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Correlation Testing of Müller's Map of Bohemia and First Military Survey Maps in the Area of Today's Czechia

Summary: The paper attempts to bring answer to a hypothesis assuming a relation of origin of maps of the First Military Survey, performed by the Habsburg Empire in the last third of the 18th century, with their predecessor – maps of Bohemia and other lands created by Johann Christoph Müller. Records in literature mention the geospatial origin of the military maps as miniatures of Müller's maps but no clear evidence to this statement has been performed. Within the paper, a correlation analysis using seamless rasters of joined map sheets adjusted to their original sheet size has been used for both map works.

The preliminary results show a significant closeness of the mentioned statement to the truth. Within the computations, the ratio of scale numbers of both works has been defined, allowing to estimate the scale number of Müller's map using the known value for the military mapping. Furthermore, deviations of rotation and position accuracy of both works have been examined. As an intermediate environment, the Křovák's system to which the Müller's maps had formerly been georeferenced was chosen. Using it, testing of normal probability distribution of errors of both map works has been performed allowing to draw conclusions about systematic or random character of the deviations. At last, visualizations showing differences between rendition of the maps' deformation grid to an ideal state as well as further outputs have been presented. A relatively serious issue in the computations is constituted by large amount of control points (several thousand for both map works and whole Bohemia) which limited deployment of more robust solutions of spatial transformation computation.

Introduction

Maps of (later named) First Military Survey from the 3rd third of the 18th century were the first detailed cartographic work covering the entire territory of the then Austrian monarchy. The lost Seven Years' War (1756–1763) meant an impulse for its creation. In this war, Müller's maps (they were available for Bohemia, Moravia, Silesia and Hungary, but not in the other territories of the monarchy) were mainly utilized. Empress Maria Teresia therefore ordered a new detailed mapping of the Austrian monarchy, which was handled in a respectable time of 23 years (1763–1785) for the entire territory of the Habsburg empire. This mapping is often called Josephian, because it was completed until the reign of Maria Theresia's son Joseph II. At that time, an unusually high scale of 1 : 28,800 was chosen. This number was based on the then units and on a requirement that one Viennese mile, which is equal to 4,000 Viennese fathoms (= 7,585.936 m), appeared as ten Viennese inches (1 inch = 26.34 mm; 1 fathom = 72 inches) in the map.

The entire territory of the Czech lands was surveyed in the years 1763–1768. As a basis for the work of topographers in the field, enlargements of the Müller's maps to scale 1 : 28,800 were distributed (there is an obvious significant lack of detail given to fourfold scale magnification compared to the original drawing). Military engineers were mapping landscape primarily using estimates, possibly by stepping and only minimally using a plane table. Nevertheless, the map contained all the essential topographical features. Altimetry was shown using ink washing and pseudo incline hachures. In addition to maps themselves, military-geographic descriptions of

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the area were created. The territory of Bohemia is covered with 273 sheets and 19 volumes of description, Moravia in 126 sheets and 4 volumes of description, and Silesia was shown on 40 map sheets.

Maps of the Austrian First Military Survey

Imperfection of these maps very early became evident in wars with Prussia in the years 1778 to 1779. Emperor Joseph II. thus tried to improve the situation by decreeing rectification of the most important map sheets (i.e., in strategically important northern third of the territory). During the rectification a necessity to practice completely new mapping showed up. Thus, in the years 1779–1783 there were 141 newly mapped map sheets in Bohemia (2 being repaired), 36 sheets in Moravia (and 4 repaired), 30 sheets in Silesia (and 10 corrected).

Already considering method of creation this new map product (i.e., when there was not any geodesic or even better astronomic-geodesic frame) and the mapping was performed by sight, it is clear that positional iconsistencies in the maps were significant, thus applicability of this work as a base for military strategic planning crucially suffered. However, up to beginning of work on the Second Military Mapping (along with which also geodesic network for the purposes of the first Austrian cadastre was being built), which represented more than five decades since rectification made to the northern sheets, these maps represented the only available contiguous detailed map work of the Austrian Empire.

