Geo Information

Special issue – Book of Abstracts

DOI: 10.5281/zenodo.17957633

State Plane Coordinate Systems of North Macedonia

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Keywords: North Macedonia, EPSG, CRS, ETRS89, Gauss-Kryger projection, Bessel 1841, Hermannskogel datum

Abstract:

The coordinate reference system (CRS) of North Macedonia constitutes a hybrid legacy of the former Yugoslav geodetic framework, founded on the Hermannskogel datum, Bessel 1841 ellipsoid, and Gauss–Krüger projection with a central meridian of 21°E. Despite multiple legal and regulatory updates, the country continues to operate simultaneously with three coordinate systems—EPSG:6204, EPSG:6316, and EPSG:9945—which differ in their treatment of false eastings and northings. These inconsistencies generate systematic offsets of 7,000 km (E) and 4,000 km (N), producing non-transformable datasets and spatial incoherence within national geospatial infrastructures. This study synthesizes the historical, technical, and projectional aspects of the CRS of North Macedonia, examining (I) the legal evolution of state coordinate definitions, (II) the mathematical characterization of its projection variants, and (III) distortions resulting from height-to-projection reductions. Results confirm both large-scale positional offsets and significant ground-to-grid discrepancies, with mean linear deformations of −16.01 cm/km under the current state projection. The findings substantiate the necessity of establishing a new ETRS89-based coordinate system that integrates geodetic accuracy with modern low-distortion projection principles.

Coordinate reference systems (CRSs) provide the mathematical foundation of geospatial positioning by linking four conceptual surfaces: the topographic surface, the sea (geoid) level, the reference ellipsoid, and the map projection plane. The accuracy and interoperability of national spatial data infrastructures depend critically on the internal consistency of this chain. In the Republic of North Macedonia, the currently enforced CRS remains based on the Hermannskogel datum and Bessel 1841 ellipsoid, initially introduced by the Military Geographic Institute (MGI) in Belgrade in the early 20th Century. The legal definition, codified as EPSG:6204, prescribes a Gauss–Krüger projection with a central meridian at 21°E and a false easting of 500,000 m (Official Gazette No. 55/2013). However, institutional practice diverges sharply: the Agency for Real Estate Cadastre (AREC) and National Spatial Data Infrastructure (NSDI) geoportals disseminate data predominantly in EPSG:6316, while first digitized cadastral products rely on the truncated coordinate form EPSG:9945.

The analysis confirmed systematic offsets between the three CRS realizations: approximately +7,000 km in easting between EPSG:6204 and 6316, and +4,000 km in northing between EPSG:6204 and 9945. Although AREC officially recognizes EPSG:6204, its operational data remain encoded in EPSG:6316. The truncated CRS (EPSG:9945) emerged during the digitization of cadastral archives, introducing a false northing of –4,000,000 m. These discrepancies produce incompatible coordinate domains that cannot be transformed without explicit definition of datum parameters. Default PROJ transformations apply low-accuracy regional parameters, yielding up to 10 m of horizontal displacement. Adoption of the high-precision parameters defined in EPSG:6206 would mitigate this error.

This coexistence of three CRSs—each internally valid but mutually offset—has created a unique geodetic situation. Misaligned datums, inconsistent transformation parameters, and the absence of uniform EPSG/PROJ definitions have collectively reduced spatial interoperability and impaired the accuracy of coordinate transformations to WGS84 and ETRS89. As a result, overlays of national datasets with global basemaps reveal planimetric shifts exceeding 10 m. The scientific objective of this study is to evaluate the structural causes and projection-induced distortions of the existing CRS and to outline the conceptual foundations for an ETRS89-based state plane system for North Macedonia.

A multi-layered analytical framework was employed, integrating legal-historical, geodetic-technical, and projectional components.

Legal-historical review: National legislation and regulations (Official Gazette Nos. 34/1972, 55/2013, 151/2013, 159/2013) were analyzed to trace the evolution of state coordinate definitions and their relationship to MGI conventions.

Geodetic registry analysis: CRS definitions and transformation parameters were examined from EPSG (codes 6204, 6316, 9945) and PROJ repositories, including Bursa–Wolf seven-parameter transformations (EPSG:6205, 6206). Comparative inspection identified inconsistencies in area extents, false eastings, and PROJ string definitions.

Projection-distortion modelling: Quantitative evaluation was performed on a 1 km national grid comprising 25,635 points. Elevations from ASTER GDEM and geoid undulations from EGM08 were used to compute successive reductions (topographic → geoid → ellipsoid → projection) following classical geodetic reduction formulas. Three projection configurations were tested: UTM Zone 34N (k=0.9996), Gauss–Krüger 21°E (k=0.9999, official), and Modified Gauss–Krüger 21°45′E (k=0.99993, optimized). The distortions were evaluated as linear deformation ΔL/L per kilometre, and visualized through raster interpolation in QGIS.

Table 1. Parameters of current CRS variants and corresponding offsets.

