On the problem of the transformation between the official Hellenic Geodetic Datum and the 'Old Bessel' or Old Greek Datum. A case study in the Serres region (Northern Greece).

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Abstract

We describe two different solutions to the transformation between the official geodetic datum of Greece, the Hellenic Geodetic Reference System of 1987 (HGRS1987), and a historic, but still used version of the Old Greek Datum (GR-Datum) called the 'Old Bessel' datum. The Old Greek Datum, the previous officially accepted datum in Greece, consists of two different versions: the 'Old Greek Datum' ('Old Bessel') and the 'New Greek Datum' ('New Bessel'). The alignment of the 'Old Bessel' version of GR-Datum to the Hellenic Geodetic Reference System of 1987 remains a crucial issue in Greece, and there is no officially accepted technical solution. Our case study in Serres (northern Greece) tests two different transformations: 2D similarity, and 2nd degree polynomial and evaluates the accuracy of each in providing a connection between the the Old Bessel version of the GR-Datum, and HGRS1987. The study relies on control stations of the state's triangulation network that have published coordinates in both systems. The control stations were identified on the ground and surveyed using RTK-GNSS.[1] For the case of the 2D similarity transformation, we find a consistency of 1.2M in our results, while the 2nd degree polynomial transformation has an improved consistency of 0.8M.

Introduction

Greece has a variety of different geodetic reference systems. Historically, the first geodetic reference systems were realized using the Bessel ellipsoid (HEMCO 1987, Fotiou 2007). After the Second World War, there was an effort to modernize the geodetic and mapping infrastructure. In 1987 the new official geodetic reference system, the Hellenic Geodetic Reference System 1987 (HGRS 1987) was established (the Greek Cadastre refers to this reference system). We will briefly describe the geodetic reference systems used by the civil services in Greece (see also Ampatzidis and Melachroinos 2017, Kalamakis et al. 2017 and Moschopoulos et al. 2020, Kalamakis 2020).

(i) The Hellenic Terrestrial Reference System of 2007 (HTRS07) (Katsambalos et al. 2010). HTRS07 is a densification of the European Terrestrial System of 1989. It uses the GRS80 spheroid and the Transverse Mercator projection (one zone, central meridian at 24 degrees).

(ii) The Hellenic Geodetic Reference System of 1987 (HGRS1987) (HEMCO 1987, Veis 1996). HGRS1987 combines classical and satellite observations (SLR, GPS and TRANSIT). It is connected through special procedures (an initial Helmert transformation and subsequently a grid based transformation—the application of national grids) to the HTRS07 with an accuracy of 8.3cm nationwide (Katsambalos et al. 2010). HGRS1987 uses the GRS80 spheroid, and the Transverse Mercator projection (the whole country is included in one zone that extends from 19° to 28° East). HGRS1987 is the official geodetic reference system of Greece

(iii) Two versions of the Old Greek Datum (GR-Datum): the 'Old Bessel' and the 'New Bessel' (Takos 1989):

(a) The 'New Bessel' (or the new version of GR-Datum) was established in the mid-80s (Takos 1989). The Bessel spheroid of 1841 is used, and the associated projection is Hatt's (Mugnier 2002). Hatt's is an equidistant projection. The country was divided into spheroidal trapezoids of 30' x 30' (1:100000 scale, see Figure 1). In total, 137 map sheets were released. Each map sheet has a different origin of coordinates, causing a lot of confusion for surveyors. The new version of GR-Datum is directly connected to HGRS1987 through 2nd degree polynomials referred to each sheet (HEMCO 1995).

(b) The'Old Bessel' (or old version of GR-Datum), was established before the Second World War and carries with it significant inconsistencies and systematic effects. The great majority of the rural areas in the northern part of the country refer to the 'Old Bessel'. It uses the Bessel 1841 spheroid and was realized by the division of the northern part of the country into spheroidal trapezoids of 6' x 6'. The derived mapping infrastructure of the 'Old Bessel' datum, were topographic maps of 1:1000, 1:2000 and 1:5000 scales. Each of the 6' x 6' trapezoids is a unique coordinate system, as each map sheet has a unique origin of coordinates. The 'Old Bessel' thus produced a very large mosaic of different coordinate systems. Unfortunately, there is no officially accepted transformation/transition algorithm to connect the 'Old Bessel' to either the 'New Bessel' or to HGRS1987.

Transforming Old Bessel to HGRS87

For the surveyor and cartographer the transformation issue between the 'Old Bessel' and HGRS1987 causes significant problems. To accomplish this he/she often uses in-situ/ad hoc techniques, focusing only on a limited area of interest (e.g., one or two city/town blocks). The GR-Datum's fundamental point (Central Pillar) is located in the National Observatory of Athens (NOA). The initial latitude and longitude of the Observatory are 37° 58' 18.68' N, 23° 42' 58.815' E. By convention, the NOA longitude value is set to 0° 00' 00.000' E (null GR-Datum meridian) for the GR-Datum, and the geodetic longitude of any point in the system is always estimated with respect to the NOA's conventional meridian. This is true for both 30' x 30' and 6'x 6' map sheet distributions. As previously mentioned, the GR-Datum uses Hatt's projection. Hatt's is not a commonly used projection (its application is limited to some French colonies, Mugnier 2002). The Hatt projection could not be used over large areas due to significantly increasing distortions for ellipsoidal trapezoids with sides greater than 55-60 km. The reason for adopting Hatt's projection was its simplicity which was appropriate to the modest skills and computational abilities of rural Greece at the beginning of the 20th Century. At that time the need for quick land surveys was great. Following the Greek-Turkish war and the resulting 1923 Treaty of Lausanne, hundreds of thousands of refugees from Pontus and Asia Minor were in need of accommodation.