A sheet of these maps was created by compiling field sketches to a rectangular section (so called Brouillon) with dimensions of 23.5 × 15.5 Viennese inches (61.9 × 40.8 cm) and the displayed area of 209 square kilometres. From each section an eight-colour fair draught was drawn – brick buildings, trunk roads and stone bridges in red, shore lines of water areas in dark blue, bodies of water in light blue, grassland in green, forests in khaki, other communications yellowish-brown and black colour was used for ink-washed hachured altimetry, rocks and the remaining objects. Labels in the map were rendered in black. The work was performed inconsistently in the various crown countries.

Georeferencing Trials and Used Methods

Due to the absence of a useable coordinate system and the method of creation, these old maps can be only roughly georeferenced into current coordinate systems, and this georeferencing has always been based mainly on the collection of a large amount of control points in the individual map sheets, which were then adjusted.

Thus, for example, the Laboratory of Geoinformatics at the University of J. E. Purkyně in Ústí nad Labem georeferenced the map work into the S–JTSK system (Křovák's projection) with standard errors of position between 400 and 700 m, depending on the relief and also depending on the time of making particular map sheets. Further attempts to geoereference maps to S–JTSK were carried out by the Research Institute for Landscape and Horticulture of Silva Taroucy (Czechia) where the positional standard errors in the area of Moravia varied from 500 to 800 m.

In the today's area of Central Europe in several past years there were many attempts to treat and publish data of the Firsty Military Survey, for example in Galicia (Affek, 2013). A comprehensive approach to the theme was brought by MAPIRE initiative where all three Austrian military surveys were adjusted and published using web application (more to this in Biszak et al., 2014 or in Biszak's presentations[‡]. An interesting view into accuracy of this mapping in mountainous conditions brought Podobnikar (2009).

[‡] one of them, for instance, at http://prezi.com/sry_eweironc/cartographic-heritage-of-the-habsburg-empire-on-the-web-the-mapire-initiative/

The Department of Geomatics at Czech Technical University in Prague was also tentatively carrying out a global adjustment of all map sheets of Bohemia on the grounds of nearly 7,000 control points available within the vast majority of sheets except for some sparsely inhabited border areas.

These control point pairs were collected by students and lecturers of the department in the years 2015 to 2016 and represent an extensive set of 7,024 control points within 269 map sheets. 19 sheets with only few or with inappropriate distribution of points (primarily in the frontier areas of Bohemia) were excluded of the further computation. Thus a final set of control points comprises of 6,848 coordinate pairs within 250 map sheets (Fig. 1).
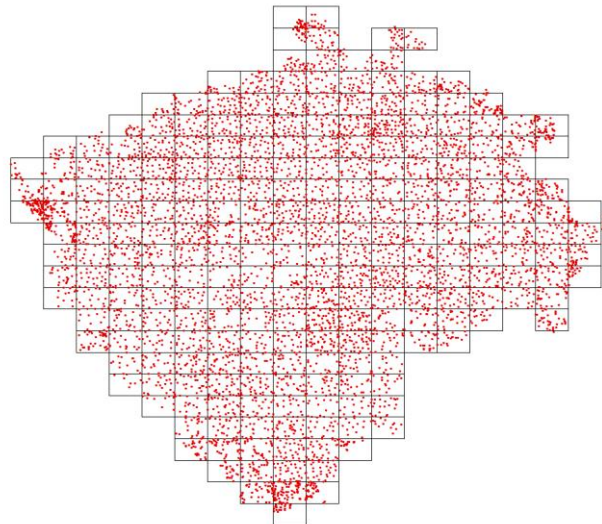

Figure 1. Distribution of control points in map sheets of the First Military Survey

The gathering of coordinates was performed using S–JTSK as an intermediate coordinate system. The map sheets were consequently adjusted using adjustment with connected-sheets conditions, where statistical testing of control points using robust methods was accomplished. This adjustment method processed by Cajthaml & Janata (2016) produced a more accurate connection of map sheets into a seamless map image as well as standard errors in order of several hundred metres.