UTM – zone 34N	**Gauss-Kruger (21°E, 0.9999)**	**Gauss-Kruger (21°45'E, 0.99993)**
Central meridian: 21° Origin of latitude: Equator Scale factor: 0.9996 False easting: 500000m False northing: 0m	Central meridian: 21° Origin of latitude: Equator Scale factor: 0.9999 False easting: 500000m False northing: 0m	Central meridian: 21°45' Origin of latitude: Equator Scale factor: 0.99993 False easting: 500000m False northing: 0m

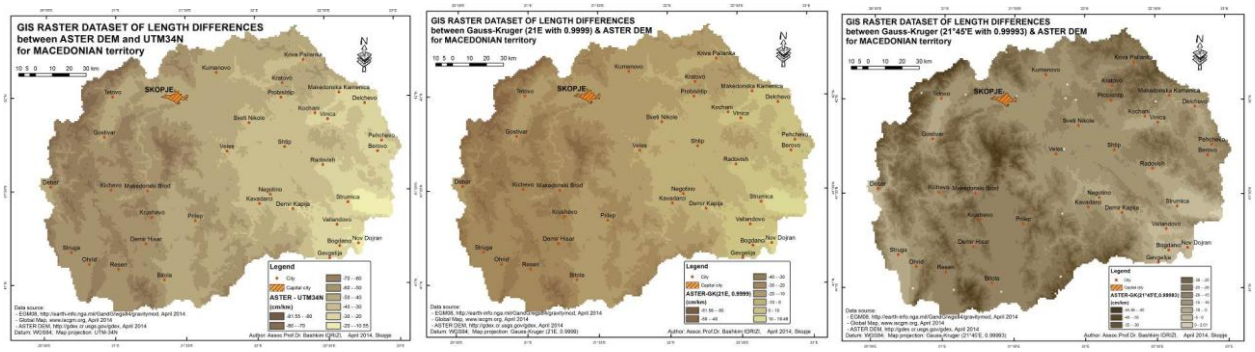

Figure 1. Spatial model of topography-to-projection reductions across North Macedonia (1 km grid resolution).

Table 2. Progressive length differences of 1km lengths between ASTER and five reference surfaces

SURFACES	**ASTER DEM – EGM08**	**ASTER DEM – WGS84**	**ASTER DEM – UTM 34N**	**ASTER DEM – Gauss-Kruger (21°E, 0.9999)**	**ASTER DEM – Gauss-Kruger (21°45'E, 0.99993)**
Θ	-13.03cm/km	-13.74cm/km	-46.01cm/km	-16.01cm/km	-17.17cm/km
Dispersion of distortions	-0.38 to -41.43cm/km	-1.07 to –42.11cm/km	-10.55 to -81.55cm/km	-51.56 to 19.48cm/km	-44.46 to 2.01cm/km
***d* positive**	-	-	-	11.32%	0.09%
***d* negative**	100%	100%	100%	88.62%	99.9%
***d* without distortions**	-	-	-	0.06%	0.01%

Successive reduction modelling revealed mean cumulative distortions of −46.01 cm/km for UTM 34N, −16.01 cm/km for the official Gauss–Krüger, and −17.17 cm/km for the modified Gauss–Krüger projection. The distribution of distortions is topographically dependent: negative contractions dominate in the high-altitude west (Šar Planina, Mavrovo), whereas minor positive expansions occur in eastern lowlands. These results confirm that the current state projection is not a low-distortion projection (LDP), as its parameterization was optimized at the ellipsoid rather than at mean terrain height. Application of root-mean-square (RMS) minimization methods or constant-height conformal projections could reduce average distortion below 5 cm/km.

As geospatial interoperability becomes central to EU spatial policy, harmonization toward ETRS89 is no longer optional but a strategic requirement. From a geodetic and cartographic standpoint, modernization should proceed through three interrelated steps:

- Datum modernization: adoption of ETRS89 with GRS80 ellipsoid as the new geodetic reference frame,

- Projection optimization: derivation of a national Low-Distortion Projection (LDP) based on RMS-minimization principles, possibly within a Transverse Mercator or Lambert Conformal Conic configuration tailored to mean terrain height, and
- Institutional integration: submission of a new CRS definition to EPSG, coordinated by AREC and academia, ensuring interoperability with European Spatial Data Infrastructure (SDI) frameworks and compliance with ISO 19111 and OGC standards.

The creation of a unified State Plane Coordinate System of North Macedonia (SPCS–NM) would eliminate legacy inconsistencies, enhance accuracy for engineering and cadastral applications, and align the national geodetic infrastructure with the European spatial reference environment.

Acknowledgement

This article is based on results from the National Scientific Project "State Plane Coordinate Reference System of the Republic of North Macedonia" (DOI: 10.17605/OSF.IO/MPUHG), publicly accessible at www.scrsproject.mk. The author gratefully acknowledges the South-East European Research Institute on Geo Sciences and all project partners for their valuable collaboration and for granting permission to use project data in this publication. The article will also be referenced on the project's official website following its publication. *https://www.scrsproject.mk*

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