We should underline that the 'Old Bessel' is used by the surveying agency of the Greek Ministry of Agriculture. It was the Ministry of Agriculture that decided that map sheets would be divided into trapezoids of 6' x 6'. Each map sheet defines its own coordinate system, with its own latitude and longitude of origin called the *centroid* (e.g., Fotiou 2007). The *centroid's* longitude, λ_0, is defined with respect to the conventional null meridian of the GR-Datum. The *centroid's* spherical coordinates play a crucial role in the Hatt projection. The projection coordinates of a specific point are estimated from the differences between the measured geodetic latitude and longitude of the point, and the latitude and longitude (φ_0, λ_0) of the centroid. In Section 3.1 we will give a description of the procedure. All 'Old Bessel' map sheets refer to the same geodetic datum, but at the same time, they define their own coordinate system. A rough parallel example is that of the UTM system, which allow a number of different zones, with a common geodetic datum. The only difference for the GR-Datum case is that we have hundreds (or even thousands) of different coordinate systems. The irony of a system created for its ease of application at the local level, lies in the complications of this diverse cartographic heritage for modern surveyors working within the unifying and generalising trends of geocentric coordinate systems. In the present study we test the transformation between the 'Old Bessel' and HGRS1987 for an area located in Serres, in Northern Greece. We shall apply two different models: the similarity and polynomial transformations.[2]

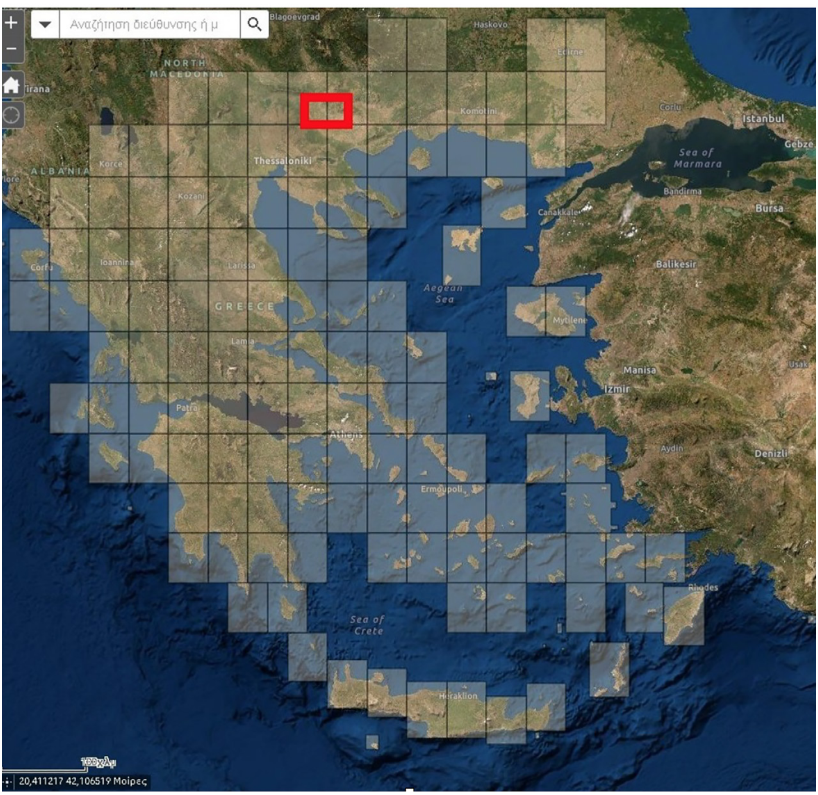

Figure 1: Distribution of the 1:100000 map sheets in Greece (www.gys.gr). The red box shows the area of our study.

Methodology

More background

As discussed above, the 'Old Bessel' is realized by the choice of 6'x 6' map sheets. Thus, for relatively large areas covered by many map sheets, there are many different coordinate systems! For our case study, we began by identifying a number of common points (control stations) between the 'Old Bessel' and HGRS1987 datums. One might keep in mind that for each map sheet, the projection coordinates (x,y) of the common points are determined—this would be the same process whether dealing with 30' x 30', or the 6'x 6' map sheets—with respect to a specified centroid (see Section 2 above for more information on the map *centroid*). The *centroid* defines the origin of the map sheet, i.e. the (φ_0, λ_0) coordinate. The projection coordinates (x,y) are determined using the so-called direct mapping equations to calculate projection coordinates from the geodetic curvilinear coordinates. The input of the direct mapping equations are the geodetic latitude and longitude difference $(\Delta\varphi', \Delta\lambda')$ between the geodetic latitude φ and longitude λ and the latitude and longitude of the *centroid*: $\Delta\varphi = \varphi - \varphi_0$, $\Delta\lambda = \lambda - \lambda_0$. It so happens that the *centroid*'s geodetic curvilinear coordinates are chosen to be placed at the 15th and 45th minutes of a degree (both for latitudes and longitudes) for the case of the 30' X 30' map sheets, and every even 6th minute for the 6' x 6', map sheets.[3]

We begin the transformation process by re-computing geodetic latitude and longitude (i.e. removing the effect of the *centroid* on geodetic latitude and longitude). Using the inverse mapping equations and with respect to the map's sheet centroid, projection coordinates (x, y) can be converted to the associated $\Delta\varphi$ and $\Delta\lambda$ geodetic latitude and longitude differences, respectively. Then it is straightforward to estimate the geodetic coordinates: $\varphi = \Delta\varphi + \varphi_0$, $\lambda = \Delta\lambda + \lambda_0$. Note that the longitude still refers to the conventional null meridian (see Section 1).

Change of Map Sheet's Centroid (CMSC)

Though the control points used in this study are common to both Old Bessel and HGRS1987 datums, the Old Bessel points are on multiple map sheets, and so it is necessary to unify all the different control points of the different 6' x 6' map sheets to a common coordinate system. This is accomplished through a change of a map sheet's centroid (CMSC, Fotiou 2007). The procedure can be summarized as follows:

a. We choose a new reference centroid as φ'_0, λ'_0. We easily compute the new differences: $\Delta\varphi' = \varphi - \varphi'_0, \Delta\lambda' = \lambda - \lambda'_0$. This centroid is used for locating all the control points on a common map sheet. The *centroid's* choice is arbitrary, or one might decide to locate the *centroid* in the middle of the area of interest which is a common choice for studies over large areas.

b. Finally, we determine the new projection coordinates (x', y') through the direct mapping equations, using as inputs the geodetic differences $(\Delta\varphi', \Delta\lambda')$.

