

Influence of Replacement Used Reference Coordinate System for Georeferencing of the Old Map of Europe

Jakub Havlicek, Jiri Cajthaml

Abstract—The article describes the effect of the replacement of the used reference coordinate system in the georeferencing of an old map of Europe. The map was georeferenced into three types of projection – the equal-area conic (original cartographic projection), cylindrical Plate Carrée and cylindrical Mercator map projection. The map was georeferenced by means of the affine and the second-order polynomial transformation. The resulting georeferenced raster datasets from the Plate Carrée and Mercator projection were projected into the equal-area conic projection by means of projection equations. The output is the comparison of drawn graphics, the magnitude of standard deviations for individual projections and types of transformation.

Keywords—Georeferencing, reference coordinate system, transformation, standard deviation.

I. PROBLEMATIC ASPECTS IN GEOREFERENCING

THE georeferencing of old maps is a process consisting of a series of individual acts. The process of digitizing map data usually does not put much emphasis on georeferencing, and georeferencing itself is subject to numerous errors. Frequent errors occurring during georeferencing are pointed out by [3]. The process of georeferencing old maps is described by [11], [10], and [12].

Provided we want to georeference an old paper map, we must first scan it. Scanning is done on large scale calibrated scanners. A map is usually scanned with a resolution of 400 DPI. Higher resolutions mostly only bring an increase in the volumes of data. The risk associated with the choice of a lower resolution, on the contrary, is losing map details. In the case of a resolution of 400 DPI, the size of one pixel is approximately 0.06 mm and with regard to the minimum width of a line on the map of 0.1 mm this resolution is sufficient.

The next step is to locate the scanned map into a reference coordinate system. Ground control points are identified on the scanned map for which coordinates in the respective reference coordinate system are available. This study addresses the issues of the influence of replacement used reference coordinate system for georeferencing of the old map of Europe [8]. In practice, this means that we have scanned an original old map in a specific reference coordinate system and are trying to transform it into a map located in another reference coordinate system by means of ground control points. In the case that the coordinate systems used on both maps are

different, the results of the transformation are affected without accuracy of ground control points.

It is important to obtain as much information about the scanned map as possible, especially regarding the used reference coordinate system, including all parameters of the cartographic projection. The possibilities of determining the used reference coordinate system were studied in more detail by [1], [2], and [4].

This study develops the influence of a cartographic projection on the results of georeferencing for conic projection and cylindrical projections for area of Europe.

After obtaining information about a map and determining ground control points, the next important step is to choose the type of transformation method. There are two types of transformation methods used in practice. The first of them are global transformation methods by means of which one transformation key is calculated from all ground control points using the Least Squares Method. This key is applied to the whole area of the map, and therefore, ground control points do not have their position in the final result as some residuals arise at these points in the case of redundant ground control points. The second group of used transformation methods is local methods. A unique transformation key is calculated for each location on the map. Ground control points have their position in the final result in this method. A considerable disadvantage is that in the case of a wrongly determined ground control point, this point cannot be identified and a relatively large distortion of the map arises in its vicinity.

The following step usually involves saving information about georeferencing. Currently, there are three saving options used. The first of them is a world file where information is stored in an auxiliary file to a raster file by using six digits – the pixel size in the x and y direction, rotation about the x and y axes, and the coordinates of the upper left corner of the raster. The disadvantage of this type of storage is that only global transformation methods, namely identity, similarity and affine transformation, can be saved in these six values. While using higher order polynomial transformations or local transformation methods, the results can no longer be stored using six unknown parameters. Another option is to store information in an XML file where information about the reference coordinate system, ground control points, transformation type, etc. is also stored. This type of storage is the best considering the usage. Unfortunately, there is currently no single XML for different geographical information systems, and for example, the ESRI Company uses its own AUX.XML file. The third option is resampling the georeferenced raster. In this case, a new raster arises which

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has always a worse resolution than the original as the pixel values are derived from the surrounding pixels using a variety of methods. The disadvantage of this option is the loss of information on ground control points. For more details on the storage possibilities of the results of georeferencing see publications by [6], [7].

