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Planimetric Transformation Models Compared between References ETRF2000 and ALB-1986

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ABSTRACT
Several GNSS campaigns were conducted in Albania in order to connect the State Geodetic Network with the Global (ITRSxx/ITRFxx) or European Reference System (ETRS89/ETRF2000). Based on the findings of the GNSS campaign conducted in the fall of 2007 and spring of 2008, the optimal transformation parameters between the references ETRF2000 and ALB1986 were determined. In the field, the transformation outcomes made possible by the two existing planimetric transformation models created by the Department of Geodesy and the Military Geographical Institute of Firenze, Italy, are evaluated and compared. The purpose of this study is to demonstrate the various planimetric transformation models and the outcomes of their tests conducted throughout Albania.

Keywords: GNSS, ITRF/ETRF/ALB reference, transformation

INTRODUCTION
Planimetric transformation models play a pivotal role in geodetic applications, enabling the conversion of spatial coordinates between different reference systems. Among the multitude of reference frames available, the European Terrestrial Reference Frame 2000 (ETRF2000) and the Albanian Reference Frame 1986 (ALB-1986) stand out as significant benchmarks, each serving distinct regional and national geodetic purposes. The study and comparison of planimetric transformation models between these two reference frames provide insights into the dynamic nature of Earth's crustal movements, contributing to accurate geospatial data integration and analysis (Nurce, 2013).

The European Terrestrial Reference Frame 2000 (ETRF2000) is a geocentric reference frame established by the International Association of Geodesy (IAG) to provide a consistent and precise reference for positioning and navigation across Europe and its surrounding regions. ETRF2000 is based on a network of continuously operating GNSS (Global Navigation Satellite System) stations, allowing for the monitoring of tectonic plate movements and crustal deformations. Its adoption has been instrumental in aligning national coordinate systems and facilitating interoperability in diverse applications, including surveying, cartography, and geodynamics (Maseroli, 2010).

On the other hand, the Albanian Reference Frame 1986 (ALB-1986) is a national reference frame specific to Albania, developed to address the unique geodetic challenges of the region. Originating from a triangulation network established in 1986, ALB-1986 has served as the foundation for cartographic and geodetic activities in Albania. While not as expansive in its coverage as ETRF2000, ALB-1986 is crucial for local mapping, infrastructure development, and land administration within the Albanian territory.

Comparing the planimetric transformation models between ETRF2000 and ALB-1986 involves a nuanced exploration of the methodologies, mathematical algorithms, and parameters employed in coordinate conversions. This comparative analysis is crucial for understanding the transformations required to bridge the spatial gap between the global ETRF2000 and the local ALB-1986. It takes into account factors such as datum shifts, coordinate rotations, and scale transformations that characterize the relationship between these two reference frames (Nurce, 2013).

Furthermore, this study delves into the implications of adopting one reference frame over the other in specific applications. Decision-makers, surveyors, and geospatial professionals must consider the accuracy, precision, and consistency of planimetric transformations when integrating data from ETRF2000 into the local ALB-1986 or vice versa. The exploration of potential discrepancies and the development of robust transformation models are essential for minimizing errors and ensuring the seamless integration of geospatial information across diverse reference frames (Maseroli, 2010).

In conclusion, the comparative analysis of planimetric transformation models between ETRF2000 and ALB-1986 offers valuable insights into the dynamic nature of geodetic reference frames. As technology advances and our understanding of Earth's crustal movements evolves, continuous research in this field remains crucial for maintaining the accuracy and reliability of geospatial data across national and international boundaries. This exploration contributes to the ongoing efforts in geodetic sciences, cartography, and spatial information management, fostering collaboration and interoperability in the ever-expanding realm of geospatial applications.