Now, all the new projection coordinates (x', y') previously belonging to different 6' x 6' map sheets, refer to a common centroid and a common coordinate system. With this object achieved we are ready to apply the first of our coordinate transformation techniques.

Coordinate Transformation

The model of similarity transformation:

The general model is defined (point wise):

$$X_i = \mu cos\theta x_i + \mu sin\theta y_i + t_x$$

(1a)

$$Y_i = -\mu sin\theta y_i + \mu cos\theta x_i + t_y$$

(1b)

where X_i, Y_i are the coordinates with respect to the HGRS1987 (final system), x_i, y_i are the projection coordinates with respect to the 'Old Bessel' and μ, θ, t_x, t_y are the four unknow parameters of the 2D similarity transformation (uniform scale, rotation and two translations of the axes, respectively), which will be estimated through least squares adjustment (e.g. Dermanis and Fotiou 1992, Kalamakis 2020). The 2D similarity model is widely used for datum transformations (DMA 1987, Hoffmann-Welhenchof et al. 1993, Yang et al. 1999). The main limitation of the 2D similarity transformation is that it is best applied locally, and should not be applied over extended areas. The main advantage of the 2D similarity transformation (in contrast to e.g. 3D Helmert transformation) is that it works without any knowledge of station heights. In the past this has been a crucial issue since height information was either non-available or weak (Torge and Müller 2012).

The model of the polynomial transformation

We choose the 2nd degree polynomials as follows. The equation yields, pointwise:

$$X_i = a_0 + a_1 x_i^2 + a_2 y_i^2 + a_3 x_i y_i + a_4 x_i + a_5 y_i$$

(2a)

$$Y_i = b_0 + b_1 x_i^2 + b_2 y_i^2 + b_3 x_i y_i + b_4 x_i + b_5 y_i$$

(2b)

where X_i, Y_i are the coordinates with respect to the HGRS1987, x_i, y_i are the coordinates with respect to the 'Old Bessel' and $a_0, a_1, a_2, a_3, a_4, a_5, b_0, b_1, b_2, b_3,$ b_4, b_5 the coefficients of the 2nd degree polynomials, estimated through least squares adjustment.

Transformation of coordinates by second-degree polynomial methods is a recognised method (HEMCO 1995, Junkins 1998, Alashaikh 2017, Ampatzidis and Melachroinos 2017). The research shows that 2nd degree polynomials can absorb more systematic effects than can a similarity transformation. However, the main drawback of the the application of the polynomial method is that it can distort shapes: E.g. a square might lose its perpendicularities in the process.

Application

We test the two aforementioned mathematical transformations in the area of Serres in northern Greece. We identified 37 common points (Figures 2 and 3) between the, Old Bessel' and HGRS1987. The common control stations have officially published coordinates for the 'Old Bessel' and the HGRS1987 geodetic systems, respectively. These control stations are located in 14 different 6' x 6' map's sheets. Implementing the CMSC (see section 2.1) we refer all the different map sheets to a common one. After in situ search, we found 23 existing control stations (the other 14 had either been destroyed or severely damaged). For the the purpose of a dataset that might be used in the future for further studies, we obtained GNSS measurements at all existing control stations, using the RTK mode. This last exercise aligned the control stations to the International Terrestrial Reference Frame 2014 (ITRF2014, Altamimi et al. 2014). The RTK survey furthermore provided height information that will undoubtedly be useful in future.