Testing Correlation Between Müller's Maps and Military Mapping

It was stated that for practical mapping of First Military Survey in the field, enlargements of Müller's maps into the scale of 1 : 28,800 were used. This has a consequence that any possible errors, inaccuracies and distortions of Müller's maps should be crucially transferred into the First Military Survey maps. This has not been tested as yet.

For these purposes, a second set of control points was used (see Fig. 2), which was obtained by Havlíček's earlier work (Havlíček, 2011). After gathering, the control points were tested for outliers which were excluded (especially in the area of Šumava and Doupov Highland). A total of 4,530 points were collected in millimetre map coordinates and the coordinates in S–JTSK, where a small portion of these points is outside the territory of Bohemia, because Müller's map covers a part of the adjacent territory of Moravia. The database of control points was used to connect the 25 sections into a seamless image of Müller's map. These adjusted maps are available for preview in the form of WMS services and vectorised content as well in the form of WFS services.[§].

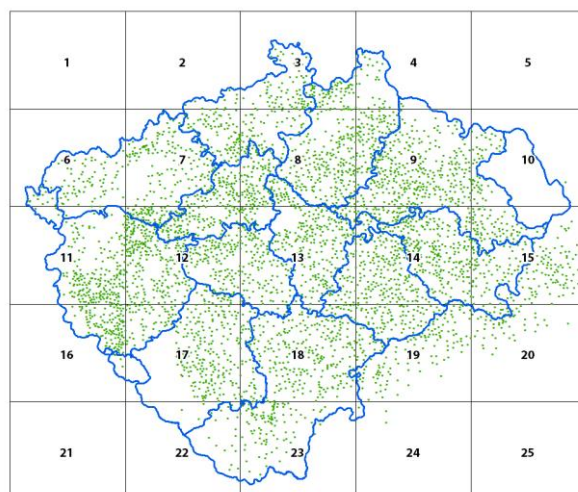§ WMS and WFS services at http://gis.fsv.cvut.cz/arcgis/rest/services/Muller_maps

Figure 2. Distribution of control points in map sheets of the Müller's map of Bohemia. The then regions of Bohemia are plot in blue colour.

A result of collecting control points was, outside the joined map image, also an estimate to a cartographic projection in which the map was constructed (more to this in Cajthaml & Havlíček, 2011). It was determined that an equidistant cylindrical projection with one undistorted parallel of 50° was probably used.

To test the correlation between data gathered for both map works, it was necessary to unify the coordinates into a single system, for which millimetre paper coordinates were chosen. Control points of Müller map were already in millimetres and for the military mapping the coordinates originally in Viennese inches were initially projectively transformed using corners of map sheets according to known layout and then converted to millimetres, while the origin of the system was established in the southwestern corner of the bottom left sheet as well as in the case of Müller's map. That meant to add constants according to sheet position in the layout. This way, two sets of coordinates, mutually comparable, originated.

For practical testing, these millimetre coordinates were transformed using ArcGIS apart from S–JTSK also into the equidistant cylindrical projection according to the above mentioned findings. For this a similarity transformation and for comparison also affine transformation were used. Results of these adjustments are shown in Table 1 and in Fig. 3a to 6b (Fig. 3a to 6b use the same colour scale rendered in Fig. 7).

