MERGING OF THE SLOVENIAN AND AUSTRIAN STATE COORDINATE SYSTEMS AND DIGITAL TERRAIN MODELS

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Abstract

Slovenian and Austrian national coordinate systems are described comparatively. The parameters for spatial calculation between them were calculated for the purpose of transformation of the Austrian digital terrain model into the Slovenian state plane coordinate system. The Austrian model was interpolated and merged with the Slovenian digital terrain model into a grid with a cell size of 100 x 100 m.

Keywords: *Austria, digital terrain model, interpolation, national coordinate system, Slovenia, transformation*

1 PURPOSE

By agreement with the Viennese Bundesamt fuer Eich- und Vermessungswesen (BEV), the Surveying and Mapping Authority of the Republic of Slovenia (SMA) purchased a part of the digital terrain model (DTM) covering the Austrian national territory almost up to Linz in the west, up to the Hungarian boundary in the east and almost up to Salzburg and Wiener Neustadt in the north. The surface area of this territory is about 30 percent greater than the surface area of Slovenia. The merging of the Austrian and Slovenian DTMs, which was performed by the Institute of Geodesy and Photogrammetry in cooperation with the Faculty of Civil Engineering and Geodesy, Ljubljana (Radovan, Stopar, 1996, Radovan et al., 1977), would have been a relatively simple task had they not been made in two different coordinate systems with different geodetic and projection bases. Parameters for the calculation (transformation) of the position of points between the two national coordinate systems were not known; therefore, their mathematical comparison was necessary prior to merging the models.

2 NATIONAL COORDINATE SYSTEM

The coordinate systems of Slovenia and Austria in which national geodetic surveys are performed differ in their position, orientation and scale in both horizontal and vertical directions. Therefore, for example, a random point on the state boundary between the two countries has different coordinates and altitudes in the two systems, even though it was surveyed reliably from both sides. The reasons for this discord lie in inevitable errors in the astronomical orientation of triangulation networks and differences in the elevation systems and cartographic projections of the two countries. The coordinate systems are therefore local – they are valid only for the territory of each individual country. Let us now examine their properties in slightly more detail.

The two horizontal coordinate systems share a common reference plane which approximates the Earth's geoid, i.e. Besell's rotation ellipsoid which was determined in 1841. They also have in common the starting triangulation point of Hermannskogel in Vienna, but the astronomical orientations of the two triangulations are not equal due to different improvements of primary results. Similar considerations apply to the two elevation systems which, however, do have a common starting point – bench mark near the automatic tide gauge in Trieste, on the Sartorio quay.

The cartographic projections in the two countries are equal as regards their mathematical basis, but their parameters are very different. Their projection is Gauss-Krueger projection, the x axis of which (in Slovenia) is the projection of the central meridian of zone 5, 15° east of Greenwich. The line scale of points on the central meridian equals 0,9999 for geodetic practice in Slovenia. The Austrian national coordinate system consists of three meridian zones, and therefore three rectangular coordinate systems with central meridians of zones 28°, 31° and 34° east of Ferro, whereby the difference between the initial meridians of Greenwich and Ferro is expressed with a rounded Albrecht constant, $\lambda = \lambda_{Ferro} - \lambda_{Greenwich} = -17^{\circ}40'00''$, while the line scale of points on the central meridian equals 1,0000. The projection systems of individual zones are named M28, M31 and M34.

3 DIGITAL TERRAIN MODEL

The DTM of Slovenia is a regular grid of quadratic cells 100 x 100 m in size (DTM 100). The grid is parallel to the axes of the national rectangular system. Data in the original were written into blocks of 1 x 1 km with 100 altitude values per block. Each block has only one pair of coordinates (y_{GK}, x_{GK}), which refers to the SW corner of the block. It is possible to calculate the coordinates of individual cells in a very simple manner. The altitudes are stated in whole metres. The accuracy of the Slovenian DTM 100 was assessed by comparing the model with altitudes of geodetic points with regard to frequency and amplitude properties of the terrain. The values are as follows (Radovan, 1991):

- 3,3 m for level terrain
- 9,0 m for uneven terrain
- 16,1 m for very uneven terrain and
- 10,0 m for the DTM as a whole.

