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Precise transformation between S-JTSK and ETRS89 (WGS-84) in GIS

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Abstract: In the history of GIS we were used to distinguish demands on data precision in GIS and in Geodesy. As long as GIS are being spread also to areas that were usually a domain of CAD systems, we should reflect this needs. One such elementary task of GIS that is closely related to data precision issues is transformation between coordinate reference systems.

Czech Republic is definitely not the only country that is dealing with the problem that national geographic data are located in an old coordinate reference system that has been established long time ago. On the other hand current measurement techniques allow wide range of engineers to acquire data with higher precision than is the precision of such system. One of these cases is the Czech local coordinate reference system S-JTSK and the global world system ETRS89 (WGS-84).

Today GIS tools let us to convert data from S-JTSK to ETRS89 (WGS-84) using method called Burša-Wolf transformation. This method gives us an accuracy of about 1 meter. The aim of this paper is to present grid based transformation method for such propose. Described method is configurable in today's GIS products and brings us the precision in centimetres. Detail analyses as well as possibilities how to use such method in the most spread GIS products (open source as well as proprietary) will be mentioned and demonstrated.

Keywords: Coordinate transformation, Spatial reference system, NADCON.

1   Introduction

The aim of this paper is to introduce the possibility how to convert S-JTSK and ETRS89 coordinate reference systems (CRS) with high precision using common GIS products. It is worth mentioning that the precision in this case is maybe not the best term to use. One of the well known fact is that the S-JTSK has been established long time ago and comparison with modern CRSs like ETRS89 shows local distortions and deformation of the network. Due these reasons the methods based on exact geometric transformation (like Burša-Wolf method) have limited ability to coincide known ground control points (GCPs) located in the whole area of Czech Rep. precisely. The problem is that when we want to combine such CRSs with zero error on GCPs we have to handle also these local deformations by the transformation method. This means that essentially we have to transform different parts of the area of interest differently. In consequence we are changing the meaning of original data as we are enlarging some areas while others are reduced. In this sense it is hard to say that such methods can be understood as precise. On the other hand it is the only possibility how to coincide both systems together absolutely.

When we want to combine S-JTSK with ETRS89 by off-the-self software tools we have these possibilities:
- Use Burša-Wolf method with parameters suitable for whole Czech Republic. The accuracy of such method is of about 1 m. This approach is often used by default in GIS (for example using Proj4 library or ESRI products)
- Use Burša-Wolf method with user defined parameters suitable for 'small' area of interest. The problem is that you have to calculate the parameters from known GCPs by yourself. Also the larger area you want to cover by the transformation the less precision you will get. This method is often used by land surveyors for processing GPS measurement and the accuracy is

of about few centimeters.
- Use some specialized software for such propose that is usually using combination of Burša-Wolf and polynomial or grid based methods. The accuracy can be on high level, but you cannot set it in your favorite GIS product because such solutions are proprietary and you usually don't have source code and is quite outside that the method is already implemented in your GIS. Usually the format of data that can be transformed is also very limited (it is mostly possible to transform just simple coordinates in ASCII file).

This paper demonstrates transformation for S-JTSK and ETRS89 based on method that is supported of most widely used GIS products. This method is from the category of Grid based and is called NADCON (originally it was used for North America conversion).

2   Basics of NADCON transformation

Grid-based methods allow you to model the differences between the systems and are potentially the most accurate method [2]. The transformation converts latitude and longitude from one CRS directly to latitude and longitude in other CRS by simple interpolating the difference and adding these values to original coordinates.

As a first step area of interest is divided into cells – the width and height of these cells depend on accuracy that we are expecting and distribution of GCPs and their differences. In this way we prepare the grid.

Then we calculate the shift in both axis (latitude and longitude) for all of the vertices's of such cells (grid) from known differences at GCPs. Usually we are using some kind of interpolation method (e.g. inverse distance weighted or thin plate spline).