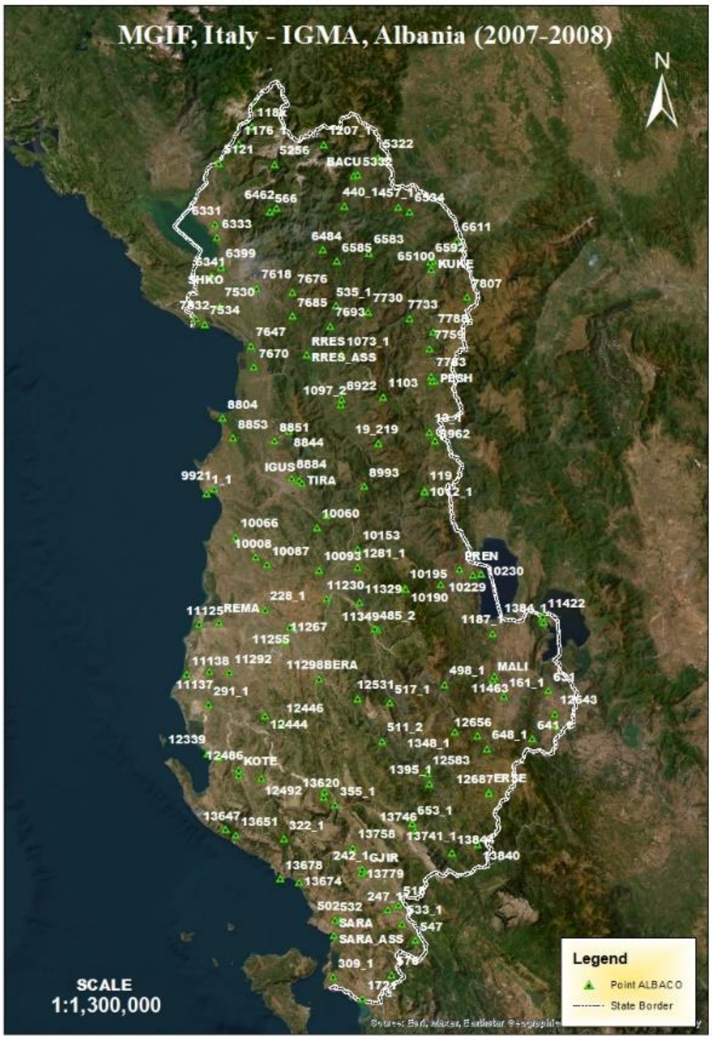


Figure 1: Scheme of the points measured Autumn 2007 - Spring 2008

METHODOLOGY

Based on the evaluation of the differences ($\Delta\varphi = \varphi ALB1986 - \varphi ETRF2000$, $\Delta\lambda = \lambda ALB1986 - \lambda ETRF2000$), an approximate correlation surface was calculated through a horizontal least squares regression model (Nurce, 2010):

$$aXi + bYi + c \approx Zi$$

The coordinates for the measured points - not vertices of the respective grids ($\Delta\varphi, \Delta\lambda$) are calculated according to the relations:

$$\varphi ALB1986 = \varphi ETRF2000 + \Delta\varphi ETRF2000 - ALB1986,$$
$$\lambda ALB1986 = \lambda ETRF2000 + \Delta\lambda ETRF2000 - ALB1986$$

or

$$\varphi ETRF2000 = \varphi ALB1986 + \Delta\varphi ALB1986 - ETRF2000,$$
$$\lambda ETRF2000 = \lambda ALB1986 + \Delta\lambda ALB1986 - ETRF2000$$

The transformation of the positions (N,E) referred ETRS89, ETRF2000, Epoch2008.0 into the reference ALB1986 is realized through the program ***ALBACO*** or 7-P Helmert transformation (Table 1) based on 90 common points:

Table 1: 7P Helmert transformation from $(N,E)_{ETRS89, ETRF2000, 2008.0}$ into $(N,E)_{ALB1986}$

T_X (m)	T_Y (m)	T_Z (m)	S (ppm)	R_X ('')	R_Y ('')	R_Z ('')
44.183	0.58	38.489	8.2703	2.3867	2.7072	-3.5196

The accuracy of the transformation from ETRS89, ETRF2000 (2008.0) to ALB-1986 through 7P Helmert has resulted (Nurce, 2013):

σ_0 = 18 cm (at confidence level of 68%) and σ_0 = 40 cm (at confidence level of 85%).

