних аркушів цифрових топографічних карт масштабу 1:50000 із застосуванням строгих аналітичних геодезичних методів на референц-еліпсоїді у геоінформаційному середовищі. У виконаних дослідженнях проаналізовано феномен виникнення топологічних неузгодженостей рамок суміжних аркушів цифрових топографічних карт масштабу 1:50000 на межах зон проекцій Гаусса–Крюгера та доцільність переходу на строгі аналітичні геодезичні методи у геоінформаційному середовищі під час створення бази топографічних даних “Основна державна топографічна карта” шляхом визначення розбіжностей між вершинами рамок номенклатурних аркушів цифрових топографічних карт масштабу 1:50000 на межах зон проекції, виявлених під час робіт в державному підприємстві "Науково-дослідний інститут геодезії і картографії". У роботі отримано і проаналізовано залежності, які демонструють зміни відстаней між вершинами рамок суміжних аркушів масштабу 1:50000 по довготі і широті. Ці величини знаходяться в межах від 1 мм до 8 мм, що веде до топологічної неузгодженості у вигляді розривів (gaps) і накладань (overlaps) суміжних аркушів топографічних карт , що ускладнює процес зведення аркушів цифрових топографічних карт та унеможливлює автоматизацію процесу зшивання об'єктів бази топографічних даних. Наукова новизна проведених досліджень полягає в обґрунтуванні застосування строгих аналітичних геодезичних методів та засобів замість аналогових картометричних і стандартних методів інструментальних ГІС; використання референц-еліпсоїда, а не лише картографічних проєкцій, сфероїда або сфери. Практична значущість досліджень полягає у використанні строгих аналітичних геодезичних методів, які значно мінімізують величини розривів і накладань, оскільки встановлення допусків для цих величин не дозволяє автоматизувати процес коректного зшивання та зведення аркушів топографічних карт. Виконані дослідження можуть використовуватися для створення бази топографічних даних "Базової топографічної карти масштабу 1:10000", під час створення та оновлення геопросторових даних в геоінформаційному середовищі і виконання геодезичних методів для визначення картометричних характеристик об'єктів за допомогою ГІС. З огляду на отримані результати досліджень можна зробити висновок, що на сучасному етапі застосування геоінформаційних систем в топографо-геодезичній діяльності вимагається підвищення рівня топології даних та точності всіх картометричних методів, що обумовлює перехід на використання виключно строгих аналітичних геодезичних методів безпосередньо на референц-еліпсоїді.

Ключові слова: референц-еліпсоїд, геодезичні методи, розриви та накладання, картографія, строгі комп'ютерні методи, база топографічних даних, картометрія, топологія.

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