Finally when we want to transform a point of our interest we have to find the cell where such point is located and then calculate the shift in both directions from known shifts of cell vertices. NADCON algorithm is using linear interpolation in each axis direction (bilinear interpolation). When we choose proper parameters of generated grid according to distribution of GCPs we should be able to transform all source control points precisely on the target control points.

This method is well implemented in lot of GIS products, but the NADCON grid configuration files are available just for transformation for few Coordinate Reference Systems (for those used in the US but also in France , Spain and Italy). The different values in decimal seconds are stored in two files: one for longitude and the other for latitude. The NADCON file header contains (in order) the number of columns, number of rows, number of z–values (always one), minimum longitude, cell size, minimum latitude, cell size. Then there is just list of shifts in degree seconds [2].

Example of NADCON file:

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NADCON EXTRACTED REGION                        NADGRD
 167 198  1   12.89116    .01000   48.84586    .01000    .00000
  -2.843056  -2.848042  -2.853026  -2.858007  -2.862987  -2.867963
  -2.872938  -2.877910  -2.882880  -2.887848  -2.892814  -2.897777
  -2.902739  -2.907699  -2.912656  -2.917612  -2.922565  -2.927518
  -2.932468  -2.937416  -2.942364  -2.947309  -2.952254  -2.957196
  -2.962138  -2.967080  -2.972020  -2.976961  -2.981899  -2.986839
  -2.991778  -2.996718  -3.001658  -3.006598  -3.011541  -3.016483
  -3.021429  -3.026375  -3.031322  -3.036274  -3.041228  -3.046185
  -3.051145  -3.056108  -3.061075  -3.066046  -3.071020  -3.075999
  -3.080983  -3.085971  -3.090962  -3.095960  -3.100963  -3.105970