The data for the DTM was acquired cartometrically with linear interpolation of altitudes from contour lines presented on the basic topographical maps at 1:5 000 and 1:10 000 scales, and for a smaller area on the topographical map at 1:25 000 scale. The data are accessible at the SMA in several different ASCII formats as individual points, profiles and grid blocks.

On the other hand, the purchased DTM of Austria is a regular quadratic grid of cells 50 x 50 m in size, except for 100 x 100 m for certain places close to the Hungarian state boundary. By agreement between the SMA and BEV, only the less dense model of 100 x 100 m may be used in Slovenia. The DTM grid is locally parallel with the projection of central meridians of zones M28, M31 and M34, which means that individual parts are rotated in relation to each other. The data on altitudes were acquired photogrammetrically by analytical evaluation of stereo overlaps and later processed by interpolation and expressed in m with two decimal points. According to BEV, the accuracy of the model is approximately 1 to 2 m for flat terrain and 10 to 15 for forested and hilly terrain. The DTM is distributed in several forms: it was received as recorded by trigonometric sections in 320 ASCII datafiles, each of which had a header with metadata which determined numerous properties of individual blocks and format details. Control between sections was ensured by overlapping marginal profiles.

4 TRANSFORMATION BETWEEN THE TWO NATIONAL COORDINATE SYSTEMS

In order to ascertain the position of the two national coordinate systems relative to each other, their common geodetic points are needed, the position of which is known in both systems. As expected, these were given only for the immediate vicinity of the Slovenian-Austrian state boundary as boundary points and points for the boundary surveying grid. The state boundary between Slovenia and Austria is divided into 27 sections which run from the triple boundary with Hungary to the triple boundary with Italy. Each of them is a rounded whole, within the framework of which technical geodetic work is performed for the determination of the position of boundary points. For each boundary section, surveying and calculations are performed separately in each country. After harmonisation and removal of any discords, official boundary records are adopted which also contain a list of points verified by both sides. Point coordinates are thus determined in both national coordinate systems and are officially valid.

However, there are only seven boundary sections with coordinates harmonised in this manner. For these sections, coordinates were taken from official boundary records of the Department for State Boundary of the SMA. For other boundary sections, coordinates were taken from lists of trigonometric points of the Department of Basic Activities of the Geodetic Institute of Slovenia and from BEV. On the Austrian side, common points were given in zones M31 and M34, which additionally complicated the procedure. Initially, trial transformation was performed by boundary section to reveal errors and discords in data, and later several different types of plane and spatial transformations between the Slovenian and the Austrian systems were performed. The best, and theoretically most suitable, results were obtained by a spatial 7-parametric transformation which can be performed only in a 3D Cartesian coordinate system (X, Y, Z) with the following sequence of steps:

- Gauss-Krueger plane coordinates of common points Y_{GK} and X_{GK} in the Slovenian coordinate system and both Austrian meridian zones are analytically transformed into ellipsoid geographical coordinates λ and φ.
- Each pair of geographical coordinates (λ, φ) is assigned a known altitude H.
- Such a triplet of ellipsoid coordinates (λ, φ, H) is analytically translated into spatial quasigeocentric coordinates (X, Y, Z).
- Spatial 7-parametric transformation is performed by comparing the common points of zone 5 and zones M31 and M34. This yields transformation parameters between the two systems which were assessed by levelling:

  $(X, Y, Z)_{\text{calculated from M31 and M34 zones}} \leftrightarrow (X, Y, Z)_{\text{calculated from zone 5}}$

111 common points were used for the assessment of transformation parameters; of which on the Austrian side 29 were in the western zone of M31 and 82 were in the eastern zone of M34. The mean error of transformation is 0,192 m. The plane deviations were lower than 1 m on almost all common points; they mostly ranged about 0,2 m. An analysis of elevation deviations on extreme corners of the Austrian DTM showed that even in the most unfavourable positions they did not exceed 1,5 m. Since the distribution of common points along the boundary is non-homogeneous and approximately colinear, it was assessed that parameter accuracy entirely satisfies its purpose, i.e. the transformation of the Austrian DTM. The parameters of reverse transformation from the Slovenian to the Austrian system were also assessed by levelling, with similarly accurate results.