Department of Geodesy, Faculty of Civil Engineering for the transformation of coordinates from ETRF2000 to ALB1986, has proposed ***linear equations of Helmert transformation*** of the form (Maseroli, 2010):

$$N_{ALB86} = N_0 + p \cdot N_{ETRF2000} - q \cdot E_{ETRF2000} + r$$
$$E_{ALB86} = E_0 + q \cdot N_{ETRF2000} + p \cdot E_{ETRF2000} + s$$

or in vector form:

$$\begin{bmatrix} N_{ALB86} \\ E_{ALB86} \end{bmatrix} = \begin{bmatrix} N_0 \\ E_0 \end{bmatrix} + \begin{bmatrix} p & -q \\ q & p \end{bmatrix} \cdot \begin{bmatrix} N_{ETRF2000} \\ E_{ETRF2000} \end{bmatrix} + \begin{bmatrix} r \\ s \end{bmatrix}.$$

with: N_0=4551000, E_0=416800, coefficients p=1.000408598, q=3.11103E-07, r=1952.142887, s=97.55894084.

For the transformation of (N,E) from ETRF-2000 to ALB-1986, Department of Geodesy also has proposed ***transforming polynomials*** of the form:

$$N_{ALB1986} = N_{ETRF2000} + (a_2 + n \cdot a_3 + e \cdot a_4 + q \cdot a_5 - p \cdot a_6)$$
$$E_{ALB1986} = E_{ETRF2000} + (a_1 + e \cdot a_3 - n \cdot a_4 + p \cdot a_5 - q \cdot a_6)$$

or in vector form:

$$\begin{bmatrix} N_{ALB1986} \\ E_{ALB1986} \end{bmatrix} = \begin{bmatrix} N_{ETRF2000} \\ E_{ETRF2000} \end{bmatrix} + \begin{bmatrix} 0 & 1 & n & e & q & -p \\ 1 & 0 & e & -n & p & -q \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ \vdots \\ a_6 \end{bmatrix}$$

with: $n = 10^{-5} \cdot N_{ETRF2000}$, $e = 10^{-5} \cdot E_{ETRF2000}$, $p = e^2 - n^2$, $q = 2 \cdot e \cdot n$, a_1 = -33.94098357, a_2 = 86.36090734, a_3 = 40.95349125, a_4 = 1.718666252, a_5 = -0.019183782, a_6 = 0.001022946.

Field Testing of the Transformation Models

To test the planimetric transformation models, static GNSS satellite measurements were performed (Figure 3), at the points referred ALB1986, which were not used to derive the transformation models in plan during Autumn 2007- Spring 2008 GNSS campaign.

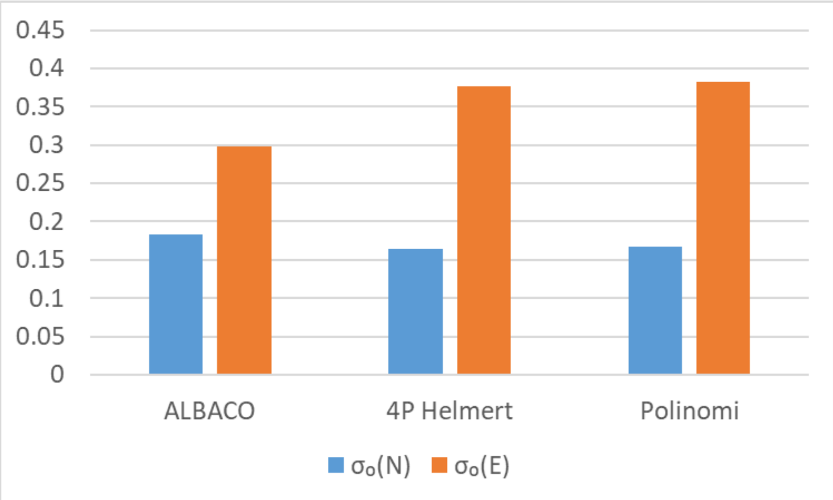
Figure 3: Test areas of transformation

After processing of GNSS observations with Trimble Business Center software we have the list of points with 3-D coordinates (φ,λ,h) and (N,E,h) referred ETRF-2000, Epoch 2022.5.