II. INFLUENCE OF REPLACEMENT USED REFERENCE COORDINATE SYSTEM USED FOR GEOREFERENCING OF AN OLD MAP OF EUROPE

As mentioned above, the principal focus of the article is the effect of the replacement of the used reference coordinate system in the georeferencing of an old map of Europe. Based on cartographic experience and measurements on the map frame, it was identified that the old map of Europe had been produced in the equal-area conic projection (Albers equal-area projection) with one standard parallel and the prime meridian passing through the map centre.

This map was georeferenced using three types of reference coordinate systems. The map was displayed in the equal-area conic projection (Albers), the cylindrical Plate Carrée projection and the cylindrical Mercator projection. The georeferencing applied the affine and the second order polynomial transformation. The information on the reference coordinate system used was assigned to the raster dataset. The georeferenced raster dataset was projected into the correct reference coordinate system – the equal-area conic map projection (Albers). All transformations were supplied with transformation protocols with standard deviations, computed in the external Alltran programme, developed by the Department of Special Geodesy of the Faculty of Civil Engineering, Czech technical University in Prague [9].

In addition, standard deviations for cylindrical projections were identified in case the map did not contain any positional deviations for the equal-area conic projection.

A. Conic Cartographic Projection

Albers Projection (Conic Equivalent Projection)

Albers projection is the most used for maps lying between the Equator and the Pole. Conic equivalent projection or conic equal-area projection for whole world is displayed in Fig. 1. In mathematical terms, this projection may be written as (1):

$$\begin{aligned}
 X &= R \cdot \sqrt{\cot^2 U + 2 - \frac{2\sin U}{\sin U_0} \cdot \sin(\sin U_0 (V - V_0))}, \\
 Y &= R \cdot \cot U_0 - R \cdot \sqrt{\cot^2 U + 2 - \frac{2\sin U}{\sin U_0} \cdot \cos(\sin U_0 (V - V_0))}.
 \end{aligned}
 \tag{1}$$

where R is radius of Earth, V is longitude, U is latitude, V₀ is prime meridian, U₀ is standard parallel of latitude.

B. Cylindrical Cartographic Projection

Two commonly used cylindrical projections of a sphere onto a plane were selected. The currently most commonly used projections are the Plate Carrée and the Mercator

projection.

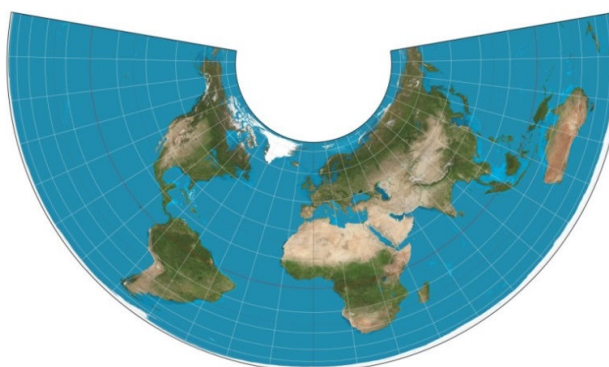


Fig. 1 Albers projection [5]

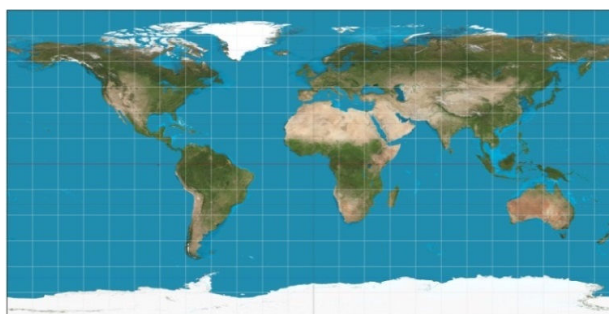


Fig. 2 Plate Carrée projection [5]