**Table 1. Results of transformation of both data sets**

MÜLLER'S MAP		Scale number		Rotation		Root mean square error	
Transformation		*x-axis*	*y-axis*	*x-axis*	*y-axis*	*x-axis*	*y-axis*
to Müller's system	similarity	129,390		3.73°		1,602 m	1,439 m
	affine	129,230	129,900	3.48°	4.24°	1,528 m	1,398 m
to S–JTSK	similarity	131,760		−3.95°		1,599 m	1,779 m
	affine	131,800	131,820	−4.18°	−3.44°	1,530 m	1,753 m

| FIRST MIL. SURVEY		Scale number		Rotation		Root mean square error	
Transformation		*x-axis*	*y-axis*	*x-axis*	*y-axis*	*x-axis*	*y-axis*
to Müller's system	similarity	29,620		3.22°		1,822 m	1,513 m
	affine	29,560	29,770	2.79°	3.77°	1,700 m	1,393 m
to S–JTSK	similarity	30,130		−4.58°		1,914 m	1,816 m
	affine	30,070	30,280	−4.99°	−4.04°	1,802 m	1,719 m

Results obtained
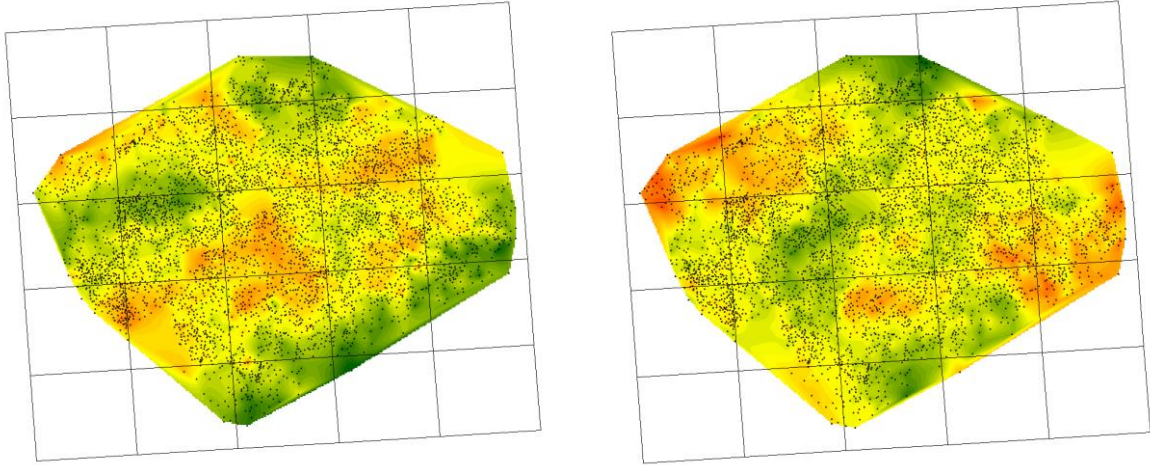
Figures 3a, 3b. Similarity transformation of Müller's map plotting x-coordinate (left) and y-coordinate (right) residuals.
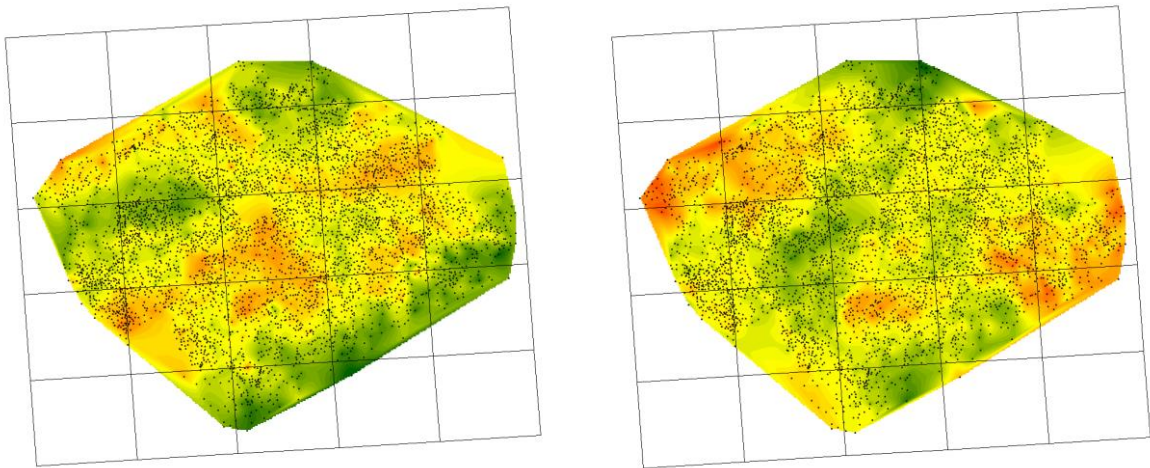
Figures 4a, 4b. Affine transformation of Müller's map plotting x-coordinate (left) and y-coordinate (right) residuals.
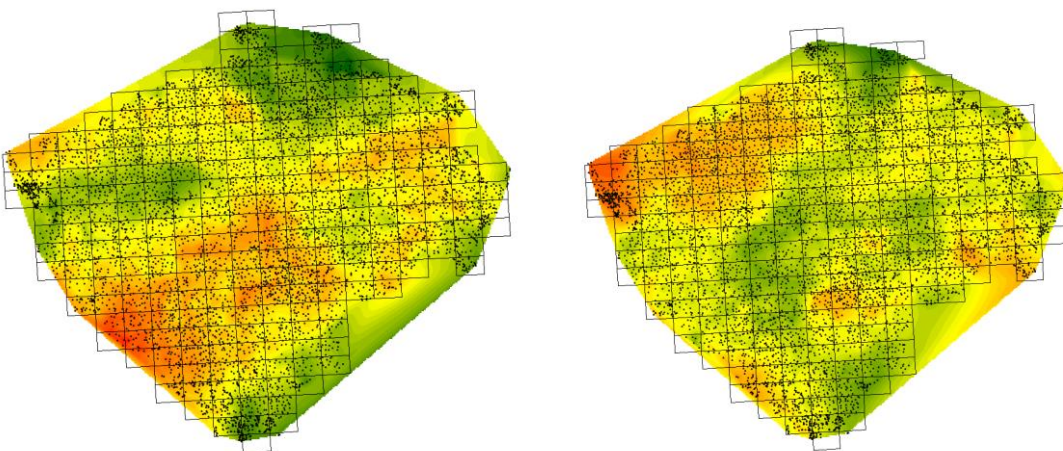
Figures 5a, 5b. Similarity transformation of First Military Survey maps plotting x-coordinate (left) and y-coordinate (right) residuals.
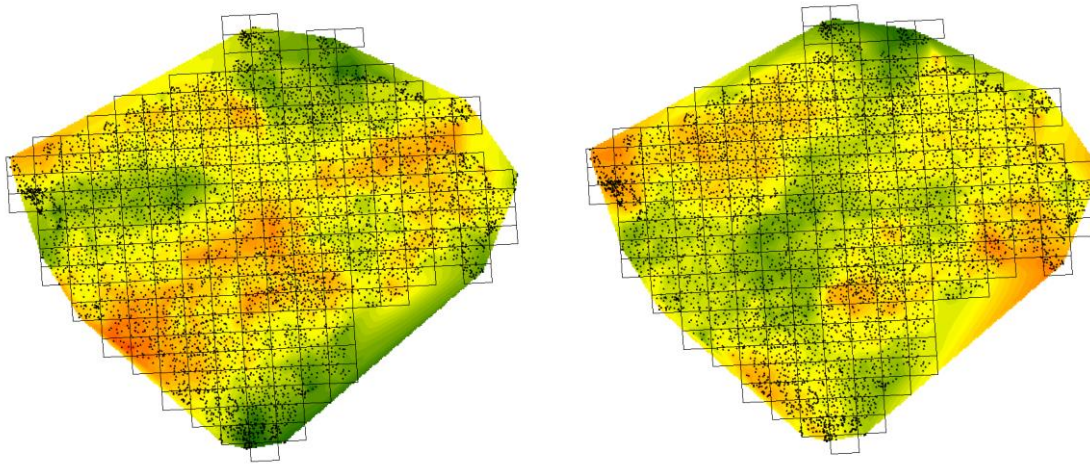
Figures 6a, 6b. Affine transformation of First Military Survey maps plotting x-coordinate (left) and y-coordinate (right) residuals.