The Tables 2, 3, …., 6 given the transformed (N,E) from reference ETRF-2000, Epoch 2022.5 into reference ALB-1986 through 3 transformation models: (1) ALBACO developed by MGIF, (2) 4-P Helmert and (3) Polynomial, as well as the corresponding quadratic mean deviations σ_{01}, σ_{02} and σ_{03} (Deakin, 2004).

Table 2: Transformed 2d Coordinates (N,E) referred Etrf2000, Epoch2022.5 into Alb1986 for the Area 1

No.	N(ALB1986)	E(ALB1986)	ALBACO		4P Helmert		Polynomial	
			$N(ALB1986)_1$	$E(ALB1986)_1$	$N(ALB1986)_2$	$E(ALB1986)_2$	$N(ALB1986)_3$	$E(ALB1986)_3$
1	4467615.67	413293.39	4467615.299	413293.733	4467615.403	413293.718	4467615.384	413293.7311
2	4471461.4	414693.18	4471461.193	414693.514	4471461.277	414693.529	4471461.261	414693.5371
3	…………..	…………..	…………..	…………..	…………..	…………..	…………..	…………..
4	…………..	…………..	…………..	…………..	…………..	…………..	…………..	…………..
17	4508777.07	410993.07	4508777.091	410993.011	4508777.169	410993.209	4508777.162	410993.2095
			$\sigma_0(N)$=0.183 m	$\sigma_0(E)$= 0.298 m	$\sigma_0(N)$= 0.164m	$\sigma_0(E)$= 0.377 m	$\sigma_0(N)$= 0.167m	$\sigma_0(E)$= 0.382 m

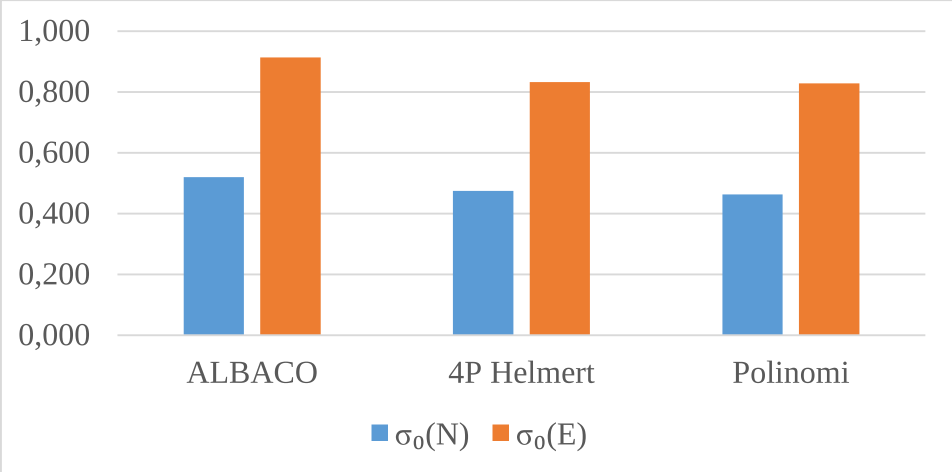


The errors of the transformed 2D coordinates (N,E) referred ETRF2000, Epoch2022.5 into ALB1986 provided through 3- transformation models: (1) ALBACO developed by IGUF, (2) 4P Helmert and (3) Polynomial for the area 1 are respectively:

	ALBACO		4P Helmert		Polynomial	
	dN	dE	dN	dE	dN	dE
0-10.0 cm	59.0%	41.5	53.0	12.0	59.0	12.0
-20.0 cm	82.5%	59.0	82.5	29.5	82.5	29.5
-30.0 cm	88.5%	82.5	100	59.5	94.1	76.5
> 30.0 cm	100%	100	100	100	100	100

Table 3: Transformed 2D coordinates (N,E) referred ETRF2000, Epoch2022.5 into ALB1986 for the Area 2

No.	N(ALB1986)	E(ALB1986)	ALBACO		4P Helmert		Polynomial	
			$N(ALB1986)_1$	$E(ALB1986)_1$	$N(ALB1986)_2$	$E(ALB1986)_2$	$N(ALB1986)_3$	$E(ALB1986)_3$
1	4495217.390	391434.69	4495217.393	391434.684	4495217.426	391434.727	4495217.406	391434.7611
2	…………..	…………..	…………..	…………..	…………..	…………..	…………..	…………..
3	…………..	…………..	…………..	…………..	…………..	…………..	…………..	…………..
4	4401057.5	437559.48	4401058.524	437559.503	4401058.426	437559.045	4401058.398	437559.056
			σ_0=0.520 m	σ_0= 0.913 m	σ_0= 0.475 m	σ_0= 0.832 m	σ_0= 0.463 m	σ_0= 0.828 m

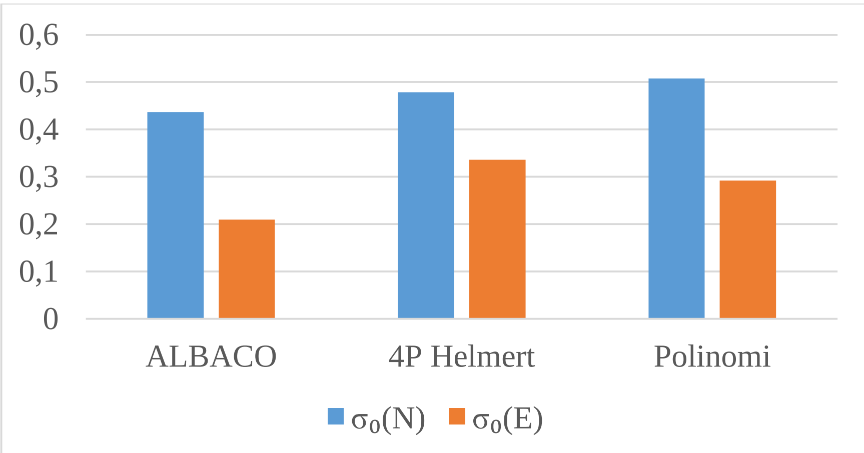


The errors of the transformed 2D coordinates (N,E) referred ETRF2000, Epoch2022.5 into ALB1986 provided through 3- transformation models: (1) ALBACO developed by IGUF, (2) 4P Helmert and (3) Polynomial for the area 2 are respectively:

	ALBACO		4P Helmert		Polynomial	
	dN	dE	dN	dE	dN	dE
0÷ 10.0 cm	50%	75	50	50	50	50
÷ 20.0 cm	75%	100	75	100	75	75
÷ 30.0 cm	100%	100	100	100	100	100
> 30.0 cm	100%	100	100	100	100	100

Table 4: Transformed 2D coordinates (N,E) referred ETRF2000, Epoch2022.5 into ALB1986 for the Area 3

No.	N(ALB1986)	E(ALB1986)	ALBACO		4P Helmert		Polynomial	
			$N(ALB1986)_1$	$E(ALB1986)_1$	$N(ALB1986)_2$	$E(ALB1986)_2$	$N(ALB1986)_3$	$E(ALB1986)_3$
1	4653436.22	366124.59	4653436.307	366124.252	4653436.267	366124.046	4653436.316	366124.1107
2	…………..	…………..	…………..	…………..	…………..	…………..	…………..	…………..
3	…………..	…………..	…………..	…………..	…………..	…………..	…………..	…………..
5	4660497.63	451755.24	4660497.639	451755.244	4660497.834	451755.298	4660497.848	451755.2297
			σ_0=0.437 m	σ_0= 0.210 m	σ_0= 0.479 m	σ_0= 0.336 m	σ_0= 0.508 m	σ_0= 0.292 m