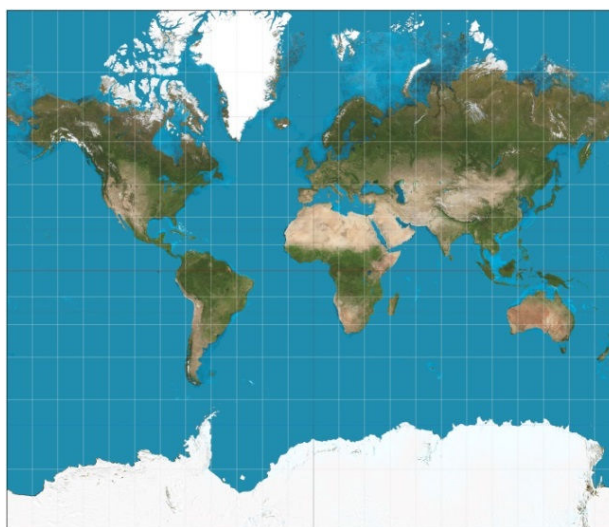


Fig. 3 Mercator projection [5]

Plate Carrée Projection

The Plate Carrée projection for the whole world is displayed in Fig. 2. In mathematical terms, this projection may be written as (2):

$$\begin{aligned}
 X &= R \cdot U, \\
 Y &= R \cdot V.
 \end{aligned}
 \tag{2}$$

where R is radius of Earth, V is longitude and U is latitude.

Mercator Projection

The Mercator projection for the whole world is displayed in Fig. 3. In mathematical terms, this projection may be written as (3):

$$X = R \cdot \cos(U_0) \cdot \log\left(\tan\left(\frac{U}{2} + 45^\circ\right)\right), \quad (3)$$

$$Y = R \cdot \cos(U_0) \cdot V.$$

where R is radius of Earth, V is longitude, U is latitude and U_0 is standard parallel of latitude.

C. Old Map of Europe

The old map, entitled "Europe, the Map of Rivers and Mountains on a 1 : 12 000 000 Scale", was elaborated by professor D. Čipera and Dr. J. Metelka for Otto's Geographic Atlas of 1924, and was positioned in the atlas as its ninth map.

The map is produced in the cylindrical projection. Parallels are displayed as circles and meridians as straight lines starting from one point. Having measured the distances between the parallels, which are displayed in Table I, the estimate of the reference coordinate system of the old map was made as follows – it was an equal-area conic projection with one standard parallel at 50° north latitude and with the prime meridian in the middle of the map at 22°30' east longitude. The reference ellipsoid chosen was the Bessel Ellipsoid as it was the ellipsoid most commonly used at the start of the 20th century in Czech lands.

TABLE I
MAP FRAME MEASUREMENT OF THE OLD MAP

Section on meridian [north latitude]	35°-40°	40°-45°	45°-50°	50°-55°	55°-60°	60°-65°	65°-70°
Length [mm]	4.74	4.62	4.60	4.60	4.62	4.70	4.80

Control points were selected on the map situated at the intersections of the map grid (the map grid density being after each 5°). The total of 139 ground control points was successfully located on the entire map.

D. Type of Transformation

There are currently numerous geographical information systems allowing different types of spatial transformations. These are global transformational methods (identity, similarity, affinity, second or third order polynomial) and local transformation methods (Thin Plate Spline, Inverse Distance Weighted transformation). In practice, the most commonly used transformation for old maps is the affine transformation (4) or the second order polynomial transformation (5):

$$\begin{aligned} x' &= ax + by + c, \\ y' &= dx + ey + f. \end{aligned} \quad (4)$$

$$\begin{aligned} x' &= ax^2 + by^2 + cxy + dx + ey + f, \\ y' &= gx^2 + hy^2 + ixy + jx + ky + l. \end{aligned} \quad (5)$$

A matrix of partial derivatives of transformation equations according to individual variables was formed for the calculation using the Least Squares Method. Then, adjusted transformation parameters and mean coordinate and position errors were calculated in a classical way. The results of errors were recalculated into a map scale of old map (1 : 12 000 000).