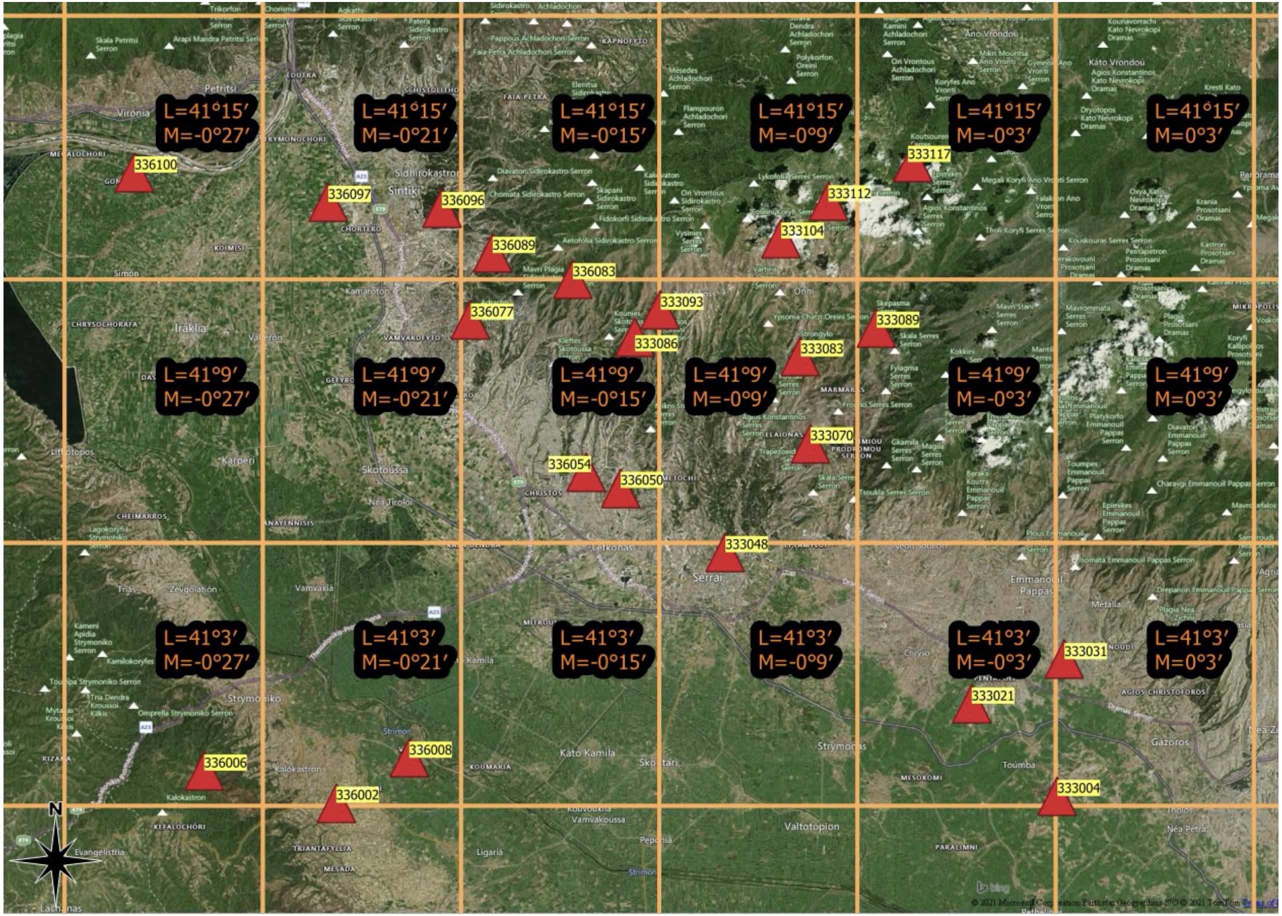

Figure 2: The initial set of the 37 common points between Old Bessel an HGRS87. The Figure comprises all fourteen 6’ x 6’ map sheets used in the present study. L corresponds to each centroid’s latitude (φ_0) *while M to each centroid’s longitude* (λ_0,) *—with respect to the conventional NOA’s meridian. The letters L and M are traditionally used for the 6’ x 6’ map sheets’ centroid’s curvilinear coordinates.*

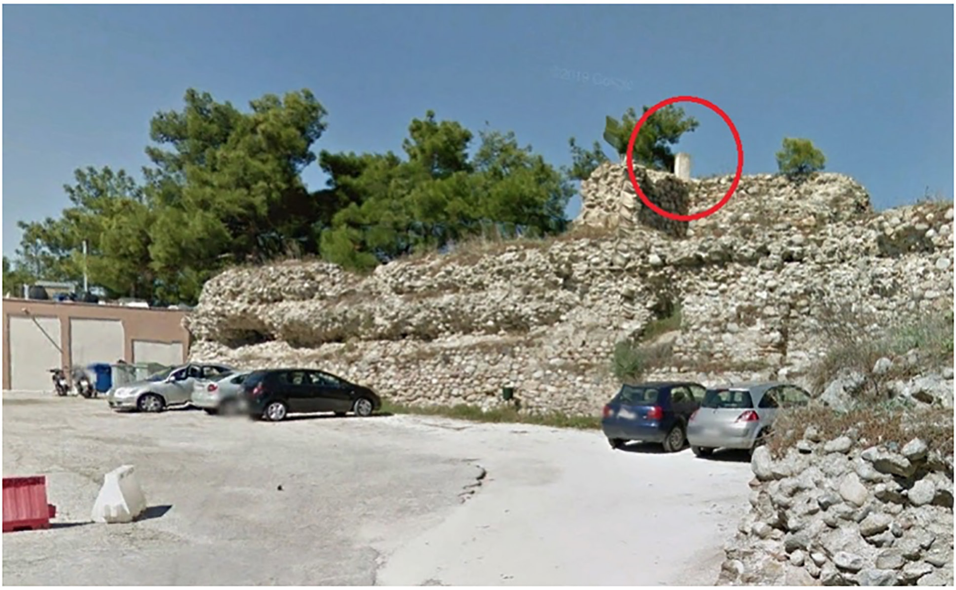

Figure 3: A benchmark (inside the red circle) located in Serres area.

Application of the 2D similarity transformation

We performed the 2D similarity transformation on the 'Old Bessel' (initial geodetic reference system) and the HGRS1987 (final geodetic reference system) datums at the common points. The application of the 2D similarity transformation leads to the estimation of the least squares adjustment's residuals. The residuals' behaviour gives a sense of the consistency between these two geodetic reference systems. The possible outliers are excluded using the 3-sigma criterion (removing points which their residuals are found 3 times larger than the standard deviation of the residuals). We repeat the least squares adjustment till no outlier is identified. In the present case, we had no need to remove any control stations, since the 3-sigma criterion control was successful. Table 1 shows the transformation parameters from 'Old Bessel' to HGRS1987 and Table 2 summarizes the statistical performance of the 2D similarity transformation. Figures 4 and 5 show the residuals per component and their associated horizontal residuals.

Table 1: The similarity transformation parameters (from 'Old Bessel' to HGRS1987)

parameter	value
$t_x(m)$	455303.161
$t_y(m)$	4566439.332
θ *(deg)*	-0.3478680055
$\boldsymbol{\mu}$	0.9996063239

Table 2: The statistical performance of the 2D similarity transformation

statistical quantity	x-residual (in m)	y-residual (in m)
minimum	-2.24	-2.95
maximum	1.68	2.83
mean average	0.00	0.00
standard deviation	1.05	1.24

Application of the 2nd degree polynomial transformation

The mathematical model described in equations *2a* and *2b* above is applied. The 3-sigma criterion was again successful, without any removal of stations (following the same concept as described in Section 3.3). Table 3 refers to the estimated polynomials, while Table 4 shows the statistical quantities of the 2nd degree transformation. Figures 6 and 7 show the residuals per component and their associated horizontal residuals representations, respectively.