```

Such NADCON grid file can be stored in ASCII format or as a binary file as well. There is also a free software tool (NADGRD) that let users to convert these files from one format to another (see [1] for more).

3   Calculation of grid based transformation for S-JTSK and ETRS89

This part explains the process of calculating NADCON method for transformation S-JTSK and ETRS89.

As the fist step we have to analyze the results of well known Burša-Wolf method with parameters used in GIS (accuracy of about 1 m). The aim is to analyze the distribution of differences of target and transformed points – consider if the errors have a systematic or random distribution and see if such errors can be handled by the interpolation. Figures 1 and 2 show the differences after Burša-Wolf method when using the values in tab 1. The dots show known 3070 GCPs (so called 'points of selected maintenance') that has been used.

Tab 1. Parameters of Burša-Wolf method used GIS

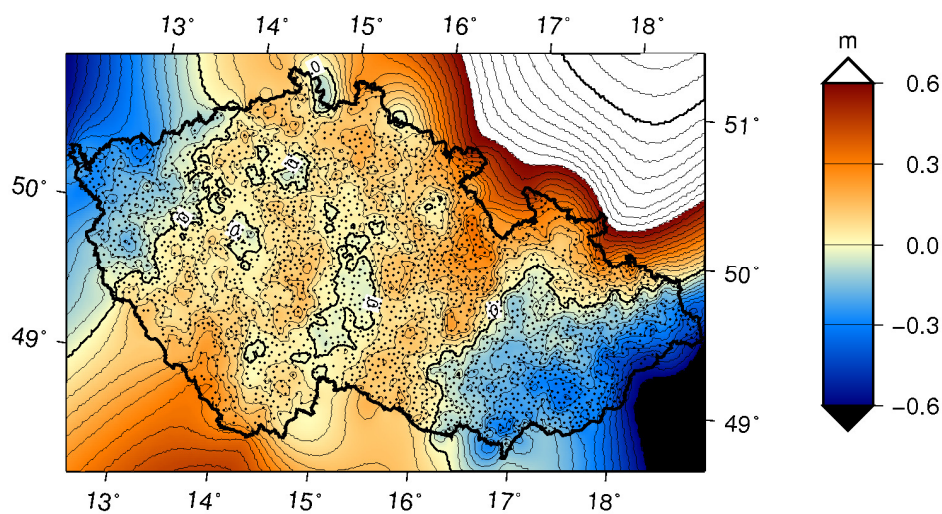| m[10− 6]	Δx[m]	Δy[m]	Δz[m]	εx ["]	εy ["]	εz ["]
3.56	570.80	85.70	462.80	4.998	1.587	5.261

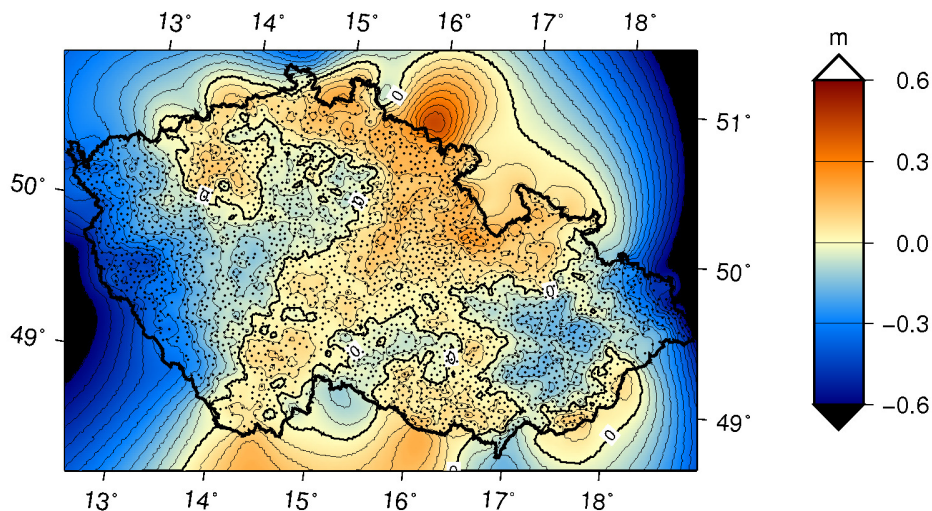**Fig. 1.** Differences in West(+) East(-) direction (Burša-Wolf method)

Fig. 2 Differences in South(+) North (-) Direction (Burša-Wolf method)

For calculation of the grid we have used these data and methods:
- We used 3070 GCPs (directly measured in S-JTSK and ETRS89). These points are freely

available and are used mostly by land surveyors. Because these points are maintained in both CRSs (S-JTSK and ETRS89) they are called 'points of selected maintenance'.

- After various tests of the grid parameters we have chosen cells high and width to be 0.02 degree.
- We tested various kinds methods to interpolate this grid – we get best results by using Thin plate spline interpolation.