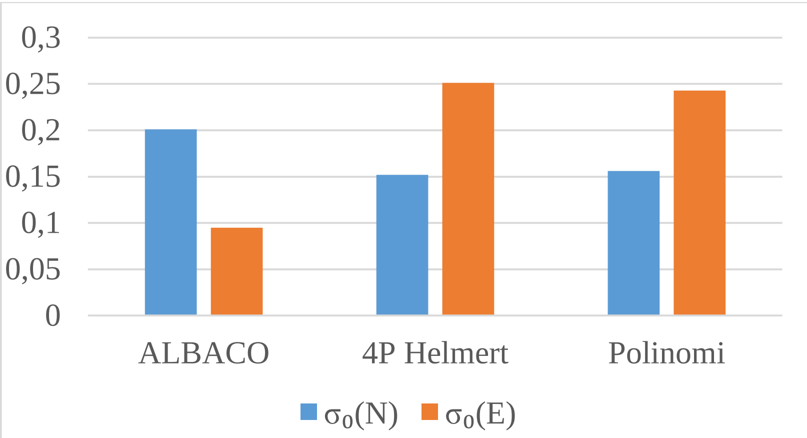


The errors of the transformed 2D coordinates (N,E) referred ETRF2000, Epoch2022.5 into ALB1986 provided through 3- transformation models: (1) ALBACO developed by IGUF, (2) 4P Helmert and (3) Polynomial for the area 3 are respectively:

	ALBACO		4P Helmert		Polynomial	
	dN	dE	dN	dE	dN	dE
0÷ 10.0 cm	60%	60	40	60	40	60
÷ 20.0 cm	60%	80	60	100	60	100
÷ 30.0 cm	80%	100	100	100	100	100
> 30.0 cm	100%	100	100	100	100	100

Table 5: Transformed 2D coordinates (N,E) referred ETRF2000, Epoch2022.5 into ALB1986 for the Area 4

No.	N(ALB1986)	E(ALB1986)	ALBACO		4P Helmert		Polynomial	
			$N(ALB1986)_1$	$E(ALB1986)_1$	$N(ALB1986)_2$	$E(ALB1986)_2$	$N(ALB1986)_3$	$E(ALB1986)_3$
1	4578517.411	401926.891	4578517.663	401926.991	4578517.579	401927.166	4578517.588	401927.1683
2	…………..	…………..	…………..	…………..	…………..	…………..	…………..	…………..
3	…………..	…………..	…………..	…………..	…………..	…………..	…………..	…………..
10	4595369.64	453386.46	4595369.645	453386.477	4595369.389	453386.78	4595369.392	453386.6989
			σ_0=0.201 m	σ_0= 0.095 m	σ_0= 0.152 m	σ_0= 0.251 m	σ_0= 0.156 m	σ_0= 0.243 m