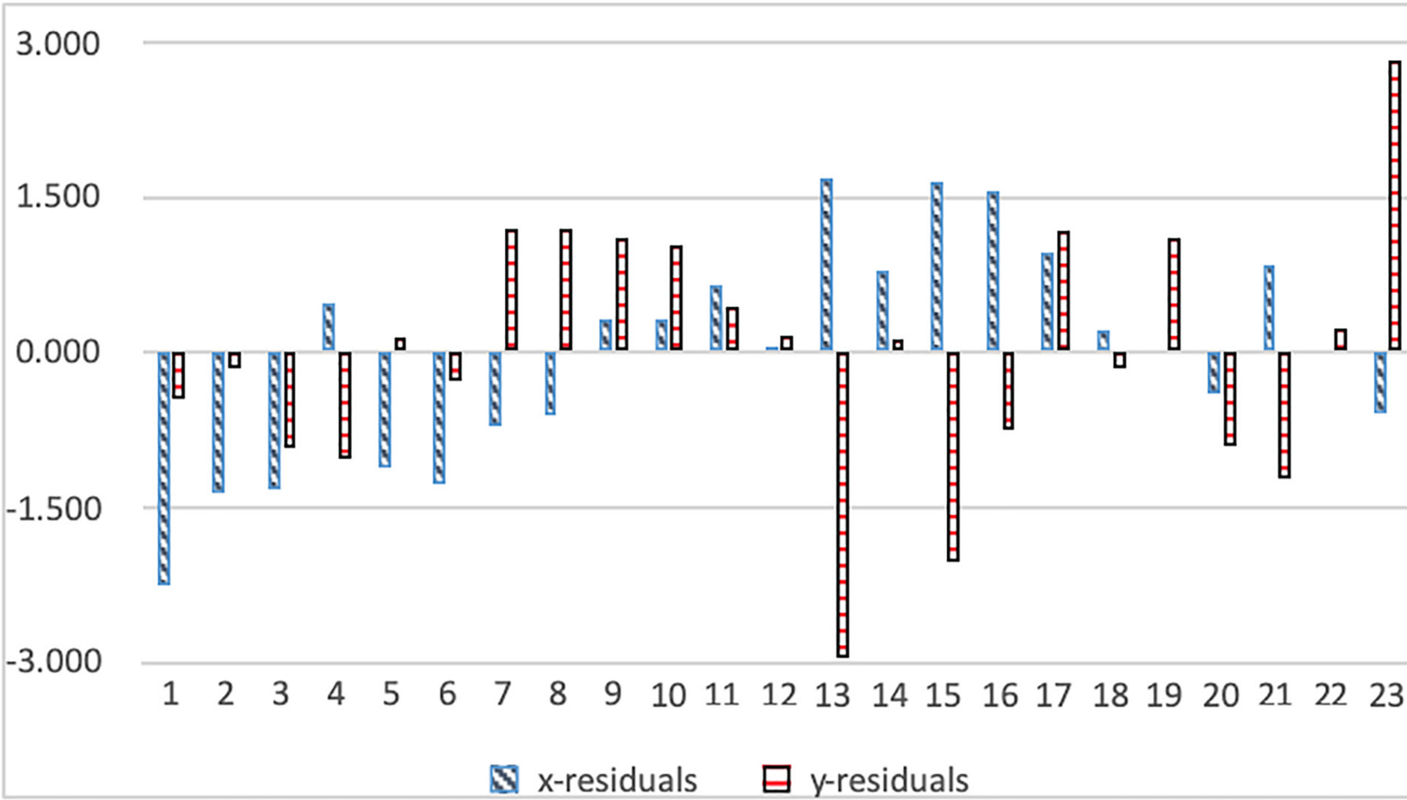

Figure 4: The residuals of the 2D similarity transformation per component.