5 MERGING OF THE DTMs

Using the estimated transformation parameters, the Austrian DTM was recalculated into the Slovenian coordinate system. Extensive preparatory and finishing work needed to be carried out, which included the following activities:

- transcription of 320 datafiles with the Austrian DTM into a simple ASCII record without redundant metadata,
- levelling of the altitude of DTM points on the edges of neighbouring blocks which differed due to the interpolation of original photogrammetric data,
- merging of 320 levelled datafiles into two datafiles for zones M31 and M34,
- levelling of the altitude of DTM point pairs with insufficient tolerance distance between them in the area where the DTM grids from zones M31 and M34 overlapped (but were not parallel),
- merging the two DTM datafiles from zones M31 and M34 into a single common one,
- spatial transformation of the common datafile of the Austrian DTM into the Slovenian coordinate system with given parameters,
- non-linear interpolation of the transformed Austrian DTM into the grid and format of the Slovenian DTM 100,
- cutting of the interpolated Austrian DTM to match the state boundary and elimination of superfluous points in the Slovenian territory,
- merging of the Slovenian and Austrian DTMs into a common datafile,

- transcript of the merged DTM into the standard form which is used by the SMA for distribution,
- positional and elevation control of contact of cells on the state boundary by hypsometric axonometric mapping.

6 PROPERTIES OF THE MERGED DTM 100

Table 1 presents the basic properties of the existing DTM 100 and the model merged in the described manner.

PROPERTY	*DTM 100*	*MERGED DTM*
Datafile size	4,1 MB	9,5 MB
No. of non-empty blocks (by 1 km^2)	21.270	48.999
No. of altitudes	2.093.161	4.863.672
Range of altitudes (m)	1 – 2.864	1 – 3.321
Minimum Y coordinate (m, zone 5)	5.375.000	5.354.000
Minimum X coordinate (m, zone 5)	5.030.000	5.030.000
Maximum Y coordinate (m, zone 5)	5.624.000	5.624.000
Maximum X coordinate (m, zone 5)	5.194.000	5.272.000
Area size in E-W direction (km)	249	270
Area size in N-S direction (km)	164	242

Table 1: *Properties of the Slovenian and merged Slovenian-Austrian DTM*

The Slovenian DTM is located in zone 5 in its entirety. Zone 5 stretches on the latitude of Slovenia approximately 127 km towards the east and west from the central meridian. It can be established from Table 1 that the new merged DTM reaches 146 km to the west, which exceeds the width of zone 5 by 19 km. Due to this, the line scale in the Gauss-Krueger projection increases on the western edge from the allowable 1,000100 to 1,000161. This means that the relative projection accuracy of length is 1:6 150 instead of the allowed 1:10 000, while line deformation is 1,6 dm/km instead of 1 dm/km. Even without further analysis, it can be established with regard to the estimated accuracy of both the Austrian and the Slovenian part of the DTM that projection deformation is negligible. Therefore, the model may be stored in only one zone, i.e. zone 5, which is also more practical.

6 CONCLUSION

All over the world, traditional national coordinate systems are still almost exclusively local, that is, dependent on the orientation of the reference ellipsoid. In times of universal globalisation of international economic cooperation, however, such systems are becoming an obstacle for undisturbed work even outside the scope of geodesy. Numerous international activities such as naval and air navigation are introducing global coordinate systems, e.g. WGS 84, GRS 80, ITRS and ETRS, rather than using local ones. The project for the connection of the Austrian and Slovenian coordinate systems is one of the first steps required for undisturbed cooperation with our northern neighbours in this field. Even though it was intended for the merging of two DTMs, transformation parameters are sufficiently accurate for the majority of geocoded data exchanges.

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