III. RESULTS OF INFLUENCE OF THE REPLACEMENT OF THE REFERENCE COORDINATE SYSTEM USED

THE ArcGIS programme developed by the ESRI Company was used to define three reference coordinate systems – the equal-area conic (Albers) projection with one standard parallel at 50° north latitude and with the prime meridian at 22°30' on the Bessel Ellipsoid, the Plate Carrée cylindrical projection on the Bessel Ellipsoid and the cylindrical Mercator projection on the Bessel Ellipsoid with standard parallels symmetrical towards the Equator at 50° latitude.

The geographic coordinate system was projected into the above reference coordinate systems. The grids thus obtained served for the georeferencing of the raster data of the old map of Europe. The georeferencing was performed using 139 control points (map grid intersections after 5°). The georeferencing applied the affine and the second-order polynomial transformation. The results are available in Figs. 4-9, including the directions and size of residuals (in blue). The results of the transformation were computed in the external Alltran programme, developed by the Department of Special Geodesy, Faculty of Civil Engineering, Czech Technical University in Prague (2009). Table II presents standard deviations of coordinates and positional deviations resulting from georeferencing. All standard deviations were recalculated into the graphic scale of the old map, which is on a 1 : 12 000 000 scale.



Fig. 4 Albers projection – affine transformation

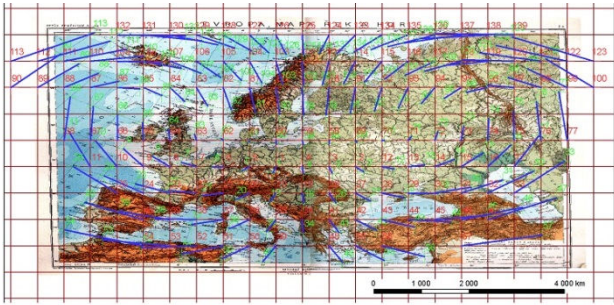


Fig. 5 Plate Carrée projection – affine transformation

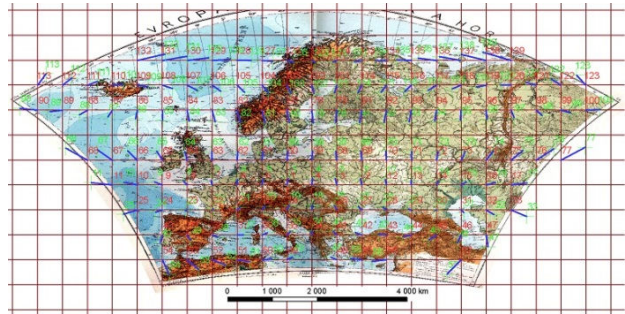


Fig. 8 Plate Carrée projection – second order polynomial transformation

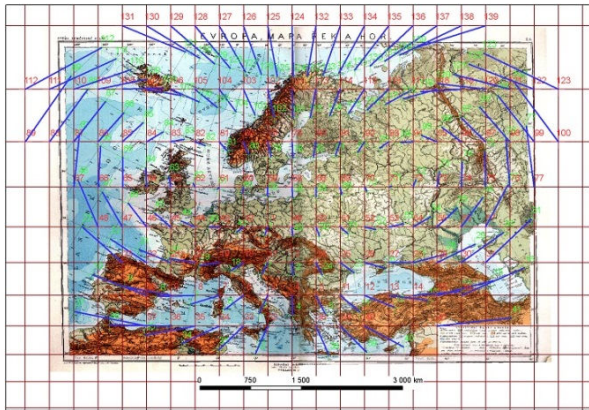


Fig. 6 Mercator projection – affine transformation

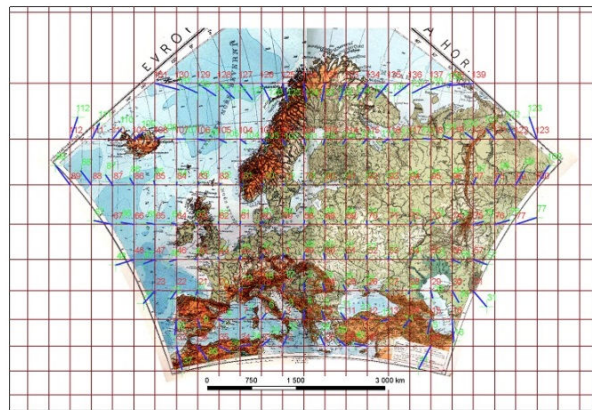


Fig. 9 Mercator projection – second order polynomial transformation



Fig. 7 Albers projection – second order polynomial transformation

TABLE II
STANDARD ERRORS OF GEOREFERENCING

Map projection	Albers	Plate Carrée	Mercator
Affine transformation			
Standard error of coordinate [km]	23,5	575,1	430,6
Graphics standard error of coordinate [mm]	2,0	47,9	35,9
Standard error of position [km]	33,3	813,3	609,0
Graphics standard error of position [mm]	2,8	67,8	50,7
Second order polynomial transformation			
Standard error of coordinate [km]	17,1	191,7	148,9
Graphics standard error of coordinate [mm]	1,4	16,0	12,4
Standard error of position [km]	24,1	271,1	210,5
Graphics standard error of position [mm]	2,0	22,6	17,5

In addition, standard deviations of coordinates and positional deviations for cylindrical projections were computed in case the old map had been projected in the equal-area conic projection without errors – see Table III. These standard deviations only result from a wrongly identified reference coordinate system. The magnitude for the graphic scale on the original map was identified, too.