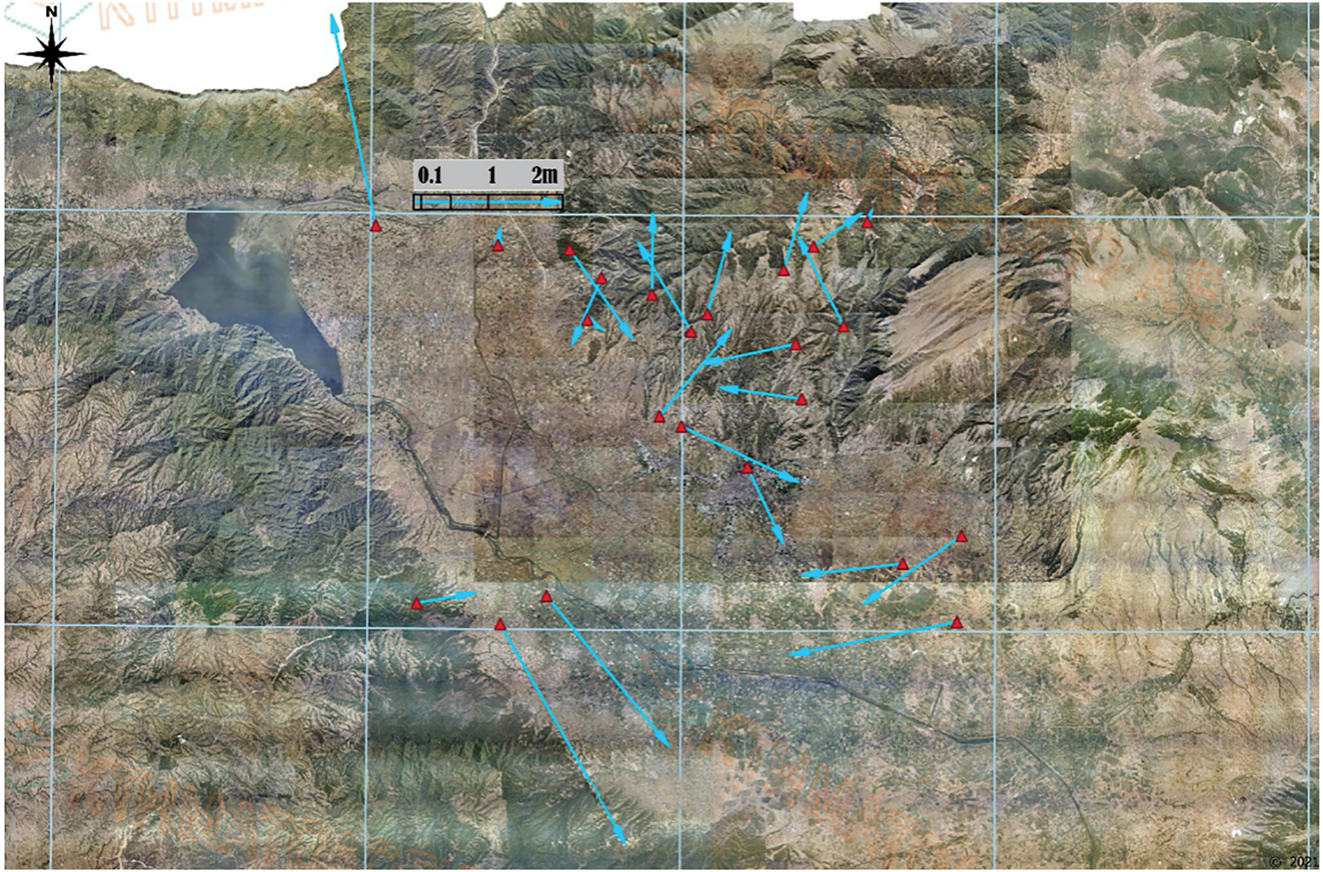

Figure 5: The horizontal residuals of the 2D similarity transformation for the examined area.

Table 3: The polynomial transformation parameters (from 'Old Bessel' to HGRS1987)

parameter	value
$a_0(m)$	455303.7852
a_1	0.9995969128
a_2	0.006132481192
a_3	-3.91E-09
a_4	3.28E-09
a_5	2.66E-09
$b_0(m)$	4566438.744
b_1	-0.006095481756
b_2	0.9994124097
b_3	6.54E-09
b_4	-9.84E-09
b_5	9.66E-10

Table 4: The statistical performance of the 2nd degree similarity transformation

statistical quantity	x-residual (in m)	y-residual (in m)
minimum	-1.03	-1.54
maximum	1.28	1.23
mean average	0.00	0.00
standard deviation	0.58	0.83

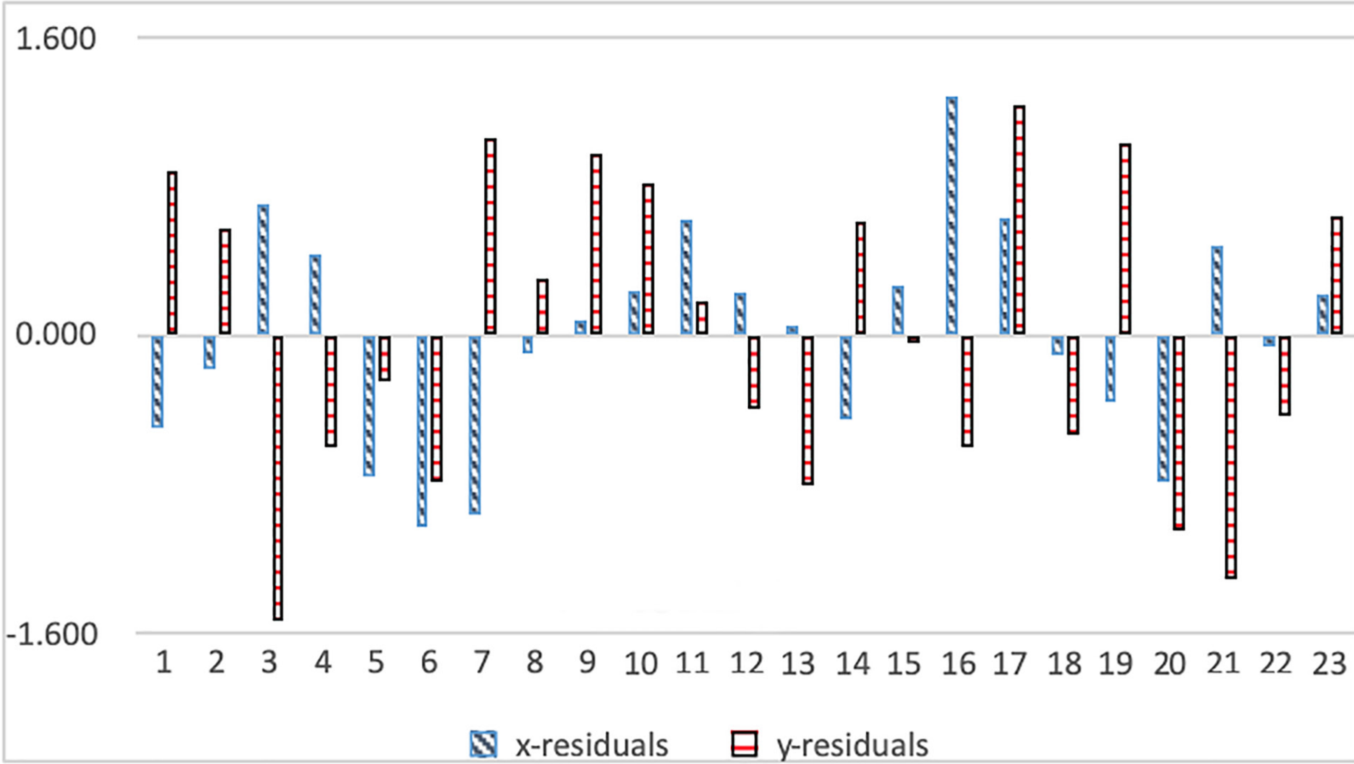

Figure 6: The residuals of the 2nd degree polynomial transformation per component.