- Generated grid covers whole area of Czech Republic.

Then we tried to test the results of this grid. The common test of this method that is often used for transformation is to test the differences between transformed source points and target points. Calculated root means square error (rms) for this method is 0.018 m.

However this characteristic is used most often we have to test this transformation also in other way – such RMS can be nearly zero if we make the grid cell smaller – on the other hand the grid shift file can be then too large and the RMS characteristic shows that the method is even more precise than original data (GCPs) what might be confusing.

3.1 Testing the grid by independent measurement

One of the basic tests was to compare the results with independent measurement acquired by GPS in ETRS89. We have tested directly measured data in both systems and we have also compared NADCON method with Burša-Wolf method that was derived just for small area of interest (what is actually official proposed approach for land surveyors). Parameters for Burša-Wolf method were calculated from 4 points of 'selected maintenance' (points 9122008, 91216013, 91220028 and 91216024 - see fig 3). Then we tested to transform newly measured points as well as some of the points of 'selected maintenance' in this are by this locally derived Burša-Wolf transformation as well as by NADCON method. Final distance (marked d) between the result of transformation and target point is shown at fig. 4. These tests have been made by Romana Kubátová as a part of student project.
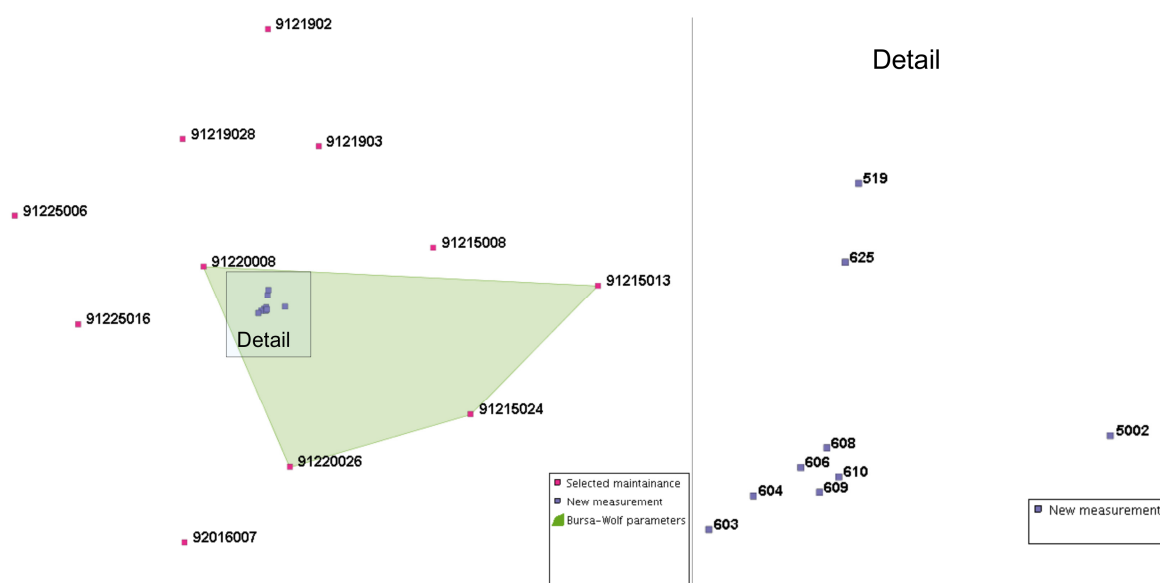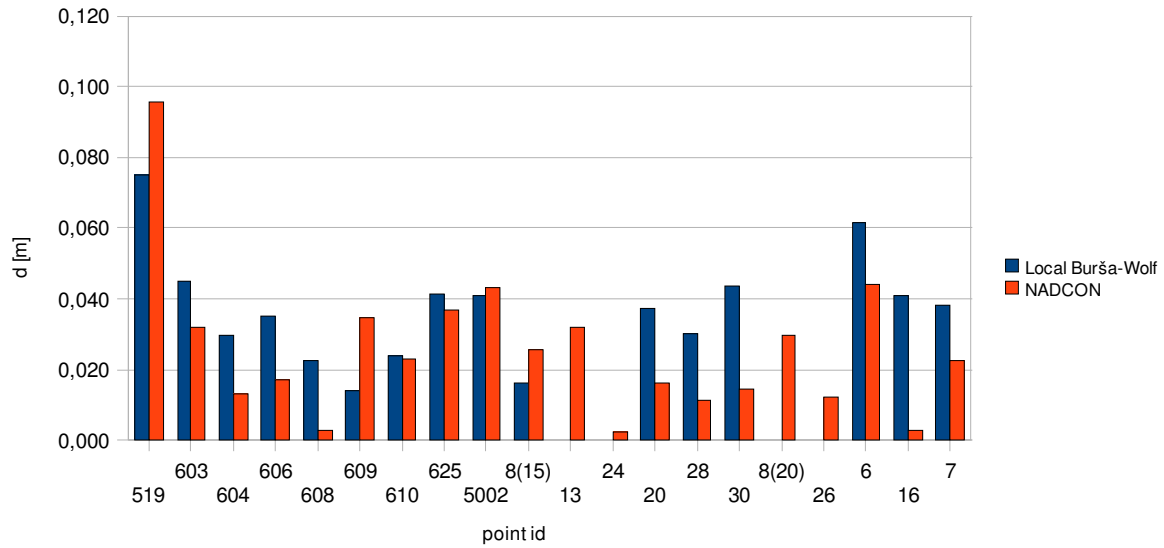

Fig. 3 Tested points

Fig. 4. Deltas on tested points

This test shows that the NADCON method is having approximately the same accuracy as locally derived Burša-Wolf method. Root mean square errors (rms = $(\sum(d_i)/N)^{0.5}$)) are in table 2.