−5,000   0   5,000

Figure 7. Colour scale used for rendition of Figures 3a to 6b and 9 to 10 (residuals in metres).

From the transformations and presented visualizations a high degree of correlation of residues for both coordinates between Müller's map and military maps reveals. It is evident in both affine and similarity transformations. Further, Fig. 8 shows a comparison of rotation of coordinate grid for both projections and it their closeness is apparent (rotation values for both works differ by less than one degree).
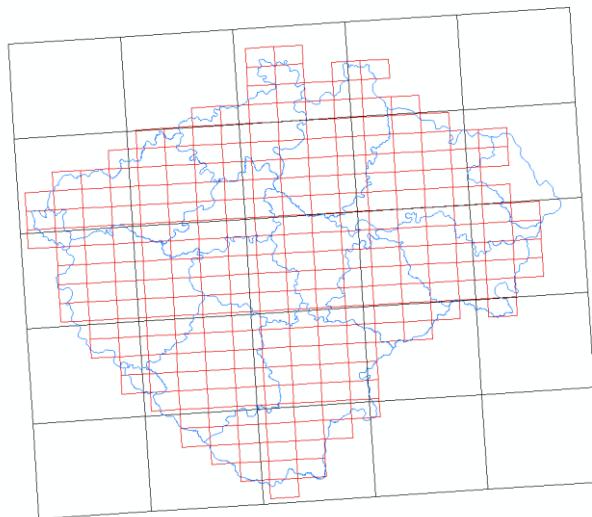

Figure 8. Rotation of map sheets after transformation.

Also some more detailed aspects of adjustments made are interesting. From Fig. 9, for instance, a partial correlation between the area of individual regions shown on the Müller's map and values of residues on control points is apparent. This may indicate the composition of the whole drawing of this map work not from individual map sheets (on which the map may have been divided then, or at least independently of its creation), but from particular regions, which is a finding historically featured but so far unsupported with measurements.
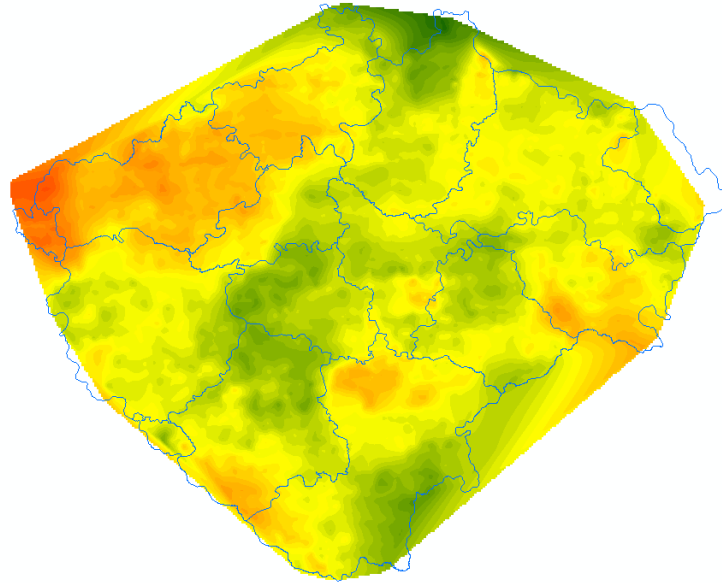
Figure 9. Adjustment of the Müller's map in comparison to the then regions of Bohemia.

Particularly, a sharply different accuracy of northwestern regions or areas on the boundary of South and Central Bohemia is perceptible. On the whole, the most northern, most southern and most western Bohemia represent areas with the lowest intrinsic accuracy of the transformation, that means areas mapped probably the least accurately.