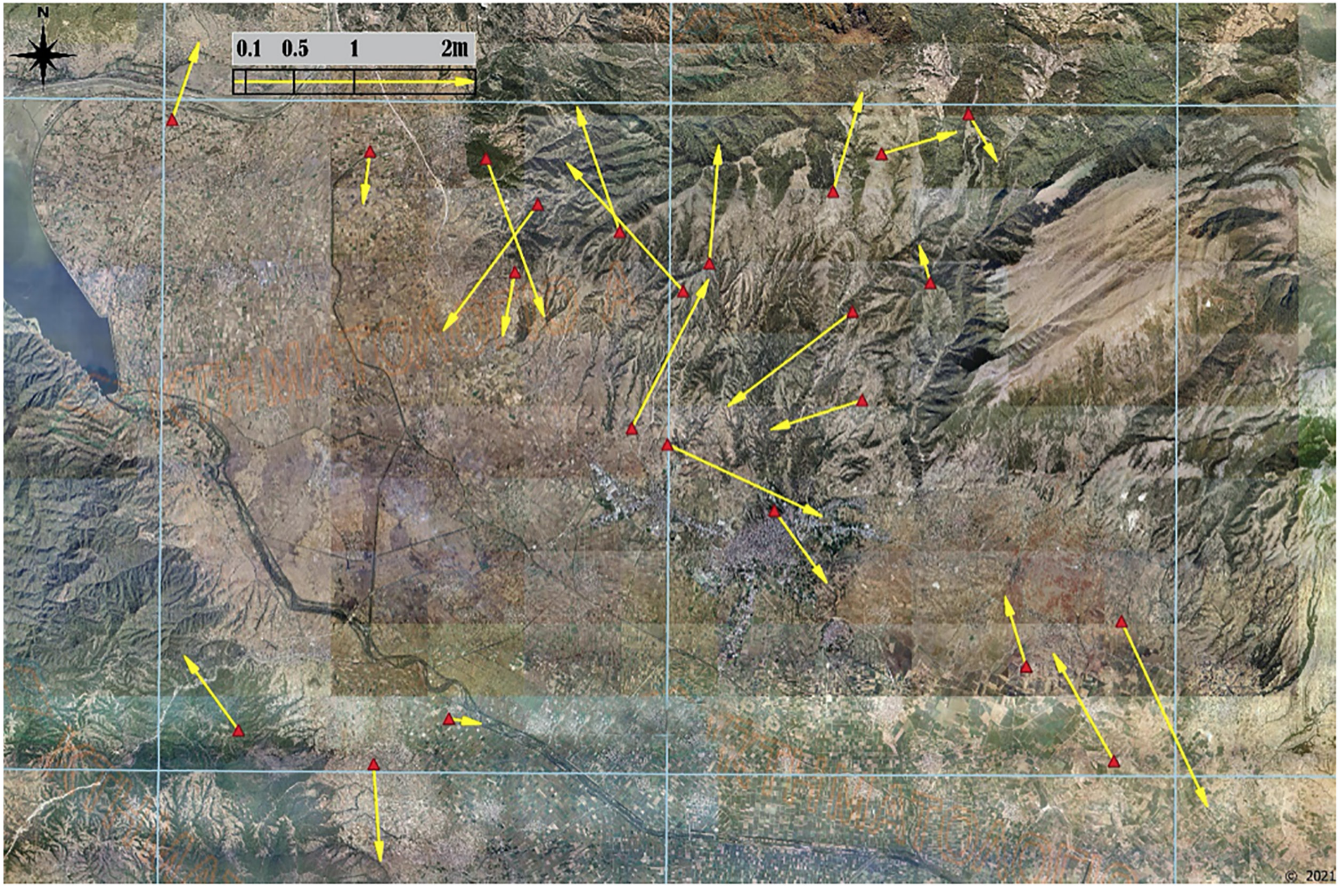

Figure 7: The horizontal residuals of the polynomial transformation for the examined area.

The residuals of both transformation types (2D similarity and polynomial, Figures 5 and 7, respectively) do not indicate any systematic influence (e.g. homogeneous orientation or scale). On the contrary, the arrows representing the residuals appear to behave randomly. This fact leads us to the conclusion that the 'Old Bessel' geodetic networks were solved independently, and were not part of a common adjustment scheme. Therefore, there is little that can be done with the associated residuals.[4] Nevertheless, this is only a local case and there definitely could be cases where the results of the transformations will be more homogeneous and suitable for further consideration. One may also reduce the examined area in order to improve the results of the initial transformations. However, this could not be done in our study of the Serres region because we did not find many benchmarks and were hence unable to limit our area of interest.

As a final comment on the transformation procedure, we would like to emphasize that the estimated parameters (both for similarity and polynomial transformation) refer to a specific common centroid. The transformation parameters are dependent on the choice of centroid and therefore, each map sheet can only be transformed (by these sets of parameters) once it has been aligned to this particular centroid.

Conclusions

The aim of the present study is to present a practical and straightforward method, using well-known mathematical tools, to perform consistent transformations between the 'Old Bessel' (the Oldest version of the GR-Datum) and the HGRS1987 datums. We hope to offer a practical means of overcoming the transformation problems experienced by surveyors and others working with these systems in Greece.

We have found that the consistency between the official HGRS1987 datum and the 'Old Bessel' is at the level of 1.2M for the case of the 2D similarity transformation and that it is significantly improved for the 2nd degree polynomial transformation case—i.e. 0.83M for the y-component. This is a clear indication that the two aforementioned datums (and especially the 'Old Bessel') carry both systematic biases and random errors.[5] Our transformation cannot be used over large areas (e.g., more than 10 x 10 km). A possible enhancement of the method would be either using a smaller area or applying further gridding of the residuals. However, on the one hand it is not easy to find common points—the 'Old Bessel's' Benchmarks were mainly established in the 1950s or even earlier—and the distribution of found points is rarely such that it might not cause distortions. Our test could be applied in other areas of the country to assess differences in the quality of the transformation. In the hope that this might eventuate, we are developing a new software package (written in Matlab) for the implementation of the algorithms presented in this article. We are ready to communicate with any agency, individual or government organisation in order to facilitate efforts to solve the transformation problem between these two geodetic reference systems.

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Notes

[1] While not a part of the coordinate transformation exercise, the control stations were surveyed in the 2014 International Terrestrial Reference Frame ITRF2014 in order to provide information for potential future studies, as well as contributing to available survey information, in particular elevations, for the stations in question.