Table 2. Root mean square errors

	Local Burša-Wolf	NADCON
m_{xy}[cm]	3.6	3.3

3.2 Testing by omitting the point from calculation

Other possibility how to test the proposed method is to test the results that we get if we omit some GCP from whole calculation of the grid and then we try to transform this omitted point and compare the result with target point.

The test includes these steps:
- Iterate through N number of GCPs (in our case N=3070 points of 'selected maintenance').
- The chosen point P_i is taken out from the list of N number of GCPs and the transformation is calculated from these N-1 GCPs.
- This chosen point P_i is then transformed by calculated transformation and the result is compared with its target point.

Figure 5. shows the deltas that we get in this test. It makes sense that the deltas are biggest on the border of the area. In other case these deltas are of about 3 cm. The calculated RMS by this test can be seen at table 3.

Table 3. Root mean square errors
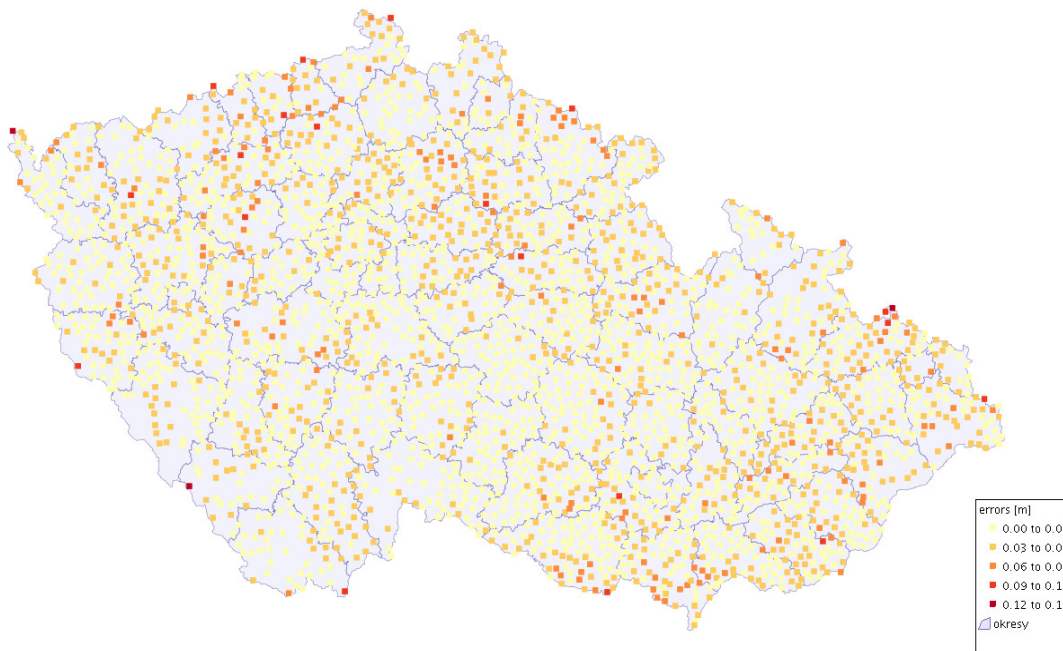
	NADCON – test by omitting GCP
m_{xy}[cm]	3.3

4 Using the grid

We have tried to test calculated NADCON grid shift files in the most widely used GIS products. We succeed in ArcGIS and in the products based on Proj library (UMN Mapserver, Grass. QGIS).

For Proj based GIS users there is a testing version of this grid including short guidelines how to set it. Visit (http://grass.fsv.cvut.cz/wiki/index.php/S-JTSK-Grid) for more. Proper setting does not require new compilation and everything work just by doing easy configuring.

To use such method in ArcGIS you need to copy proper configuration files into the ArcGIS/pedata/NADCON directory. Testing files for such propose are available at *http://git.zcu.cz/wiki/index.php/CRS* . Then you can define new method using ArcToolbox. For example see fig. 6.