To conclude, the georeferenced raster datasets were projected by means of transformation equations from the cylindrical projection (Plate Carrée and Mercator) into the equal-area conic (Albers) projection. The results are presented in Figs. 10-13.

TABLE III
STANDARD ERRORS OF TRANSFORMATION BETWEEN MAP PROJECTIONS

Transformation between map projections	Albers to Plate Carrée	Albers to Mercator
Affine transformation		
Standard error of coordinate [km]	524,6	421,7
Graphics standard error of coordinate [mm]	43,7	35,1
Standard error of position [km]	741,8	596,4
Graphics standard error of position [mm]	61,8	49,7
Second order polynomial transformation		
Standard error of coordinate [km]	142,2	147
Graphics standard error of coordinate [mm]	11,9	12,2
Standard error of position [km]	201,1	207,9
Graphics standard error of position [mm]	16,8	17,3



Fig. 10 Plate Carrée (affine transformation) to Albers projection



Fig. 11 Plate Carrée (second order polynomial transformation) to Albers projection



Fig. 12 Mercator (affine transformation) to Albers projection



Fig. 13 Mercator (second order polynomial transformation) to Albers projection

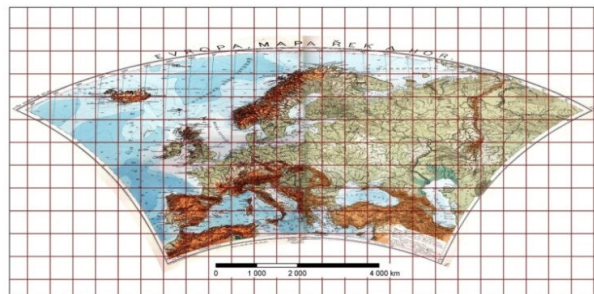


Fig. 14 Properly georeferenced map (into Albers projection) reprojected in Plate Carrée projection

At the end properly georeferenced map (into Albers projection) was in GIS environment reprojected into Plate Carrée and Mercator projections. See differences between Figs. 10, 11, and 14, and differences between Figs. 12, 13 and 15.



Fig. 15 Properly georeferenced map (into Albers projection) reprojected in Mercator projection

IV. CONCLUSION

The georeferencing of an old map of Europe into three reference coordinate system was performed – the Albers equal-area conic projection, Plate Carrée cylindrical projection and Mercator cylindrical projection. The standard deviations in Table II imply that a wrongly selected reference coordinate system is the cause of great distortion in georeferencing. Old maps always contain cartographic errors and the standard deviation of the transformation will always be of some magnitude. By comparing map errors with errors caused by the selection of a wrong reference coordinate system, it becomes evident that the map error is negligible in such a case.

New technologies in the form of geographic information systems (GIS) allow us to convert correctly georeferenced raster datasets into other reference coordinate systems by means of projection equations, not by means of repeated transformation.

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