[2] We should also underline that in Greece there are no officially implemented dynamic or semi-dynamic datum realizations as there are in New Zealand and Australia (see e.g., Donelly et al. 2014, Blick and Donelly 2016). The merit of the semi- or pure dynamical datums, respectively, is based on the exploitation of 2D and 3D velocities (derived from a velocity model) in order to relate the geodetic coordinates of a point to a specified reference epoch (e.g. Chatznikos and Kotsakis 2017). This is a crucial issue for geo-dynamically active areas like Greece, since points move with an average velocity of 2 cm/yr with respect to the Eurasian plate (Ampatzidis 2011). We believe that the tectonic deformation is one of the major bias sources causing inconsistencies among the Greek datums. However, the issue of the tectonic deformation is beyond the scope of the current paper.

[3] The 30'x 30' map sheets are called the 'Big Sheets' while the 6' x 6' sheets are called the 'Small Sheets' in Greek geodetic jargon.

[4] E.g. application of a gridding method. The gridding concept is based on an interpolation of residuals using such mathematic tools as variograms, least squares collocations, splines etc.

[5] Sources of these errors include: tectonics; historical measurements biases; network adjustment failures and random errors which cannot be identified or removed.

References

Alashaikh, A.H. Numerical transformation technique for coordinate systems in the Kingdom of Saudi Arabia. Arab J Geosci 10, 129 (2017). https://doi.org/10.1007/s12517-017-2903-6.

Altamimi, Z., P. Rebischung, L. Métivier,and X. Collilieux (2016), ITRF2014: A new release of the International Terrestrial Reference Frame modelingnonlinear station motions, J. Geophys.Res. Solid Earth, 121, 6109–6131,doi:10.1002/2016JB013098.

Ampatzidis, D. (2011). Study for the optimal Geodetic Reference System realization in the Hellenic Area. Doctoral Dissertation, Department of Geodesy and Surveying, Aristotle University of Thessaloniki (in Greek).

Ampatzidis,D., S. A. Melachroinos (2017). The connection of an Old geodetic datum with a new one using Least Squares Collocation: The Greek case. Contributions to Geophysics and Geodesy, 47(1). DOI:10.1515/congeo-2017-0003.

Blick G., N Donnelly (2016) From static to dynamic datums: 150 years of geodetic datums in New Zealand, *New Zealand Journal of Geology and Geophysics,* 59:1, 15-21, DOI: 10.1080/00288306.2015.1128451.

M. Chatzinikos & C. Kotsakis (2017) Appraisal of the Hellenic Geodetic Reference System 1987 based on backward-transformed ITRF coordinates using a national velocity model, *Survey Review,* 49:356, 386-398, DOI: 10.1080/00396265.2016.1180797.

Dermanis A. and A. Fotiou (1992). Methods and Applications of the Adjustments of the Observations. Ziti Publications, Thessaloniki, Greece (in Greek), 360 pp.

DMA, (1987): Supplement to Department of Defence World Geodetic System 1984 technical repot: Part II - Parameters, formulas for the practical application of WGS 84, DMA TR 8350.2-D, NAtional Imagery and Mapping Agency, Washington, WA, USA.

Donnelly, N., C. Crook, R. Stanaway, C. Roberts, C. Rizos and J. Haasdyk (2015). A Two-Frame National Geospatial Reference System Accounting for Geodynamics. In: van Dam T. (ed.) REFAG 2014. International Association of Geodesy Symposia, Vol. 146. https://doi.org/10.1007/1345_2015_188

Fotiou A. and E. Livieratos (2000). Geometric Geodesy and Networks. Ziti Publications, Thessaloniki, Greece (in Greek).

Hellenic Mapping and Cadastral Organization (HEMCO) (1987). The Hellenic Geodetic Reference System 1987. Report, Ministry of Environment, Urban Planning and Public Works (in Greek).

Hellenic Mapping and Cadastral Organization (HEMCO), 1995, Tables of coefficients for coordinates transformation of the Hellenic area, HEMCO Report (in Greek).

Hofmann-Wellenhof B., Lichtenegger H., Collins J. (1993) Transformation of GPS results. In: Global Positioning System. Springer, Vienna. https://doi.org/10.1007/978-3-7091-3293-7_10

Junkins, D. 1998. NTv2 procedures for the development of a grid shift file. Geodetic Survey Division, Geomatics Canada, Ottawa, Canada

Kalamakis, N., D. Ampatzidis, N. Demirtzoglou, K. Katsambalos (2017). The theoretical and the practical aspects of the transformations among the different Greek geodetic datums. The case of the mapping layouts of the Ministry of Agriculture. Proceedings of the 5th Panhellinc Conference of the Association of the Rural and Surveying Engineers, Athens, Greece.

Kalamakis Nikolaos (2020). A study towards a best fitting between two different versions of the classical greek datum, using legacy data. Doctoral Dissertation, Department of Geodesy and Surveying, Aristotle University of Thessaloniki (in Greek).

Katsambalos K, Kotsakis C. and Gianniou M. (2010). Hellenic terrestrial reference system 2007(HTRS07): a regional realization of ETRS89 over Greece in support of HEPOS. Bulletin of Geodesy and Geomatics, LXIX(2–3), pp.151–64.

Moschopoulos, G., N. Demirtzoglou, A. Mouratidis, D-G Perperidou, D. Ampatzidis(2020). Transforming the Old map series of the Greek Ministry of Agriculture to the modern geodetic reference system. Volume XVI, issue 7.

Mugnier, C. (2002). The Hellenic Republic (Grids and Datum). *Photogrammetric Engineering & Remote Sensing*, December, pp. 1237-1238.

Takos I. (1989). New adjustment of Greek geodetic networks. Journal of the Hellenic Military *Geographic Service*, Issue No. 36, pp.15–30 (in Greek).

Torge, W.; Müller, M.; Geodesy, New York: deGruyter, 2012, ISBN-13: 978-3110207187

Veis G., (1996). National report of Greece. Report on the Symp. of the IAG

Subcommission for the European Reference Frame (EUREF), Ankara, 22–25 May 1996. Report, Verlag der Bayerischen Akademie der Wissenschaften, Heft Nr. 57.

Yang, Q., Snyder, J., Waldo Tobler, W. (1999). Map Projection Transformation: Principles and Applications, CRC Press, ISBN-13: 978-0748406685.

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