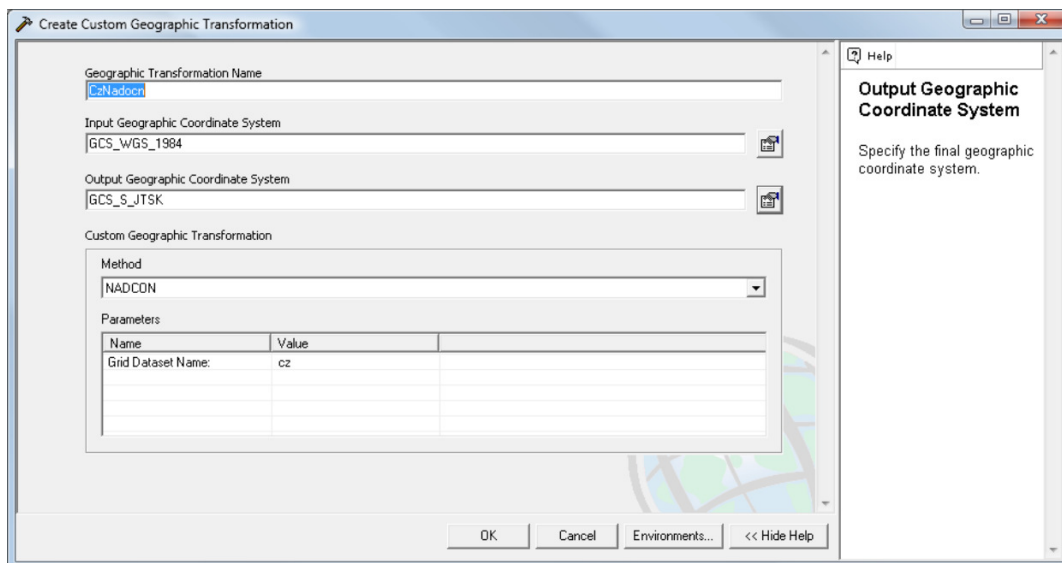

Fig. 6. Configuring NADCON method in ArcMap

Both products require slightly different formats of grid shift file, but the results were exactly the same. In this way users can define and use

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proposed method for high accurate transformation of whatever type of data within these most widely spread GIS Products.

5   Conclusion

Tests show that proposed method and used configuration can reach two main goals:
- We get the transformation that can be used for whole area of Czech Republic and is having accuracy suitable for the demands in Geodesy and Cadaster.
- The transformation can be used in common GIS tools without any additional software development. In this way we can transform whatever data are supported (rasters as well as vectors)

It is also worth mentioning that we did not yet tested the transformation of height – this part is actually work in progress. Another thing is that there are also several other software libraries that are not supporting directly this kind of method (e.g. GeoTools) - but as far as this functionality is missing also by other GIS vendors from other states (France, Italy, Spain) we hope and trying to help to implement such functionality soon.

In this way we hope to bring this level of accuracy for S-JTSK to software tools like UMN Mapserver, GeoServer, PostGIS, GRASS, QGIS or uDig as well as proprietary products produced by ESRI or Intergraph.

Reference:

1. National Geodetic Surway home page：http://www.ngs.noaa.gov/PC_PROD/NADCON
2. ArcGIS 9.2 Desktop Help: http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=Grid-based_methods
3. GRASSwikiCZ: http://grass.fsv.cvut.cz/wiki/index.php/S-JTSK