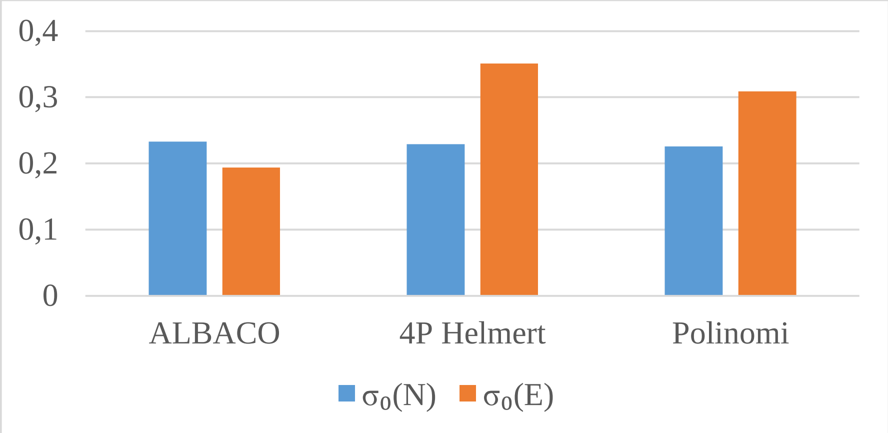


The errors of the transformed 2-D coordinates (N,E) referred ETRF2000, Epoch2022.5 into ALB1986 provided through 3- transformation models: (1) ALBACO developed by IGUF, (2) 4P Helmert and (3) Polynomial for the area 4 are respectively:

	ALBACO		4P Helmert		Polynomial	
	dN	dE	dN	dE	dN	dE
0÷ 10.0 cm	30%	80	70	00	50	00
÷ 20.0 cm	60%	100	80	40	80	30
÷ 30.0 cm	90%	100	100	100	100	100
> 30.0 cm	100%	100	100	100	100	100

Table 6: Transformed 2D coordinates (N,E) referred ETRF2000, Epoch2022.5 into ALB1986 for the Area 5

Nr. Pikës	N(ALB1986)	E(ALB1986)	ALBACO		4P Helmert		Polynomial	
			$N(ALB1986)_1$	$E(ALB1986)_1$	$N(ALB1986)_2$	$E(ALB1986)_2$	$N(ALB1986)_3$	$E(ALB1986)_3$
1	4656566.350	447706.500	4656566.272	447706.613	4656566.431	447706.638	4656566.445	447706.5749
2	…………..	…………..	…………..	…………..	…………..	…………..	…………..	…………..
3	…………..	…………..	…………..	…………..	…………..	…………..	…………..	…………..
23	4605925.280	453865.890	4605925.382	453865.849	4605925.084	453866.283	4605925.089	453866.2007
			σ_0=0.233 m	σ_0= 0.194 m	σ_0= 0.229 m	σ_0= 0.351 m	σ_0= 0.226 m	σ_0= 0.309 m



The errors of the transformed 2-D coordinates (N,E) referred ETRF2000, Epoch2022.5 into ALB1986 provided through 3- transformation models: (1) ALBACO developed by IGUF, (2) 4P Helmert and (3) Polynomial for the area 5 are respectively (Mikhail, 1976):

	ALBACO		4P Helmert		Polynomial	
	dN	dE	dN	dE	dN	dE
0-10.0 cm	74%	91.5	56.5	21.7	56.5	34.8
- 20.0 cm	91.5%	100	91.5	43.5	91.5	56.5
- 30.0 cm	91.5%	100	100	56.5	95.7	91.5
> 30.0 cm	100%	100	100	100	100	100

CONCLUSION AND RECOMMENDATIONS

1. Based on the mean square deviations of the three coordinates transformation models, we conclude that the ALBACO and 4-P Helmert model proposed give almost the same results.

2. The standard deviation of the transformed 2-D coordinates (N,E) referred ETRF-2000, Epoch-2021.5 into ALB-1986 of test points in the areas (a) Berat, (b) Tepelena, (c) Shkoder, (d) Tirana and (e) Kukës-Peshkopi has resulted:

- up to 20 cm (with 80% confidence level),
- up to 40 cm (with 95% confidence level).

3. Three models of the transformed 2-D coordinates (N,E) referred ETRF-2000, Epoch-2021.5 into ALB-1986, which are not officially approved recommended to be used for the topographic mapping of the territory of Albania up to a scale of 1: 5000.

4. Three models of the transformed 2-D coordinates (N,E) referred ETRF-2000, Epoch-2021.5 into ALB-1986 can be improved if we will perform additional measurements in existing points referred ALB-1986.

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