Fig. 10 shows detail of Central to northwestern Bohemia, where there is noticeable loss of accuracy of control points in the sheets of the First Military Survey away from the edges to the inside (the areas of a relatively higher accuracy form a mesh appropriate with edges of the sheets, which corresponds well to the situation where the data of originally separate sheets were forcibly „glued" together and where the created „continuity" of data causes abrupt changes in the intrinsic precision.
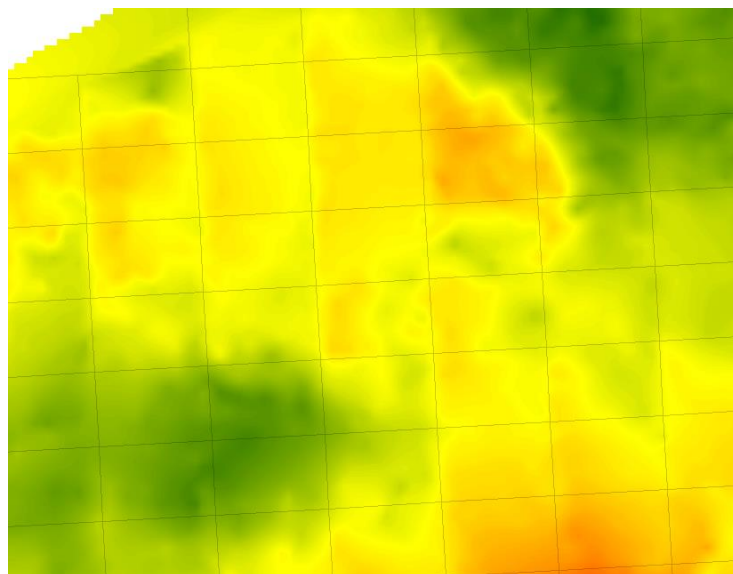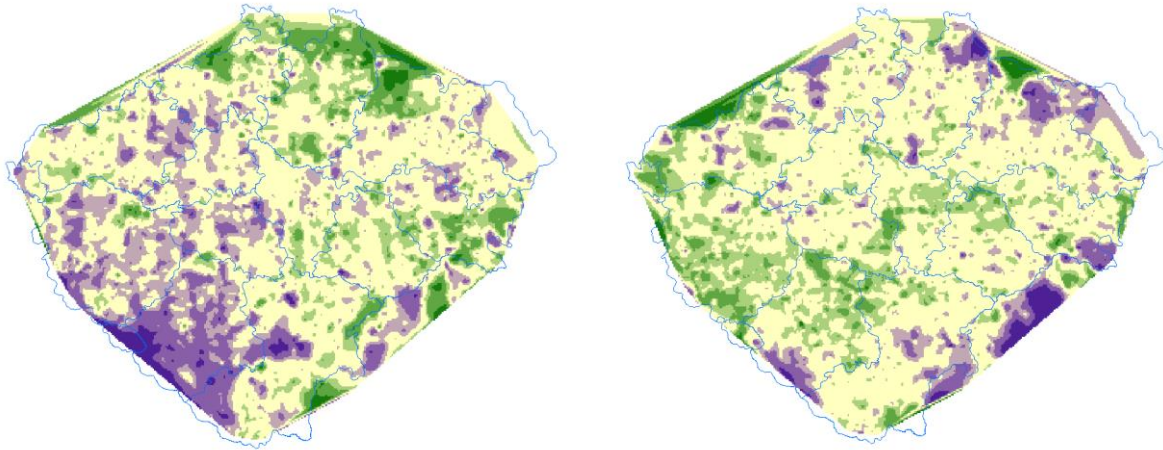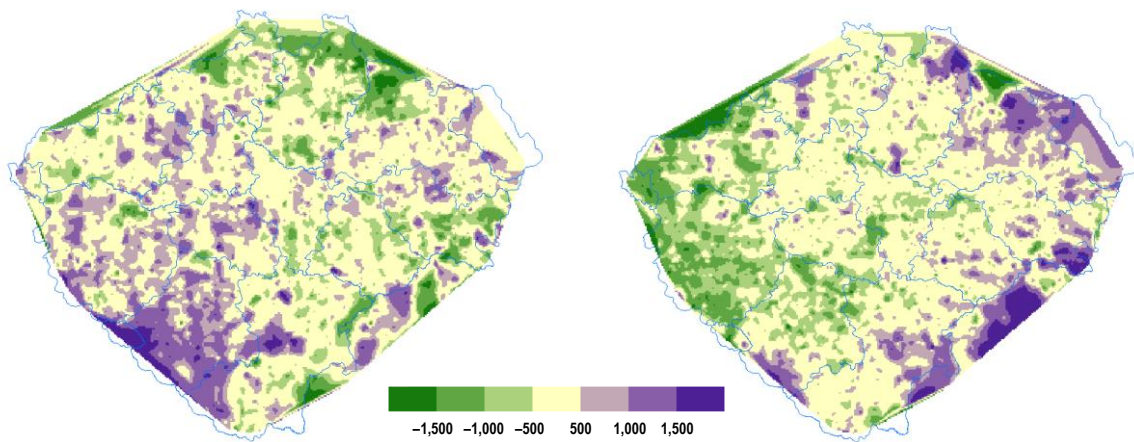

Figure 10. Detail of adjusted sheets of the First Military Survey maps.

Figures 11a, 11b. Differential visualization of residuals between the First Military Survey and Müller's maps using similarity transformation, plot for the x (left) and y coordinate (right).

Figures 12a, 12b. Differential visualization of residuals between the First Military Survey and Müller's maps using affine transformation, plot for the x (left) and y coordinate (right); residual differences in metres.

In general, a strong correlation between the results of adjustment of the studied map works can be seen mainly from coordinate-residue differences, which were calculated both for similarity and affine transformation (Figs 11a to 12b). From the images, the overwhelming dominance of territory (between 60–70%), where the difference for each coordinate ranges between plus and minus half a kilometre, is apparent. Distribution of residues is very close to a normal distribution. If we consider that the standard deviation of each adjustment varies between 1,500 and 2,000 m (thus that 60–70% of the territory lies in the range 0 to 1/3 σ), and that the area where the value of σ is exceeded represents only small portions especially at the borders of Bohemia, is thus given a clear relationship between the two map works and is therefore more than likely that the First Military Survey maps really originated on the base of earlier Müller's mapping – apparently to enlargements of these maps, as historically stated.

Conclusion

On the grounds of testing performed it could be declared that the hypothesis of utilizing maps of Johann Christoph Müller as a basis for creation of maps of the First Military Survey is

correct. From the accomplished transformation of joined map works a high degree of correlation between characteristics of the both works is obvious – primarily of residues but also of the general rotation.

As a secondary product of computations the values of scale numbers were verified (for Müller's map of Bohemia literature commonly states value of 1 : 132,000), for maps of the First Military Survey a value differing in approximately 3.5 % from nominal value stated in written mapping documentation was computed, though. This may indicate a false assumption of the brouillon size of 15.5 × 23.5 Viennese inches that could actually be 16 × 24 inches, which is a figure also sometimes featured in literature.

It can be declared that the testing proved Müller's maps being the basis for a framework of maps of the First Military Survey and probably also identical coordinate system was used within both map works (although no exact information on it has been preserved at any of the works). The strongest argument for this claim is an overwhelming preponderance of the territory of Bohemia, where the difference of coordinate residues ranges from –0.5 to +0.5 kilometre, which corresponds to only about one third of the value of standard errors achieved within calculation of the adjustment.

During a detailed survey of results there are also evident observations supporting the theory of separate processing of Müller' maps of each region and their subsequent composition.

Acknowledgement

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